




Seafaring megaliths: A geoarchaeological approach to the Matarrubilla giant stone basin at Valencina (Spain)

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ABSTRACT

A broad multidisciplinary approach is deployed to study an exceptional megalithic feature: the stone basin that presides over the chamber of the Matarrubilla tholos, part of the Valencina Copper Age mega-site (Sevilla, Spain). The study, including geoarchaeological characterisation and sourcing of the stone, traceological analysis of its surfaces based on photogrammetry and morphometrics, digital image analysis as well as OSL dating, leads to a number of substantial findings of great relevance to understand the significance of this stone basin, the only of its kind documented to this date in the Iberian Peninsula, with parallels only in Ireland and Malta. Among the most relevant conclusions, it is worth noting the fact that the gypsiferous cataclastic block the basin was made of was brought from the other side of the marine bay that five thousand years ago extended across the south-east of Valencina, this is the first evidence of waterborne transport of a megalithic stone in the Iberian Peninsula. In addition, the basin appears to have been put where it stands today sometime in the first half of the 4th millennium BC, long before any tholoi were built at Valencina, which suggest a prior history of still poorly documented monumentality at this mega-site.

1. Introduction

Most of the stones used in prehistoric megalithic constructions were transported by land through a diversity of technical procedures (see discussion in Garfitt, 1979; Hoskin, 1986; Van Tilburg, 1995; Kalb, 1996; Adams, 2007; Harris, 2018; etc.). For a long time, however, there have been suggestions that, in some specific cases, stones were transported by water ways, either along rivers or marine coasts.

Transport of megaliths by water is well attested among the

prehistoric societies of Micronesia (Hazell and Fitzpatrick, 2006) and, of course, in ancient Egypt (Landström, 1970). Although little is known about navigation and sailing technology in Neolithic Europe (Morgado et al., 2018; Gibaja et al., 2024; Morgado-Rodríguez et al., 2025), water transport was probably restricted to stones of a limited size. It is unlikely that massive stones weighting several tens of tons were transported by boat. At any rate, there are very few cases for which water transportation of megaliths has been postulated. Probably, the best-known case is that of Stonehenge (Wiltshire, UK), where the ‘bluestones’ have

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been interpreted to have been carried over a distance of 210 km from their geological place of origin in the Preseli mountains (Wales) to the building site (Parker Pearson, 2012; Parker Pearson et al., 2015) and the “Altar Stone”, whose provenance could be in Scotland, some 700 km north of the monument (Clarke et al., 2024; Bevins et al., 2024). Both coastal and river routes have been hypothesised for the ‘bluestones’ (Parker Pearson, 2012; Clarke et al., 2024), which are relatively small, weighting between two and five tons each, and therefore would not have posed an unsurmountable challenge for boat transportation to Late Neolithic communities. A water route has also been postulated for the kerbstones of Newgrange (Ireland), which, weighting around three tons each, were quarried at Cloger Head and transported strapped underneath boats along the coast and up the River Boyne (Stout and Stout, 2008). Seafaring transportation of megalithic stones over distances of up to 40 km have also been suggested for some of the Neolithic monuments of the Locmariaquer region, in French Brittany (Cassen et al., 2019).

This paper presents the first-ever demonstrable case of water transportation of a megalith in prehistoric Iberia. The stone concerned is the giant basin of Matarrubilla, a tholos monument located at the Valencina Copper Age mega-site (Seville, Spain). The multi-disciplinary analysis of this exceptional stone, which had never been studied before, includes a full geological analysis that shows that it came from beyond the left (eastern) shore of the marine bay into which the Guadalquivir River

emptied 5000 years ago. Given that the Valencina mega-site sits on the northern half of El Aljarafe plateau, c. 140 m above sea level, on what were the right (western) shores of the river (Fig. 1), the stone necessarily had to be transported across the water and then uphill to its final setting. However, the study presented here goes beyond the geological characterisation and provenancing of this remarkable stone, as it also provides fresh and detailed evidence about its materiality, morphology, manufacture and chronology. Altogether, this leads to a completely new interpretation of the basin, a unique feature of the Iberian megalithic phenomenon, and the Matarrubilla tholos as a whole.

2. The matarrubilla tholos

Matarrubilla is one of the largest megalithic constructions of the Valencina Copper Age mega-site (Fig. 1), alongside La Pastora (Vargas Jiménez, 2021), Montelirio (Fernández Flores et al., 2016), Cerro de la Cabeza (Fernández Gómez and Ruiz Mata, 1978), Structure 10.042–10.492 (García Sanjuán et al., 2019a) and Ontiveros (Carriazo y Arroquia, 1962). Valencina has emerged as a key site for understanding third-millennium BCE Europe, due to its megalithic monuments, massive ditches, extensive burial record and refined material culture that reveals connections across Iberia, North Africa and the Mediterranean (García Sanjuán et al., 2017, 2018; Whittle, 2018; Gaydarska and

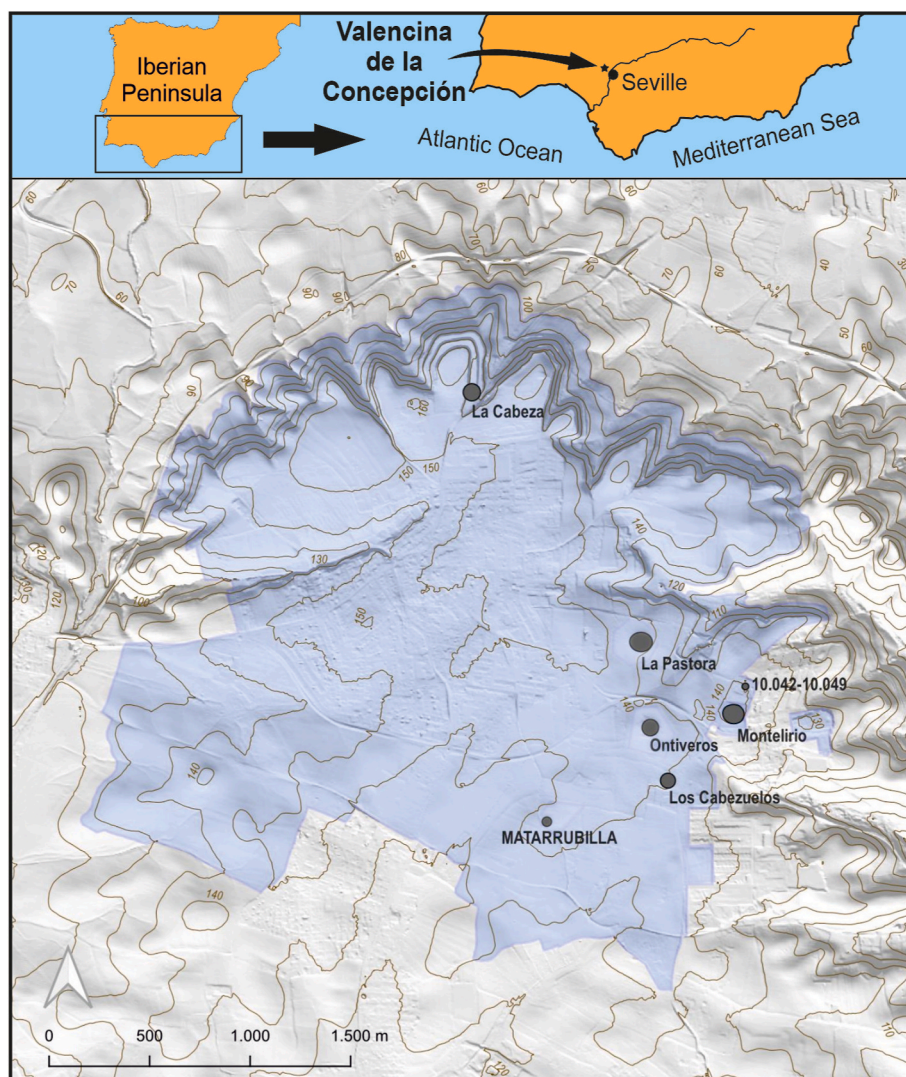


Fig. 1. Location of Valencina de la Concepción in southern Spain and the archaeological mega-site (blue), with the main megaliths mentioned in the text (map art by Francisco Sánchez Díaz and final design by L.M. Cáceres Puro).

Chapman, 2022). Together with tholoi such as La Pastora (Valencina), El Romeral (Antequera) and those at Alcalar in Portugal (Morán Hernández and Parreira, 2004), Matarrubilla represents the climax of stone monumentality in Copper Age Iberia.

Discovered in 1917 just 1 km from La Pastora, Matarrubilla was initially excavated by Hugo Obermaier (1919), who began at the chamber and worked alongside the corridor. However, he ceased excavation prematurely, believing he had reached the passage's end, uncovering some 10 m of it. In 1955, Francisco Collantes de Terán resumed the work and excavated a further 12 m of the corridor, uncovering a remarkable assemblage: more than 100 ivory objects (including what appears to be a pectoral, according to Schuhmacher et al., 2013), gold foil fragments, flint tools, a serpentinite axe, ceramic pots and variscite beads (Collantes de Terán, 1969) sourced from Palazuelo de las Cuevas (Zamora), over 600 km to the north (Odrizola Lloret and García Sanjuán, 2013). A single human burial in a

hyper-flexed position was also found.

The monument is architecturally impressive (Fig. 2 A): it measures 36.21 m in total length, with a 33.46 m corridor and a chamber 2.75 m in diameter. The height of the passage increases towards the chamber, from 1.79 m to 2.08 m. The monument was fully restored after the second excavation, with some capstones raised above their original height between 20 and 40 cm (Gómez De Terreros Guardiola, 2005). The walls are made of superimposed layers of small oncolithic limestone slabs held with a mud mortar, and the roof comprises 17 large capstones mostly calcareous sandstone, with two made of granite: the one covering the chamber and another in the corridor (Cáceres et al., 2019). The monument's orientation is unusual, at just under 18° azimuth, outside the typical solar alignments of Iberian megaliths (Belmonte Avilés and Pimenta, 1998; Hoskin, 2001). This led Michael Hoskin to propose a stellar orientation towards Arcturus, one of the brightest stars visible locally in the late 4th millennium BCE (Hoskin, 2001).

