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RESEARCH

Choosing the site, getting the stones, building the dolmens: local sourcing of andesites at the El Pozuelo megalithic complex (Huelva, Spain)

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Abstract
The geoarchaeological study focuses on the lithological characterization and provenance determination of the rocks of the El Pozuelo dolmens. The difficulty of identifying volcanic rocks in the intensely altered and deformed environment of the Iberian Pyrite Belt has required the implementation of a research methodology combining the archaeological and geological analysis of the megaliths and the area surrounding the Los Llanetes group. A total of 29 thin sections and 14 geochemical analyses (ICP-AES, ICP-MS and REE) have been carried out on samples from the dolmens and potential source areas, focusing on the chemical elements considered immobile during alteration processes. The petrological analyses confirm the identification of different andesite lithotypes and enable us to correlate the rocks used in the construction of the megaliths with source areas and quarries located within a 50–350 m radius. Several patterns are observed in the selection of the rocks, based on the material, visual and symbolic properties of the different lithologies. Foliated andesite is the most common stone used in the monuments, due to its excellent physical properties and technological suitability for extraction and transformation into megalithic supports. Other types of andesite (sheared, massive and amphibole-phyric), white quartz, ferruginous agglomerate and gabbro were also used for different architectural purposes. The results confirm the importance of locally available suitable rocks in determining site location, raw material procurement and monument construction during the Late Neolithic.

Keywords Megaliths · Neolithic · Megalithic quarrying · Volcanic rocks · Petrology · Geochemistry (ICP-AES · ICP-MS and REE)

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Introduction

The identification of the materials used in construction is one of the central aspects of research on megalithic monuments. Indeed, many studies focus on the identificaction of the lithologies and the provenance of the large stone supports. This information is essential for understanding the choice of the sites, the operational sequences, including transport, the degree of architectural specialization, the symbolic meaning of the stones and, even, the mobility and territorial interaction of the social groups.

The selection and procurement of the materials used in the megaliths may depend on several factors, among which the main research variables are accessibility, physical properties, visual qualities, symbolic attributes, cultural significance and technical tradition.

In most western European megaliths, the rocks available in the immediate surroundings of the megaliths were used, preferably in the form of detached blocks (Scarre 2009). However, larger megalithic sites include stones transported over greater distances, such as the Stones of Stennes and Ring of Brodgar, which incorporate sandstone blocks from the quarries of Vestra Fiold, Staneyhill and Houton, at a distance between 3 and 12 km (Richards 2013). Stones were transported over larger distances still, for instance, those of the passage tombs of Brú na Boinne, which include a variety of lithologies (white quartz, granite, granodiorite and sedimentary rocks) from sources located between 35 and 40 km (Cooney 2000: 136). More exceptionally, the source of the famous 'bluestones' (dolerites) of Stonehenge has been confirmed as the Carn Goedog and Craig Rhos-y-felin quarries, located 230 km from the site, in the Preseli Hills of western Wales (Parker Pearson et al. 2019, 2020).

In relation to the physical properties of the rocks, in addition to their hardness, consistency and strength, the visual and aesthetic properties of certain lithologies and minerals, displaying particular features of colour, light, lustre and texture, were also important in the selection of materials (Scarre 2004; Darvill 2011). Examples include the common use of quartz in the external areas of megaliths in order to enhance their visual impact (Jones 1999; Trevarthen 2000; Cummings 2002a), the use of limestone with ichnofossils for the headstones of the dolmens of the Lisbon region (Cardoso and Boaventura 2011), the placement of sedimentary rocks with bioturbation and sedimentary structures resembling megalithic art in the *tholos* tombs of La Pastora and Matarrubilla (Cáceres et al. 2019) and among others.

Likewise, the choice of sites and construction materials may have been influenced by symbolic reasons, as is suggested by the frequent spatial association between rocky outcrops (with or without rock art) and megaliths, shaping monumental landscapes with a strong territorial imprint (Tilley 1994, 1996; Bradley 1998, 2000; Bueno Ramírez and Balbín Berhmann 2009; Linares-Catela et al. 2022), or the practices of reuse and recycling of standing-stones and steles in the tombs of Brittany (L'Helgouach 1983, 1996; Le Roux 1985), the British Isles (Richards 1996; Robin 2010), the Iberian Peninsula (Bueno Ramírez et al. 2007, 2014, 2018) and other European regions.

The use of particular materials may also have had a cosmogonic and cultural dimension, with monuments embodying the lithologies and geological formations of the environment in which they were located (Richards 1996; Scarre 2004), the geographical places of origin of the rocks (Giot 1987) or the places of origin of the monument builders (Richards 2013). In relation to these aspects, it is necessary to consider the technical tradition of the megalithic groups, in which the correlation between certain architectural styles and lithotypes is common, as is the case of the dolmens of the eastern Andévalo built with volcanic rocks from the Iberian Pyrite Belt (Linares Catela 2016).

The analysis of provenance areas occupies a prominent place in research. Indeed, the identification of the rocky outcrops where the stone blocks were sourced and extracted provides information on the criteria of selection, strategies of exploitation and conditions of transport. The case of Stonehenge is undoubtedly one of the most paradigmatic, best-studied and best-known sites in Western Europe (Thorpe and Williams Thorpe 1991; Patton 1992; Darvill and Wainwright 2014; Bevins et al. 2012, 2021; Parker Pearson et al. 2015, 2019, 2020; Ixer and Bevins 2017). Along similar lines, although on a different scale, we may highlight the work carried out at several sites in the Iberian Peninsula: the dolmens of Menga and Viera (Carrión et al. 2010; Lozano et al. 2014), the *tholos* tomb of La Pastora in the necropolis of Valencina de la Concepción (Cáceres et al. 2014, 2019), the dolmen of La Chabola de la Hechicera in the Basque Country (Martínez Torres et al. 2014) or the megalithic necropolis of Panoría in the Guadix Depression (Aranda Jiménez et al. 2018), among others.

This paper focuses on the megalithic complex of El Pozuelo (Zalamea la Real, Huelva), which displays certain peculiarities in terms of its geological location, considering that the dolmens are distributed along the southern edge of the central section of the Volcano-Sedimentary Complex (VSC) of the Iberian Pyrite Belt (IPB). In this geological context, the volcanic and subvolcanic rocks are intensely altered and deformed, making the lithological identification of the megalithic stones difficult by means of simple visual observation. This circumstance has led to the proposal of different identifications for the rocks from which the monuments were built. Early research suggested that the dolmens of El Pozuelo were built on a slate substrate with large slabs of greyish-green slaty porphyry (Cerdán 1951: 163; Cerdán et al. 1952: 14; Leisner and Leisner 1956: 65), and this denomination was maintained in later studies (Gómez Ruiz 1978: 19; Cabrero 1982: 64; Cabrero 1985: 210). In the 1980s and 1990s, it was sustained that all the materials used in the monuments were slate blocks and slabs from the surrounding outcrops (Piñón Varela 2004: 790-791; Nocete et al. 1999: 22-31, 2004). In our own previous works, we erroneously identified these materials as phyllites (Linares Catela 2020). Only the most recent geological studies and petrographic analyses have shed light on this terminological confusion, confirming the identification of the rocks as andesites (Linares Catela 2021).

We focus specifically on the geoarchaeological study of the eastern cluster of the El Pozuelo complex, known as the Los Llanetes group. This group of monuments is located on a substrate that was strongly affected by the Variscan orogeny. Coherent igneous rocks and volcaniclastic deposits (sensu McPhie et al. 1993) of andesitic composition outcrop in the immediate area, with different degrees of alteration and deformation that make their visual identification and classification very difficult. To overcome this problem, research has been carried out with geoarchaeological aims and methods, in order to enable the systematic study of the stones of the monuments, the geological environment and the surface outcrops. Archaeology and geology have been combined in a balanced and transversal approach, in which both scientific disciplines contribute equally to the analysis, discussion and interpretation of the data (Chazan 2017).

In this study, we aim to achieve three complementary objectives: (a) the lithological characterization of the rocks of the megaliths; (b) the identification of the potential source areas within the geological environment and the provenance of the exploited materials; (c) the interpretation of the selection criteria and patterns of use of stones in the construction of the dolmens during the Late Neolithic and their subsequent monumentalization processes during the Copper Age and Early Bronze Age. The clarification of the selection practices and the provenance of the rocks are key aspects for the reconstruction of the multiple dimensions of the construction processes carried out by the prehistoric communities, making it possible to cross-reference the data with the different stages of the megalithic operational sequences (choice of site, acquisition, transport, technical treatment and placement of stones) and with the organization of the work.

The rocks considered andesites in the Iberian Pyrite Belt (IGME 2015) do not have similar geochemical characteristics along this geological domain (Donaire et al. 2020a, b). For this reason, the methodology has combined archaeological analysis with petrography and geochemistry, carrying out a systematic examination of the lithologies of the megaliths and the local geological environment, outcrops and potential source areas. On the one hand, the petrographic analysis has enabled the observation and study of the main alteration facies of these materials. On the other hand, the geochemical analysis has considered the chemical elements that remain immobile during geological processes involving aqueous fluids or metamorphism (Gifkins et al. 2005). As a result of this work, it has been possible to identify and classify the rocks used in the monuments and to determine their provenance, by correlating petrographically and geochemically the materials in the dolmens with those of the quarries and source areas.

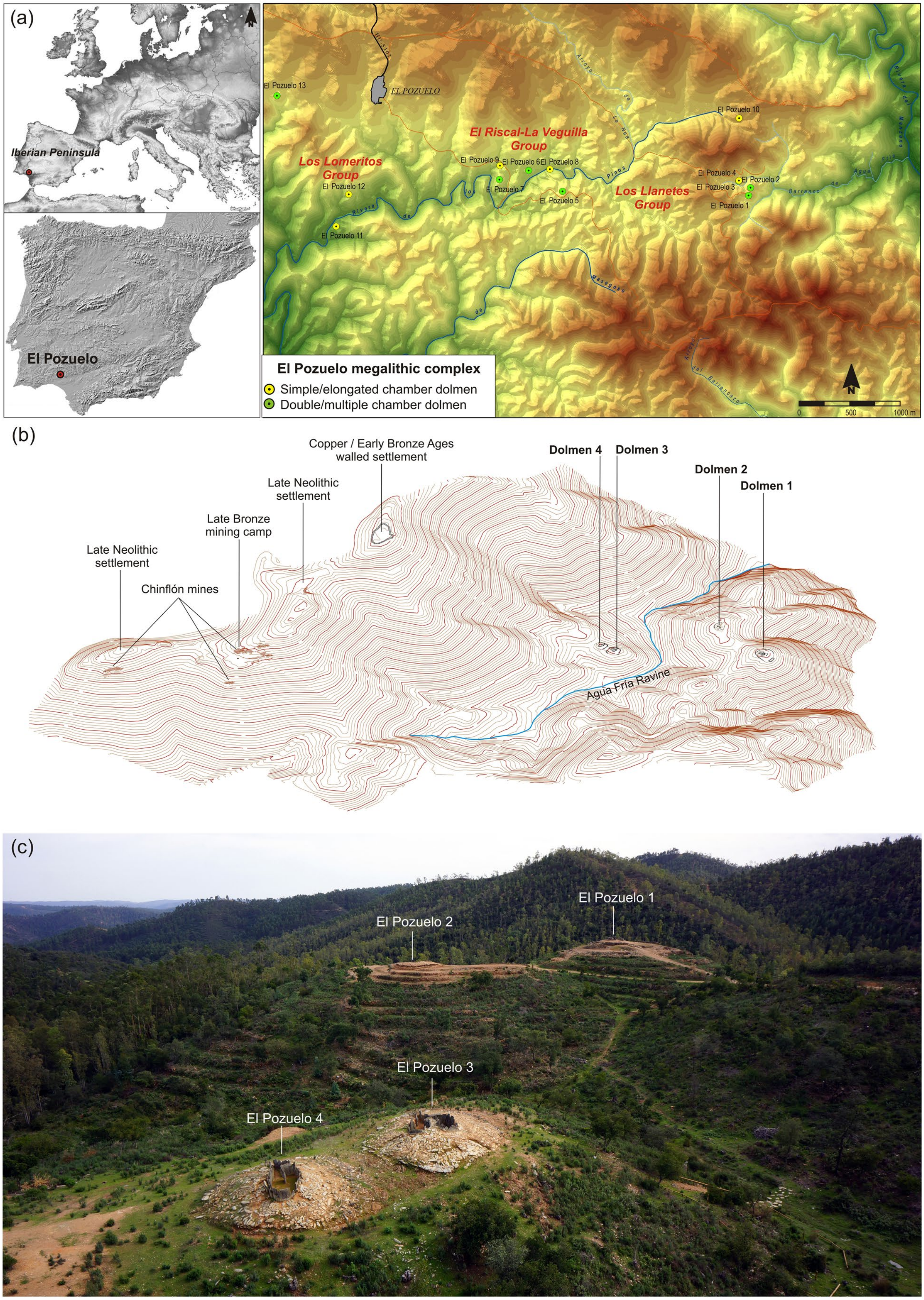
Archaeological, geological and geomorphological context

The archaeological site

The Los Llanetes group (37° 36′ 12.03″ N, 6° 38′ 06.88″ W) is part of the El Pozuelo megalithic complex formed by thirteen monuments distributed in three groups (Los Llanetes, El Riscal-La Veguilla and Los Lomeritos) along a 5 km strip of a peneplain on the southern edge of Sierra Morena (Fig. 1a; SM-Table 1). The El Pozuelo complex is noteworthy for its territorial extension, architectural diversity and singularity, with single chamber dolmens (Dolmens 8, 11 and 12), elongated chamber dolmens (Dolmens 9 and 10), covered galleries with central pillars (Dolmen 4) and monuments with multiple chambers and diverse spatial layouts: double chambers (Dolmens 1, 2, 3), cruciform plan with two (Dolmen 7) or four side-chambers (Dolmen 13), and asymmetric structures with four off-set chambers, antechambers and passages (Dolmens 5 and 6) (Cerdán et al. 1952; Leisner and Leisner 1956, 1959; Piñón Varela 1987, 2004; Linares Catela 2016).

The Los Llanetes group is located at the head of the Agua Fría ravine and is sheltered by the Chinflón hill. The site displays an abrupt, irregular and variable topography with alternating slopes on the right bank of the Tinto river basin (Fig. 1b). On the hilltop, there are several Late Neolithic habitational areas linked to the megalith builders, a Copper Age-Early Bronze Age walled settlement located on the highest point, a mining camp and several Late Bronze Age copper mines (Blanco and Rothenberg 1981; Pellicer and Hurtado 1980). The megalithic group consists of four monuments in two pairs located on two topographic elevations at a linear distance of 150 m (Fig. 1c). Dolmens 1 and 2 are located on two higher hilltops to the east, with an elevation between 330 and 335 m. Dolmens 3 and 4 are located on a promontory, at an elevation of 325 m, with a more amiable topography that connects the promontory to the eastern slope of the Chinflón hill.

The archaeological excavations at the site have demonstrated the long biography, the dilated timespan and the architectural complexity of the Los Llanetes group. The final form of the megaliths is the result of several construction projects, monumentalization processes and practices of reappropriation, from the beginning of the 4th to the beginning of the 2nd millennium cal BC (Linares Catela, 2017, 2022). The group dates between ca. 3970 and 1980 cal BC (68% probability). During the Late Neolithic, several models of dolmens were built in succession (Fig. 2), with a single chamber (3970–3760 cal BC), an elongated chamber (3790–3620 cal BC) or a multiple chamber (3660–3260 cal BC). These monuments would eventually take the form of three dolmens with multiple chambers (Dolmens 1, 2 and 3) and one with an elongated chamber or covered gallery (Dolmen 4). They were covered by circular mounds formed by alternating layers of stone slabs and clay, delimited by prominent kerbstones, with diameters between 15 and 20 m. The creation of the Neolithic funerary monuments would have required an enormous volume of stone materials in order to fulfil the scale of the construction works and the architectural projects.


(a)
Iberian Peninsula
El Pozuelo
EL POZUELO
El Pozuelo 13
El Riscal-La Veguilla Group
Los Lomeritos Group
El Pozuelo 12
El Pozuelo 11
El Pozuelo 9
El Pozuelo 6
El Pozuelo 8
El Pozuelo 7
El Pozuelo 5
Los Llanetes Group
El Pozuelo 10
El Pozuelo 4
El Pozuelo 2
El Pozuelo 3
El Pozuelo 1
El Pozuelo megalithic complex
Simple/elongated chamber dolmen
Double/multiple chamber dolmen
0 500 1000 m
(b)
Copper / Early Bronze Ages walled settlement
Late Neolithic settlement
Late Bronze mining camp
Late Neolithic settlement
Chinflón mines
Dolmen 4
Dolmen 3
Dolmen 2
Dolmen 1
Agua Fría Ravine
(c)
El Pozuelo 1
El Pozuelo 2
El Pozuelo 3
El Pozuelo 4

◂**Fig. 1** Location of the Los Llanetes megalithic group (Zalamea la Real, Huelva). **a** Distribution of the El Pozuelo complex; **b** Topography and location of the archaeological sites of the Los Llanetes group: isometric perspective; **c** Aerial view of the dolmens of Los Llanetes from the northwest

The dolmens were monumentalized during the Copper Age (2980–2580 cal BC) with pavements, steles and altars with hearths in the atriums, entrances and surrounding spaces, in accord with the increase in ritual practices of ancestor worship in the external areas of the monuments. Later on, during the Early Bronze Age (2230–1940 cal BC), the dolmens were partially dismantled and integrated as architectural elements within the dry-stone terraced enclosures with circular platforms. Subsequently, the site and the monuments were reused in various phases in different historical periods.

The geological context

The study area is located in the South-Portuguese Zone of the Iberian Massif (Fig. 3a), extending from southwestern Portugal to the Sierra Norte de Sevilla, bordered to the north by the Ossa-Morena Zone through a complex shear zone (South Iberian Shear Zone) and to the south by the more recent formations of the Guadalquivir Basin. The South-Portuguese Zone is characterized by rocks belonging to the Middle Devonian to Permian periods and divided into five geological domains based on their different lithological, structural and palaeogeographic features. From north to south, these are the Pulo do Lobo Domain, the Iberian Pyrite Belt, the Southwest Portuguese Domain, the Sierra Norte Batholith and the Permian Viar Basin (Fig. 3b).

The substrate of the Los Llanetes dolmen group belongs to the Iberian Pyrite Belt, internationally known as the region with the world's highest concentration of massive sulphide deposits and with important manganese deposits (Leistel et al. 1997; Inverno et al. 2015; IGME 2015). Within the Iberian Pyrite Belt, three main units with different geological features are differentiated: the Phyllite Quartzite Group (PQG), the Volcanic-Sedimentary Complex (VSC) and the Culm Group or Baixo Alentejo Flysch Group (BAFG) (Fernandes et al. 2019) (Fig. 3b).

The PQ Group consists mostly of shales with intercalated levels of quartzarenites, of Middle Devonian to Late Devonian (Givetian to the Late Famennian) age. The minimum estimated thickness of these materials is approximately 2000 m. These materials were deposited on a shallow marine platform, sporadically affected by storms and waves.

The VSC overlies the PQG and consists of a complex formation of magmatic and sedimentary rocks of Late Famennian to Middle-Late Visean age (Leistel et al. 1997). It displays very significant variations in thickness (up to 1300 m), interpreted as a consequence of the compartmentalization of the area into numerous basins at the end of the Devonian (Quesada 1996; Simancas et al. 2003, 2006). The magmatic rocks are mainly of volcanic and subvolcanic origin and vary in composition from acid to basic, with a smaller volume of andesitic rocks (Munhá 1983; Mitjavila et al. 1997; Thiéblemont et al. 1997; Soriano and Marti 1999; Onezime et al. 2003; Díez-Montes and Bellido Mulas 2008; Conde and Tornos 2019; Oliveira et al. 2019). Observations in the field indicate that volcanic activity was essentially submarine, as is evidenced by pillow lavas and some reworked hyaloclastite deposits (Rosa et al. 2010; Valenzuela et al. 2011; Donaire et al. 2020a). The sedimentary rocks of the VSC are mainly fine-grained detrital rocks and cherts. Interbedded in this sequence of magmatic and sedimentary rocks are massive sulphide deposits. The upper part of the VSC is characterized by a marker horizon of purple shales, below which levels of jasper and manganese mineralization can sometimes appear. On top of these shales, there are other slate levels and volcaniclastic rocks that gradually transition to the shale sequence of the base of the Culm Group.

Finally, the Culm Group consists mainly of a turbiditic Culm facies formation, several thousand metres thick. It is formed by alternating shales and greywackes. It is sometimes preceded by a stratigraphic layer of approximately 50 m in average thickness, known as the Basal Shale Series.

In relation to tectonics, Mantero et al. (2007) subdivided the IPB into two subdomains according to different structural criteria: the Aljustrel-Mértola-Riotinto Thrust Belt and the Major Fault-Propagation Fold Region, separated by a broad shear band. The VSC materials of our study area are located within the latter.

The Aljustrel-Mértola-Riotinto Thrust Belt is characterized by deformation associated with complex ductile-brittle shear bands, defining a mylonitic belt with a general E-W orientation and subvertical to 60–70°N dip, with a predominantly sinistral tear movement with a thrust component to the S (IGME 2015).

