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Review

Prehistoric engineering and astronomy of the great Menga Dolmen (Málaga, Spain). A geometric and geoarchaeological analysis

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ABSTRACT

The Menga Dolmen in Antequera (Malaga province, Spain), measuring 27.5 m long and composed of 32 large stones, is recognized as possibly the largest megalithic burial monument of Prehistory. However, until now, no studies of Menga have ever been internationally published. This article, while aiming to be the first is also the first geoarchaeological and geometric analysis of this a monument of this kind. The purpose of this analysis is to combine the results of the geological study of Menga (identification and description of the rock used in its constructions) with those of the geometric design survey. The results show a detailed understanding of the architecture and engineering among the dolmen builders, and what is most important, as well as novel, a clear and intentional asymmetry of the dolmen along its longitudinal axis. This asymmetry has a cultural background, evidenced in other similar monuments and may also be related to the orientation of Menga, traditionally set to a nearby geographical feature but also oriented to a certain chamber lighting during the summer solstice.

1. Introduction

The appearance of megalithic monuments is a pan-European phenomenon that originated in early communities of farmers and herders. Its most remarkable expressions appeared during the 6th and 5th millennia cal. BP, with the development of the large monuments, which often required the mobilization of an extensive labour force, as well as the deployment of previously unseen engineering and architectural knowledge. The southern Iberian Peninsula, particularly Spain, has a wide variety of megaliths that have been investigated since the late 19th century. The best known sites include individual monuments such as Soto (Trigueros, Huelva), Huerta Montero (Badajoz), and Alberite (Villamartín, Cádiz). Complex clusters of monuments associated with settlements such as Valencina de la Concepción (Seville), and Los Millares (Almería), as well as extensive megalithic landscapes such as Gorafe (Granada) or El Pozuelo (Huelva). (For recent reviews in English, see Aguayo de Hoyos and García-Sanjuán, 2002; García-Sanjuán and Ruíz González, 2009; Wheatley et al., 2010). Of all of these, the Antequera Megalithic Complex is possibly the most extraordinary.

The Antequera Megalithic Complex includes the Menga and Viera dolmens and the El Romeral tholos. Prominent among these three monuments, Menga can be considered one of the world's most significant expressions of the megalithic phenomenon, having a long history of research.

The earliest known written reference appeared in the 16th century is when César Ricario, bishop of Malaga, wrote about the "Cave of Menga" in a document signed in 1530. Afterwards, other references appeared from the 16th through the 18th centuries in different manuscripts about the history of Antequera, such as those noted by Agustin Tejada Páez in 1587, Alonso García de Yegros in 1609, Francisco de Tejada y Nava and Francisco de Cabrera at the beginning of the 17th century, and Rodrigo Méndez de Silva in 1675 (Escalante Jiménez and Fernández Paradas, 2003). References to this megalithic monument multiplied during the 19th century (for recent reviews, see Sánchez-Cuenca López, 2012; García-Sanjuán and Lozano, 2014, and references therein).

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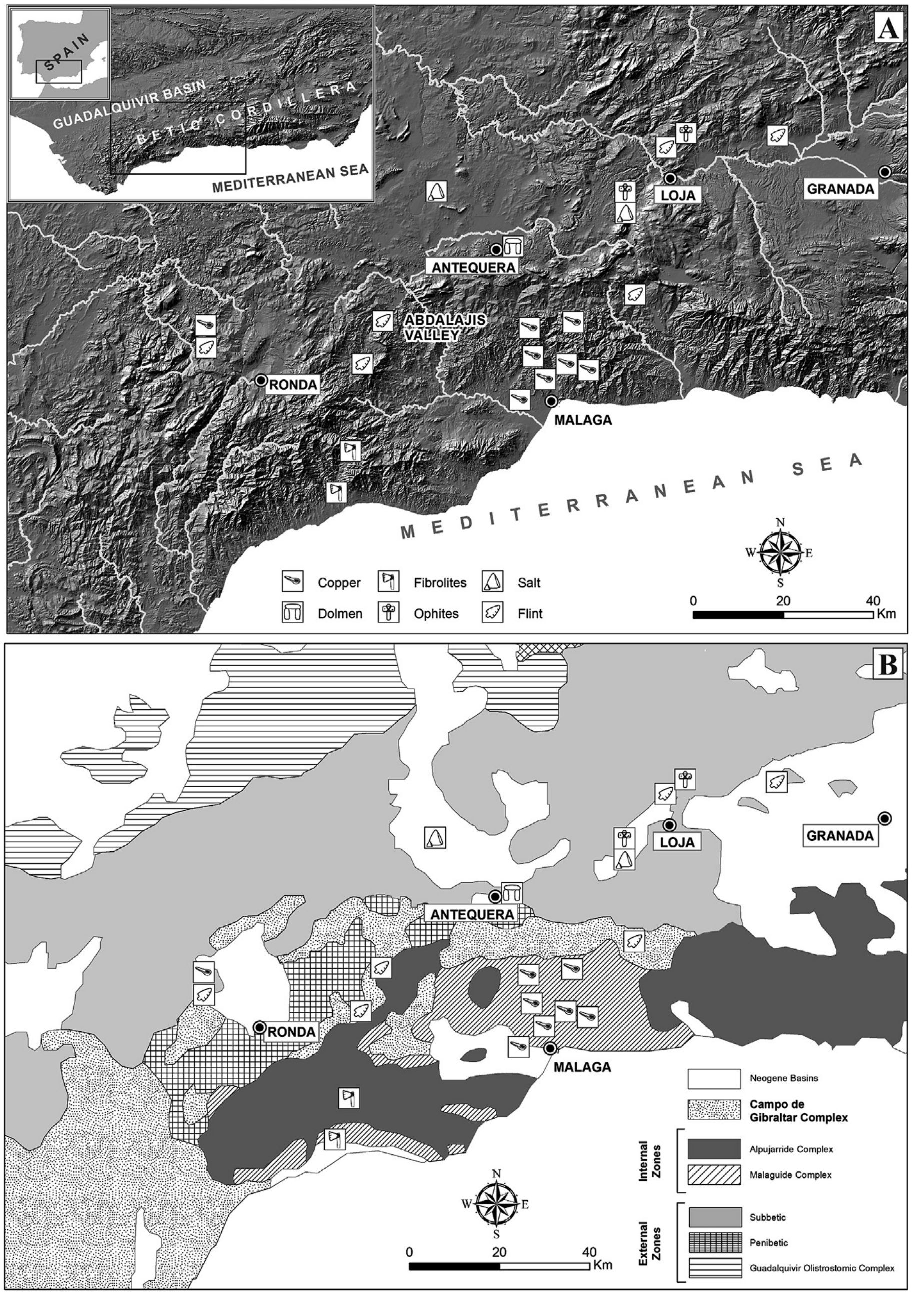

Fig. 1. Location of the Antequera Megalithic Complex, in relation to abiotic resources of its environment.

However, despite this long history of research, the architectural design of the Menga Dolmen has never been studied from a broad engineering perspective that analyzes its building materials, dimensions, and geometry. The present study follows this approach, based on a systematic geoarchaeological, archaeometric, and statistical analysis which, as discussed below, provides the basis for a new understanding of this extraordinary megalithic monument.

2. Description of the Antequera Megalithic Complex

2.1. Geographical and geological context

The Megalithic Complex of Antequera is located on the southern edge of the Antequera basin (Malaga province, Spain). Its geographic coordinates are latitude 37° 1′31.62″ N, longitude 4° 32′48.97″ W and it is situated at 500 m a.s.l. This area had a great strategic importance in southern Iberia, being the major connection point between the Guadalquivir valley and the Betic Cordillera. It is also the region where Mediterranean and the Atlantic influences meet in the southern Iberian Peninsula (Fig. 1).