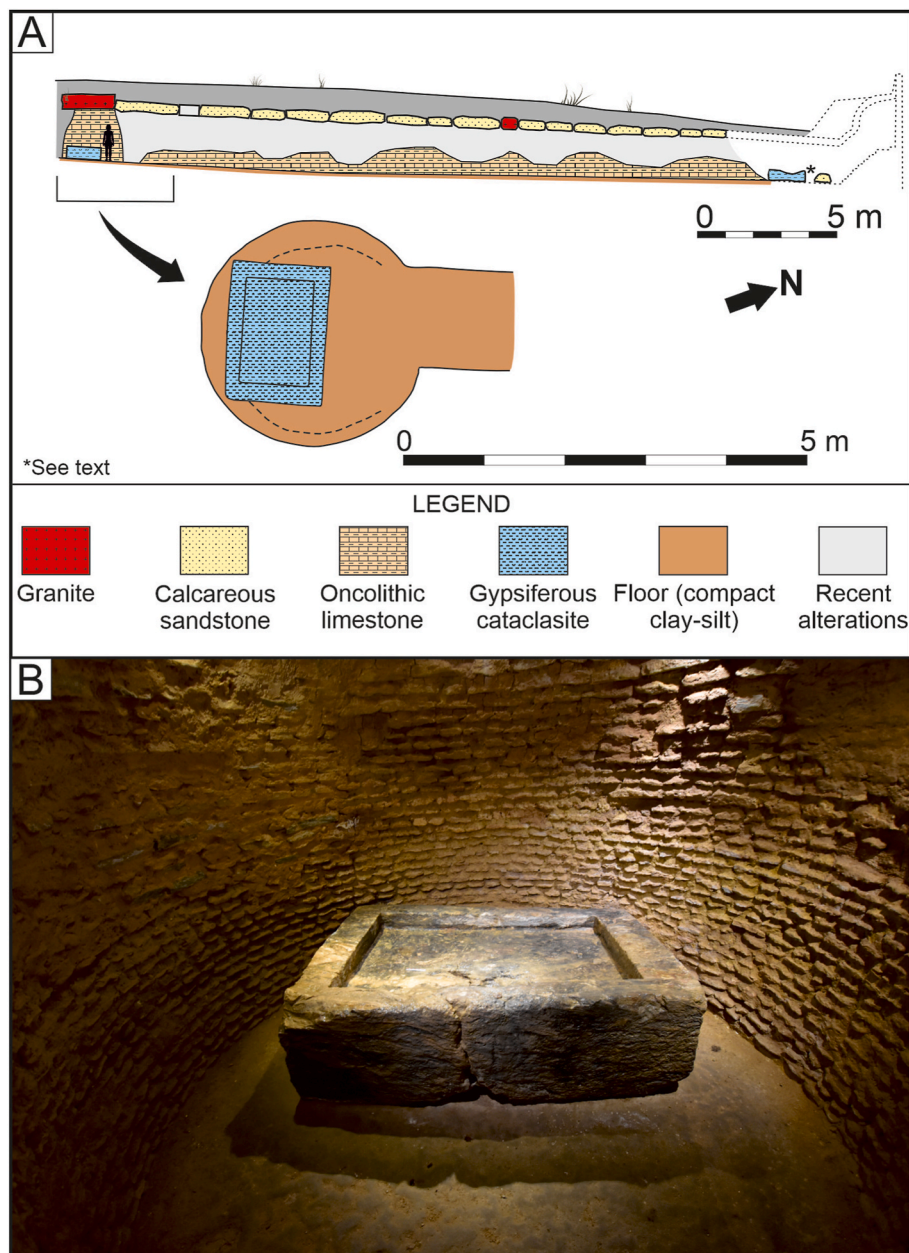


Fig. 2. Tholos of Matarrubilla. A. Longitudinal section of the monument with human figure in the chamber to compare its size (modified from Cáceres et al., 2019), and plan view of the chamber with layout of the basi; B. Chamber of Matarrubilla with basin fitted in it (Figure by L.M. Cáceres Puro with photograph taken by L. García Sanjuán).

Matarrubilla’s most distinctive and original feature is the large square stone gypsum basin placed at the centre of its chamber (Fig. 2 B). This stone measures nearly 1 m³ and carved with almost perfectly quadrangular in shape, its upper side carved with a rectangular inner depression. It occupies most of the available space, leaving only narrow spaces along the sides (Fig. 2 A), where it is impossible for a person to stand in a fully upright position. Obermaier interpreted it as an altar or offering table (Obermaier, 1919), and it remains unique within the Iberian megalithic tradition.

A second gypsum block, possibly related, lies at the monument’s entrance (Fig. 2 A). It is an elongated monolithic block of 1.53 m in length and variable width from 0.59 to 0.63 m and thickness also variable from 0.44 to 0.27. At least one of its faces is carved in the form of three steps of similar width and with height differences of approximately 4–5 cm between each step. It is likely that this block was originally connected with the basin, but is now possibly displaced and out of context.

Despite being recognised as a singular feature over a century ago, no in-depth study of this stone basin has ever been carried out. This paper

presents the first comprehensive, multidisciplinary analysis, including geological characterisation and provenance, high-resolution modelling of its form and dressing, including tool marks, and OSL dating of the sediments beneath. These methods offer a significantly renewed understanding of this remarkable megalithic feature and the monument it is part of.

3. Geological settings

Geologically, the Valencina Copper Age megalithic site is located in the Guadalquivir Basin (Fig. 3), a depression filled with marine and continental sediments of Neogene and Quaternary age. In the immediate surroundings of Valencina, there are sediments of little or no consolidation. Only the unit known as the Transition Facies (Mayoral and González, 1987) presents an alternation of levels of sandstones with carbonate cement alternating with barely consolidated clays. These carbonate sandstones were used as construction material in some of the megaliths (Cáceres et al., 2014, 2024).

Other types of rocks not available in the immediate surroundings of

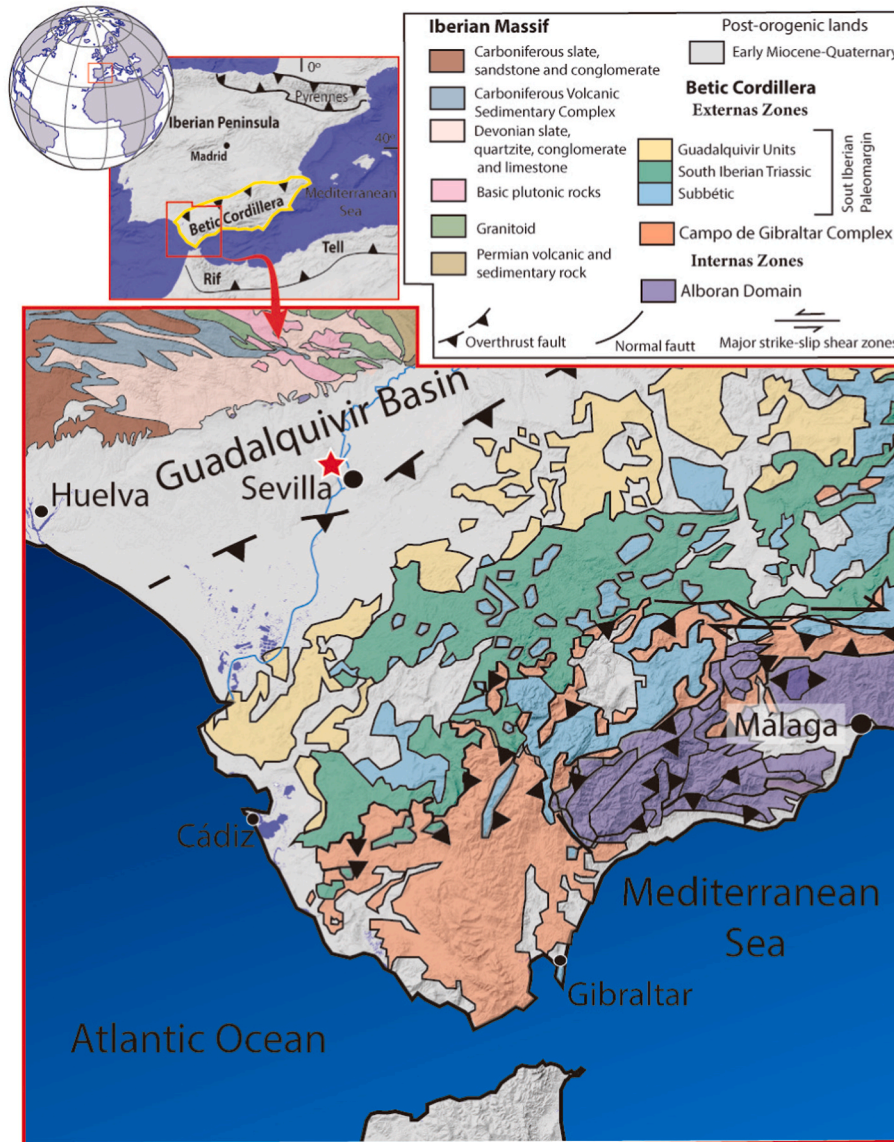


Fig. 3. Geological framework. Geological DTM map showing the location of the archaeological site of Valencina, located in the western basin of the Guadalquivir, south of the Iberian Massif and northwest of the Betic Codillera (modified from Lozano Rodríguez, 2019). Source of the DTM data: National Geographic Information Center of Spain (IGN). Reference: National Geographic Information Center of Spain (IGN), Centro de Descargas del CNIG (IGN) (Figure by J.A. Lozano Rodríguez).

Valenciana were also used to build these monuments, which meant that these materials had to be brought from a distance greater than 15 km (Cáceres et al., 2014, 2024). These include Neogene-age cream-colored oncolithic limestone which, dressed as narrow and small slabs (2–4 cm), forms the walls of the Matarrubilla tholos (Cáceres et al., 2019). Other materials used to build this monument came from the Iberian Massif, specifically from outcrops to the north of the site, with a wide variability of igneous, metamorphic and sedimentary rocks of Precambrian and Palaeozoic age (Fig. 3). So, Carboniferous-age granite was used in some of the Valencina tholoi, for example as capstones, while Devonian-age quartz arenite was used for the dry masonry walls of La Pastora (Cáceres et al., 2024).

All these rocks mentioned so far outcrop to the right bank and north of the Guadalquivir River, so in no case was it necessary to cross the river to reach them from the Valencina site.

