ORIGINAL PAPER

Beyond images: the external archaeological context of Palaeolithic rock art (EAC). A case study from the Nalón river basin (northern Iberia)

Miguel Ángel Fano[1] · Alejandro García-Moreno[2] · Fabiola Portillo[3] · Diego Garate[2] · Eduardo Palacio-Pérez[4] · Mª Soledad Corchón-Rodríguez[5]

Abstract

In this study of the location and physical characteristics of the surroundings of a series of decorated caves in the Nalón river basin in Asturias (northern Iberia), the spatial analysis, which included fieldwork and the use of GIS, has defined the *external archaeological context* (EAC) of pre-Magdalenian art in that area. The spatial information has been integrated with the study of the rock art in order to observe tendencies that are statistically quantifiable by means of multidimensional scaling (MDS), hierarchical cluster analysis (HCA) and property fitting. The study of the potential association between the location of the caves and the rock art constitutes a new approach within Palaeolithic cave art research. First, the sample of decorated caves was analysed to discriminate different situations as regards the total number of representations, relative importance of figurative and non-figurative motifs, and the type of figurative representations. Second, the relationship between the EAC and graphic activity was tested. The location of the decorated caves does not fit a homogeneously distributed pattern owing to marked contrasts in the spatial variables. The greater or lesser ease of access to the location of the cave art sites does not condition the type of graphic expression. Instead, visibility is clearly associated with the total number of representations, and particularly with the number of non-figurative representations. However, this particular association between high visibility and non-figurative motifs should be nuanced because the issues of the conservation and interpretation of the exterior engravings mostly affect the identification of the figurative representations.

Keywords Rock art · Iberia · Visibility · Accessibility · GIS · Statistics

✉ Miguel Ángel Fano
miguel-angel.fano@unirioja.es

1 Departamento de Ciencias Humanas, Universidad de La Rioja, Edificio Vives. C/ Luis de Ulloa, 2, 26004 Logroño, Spain

2 International Institute for Prehistoric Research of Cantabria (IIIPC), University of Cantabria, Edificio Interfacultativo. Avda. de Los Castros, 52, 39005 Santander, Spain

3 Departamento de Economía y Empresa, Universidad de La Rioja, Edificio Quintiliano, C/ La Cigüeña, 60, 26006 Logroño, Spain

4 Gobierno de Cantabria, Cuevas Prehistóricas, Monte Castillo, 39670 Puente Viesgo, Spain

5 Departamento de Prehistoria, Historia Antigua y Arqueología, Universidad de Salamanca, C/ Cerrada de Serranos, s/n, 37008 Salamanca, Spain

Introduction

The location and physical characteristics of the settings of archaeological sites are aspects that are rarely considered in studies of Upper Palaeolithic hunter-gatherer societies. The first reflections on these factors took place in the times of the pioneers of Prehistory (see, the references made by M. Sanz de Sautuola, E. Cartailhac and H. Breuil to the inhabitability of caves in García-Moreno, 2016). However, these initial considerations did not crystallise into specific studies in the framework of historical-cultural archaeology. Population patterns were later an important topic of study within New Archaeology. Special attention was paid to economic territories and the functionality of sites, which were assessed through the archaeological evidence, and the 'inhabitability' and location of settlements. Even so, the information employed since the 1960s was not the product

of a systematic analysis of the factors that define the location and setting of sites occupied in the Palaeolithic (e.g. Straus, 1987).

Today, the situation is fortunately very different, for theoretical and technical reasons. The places containing the archaeological deposits are now explicitly regarded as part of the archaeological record. Those places were chosen as part of a decision-making process and it seems appropriate to assess that choice (as a dwelling, a place to process prey, a waste tip, a 'shrine' etc.) as a potential source of information to propose solid hypotheses about the nature of Palaeolithic occupations (Fano, 2001; García-Moreno et al., 2013; García-Moreno & Fano, 2014). At the same time, the application of a specific study methodology including the use of Geographical Information Systems (GIS) facilitates the definition of a series of indicators that objectively and quantitatively describe the location of a site and the territory in which it is situated (García-Moreno, 2013a).