Geologically, the entire Antequera basin is characterized by materials from the so-called "Triassic of Antequera" (Sanz de Galdeano et al., 2008; Pérez-Valera et al., 2011), the Middle Subbetic, and northern and southern Penibetic calcareous materials (Martín-Algarra, 1987). The Antequera basin is one of the post-orogenic basins of the Betic Cordillera. These basins started with common sea sediments, marls and diatoms in the Upper Burdigalian–Middle Miocene. Subsequently, by the end of the Serravalian, a new tectonic stage separated the Antequera basin, which was still under the sea level. The hilly relief surrounding the basin provided abundant detrital material, with a predominance of breccias, conglomerates, calcirudites, and calcarenites, materials from the basin edges. However, in more remote areas of the basin, smaller sediments with marls and sandy silts predominate. The Antequera basin is a low subsidence area, with sediments of some 100 m deep in the areas of higher accumulation (Serrano, 1979). During the Upper Tortonian and the Messinian, new tectonic stages rose to sea regressions that induced a continental-influenced regime in the basin. In Plio-Quaternary, endorheic basins with lake environments of detrital, carbonate, and evaporitic sedimentation were generated. During the Quaternary, alluvial fans developed on the edges of this basin, at the foot of the mountains. The alluvial fans frequently made contact with each other and they were anasthomosed until they generated glacis surfaces. Towards the centre of the basin, alluvial material accumulated, generating fluvial terraces.

The Menga Dolmen is located on top of detrital sedimentary materials from the Upper Tortonian (Serrano, 1979), with an abundance of sands, some lightly cemented, mostly uniform in size and subrounded. Varying thicknesses of polygenetic and heterogenetic gravels, as well as a few rather large blocks are found in these same materials. Moreover, there are also layers of low-energy shales. These sequences came about due to landfill processes in canals with erosive bases and upward coursing, many of them imbricated, this being typical of deltaic facies.

The Menga Dolmen is located close to the Viera Dolmen on top of a low hill on the north-eastern outskirts of Antequera. The entrance to the monument is oriented towards the north-east, with a panoramic view overlooking a large area that includes a mountain called Peña de los Enamorados and an extensive area of the Antequera basin (Figs. 2 and 3).

2.2. Natural resources available

The area around the Antequera Megalithic Complex is exceptionally rich in both biotic and abiotic resources. As a mineral resource, flint was of particular importance when the Antequera megaliths were built during the Neolithic and Copper Age. This flint is abundant in the north-east of the basin, mixed among the marble limestone materials of the Middle Subbetic, where several outcrops

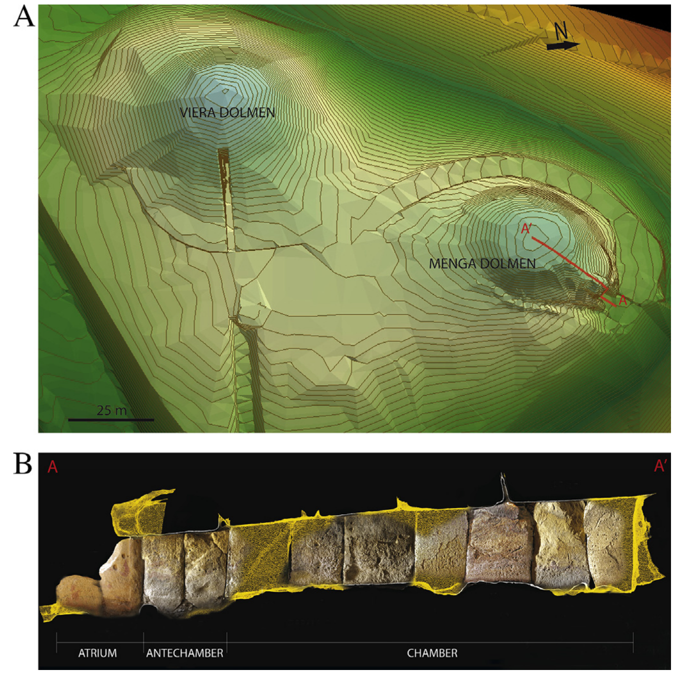

Fig. 3. A. Map of equidistance curves of Viera and Menga mounds. B. Menga Dolmen (cut A, A′): The orthostats of the chamber differ from the rest (antechamber and atrium).

of flint mines have been documented (Milanos-type flint). These mines were worked during the Neolithic (Morgado and Roncal, 2009; Morgado et al., 2011; Morgado and Lozano, 2011a). There are also areas exploited for Turon-type flint (Lozano et al., 2010; Rodríguez-Tovar et al., 2010a, 2010b) in the south of the basin, in the Internal Betic Zones where they meet the Campo de Gibraltar Complex. Other types of abiotic resources are the salts associated with Triassic diapiric materials in Fuente de Piedra and Fuente Camacho (Sanz De Galdeano et al., 2008) and the fibrolites of Ronda (Aguayo et al., 2004). In addition, the copper carbonates from the

Fig. 2. Panoramic of Antequera Megalithic Complex.

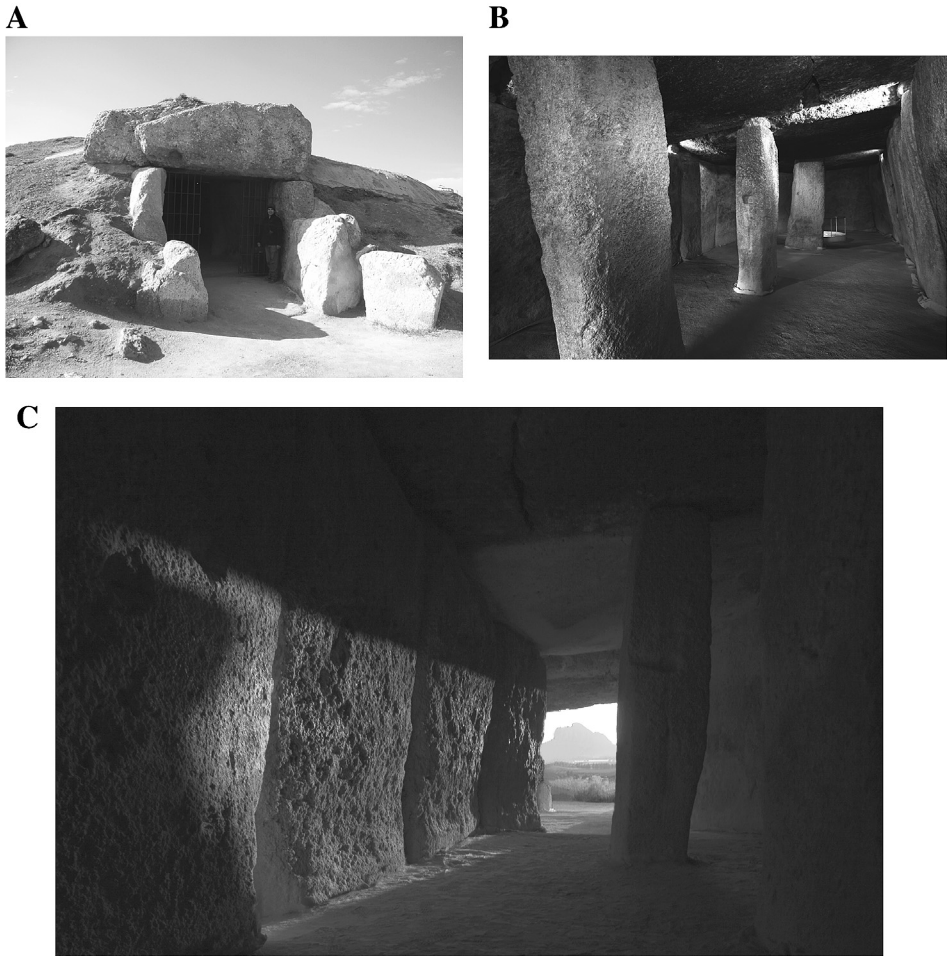

Fig. 4. Menga Dolmen. A. Atrium. B. Interior chamber. C. View from the chamber towards the outside in summer solstice.

forest of Malaga were used in metallurgy (Rodríguez-Vinceiro and Fernández Rodríguez, 1998), and the ophitic rocks from the "Triassic of Antequera", used to make polished lithic tools (Morgado and Lozano, 2011b).