On the left and south banks of the Guadalquivir River, there is the transition and contact between the sediments of Guadalquivir Basin and the External Zones of the Betic Cordilleras. This transition takes place through a complicated tectonic structure called the Guadalquivir Accretion Complex, formed by Guadalquivir Units and Neogene sequences (Pérez-Valera et al., 2017). One of the most characteristic features of the Guadalquivir Units is the abundance of Triassic gypsum breccias at the surface, that show abundant deformational processes, being included in a *mélange*-type (Pérez-Valera et al., 2017). To the east, the Guadalquivir Units pass into the External Zones of the Betic Cordilleras, with a wide presence of Triassic materials, among which the Keuper facies stand out, characterized by red, greenish and yellowish clays and sandstones, some limestones and dolomites, ophites and, above all, evaporites, essentially gypsiferous. This Triassic formation has a chaotic internal structure, also of a *mélange*-type (Cano Medina and Ruiz Reig, 1990; Martín-Serrano, 1986). There is no general agreement on the boundary between the Guadalquivir Units and the External Zones, largely due to the wide extension of evaporites occurring in both units (Pérez-Valera et al., 2017; Rodríguez Fernández et al., 2013). However, the most significant fact in relation to this study of the Matarrubilla stone basin, is that it was manufactured in a breccia block composed mostly of strongly deformed gypsum (described in a later section).

4. Methodology

4.1. Geological survey

The Matarrubilla basin has been described essentially by means of direct petrographic observations. Thin sections of a small fragment detached from the upper left area of the basin and from the gypsum block that appears at the entrance of the tholos were made. On the other hand, to determine the provenance of this material, several areas were visited in the south of the Guadalquivir Basin where rocky outcrops of the same material were described previously. The petrographic comparison between the basin under study and the outcrops was also carried out visually. However, from the rocky outcrops, several samples were also selected for thin sections to be studied by petrographic microscopy. Among the petrographic features, their texture, structure, fabric and compositional features have been determined.

4.2. Photogrammetry and morphometrics

For the morphometric and technological study of the basin, 3D and 2.5D high definition (HD) models were created using close-range, HD SfM photogrammetry and Reflectance Transformation Imaging (RTI), respectively. The usefulness of 3D modelling and RTI for the analysis of tool marks on archaeological stone surfaces and ancient manufacturing processes has been demonstrated through abundant previous scholarship, mainly focused on rock art and sculpture (e.g. Moitinho et al., 2013; Díaz-Guardamino et al., 2015; Horn et al., 2018; Seidl and Zepfzauer, 2019; Díaz-Guardamino, 2023; Serotta, 2023).

For the creation of the 3D surface model of the Matarrubilla stone basin, 290 HD photographs were taken with a Nikon D810 DSLR and a lens Nikon 24–85 mm f/2.8-4D IF AF Nikkor, using a focal length of 50.0 mm. This data set was processed in Agisoft Metashape using the medium quality settings. The resulting 3D model has 1 mm accuracy. The control scale bars' total error is 0.200 mm. The mesh has more than 52 million vertices. The 3D model was examined with various tools in the free software Meshlab (<https://www.meshlab.net/>) and Blender (<https://www.blender.org/>). Four RTI/PTM files were produced from 113, 58, 83 and 95 HD photographs, respectively, with the free software RTIBuilder (<https://culturalheritageimaging.org/>). These provide additional detail of the surface texture, especially showing relevant details of the tool marks.

4.3. Technological and use-wear analysis

The technological and manufacturing analysis has been carried out through a macroscopic study directly on the basin and from the 3D model. The detailed photographs were taken with a Nikon D810 camera with a Nikon 24–85 mm f/2.8-4D IF AF Nikkor lens, using focal length 50.0 mm. The marks have been categorized morphologically and metrically using the 3D model. According to the traces identified, consisting of elongated impacts inside the depression of the basin and levelling marks for the exterior configuration of the basin, the technological study has focused on identifying the type of tool that was used and the orientations of this work, to determine if the basin could have been manufactured or modified inside the tholos (Figs. 4 and 5).

The determination of the tools used in the carving of the basin and its inner depression were based on the morphological and metric categorization of the elongated impact marks and their comparison with the width of the edge of late prehistoric polished stone tools from southern Iberia, as previously studied (Lozano Rodríguez et al., 2016, 2017; Martínez-Sevilla et al., 2020; Martínez-Sevilla and Linares-Catela, 2024). To determine whether the carving was carried out with a single tool or several of them, the Coefficient of Variation (CV) of the different traces recorded on the surface of the inner depression of the basin was calculated (Table 1). The traces were then grouped according to their orientation to the cardinal axes and their concentration (Supplementary Fig. 1 and Table 1). The CV relates the size of the mean and the variability of the variable. Its formula expresses the standard deviation as a percentage of the arithmetic mean, showing a more robust percentage interpretation of the degree of variability than the standard deviation. Thus, the higher the CV value, the greater the heterogeneity of the variable; and the lower CV, the greater homogeneity of the variable. The calculations were carried out using the formula:

$$C_V = \frac{\sigma}{\bar{x}} \cdot 100$$

Where σ is the standard deviation and \bar{x} is the mean. In statistics, there is homogeneity in the variables as long as the CV is less than 20 %. In the case at hand, as these are manufacturing traces created by violent impacts, in many cases altered by erosion processes, the percentage should be considered as a guideline.

The orientation of the marks on the basin has been based on the morphological study of the traces and angles caused by the impacts by generating sections from the 3D model and direct visual inspection (Fig. 5A and B). The state of conservation of the impact traces is uneven, which is why they were grouped into two types: 1) clear impact traces, in which the orientation was determined reliably; and 2) worn marks, in which the orientation is more difficult to establish (Fig. 5 C).

4.4. Image analysis

An analysis of images of the Matarrubilla basin was carried out in order to look for evidence of the possible use of decorative pigments. Visible photographs were taken using a Nikon D3400 camera (F/6.3,

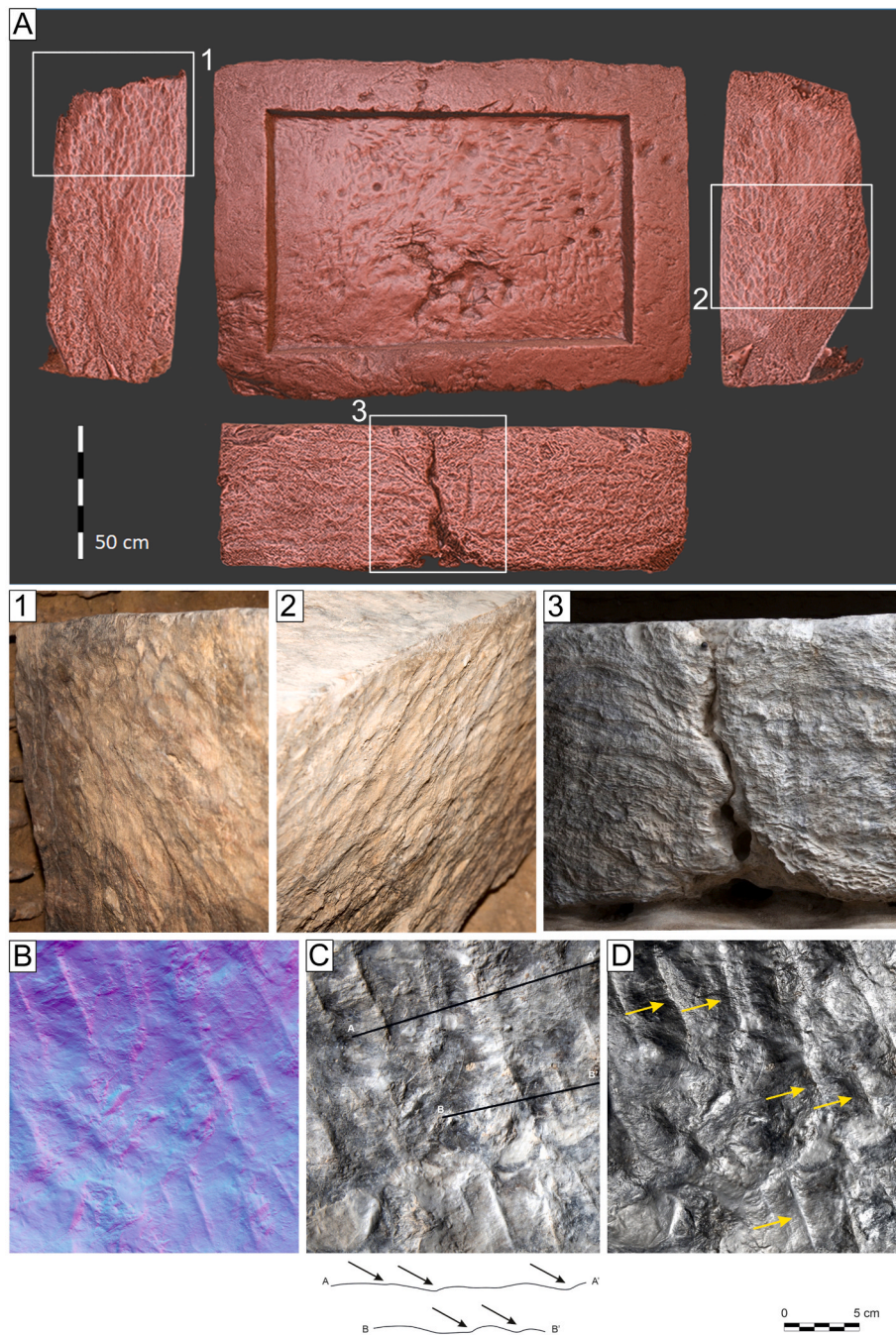


Fig. 4. Technological and manufacturing analysis. A. Enhanced visualization of the 3D surface of the basin showing technological manufacturing details: 1 and 2. Traces formed by removing material through impact with a cutting-edge element, 3. Detail of the areas eroded through dissolution processes; B, C and D. Different RTI visualizations of traces created by removing material and cross-sections of them obtained from the HD 3D model (Figure by M. Díaz-Guardamino and F. Martínez-Sevilla). A medium resolution 3D model of the basin can be visualized and downloaded here: <http://skfb.ly/oNYwV>.

3000x4496 pixels, 300 dpi), and a Canon EOS 200D (F/4, 6000x4000 pixels, 72 dpi).