Recent applications of this methodology have shown that the integration of spatial information with data from the archaeological record *sensu stricto* (intensity of occupations, activities carried out, subsistence strategies etc.) allow more precise interpretations of the nature of the sites and therefore of their role in their social context (Fano et al., 2016; Fano & García-Moreno, 2017a). Nonetheless, it may be possible to go beyond a mere materialistic perspective and consider that the choice of a given site may be influenced by more subtle factors, such as the significance or symbolism of particular elements in the landscape or 'landmarks' (Tilley, 1994; Langley, 2013; García-Moreno, 2013b), or of certain practices (Grøn, 2018). In this regard, the location and setting of caves and rock-shelters with rock art are a particularly interesting source of information, owing to the likely symbolic interaction between Palaeolithic groups and their landscapes (cf. Fuentes et al., 2019).

Until the mid-twentieth century, the study of Palaeolithic art by such authors as E. Cartailhac, H. Breuil, H. Obermaier, H. Alcalde del Río, and J. Cabré focused on the analysis of the figures themselves, especially as regards their chronology and meaning (Palacio-Pérez, 2010, 2013, 2017; Moro Abadía, 2015). From the late 1950s, attention began to be paid to the spatial variable and the possible compositional relationship between the different representations. Authors who have been attributed the controversial label of structuralists (cf. Moro Abadía & Palacio-Pérez, 2015), such as A. Leroi-Gourhan (1958a, b, 1965) and A. Laming-Emperaire (1962), studied the iconographic and spatial organisation of the decorated caves in search of an ideal model of 'cave-shrine', whose iconography would be the structured reflection of the mythological beliefs of Upper Palaeolithic societies. Later reformulations of this approach still attended exclusively to what can be observed inside the caves (Sauvet &

Wlodarczyk, 1992, 1995; Vialou, 1986). Processual Archaeology did not contribute new insights in this regard, despite the change of focus, which concentrated on the function of the art rather than its ultimate meaning (e.g. Barton et al., 1994; Conkey, 1978). The lack of a systematic study of the location and setting of the caves implicated in the definition of the so-called 'aggregation sites' is an example of this (Conkey, 1980, 1992).

Following the proposals of A. Laming-Emperaire (1962) and F. Rouzaud (1978) and especially the concept of *Internal Archaeological Context* (IAC) defined by J. Clottes (1993), recent research has aimed to determine the remains and traces of anthropic origin that, apart from the graphic activity itself, are preserved inside the caves (e.g. Clottes, 2001; Arias, 2009; Arias & Ontañón, 2012; Ferrier et al., 2014; Medina-Alcaide et al., 2018; Pastoors et al., 2016). In addition, methodologies have been developed for the precise observation of aspects that are essential within the interpretation of parietal representations, such as the visibility of the motifs, the artificial illumination needed to create and later view them, accessibility to the decorated walls, and the number of people able to visualise them at the same time (Beaune, 2000; Bourdier et al., 2017; Intxaurbe et al., 2020; Jouteau et al., 2019; Maximiano et al., 2015; Medina-Alcaide, 2020; Ochoa, 2017; Ochoa & García-Diez, 2018; Pastoors & Weniger, 2011; Villeneuve, 2008, among other contributions). These studies, which sometimes include experimentation and quantification of the observations, have succeeded in assessing particularly interesting points, like the relationship between the lighting systems and the visibility of the panels, the characteristics of the artists themselves and the time invested and the technology required in their movements through the cave systems (Intxaurbe et al., 2021; Medina-Alcaide et al., 2021).