The Major Fault-Propagation Fold Region is characterized by thin-skinned tectonics that mainly affect the upper part of the Earth's crust. It corresponds to a belt of S-vergent folds and thrusts rooted in a detachment level at a depth of 12–15 km (Simancas et al. 2003). The first deformation phase (F1) is mainly represented by asymmetric, tight, S- or SW-vergent folds associated with axial-plane foliation (slaty cleavage) (S1) in a NW-ESE direction, with a dip to the N (Mantero et al. 2006). The second deformation phase (F2) is characterized by the generation of kilometre-scale thrusts with NW-ESE directions and 20–45° NNE dips. These thrusts are associated with bands of brittle fault rocks, which are brittle-ductile in the deeper zones, with the development of S-C structures (Mantero et al. 2003, 2006). These tectonic

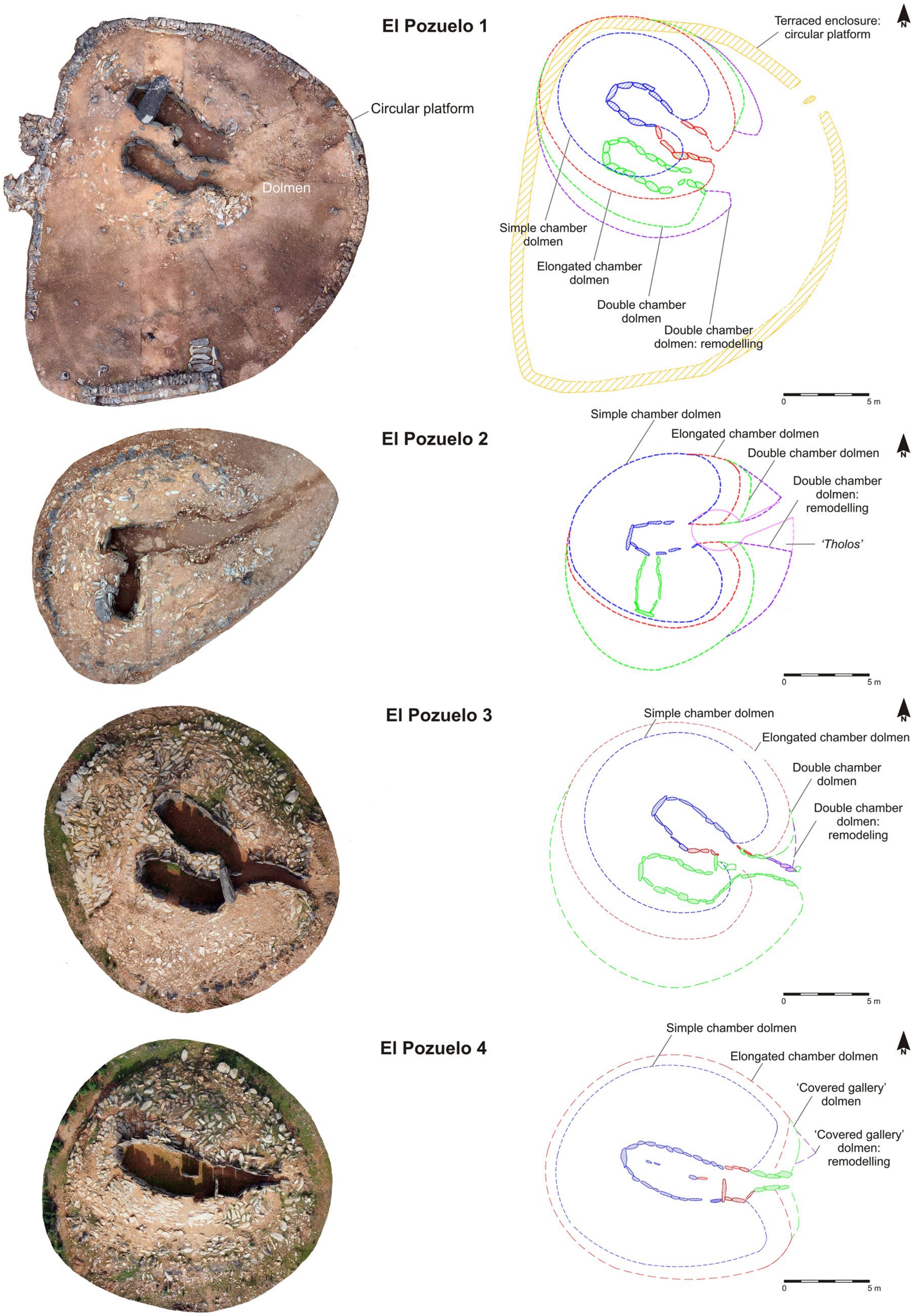


Fig. 2 Architectural sequence of the Los Llanetes group. Zenital aerial photographs and schematic evolution of the monuments

structures are a primary factor in the morphology of the megalithic blocks available in our study area.

Geomorphology

The geomorphological situation of the site of Los Llanetes is quite peculiar. It is located in the vicinity of a watercourse divide, surrounded and protected by elevations that rise between 30 and 80 m above the ground on which the dolmens were built. The group is located at the head of the Agua Fría ravine, very close to the divide between this watercourse, the Manzano stream and the Lobo stream, which joins the Los Pinos stream and flows west (Fig. 4). Although the actual divide is wider, with extensions to the north and south, the perception from the head of the ravine is that of a semi-enclosed U-shaped depression, open to the east, from the edges of which the entire inner space, and thus the monuments, can be visually dominated. In addition, a large part of the adjacent territory is also visible from the divide, with a wide view to the north and west, especially from the northwestern edge, and also to the east.

The surrounding landscape is generally formed by more or less flattened summits at an altitude of around 400 m. This elevation and morphology corresponds to the remains of the planation surface that may have originated in the generalized Palaeogene erosion, widely represented in other sectors of the Iberian Massif (Flores Hurtado 1994; Rodríguez Vidal and Díaz del Olmo 1994). On this surface, the various watercourses became intrenched, dismantling the flat surface to a great extent and modelling the present relief.

At the site of Los Llanetes, the Agua Fría ravine is noticeably more intrenched than the Los Pinos stream. There are several reasons for this greater depth. Firstly, the direction of the ravine in this area coincides with that of some of the ENE-WSW fractures identified on the geological cartography. These fractures may have induced not only the direction of the ravine, but also its greater intrenchment, as they constitute lines of geological weakness along which watercourses may erode with greater intensity. The Agua Fría is indeed a highly energetic course, with sufficient strength to tumble and displace detached rocky blocks.

Secondly, it may have been influenced by the different geological formations on which these fluvial networks developed. Thus, while the ravine is intrenched in the VSC andesites, the riverbank cuts into the PQ Group. This association may appear contrary to the general pattern, in which the VSC tends to create smoother reliefs, while the fluvial network in the PQ is intrenched to a greater extent and develops more abrupt reliefs. However, in this particular area, the earlier lithology is affected by shearing along the aforementioned fractures, a process that creates weaknesses in the form of discontinuity planes through which it is easier for the fluvial network to become intrenched. On the other hand, the PQ Group in the immediate area displays a lesser intrenchment of the watercourses, probably because these correspond to secondary streams and gullies, and the lithology is not weakened to the same extent.

Thirdly, and possibly the most influential factor, is the greater general slope of the Agua Fría ravine. In the first section, from its headwaters to its connection with the Manzano river, its gradient is 5.5%, flowing into the Tinto River after 9.5 km with an average gradient of 2.27%. In contrast, from its headwaters to its connection with the Los Pinos river, the Lobo stream has a gradient of 3%, running for 30 km until it flows into the Tinto River, with a gradient of only 0.85%. The greater proximity of the base level implies a greater gradient in the Agua Fría ravine and, therefore, greater energy of the fluvial network and, as a consequence, greater erosion and intrenchment.

Through their intrenchment, the different minor channels at the head of the ravine have undermined the substrate unevenly, in such a way that a residual surface between them has remained above an altitude of 320 m. It is on this residual surface that the dolmens are located, with Dolmens 1 and 2 above 330 m and Dolmens 3 and 4 above 320 m.

Materials and methods

The geoarchaeological study may be broken down into five interrelated approaches:

1) Lithological plans and techno-morphological analysis of the supports of the monuments.
2) Geoarchaeological survey and geological mapping of the surrounding area.
3) Selection of rock samples for analysis.
4) Petrographic and geochemical analysis.
5) Discussion and interpretation of the evidence on sourcing, selection and procurement of stone materials.

Lithological plans and techno-morphological analysis of the supports of the monuments

Lithological plans were created in order to identify and represent the lithotypes of each monument. The scale of the monuments and the variable number of constructive stone elements required the articulation of three sequential documentation processes. A visual reconnaissance of the rocks was carried out. Subsequently, a topographic survey was conducted, including the delimitation and individualized positioning of each stone with a total station, photogrammetry (low-aerial and terrestrial) and 3D-scanning of the four dolmens. Finally, a detailed plan of the monuments was produced using CAD software, on which the lithology of each stone was represented.

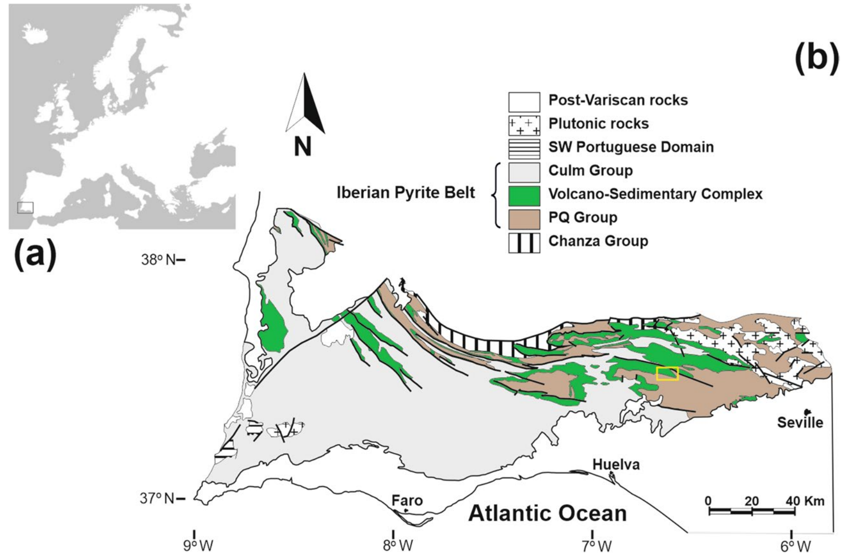


Fig. 3 Geological map of the Iberian Peninsula and the Iberian Pyrite Belt. **a** Location of the Iberian Pyrite Belt. **b** Simplified geological map of the Iberian Pyrite Belt. The yellow square indicates the study area

The techno-morphological analysis of the stone supports focused on the analysis of the format and the identification of the technical traces of each construction element and architectural phase. The stones of the megalithic structures (orthostats, capstones and shoring slabs), tomb structures (mounds, kerbs and levelling platforms) and external structures (pavements, steles, altars, etc.) of the dolmens were studied individually. The construction elements (contention walls, dry-stone platforms, etc.) of the terraced enclosures were also analysed.

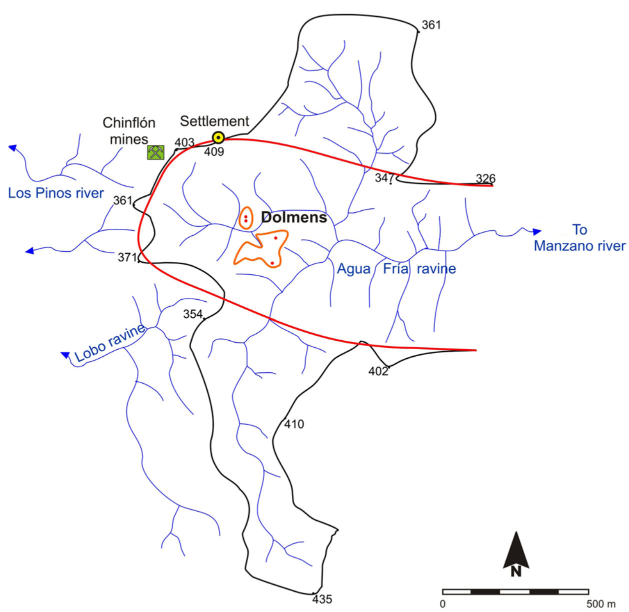


Fig. 4 Geomorphological setting of the Los Llanetes megalithic group. The black line represents the divide of the Agua Fria ravine. The red line marks the perception of space

Geoarchaeological survey and geological mapping of the surrounding area

The geoarchaeological survey was directed towards the knowledge of the local geological formations, the identification of the lithologies in the surrounding landscape, the characterization of the potential source areas, the location of the nearby archaeological sites and the creation of a complete geological cartography of the study area. This area spans over 13 km^2.

As a preliminary step, a detailed review was carried out of the printed and digital maps of Sheet 960 (1:50.000), Zone Z3100 (GEODE 1:50.000) and Sheets 74-75 (1:200.000) of the National Geological Map (MAGNA) available through the websites of the Spanish Geological and Mining Institute in different versions, forms of representation and scales (IGME 1970, 1982, 2004, 2015).

The field work involved the identification and spatial delimitation of the different lithologies at a scale of 1:2000, the creation of control points (geomechanical stations and sclerometer measurements), the acquisition of data and the recording of observations at the outcrops where the rock samples were taken for petrographic and geochemical analysis. The data have been organized and arranged in a GIS (Gillings et al. 2019) created in QGis software, which enabled the systematization of the spatial information, and the design and production of detailed geological maps (Fig. 5). These maps represent the local geological setting, lithological formations, conventional structural signs and superficial rock outcrops with a greater level of information and precision than the conventional geological maps, providing a high-resolution base cartography for the location and study of the potential source areas exploited for the construction of the megaliths.

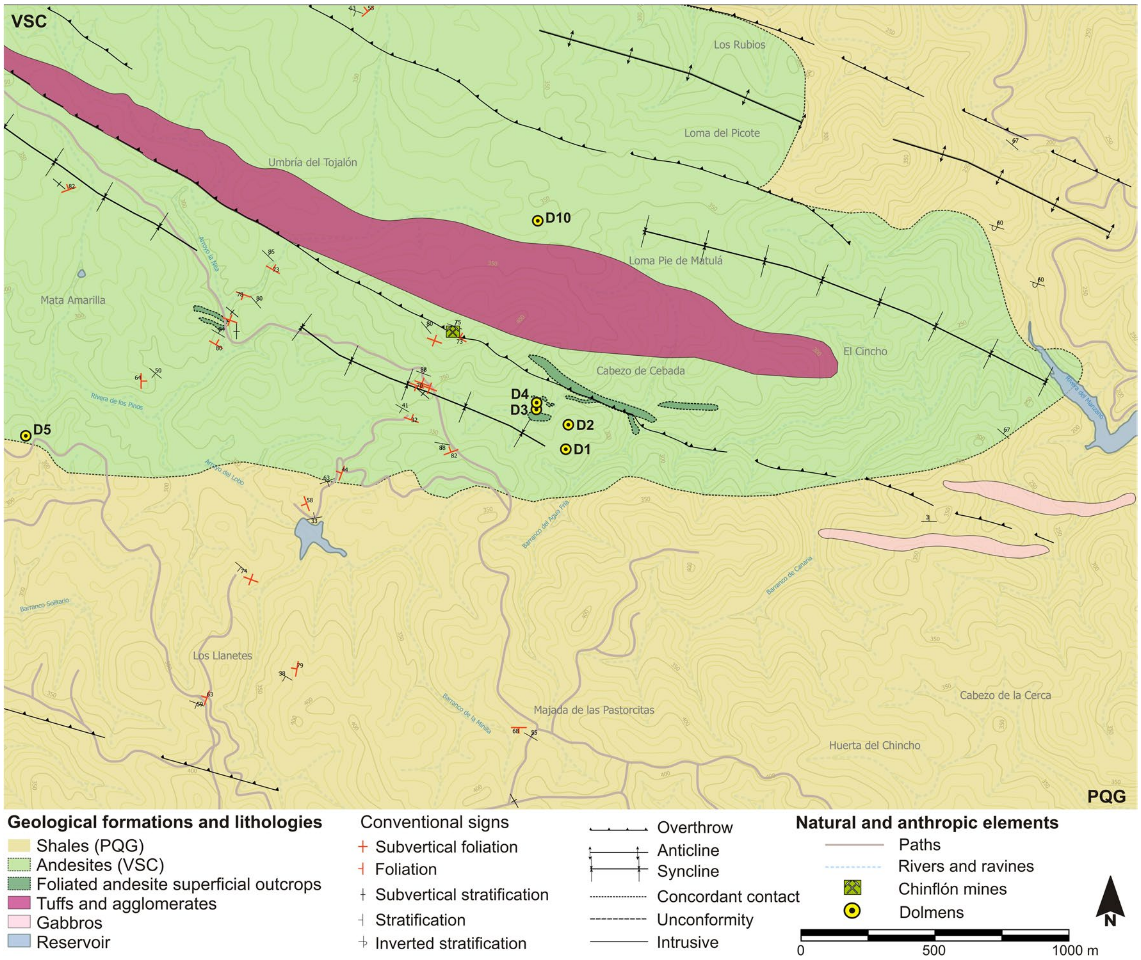


Fig. 5 Geological map of the area immediately surrounding the Los Llanetes group

Selection of rock samples for analysis

The sampling strategy for petrographic and geochemical analysis focused on the selection of the dominant and most representative lithologies of the megaliths and outcropping rocks of the potential source areas in the surrounding landscape (Fig. 6). This sampling has been restrained and non-invasive, without altering the original surfaces of the supports or destroying geoarchaeological materials of any kind. Small fragments of stone detached from the orthostats, from the archaeological deposits in the external spaces of the megaliths, from the faces of the quarries and from the blocks on the surface of the source areas were carefully collected.

From the dolmens (numbered D1 to D4 on the cartography), representative samples of the different lithologies were selected, collecting in the case of the orthostats a sample with specific macroscopic characteristics and discriminating physical features. From the foliated andesite source areas (numbered S1 to S6), samples were taken from four quarries and two source areas located in the bed of the Agua Fria ravine, identified on the basis of anthropic traces of extraction on the rocky outcrops, waste derived from exploitation and/or materials suitable for the construction of the megaliths.

Rock samples were therefore taken from different elements and places (SM-Table 2). On the one hand, 14 samples were selected from the four dolmens (n= 7) and the source areas (n= 7), collecting one or two fragments at each site, with which 14 thin sections were made (duplicating the section from one site) and 14 geochemical analyses were carried out (Table 1). On the other hand, 15 additional samples were chosen for thin section from different sites (8 from dolmens, 3 from source areas, 3 from nearby outcrops and 1 from the Chinflón mining site), to serve as comparative petrographic material (Table 2).

Petrographic and geochemical analysis

The aim of the petrographic analysis implemented in this study was to identify and characterize the stone materials used in the

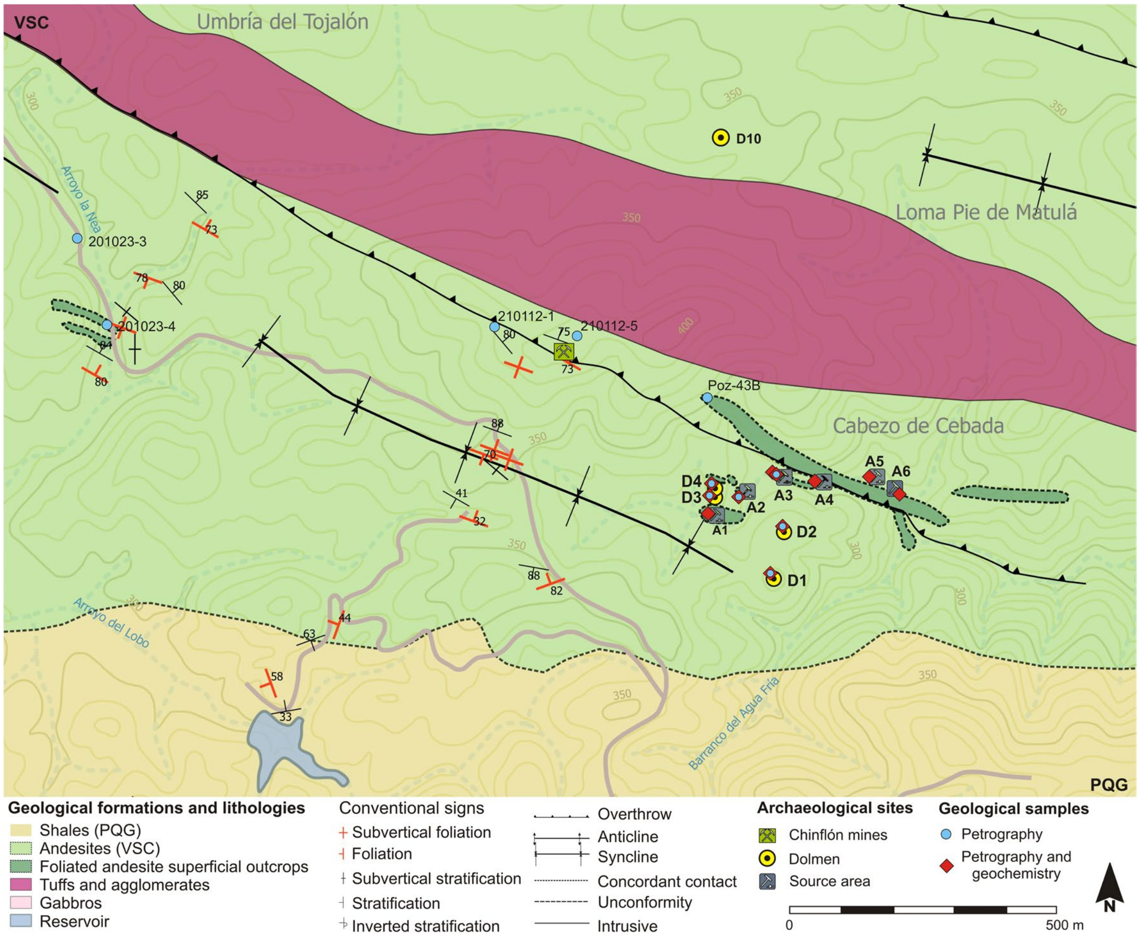


Fig. 6 Rock samples for petrographic and geochemical analysis from the dolmens of Los Llanetes, nearby source areas and outcrops on a geological map

construction of the megalithic architectures on the basis of their structural, textural and mineralogical features. It was postulated that this would make it possible to determine the physical characteristics that contributed to the choice of these materials and to determine their source areas. This study was based initially on visual petrographic observations of the rocks of the dolmens and was complemented by a detailed study of thin sections from the samples selected from the outcrops and potential source areas using a petrographic microscope. In total, 29 thin sections (18 prepared at the University of Huelva and 11 at the University of Granada) were studied and classified according to the descriptive terminology of McPhie et al. (1993) and Gifkins et al. (2005). A Nikon Eclipse LV-100 POL petrographic microscope connected to a Nikon DS-Fi1 camera was used to obtain the images of the thin sections. The camera was connected to an Intel Pentium 4 2.66 GHZ with NIS-Elements image capture software.

In the 14 geochemical analyses, performed at ALS Laboratory Group, ICP-AES was used for the main major elements and Lithium Borate Fusion ICP-MS for the trace elements. Because petrographic observations detected alterations linked to regional metamorphism and fluid circulation during deformation, the geochemical characterization of the analysed materials was considerate of these processes (Pin and Waldhausrová 2007). Published studies have shown that Al, Zr, Hf, Ti, Nb and REE remain relatively immobile during such processes. In contrast, large-ion lithophile elements (Rb, Sr, Ba, Na, K, Cs, Pb) are often mobilized under the same conditions (Humphries 1984). We therefore focused the geochemical characterization on the concentration of the elements considered immobile in aqueous fluids or during metamorphism, in accord with the parameters applied in the study of dolerites from the Stonehenge and Waun Mawn monuments (Bevins et al. 2012, 2021, 2022; Pearce et al. 2022).

The geochemical classification of deformed and altered volcanic rocks was supported by Nb/Y versus Zr/TiO_2 diagrams (Winchester and Floyd 1977). The chondrite-normalised rare earth element (REE) values were plotted according to Nakamura (1974). These results were assessed, along with the Ce_N/Yb_N versus TiO_2/Zr diagrams from the dolmens, quarries and source areas.