The images obtained were processed by Principal Component analysis (Gillespie et al., 1986) using the HyperCube software package (R. Pazak, Army Geospatial Center, Alexandria, Virginia, USA). The ImageJ software package (W. Rasband, National Institutes of Health, Bethesda, Maryland, USA) was used to view and reformat the image files for better processing.

4.5. Optically stimulated luminescence dating (OSL)

OSL was applied to establish the time when the basin was placed on

its present location. OSL dating makes it possible to estimate the time when mineral grains, quartz in this case, were exposed to sunlight for the last time. It can be assumed that this happened when the basin was placed in the position it stands on today, shielding the sediment underneath from daylight. The estimated age is based on the relation $\text{Age (ka)} = \text{Burial dose (Gy)} / \text{Dose rate (Gy/ka)}$, where the burial dose is derived from the OSL measurement of quartz single grains and the environmental dose rate is based on the radionuclide concentration in the sample matrix.

Opaque tubes were inserted horizontally under the basin, parallel to its base, to collect the sediment immediately underneath, avoiding exposure to light. Two samples were collected from two different angles.

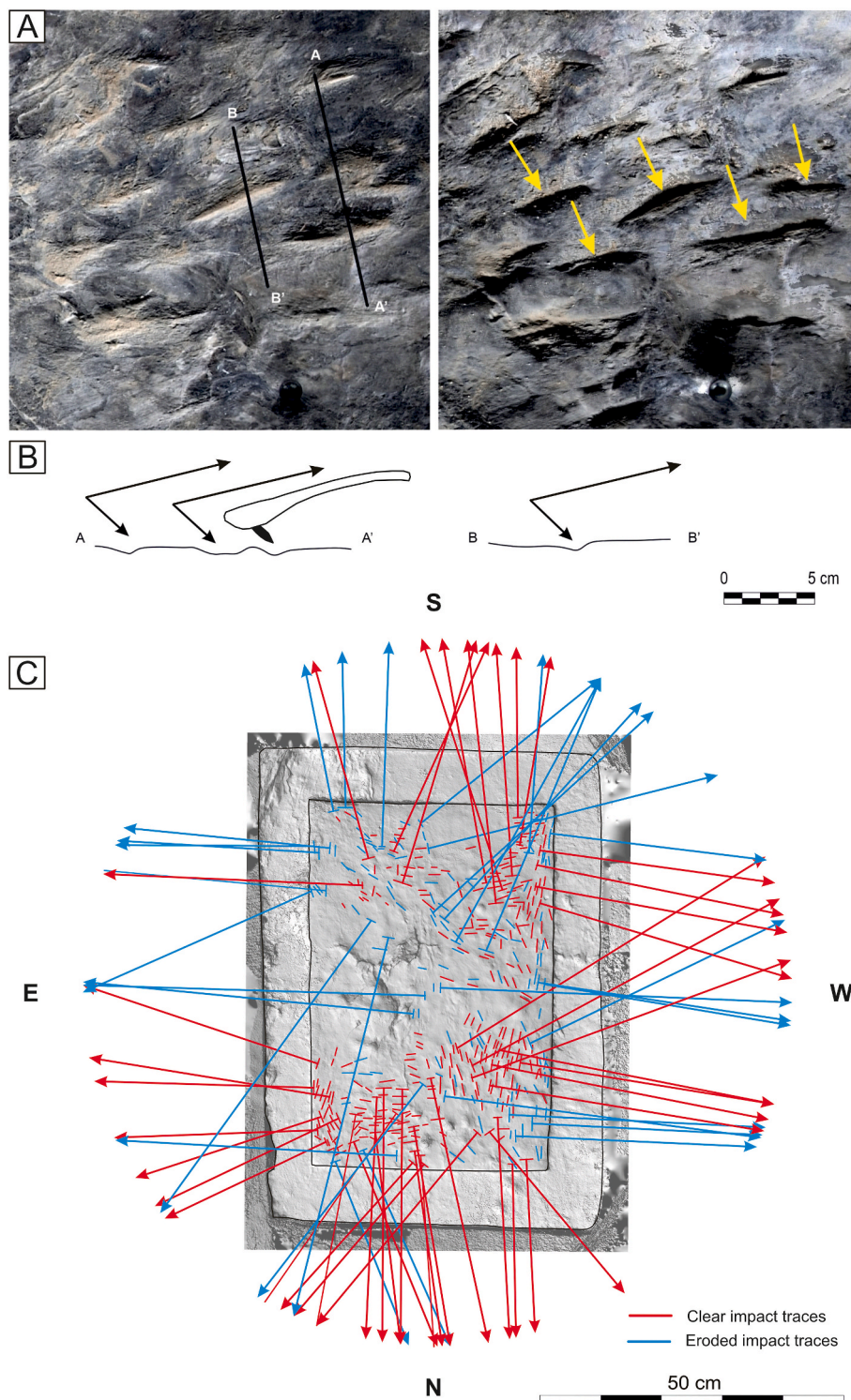


Fig. 5. Technological and manufacturing analysis. A. RTI visualizations of longitudinal impact traces produced by a cutting-edge element; B. Cross-section of impact traces generated from the HD 3D model and criteria followed for the carving work orientation; C. Orientation of the carving work within the inner depression of the basin based on the identified impact traces (Figure by M. Díaz-Guardamino and F. Martínez-Sevilla).

Samples were treated under controlled light conditions in the laboratory to extract the quartz grains of sizes 180–250 μm .

OSL from single grains was measured using an automated Risø TL/OSL DA-20 luminescence reader, following the Single-Aliquot Regenerative-Dose (SAR) protocol (Murray and Wintle, 2003) to obtain representative dose distributions. The derived dose populations are widely scattered indicating the mixture of grains with different degree of

bleaching (i.e. exposure to light that derives in a deletion of the OSL signal). Therefore, the application of the IEU minimum age approach (Internal-External Uncertainty Criterion; Thomsen et al., 2007) was considered appropriate in order to base the estimation of the burial dose on the population most likely to be well bleached (view results).

Environmental dose rates were calculated as a contribution of beta radiation derived from the radionuclide activity concentration,

Table 1

Measurements of the impact traces documented on the basin and their correlation with polished stone axes.

	N	Minimun	Maximun	Mean	Standard Dev.	Coefficient of Variation (CV)
Impact traces	144	24.5	89.0	45.53	9.52	20.9 %
S	84	24.5	62.0	45.0	8.36	18.5 %
N	16	32.0	63.3	39.52	8.75	22.1 %
E	18	30.7	89.0	45.11	14.55	32.2 %
W	25	35.6	65.6	51.0	6.33	12.4 %

determined by high resolution gamma spectrometry (HPGe) and gamma radiation measured in-situ with a NaI portable scintillator.

Bayesian modeling was applied to maximize precision in the chronometric data, employing two distinct chronological approaches: the widely established "Phase Model" (Bronk Ramsey, 2009) and the more recently developed "Event Model" (Lanos and Philippe, 2018). While both methods are aimed at reducing uncertainty in the observed estimates (among other advantages), their primary difference lies in their underlying assumptions. The "Phase Model" assumes the existence of a continuous process within which the dated events are situated, typically following a uniform distribution. This process is bounded by start and end events that are also estimated alongside the observed dates. In contrast, the "Event Model" establishes a single event, potentially dated using multiple determinations (even from different dating methods), and consequently assumes contemporaneity among the dates obtained from this event.

The modelling was conducted using the software packages OxCal 4.4 (Bronk Ramsey, 2009) and ChronoModel 3.2.7 (Lanos and Philippe, 2018), employing Gaussian likelihoods and taking 2021 as the reference year for the OSL estimations. Specifically, the OxCal model was implemented using a uniform "Phase Model," in which the dates were introduced by the C_Date command, while the "Event Model" was

implemented as a single event incorporating the two OSL dates.

5. Results

5.1. Lithological and structural analysis

The Matarrubilla basin is carved from a single block of a very heterogeneous cataclasite formed by lithic fragments of diverse size and compositions (dolomites, limestones, gypsum, etc.), surrounded by a banded and foliated gypsum-rich matrix. This rock could be considered as a "foliated cataclasite" sensu Chester et al. (1985) (Fig. 6). This lithofacies is composed of breccias of red clayey matrix, cemented by gypsum, which include millimetric to centimetric sized lutites, gypsums, sandstones, ophites and carbonates (Fig. 6B and C). With a banded arrangement with mylonitic or cataclastic foliation, depending on whether it develops in gypsum or in more rigid materials (Pérez-Valera, 2005). The tectonic nature of this rock is evidenced by stretched and broken levels (boudins) of lithic fragments included in a foliated gypsum matrix. These later sometimes show asymmetric rotated forms suggesting a tectonic movement, tension veins and S-C structure. The matrix locally shows a mylonitic appearance, with the development of asymmetric folds in layered of gypsum, stretching lineation in gypsum