Some of these studies of the IAC have explicitly indicated the need to consider also the exterior of the caves in research on graphic activity, since factors such as the type of access or the visual prominence of the entrances may have conditioned the choice of caves to be decorated (Ochoa, 2017). However, after more than a century of studies on Palaeolithic art, the *External Archaeological Context* (EAC) has not been investigated systematically, and the few contributions have concentrated on particular cases and aspects (Bourdier et al., 2017; García-Moreno et al., 2013; Genuite et al., 2021; Fano & García-Moreno, 2017b; Ortega-Martínez & Ruiz-Redondo, 2018; Rasilla & Duarte, 2018; Forgia & Sineo, 2021).

The present study aims to overcome this limitation by stressing the EAC. The questions to be asked of the archaeological record are varied and of undoubted interest. Did the symbolic expression of Palaeolithic groups requires particular places, with a homogeneous distribution in the

landscape? Were they accessible places or was it relatively difficult to reach them? Did they choose visible entrances in the landscape or inconspicuous and even hidden sites? Did the art add a symbolic dimension to the territory, generating a *social landscape*? When caves were used exclusively for graphic activity, was the artistic phenomenon an isolated fact, with a distribution pattern different to that of inhabited sites? Does the distribution of caves in the landscape provide any keys for the interpretation of such evidence as the variability of parietal ensembles: larger, medium and small? Is there any relationship between the location of the caves and the decoration preserved inside them?

The last question is a reminder that the results of spatial analyses become meaningful when they are integrated with information obtained through conventional studies of the archaeological record (e.g. Fano et al., 2016). Once the spatial distribution pattern of sites preserving parietal representations has been determined, the data should be integrated with the results from the study of the art in order to observe tendencies that are statistically quantifiable. This requires the use of a series of statistical tools that will be described in the corresponding section.

The described approach has been applied to a group of decorated caves in northern Iberia, one of the most important concentrations of Palaeolithic parietal art at an international level (González-Echegaray & González-Sainz, 1994; Garate, 2014; Bahn, 2016). These caves are in the Nalón river basin, in Asturias (Fig. 1), a region that has proved to be of great importance in Upper Palaeolithic research in the north of the Iberian Peninsula thanks to

the work started in the 1980s by F. J. Fortea. That project involved the excavation of several caves with long archaeological stratigraphic sequences, as well as the discovery and study of a large number of decorated caves (Fortea, 1981) situated along the Nalón river basin and some of its tributaries (Trubia, Nora and Riosa).

The present study will thus begin to answer some of the questions posed above. To be exact, two objectives are sought:

(i) To specify the distribution pattern of the decorated caves in the territory, which has been defined as the EAC.

(ii) To determine any possible association between the location of the decorated sites and the characteristics of the graphic activity they conserve. This will involve the use of a new approach within Palaeolithic rock art studies.