The detrital rocks used for the construction of Menga Dolmen and the other two Antequera megaliths were transported from not more than 500 m away from the Antequera dolmens site (Ferrer and Marqués, 1993; Ferrer et al., 2004).

Also, the Antequera valley is one of the most fertile regions in terms of biotic resources as well as one of the widest intramountain depressions of the Betic Cordillera. This area historically was and continues to be so potentially agriculturally rich that it presumably played a key role in Prehistory (Figs. 1B and 2).

2.3. Chronology and cultural context

Menga Dolmen has been classified as a gallery dolmen because it has no inner structure. Menga is considered a megalithic structure with a single aperture, even though there is a subtle, narrow, transition space leading into the chamber, something like a pseudo-passage or antechamber. The chamber is lined by fourteen orthostats (seven on each side) and only one backstone, all of which together form a large space of 16.5 m long and 6 m wide at its maximum width. The roof is formed by five capstones supported by the aforementioned orthostats and three large pillars axially aligned in the chamber. The antechamber has two walls with three orthostats on each side and one capstone that today does not have any supporting pillar (Fig. 4). The results from the latest excavations conducted inside the dolmen show the possible existence of one or even more orthostats in the atrium and one additional pillar. This pillar would have been aligned with the above-mentioned ones, located between the rear of the chamber and the front of the antechamber.

Traditionally, the Antequera Megalithic Complex has been dated by indirect analysis from the cultural context as part of the megalithic phenomena of the southern Iberian Peninsula during the 5th millennium BP (Leisner and Leisner, 1943; Cruz-Auñón, 1984; Ferrer, 1982, 1987, 1995; Cabrero, 1988). This dating being a constituent of the chronology of the Copper Age. The typologic diversity of the three structures that form the Antequera Megalithic Complex aligns with the evolution in time of this necropolis. Therefore, we take the simplicity of the architectonic design as a characteristic indicating the age of the dolmen age. Menga Dolmen is considered to be the most ancient dolmen in the Antequera Megalithic Complex because it does not present a clear distinction between the chamber and the corridor. This dolmen can be considered a transition between the simple structures of dolmens without a clear break in the internal space and dolmens that show a well-differentiated corridor and chamber. This dating system indicates that the Viera Dolmen was constructed after Menga given that it has a clear distinction between a long corridor and a small funeral chamber. Finally, the Romeral, a tholos, has been considered the most recent construction. It has its own architectonic structure that differs from that of Menga and Viera.

Table 1
Antequera Megalithic Complex. C14 radiometric dates.

Dolmen	Reference	Date (BP)	Cal. 1σ (BC)	Cal. 2σ (BC)	Type	Bibliography
Menga	Ua-24582	4935 ± 40	3760–3650	3790–3690	Charcoal, fossa of atrium	Unpublished[a]
Menga	Ua-24583	4865 ± 40	3700–3635	3760–3530	Charcoal, fossa of atrium	Unpublished[a]
Menga	Ua-36216	4760 ± 30	3634–3522	3639–3384	Charcoal, burial mound base	Unpublished[a]
Viera	GrN-16067	4550 ± 140	3510–3020	3650–2900	Charcoal, burial mound base	Ferrer y Marqués 1993: 359

[a] Courtesy of the Conjunto Arqueológico de los Dólmenes de Antequera (CADA).

However, the above-mentioned affirmations have not been accepted as absolutely reliable dating methods until recently. The oldest dolmen in Andalucía, according to the datings, is the Alberite Dolmen (Cadiz) which has three construction dates, 5320 ± 70, 5110 ± 140, and 5020 ± 70 BP (Ramos Muñoz and Giles, 1996). These datings would seem to mean that megalithic building began between the end of 7th millennium and the beginning of 6th millennium cal. BP, even though most of the dates established for the structures show that the megalithic phenomena was at its peak during the Copper Age (c. 5200–4200 cal. BP) (Aguayo and García-Sanjuán, 2002; García-Sanjuán and Ruíz González, 2009).

Recent excavations by the Regional Andalusian Government Council of Culture of the have, for the first time, enabled absolute dating of the Antequera Megalithic Complex. Table 1 presents the carbon material analysed, its location, and its dating. The first dating of the complex corresponds to a plant-charcoal fragment located at the bottom of the tumulus from the Viera Dolmen (Ferrer and Marqués, 1993; Ferrer, 2003). Therefore, with a result of 4550 ± 140 years cal. BP, it is interpreted that this date corresponds at least to the time of the beginning of the construction of the tumulus.

From the 2005–2006 excavations of the Menga Dolmen, another three samples of plant charcoal were found, two from two pits situated in the atrium and another from the base of the tumulus (García-Sanjuán and Lozano, 2014). These three datings (see Table 1) refer to the 6th millennium cal. BP, and thus the construction of the dolmen corresponds at least as early as the late Neolithic (García-Sanjuán and Ruíz González, 2009).

Nevertheless, all the samples were found in the geological substrate under the dolmens, not inside them, indicating a *terminus post quem*, i.e. the oldest date at which the construction of the dolmens could have started.

3. Methods

This presented Menga study seeks to explain its geometric design through the analysis of the lithologies, volumes, dimensions, and the weight of its orthostats. The analysis is broken down into three specific levels: materials, geometry, and orientation.

The first level of the analysis concerns the stratigraphy and sedimentology of the orthostats forming the dolmen. For this, we conducted a detailed lithological mapping of its structural elements. The analysis was performed by studying thin sections by optical microscopy.

The second level of the analysis was the metric, volumetric, and geometric study of the architectonic elements forming the dolmen

Table 2
Types of rocks comprising the orthostats of Menga Dolmen. Based on the classification of Dunham (1962) for carbonate rocks.