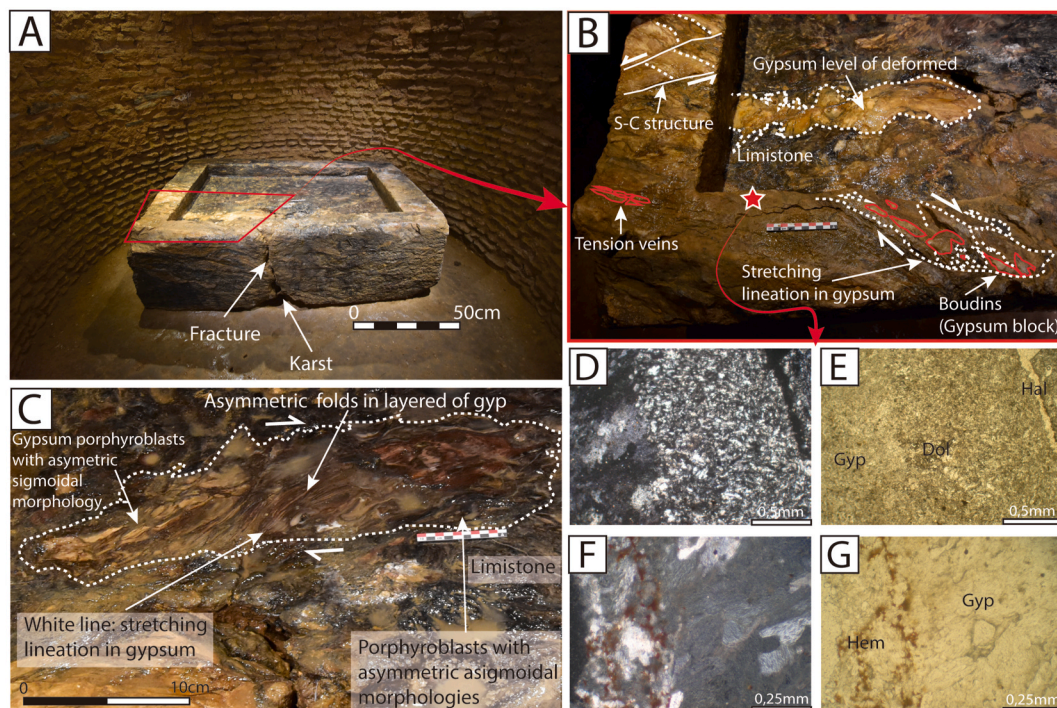


Fig. 6. Lithological and petrographic analysis. General view of the basin inside the Matarrubilla tholos chamber, with the location (red box) of the detailed part in B. Note the fracturing and dissolution (karst) in its favour; B-C. Representation of the tectonic deformation structures and fabric. The red star is the area chosen for the thin section; D-G: Photomicrographs of tabular gypsum microcrystals (Gyp), -some idiomorphic-, in irregular reticular texture, as well as some inclusions of dolomite (Dol), hematite (Hem) and small veins filled with halite (Hal) in subparallel fibers oriented perpendicularly to the tectonic banding. The photos in the left column are taken between crossed nicols and those on the right without crossed nicols (Figure by J.A. Lozano Rodríguez).

and porphyroblasts with asymmetric sigmoidal morphologies (Fig. 6B and C).

Under the microscope, the gypsum matrix appears essentially as an intergrowth of irregular millimeter-sized crystals (Fig. 6D–G). This texture is commonly attributed to the replacement of anhydrite. Gypsum is also observed filling pressure shadows and tension veins. Finally, clasts of dolomites and small scattered nuclei of pelitic material are frequent.

The other block located at the entrance of the tholos is also composed mostly of gypsum and has the same lithological characteristics as the basin.

5.2. Morphometric analysis

The photogrammetric reconstruction of the basin (<https://skfb.ly/oNYwV>) shows that it is an almost perfect rectangular parallelepiped with a lowered rectangular-shaped depression on its upper side. The 3D model confirms that the block measures between 1.71 and 1.73 m in length, 1.22–1.25 m in width and 0.48–0.50 m in height, giving a total volume of 1.08 m³. However, the cut area of the inner depression measures 0.86–0.90 x 1.33–1.34 x 0.07–0.10 m, which determines a (negative) volume of 0.12 m³. Therefore, the volume of the carved basin is 0.93 m³. The approximate weight of the block has been estimated based on its volume multiplied by the average density of gypsum (2.32 g/cm³), which results in about 2227 kg. If the block is considered to have some dissolution voids, its actual exact weight could be somewhat less, but more than 2000 kg.

5.3. Manufacturing technology: tools and carving

The Matarrubilla stone basin is in a final context of deposition and, probably, has a long history of use, making it difficult to recognize the first phases of production. The only traces that can be used to reconstruct the technology deployed for its original manufacture are those not eliminated by the regularization processes or by subsequent use-wear and/or post-depositional factors. In the same way, the traces present cannot be directly connected with the initial stages of its making or with subsequent transformations.

In those areas where the surface was not regularized through abrasion and polishing the basin presents different traces of manufacturing (Fig. 4 A). The traces identified and studied are those of the external configuration and the depression within the inner basin. Those related to

the levelling of the exterior part were produced through the removal of material with a cutting-edge tool, which after successive impacts regularized the surface (Fig. 4 1 and 2). This basin is unique in the context of Iberian megalithic phenomenon, both for its rectangular morphology and for its soft lithology, and has very few parallels in Europe, none of which can be used comparison as they have not been studied with the approach followed here. The traces resulting from the carving of this basin resemble the marks left on wood by sharp-edged stone tools such as axes and adzes. Experiments with axes and adzes in woodwork show this type of traces (López et al., 2012; Elburg et al., 2015), and similar traces have been recorded on archaeological examples of later prehistoric worked wood (e.g. Palomo et al., 2013; Rybníček et al., 2018; Fermé et al., 2021; Muigg et al., 2023; Martínez-Sevilla et al., 2023; Gibaja et al., 2024). The finish on the edges of the basin shows the same type of marks as those produced on hardwoods with oval convex areas with soft edges superimposed in the same direction of work (Fig. 4B and C and D). The marks of the inner depression are of the same type, but when the inclination of the tool changes, it generates elongated traces produced by the impact of the edge of the cutting tool (Fig. 5 A). In this case the convexities are smaller, forming an area with an acute angle at the end whose section has allowed us to define the orientation of the blows during the carving work (Fig. 5 B).

To correlate these marks with a specific tool, the dimensions of the marks on the basin (Supplementary Fig. 1 and Table 1) were compared with the edges of later prehistoric polished tools from southern Iberia. The width of the marks in the different areas of the basin coincides with the average width of the edges of polished stone tools (Fig. 7). The comparison with copper axes was ruled out since these generate elongated and flat non-convex rectangular marks (Blackwell, 2020). The use of copper chisels that create regular surfaces without deep marks on the surfaces was not considered (Stocks, 2022) as the OSL results (described below) suggest the basin was made before any metallurgy had developed in Iberia. Indeed, the fact that thin morphologies of less than a centimetre thick and the absence of traces of violent impacts on hard materials on the edges (Ruiz-Taboada et al., 2019; López Rodríguez et al., 2021) make implausible the use of copper axes for stonework supports the OSL results.

Based on the technological traces identified and the statistical comparison of their dimensions with the edges of stone polished axes and adzes, the most plausible tool for the external configuration of the basin and the creation of the interior depression within the basin is a polished stone adze. These tools are made from massive and solid rocks of

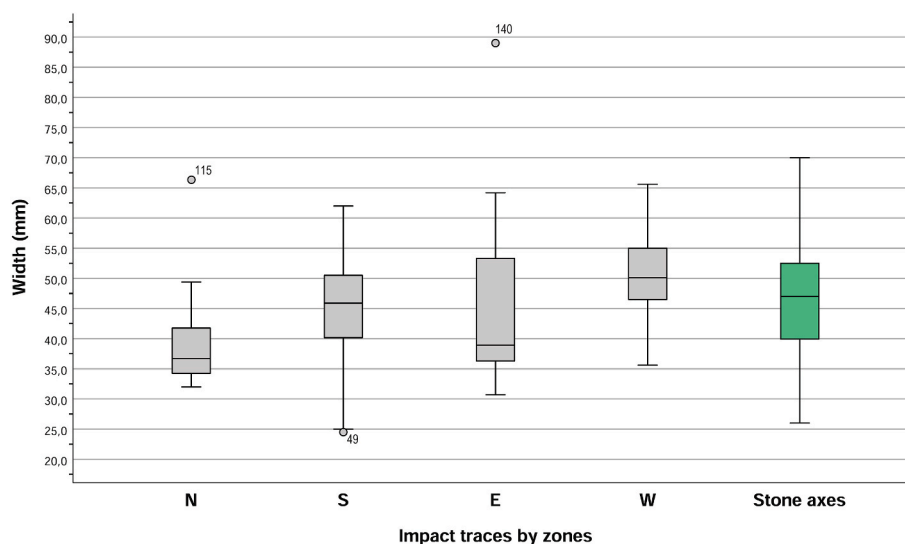


Fig. 7. Comparison of the width of impact traces by zones with polished stone axes from Late Prehistory sites (Data in Supplementary Table 1) (Figure by F. Martínez Sevilla and M. Díaz-Guardamino).

volcanic or subvolcanic origin that make them very resistant to violent blows (Lozano Rodríguez et al., 2017) such as those needed to carve the basin.

The widths of the traces within the inner depression of the basin and their Coefficient of Variation (CV) indicate that the work was probably carried out with the same tool or tools whose edge was similar in width (Table 1). Depending on the groupings of marks made, the CVs vary from 12.4 % to 32.2 %. Of the total of 144 impact traces measured, the CV is 20.9 %, which indicates a strong standardization of the measurements, even more so if one considers that these are impact traces that are, in some cases, worn.

Regarding the direction of the impacts, the traces in which its orientation could be reliably determined and the most eroded traces, suggest that the work of carving the depression within the basin was carried out from all possible directions (Fig. 4. C). Considering the position occupied by the basin in the main chamber of the tholos next to the west wall, the inner depression must have been made outside the monument or before its construction, which, again, is concomitant with the results of the OSL dating. Repetitive impact actions with a heavy tool could not have been effectively carried out in the current position occupied by the basin, within the tholos chamber.

In summary, the traceological evidence, both morphological, metric and its orientation, reveals that the basin was carved with a polished adze, probably with just one type of tool, and outside its current location or before the construction of the tholos.

5.4. Image analysis

Image analysis was used to test for the presence of pigments on the basin. Abundant intentionally-applied red pigment made of cinnabar has been documented on the slabs and floors of monuments such as Montelirio and Structure 10.042–10.049 (García Sanjuán et al., 2024). Pixel values forming their bands (Red, Green and Blue) are highly correlated to each other, so they are, a priori, useful to differentiate very minor elements in the image, such as paints intentionally applied on the rock.

As an example, the correlation coefficient matrices between bands give values that fluctuate between 0.85 and 0.98 in one of the cases (Table 2.1) or between 0.99 and 0.93 in the other (Table 2.2).

The pseudo-colour images produced, either by using the three bands produced by Principal Component analysis or by weighting any of them, did not reveal any coating or painted motif, or remains of sprayed pigment that would suggest that the basin was intentionally decorated (Fig. 8).

5.5. OSL dating

Two OSL samples were taken from sediments lying underneath the basin (Fig. 9). Given the limitation of space to access under the basin and the 5 cm diameter of the sampling tubes, it was assumed that sediment in the tubes would have grains with different degrees of bleaching (i.e. the

Table 2

Correlation coefficient matrix between image bands. 2.1 top, image DSC_5331. 2.2 below image DSC_5333.