Table 1 Geological samples for petrographic and geochemical analyses from the Los Llanetes group. GA, geochemical analysis; TS, thin sections

Site	Sample	GA	Code	TS	Code	Lithology
Dolmen 1, north chamber	Mound slab, north chamber backside	X	210416-2	X	210416-2	Foliated andesitic breccia
Dolmen 1, south chamber	Fragment of orthostat 14 from the south chamber	X	210416-3	X	210416-3	Foliated andesite
Dolmen 2, south chamber	Fragment of orthostat from south chamber	X		X	210416-5	Foliated andesite
Dolmen 3, north chamber	Fragment of orthostat 15 from the north chamber	X	200728-3	X	200728-3	Foliated andesite
Dolmen 4	Fragment of orthostat 25 on the mound	X	200728-1	X	200728-1	Foliated andesite
Dolmens 3–4: stockpile area	Stone used in pavements and mounds	X	210128-2	X	210128-3	Amphibole-phyric andesite
Dolmens 3–4: stockpile area	Stone used in pavements and mounds	X	210128-4	X	210128-5	Massive andesite
Quarry 1	Fragment of outcrop from extraction face	X	210617-1	X	Poz-R	Foliated andesite
Quarry 2	Fragment of outcrop from extraction face	X	210617-2	X	200728-4	Foliated andesite
Quarry 3	Fragment of outcrop from extraction face	X	200728-8	X	200728-8	Dacite
Quarry 4	Fragment of outcrop from extraction face	X	200728-5	X	200728-5 200728-6	Foliated andesite
Source area 5	Detached block in the Agua Fria Ravine	X	210617-3	-	-	Foliated andesite
Source area 6	Detached block in the Agua Fria ravine	X	210617-4	X	200728-7	Foliated andesite
Agua Fría ravine, west of the Quarry 3	Rolled block from the Agua Fria ravine	X	210416-7	X	210416-7	Foliated andesite

Results

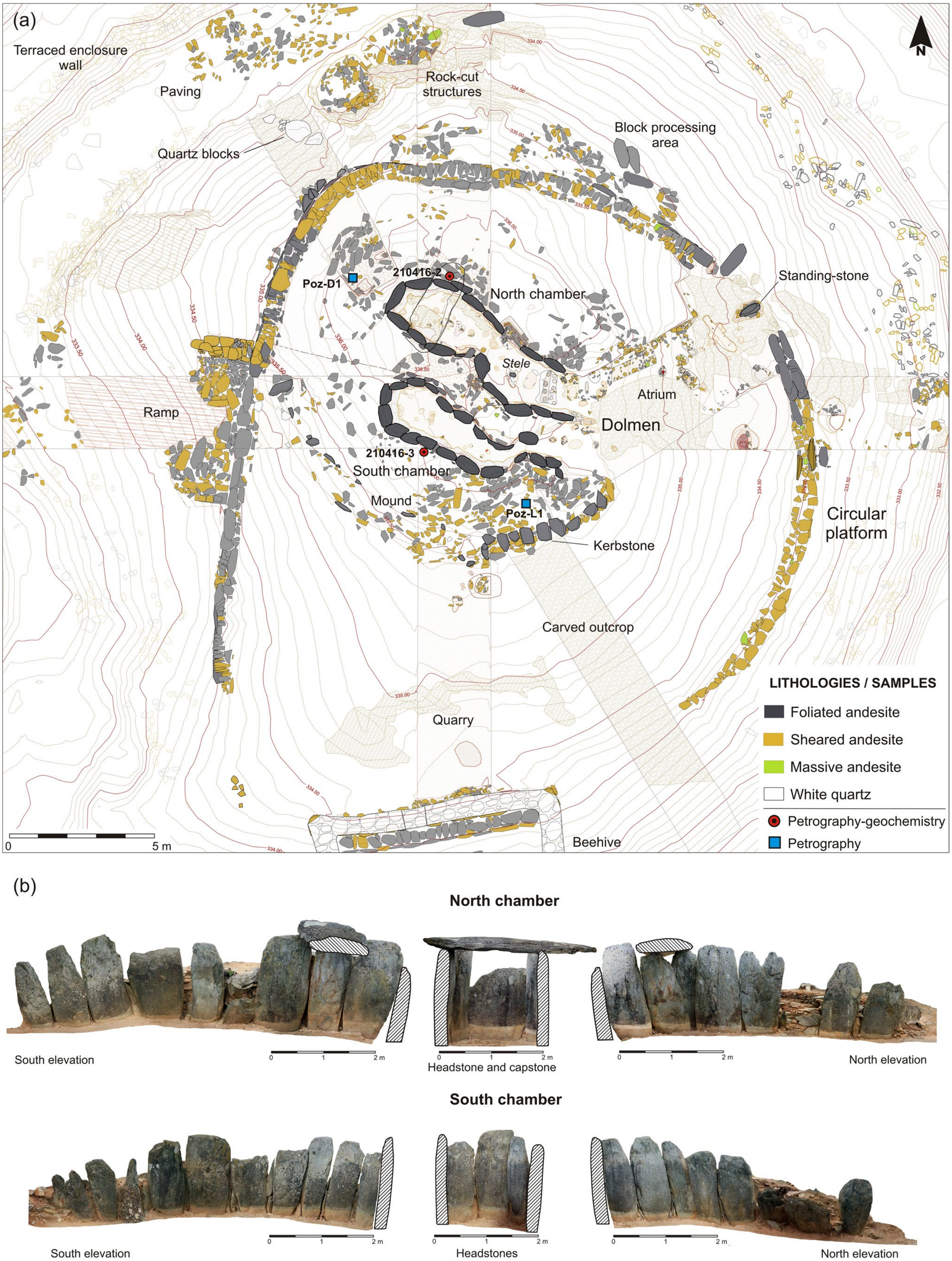
Geological setting

The Los Llanetes area is located to the north of the Valverde del Camino anticline (Fig. 3b). Structurally, it is a synclinorium (El Pozuelo synclinorium) with a symmetrical structure that shows an angle between the main limbs of the order of 90° (Monteserín et al. 1999). In this tectonic macrostructure, the CVS is at its core and lies concordantly on the PQ Group, which is essentially composed of shales. The entire area shows penetrative deformation at all scales, characteristic of a complex shear zone, with discrete shear bands associated with the main thrusts (Fig. 5).

The outcropping rocks of the CVS are coherent and occasionally volcaniclastic facies of andesitic composition (Fig. 5). The coherent facies, resulting from the

Table 2 Thin sections from the Los Llanetes group. Rock samples from dolmen, source areas and geological surroundings for comparative petrographic analysis

Site	Sample	Code	Lithology
Dolmen 1	Mound slab, nothern sector	Poz-D1	Foliated andesite
Dolmen 1	Mound slab, southern sector	Poz-L1	Foliated andesite
Dolmen 2	Mound slab, nothern sector	Poz-D2	Foliated andesite
Dolmen 3	Fragment of orthostat 2 from the passage	D3-E2	Foliated andesite
Dolmen 3	Orthostat 30 of the south chamber	Poz-D	Foliated andesite
Dolmen 3	Mound slab, nothern sector	Poz-D3	Foliated andesite
Dolmen 4	Fragment of orthostat 21 from the chamber	D4-O21	Foliated andesite
Dolmen 4	Atrium paving	200728-2	Amphibole-phyric andesite
Quarry 2	Fragment of outcrop	BH-104	Foliated andesite
Quarry 3	Fragment of outcrop	BH-100	Foliated andesite
Outcrop of the Chinflón Hill, eastern slope	Outcrop on the eastern slope of the Chinflón Hill	Poz-43B	Foliated andesite
Outcrop of the Chinflón Hill. Western slope	Outcrop on the western slope rocky outcrop	210112-1	Sheared andesite
Chinflón mines	Fragment of miner's hammer	210112-5	Diabase
Outcrop next to the road parallel to the Nea ravine	Massive andesite outcrop	201023-3	Massive andesite
Foliated andesite outcrop at the intersection of the road with the Nea ravine	Foliated andesite rocky outcrop	201023-4	Foliated andesite


(a)
Terraced enclosure wall
Paving
Rock-cut structures
Quartz blocks
Block processing area
N
Standing-stone
Poz-D1
210416-2
North chamber
Stele
Atrium
Dolmen
Ramp
210416-3
South chamber
Mound
Poz-L1
Kerbstone
Circular platform
Carved outcrop
Quarry
Beehive
0
5 m
LITHOLOGIES / SAMPLES
Foliated andesite
Sheared andesite
Massive andesite
White quartz
Petrography-geochemistry
Petrography
(b)
North chamber
South elevation
Headstone and capstone
North elevation
South chamber
South elevation
Headstones
North elevation
0 1 2 m

◂**Fig. 7** El Pozuelo Dolmen 1. **a** Lithological plan of the monument and location of the rock samples for petrographic and chemical analysis. **b** Photogrammetric elevations of the north and south chambers

crystallization of a magma, displays a porphyritic aphanitic texture and is essentially formed by millimetre-sized (< 2 mm) plagioclase phenocrysts and, rarely, quartz, embedded in a microcrystalline matrix of plagioclase microlites. All plagioclases, initially rich in calcium, have undergone albitization processes. This process is common in most volcanic rocks of the IPB and is attributed to regional pervasive alteration by low-temperature volcanic rock-sea water interaction. This process came before the tectonic deformation of the rocks. Where andesites are affected by deformation, textural and mineralogical changes lead to the development of phyllosilicate-rich oriented fabrics (foliation) and mineralogical transformations of the pre-existing phases. However, it is often difficult to establish whether the development of these mineralogical changes is linked solely to deformation, to regional or local hydrothermal alteration and/or to metamorphism. To the south of this andesitic sequence, the PQ materials are formed of alternating quartzarenites and shales.

Lithology and techno-morphology of the supports of the monuments

The archaeological study and topographic survey of the megaliths included the morphological classification and visual lithological identification of the rocks, distinguishing between andesites (foliated, sheared, massive and amphibole-phyric), white quartz, gabbro and ferruginous agglomerate.

Foliated andesite is the majority and most represented rock, and was used exclusively in the megalithic structures (passages, antechambers and chambers) and ringstones of the dolmens. Thus, all the orthostats, steles, pillars, capstones, shoring slabs and stone rings belong to this lithology. The orthostats display a range of formats (rectangular, lenticular, trapezoidal and oval), with a predominance of elongated and slender morphologies, with thin thicknesses and lenticular sections, with the exception of the oval or boudin-shaped supports. Their maximum dimensions range from 1.10 to 2.50 m and their estimated weights vary between 250 and 2750 kg. The preserved cover-stones correspond to elongated lenticular and rectangular formats. The technological study has detected a common operational sequence with successive technical treatments for the shaping of the vertical supports: (a) lateral rough shaping by direct percussion to define the edges and sections; (b) fine carving by direct percussion of the upper extremity in the case of orthostats and pillars, creating horizontal surfaces for the even support of the cover-slabs; (c) homogeneous treatment by continuous direct percussion hammering, by indirect continuous and fine pecking and/or discontinuous hammer and chisel pecking, creating uniform and rough-textured surfaces; (d) abrasion and polishing of specific areas of particular supports. This 'megalithic operational chain' required planning, technical sophistication, architectural specialization and continuity of the building tradition during the Late Neolithic (Linares Catela 2021).

Foliated andesite is observed in combination with sheared andesite in the mounds, external structures and dry-stone walls of the terraced enclosures. Sheared andesite was used in raw form, with a predominance of medium to large, subrectangular slim slabs. The massive andesite blocks and boulders were placed in rough form in the pavements of the access and ambulatory areas outside the kerbstones. The polyhedral and decimetric-sized white quartz pebbles were bonded with clay in the packing trenches and pits of the vertical supports, and in the paving of the external areas of the dolmens. There are also larger white quartz blocks, between 0.50 and 1 m in size, arranged as visual landmarks in the transit areas. Other materials, such as ferruginous agglomerates and gabbro, were sporadically used in rough form in the external peripheral spaces of the mounds.

Each monument displays its own formal characteristics, proportion of lithologies, types and number of megalithic supports. Dolmen 1 has two parallel orthostatic chambers with independent entrances facing east (90°) contained in a circular mound with a diameter of 12.60 m delimited by a kerb (Fig. 7a). It preserves 40 vertical supports (39 orthostats and 1 axial stele in the north chamber) and 1 large capstone 3.30 m long and weighing an estimated 2.75 tons (Fig. 7b). The orthostats range between 1.50 and 2.30 m and weigh between 500 and 2200 kg. The dolmen is surrounded by a circular dry-stone platform with a ramp to the west and several entrances, one of them flanked by an orthostat from the north chamber reused as a menhir, and two lower levels delimited by the walls of the terraced enclosure.

Dolmen 2 has two perpendicular chambers with axial access to the east (90°), contained in a large elliptical mound 12.75 m in diameter surrounded by a prominent ringstone (Fig. 8a). The 21 orthostats range between 1.20 and 2 m and weigh an estimated 300–1800 kg (Fig. 8b). The dolmen was reused for the construction of a tholos and the mound was reconstituted in historical times. The monument is surrounded by an elliptical ditch enclosure cut into the substrate.

Dolmen 3 is notable for its layout with two parallel chambers, an antechamber and passage oriented 110° southeast, contained in a circular mound with a diameter of 16.50 m and a height of up to 3.50 m, delimited by a kerb (Fig. 9a). This complex monument is formed by a total of 50 upright supports (47 orthostats, 2 jambs and 1 transversal slab) ranging between 1.10 and 2.50 m and weighing between 250 and

2750 kg, as well as an elongated rectangular cover-slab, 2 m in length and weighing an estimated 525 kg (Fig. 9b).

Dolmen 4 is an elongated monument built in a circular mound 16.50 m in diameter and up to 3.50 m height. It is notable for its covered gallery, segmented into three distinct sections: an open passage facing 90° east, an antechamber and a chamber with central pillars (Fig. 10a). It has a total of 40 vertical supports: 34 orthostats, 4 pillars, 1 transversal slab and 1 stele at the entrance (Fig. 10b). The orthostats, between 1.20 and 2.30 m, weigh an estimated 450–2650 kg. Surrounding Dolmens 3 and 4, there are three descending levels of dry-stone walls forming the terraced enclosure.

Source areas

The geoarchaeological survey enabled us to recognize the types of blocks available in the environment, to map the surface outcrops and to identify potential sources located in the immediate vicinity (Fig. 6). Other potential 'source areas' of andesites could be found more than 2 km to the north and west. However, the analysis has focused on the area around Los Llanetes for two reasons. It is the only space in the surrounding area where outcrops have been identified with clear evidence and materials derived from prehistoric supply and extraction. Furthermore, the irregular orography of the terrain, with significant hills and depressions, would make it difficult to move and transport large stone blocks from more distant outcrops. This same pattern of local procurement may have been carried out in the El Riscal-La Veguilla group, located to the west, as the dolmens were built with the same andesites and other rocks that appear in the environment.

We have differentiated two types of sources according to the strategies of stone procurement and extraction. 'Source areas' are places where natural detached blocks, slabs and pebbles of different sizes and lithologies are found, and may be identified as potential procurement areas for surface materials. 'Quarries' are places where stone was extracted from an outcrop using diverse techniques to create blocks, quarry faces or trenches. Quarries can be recognized by the topographical alteration of the site, the morphological transformation of the outcrops, the existence of one or more extraction faces with technological traces and the presence of fractured blocks, discarded material and tools (mallets, hammers, picks and hammerstones) of massive andesite, gabbro and diabase.

The monuments are located on elevations with a highly deformed and altered andesitic substrate, with multiple penetrative foliation planes. This substrate, which is easily broken and fractured, makes it possible to carry out earthworks (levelling, cutting and carving), including the trenches or foundation pits for the vertical supports and the extraction of materials in quarries. The sheared andesite was sourced and quarried at the site of the megaliths themselves. A small quarry is located on the top of the hill of Dolmen 1, a few metres to the south. A larger quarry is located in the gully between Dolmens 1 and 2, exploiting a stepped, massive rocky ridge with a 110–120° NW-SE orientation. It displays an 8.50 m quarrying face on the west side, up to 1 m in height and 7 m in length, from which up to 60 m^3 of slabs and small and medium-sized blocks may have been extracted (Fig. 11a). Two quarries are associated with Dolmens 3 and 4, opened to the outside of each monument. The quarry located to the south of Dolmen 3 is a trench, 5 m long and 3.50 m wide, with a northern extraction face, from which at least 11 m^3 of material was extracted, in the form of 30–60 cm long blocks and slabs for use in the rough. The quarry to the north of Dolmen 4 appears to be a SE-NW oriented pit, 17 m long by 14 m maximum width and an estimated depth of 0.70 m (Fig. 11b). At least 75 m^3 of material, both stone slabs and clay, may have been extracted.

Several foliated andesite outcrops have been mapped in the geological study area, located on the flanks of a thrust fold with a N110°–130°E direction and a steep dip, generally to the north, taking the form of boudins (Fig. 6). They are concentrated in two zones with distinct outcrops. The first is located at the head of the Los Pinos stream and is formed by two parallel northwest-southeast oriented strips 100 m long and 20 m wide, visible in the riverbed. This outcrop is located 1.1 km west of the Los Llanetes group. The second corresponds to an irregular strip 500 m long and 50 m wide, with a northeast-southeast orientation, running parallel to the thrust fold, extending from the southern slope of the Chinflón hill to the intersection of the beds of the Agua Fría and La Canaria ravines. The largest rocky outcrops emerge in the bed of the Agua Fría ravine, where the detached blocks of foliated andesite take diverse shapes and sizes, depending on the fractures and foliation planes of the rock in the outcrops. Three main formats are represented:

a) Lenticular blocks (elongated lenticles), with ductile-deformed edges and straight lateral fractures. They are elongated stones with an elliptical tendency, up to 3 m in length and not too thick, with a greater width in the middle than at the ends, which are usually rounded (Fig. 12a). They are associated with massive stepped outcrops with marked foliation planes (Fig. 12b).
b) Boudin blocks, with elongated pseudo-oval shapes with a marked widening and thickening in the central section compared to the extremities, which are usually narrower, thinner and rounded. They have elliptical and oval sections and curved edges. These blocks, 1–2.5 m in length, occur in medium-sized outcrops, coinciding with the closed flanks of the thrust folds and the bed of the Agua Fria ravine (Fig. 12c).

c) Barrel blocks, with somewhat rounded edges, occurring in medium-sized continuous outcrops in the narrow area of the ravine. These are smaller blocks, less than 2 m in length, with elongated prismatic or pseudo-oval shapes with oblong cross-sections, and displaying oblique fracture planes (Fig. 12d).

Four foliated andesite quarries and two potential source areas have been located. The quarries were opened in the larger rocky outcrops which constituted the only visible and accessible places for the extraction of large stone blocks from the surface, and were compatible with the extractive techniques of the Neolithic community of Los Llanetes. The quarries are emplaced in two distinct locations: the hill on which Dolmens 3 and 4 were built and the bed of the Agua Fría ravine, located in a linear radius between 50 and 350 m around the megaliths (Fig. 13a).

Quarries 1 and 2 are located on the promontory of Dolmens 3 and 4. Quarry 1 is developed around a medium-sized continuous outcrop on the southern slope, 80 m long and 30 m wide, in which subvertical rocky crests emerge to a height of 0.50–1.50 m. This outcrop is highly fractured and displays a marked penetrative foliation. The surface is dominated by pseudo-oval blocks and medium-sized discarded slabs (Fig. 13b). Quarry 2 is located on the eastern slope, characterized by several discontinuous surface outcrops and linear ridges, 10–20 m long, 3 m wide and approximately 1 m high, with a marked vertical arrangement (ca. 90°). The outcrops still show the negative spaces created by the extraction of stones of various shapes and sizes (Fig. 13c). Both blocks used in the megalithic walls and medium-sized slabs for the rings and mound structures were extracted, and discarded medium-sized lenticular blocks are readily observed on the surface.

The largest areas of exploitation are located in the Agua Fría ravine, exposed by the strong erosive action of the river. Two quarries and two potential source areas have been recorded in this ravine. The quarries were opened in the larger massive and stepped outcrops, with rectangular profiles, vertical sections (ca. 80–90°) and slightly rounded edges. These outcrops have a northwest-southeast orientation, with a southward vergence and marked foliation lines, and protrude vertically from the ground between 1 and 3.5 m. These geological conditions favoured the extraction of large, elongated and slender lenticular blocks, as evidenced by the traces left on the extraction faces, the detached blocks and the refuse material observed on the surface.

From Quarry 3, with an extraction face 1.5 m high and regular foliation lines approximately 15–30 cm apart, it would have been possible to extract medium-sized elongated slender lenticular blocks, up to 2 m (Fig. 13d).

Quarry 4 is located at the intersection between a thrust fold and two massive stepped surface outcrops, which constitute a zone of strong shearing and vertical emergence of foliated andesite. It is the largest of the known quarries, with an extraction area of 10 m by 15 m, and the most intensively worked, judging by the volume of extracted material and the quantity of discarded blocks (Fig. 13e). It has two vertical faces of up to 3.5 m in height, in which the regularity of the fracture and foliation planes of the rock can be observed at an average interval of 25 cm (Fig. 13h). The shapes, sizes and thicknesses of the blocks extracted and discarded from this quarry are analogous to those of the megalithic supports of the dolmens with lenticular and elongated rectangular formats.

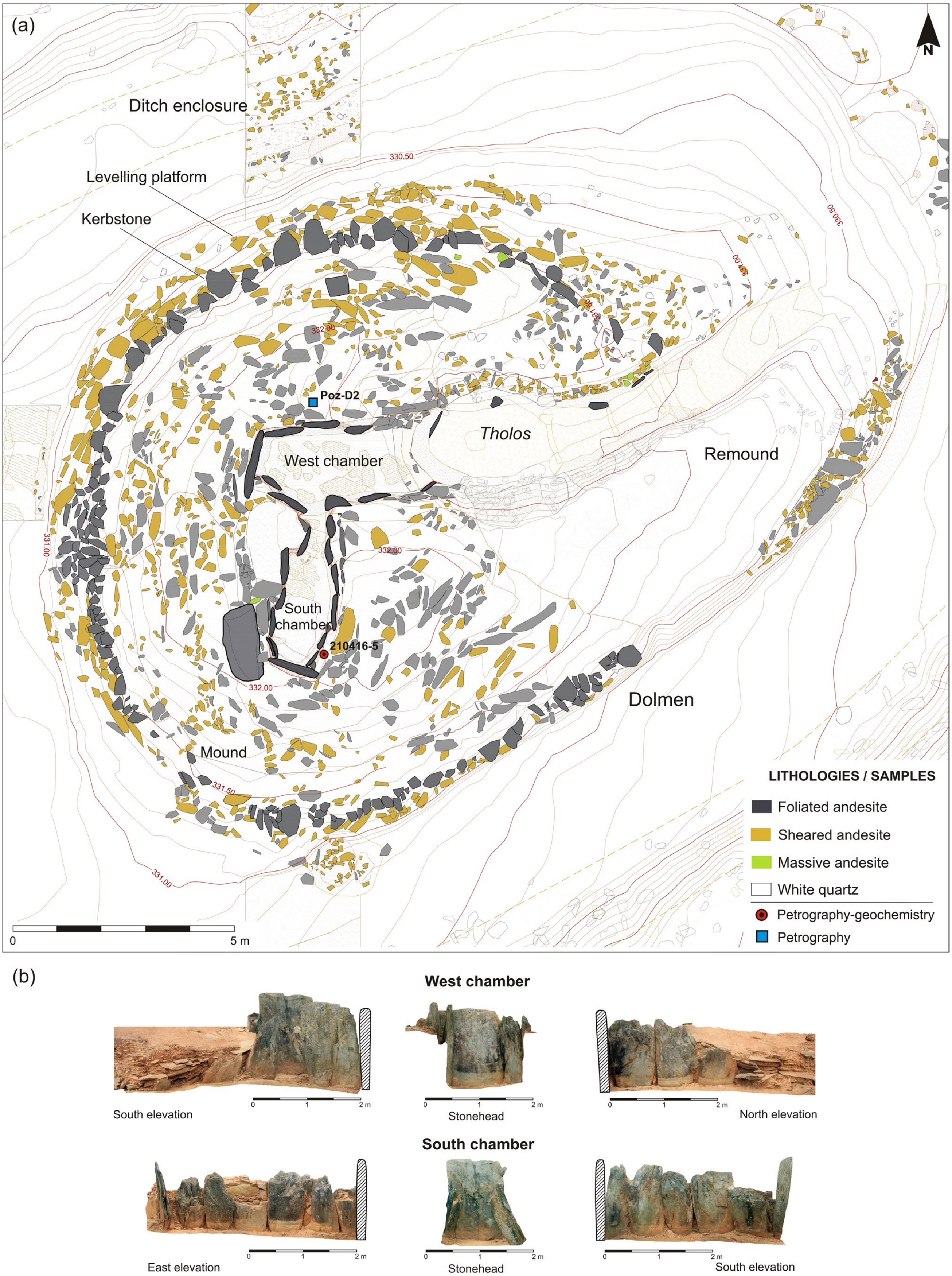
Source areas 5 (Fig. 13f) and 6 (Fig. 13g) are located downstream of the ravine, at a linear distance of over 350 m. The largest concentration of material is located in a bend in the watercourse. In both areas, a small amount of detached and water-tumbled blocks of lenticular or boudin formats can be observed, between 1 and 3 m in length, transported from the outcrops located upstream by the strong energy and gradient of the riverbed (5.5%).