Type	Rock	Sedimentary facies	Grain size (mm)	Mineralogical composition	Skeletal grains	Non-skeletal grains	Matrix	Microstructure and sedimentary structure	Texture
1	Bioclastic calcirudite	Factory: Nodular bryozoan-bivalve facies	>2	70–80% Calcite 30–20% Quartz	Main components: Bryozoans, bivalves (Clamys, pectinid). Other components: Echinoids, coralline algae, solitary corals, benthic foraminifers (Amphisteginas, globigerinas), Brachiopods, balanids	Intraclasts (limestone, quartz, iron oxides, feldspar and glauconite) pellets	Low sparite and absence of micrite	Syndepositional intergranular voids, parallel-laminated	Rudstones
2	Bioclastic calcarenite	Factory: Coralline algal facies	<2	70–80% Calcite 30–20% Quartz	Main components: Coralline algae. Other components: Nodular and branching bryozoans, bivalves, solitary corals, espinas de erizo.	Intraclasts (quartz, iron oxides, feldspar and glauconite), pellets	Contains carbonate mud	Syndepositional intergranular voids, parallel-laminated	Packstone –rudstone, crusts are bindstones
3	Bioclastic calcarenite	Foreshore	<2	70–80% Calcite 30–20% Quartz	Bivalves (Clamys, pectinid), brachiopods, espinas de erizo, Bryozoans, Echinoids	Intraclasts (quartz, iron oxides, feldspar and glauconite), pellets	Low sparite and absence of micrite	Syndepositional intergranular voids, low-angle, parallel laminated, burrows	Grainstone
4	Calcareous breccia	Foreshore: Beach Rocks	>2	70% Calcite 15% Quartz 10% Feldspar	Bivalves (pectinid), bryozoans, coralline algae	Dolomite, oolitic limestones, iron oxides, (oncolites), marly limestones, sandstone and flint lesser extent, filositicatos, slates, coal	Contains carbonate mud	Synsedimentary cement, low-angle, parallel laminated, Overlapping edges	Rudstones

(Calter, 2000; Hardaker, 2001; Esquivel, 2008). On one hand, the dimensions of the orthostats of the left and right sides of the dolmen main axis were compared by using a two-sample analysis. Also, a mathematic analysis was made of the geometric design of the dolmen chamber. For this, the curvilinear morphology of each side was modelled, obtaining an almost perfect curve through polynomial equations. To determine the height of the orthostats, the visible part was measured and the non-visible part (foundation) was estimated. Since some of the edges are rounded, creating a certain lack in precision, the height and thickness of the orthostats were estimated by making several measurements in each case and calculating their mean value. The visible surface of each orthostat was calculated from planimetric survey and 3D laser scan of the dolmen. To determine the volume, this surface area was multiplied by the estimated thickness; and for the weight, the volume was multiplied by the mean density of each orthostat according to its lithology. The architectural parts forming the dolmen denomination were codified as follows: B(Backstone) = head orthostat; R(right) = orthostats located on the right (from the entrance towards the back); L(left) = orthostats to the left (from the entrance), P(Pillar) = pillar, and C(Capstone) = capstone. Also, the Menga Dolmen's orthostat variability on both sides has been analysed applying a *Z*-Test (Martín Andrés and Luna del Castillo, 2004).

The third level of analysis concerns the orientation of the Menga Dolmen in relation to the sun, comparing this with other large gallery dolmens preserved in the southern Iberian Peninsula (Pozuelo 4, Alberite, and Soto). This analysis was made by calculating how the sunlight entered the dolmens during the equinoxes and the summer solstice. This part of the study is based on modelling the natural illumination reaching the dolmen inner spaces by using the 3D Studio Max program. Thus, a virtual modelling to scale of the dolmen was performed, simulating the textures of the orthostats and the effects of the light reflection and shadows cast. Since almost all the capstones had to be eliminated to see the inside of the dolmen, different photometric light had to be focused in strategic positions. All the parameters used in the virtual modelling were based on real photographs of the summer solstice in order to guarantee that the simulated effects were realistic. The

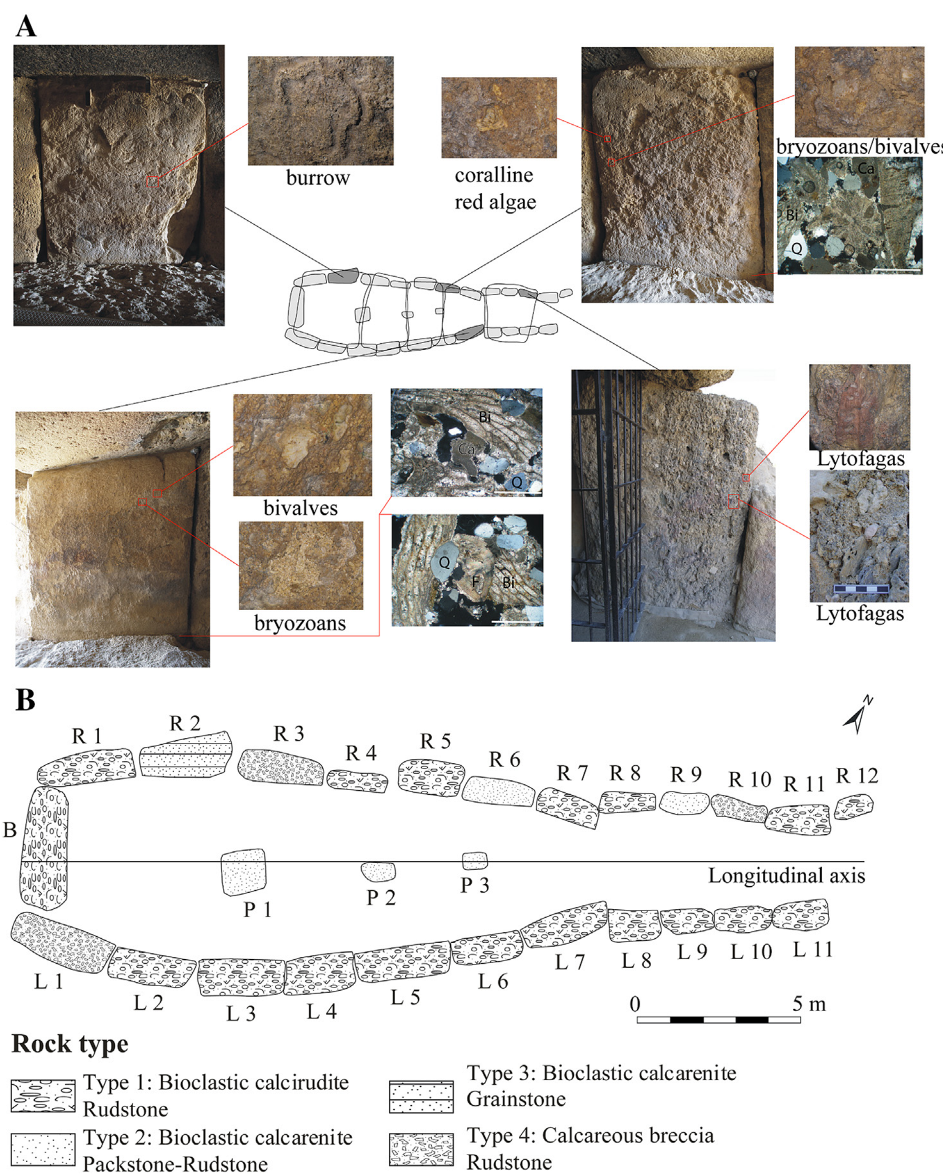

Fig. 5. Menga Dolmen. A. Representation of bioclasticfacies (microfacies) of the orthostats. B. Plan of the dolmen with the distribution of the different types of microfacies (L: Left; R: Right; P: Pillar; B: backslap).

results of this modelling of Menga were then compared with similar analyses carried out for the other three major megalithic monuments mentioned above.

4. Level 1. Lithological characterization of the Menga Dolmen

At the end of the last century, it was established that the materials of Menga Dolmen building were sandstones with a chemical composition of calcite of 65–95%, 5–30% of quartz, and a very fine micritic fraction. The entire structure was held together by limited sparitic post-depositional and crystallized foundations in the stone empty spaces (Espinosa Gaitán, 1998).

In the lithologic thin-section study, rudstones and packstone–rudstone, crusts, and bindstones are derived from the so-called factory facies and foreshore grainstone factories, a particular area of the marine platform with primary, biogenic production of carbonate, typical of temperate carbonates (Martín et al., 1996; Pomar and Hallock, 2008). There were also rudstones in the form of calcareous breccia from the foreshore environment (beach rocks) (Table 2). This means that the rocks forming the structural elements of the dolmen can be broken down into four clearly differentiated groups (Fig. 5 and Table 2), each group corresponding to a particular depositional environment characterized by facies that present a defined textural composition and that are associated with specific structures.