Table 2.1			
	R	G	B
R	1.00000000	0.92132785	0.84754689
G	0.92132785	1.00000000	0.98136314
B	0.84754689	0.98136314	1.00000000

Table 2.2			
	R	G	B
R	1.00000000	0.96574389	0.92678106
G	0.96574389	1.00000000	0.98712268
B	0.92678106	0.98712268	1.00000000

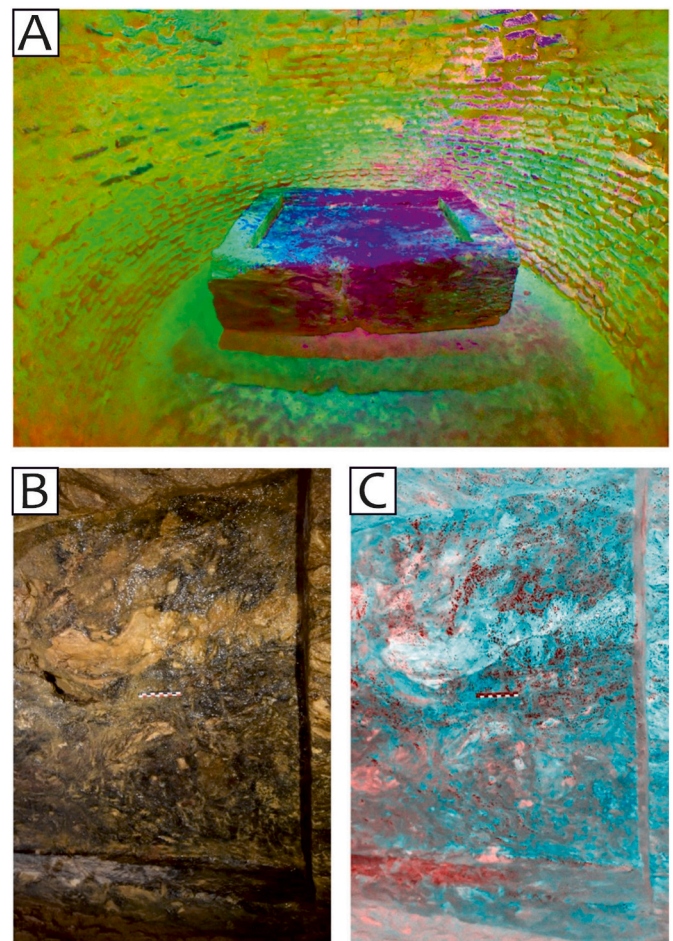


Fig. 8. Image analysis of the Matarrubilla basin. A. Pseudocolour of image 5333 (Fig. 2 B) using the PC bands (combination 321); B. Image 5331, detail of the central area; C. Pseudocolour of image 5331 using the PC bands (combination 322). The reddish spots correspond to the shine of water droplets (Figure by M.A. Rogerio-Candelera).

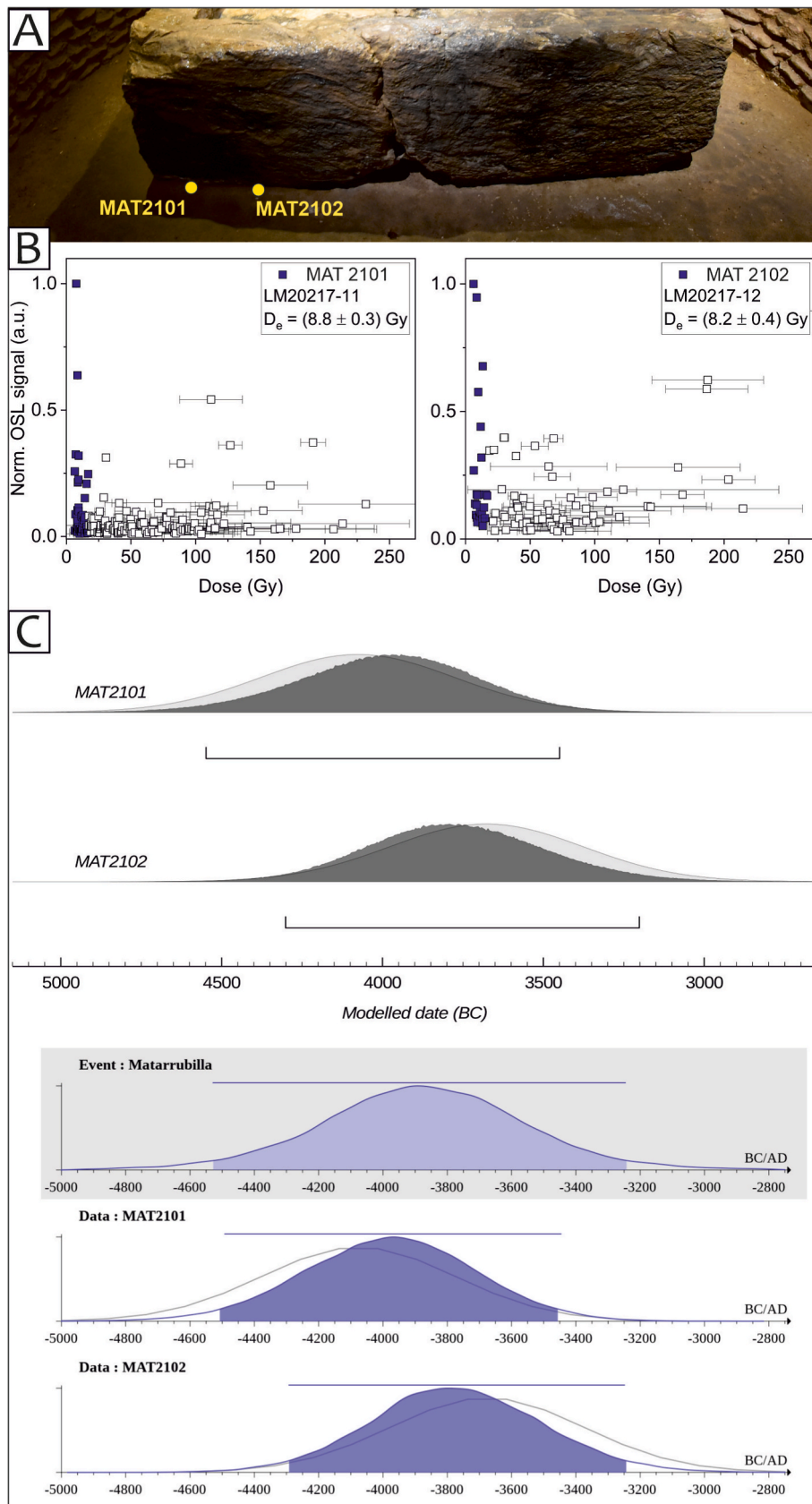
grains at the uppermost 1–2 cm of the sediment, would have been exposed to light until the basin was placed shielding daylight, while grains at a lower stratigraphic position, would have been shielded from daylight at the time they were deposited after their last transport event, previous to the time the basin was placed).

The two OSL ages obtained from these samples yielded ages of 4100 ± 300 BCE and 3700 ± 300 BCE. Estimated burial doses, dose rate and derived ages for the two samples are summarized in Table 3, and dose distribution of quartz single grains in Fig. 9.

In general terms, the results of the two Bayesian models yield similar posterior estimations for the OSL dates, effectively constraining their temporal uncertainty (Table 4, Fig. 9). The Bayesian approach reduced the chronological dispersion (standard deviation) of the individual dates, from 300 years to approximately 270 years, and dated the event of the basin placement between 4549 and 3203 BCE (95.4 % HDP) in the “Phase Model” and between 4516 and 3231 BCE (95.4 % HDP) in the “Event Model.”

These two dates must represent a single contemporaneous event, since the basin emplacement must have occurred in one construction episode. Thus, the estimated parameters suggest consistent inferences about this episode. Despite the extreme dispersion in the start and end events of the “Phase Model” (Table 4) closely align with the combined distribution of the “Event Model” (4544–3227 BCE, 95.4 % HDP) (Table 4 and Fig. 9), reinforcing the reliability of the Bayesian modeling.

In summary, according to the OSL ages, the basin must have been



(caption on next page)

Fig. 9. OSL Dating. A. Location of the samples for OSL under the Matarrubilla basin; B. Dose distribution derived from the OSL measurement of quartz single grains. The plots show the OSL signal as a function of the individual doses and corresponding uncertainties. Blue icons indicate the values included in the dose estimation and derived age. White icons indicate the values discarded from the age estimation based on the IEU approach; C. Results of the Bayesian model for the OSL dates. Upper panel: Distributions of the modeled and unmodeled dates (gray fill and transparent gray fill, respectively) according to the OxCal “Phase model”. Lower panel: Distributions of the combined event and the modeled (blue line) and unmodeled (gray line) individual dates according to the “Event model”. The blue fill represents the 95.4 % HPD interval of the modeled dates (Figure by Alicia Medialdea, Jonàs Alcaina-Mateos and final design by L.M. Cáceres Puro).

Table 3

Summary of the results from OSL dating including the estimated burial dose, environmental dose rate and derived burial age (1-sigma). The laboratory and field codes are also reported.

Sample	Lab code	Dose rate (Gy/ka)	Burial dose (Gy)	Age (ka)
MAT2101	LM20217-11	1.45 ± 0.06	8.8 ± 0.3	6.1 ± 0.3
MAT2102	LM20217-12	1.45 ± 0.06	8.2 ± 0.4	5.7 ± 0.3

Table 4

Results of the Bayesian model for the OSL dates.

Model	Sample	95.4 % HPD interval	median value	σ
Phase model	MAT2101	4549–3450	3980	274
	MAT2102	4302–3203	3775	273
Event model	MAT2101	4516–3443	3977	268
	MAT2102	4303–3231	3776	267
Phase model	MAT2101	4549–3450	3980	274
	MAT2102	4302–3203	3775	273
Event model	Start-End	9275-3504/4247-1531	4457/3302	
	MAT2101	4516–3443	3977	268
Event model	MAT2102	4303–3231	3776	267
	Combined even	4544–3227	3876	

placed on its current position at some point between 4544 and 3227 BCE. This chronology is significantly earlier than the conventionally accepted age range for tholoi in southern Iberia. In Valencina, the earliest dated tholos monument is Montelirio, which, according to a series of 43 radiocarbon dates (García Sanjuán et al., 2018, 2025), was probably built between 2850 and 2700 cal BCE. La Pastora appears to be a later monument, built sometime between 2700 and 2400 cal BCE (García Sanjuán et al., 2018). Within southern Iberia, the earliest burial activity in tholos-type monuments correspond to the site of Los Millares (Almería, south-east Spain), with various dates on human bone ranging between c. 3400 and 2900 cal 2 σ BCE (Aranda Jiménez et al., 2020). Therefore, if the Matarrubilla basin was set in place between 4544 and 3227 BCE, as pointed out by the OSL ages, that would have occurred quite some time before the earliest tholos monuments were built, either in Valencina, or in southern Iberia at large. This suggests that the Matarrubilla stone basin having been made and used before the Matarrubilla tholos was built. The implications are discussed below.