Other potential source areas corresponding to the other lithologies documented in the megaliths have been documented in the surrounding area. Some of these rocks outcrop in the immediate surroundings, such as white quartz, which occurs in small veins on the northern slopes of Dolmens 1 and 2, and in pebbles scattered around this area and accumulated in the bed of the Agua Fría ravine. The massive and amphibole-phyric andesites are found in secondary deposits in the Matulá and Agua Fría ravines, due to the strong fluvial energy and the transport of detached blocks in a terrain of abrupt topography, with a gradient over 10%. Massive andesite is also found in prominent surface outcrops along the northern flank of the Los Rubios estate, over 500 m north of Los Llanetes. Amphibole-phyric andesite outcrops in massive formations around the Loma Pie de Matulá, 500 m to the northeast. Both lithologies occur in small blocks and boulders in the backwaters of the two ravines, at a distance of over 350 m from the dolmens.

Other stones occasionally used in the dolmens can be found in the environment, such as the ferruginous agglomerates, present in the strip of volcanic tuffs with agglomerates located 300 m to the north, and the gabbro boulders, found in massive outcrops and in deposits in the Agua Fría ravine, over 1 km to the east.

Petrography

Petrographic analysis of the monuments The petrological analysis confirms the identification of the different lithotypes of andesite and the lithologies classified as white quartz, gabbro and ferruginous agglomerates. Thin section petrography


(a)
N
Ditch enclosure
Levelling platform
Kerbstone
330.50
331.00
332.00
Poz-D2
Tholos
West chamber
Remound
South chamber
210416-5
332.00
Dolmen
Mound
331.50
331.00
LITHOLOGIES / SAMPLES
Foliated andesite
Sheared andesite
Massive andesite
White quartz
Petrography-geochemistry
Petrography
0
5 m
(b)
West chamber
South elevation
Stonehead
North elevation
South chamber
East elevation
Stonehead
South elevation
0
1
2 m

◂**Fig. 8** El Pozuelo Dolmen 2. **a** Lithological plan of the monument and location of the rock samples for petrographic and chemical analysis. **b** Photogrammetric elevations of the west and south chambers

focuses on the characterization of the petrographic features of the andesites, as they are the most common rocks used in the megaliths, as well as the most difficult to identify.

Foliated andesite is a greyish to light green rock (greenish-grey 5GY 6/1) with a planar fabric and a highly penetrative foliation. The foliation planes are irregular and may display a shiny lustre due to their high phyllosilicate content. White to cream-coloured plagioclase porphyroclasts of larger grain-size than the surrounding matrix are occasionally observed (Fig. 14a). These grains may appear fractured and oriented within the foliation planes, and are characteristic of rocks that have undergone tectonic deformation.

Microscopically, the orthostat samples from Dolmens 2, 3 and 4 are highly altered, with plagioclase porphyroclasts completely replaced by quartz and carbonates (Fig. 14b). These crystals are embedded in a microcrystalline quartz-feldspar matrix with bands rich in phyllosilicates (sericite ± chlorite) and carbonates. The sericitic bands, recrystallized from the original magmatic matrix, correspond to the foliation planes observed macroscopically. Rutile, zircon and opaque minerals are observed as accessory minerals. Only the orthostat from the south chamber of Dolmen 1 (210416-3) clearly displays plagioclase porphyroclasts partially transformed to carbonates. This sample also includes quartz phenocrysts.

The original plagioclase phenocrysts may appear rotated with asymmetric pressure shadows filled with quartz, sericite or carbonates (Fig. 14c). They tend to break along crystallographic fractures or planes and form angular millimetre to microcrystalline porphyroclasts that may form a domino texture (Fig. 14d). The space between these fragments is also formed by alteration minerals, indicating an important role of fluids during deformation.

The microstructures of these foliated andesites are analogous to those observed in mylonites, although to define them as such would require evidence of plastic deformation, which in this case is not clear at the microscopic scale. Some authors use the term foliated cataclasites in this case (Sibson 1977; Brodie et al. 2007). The presence of rotated crystals with pressure shadows and microfracturing, and the development of domino structures, indicates initial cataclasis during a brittle shear event. Subsequent filling of the voids between the crystal fragments and pressure shadows suggests fluid circulation that may have favoured the pressure dissolution processes. The migration of these fluids during shearing is indicated by the widespread growth of syntectonic sericite along the foliation planes.

Sheared andesite has been observed visually, as thin sections of the samples could not be made due to disintegration during preparation. This lithotype occurs in the areas closest to the shear zones where the foliation is more intense, and constitutes the geological substrate of the dolmens. Petrologically, there are no major differences with foliated andesite, since they belong to the same lithology, although it is a material with a higher degree of tectonic deformation, penetrative foliation and alteration, which provide it with different physical qualities and visual properties. It is a rock of variable colour, with a predominance of ochre tones (greyish-orange 10 YR 7/4), highly fractured, of weak consistency, breaking easily into small-sized blocks and slabs, which makes it impossible to use for weight-bearing elements.

Massive andesite is a homogeneous hard and compact rock, with an isotropic fabric, and a lower degree of alteration. It clearly shows its original texture and mineralogical composition, making possible the identification of its origin. It displays coherent facies, resulting from the crystallization of a magma (McPhie et al. 1993), with a porphyritic aphanitic texture and composed essentially of millimetre-sized (< 2 mm) phenocrysts of plagioclase, rarely of quartz, embedded in a microcrystalline matrix formed by microlites of the same composition (Fig. 14e).

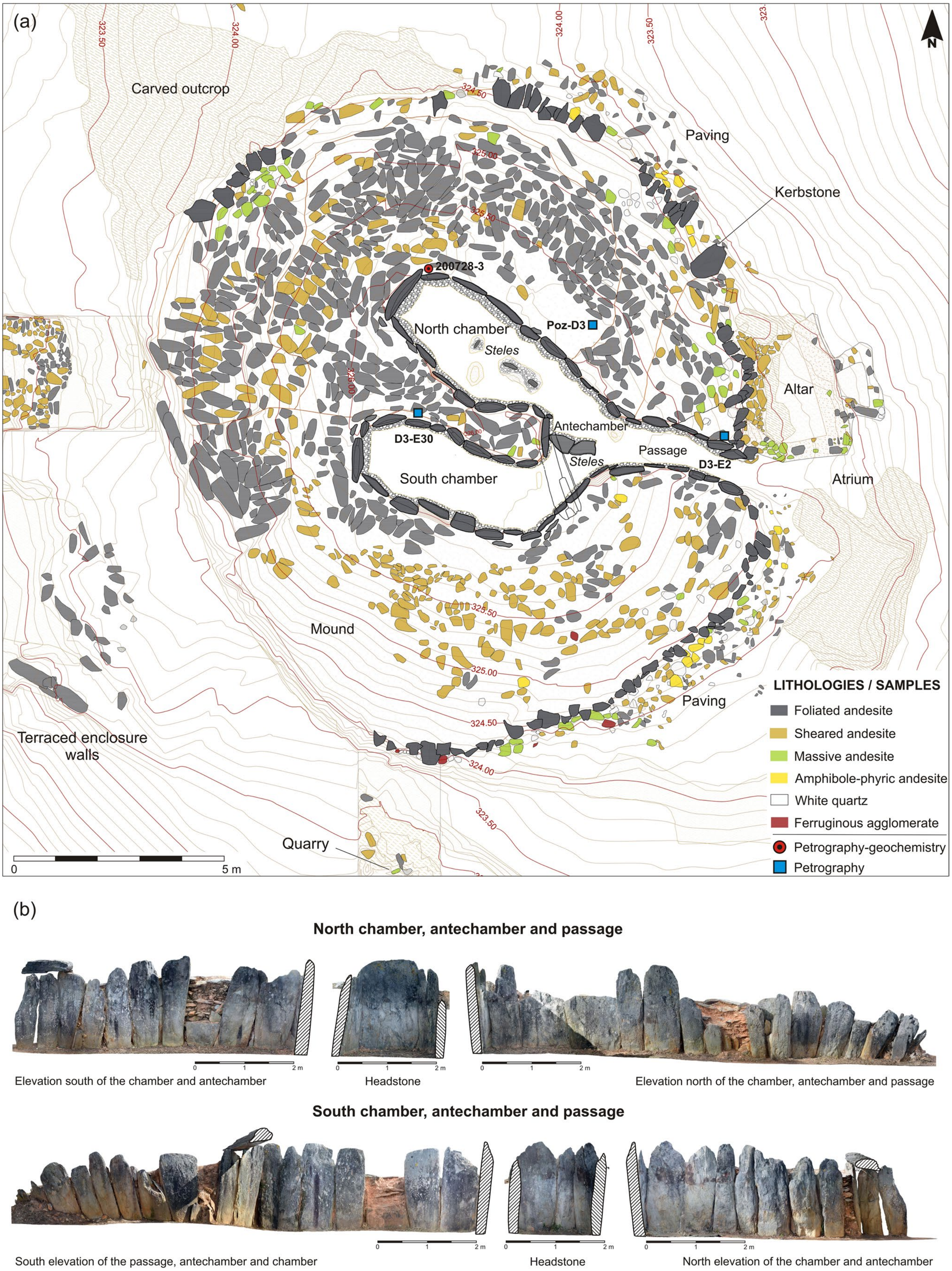
Microscopically, the amphibole-phyric andesites display a clear porphyritic aphanitic texture with abundant hornblende phenocrysts embedded in a matrix composed essentially of plagioclase microlites (Fig. 14f). The dark-coloured amphiboles contrast with their lighter, greenish-grey (greenish-grey 5 G 6/1) microcrystalline matrix. Visually, the rock is light-coloured, with predominantly beige tones when weathered (greyish-yellow 5 Y 8/4).

Petrographic analysis of the source areas The quarry samples also belong to coherent (Quarries 3 and 4; Fig. 15a) and volcanoclastic (Quarry 2; Fig. 15b) facies of andesitic composition with a moderate to strong penetrative foliation. The foliation is defined by sericite (Quarries 3 and 4) or carbonates (Quarry 2). They contain medium to fine and very fine (5–10%, 0.1–5 mm) plagioclase porphyroclasts, partially replaced by carbonates (Quarry 2) and sericite (Quarries 3 and 4). Pseudomorphs of ferromagnesian minerals replaced by carbonates, sericite, iron oxides and rutile are also observed. These crystals are rotated, with pressure shadows filled by quartz and sericite.

Sample 210416-7, from a surface block located west of Quarry 3 (Fig. 15c), displays similar textural characteristics to the quarries and dolmens, in which rocks of an andesitic nature are predominant, with plagioclase porphyroclasts partially altered to carbonates and sericite and a moderate foliation marked by carbonates. The sample from source area 6 (Fig. 15d) shows a matrix and textural features analogous to the foliated andesitic breccia from Dolmen 1.

Geochemistry

From a geochemical point of view, all samples correspond to the igneous series from andesites to less evolved dacites.


(a)
Carved outcrop
Paving
Kerbstone
200728-3
North chamber
Steles
Poz-D3
Altar
Antechamber
Passage
D3-E30
D3-E2
Steles
South chamber
Atrium
Mound
Paving
Terraced enclosure walls
Quarry
0
5 m
LITHOLOGIES / SAMPLES
Foliated andesite
Sheared andesite
Massive andesite
Amphibole-phyric andesite
White quartz
Ferruginous agglomerate
Petrography-geochemistry
Petrography
(b)
North chamber, antechamber and passage
Elevation south of the chamber and antechamber
Headstone
Elevation north of the chamber, antechamber and passage
South chamber, antechamber and passage
South elevation of the passage, antechamber and chamber
Headstone
North elevation of the chamber and antechamber

◂**Fig. 9** El Pozuelo Dolmen 3. **a** Lithological plan of the monument and location of the rock samples for petrographic and chemical analysis. **b** Photogrammetric elevations of the megalithic structure

Andesites are the predominant lithotype. This sequence of igneous rocks is characterized by many changes of facies and chemistry at the outcrop scale, in such a way that it is common to find rocks with slightly different petrographic and chemical features separated by only a few metres.

Geochemistry of the rocks of the monuments Of the 7 analysed samples from the dolmens, 6 belong to the andesite field of the Winchester and Floyd (1977) diagram. The sample obtained from the south chamber of Dolmen 1 (210616-3) lies midway between the andesite and dacite fields (Fig. 16).

The chondrite-normalized REE plots (Nakamura 1974) (Fig. 17a) of the samples from the dolmens show in all cases slight enrichments in light rare earth elements (LREE) with respect to heavy rare earth elements (HREE). The Ce_N/Yb_N ratios are very similar for the samples from Dolmens 2, 3 and 4, with values between 2.46 and 2.82; while the two samples from Dolmen 1 have slightly steeper Ce_N/Yb_N slopes (4.52, north chamber; 6.75, south chamber). In relation to Eu content, these samples display negative anomalies, with Eu/Eu_N values between 0.69 and 0.89 (Table 3). Regarding the REE content, only the amphibole-phyric andesite sampled from the area of Dolmens 3 and 4 shows a high LREE enrichment, with a Ce_N/Yb_N ratio of 12.45 and no Eu anomaly (Fig. 17b). In the case of massive andesite, the chondrite-normalized REE plots display a slight enrichment in LREE, in consonance with the Ce_N/Yb_N value of 4.32 (Table 3).

Geochemistry of the rocks from the source areas Of the 7 analysed samples from quarries and source areas, 6 are included in the andesite field according to the Winchester and Floyd diagram (Fig. 16). The only exception is the sample from Quarry 3 (200728-8), which falls in the dacite field, although it is petrographically identified as an andesite (Fig. 15a). This incongruence can be explained petrogenetically, since the andesitic facies is a series with slight chemical variations related to processes of magmatic differentiation, which may have created in this sequence some rocks with a more evolved dacitic nature. Thus, the higher Ce_N/Yb_N ratio and the higher negative Eu anomaly can be attributed to the fractional crystallization processes of clinopyroxene and plagioclase (Rollinson and Pease 2021). They are petrogenetically related rocks, but show some chemical differences on a very local scale.

In the quarries, the chondrite-normalized REE plots also show slight enrichments in LREE relative to HREE (Fig. 17c). The Ce_N/Yb_N ratios in this case are between 2.43 and 4.82, the latter corresponding to the sample from Quarry 3, which is also the only case with a significant negative Eu anomaly (0.55). The rest of the samples have very similar negative Eu anomalies, between 0.73 and 0.77 (Table 3). The samples from source areas 5 and 6 and the area to the west of Quarry 3 (Fig. 17d) also fall within the andesite field of the Winchester and Floyd (1977) diagram, with very similar negative Eu anomalies, ranging between 0.63 and 0.87. The values of the surface blocks display a slight enrichment in LREE with respect to HREE, in accord with the Ce_N/Yb_N ratios, with values between 3.08 and 4.03 (Table 3).

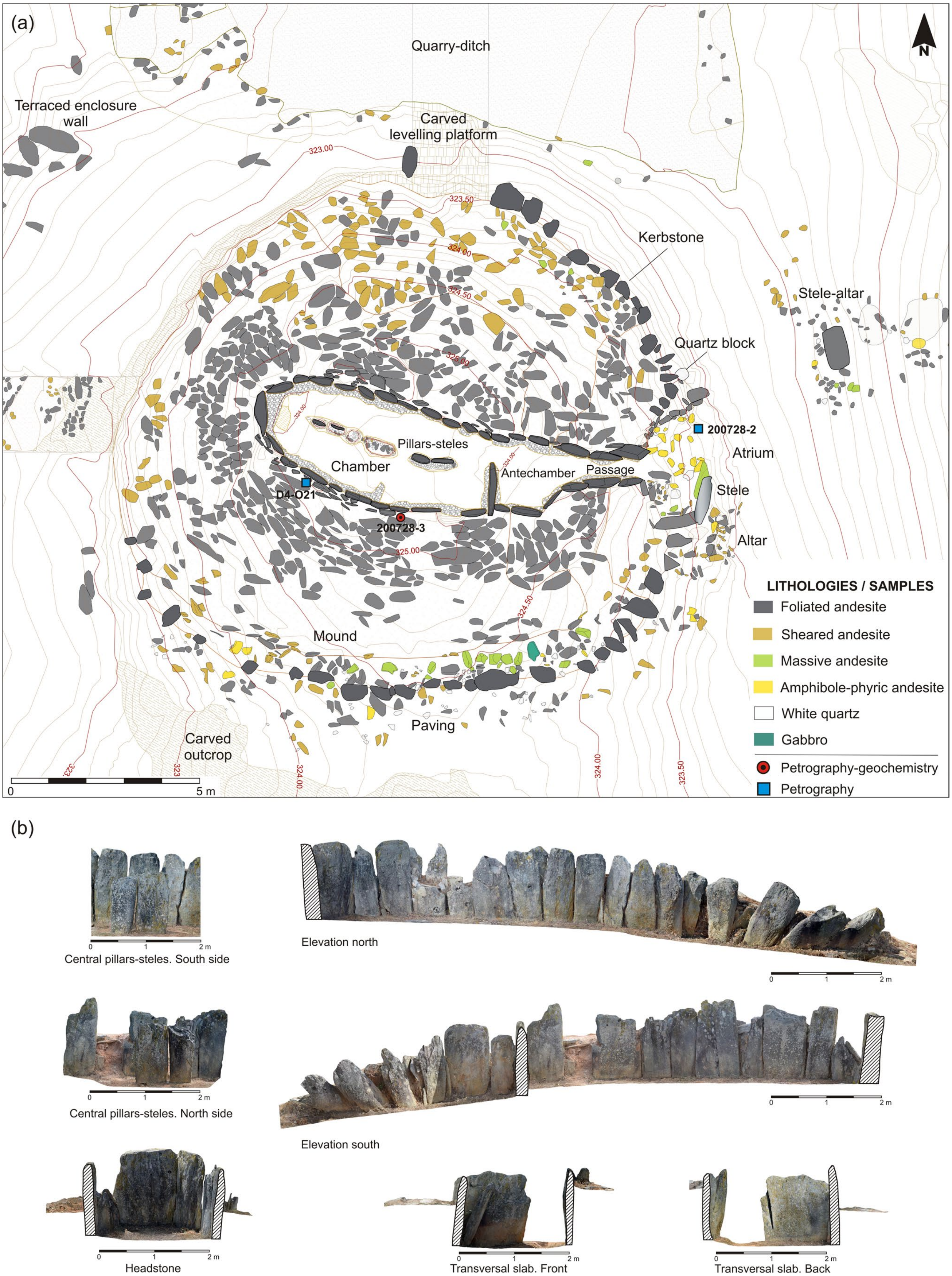
Discussion: selection, provenance, location and sourcing

The observation and comparison of the data derived from the archaeological and petrological analysis of the dolmens and the source areas enable us to discuss two central questions: (a) the selection and provenance of the stones; (b) the choice of the site and the sourcing of the materials. Thus, on the one hand, the petrological identification and observation of the properties of the materials allow us to evaluate the criteria applied in the choice of rocks by the Neolithic community of Los Llanetes for the construction of the megaliths. The geochemical analyses, especially the comparative study of the immobile elements TiO_2/Zr versus Ce_N/Yb_N of the megaliths and the source areas (Fig. 18), enable us to correlate the stones of the dolmens with the potential quarries and preferentially exploited sources. On the other hand, the observation of the geomorphological characteristics of the site, the identification of suitable lithologies in the local environment and the definition of the patterns of stone use enable us to interpret the reasons that may have motivated the choice of the site, conditioned the procurement strategies and influenced the creation of the megalithic landscape.

Selection and provenance

The megaliths were built with a range of rocks: andesites (foliated, sheared, massive and amphibole-phyric), white quartz, gabbro and ferruginous agglomerate, from different areas of the local geological environment (Fig. 19).

Foliated andesite is the most commonly used stone in the construction of monuments, both in the visible architectural elements (kerbstones and entrances) and in the internal spaces (passages, antechambers and chambers). Their greenish-grey hue contrasts with the browns and ochres of the floors, mounds and external spaces. Its selection and exclusive use for the large supports of the dolmens could be due to several factors: (a) it is the only rock in the nearby area that can be located on the surface and outcrops in a


(a)
Quarry-ditch
N
Terraced enclosure wall
Carved levelling platform
323.00
323.50
324.00
324.50
325.00
Kerbstone
Stele-altar
Quartz block
200728-2
Atrium
Pillars-steles
Chamber
Antechamber
Passage
Stele
D4-O21
200728-3
Altar
LITHOLOGIES / SAMPLES
Foliated andesite
Sheared andesite
Massive andesite
Amphibole-phyric andesite
White quartz
Gabbro
Petrography-geochemistry
Petrography
Mound
Paving
Carved outcrop
0
5 m
(b)
Central pillars-steles. South side
Elevation north
Central pillars-steles. North side
Elevation south
Headstone
Transversal slab. Front
Transversal slab. Back
0 1 2 m

◂**Fig. 10** El Pozuelo Dolmen 4. **a** Lithological plan of the monument and location of the rock samples for petrographic and chemical analysis. **b** Photogrammetric elevations of the megalithic structure

massive form, enabling the extraction of large blocks up to 3 m in length; (b) it is the only material that, due to its physical and mechanical conditions, permits its procurement, extraction, transport, transformation and placement in walls and covers; (c) it offers adequate consistency for its technical treatment; (d) it is a material of great hardness and resistance to compressive stress, with a density of 2.7 g/cm^3, which meets the appropriate conditions for a structural function, according to the values obtained from geotechnical strength tests (simple compressive strength of 489.39 Kp/cm^2 and deduced tensile strength of 24.07 Kp/cm^2).

Foliated andesite is found at superficial outcrops and is available on the surface, with some natural blocks in suitable shapes and sizes for use in the megaliths. It stands out for being the only stone in the environment that enables extraction from quarries and physical transformation into large blocks through the conversion of raw rock into supports of regular formats. Controlled extraction is made possible by the subvertical morphology of the outcrops, the planar fabric, the penetrative foliation and the regular spacing of the cleavage planes within the rock, allowing large-sized elongated lenticular supports to be obtained. Blocks ranging from 1 to 3.5 m in length and 250 to 2750 kg were used.