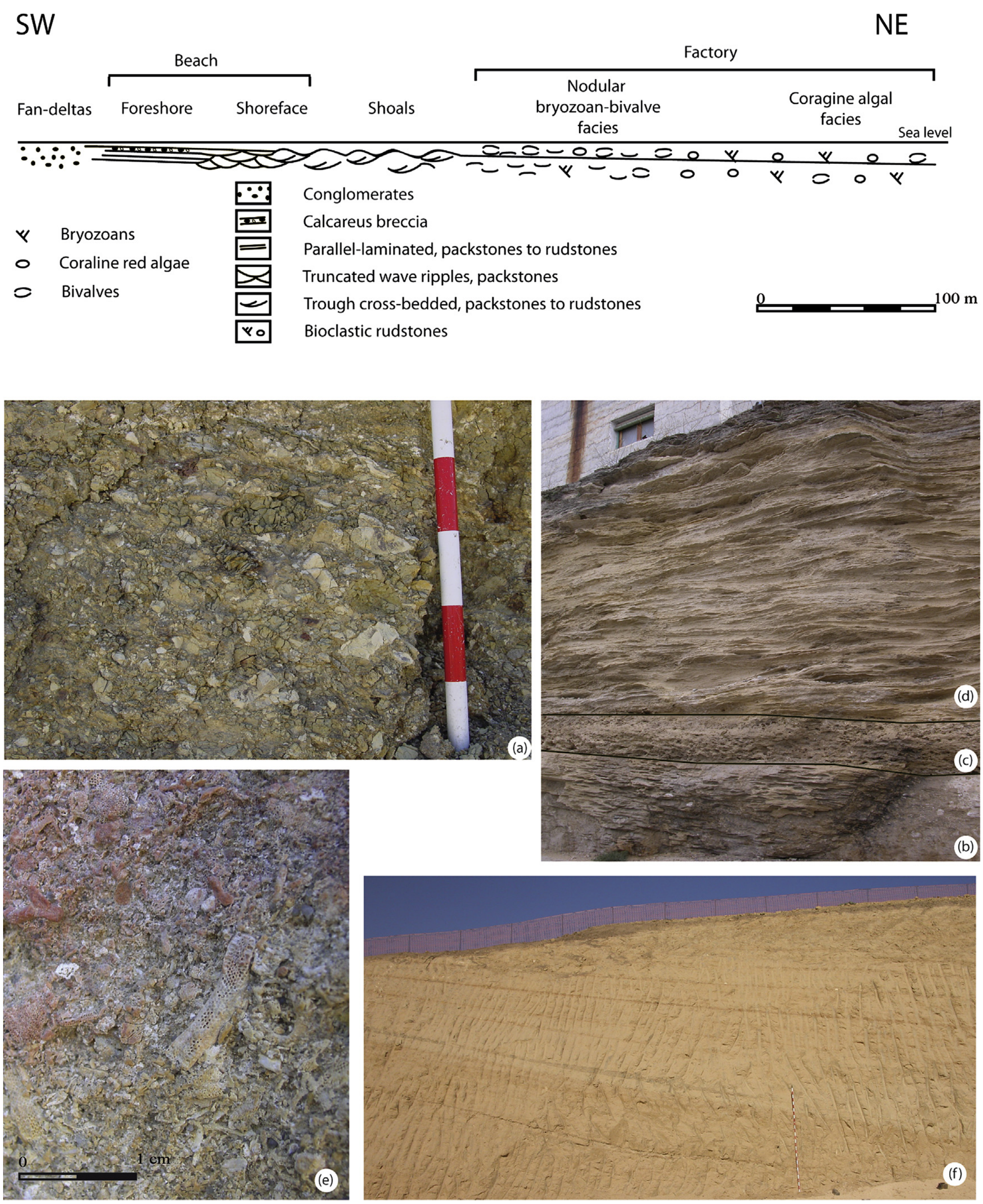

Fig. 6. Diagram of a soft platform of temperate carbonates from Upper Tortonian–Messinian of Antequera basin. Based on temperate carbonate platforms from the same period of the Southeast of the Iberian Peninsula (Martín et al., 1996; Braga et al., 2001). a) Fan-deltas. b) Foreshore facies. c) Beach rocks facies. d) Shoals facies. e) Nodular bryozoan-bivalves facies. f) Fan-bedded zone.

Table 3
Statistic relations of the orthostats of the antechamber-atrium, the chamber and the total, comparing the right and left sides of Menga Dolmen. X: mean, SE: standard error; CV: variation coefficient; Z: statistical value; p: statistical probability.

		Left side		Right side		Z test	
		$X \pm$ SE	CV	$X \pm$ SE	CV	Z	p
Atrium	Height	1.66 ± 0.04	0.2717	1.54 ± 0.13	0.1233	2.6534	0.0040
	Width	2.46 ± 0.33	0.0494	2.17 ± 0.26	0.1888	3.8820	0.0001
	Thickness	0.82 ± 0.04	0.1068	0.67 ± 0.05	0.1333	0.7591	0.2239
	Volume	3.34 ± 0.98	0.2642	2.33 ± 0.35	0.3179	0.6221	0.2669
	Weight	7.41 ± 0.44	0.2634	5.27 ± 0.82	0.3641	1.0724	0.1418
Chamber	Height	2.45 ± 0.17	0.2711	2.39 ± 0.18	0.0994	5.5315	0.0000
	Width	3.01 ± 0.14	0.1958	2.99 ± 0.11	0.1979	0.0643	0.4744
	Thickness	1.03 ± 0.05	0.1772	0.88 ± 0.08	0.2416	1.8321	0.0335
	Volume	8.06 ± 0.97	0.3392	6.62 ± 1.14	0.4553	1.7097	0.0437
	Weight	18.31 ± 2.52	0.3499	14.91 ± 2.58	0.4574	1.5573	0.0597
Total	Height	2.16 ± 0.16	0.1935	2.04 ± 0.17	0.2245	1.5496	0.0606
	Width	2.81 ± 0.16	0.2484	2.65 ± 0.17	0.2894	1.5882	0.0561
	Thickness	0.95 ± 0.05	0.1657	0.80 ± 0.06	0.2584	4.5419	0.0000
	Volume	6.34 ± 0.95	0.4948	4.84 ± 0.92	0.6566	2.8491	0.0022
	Weight	14.34 ± 2.30	0.5313	10.90 ± 2.07	0.6572	2.1466	0.0159

The rocks forming the dolmen are warm-temperate carbonates and mixed levels of carbonate and siliciclastic from the Upper Tortonian and Messinian. The rocks were deposited in a narrow platform along the southern margin of the Torcal de Antequera and Alta Cadena to form a smooth ramp with beaches and shoals in the higher areas. The factory facies zone (Martín et al., 1996) is found towards the sea and it would be in this area where the greater part of the carbonate was produced (Fig. 6). Some skeletons of the organisms from the factory area were carried by the waves or currents during storms and were transported towards the coast, where they were incorporated into the shoals or the beaches, or they were carried downwards to form a fan-bedded zone following the incline of the ramp formed by the mass fluids (Martín et al., 1996, 2004).

Regarding the distribution of lithology, it turns out that on the dolmen left side all orthostats, except the L1, correspond to type 4 (calcareous breccia rudstone). However, on the right side, four lithologies can be discerned with no set pattern. Thus, based on the lithological criteria used, the left side is homogeneous while the right side is heterogeneous.