5.6. Gypsum outcrops closest to Valencina

As was explained before, outcrops of gypsum or gypsum-based mélanges are only found on the left side of today’s Guadalquivir River, or in what 5000 years ago were the Eastern shores of the marine gulf that extended over what today is the river’s lower valley (Fig. 3). In this context, although there are some outcrops somewhat closer, they are dominated by clayey terms while the gypsum is scarcer and discontinuous. Thus, the nearest suitable outcrops have been located some 8.5 km to the east-southeast of the modern town of Las Cabezas de San Juan (province of Sevilla), some 55 km to the south-east of Valencina as the crow flies. In these outcrops, fragments of gypsum of variable size (from a few centimetres up to over a meter) and other carbonate lithologies in a marl-gypsum matrix can be found, which resemble the mélange described by Pérez-Valera et al. (2017). The gypsum fragments are banding and very deformed, with white, red and black colour

(Fig. 10). At some points, heterogeneously, layers of limestone and dolomite several meters thick, and difficult to ascribe, have been recently quarried away. About 10 km further to the south, ophite outcrops can be found in connection with this formation. Given their hardness and resistance, these subvolcanic rocks, of Triassic age, were locally exploited in the Neolithic and Copper Age to manufacture macro-lithic tools used in quarrying and mining (Morgado and Lozano Rodríguez, 2011).

Further to the East, the mélange, mostly made of gypsums, become more obvious, abundant and continuous. Between 65 and 70 km to the south-east of Valencina, as the crow flies, near the modern towns of Morón de la Frontera and Coripe (province of Sevilla) the gypsums are so massive, that they have been quarried in recent times, and in some cases they still are. These masses of gypsum present a thick stratification with layers of primary origin and variable colours (Fig. 10): white, black, reddish and orange-ish. The layers sometimes present an intense deformation, with marly levels and inclusions of carbonate pebbles. Altogether, this formation can be several meters thick, according to what can be observed in some of the recent and contemporary quarries in the area.

6. Discussion

The results presented in this study reveal several new aspects concerning the Matarrubilla stone basin, and the monument as a whole.

Uniqueness. A century after its discovery, the Matarrubilla basin still stands as the only megalithic stone of its kind in Iberia. Stone basins are rare even across European megalithic contexts. The most obvious parallels are found in Ireland and, to a lesser extent, Malta (Obermaier, 1919). Ireland records the majority, with twenty-five examples from sixteen sites (Shee Twohig et al., 2010), most concentrated in the Brú na Bóinne and Loughcrew complexes. The great megalithic temple at Newgrange, built around 3200-3100 BCE, stands out with four basins of varying shapes and layouts, one of them is rectangular in shape, like the one in Matarrubilla. Knowth has an especially elaborate example with carved decoration, possibly positioned before the passage was built (Hensey, 2015). These Irish basins are often interpreted as receptacles for human remains (O’Kelly, 1982; Stout, 2002), with hemispheric shapes resembling saddle querns, which were widely used by Neolithic communities for grinding (Stout and Stout, 2008).

In Malta, although less frequent, stone basins are also associated with megalithic monuments. At Tarxien, a large stone bowl was placed in the first apse left of the central temple (Trump, 2002), and at Kordin III, a oval limestone block with seven carved basins—referred to as a ‘trough’—stood prominently on the central court of the western temple (Vella, 2004), likely used in ritual liquid handling.

Obermaier (1919) mentioned possible Iberian parallels, including dolmen de Soto, but these do not resemble Matarrubilla basin in shape or size, nor with any of those mentioned from Ireland and Malta. Therefore, the Matarrubilla stone basin stands as a singular architectural and ceremonial feature within Iberia. Whether it shares origins or influence with Irish or Maltese examples remains uncertain, though its dating may offer critical insights, as discussed below.

Special lithology. The Matarrubilla stone basin is not only unique on account of its morphology, likely used (as an altar) and context (as part of a magnificent monument), but also because of its special lithology. The gypsum mélange it was made of has not been reported for any other megalithic monument at the Valencina mega-site (where a wider range

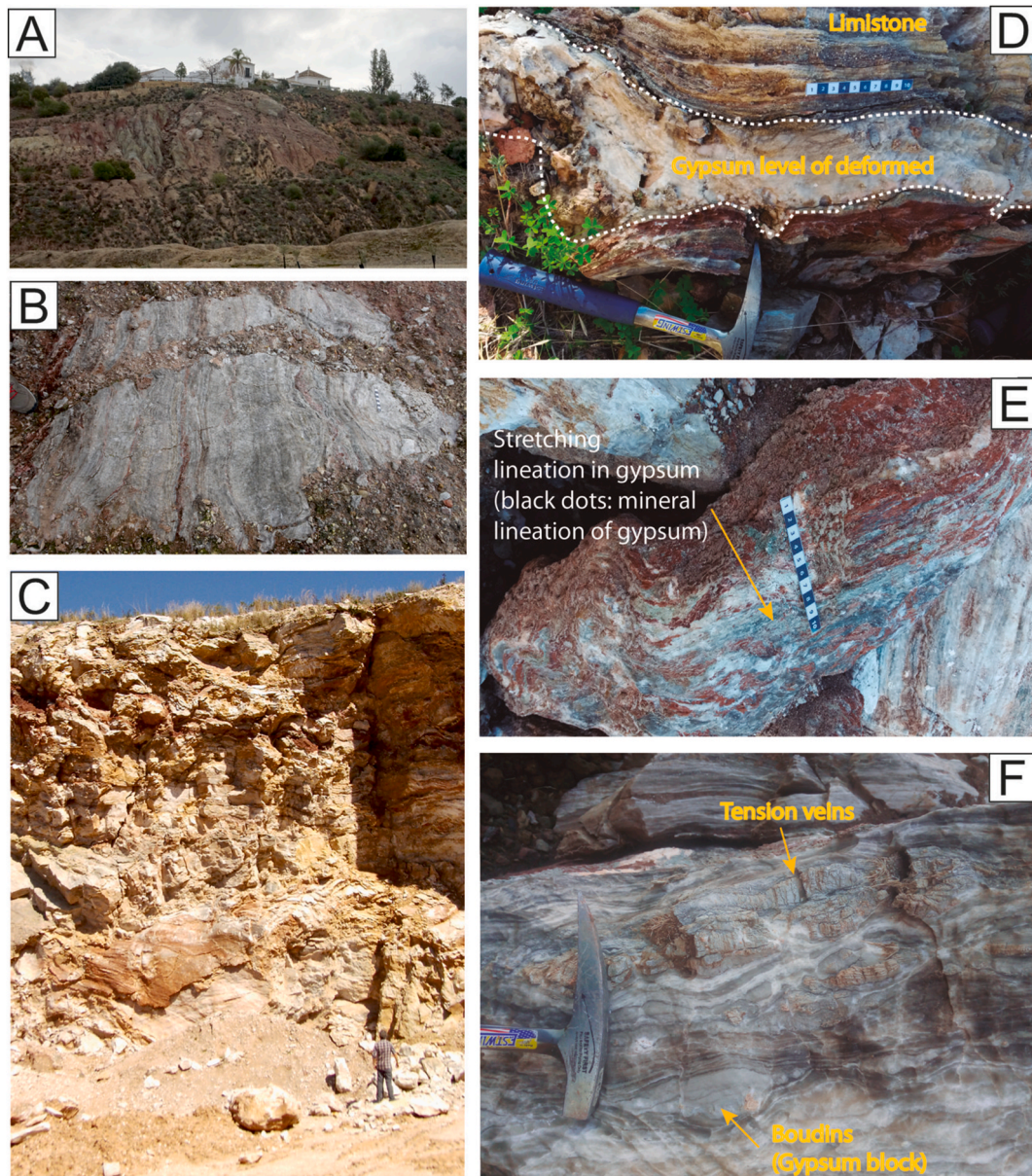


Fig. 10. Outcrops of gypsiferous cataclasite (mélanges). A. Gypsum and limestones quarry; B. Gypsum mélanges with metric blocks, both A and B in the area around Finca el Concejo (Cabezas de San Juan - Sevilla). C. Gypsum quarry in Coripe (Seville); D, E and F. Gypsiferous cataclasite in Coripe with different degrees of deformation similar to those observed in the pile (Fig. 6B and C) (Figure by L.M. Cáceres Puro, J.A. Lozano Rodríguez and T. Donaire Romero).

of stones were used), or Iberia as a whole. This rock has special visual qualities, with a banding, sometimes folded, in different colours and degrees of crystalline brightness. The multi-colored nature of the rock, with tones of dark green, white and red, must have made it quite appealing, both symbolically and aesthetically. It is important to note that green, red and white (as represented, respectively, by variscite, jadeite and slate, red conglomerates as well as cinnabar and iron pigments and quartz and limestones) are the most pervasive colours associated with megalithic architectures in southern Iberia (García Sanjuán et al., 2019b). This is consistent with previous studies that have revealed the importance of colours in megalithic architectures across Europe (Bueno Ramírez and De Balbín Behrmann, 1997; Jones, 1999; Owoc, 2002; Scarre, 2002; Rojo Guerra et al., 2005, 2013; Bueno Ramírez et al., 2015; etc.). In the image analysis carried out, no traces of paint or pigments used to decorate the basin were found, which reinforces importance given to the rock as such, with its “natural art” and explain its singular choice among the set of rocks available at medium and long

distances. In addition, the gypsum mélange is a relatively soft and moderately compact rock, which makes it suitable for quarrying and carving work executed with stone tools. On account of the relative softness of the material, however, the basin shows evidence of substantial dissolution on its lower and back sides (mostly not visible today).