The techno-morphological study indicates that the stone supports were obtained both on the surface and extracted in quarries. Some of the blocks may have been collected in the source areas of the ravine, in the case of the stones of the kerbs, and a small proportion of the megalithic supports. The latter display similar morphologies and features to the boulders of the bed of the Agua Fria ravine, characterized by their sub-cylindrical sections, rounded edges and traces of wear due to tumbling and weathering. The sourcing of detached blocks used in the rough is the most recurrent pattern in European megaliths (Scarre 2009, 2020), choosing from among the materials found within close range and visible from the building sites, as has been documented in most of the Neolithic standing-stones and funerary monuments in Brittany and the British Isles (Scarre 2011, 2013), and in various types of megaliths built using erratic blocks from the moraines of the northern regions, such as the hunebedden of the Drente area (Bakker 2009), the passage graves of Denmark (Dehn 2009) or the covered galleries of Sweden (Sjögren 2020).

However, the morphological analysis and the study of the technological traces on the orthostats of the dolmens of Los Llanetes enable us to argue that most of the blocks were extracted in quarries, as has been documented in the dolmens of the Loire Estuary and in the menhir alignments of Carnac, where blocks extracted from superficial granite outcrops were used (Mens 2008, 2013). At Los Llanetes, quarrying activities must have been motivated by the insufficient quantity of large, physically sound, detached blocks for use as megalithic supports, with the largest and closest stones probably being used up during the first architectural phase of the group, in which the single-chamber dolmens were built. At present, very few foliated andesite blocks are seen on the surface, most of which are heavily weathered and covered by lichens due to prolonged exposure to the elements.

The orthostats, pillars and steles are of different shapes and have different characteristics to natural blocks. Orthostats are elongated and slender supports in rectangular, lenticular, trapezoidal and oval formats, with slender and lenticular sections, formed on fresh, massive, compact and unweathered stone blocks. The technological study suggests that the vast majority of these blocks were extracted in quarries and transformed by common treatments (roughing, carving, pecking and partial abrasion) carried out on site. The orthostats stand out for the standardization of the formats, the even pecking of the faces and the regularity of the edges and ends. They are optimal supports for the construction of straight, vertical walls with minimum separations between the supports, favouring the creation of hermetic internal spaces by sealing them with clay, in accordance with their function as collective tombs. In the same way, a large part of the shoring slabs and a significant proportion of the slabs of the mounds and external structures may have been obtained through extractive activities, as evidenced by the sharp edges and the lack of traces of tumbling and/or weathering of the stone supports.

Due to its solidity and physical resistance, foliated andesite is the only lithology used as a megalithic support for weight-bearing (orthostats and pillars), segmentation (transversal slabs and steles) and covering (roof slabs) elements. The steles occupy a prominent place due to their high symbolic value and ancestral significance. They were placed as freestanding elements inside the structures, marking the axis or the entrance, as well as part of the walls of the antechambers and specific sectors of the chambers. They are generally reused supports, subjected to diverse superimposed technical treatments, changing position according to the architectural evolution and chronological sequence of the monuments. Some of them may even be identified as supports that may have predated the dolmens, forming part of open-air standing stone monuments. Foliated andesite was also used as shoring slabs, rings and mound fillings, and even as part of the pavements of the external areas, accesses and altars of the atriums. It is also the main rock used in the dry-stone walls of the terraced enclosures and the circular platform surrounding Dolmen 1, as the materials from the funerary monuments that were partially dismantled during the Early Bronze Age were reused.

Fig. 11 Sheared andesite quarries. **a** Quarries in the periphery of Dolmens 1 and 2. **b** Quarries adjacent to Dolmens 3 and 4

Fig. 12 Types of foliated andesite blocks: detached and in outcrops. **a** Lenticular block extracted from Quarry 4. **b** Detached lenticular block in source area 6. **c** Boudin block from the outcrop of Quarry 1. **d** Barrel block in the surroundings of Quarry 2

Both petrographically and geochemically, the samples analysed from the quarries and source areas, with the exception of Quarry 3, correspond to foliated andesites similar to those documented in the dolmens. In order to determine the provenance of the materials, the chemical composition of the samples from the megaliths and the source areas is assessed and the immobile elements TiO_2/Zr versus Ce_N/Yb_N are compared (Fig. 18). The chemical results and the graph show a good similarity between most of the samples of foliated andesites, except for the values of three samples: (a) 210128-2, amphibole-phyric andesite from Dolmens 3 to 4; (b) 200728-8, from Quarry 3; (c) 200728-8, from the south chamber of Dolmen 1.

All the geological samples and most of the rocks from the dolmens are highly foliated coherent facies and, to a lesser extent, volcanoclastic facies of andesitic composition. Quarry 3 and the sample from the south chamber of Dolmen 1, which can be geochemically classified as dacites, also correspond petrographically to andesites. The latter discrepancy is frequent in petrogenetically related rock series in which slight magmatic differentiation processes have taken place. Only the samples of amphibole-phyric andesite from Dolmens 3 to 4 and gabbro show particular petrographic and chemical features, different to the former rocks, suggesting their origin from distinct source areas. The great similarity of the petrographic and chemical data between the orthostats and the geological samples confirms the correspondence of the megalithic materials with the group of rocks outcropping in the local context and the nearby provenance of the stone blocks.

The detailed observation of the geochemical data enables us to recognize group associations between the dolmen samples and the source areas. The analysis of these groups allows us to explore initially whether it is possible to establish a specific correlation between the stones of the megaliths and the quarries and source areas. The small number of samples leads us to make preliminary approaches and to be cautious in interpreting the data. Therefore, the evaluation and discussion of such correlations require further geochemical studies and archaeological analysis in the future to better characterize and define the identified groups.

A first group is formed by the samples from Quarries 1 and 4 and Dolmens 2, 3 and 4. The comparison between the immobile elements of TiO_2/Zr versus Ce_N/Yb_N allows us to identify similarities between the samples from Quarry 1 and those from Dolmens 2, 3 and 4, located at a variable linear distance between 75 and 180 m. However, the marked fractures and penetrative foliation of this outcrop make

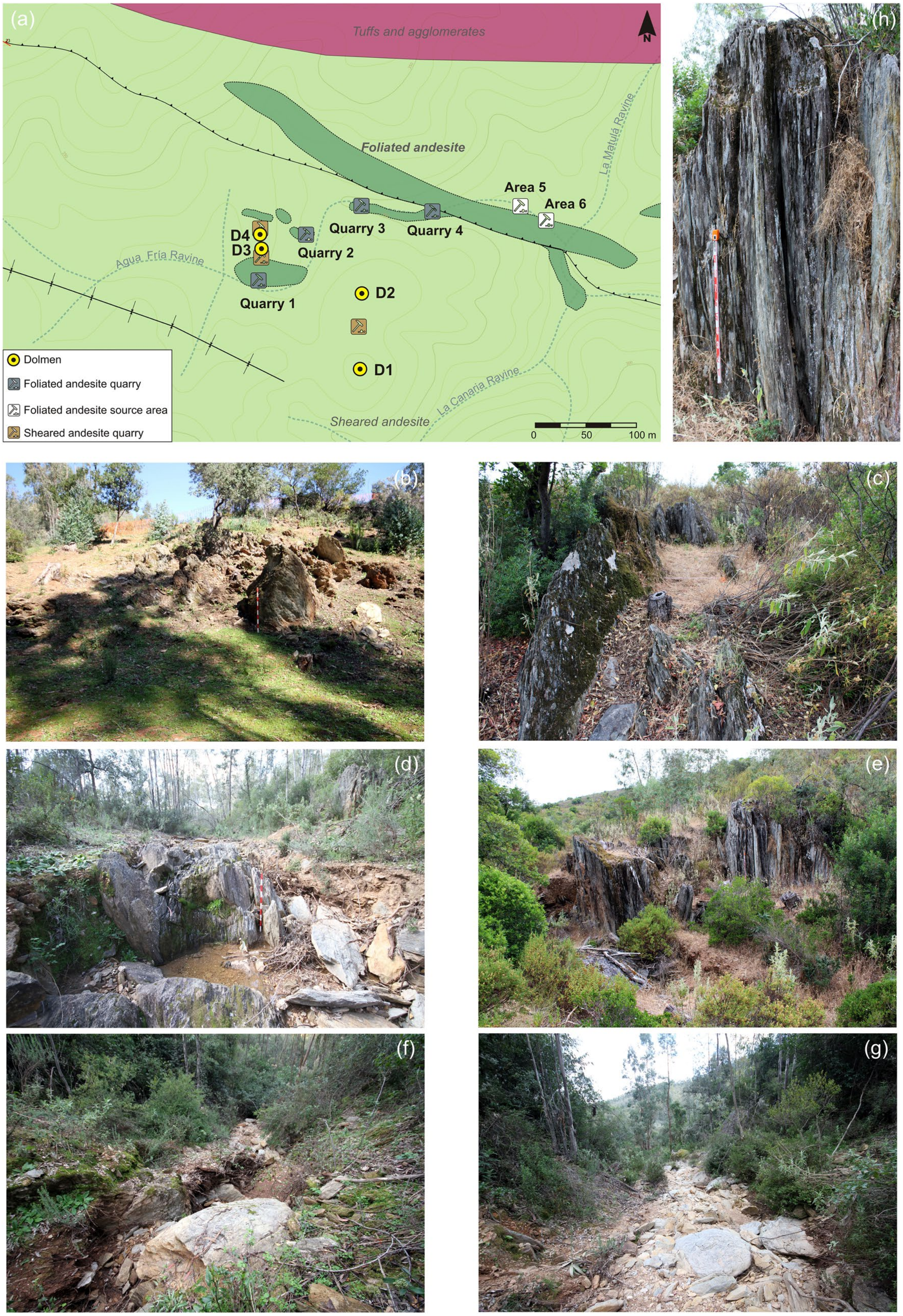


Fig. 13 Foliated andesite quarries and source areas of the Los Llanetes group. **a** Location on a geological map. **b** Quarry 1. **c** Quarry 2. **d** Quarry 3. **e** Quarry 4. **f** Source area 5. **g** Source area 6. **h** Vertical extraction face of Quarry 4

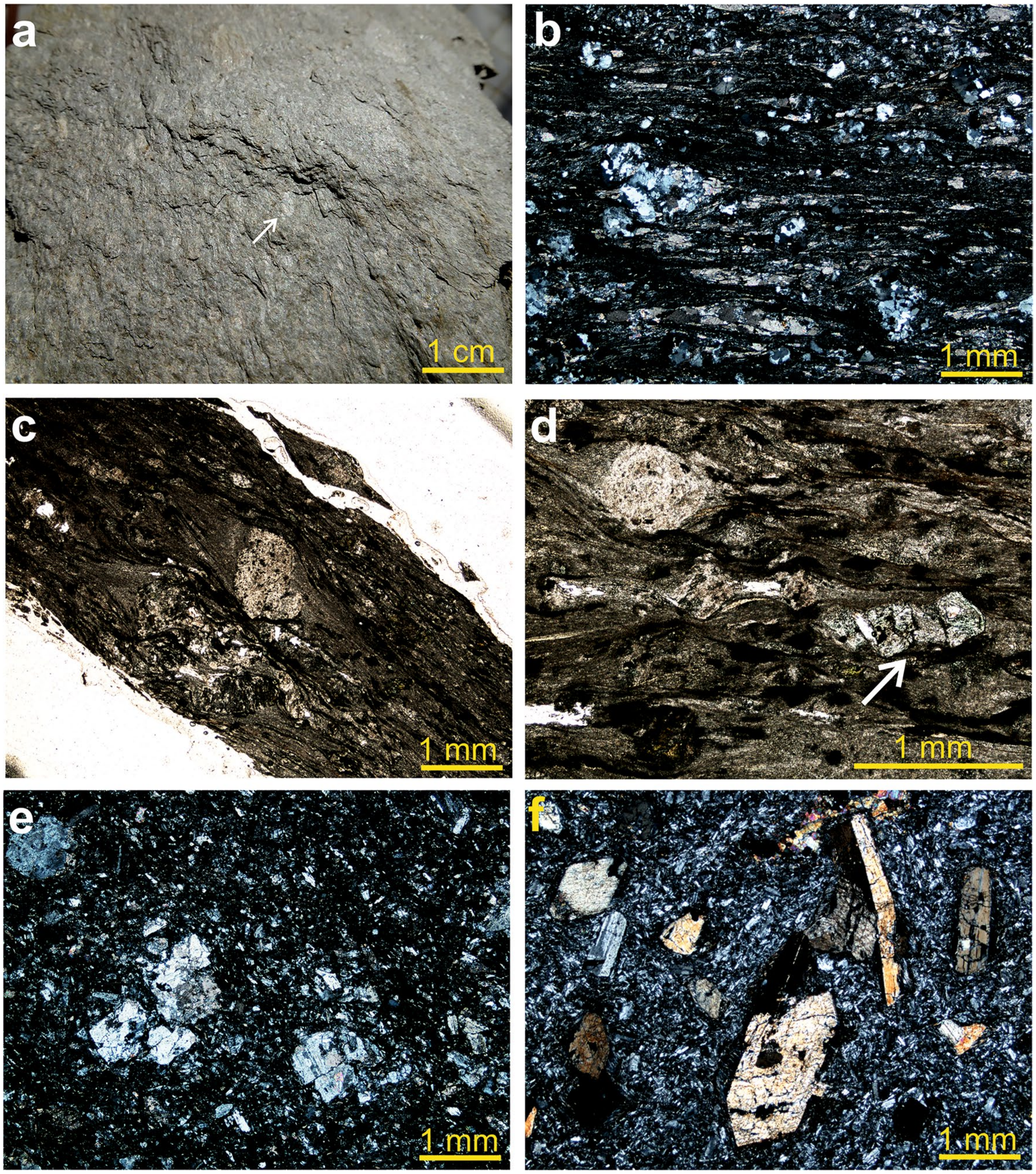


Fig. 14 Petrographic features of the andesites in the Los Llanetes monuments. **a** Macroscopic features of the foliated andesite. The foliation planes display a satin sheen in which the oriented plagioclase porphyroclasts (arrow) stand out. **b** Petrographic photomicrograph showing the general texture of a foliated andesite. It has a porphyrolepidoblastic texture, with plagioclase porphyroclasts completely replaced by quartz and carbonates, in a microcrystalline matrix of quartz-feldspar with bands rich in phyllosilicates (sericite ± chlorite) and carbonates (210416-5; Dolmen 2). Crossed polars. **c** Rotated plagioclase porphyroclasts with asymmetric pressure shadows filled with quartz, sericite and carbonates (D4-021; Dolmen 4). Plane-polarized light. **d** Broken plagioclase porphyroclast with rotated fragments forming a domino texture (D4-021; Dolmen 4). Plane-polarized light. **e** Non-foliated massive andesite in which plagioclase phenocrysts can be observed with no orientation and hardly any alteration (210128-5; Dolmens 3-4). Crossed polars. **f** Amphibole-phyric andesite. Crossed polars (210128-3; Dolmens 3-4)

the extraction of large blocks very unlikely. It is therefore probable that the materials obtained from this quarry were predominantly used in the fills of mounds, kerbs, levelling platforms and external elements of the dolmens.

The chemical results from Quarry 4 show a great similarity with the data obtained from Dolmens 2, 3 and 4 (Fig. 18), located 200–335 m away. The archaeological study of Quarry 4 suggests that it is the most regularly and

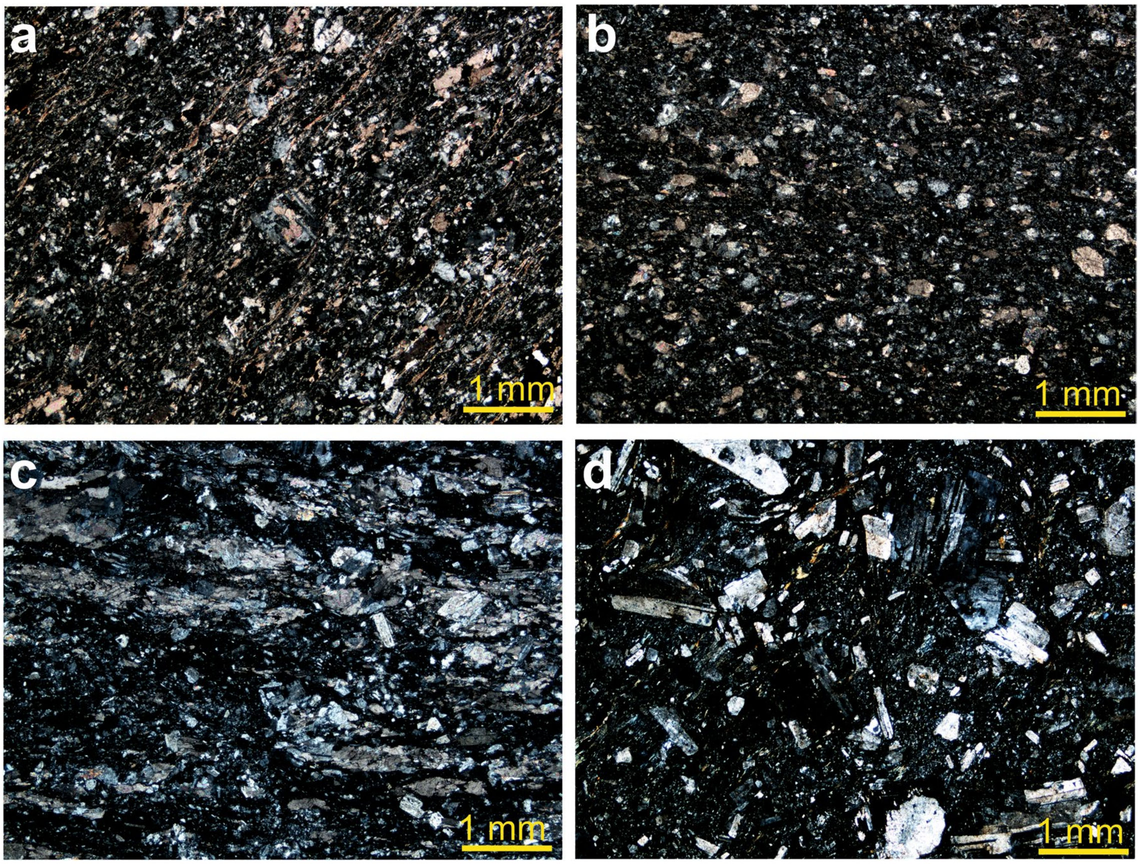


Fig. 15 Microscopic petrographic features of foliated andesites from quarries and source areas associated with the Los Llanetes megalithic group. **a** Coherent facies with andesitic composition and moderate to very penetrative foliation defined by sericite (200728-8; Quarry 3). Plagioclase porphyroclasts partially replaced by sericite are observed. Crossed polars. **b** Volcanoclastic facies: volcanic sandstones with plagioclase porphyroclasts partially replaced by carbonates (200728-4; Quarry 2). Crossed polars. **c** Andesite from surface block (210416-7; Agua Fria ravine, to the west of Quarry 3). These are andesitic rocks, with plagioclase porphyroclasts partially altered to carbonates and sericite, and moderate foliation marked by carbonates. They display a texture similar to that of the quarries and dolmens. Crossed polars. **d** Andesite with massive and isotropic porphyritic aphanitic texture (200728-7; Source area 6). Crossed polars

intensively quarried area, based on its size and the volume of stone extracted from the outcrop. The vertical length of its two faces and the discarded blocks indicate that large elongated supports of up to 3 m in length were extracted. Dolmens 2, 3 and 4 are characterized by the predominance of 'standardized' orthostats and the fresh appearance of the stones, their slender and elongated shapes, uniform sizes, flat sections and thin thicknesses. These formal characteristics are similar to the lenticular blocks obtained from Quarry 4. Therefore, Quarry 4 may have supplied most of the materials for the construction and reconstruction of these dolmens during the 4th millennium BC, exploited from the first stage of construction of the single-chamber dolmens and later for their remodelling as elongated dolmens and double chamber dolmens.

The TiO_2/Zr versus Ce_N/Yb_N plot enables us to distinguish a second group of andesites with a wider dispersion: Quarry 2, source areas 5 and 6, north chamber of Dolmen 1 and the stockpile area of Dolmens 3 and 4. The presence in this group of scarcely altered and weathered massive andesite (stockpile sample) alongside more altered and weathered foliated andesites (remaining samples) suggests that these chemical differences are due to primary petrogenetic processes within this andesitic series. However, the geochemical data obtained from Dolmen 1 differ slightly from those of the other three dolmens. This sample belongs to the section at the head of the north chamber of the monument, where the orthostats are thick and display partially weathered cortical surfaces. Sub-cylindrical or oval-shaped blocks with natural edges predominate, with a lesser degree of technological treatment, limited to the continuous pecking of the surfaces to make them even. These supports are analogous to the natural blocks located in the surface areas, 365 m downstream of the ravine, where lenticular or fissured

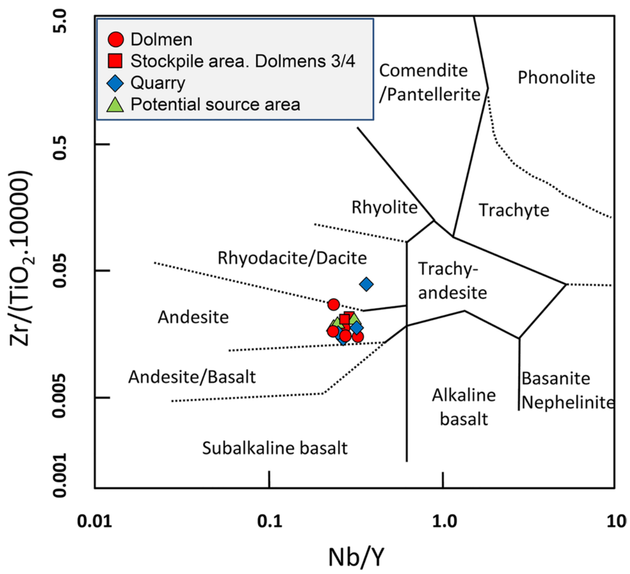


Fig. 16 Classification of volcanic rocks in the Los Llanetes area according to the proposal by Winchester and Floyd (1977)

monoliths between 1 and 3 m in maximum length can be found with clear evidence of surface alteration. Therefore, the archaeological analysis and the petrological data of the samples suggest that part of the orthostats of the oldest monument (single-chamber dolmen) could correspond to detached blocks selected in these areas or from other areas of the ravine closer to the site. It is also plausible that for the construction of this chamber and its later extension as a dolmen with an elongated chamber, blocks extracted from Quarry 2, located 200 m to the northeast, could have been used.

A third group is formed by the samples from Quarry 3 (200728-8) and from the south chamber of Dolmen 1 (210416-3). The lithology of Quarry 3 is somewhat more peculiar or atypical. Petrographically, it is similar to the samples from the other source areas, and displays features in common with foliated andesite. However, the geochemistry places this rock in the dacite field (Figs. 16 and 17c), due to the local petrogenetic variations mentioned above. The dacite from Quarry 3 is a harder and more compact material than foliated andesite, and, in principle, appears less suitable for the extraction of large blocks. Therefore, this quarry has a lower exploitation potential than Quarries 2 and 4, in accordance with its reduced extracted volume. Nevertheless, and despite its modest dimensions, smaller-sized stone blocks used in the dolmens were extracted from this location, as is evidenced by the morphology, the foliation planes and the extractive traces on the extraction face. The geochemical and archaeological data suggest that part of the blocks from the southern chamber of Dolmen 1 may have been extracted from this quarry. On the one hand, the chondrite-normalized REE plot (Fig. 18) show a chemical similarity between the samples from Quarry 3 and orthostat 14 from the south chamber. The observation of the more evolved features of the sample from this dolmen can be explained by the presence of sparse quartz porphyroclasts in the stone. On the other hand, the south chamber displays orthostats with different characteristics to those of the north chamber, which are specific, standing out for their regular formats, with heights of less than 2 m, an average width of 60 cm and a thickness of less than 25 cm (Fig. 7b). Therefore, it is plausible that Quarry 3, located 265 m away, provided some supports for the construction of the south chamber during the conversion of the monument into a dolmen with double parallel chambers with independent accesses.