5. Level 2. Metric and geometric parameters of Menga Dolmen

5.1. Orthostat metrics and morphology

The five variables analysed in the orthostats were normal (Shapiro–Wilk test), with the exception of thickness. However, this exception was not severe. Furthermore, the variables were homoscedastic. Due to the low sample size, the differences between the two sides of the dolmen were minor for any of the variables considered. However, a Z-test revealed major differences in the coefficient of variation for the orthostats of the different sides (Table 3). This revealed that, despite that the average dimensions of the orthostats not being so different, they were more variable, in general, on the right side of the dolmen.

The analysis of the distribution of each of dolmen orthostats width indicated that on the left side, the width tends to decrease from the atrium to the antechamber. On the other hand, in the chamber, there are alternating wide and narrow orthostats together with others of similar width. However, on the right side of

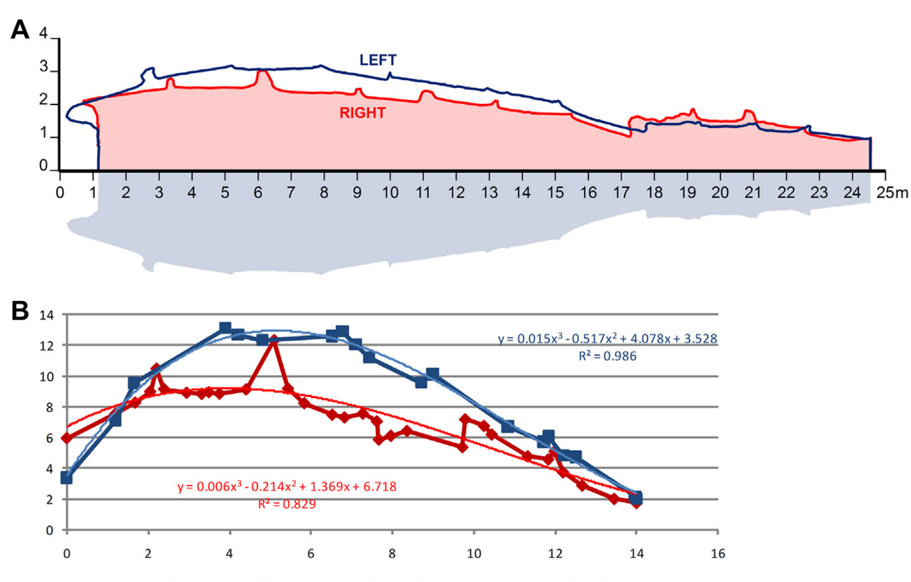

Fig. 7. Relation between the right and left sides in relation to the longitudinal axis. A. Asymmetry between the two sides. B. Comparative of the third grade polinomic curves between the right and left side of the chamber.

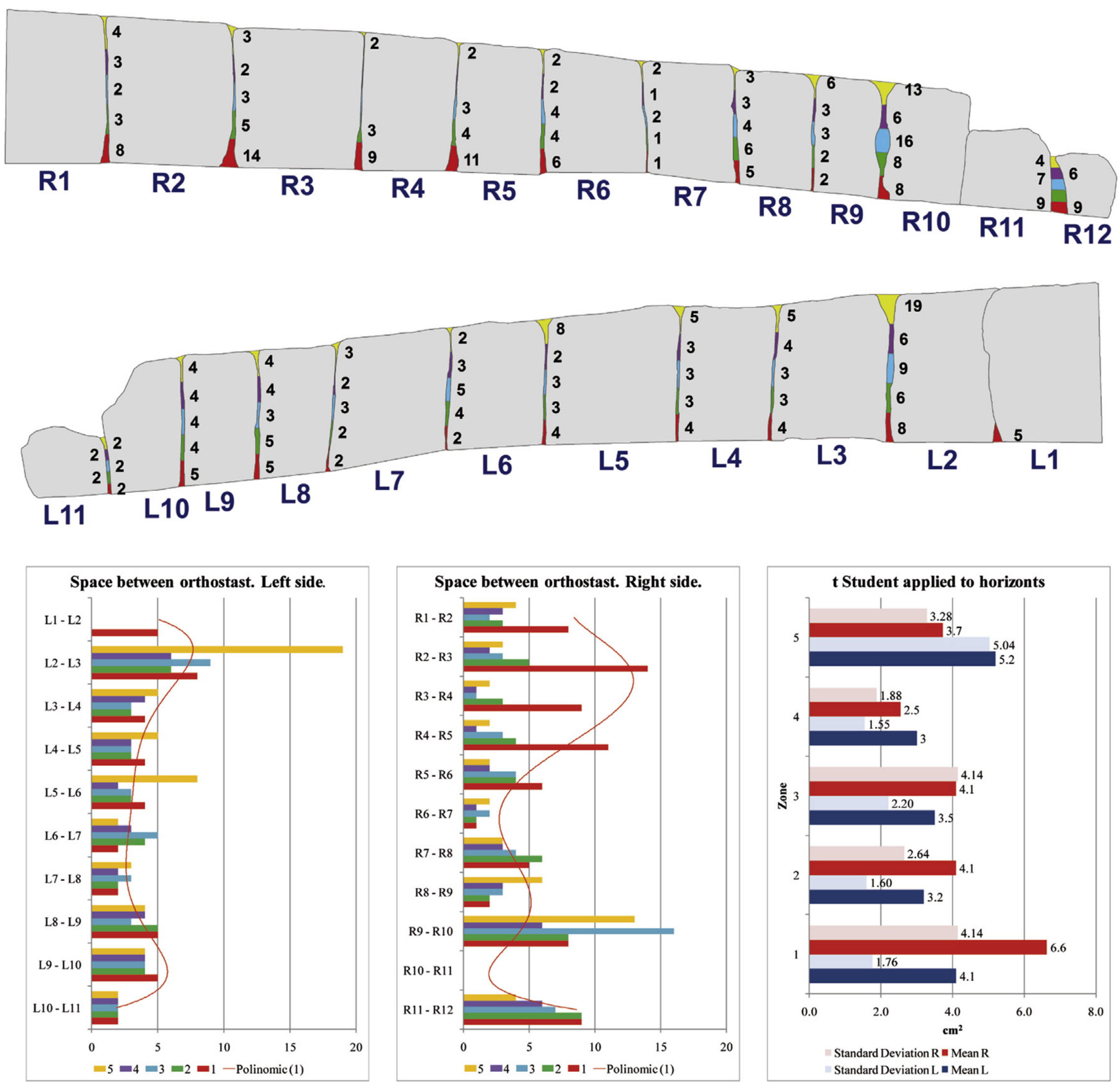

Fig. 8. Spacing between orthostats of the right and left sides.

the dolmen, the atrium, and the antechamber, an alternating pattern of wide and narrow orthostats appears, while in the chamber the widths of the orthostats vary randomly.

With respect to the thickness, neither side of the dolmen has a discernible distribution pattern, even though the right side is clearly more heterogeneous than the left side (Fig. 7).

5.2. Spacing between orthostats

For the analysis of the spacing between orthostats, every joint between the upright stones was divided into five proportional areas and each was then calculated. The analysis showed that on the left side of the dolmen, the spacing between orthostats is highly uniform, apart from two exceptions (Area 5 between R2 and R3 between R5 and R6). These exceptions were caused by breaks which occurred after the construction of the dolmen.

However, the right side has larger, more variable and more repeated differences in the orthostat spacing, especially in area 1. The separations found between L9 and L10 are also due to subsequent breaks in the uprights, and for this reason they should not be taken into account (Fig. 8).