Provenance and water transportation. All the rocky outcrops of this nature are on the other side of the Guadalquivir (southeast). Therefore, it seems that some kind of boat or raft was used to transport the basin across the gulf or the river to its location in Valencina (Fig. 11). The most suitable source is those found at Finca del Concejo, near Las Cabezas de San Juan, approximately 55 km from Valencina. Although the gypsum blocks there are fractured and mixed, blocks of sufficient size have been identified. This location benefits from its proximity to both the archaeological site and, above all, its proximity to the old gulf shore at the mouth of the Guadalquivir. Some 10 km to the NW or 14 km to the W of the outcrops found, the coastline reached in the Flandrian

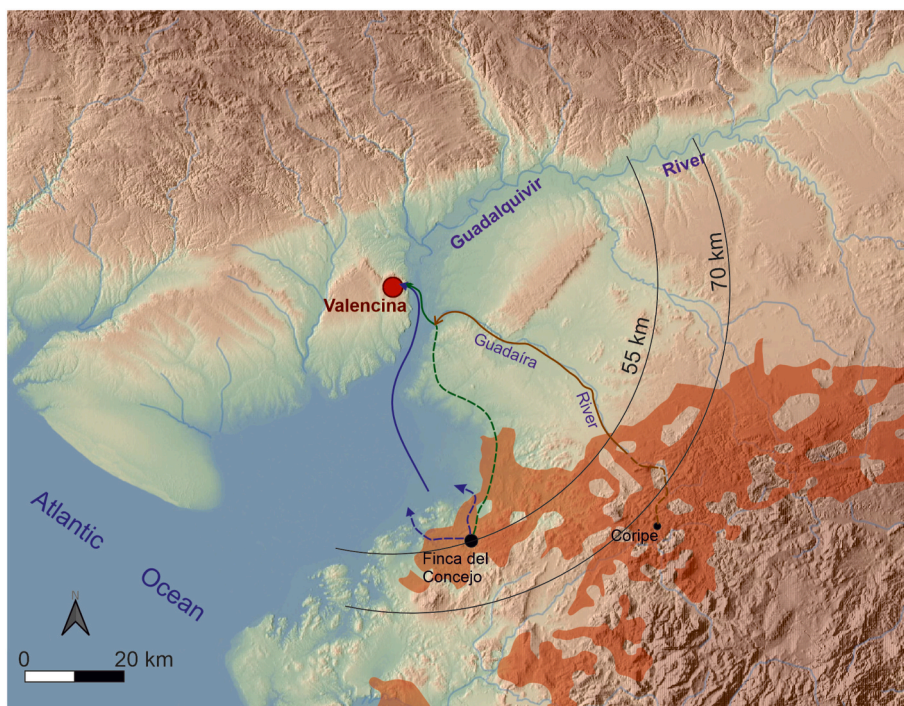


Fig. 11. Map showing the approximate location of the mouth of the Guadalquivir in the 4th millennium BCE, with the representation, in red, of the gypsum outcrops and the distances to the Valencina mega-site. Possible routes from the basin to Valencina: in blue, from the area around Finca del Concejo by land (dashed line) to the paleobay at the mouth of the Guadalquivir and, from there to near Valencina by boat (continuous line); in green, from the same starting point bordering the bay by land (dashed line), to the mouth of the Guadaíra River and, from there, crossing the Guadalquivir estuary by boat to near Valencina (continuous line); in brown, from the vicinity of Coripe, following the course of the Guadaíra River, in a first stretch by land (discontinuous line) until overcoming the steepest terrain and coming out onto the plain, where perhaps with greater flow some it would be possible to use some kind of boat until its mouth, and from there the same as the green route (base map art by Francisco Sánchez Díaz and final desing by L.M. Cáceres Puro).

maximum, currently delimited by the Guadalquivir marshes, would be located. In this way, it would have been easier to reach an access to load the stone onto a boat or raft and from there to the closest shore in Valencina site (Fig. 11).

Another potential source is the area around Coripe, 72 km away in a straight line from Valencina. There the outcrops of gypsiferous cataclasite are more massive but the route is more challenging. The Guadaíra River might have provided a partial overland and water route (Fig. 11), but its low flow today suggests it was unlikely to have been navigable. Thus, a source closer to the bay remains the more plausible option. In addition, the structural and lithological weakness of the rock would discourage a longer overland journey.

The stone weighs more than two tons, which would still have been within the limits of what could be manageable by boat at the time. Once on the western shore, below the El Aljarafe plateau, the block would have been dragged 3 km uphill to its final location in Valencina, likely using a sledge pulled by people and/or oxen (Lozano Rodríguez et al., 2024).

This form of water transport aligns Valencina with other major prehistoric ceremonial sites such as Stonehenge, Newgrange, and Carnac, where special stones were also brought from distant sources, in some cases probably by water (Landström, 1970; Hazell and Fitzpatrick, 2006; Stout and Stout, 2008; Parker Pearson, 2012; Cassen et al., 2019; Parker Pearson et al., 2024). Evidence supports the existence of Neolithic seafaring technology capable of such tasks (Gibaja et al., 2024). There is even evidence of complex vessels as early as the Upper Pleistocene in Southeast Asia (Fuentes and Pawlik, 2025) and possible sailing vessels in the Neolithic-Chalcolithic Mediterranean (Morgado et al., 2018; Morgado-Rodríguez et al., 2025).

Chronology: According to OSL dating and Bayesian modelling, the Matarrubilla basin was placed on its current position between 4544 and 3227 BCE, pre-dating the expected timeline for tholos-type monuments,

which in Valencina appear around 3000–2900 cal BCE, and slightly earlier than in Los Millares, between c. 3400 and 2900 cal BCE. The construction date of the Matarrubilla tholos as such has ever been obtained, but its architectural characteristics more similar to La Pastora, dated to 2700–2400 BCE, than Montelirio, probably built around 2850–2700 BCE (García Sanjuán et al., 2018). These findings suggest the stone basin may have been in place before the tholos was constructed, potentially as part of an earlier, undocumented monument. In this respect, very little is known about activity at Valencina prior to the start of the Copper Age c. 3200 cal BCE. One burial outside the main corridor of the Montelirio tholos yielded an age of 4727–4547 2σ cal BCE, therefore unrelated to this monument.

The installation of the basin pre-dating the construction of the Matarrubilla tholos is also supported by the way its central area was carved, from all directions—indicating it was shaped before being enclosed by the walls of the chamber—and the impracticality of moving such a large stone through the tholos’s narrow and long (30 m) corridor. Thus, the basin was likely created and perhaps used before the tholos chamber was built around it.

On-site burial or ritual activity prior to the construction of major megaliths is well attested in southern Iberia, including cases such as Menga (Antequera, Málaga) (García Sanjuán et al., 2023), Soto (Trigueros, Huelva, Spain) (Linares Catela and Mora Molina, 2015, 2018) or Alcalar 7 (Faro, Portugal) (Díaz-Guardamino, 2004). In the 4th and 3rd millennia BCE, most major megalithic monuments were built on locations that had a previous history of cult and frequentation. Matarrubilla appears to be one of them.

Social significance. The fact that the Matarrubilla stone basin was transported across the marine gulf east of Copper Age Valencina enhances our understanding of its symbolic and social significance. A significant body of evidence suggests that Valencina operated as an ‘aggregation place’, a central place that congregated people from a large

territory across south-western Iberia, and perhaps beyond. This centrality is evidenced by the large quantities of non-local and exotic materials found at the site, such as flint, variscite, rock crystal, ivory, ostrich eggshell, amber and cinnabar (García Sanjuán et al., 2017). The early transportation of the basin would fit into this context of an initial state of development of the site as a place of congregation and ritual importance, where communities living across what today is the lower Guadalquivir valley identified Valencina as central social and cultural focus. The lithological nature of the basin, a multicoloured gypsum melange, that has not been reported for any other of the megalithic monument at the site, adds to the 'uniqueness' of Matarrubilla. In fact, although Matarrubilla, Montelirio, and La Pastora, the three best known megaliths of the site, share the general tholos-type structure, each displays unique architectural features, orientation and symbolic elements.

The influx of materials and people made Valencina a central place, a major focus of social life in 3rd millennium BCE Iberia. To put it metaphorically, what made Valencina the 'crucible' in which specific identities from communities scattered across a large territory were forged into a broad, powerful, lasting and remarkable single block of human experience.

7. Conclusion

The Matarrubilla basin is an exceptional piece of peninsular prehistory. It is so both for its morphology (almost perfect rectangular parallelepiped), manufacture (worked with polished stone adzes to give it its final shape) and size (1 m³ and 2000 kg of weight), and for its lithology (gypsiferous cataclasite), which was not hidden or highlighted by any type of pigment. But it is also due to the dates obtained for its placement (4544–3227 BCE, 95.4 % HDP), prior to that of the main megalithic monuments of the Valencina megasite and, therefore, prior to the construction of the monument that houses it. The location of the outcrops of this peculiar rock located south of the Guadalquivir River undoubtedly implies the use of some kind of boat to transport it to Valencina, whatever the route used, which must have taken place between the 5th and 4th millennium BCE. All this points to the complexity of the megasite and, once again, that of the society that occupied it, even at a date prior to its maximum activity in the Copper Age.

CRedit authorship contribution statement

Luis M. Cáceres Puro: Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Conceptualization. **Teodosio Donaire Romero:** Writing – review & editing, Investigation, Conceptualization. **José Antonio Lozano Rodríguez:** Writing – review & editing, Visualization, Investigation, Conceptualization. **Marta Díaz-Guardamino:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Francisco Martínez-Sevilla:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Alicia Medialdea:** Writing – original draft, Visualization, Methodology, Formal analysis. **Miren del Val:** Writing – original draft, Visualization, Methodology, Formal analysis. **Jonàs Alcaina-Mateos:** Writing – original draft, Visualization, Formal analysis. **Joaquín Rodríguez-Vidal:** Validation, Funding acquisition. **Fernando Muñoz Guínea:** Writing – review & editing, Investigation. **Juan Manuel Vargas Jiménez:** Writing – original draft, Investigation. **Miguel Ángel Rogerio-Candelera:** Methodology, Investigation, Formal analysis. **Leonardo García Sanjuán:** Writing – review & editing, Writing – original draft, Validation, Investigation, Conceptualization.

Data availability statement

All data and results are provided in the manuscript and the Supplementary Materials.

Declaration of generative AI and AI-assisted technologies in the writing process

No AI-assisted technologies were used in the preparation of this article.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jas.2025.106263>.

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