The data obtained suggest that the Los Llanetes community carried out a simultaneous exploitation of the foliated andesite source areas for the acquisition of the stones used in the dolmens, with majority sourcing in the megalithic quarries (Fig. 19). The stones of the dolmens cannot be exclusively linked to specific quarries, as the monuments appear to incorporate stone supports from various sources. However, a certain evolution in the selection and exploitation patterns of these sources can be discerned in relation to the architectural sequence of the megalithic group during the Late Neolithic. For phase 1, of single-chamber dolmens, built with orthostats and large capstones, the materials extracted from Quarries 2 and 4, documented in Dolmens 2, 3 and 4, as well as some surface-selected blocks documented in Dolmen 1, may have been used. For phase 2, of dolmens with elongated chambers, created through the addition of antechambers with medium and large supports, the same quarries continued to be exploited. For phase 3, with multi-chamber dolmens, formed by attaching megalithic structures with supports of variable sizes, in addition to the exploitation of Quarries 2 and 4, quarrying appears to have been intensified in Quarry 3 for the construction of the south chamber of Dolmen 1. From Quarry 1 and the surface source areas, small and medium-sized blocks were obtained for the construction of the kerbs, mounds and external structures.

The transport routes of the foliated andesite blocks must have been designed according to the favourable topography of the river network of the Agua Fria ravine, and the materials may have been taken along three routes (Fig. 19): (a) through the course of the ravine, with an average gradient of 5%, along which the blocks from Quarries 3 and 4 and the materials from source areas 5 and 6 could be moved; (b) the east and west slopes of the promontory of Dolmens 3 and 4, where the materials from Quarries 1 and 2 and those from the source areas located to the east were transported, preferably along the southwest slope; (c) along the northeast gully between Dolmens 1 and 2, through which the material was taken to the site of Dolmen 1 (via the west ramp) and to Dolmen 2. These three routes are the potential and

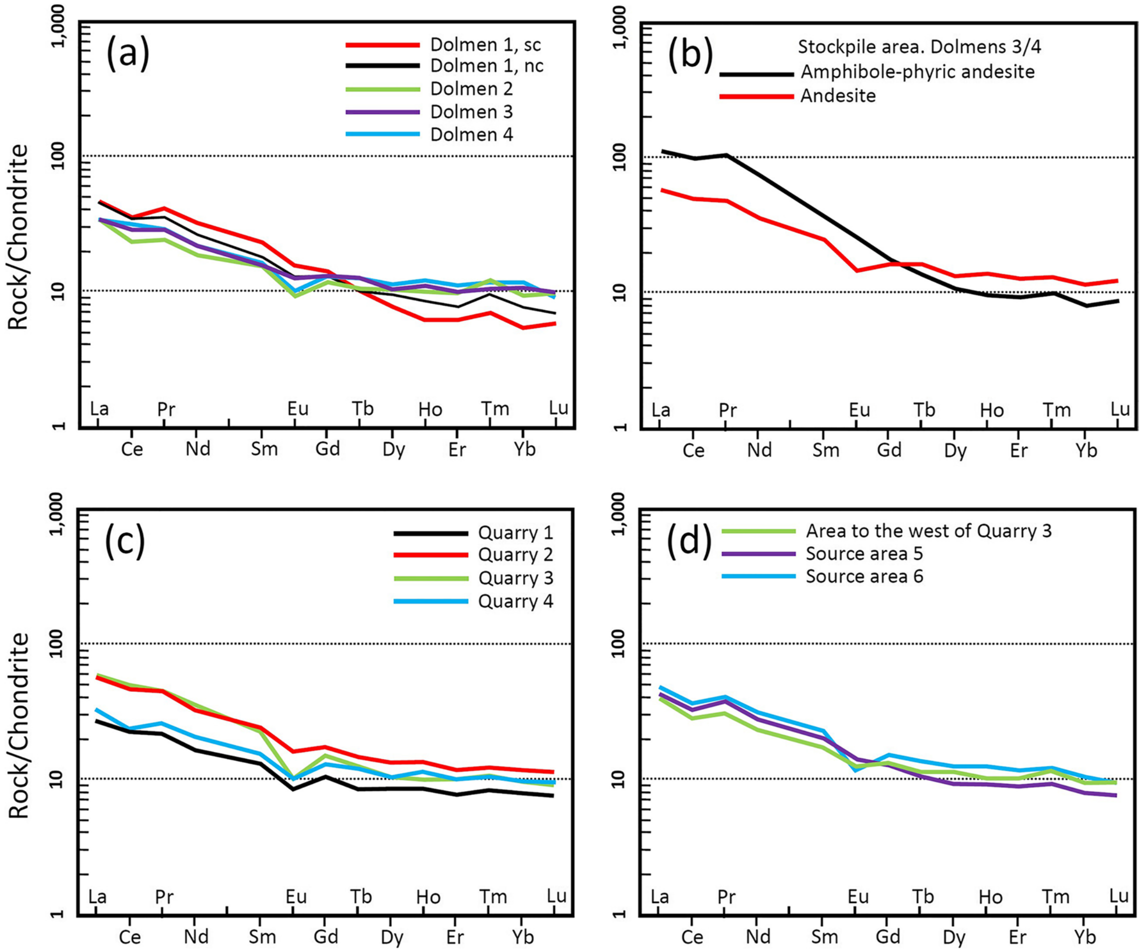


Fig. 17 Chondrite-normalized REE plots (Nakamura 1974) of the analysed samples from the dolmens and source areas of the Los Llanetes group. **a** Dolmens. **b** Stockpile area of Dolmens 3–4: massive and amphibole-phyric andesites. **c** Quarries: foliated andesite. **d** Source areas and blocks of the Agua Fría ravine

topographically favourable transit areas, with slopes between 5 and 20%. The rest of the surroundings would have been impracticable for transport, as the relief displays slopes with higher gradients. The linear distance of these routes ranges between 50 and 365 m, depending on the location of each source.

Sheared andesite is the second lithotype, in terms of its quantity and representativeness in the monuments. It was used in proportions similar to foliated andesite for the fillings of the mounds, the walls of the platforms, the surrounding pavements, the external structures of the atriums (altars) and the dry-stone walls of the terraced enclosures. In Dolmen 3, it was the main material of the enlarged tumulus during its conversion in the last third of the 4th millennium BC into a monument with double chambers. Small and medium-sized slab formats predominate, with some material collected on the surface and most of it extracted from the surrounding quarries. The effort and cost of transport would have been minimal. The sheared andesite quarries of the two subgroups, located in the immediately surrounding area (Dolmens 1 and 2) or adjacent to the monuments (on each side of Dolmens 3 and 4), contributed to the monumentalization of the site. In the dolmens of the Iberian southwest, as many external spaces have not been extensively excavated, there are no other known cases similar to that documented in the Los Llanetes group. Open quarries on the same sites as the megaliths have been observed in several types of monuments in western France, notably the elongated barrows of Bougon (Mohen and Scarre 2002), Champ Châlon (Joussaume 2006), Er Grah (Le Roux 2006) and Prissé-la-Charrière (Laporte 2013), and in the Angoumoisin type dolmens with circular mounds in the Charente region, as in the case of Motte de la Jacquille (Ard et al. 2016). At these sites, as at Los Llanetes, the materials extracted from the rocky substrate were used in the mounds, and in structures and elements formed by smaller stone blocks and slabs.

The massive andesites and amphibole-phyric andesites are rocks of great hardness, with a massive structure and

Table 3 Chemical analysis of major and trace elements of the Los Llanetes group

Sample	210416-2	210416-3	210416-5	200728-3	200728-1	210128-2	210128-4	210617-1	210617-2	200728-8	200728-5	210617-3	210617-4	210416-7
Petrography	Foliated andesitic breccia	Foliated andesite	Foliated andesite	Foliated andesite	Foliated andesite	Amphibole-phyric andesite	Massive andesite	Foliated andesite	Foliated andesite	Dacite	Foliated andesite	Foliated andesite	Foliated andesite	Foliated andesite
Site	Dolmen 1, north chamber	Dolmen 1, south chamber	Dolmen 2, south chamber	Dolmen 3, north chamber	Dolmen 4	Dolmens 3–4: stockpile area	Dolmens 3–4: stockpile area	Quarry 1	Quarry 2	Quarry 3	Quarry 4	Source area 5, Agua Fría ravine	Source area 6, Agua Fría ravine	West of the Quarry 3, Agua Fría ravine
Major elements (%)														
SiO_2	59.40	64.00	58.60	58.10	62.00	61.20	63.00	56.70	59.40	68.50	58.00	62.60	64.50	59.50
TiO_2	0.65	0.56	0.78	0.82	0.89	0.80	0.77	0.64	0.90	0.42	0.82	0.66	0.78	0.78
Al_2O_3	15.70	15.60	15.55	16.45	17.35	15.40	16.15	15.05	17.15	14.90	16.35	15.75	15.25	15.60
Fe_2O_3t	5.82	4.14	6.67	6.85	7.01	5.42	5.32	6.38	6.02	4.77	7.10	5.66	6.12	6.02
MnO	0.11	0.07	0.14	0.15	0.12	0.05	0.08	0.13	0.11	0.11	0.13	0.07	0.10	0.12
MgO	5.07	3.33	3.92	3.49	3.74	4.42	1.97	4.12	2.53	2.15	3.99	4.69	3.91	3.62
CaO	2.41	3.25	3.74	4.37	0.39	3.38	2.37	4.37	3.44	1.93	3.11	0.54	1.72	3.72
Na_2O	4.44	4.31	2.71	3.13	2.98	5.03	4.36	2.48	2.99	4.21	3.19	3.36	3.80	4.22
K_2O	0.99	1.16	0.86	0.79	0.97	2.88	3.09	1.20	1.73	0.91	0.83	1.28	1.10	0.89
P_2O_5	0.09	0.14	0.12	0.13	0.12	0.25	0.15	0.09	0.17	0.13	0.12	0.10	0.10	0.11
LOI	3.76	2.84	5.48	6.55	3.95	1.42	1.74	6.87	5.51	3.59	5.78	4.52	3.71	4.47
Sum	98.44	99.40	98.57	100.83	99.52	100.43	99.08	98.05	99.98	101.62	99.42	99.26	101.14	99.05
Trace elements (ppm)														
Rb	19.8	22.6	21.1	20.7	25.2	34.1	63.8	25.3	47.5	26	19.8	26.4	24.6	21.6
Sr	155.5	1320	132	163	160.5	1010	224	88.5	148	107	153	87.9	220	116.5
Ba	138	288	136	129.5	170	510	644	106.5	219	170.5	163	127.5	171.5	143
Zr	121	157	119	130	137	166	168	94	159	158	125	134	147	129
Y	17	13.6	20.7	20.9	22.4	19.2	26.9	15.1	24	19.3	21	16.6	24.8	20.8
Nb	4.7	3.4	5.2	5.6	7.8	5.3	7.7	4	7.8	7.3	5.4	5.3	6.5	5.2
V	122	85	120	122	113	121	61	143	79	39	110	133	115	114
Cr	110	90	50	40	40	90	30	60	30	20	30	120	70	40
Hf	3.5	4.6	3.3	3.5	3.8	4.5	4.6	2.4	4	4.4	3.4	3.4	3.8	3.7
Ta	0.2	0.1	0.2	0.5	1.2	0.2	0.4	0.3	0.6	0.7	0.6	0.3	0.4	0.2
Th	3.37	3.21	2.59	2.88	3.54	6.67	4.47	2.43	4.21	4.87	2.24	3.59	3.86	2.83
La	15.1	15.5	11.1	11.3	11.4	36.4	19.1	9	18.4	19.4	10.9	14.5	16	13.3
Ce	30.2	31.3	20.1	25.2	28.3	87.1	42.5	20.1	40.6	43.2	20.9	28.2	32	25.3
Pr	4.01	4.62	2.77	3.22	3.29	11.6	5.44	2.47	4.91	5.2	2.95	4.33	4.59	3.43
Nd	16.6	20.4	11.9	13.9	13.9	46.8	22.4	10.6	20.4	22.2	13.3	17.7	19.3	15
Sm	3.69	4.75	3.15	3.29	3.34	7.47	5.05	2.71	4.99	4.6	3.21	4.09	4.71	3.57

Table 3 (continued)

Sample	210416-2	210416-3	210416-5	200728-3	200728-1	210128-2	210128-4	210617-1	210617-2	200728-8	200728-5	210617-3	210617-4	210416-7
Eu	0.98	1.19	0.72	1	0.78	1.99	1.12	0.68	1.24	0.79	0.82	1.1	0.92	0.98
Gd	3.56	3.81	3.3	3.63	3.6	4.87	4.55	2.89	4.86	4.22	3.68	3.67	4.31	3.7
Tb	0.48	0.49	0.5	0.59	0.59	0.66	0.77	0.41	0.69	0.6	0.58	0.5	0.64	0.54
Dy	3.3	2.71	3.53	3.53	3.84	3.66	4.52	3	4.64	3.49	3.66	3.25	4.38	3.72
Ho	0.6	0.44	0.7	0.78	0.84	0.69	0.98	0.61	0.95	0.7	0.8	0.66	0.89	0.71
Er	1.75	1.39	2.27	2.25	2.49	2.15	2.86	1.76	2.71	2.21	2.3	2	2.59	2.36
Tm	0.29	0.21	0.36	0.31	0.35	0.3	0.39	0.26	0.37	0.33	0.32	0.28	0.36	0.36
Yb	1.7	1.18	2.08	2.38	2.55	1.78	2.5	1.77	2.62	2.28	2.19	1.78	2.31	2.09
Lu	0.24	0.2	0.33	0.34	0.31	0.3	0.42	0.26	0.39	0.31	0.33	0.26	0.33	0.33
Ga	17.7	23	18.2	18.5	20.2	20.5	17.9	15.2	20.2	16.1	18.4	17.3	16.5	17.1
Eu/Eu_N	0.83	0.86	0.69	0.89	0.69	1.01	0.72	0.75	0.77	0.55	0.73	0.87	0.63	0.83
Ce_N/Yb_N	4.52	6.75	2.46	2.69	2.82	12.45	4.32	2.89	3.94	4.82	2.43	4.03	3.52	3.08

isotropic fabric, which make them impossible to extract and transform into medium-large supports. Both materials are present in a small proportion in the dolmens. The small blocks and boulders were used in their raw form and in combination with other lithologies for the construction of the pavements of the accesses, ambulatories and external elements. In a minority of cases, they formed part of the final covering of the burial mounds. In addition, the oblong pebbles were used as hammerstones in the technical treatment of the supports. Massive andesite may have been selected for its hardness, compactness and resistance to impact, and was regularly used in the backing of the orthostats and the contention of the platforms of the kerbs in order to counteract the compression and lateral thrust of the mound. The amphibole-phyric andesite may have been selected for its particular physical characteristics, visual properties and aesthetic qualities. Macroscopically, it stands out for the chromatic and luminous contrast of the dark and bright amphibole crystals in the light-coloured matrix. Its spatial arrangement in visible and external elements would have contributed to the ornamentation and/or decoration of dolmens, highlighting this material in the incidence of the sun's rays on the amphibole crystals. Both andesites occur together in secondary deposits in the Agua Fría and Matulá ravines, the potential source areas being located in the backwaters of the confluence zone of the two watercourses, located 350–500 m to the east.

White quartz was used in raw or fractured form as cobbles in the external pavements, atriums and as packing stones for the orthostats. It is a lithology noted for its hardness, visual properties (white colour, lustre and texture) and symbolic significance. It was frequently used in the external spaces of dolmens to increase their visual impact in the landscape, contrasting the light colour and luminous shine with the dark and opaque materials of the mounds and external elements. Its presence in larger blocks in the access of Dolmen 4 and outside Dolmen 1 (where a natural block was carved), for the signposting of the accesses and transit areas, is noteworthy. This lithology is found in small phyllonian outcrops in the immediate surroundings, with abundant presence of pebbles in the bed of the Agua Fría ravine. Its proximity to the megaliths led it to be readily available and regularly used in the dolmens for the foundations of the orthostats, in the pavements and in the access structures.

A few small blocks and pebbles of agglomerates of ferruginous alteration were occasionally used in the external pavement and levelling platform of Dolmen 3. It is a dark reddish-brown stone with a rough texture and multiple dimples, and is very noticeable and visible due to the contrast with the rest of the materials. Its selection and use in the levelling platform and southern external pavement may correspond to an intentional aesthetic or ornamental use in this sector of the dolmen. This material may have come from the

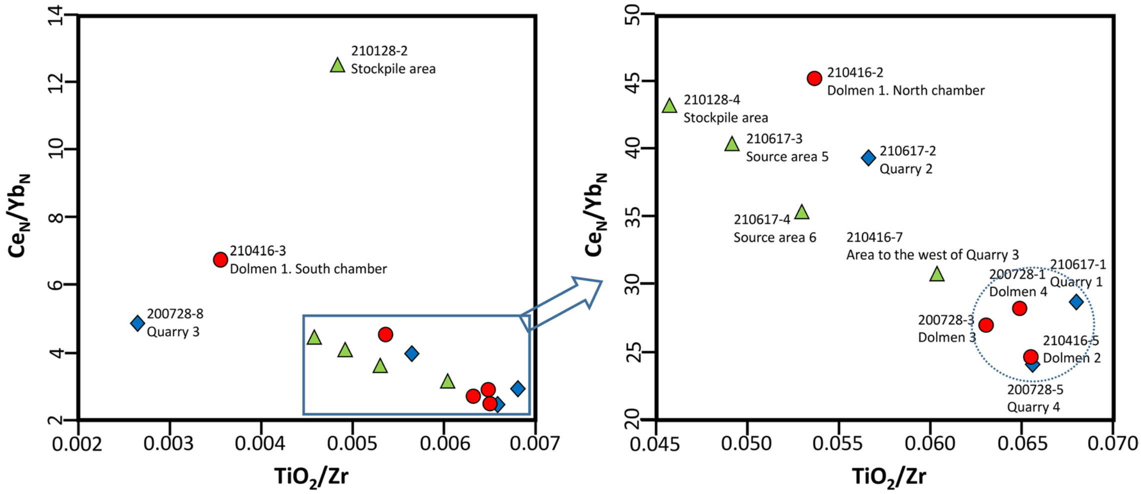


Fig. 18 Ce_N/Yb_N vs TiO_2/Zr diagram of samples from the dolmens and source areas of the Los Llanetes group

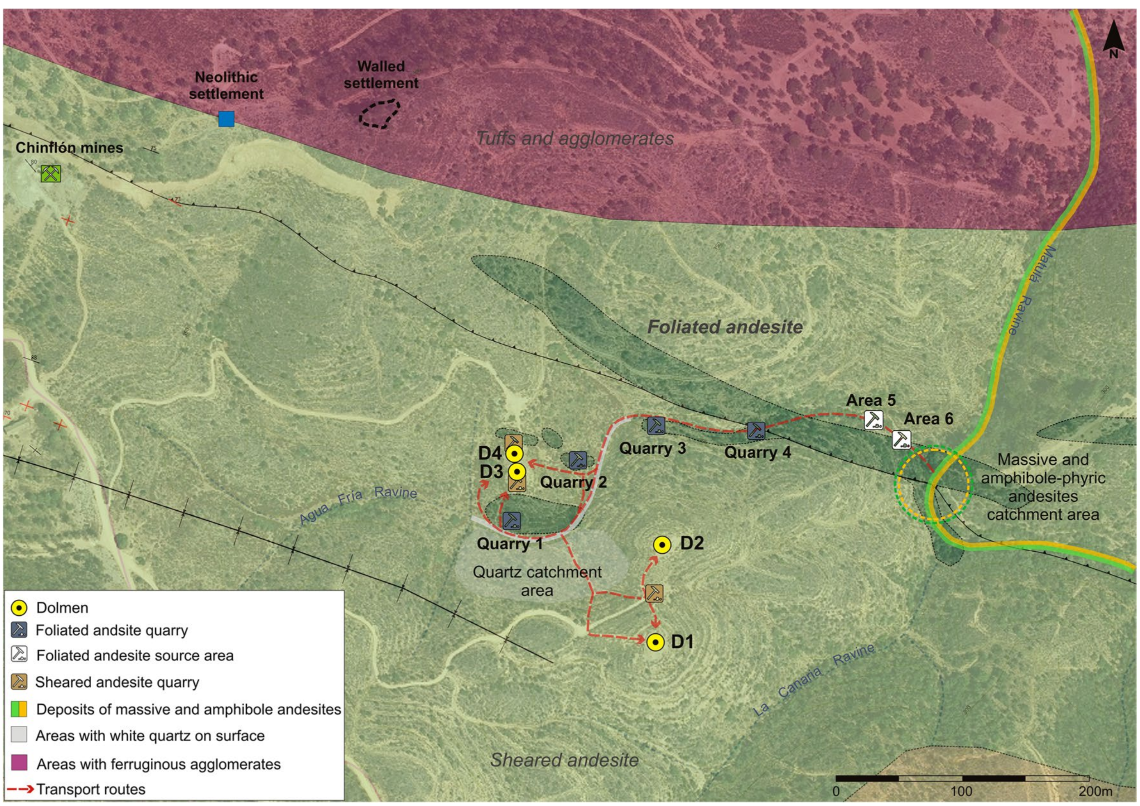


Fig. 19 Selection and provenance of the materials used in the Los Llanetes megalithic group. Quarries, source areas and transport routes

summit of Chinflón hill, where crests of agglomerates with iron oxides outcrop beside the sheared andesites.

Gabbro was used very occasionally in Dolmen 4, where an eroded block is documented in the intrados of the southern part of the kerb. This igneous rock has a massive structure, isotropic fabric, equigranular phaneritic texture and fine grain, with a predominantly greenish tone. These properties make it very hard and resistant. Pebbles were used as hammerstones in the quarries and in the activity areas surrounding the megaliths. This lithology outcrops approximately 1 km to the east, and may have been obtained from deposits in the bed of the Agua Fria ravine.

Location and sourcing

The geoarchaeological study suggests that the choice of the site of the Los Llanetes group is the result of an intentional appropriation of space and a planned strategy for the acquisition of materials for the construction of the megaliths, in symbiosis with the surrounding landscape.

At Los Llanetes, the geomorphological and geological conditions of the site made possible the creation of a megalithic landscape tied to the natural formations and rocky outcrops of the area. On the one hand, the higher surrounding foothills define a semi-enclosed U-shaped space, open to the east and with a clear horizon, which was used for the emplacement, organization and orientation of the monuments from the beginning of the 4th millennium BC onwards (Fig. 20). The dolmens were built within this space, at the head of the Agua Fría ravine, protected and hidden from the outside, and visible only from the habitat areas located on the summit of Chinflón hill. The megaliths display axial and visual orientations in line with prominent natural features that are the landmarks of this environment, the layout of which coincides with the oscillation of the sun's orbit. Thus, the hills of La Cebada and La Canaria coincide with the summer and winter solstices, respectively, while the course of the river is aligned with the spring and autumn equinoxes. The association with rocky outcrops, the emulation of rocks and the visual connection with the main natural features of the surrounding landscape are characteristic of early prehistoric monumentality, with natural forms serving as inspiration for the Neolithic communities (Tilley 1994, 1996; Bradley 1998, 2000; Calado 2002; Cummings 2002b; Scarre 2002).