Applying the *Z*-test, we found no statistically significant differences despite the fact that the coefficients of variation proved higher on the right side than on the left side (apart from the area 5) due to the anomalous spacing between orthostats L2 and L3, which occurred after the construction of the dolmen.

5.3. Curvature and distance to the main axis of the dolmen

The geometric distribution of the orthostats on the two sides of the chamber shows significant design differences with respect to the axis of symmetry. From the curvatures that form the orthostats on each side of the chamber with respect to the main axis, the polynomial equations that best fit each outline were calculated. On the left side, a third-degree curve was fitted with a tolerance of 0.986 (perfect adjustment = 1), while the right side showed a tolerance of 0.829 (significantly lower; Fig. 9). This difference shows how precisely designed the left side is with respect to the right. This feature can be observed in other large dolmens of the southern Iberian Peninsula.

6. Menga Dolmen orientation, other large-gallery southern Iberian Peninsula dolmens and their astronomic implications

Geoarchaeological and metric analysis of the Menga Dolmen shows a clear intention for the dolmen to be asymmetrical with

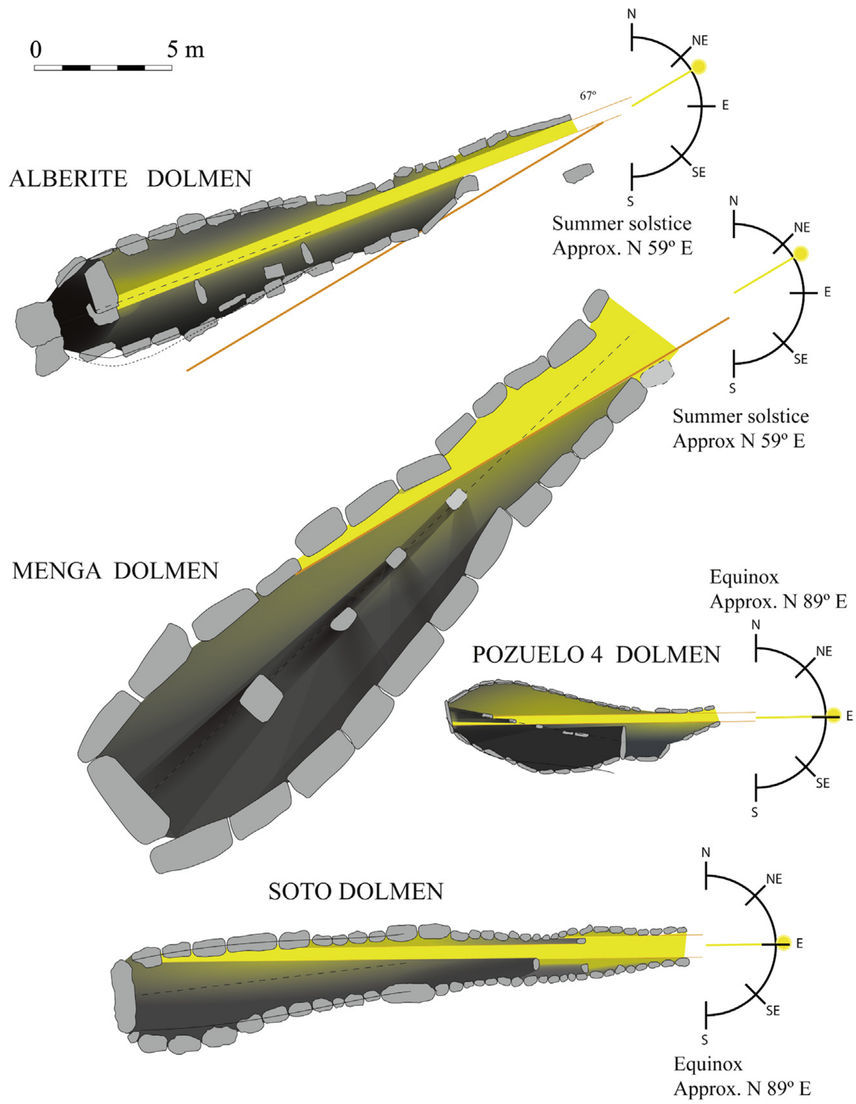

Fig. 9. The largest gallery dolmens from the South of the Iberian Peninsula according to their summer equinox orientation. In yellow, the light at the moment of the solstice or equinox; in grey shades, the gloom generated inside; in black, the shadow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

respect to the civil engineering most outstanding architectonic design main axis. In other large-gallery dolmens in the same region, we find identical structural characteristics in terms of the higher curve on the left side of the chamber and the heterogeneity on the right side (e.g. Pozuelo 4, Alberite, and Soto; Hoskin et al., 1994; Hoskin, 2001, 2002, 2008, 2009; González García and Belmonte, 2010).

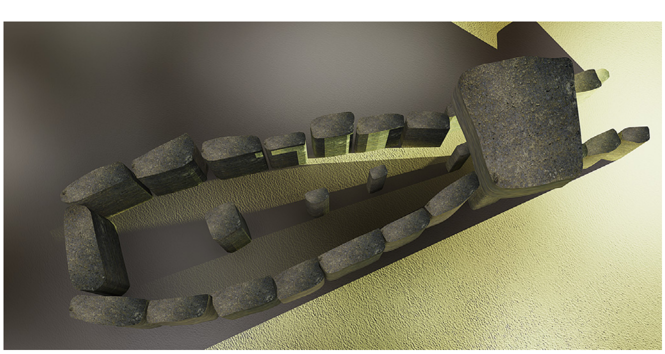

Fig. 10. Elevation of Menga Dolmen with AutoCAD at the moment of summer solstice. To represent all possible, we have simulated the fourth pillar disappeared today.

This characteristic of large-gallery Iberian dolmens appears to be related to their astronomic orientation (Fig 10). As other authors have already demonstrated, statistically the dolmens of the Iberian Peninsula were and are in their majority oriented to the east (Hoskin et al., 1994; Hoskin, 2001, 2002, 2008, 2009; González García and Belmonte, 2010). Likewise, the large dolmens studied here have a preferential orientation towards sunrise in the summer solstice (Menga and Alberite) or in the equinoxes (Soto and El Pozuelo 4). It can be considered that the asymmetry of the chamber laterals are related to the light, semi-darkness, and shadows generated when the sun rises and sunlight enters the chamber. Therefore, making the left side more curved than the right means that semi-darkness and shadows occur on this side of the dolmen. As for the other side, being less curved, the illumination is more even.

The dolmens of Pozuelo 4, Alberite, and Soto, are almost perfectly aligned with the sunrise. There are orthostats transversal to the dolmen axis to prevent the sunlight from coming directly into contact with the left side of the chamber. These screens or dark orthostats (dark slabs) allow dark spaces to be generated on the more curved left side.