On the other hand, the presence of all the lithologies used in the construction of the megaliths in the immediate environment would have conditioned the choice of the location of the megalithic group, facilitated their procurement and enabled their restricted use, especially of the foliated andesite outcrops contained entirely within this sacralized space. As Scarre (2020) noted, the choice of megalithic sites is determined by the presence of large rocky outcrops and abundant blocks scattered on the surface, and at the Los Llanetes group, there is a clear spatial association between the construction sites and the source areas. Furthermore, construction at this site and the progressive monumentalization of the Los Llanetes dolmens reveals the intention of the prehistoric communities to fix the territory of their ancestors (Bradley 1998) and create the permanence of memory (Bradley 2002; Furholt and Müller 2011) over a long period of time.

The Neolithic community of Los Llanetes developed a procurement strategy for the acquisition of various lithologies from the local geological environment for the construction of the megaliths. Research shows that this pattern was common in the small and medium-sized dolmens of the southwest of the Iberian Peninsula during the Late Neolithic. For instance, the petrographic and geochemical analyses of the Freixo-Redondo dolmens, in the Alentejo region of Portugal, have determined that the granodiorite blocks were collected from outcrops located 150–3500 m from the megaliths (Boaventura et al. 2020). There are few sites where the acquisition of allochthonous materials transported over long distances has been observed, corresponding to monuments of a larger architectural scale, such as the necropolis of Vale de Rodrigo, whose dolmens incorporate granite blocks from a distance of 2–10 km (Kalb 1996, 2013), or the dolmen of Soto, which was built with supports of various sedimentary (greywacke, calcarenite, sandstone, conglomerate, dolomite) and igneous (dacite and granite) rocks from sources between 3 and 60 km (Linares Catela and Mora Molina 2018).

In the case of Los Llanetes, local lithologies were selected according to their physical and symbolic properties, most of them being located within the semi-enclosed construction site itself. The Neolithic community undertook an intensive exploitation of foliated andesite, despite it being a minority rock in the andesitic substrate and with a low visibility on the surface in comparison with other igneous rocks outcropping in the geological environment. Indeed, its presence is limited to the rocky outcrops exploited as quarries and to the source areas of the Agua Fría ravine. However, it is the main rock, used exclusively as a weight-bearing structural element and for the contention of the mounds, as well as in combination with other stones for the fillings of the mounds and external structures.

The choice and use of this stone may be explained by its material qualities and symbolic significance. It is the only stone in the local geological environment available within a radius of 2 km that outcrops in the form of large blocks, with favourable conditions for their procurement and with physical properties suitable for use as megalithic supports. The acquisition and use of this material is not an opportunistic practice, given the low quantity of detached blocks on the surface and, fundamentally, the need to obtain stone supports with suitable morphological and structural characteristics for the architectural stability of the dolmens. The intensive exploitation of this material would have required prior planning and the articulation of an operational sequence of tasks, materialized in a systematic selection of the blocks, an effective technology of the extractive activities in the quarries and a technical expertise in the placement of the stones. All of this implies an architectural project or plan, as proposed for the elongated barrows of western France (Laporte 2016) or Danish passage graves (Dehn 2016), which would have determined the design, shape and size of the dolmens in their various forms (single, elongated and double chamber), as well as the operational sequences of their primary construction and transformation (Linares Catela 2021) that would have determined the stages and organization of the works.

The construction works would probably have been carried out in a linear and continuous sequence, through the execution of concatenated and spatially segmented operations: acquisition, transport, transformation and placement of blocks. The construction of the megaliths required a collective organization of work and the participation of a group of builders, among whom there may have been individuals with a high degree of experience, expert knowledge and technical specialization, as can be inferred from the study of numerous Neolithic monuments in Western Europe (Laporte et al. 2020). The scale of the architectural projects, the multiplicity of the tasks and the volume of materials mobilized may have exceeded the capacity of the workforce of the community of Los Llanetes. The construction of the dolmens may, therefore, have involved individuals from other settlements associated with the El Pozuelo complex, other communities in the eastern Andévalo that shared a similar architectural style or even individuals from more distant geographical areas. This practice of mobility of people for the construction of megaliths may have been common in Western Europe during the Late Neolithic, as suggested by the alliances between different social groups in the Swedish region of Falbygden for the construction of gallery dolmens (Sjögren 2020).

It is also likely that this peculiar lithology had specific symbolic connotations and ideological meanings due to several factors. Firstly, it is the rock without which the monuments dedicated to death, ritual practices and ancestor worship could not be built. Secondly, its presence within the space of the ancestors would give it a sacred value and a physical protection within this space. Thirdly, the quarries and source areas, despite being located in hidden places of low visibility, would have been essential elements of the megalithic landscape, linking the megaliths with the outcrops and areas of origin located in the Agua Fría ravine, a primordial natural element in the spatial organization of the group. For all these reasons, it is very possible that the foliated andesite from this area was obtained and exploited exclusively by the Los Llanetes community, being an inaccessible material for the supply of other social groups from the El Pozuelo complex or from other more distant places, thus avoiding competition for this critical resource for the construction of the megaliths in the geographic area during the Late Neolithic by means of symbolic and ideological sanction.

Other materials may have been chosen for their particular visual properties (lustre, colour, texture), such as white quartz, amphibole-phyric andesite, gabbro and ferruginous agglomerates. The combined use of all the rocks found in the local geological environment goes beyond purely constructive needs, and there may have been other symbolic and ideological reasons, as is common in many dolmens on the French Atlantic coast, where the diversity of forms of the stone supports, treatments, chromatism, textures and granulometries obeys an ordered 'symbolic codification' of the sepulchral spaces (Mens et al. 2021). At Los Llanetes, the combined use of stones and clays is suggestive of an association with the geological context and a connection with the surrounding environment, as is common in Neolithic monuments. On the one hand, the lithologies used in the dolmens figuratively represent and mimetically reproduce the rocks found in the environment. On the other hand, the monuments merge and interrelate with natural (relief, Agua Fría ravine and outcrops) and anthropic elements (settlements and quarries), creating a harmonious megalithic landscape with a strong territorial imprint and visual perceptibility.

Conclusions

The community of Los Llanetes would have had to consider two complementary factors when choosing the location of the megalithic site: the geomorphology and the nearby availability of materials suitable for the construction of the dolmens.

The geomorphology of the site favoured the creation of a singular megalithic landscape reserved for the domains of the dead, the ancestors and the ritual practices from the beginning of the 4th millennium to the beginning of the 2nd millennium BC. The narrowing of the waters of the Agua Fría ravine, the morphology and the relief created a semi-enclosed U-shaped space open to the east and sheltered from the surrounding area, which was used for the protected placement of the monuments on two distinct elevations.

The monuments are located on a rocky substrate that allows for topographic conditioning, the excavation of foundation structures for the vertical supports and the opening of quarries for the acquisition of material. The megaliths were built with the rocks available in the local geological environment, obtained in superficial outcrops and in secondary deposits in the ravines at a maximum linear distance of 500 m. The stones were selected on the basis of their physical, visual, aesthetic and symbolic qualities. Each lithology is represented in accordance with its material properties, architectural function, physical suitability and spatial arrangement, contributing jointly and in combination with clay to the structural solidity, chromatic contrast between elements and visibility in the landscape.

The geoarchaeological study of the El Pozuelo site has made it possible to identificate the lithology of the megaliths and sources areas, corresponding to igneous rocks of andesitic composition, ranging from intensely foliated to more isotropic structures. Foliated andesite is the main material used, a consistent rock with a penetrative planar fabric that favours its detachment and extraction in large

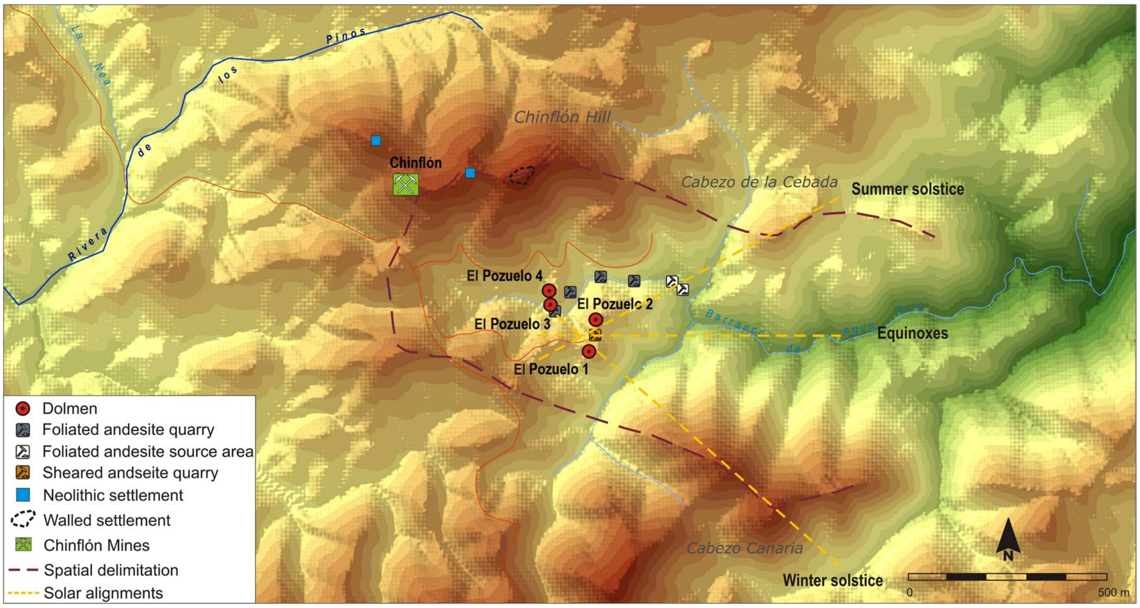


Fig. 20 Megalithic landscape of Los Llanetes. Natural and anthropic elements

blocks. This rock presents recrystallizations and alterations associated with deformation, as is the case of most of dolmens located in the VSC of the Iberian Pyrite Belt, that make their visual identification difficult. To overcome this problem, we have combined petrography and geochemical analysis of immobile rare earth elements. Foliated andesite was used as the exclusive rock in the megalithic structures and kerbstones due to its suitable physical properties and formats, as well as in combination with other materials in the mounds and external structures. It is the only lithology in the environment suitable for use as megalithic supports and for the building the dolmens, which allows it to be sourced, extracted and shaped as large blocks for weight-bearing, covering and segmentation functions. Part of the foliated andesite blocks may have come from the source areas of the bed of the Agua Fria ravine. However, most of the large stone supports come from megalithic quarries, as evidenced by the extractive traces, the morphologies of the orthostats and the geochemical analyses. It is possible that most of blocks of Dolmens 2, 3 and 4 could have been extracted in Quarry 4, in which extractive activity was the most intensive. Dolmen 1 may have been built with stones from various sources: (a) north chamber with blocks selected from the source areas 5 and 6 and Quarry 2; (b) south chamber with dacite othostats from Quarry 3. Quarries 1 and 2 may have supplied medium-sized blocks and slabs for the construction of the four dolmens.

Other andesites (sheared, massive and amphibole-phyric) were used to a lesser extent, with different functions and architectural intentions. These materials were mostly used in their rough state, being worked with clay mortar for the construction of the mounds, pavements and external elements. Slabs of sheared andesites, extracted from the quarries surrounding the dolmens, were used for the construction of the mounds and external structures. The blocks and boulders of massive and amphibole-phyric andesites, obtained in secondary deposits, were used for their hardness and aesthetics qualities in the tomb coverings and in the pavements of the access areas. Other surrounding lithologies, such as quartz, gabbro and ferruginous agglomerates, were chosen for their material properties and their visual, aesthetic and/or symbolic qualities, enhancing the perceptibility and ornamentation of the external spaces.

These practices suggest that the Neolithic community of Los Llanetes carried out a planned strategy of appropriation of the space where the dolmens are located. The configuration of a megalithic landscape with a clear spatial delimitation reveals profound knowledge of the territory, the materials and the megalithic construction process. The multiple and complex operations of acquiring, transporting and transforming the stone blocks would have required a collective organization of work and the technical division of tasks during construction. The Late Neolithic social group deployed a procurement strategy centred on the selection, supply, transformation and use of various lithologies in the local environment, perpetuating the exploitation of the source areas, the technology and the technical treatments for the construction and remodelling of the dolmens throughout the 4th millennium BC. The communal efforts were mainly focused on the acquisition, technical treatments and placement of the foliated andesite blocks. This pattern was maintained during the first half of the 3rd millennium BC, with the recurrent use of this material for the arrangement of steles and structures in the entrances and atriums. The re-appropriation of the site during the Early Bronze Age meant a change in the patterns of selection and use of materials. The stones from the dolmens were reused opportunistically, in the case of the slabs and blocks of the terraced enclosures, and/or with a symbolic connotation, in the case of the large fractured and recycled supports in the dry-stone walls of the terraces and the circular platform of Dolmen 1. Sheared andesite slabs were also extracted from the quarry located between Dolmens 1 and 2.

The methodological approach to the Los Llanetes group has provided strong empirical results in terms of the lithological identification and the determination of the areas of local provenance, and can be applied to other geological environments with megaliths built with foliated rocks, from both igneous and metamorphic protoliths.

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Data availability Data are available in Supplementary Information: Table 1. Geographical coordinates (DMS) of the archaeological sites cited in the text; Table 2. Geographical coordinates (DMS) of geological samples at the Los Llanetes group (El Pozuelo megalithic complex).

Code avaibability 'Not applicable' for that section.

Author contribution JALC: funding acquisition, conceptualization, methodology (archaeological study, geoarchaeological fieldwork, sampling, planimetry and mapping), data analysis, geo and archaeological figures and writing (original draft, review and editing). TDR: conceptualization, methodology (geoarchaeological fieldwork, sampling and mapping), petrographic and geochemical analysis, geological figures and writing (original draft, review and editing). CMM: archaeological study, geoarchaeological fieldwork and mapping. LMCP: geoarchaeological fieldwork and geormorphological context. All authors read and approved the final text.

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Declarations

Ethics approval 'Not applicable' for that section.

Consent to participate 'Not applicable' for that section.

Conflict of interest The authors declare no competing interests.

References

Aranda Jiménez G, Lozano JA, Pérez Valera F (2018) The megalithic necropolis of Panoria, Granada, Spain: geoarchaeological characterization and provenance studies. Geoarchaeol Int J 33:260–270. https://doi.org/10.1002/gea.21643

Ard V, Mens E, Poncet D, Cousseau F, Defaix J, Mathé V, Pillot L (2016) Life and death of Angoumoisin-type dolmens in west-central France. Architecture and evidence of the reuse of megalithic orthostats. Bulletin de la Société Préhistorique Française 113(4):737–764. https://doi.org/10.3406/bspf.2016.14686

Bakker JA (2009) Hunnebedden and Hünengräber: the construction of megalithic tombs west tombs of River Elbe. In: Scarre C (ed) Megalithic quarrying. Source, extracting and manipulating the stones. BAR International Series 1923. Archaeopress, Oxford, pp 27–34

Bevins RE, Ixer RA, Webb PC, Watson JS (2012) Provenancing the rhyolitic and dacitic components of the Stonehenge landscape bluestone lithology: new petrographical and geochemical evidence. J Archaeol Sci 39(4):1005–1019. https://doi.org/10.1016/j.jas.2011.11.020

Bevins RE, Pearce NJG, Ixer RA (2021) Revisiting the provenance of the Stonehenge bluestones: refining the provenance of the Group 2 non-spotted dolerites using rare earth element geochemistry. J Archaeol Sci Rep 38:103083. https://doi.org/10.1016/j.jasrep.2021.103083

Bevins RE, Pearce NJG, Parker Pearson M, Ixer RA (2022) Identification of the source of dolerites used at the Waun Mawn stone circle in the Mynydd Preseli, west Wales and implications for the proposed link with Stonehenge. J Archaeol Sci Rep 45:103556. https://doi.org/10.1016/j.jasrep.2022.103556

Blanco A, Rothenberg B (1981) Exploración Arqueometalúrgica de Huelva (EAH). Río Tinto Minera/Labor, Barcelona

Boaventura R, Moita P, Pedro J, Mataloto R, Almeida L, Nogueira P, Máximo J, Pereira A, Santos JF, Ribeiro S (2020) Moving megaliths in the Neolithic - a multi analytical case study of dolmens in Freixo-Redondo (Alentejo, Portugal). In: Boaventura R, Mataloto R, Pereira A (eds) Megaliths and Geology / Megálitos e Geologia. MEGA-TALKS 2, 19-20 November 2015 (Redondo, Portugal). Archaeopress, Oxford, pp 1–24

Bradley R (1998) The significance of monuments. On the shaping of human experience in Neolithic and Bronze Age Europe. Routlegde, London

Bradley R (2000) An archaeology of natural places. Routledge, London

Bradley R (2002) The past in prehistoric societies. Routledge, London

Brodie K, Fettes D, Harte B (2007) Structural terms including fault rock terms. In: Fettes D, Desmonds J (eds) Metamorphic rocks: a classification and glossary of terms. Cambridge University Press, Cambridge, pp 24–31

Bueno Ramírez P, Balbín Berhmann R (2009) Marcadores gráficos y territorios tradicionales de la Prehistoria de la península ibérica. Cuadernos de Prehistoria y Arqueología de la Universidad de Granada 19:65–100. https://doi.org/10.30827/cpag.v19i0.185

Bueno Ramírez P, Balbín Berhmann R, Barroso Bermejo R (2007) Chronologie de l'art Mégalithique ibérique: C14 et contextes archéologiques. L'Anthropologie 111(4):590–654. https://doi.org/10.1016/j.anthro.2007.07.006

Bueno Ramírez P, Balbín Berhmann R, Barroso Bermejo R (2014) Custodian bones: human images in the megalithism of the Southern Iberian Peninsula. In: Cruz A, Cerrillo-Cuenca E, Bueno P, Caninas JC, Batata C (eds) Rendering Death: ideological an archaeological narratives from recent prehistory (Iberia). BAR International Series 2648. Archaeopress, Oxford, pp 3–12

Bueno Ramírez P, Linares Catela JA, Balbín Berhmann R, Barroso Bermejo R (eds) (2018) Símbolos de la muerte en la Prehistoria Reciente del sur de Europa. España. Arqueología Monografías. Consejería de Cultura, Junta de Andalucía, Sevilla, El dolmen de Soto, Huelva

Cabrero R (1982) El fenómeno megalítico en Andalucía Occidental. PhD Dissertation, Universidad de Sevilla (digital edition 1985)

Cabrero R (1985) Tipología de los sepulcros calcolíticos de Andalucía Occidental. Huelva Arqueológica VII:207–263

Cáceres LM, Muñiz F, Rodríguez-Vidal J, Vargas JM, Donaire T (2014) Marine bioerosion in rocks of the prehistoric tholos of La Pastora (Valencina de la Concepción, Seville, Spain): archaeological palaeoenvironmetal implications. J Archaeol Sci 41:435–446. https://doi.org/10.1016/j.jas.2013.09.001

Cáceres LM, Vargas JM, Muñiz F, Donaire T, García Sanjuán L, Odriozola C, Rodríguez-Vidal J (2019) Natural "megalithic art" at Valencina (Seville): a geoarchaeological approach to stone, architecture, and cultural choice in Copper Age Iberia. Archaeol Anthropol Sci 11:4621–4641. https://doi.org/10.1007/s12520-019-00870-z

Calado M (2002) Standing stones and natural outcrops: the role of ritual monuments in the Neolithic transition of the Central Alentejo. In: Scarre C (ed) Monuments and landscape in Atlantic Europe: perception and society during the Neolithic transition and Early Bronze Age. Routlege, London, pp 17–35

Cardoso JA, Boaventura R (2011) The megalithic tombs in the region of Belas (Sintra, Portugal) and their aesthetic manifestations. Trab Prehist 68(2):297–312. https://doi.org/10.3989/tp.2011.11071

Carrión F, Lozano JA, García D, Muñiz T, Félix P, López CF, Esquivel JA, Mellado I (2010) Estudio geoarqueológico del conjunto de los Dólmenes de Antequera (Málaga, España). In: Calado D, Baldia M, Boulanger M (eds) Monumental questions: prehistoric megaliths, mounds and enclousures. BAR International Series 2122. Archaeopress, Oxford, pp 57–69

Cerdán C (1951) Los sepulcros megalíticos de Huelva. In: II Congreso Arqueológico Nacional (Zaragoza). CSIC, Madrid, Zaragoza, pp 161–170

Cerdán C, Leisner G, Leisner V (1952) Los sepulcros megalíticos de Huelva. In: Informes y Memorias de la Comisaría de Excavaciones Arqueológicas, 26. Ministerio de Educación Nacional, Madrid

Chazan M (2017) Geology/archaeology in action: a personal perspective. Archaeol Anthropol Sci 9:1671–1676. https://doi.org/10.1007/s12520-016-0412-2

Conde C, Tornos F (2019) Geochemistry and architecture of the host sequence of the massive sulfides in the northern Iberian Pyrite Belt. Ore Geol Rev 127:103042. https://doi.org/10.1016/j.oregeorev.2019.103042

Cooney G (2000) Landscape of Neolithic Ireland. Routledge, London

Cummings V (2002a) Experiencing texture and transformation in the British Neolithic. Oxf J Archaeol 21(3):249–261. https://doi.org/10.1111/1468-0092.00161

Cummings V (2002b) All cultural things: actual and conceptual monuments in the Neolithic of western Britain. In: Scarre C (ed) Monuments and landscape in Atlantic Europe: perception and society during the Neolithic transition and Early Bronze Age. Routlege, London, pp 107–122

Darvill T (2011) Megaliths, monuments and materiality. In: Furholt M, Lüth F, Müller J (eds) Megaliths and identities. Early Monuments and Neolithic Societies from the Atlantic to the Baltic, Dr Rudolf Habelt GmbH, Bonn, pp 35–46

Darvill T, Wainwright G (2014) Beyond Stonehenge: Carn Menyn Quarry and the origin and date of bluestone extraction in the Preseli Hills of south-west Wales. Antiquity 88(342):1099–1114. https://doi.org/10.1017/S0003598X00115340

Dehn T (2009) The megalithic building site. In: Scarre C (ed) Megalithic Quarrying. Source, extracting and manipulating the stones. BAR International Series 1923. Archaeopress, Oxford, pp 21–25

Dehn T (2016) The megalithic construction process and the building of passage graves in Denmarrk. In: Laporte L, Scarre C (eds) The megalithic architectures of Europe. Oxbow Books, Oxford, pp 59–68

Díez-Montes A, Bellido Mulas F (2008) Magmatismo TTG y Al-K en la Zona Surportuguesa. Relaciones entre plutonismo y vulcanismo Geo-Temas 10:1449–1452

Donaire T, Pascual E, Sáez R, Toscano M (2020a) Facies architecture and palaeoenvironmental constraints of subaqueous felsic volcanism in the Iberian Pyrite Belt: the Paymogo Volcano-Sedimentary Alignment. J Volcanol Geotherm Res 405:107045. https://doi.org/10.1016/j.jvolgeores.2020.107045

Donaire T, Pascual E, Sáez R, Pin C, Hamilton MA, Toscano M (2020b) Geochemical and Nd isotopic signature of felsic volcanic rocks as a proxy of volcanic-hosted massive sulphide deposits in the Iberian Pyrite Belt (SW, Spain): the Paymogo Volcano-Sedimentary Alignment. Ore Geol Rev 120. https://doi.org/10.1016/j.oregeorev.2020.103408

Fernandes P, Jorge RS, Rodrigues B, Oliveira JT (2019) The Carboniferous Baixo Alentejo Flysch Group: sedimentary provenance and basin development. In: Quesada C, Oliveira JT (eds) The geology of Iberia: a geodynamic approach. Volume 2: The Variscan Cycle. Springer, Cham, pp 391–400. https://doi.org/10.1007/978-3-030-10519-8_11

Flores Hurtado E (1994) Tectónica reciente en el margen ibérico suroccidental. PhD Dissertation,. Universidad de Huelva

Furholt M, Müller J (2011) The earliest monuments in Europe architecture and social structures (5000 3000 BC). In: Furholt M, Lüth F, Müller J (eds) Megaliths and identities. Early Monuments and Neolithic Societies from the Atlantic to the Baltic, Dr Rudolf Habelt GmbH, Bonn, pp 15–32

Gifkins C, Herrmann W, Large R (2005) Altered volcanic rocks: a guide to description and interpretation. Centre for Ore Deposit Research, Hobart

Gillings M, Hacigüzeller P, Lock G (2019) Re-mapping archaeology: critical perspectives, alternative mappings. Routledge, New York

Giot PR (1987) Barnenez, Carn, Guennoc. Travaux du Laboratoire "Anthropologie-Prehistoire-Protohistoire-Quaternaire Armoricans", Equipe de Recherche n° 27. CNRS, Université de Rennes, Rennes

Gómez Ruiz A (1978) Nuevas aportaciones al estudio de los Dólmenes de El Pozuelo: El Dolmen de "Martín Gil. Huelva Arqueológica IV: 11-78

Humphries SE (1984) The mobility of the rare earth elements in the crust. In: Henderson P (ed) Rare Earth Element Geochemistry. Elsevier, Amsterdam, pp 317–342

Inverno C, Díez-Montes A, Rosa C, García-Crespo J, Matos J, García-Lobón JL, Carvalho J, Bellido F, Castello-Branco JM, Ayala C, Batista MJ, Rubio F, Granado I, Tornos F, Oliveira JT, Rey C, Araújo V, Sánchez-García T, Pereira Z, Represas R, Solá AR, Sousa P (2015) Introduction and geological setting of the Iberian Pyrite Belt. In: Weihed P (ed) 3D, 4D and predictive modelling of major mineral belts in Europe. Springer, pp 191-208. https://doi.org/10.1007/978-3-319-17428-0_9

IGME (1970) Valverde del Camino. Mapa Geológico de España, escala 1:50.000 (1ª serie). Instituto Geológico y Minero de España, Ministerio de Industria, Madrid. https://info.igme.es/cartograficadigital/geologica/Geo50Hoja.aspx?language=es&id=960

IGME (1982) Valverde del Camino. Mapa Geológico de España, escala 1:50.000 (2ª serie). Instituto Geológico y Minero de España, Ministerio de Industria y Energía, Madrid. https://info.igme.es/cartografiadigital/geologica/Magna50Hoja.aspx?Id=960&language=es

IGME (2004) GEODE - Cartografia geológica digital continua a escala 1:50.000. Zona Z3100 (Sudportuguesa). Instituto Geológico y Minero de España, Ministerio de Industria, Turismo y Comercio, Madrid. https://info.igme.es/cartografiadigital/geologica/geodezona.aspx?Id=Z3100&language=es

IGME (2015) Mapa Geológico de España. Escala 1/200.000. 75-74. Instituto Geológico y Minero de España, Ministerio de Economía y Competitivad, Madrid. https://info.igme.es/cartografiadigital/geologica/Geologico200Hoja.aspx?language=es&id=74

Ixer R, Bevins R (2017) The bluestones of Stonehenge. Geol Today 33:180–184. https://doi.org/10.1111/gto.12198

Jones A (1999) Local colour: megalithic architecture and colour symbolism in Neolithic Arran. Oxf J Archaeol 18:339–350. https://doi.org/10.1111/1468-0092.00088

Joussaume R (2006) Les tumulus de Champ-Châlon à Benon (Charente-Maritime). Groupe Vendéen d'Études Préhistoriques 42. GVEP, La Roche sur Yon

Kalb P (1996) Megalithic transport and territorial markers: evidence from Vale de Rodrigo, Évora, South of Portugal. Antiquity 70:683–685. https://doi.org/10.1017/S0003598X00083848

Kalb P (2013). Vale de Rodrigo. A case study in early technology and building material management in the megalithism of southern Portugal. In: Guyodo JN, Mens E (dirs) Les premières architectures en pierre en Europe occidentale du Ve au IIe millénaire avant J.-C. Presses Universitaires de Rennes, Rennes, pp 123–131

Laporte L (2013) Les carrières fournissant le petit appareil employé dans le construction de masses tumulaires. Megalithismes de l'ouest de la France, projets archicteuraux, strategies d'approvisionnement et techniques mises en ouvre pour l'extraction. In: Guyodo JN, Mens E (dirs) Les premières architectures en pierre en Europe occidentale du Ve au IIe millénaire avant J.-C. Presses Universitaires de Rennes, Rennes, pp 79–106

Laporte L (2016) Structural functions and architectural projets within the elongated megalithic monuments of western France. In: Laporte L, Scarre C (eds) The megalithic architectures of Europe. Oxbow Books, Oxford, pp 17–30

Laporte L, Cousseau F, Gouezin P, Linares-Catela JA, Piofett H (2020) Chapter 1. Stonemasons, and even engineers, for megalithic building in Neolithic Europe? Des maçons, voire quelques ingénieurs, pour le bâti mégalithique du Néolithique européen? In: Laporte L, Cousseau F (eds) Pre and Protohistoric stone architectures Comparisons of the social and their technical contexts associated to building. UISPP Proceedings Series Volume 1 – UISPP XVIII World Congress 2018 (4-9 Juin 2018, Paris), Session XXXII-3. Archaeopress, Oxford, pp 1–26

Leisner G, Leisner V (1956) Die Megalithgräber der Iberischen Halbinsel. Der Westen. Madrider Forschungen Band 1. Walter de Gruyter & Co, Berlín

Leisner G, Leisner V (1959) Die Megalithgräber der Iberischen Halbinsel. Der Westen. Madrider Forschungen Band 1/2. Walter de Gruyter & Co, Berlín

Leistel JM, Marcoux E, Thiéblemont D, Quesada C, Sánchez A, Almodóvar GR, Pascual E, Sáez R (1997) The volcanic-hosted massive sulphide deposits of the Iberian Pyrite Belt. Mineral Deposita 33(1-2):2–30. https://doi.org/10.1007/s001260050130

Le Roux CT (1985) New excavations at Gavrinis. Antiquity 59(227):183–187. https://doi.org/10.1017/S0003598X00057240

Le Roux CT (dir)(2006) Monuments mégalithiques à Locmariaquer (Morbihan). Le long tumulus d'Er Grah dans son environnement. Supplément XXXVIIIe à Gallia-Préhistoire. CNRS, Paris

L'Helgouach J (1983) Les idoles qu'on abat. Archéologie armoricaine. Bulletin de la Société Pollymathique du Morbihan 110:57–68

L'Helgouach J (1996) Mégalithes armoricains: stratigraphies, réutilisations, remaniements. Bulletin de la Socieceté Préhistorique Française 93(3):418–424. https://doi.org/10.3406/bspf.1996.10185

Linares Catela JA (2016) The megalithic architecture of Huelva (Spain): typology, construction and technical traditions in eastern Andévalo. In: Laporte L, Scarre C (eds) The megalithic architectures of Europe. Oxbow Books, Oxford, pp 111–126

Linares Catela JA (2017) El megalitismo en el sur de la península ibérica. Arquitectura, construcción y usos de los monumentos del área de Huelva, Andalucía occidental. PhD Dissertation, Universidad de Huelva. http://hdl.handle.net/10272/15504

Linares Catela JA (2020) Construction materials of the monuments of Los Llanetes group, El Pozuelo cemetery (Huelva, Spain). Selection, exploitation and provenance of stone blocks. In: Boaventura R, Mataloto R, Pereira A (eds) Megaliths and Geology / Megálitos e Geologia. MEGA-TALKS 2, 19-20 November 2015 (Redondo, Portugal). Archaeopress, Oxford, pp 87–108

Linares Catela JA (2021) « Chaînes opératoires mégalithiques »: construction et transformation des architectures funéraires dans la région de Huelva (Espagne). Dolmens de Los Llanetes, ensemble d'El Pozuelo. In: Ard V, Mens E, Gandelin M (eds) Mégalithismes et monumentalismes funéraires. Passé, présent, futur. Sidestone Press, Leiden, pp 203–224

Linares-Catela JA (2022) Radiocarbon chronology of dolmens in the Iberian southwest: architectural sequence and temporality in the El Pozuelo megalithic complex (Huelva, Spain). Radiocarbon 64(5):989–1064. https://doi.org/10.1017/RDC.2022.48

Linares Catela JA, Mora Molina C (2018) Capítulo 7. El dolmen de Soto 1, Huelva. Arqueología del monumento. In: Bueno Ramírez P, Linares Catela JA, Balbín Berhmann R, Barroso Bermejo R (eds) Símbolos de la muerte en la Prehistoria Reciente del sur de Europa. El dolmen de Soto, Huelva. España. Arqueología Monografías. Consejería de Cultura, Junta de Andalucía, Sevilla, pp 98–130

Linares-Catela JA, Mora Molina C, López López A, Donaire Romero T, Vera-Rodríguez JC, Bueno Ramírez P (2022) El sitio megalítico de La Torre-La Janera (Huelva): monumentalidades prehistóricas del Bajo Guadiana. Trab Prehist 79(1):115–130. https://doi.org/10.3989/tp.2022.12290

Lozano JA, Ruiz G, Hódar M, Pérez-Valera F, Morgado A (2014) Prehistoric engineering and astronomy of the great Menga Dolmen (Málaga, Spain). A geometric and geoarchaeological analysis. J Archaeol Sci 41:759–771. https://doi.org/10.1016/j.jas.2013.10.010

Mantero EM, Alonso-Chaves FM, Azor A (2003) El abanico imbricado de Valverde del Camino (parte meridional de la Zona Sudportuguesa, Huelva). Geogaceta 34:175–178

Mantero EM, Alonso-Chaves FM, Azor A (2006) Geometría y Cinemática de un Sistema Imbricado de Cabalgamientos en la Faja Pirítica Ibérica (Zona Sudportuguesa). Geogaceta 39:47–50

Mantero EM, García Navarro E, Alonso-Chaves FM, Martín Parra LM, Matas J, Azor A (2007) La Zona Sudportuguesa: propuesta para la división de un bloque continental en dominios. Geogaceta 43:27–30

Martínez Torres LM, Fernádez Eraso J, Mujika JA, Rodríguez Miranda A, Valle Melón JM (2014) Geoarchaeology and construction of the La Chabola de la Hechicera Megalithic Tomb, Elvillar. Northern Spain Geoarchaeol An Int J 29:300–311. https://doi.org/10.1002/gea.21479

Mcphie J, Doyle M, Allen R (1993) Volcanic textures: a guide to the interpretation of textures in volcanic rocks. University of Tasmania, Centre for Ore Deposit and Exploration Studies

Mens E (2008) Reffitting megaliths in western France. Antiquity 82(315):25–36. https://doi.org/10.1017/S0003598X00096411

Mens E (2013) Technologie des premières architectures en pierre dans l'Ouest de la France. In: Guyodo JN, Mens E (dirs) Les premières architectures en pierre en Europe occidentale du Ve au IIe millénaire avant J.-C. Presses Universitaires de Rennes, Rennes, pp 39–52

Mens E, Ard V, Poncet D, Kervidel G, Bichot F, Marticorena P, Laurent A, Leroux VE, Baleux F (2021) Systèmes techniques et productions symboliques du mégalithisme funérarire de la façade atlantique entre Bretagne e Pays Basque. In: Ard V, Mens E, Gandelin M (eds) Mégalithismes et monumentalismes funéraires. Passé, présent, futur. Sidestone Press, Leiden, pp 79–131

Mitjavila J, Martí J, Soriano C (1997) Magmatic evolution and tectonic setting of the Iberian Pyrite Belt volcanism. J Petrol 38(6):727–755. https://doi.org/10.1093/petroj/38.6.727

Mohen JP, Scarre C (2002) Les Tumulus de Bougon, complexe mégalithique du Ve au IIIe millénaire. Errance, Paris

Monteserín V, Bellido F, Díez Montes A (1999) Investigación geológica y cartografía básica en la Faja Pirítica y áreas aledañas. Hoja 960-II Berrocal (1:25.000). Junta de Andalucía, Sevilla. https://portalrediam.cica.es/geonetwork/static/api/records/00caf49d-298e-447d-8eab-a9d6d938be53

Munhá J (1983) Hercynian magmatism in the Iberian Pyrite Belt. In: Lemos de Sousa L, Oliveira JT (eds), The Carboniferous of Portugal. Memórias dos Serviços Geológicos de Portugal, Direçao-Geral de Geologia e Minas 29, Lisboa, pp 39–81

Nakamura N (1974) Determination of REE, Ba, Fe, Mg, Na, and K in carbonaceous and ordinary chondrites. Geochim Cosmochim Acta 38:757–775

Nocete F, Lizcano R, Bolaños C (1999) Más que grandes piedras. Patrimonio, Arqueología e Historia desde la Primera Fase del programa de puesta en valor del Conjunto Megalítico de El Pozuelo (Zalamea la Real, Huelva). In: Consejería de Cultura, Junta de Andalucía, Sevilla

Nocete F, Lizcano R, Nieto JM, Sáez R, Linares JA, Orihuela A, Rodríguez MO (2004) El desarrollo del proceso interno: el territorio megalítico en el Andévalo oriental. In: Nocete F (coord) Odiel. Proyecto de investigación arqueológica para el análisis del origen de la desigualdad social en el Suroeste de la Península Ibérica. Monografías Arqueología. Consejería de Cultura, Junta de Andalucía, Sevilla, pp 47–77

Oliveira JT, Quesada C, Pereira P, Matos JX, Solá AR, Rosa D, Albardeiro L, Díez- Montes A, Morais I, Inverno C, Rosa C, Relvas J (2019) South Portuguese Terrane: a continental affinity exotic unit. In: Quesada C, Oliveira JT (eds) The geology of Iberia: a geodynamic approach. Volume 2: The Variscan Cycle. Springer, Cham, pp 173–206. https://doi.org/10.1007/978-3-030-10519-8_6

Onezime J, Charvet J, Faure M, Bourdier JL, Chauvet A (2003) A new geodynamic interpretation for the south Portuguese Zone (SW Iberia) and the Iberian pyrite belt genesis. Tectonics 22(4):1027. https://doi.org/10.1029/2002TC001387

Parker Pearson M, Bevins R, Ixer R, Pollard J, Richards C, Welham K, Chan B, Edinborough K, Hamilton D, Macphail R, Schlee D, Schwenninger JL, Simmons E, Smith M (2015) Craig Rhos-y-felin: a Welsh bluestone megalith quarry for Stonehenge. Antiquity 89(348):1331–1352. https://doi.org/10.15184/aqy.2015.177

Parker Pearson M, Pollard J, Richards C, Welham K, Casswell C, French C, Schlee D, Shaw D, Simmons E, Stanford A, Bevins R, Ixer R (2019) Megalith quarries for Stonehenge's bluestones. Antiquity 93(367):45–62. https://doi.org/10.15184/aqy.2018.111

Parker Pearson M, Bevins R, Ixer R, Pollard J, Richards C, Welham K (2020) Long-distance landscapes: from quarries to monument at Stonehenge. In: Boaventura R, Mataloto R, Pereira A (eds) Megaliths and Geology / Megálitos e Geologia. MEGA-TALKS 2, 19-20 November 2015a (Redondo, Portugal). Archaeopress, Oxford, pp 151–170

Patton M (1992) Megalithic transport and territorial markers: evidence from the Channel Islands. Antiquity 66(251):392–395. https://doi.org/10.1017/S0003598X00081503

Pearce NJ, Bevins RE, Ixer RA (2022) Portable XRF investigation of Stonehenge Stone 62 and potential source dolerite outcrops in the Mynydd Preseli, west Wales. J Archaeol Sci Rep 44. https://doi.org/10.1016/j.jasrep.2022.103525

Pellicer M, Hurtado V (1980) El poblado metalúrgico de Chinflón (Zalamea la Real, Huelva). Universidad de Sevilla, Sevilla

Pin C, Waldhausrová J (2007) Sm-Nd isotope and trace element study of Late Proterozoic metabasalts ("spilites") from the Central Barrandian domain (Bohemian Massif, Czech Republic). In: Linnemann U, Nance RD, Kraft P, Zulauf G (eds) The evolution of the Rheic Ocean: From Avalonian-Cadomian active margin to Alleghenian-Variscan collision, Geological Society of America Special Paper, vol 423, pp 231–247. https://doi.org/10.1130/2007.2423(10)

Piñón Varela F (1987) Constructores de sepulcros megalíticos en Huelva: problemas de una implantación. In: El Megalitismo en la Península Ibérica. Ministerio de Cultura, Madrid, pp 45–72

Piñón Varela F (2004) El horizonte cultural megalítico en el área de Huelva. Monografías Arqueología, Consejería de Cultura, Junta de Andalucía, Sevilla

Quesada C (1996) Estructura del sector español de la Faja Pirítica: implicaciones para la exploración de yacimientos. Bol Geol Min 107(3-4):65–78

Richards C (1996) Monuments as landscape: creating the centre of the world in late neolithic Orkney. World Archaeol 28(2):190–208. https://doi.org/10.1080/00438243.1996.9980340

Richards C (ed) (2013) Building the great stone circles of the north. Oxbow Books, London

Robin G (2010) Spatial structures and symbolic systems in Irish and British passage tombs: the organization of architectural elements, parietal carved signs and funerary deposits. Camb Archaeol J 20(3):373–418. https://doi.org/10.1017/S0959774310000478

Rodríguez Vidal J, Díaz Del Olmo F (1994) Macizo Ibérico Meridional. In: Gutiérrez M (ed) Geomorfología de España. Rueda, Madrid, pp 101–122

Rollinson H, Pease V (2021) Using geochemical data: to understand geological processes, Cambridge University Press, Cambridge (2nd edition) https://doi.org/10.1017/9781108777834

Rosa CJP, McPhie J, Relvas JMRS (2010) Type of volcanoes hosting the massive sulfide deposits of the Iberian Pyrite Belt. J Volcanol Geotherm Res 194(4):107–126. https://doi.org/10.1016/j.jvolgeores.2010.05.005

Scarre C (2002) Introduction: situating monuments. The dialogue between built form and landform in Atlantic Europe. In: Scarre C (ed) Monuments and landscape in Atlantic Europe. Perception and society during the Neolithic and Early Bronze Age. Routledge, London, pp 1–14

Scarre C (2004) Choosing stones, remembering places. Geology and intention in the megalithic monuments of western Europe. In: Boivin N, Owoc MA (ed) Soils, Stones and Symbols. Cultural

perceptions of the mineral world. UCL Press, London, pp 187–202
Scarre C (2009) Stony ground: outcrops, rocks and quarries in the creation of megalithic monuments. In: Scarre C (ed) Megalithic quarrying. Source, extracting and manipulating the stones. BAR International Series 1923. Archaeopress, Oxford, pp 3–20
Scarre C (2011) Landscape of Neolithic Brittany. Oxford University Press, Oxford
Scarre C (2013) Pierres et paysages: blocs naturels et elements mégalithiques dans les monuments néolithiques britanniques. In: Guyodo JN, Mens E (dirs) Les premières architectures en pierre en Europe occidentale du Ve au IIe millénaire avant J.-C. Presses Universitaires de Rennes, Rennes, pp 181–192
Scarre C (2020) Geology, landscape and meaning in the megalithic monuments of western and northern Europe. In: Boaventura R, Mataloto R, Pereira A (eds) Megaliths and Geology / Megálitos e Geologia. MEGA-TALKS 2, 19-20 November 2015 (Redondo, Portugal). Archaeopress, Oxford, pp 135–149
Sjögren KJ (2020) Raw material and work force in Falbygden passage graves. Identity, competition and social dynamic. In: Boaventura R, Mataloto R, Pereira A (eds) Megaliths and Geology / Megálitos e Geologia. MEGA-TALKS 2, 19-20 November 2015 (Redondo, Portugal). Archaeopress, Oxford, pp 171–186
Sibson RH (1977) Fault rocks and fault mechanisms. J Geol Soc 133:191–213
Simancas JF, Carbonell R, González Lodeiro F, Pérez-Estaún A, Juhlin C, Ayarza P, Kashubin A, Azor A, Martínez Poyatos D, Almodóvar GR, Pascual E, Sáez R, Expósito I (2003) Crustal structure of the transpressional Variscan orogen of SW Iberia: SW Iberia deep seismic reflection profile (IBERSEIS). Tectonics 22(6):1062. https://doi.org/10.1029/2002TC001479
Simancas JF, Carbonell R, González Lodeiro F, Pérez Estaún A, Juhlin C, Ayarza P, Kashubin A, Azor A, Martínez Poyatos D, Sáez R, Almodóvar GR, Pascual E, Flecha I, Martí D (2006) Transpressional collision tectonics and mantle plume dynamics; the Variscides of southwestern Iberia. Geol Soc Mem 32:345–354. https://doi.org/10.1144/GSL.MEM.2006.032.01.21
Soriano C, Marti J (1999) Facies analysis of volcano-sedimentary successions hosting massive sulfide deposits in the Iberian Pyrite Belt, Spain. Econ Geol 94:867–882. https://doi.org/10.2113/gsecongeo.94.6.867
Thiéblemont D, Pascual E, Stein G (1997) Magmatism in the Iberian Pyrite Belt: petrological constraints on a metallogenetic model. Mineral Deposita 33(1-2):98–110. https://doi.org/10.1007/s001260050135
Thorpe RS, Williams Thorpe O (1991) The myth of long-distance megalithic transport. Antiquity 65(246):64–73. https://doi.org/10.1017/S0003598X00079308
Tilley C (1994) A phenomenology of landscape. Places, paths and monuments, Berg, Oxford
Tilley C (1996) The powers of rocks. Topography and monument construction on Bodmir Moor. World Archaeol 28(2):161–178. https://doi.org/10.1080/00438243.1996.9980338
Trevarthen D (2000) Illuminating the monuments: observation and speculation on the structure and function of the cairns at Balnuaran of Clava. Camb Archaeol J 10(2):295–315. https://doi.org/10.1017/S0959774300000111
Valenzuela A, Donaire T, González-Roldán M, Toscano M, Pascual E (2011) Volcanic architecture in the Odiel river area and the volcanic environment in the Riotinto-Nerva Unit, Iberian Pyrite Belt, Spain. J Volcanol Geotherm Res 202:29–46. https://doi.org/10.1016/j.jvolgeores.2010.12.018
Winchester JA, Floyd PA (1977) Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chem Geol 20:325–343. https://doi.org/10.1016/0009-2541(77)90057-2