The particularity of the orientation of the Menga Dolmen orientation is that, given the anthropomorphic profile of the Peña de los Enamorados (resembling a gargantuan recumbent human head). In fact, many experts have repeatedly contended that its orientation was designed taking into consideration the mountain Peña de los Enamorados, which has an imposing silhouette that

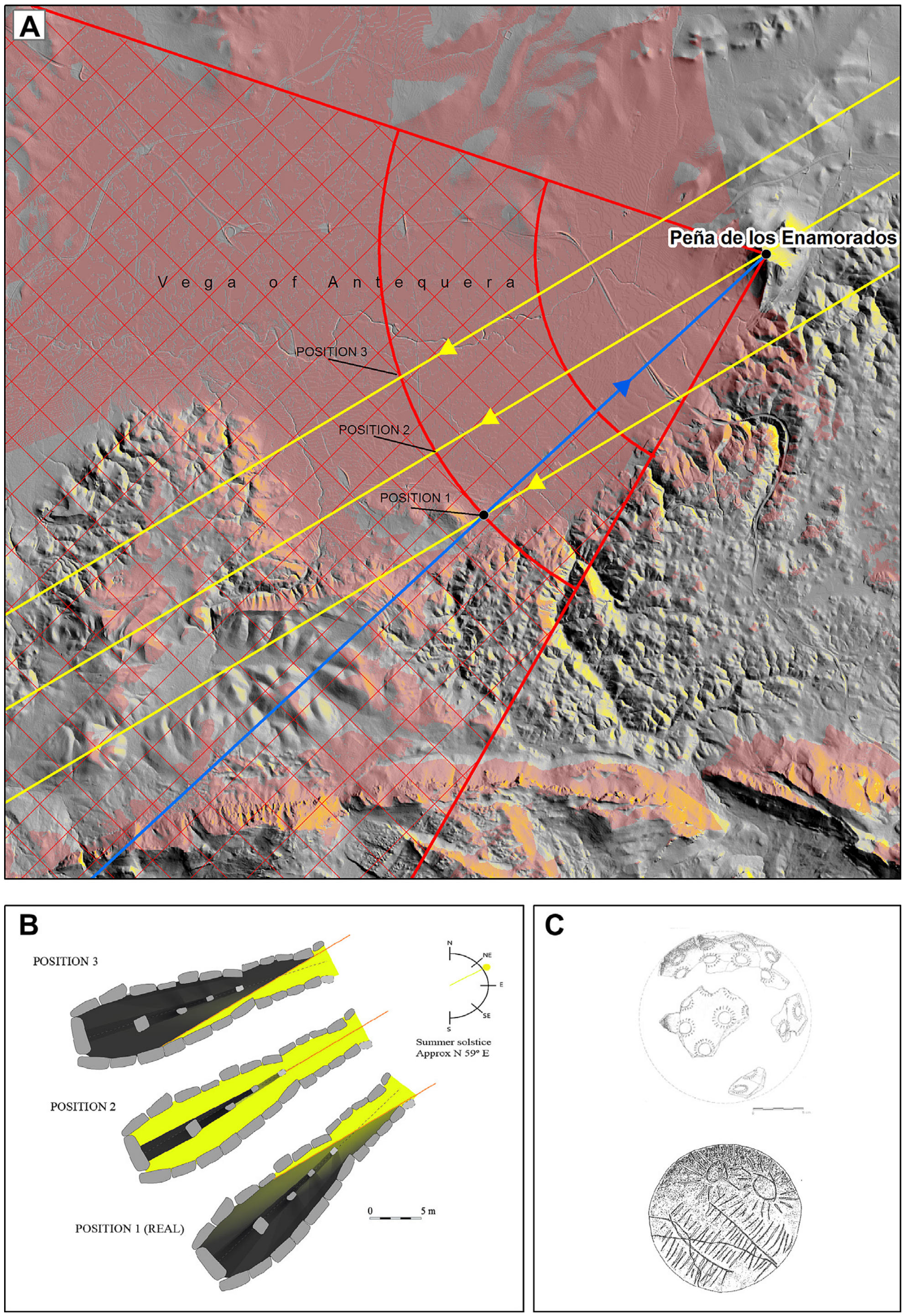

Fig. 11. A. Digital terrain map with the location of the Menga Dolmen (position 1) and its orientation to the Peña de los Enamorados, represented by a blue line. The yellow lines show the direction of the sun at the sunrise on the summer solstice. The yellow hues on the terrain are the sunlit areas at that time. The red hues are the areas from which the Peña de los Enamorados can be seen. The squared web in red, would include all the possible areas where the dolmen could have been placed, orientated to the Peña de los Enamorados. Position 2 (and any other point on this yellow line that is within the red squared web) consist of the place or places where the dolmen would be orientated to both the Peña de los Enamorados and the summer solstice. Position 3 (and any other point on this yellow line that is within the red squared web) consist of the place or places where the dolmen would be orientated to the Peña de los Enamorados, but in this case the only lit part is the left (or perfect) side of the dolmen. This side is dark in the rest of the large gallery dolmens. B. Lighting inside the dolmen in the ideal position (position 2) (orientated to the Peña de los Enamorados and the summer solstice) and in each of the symmetrical positions on both sides of the ideal position. C. Neolithic sherds with carved suns motif, from the Poblado de Campos de Cuevas de Almanzora, Almería (Martín Socas et al., 1982, 1986). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

stands out over the landscape (García-Sanjuán and Wheatley, 2009, 2010). From a geometric point of view, a straight line can be drawn from many different locations towards the Peña de los Enamorados, but only from some very specific locations are the light and shadow effects appreciable in the dolmen. As shown in Fig. 11(a and b), for position 3, the shadow would be cast onto the right side, breaking the pattern of all major dolmens in the southern Iberian Peninsula. Meanwhile, position 2 would require a dark orthostat on the left side in order to cast this side in shadow. Finally, position 1 allows a precise orientation to the Peña de los Enamorados and the left side remains in shadow without any dark orthostats. With this orientation, 15° north at sunrise on the summer solstice, the sunrays shine inside the chamber only onto half of the 18 orthostats on the right side of the structure. At this moment, the contrast between the light, the semi-darkness and the shadow generated by the design of the dolmen is analogous to that of the other three dolmens, but in this case there is no need of any traversal orthostats (Figs. 10 and 11). In addition, this geometric contention is not inconsistent with the cult of the sun, which is a common characteristic in the cultures of the time, as demonstrated by the sun motifs in ceramics from Recent Prehistory found in southern Iberian Peninsula sites (i.e., Carrasco et al., 1982) (Fig. 11C).Therefore, this design appears to be a deliberate decision, implying detailed knowledge of the annual cycles of the sun.

7. Conclusions

The megalithic structure of Menga Dolmen presents unique architectonic characteristics in terms of its size, weight, volume, and lithology, all of which make it into one of the most important civil engineering and architectural works of European Prehistory.

However, this monumentality was designed using an irregular geometry reflected in the weights, lengths, volumes, and lithologies used on both sides of the longitudinal axis that divide the dolmen in two halves from the entrance to the back. The left side of the chamber can be considered uniform in all these characteristics, while the right side is not. Moreover, the geometric precision is greater on the left side than on the right, the former almost perfectly fitting a third-degree polynomial curve. This does not appear to have happened by chance, since, when the dolmen was constructed, cultural factors influenced the design and led to this contrast in precision between the lineal geometry of the left side and the fractality of the right side.

This cultural factor can be found not only in Menga Dolmen, but also the other aforementioned large dolmens of the southern Iberian Peninsula, such as Pozuelo 4, Alberite, and Soto, all of which have similar geometric patterns. Pozuelo is precisely oriented to the summer solstice as are Alberite and Soto to the equinox. However, Menga Dolmen is slightly shifted with respect to the summer solstice. The location of Menga Dolmen can be explained both by its orientation towards the Peña de Los Enamorados as well as its orientation to sunrise during the summer solstice, as demonstrated by the intentionality of the shadows generated on the left side. The absence of dark orthostats in Menga Dolmen demonstrates the full knowledge of the annual cycle of the sun and a profound symbolic sense of illumination of the chamber at sunrise in the summer solstice. This symbolic sense is repeated in Pozuelo 4, Alberite, and Soto.

These patterns, repeated in the four considered dolmens, demonstrates that both the dolmen geometry as well as their orientation can be explained by a common cultural factor in which the imperfect right side is related to an uneven refraction of the light, while the precise left side is related to an even distribution of the darkness.

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