Consequently, the present paper will describe the area of study, the Nalón river basin, in its geographic framework, including the main geomorphological and geological characteristics of the area with the decorated caves. Secondly, the Palaeolithic graphic activity being studied will be defined, considering its chronology and technical and stylistic traits. The methodology will then be explained, both the methods employed to define the location and physical characteristics of the settings of the caves and those used to assess the possible association between the location of the caves and the art. The paper concludes by presenting and discussing the results obtained in the research.
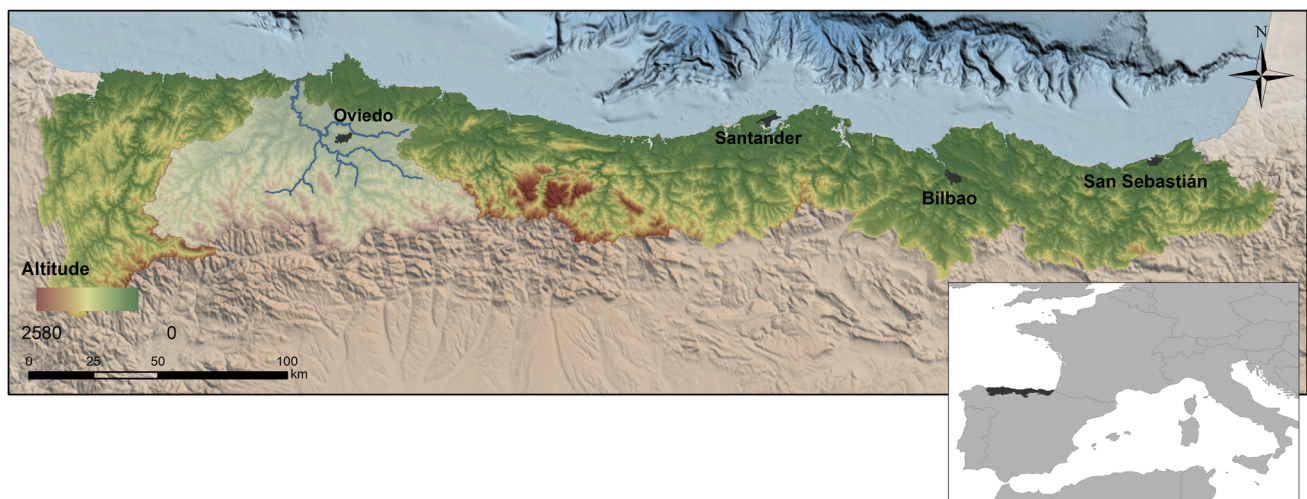

Fig. 1 Map of northern Iberia with the location of the Nalón river basin. Only the water courses implicated in the present study are shown (A. García-Moreno. Base DEM: ©IGN-CNIG)

Materials

Study area

The Nalón river basin is located in Cantabrian Spain (Fig. 1). This region is defined by the Cantabrian Mountains, a coastal range over 400 km long, from the Galician Mountains to the Pyrenees in North Iberia, and includes the administrative regions of Asturias and Cantabria, and the Atlantic part of the Basque Country (Biscay and Gipuzkoa). The east–west orientation of the Cantabrian Mountains, whose altitude (including many peaks above 2000 m.a.s.l.) and continuity stops the movement of oceanic air masses, results in a very humid temperate climate and Atlantic vegetation cover. However, the region is clearly diverse, as a consequence of several climatic and geomorphologic factors (García-Codron, 2004). The latter are related to the characteristics of the relief, as determined by the different geological structures in the region (Alonso et al., 2007). Two sectors can be differentiated: the 'Asturian Massif' and the Eastern Sector, including most of Cantabria and the Basque Country. In contrast with the first, the relief in the second is more modest with discontinuous altitudes and gentler slopes.

The environmental units that are differentiated in Cantabrian Spain are the coastal strip, the high mountains and the inland valleys. These valleys form the true heart of the Cantabrian range, because of their size and their human and scenic significance. The river network originated in a period before the Pleistocene and is associated with the Alpine orogeny (Bertrand, 1971). Unlike most rivers in Asturias and in northern Iberia in general, which flow from south to north, the Nalón occupies a south-east to north-west valley 145 km long; its high erosive capacity has shaped the landscape and created a system of well-identified river terraces (Jordá Pardo et al., 2014).

The + 5 m terrace (T6) is of particular interest since it is directly related to the Upper Palaeolithic occupations. This has been demonstrated in the case of La Lluera I, located next to the course of the Nalón (Rodríguez-Asensio et al., 2012). The occupation levels corresponding to the Solutrean period cover the remains of the + 5 m terrace, which had been dismantled by erosion. Several flooding episodes took place during the human occupation of the cave, and traces of fluvial action are evident in the archaeological stratigraphy (floodwater silt, dismantled anthropic levels etc.). Consequently, the general form of the modern landscape is not significantly different from its appearance in the Upper Palaeolithic, at least as regards key aspects of the present study, such as the form of the river network and the relief. Other factors, such as changes to the vegetation, are more difficult to determine with the available information because of the difficulty in modelling the distribution of vegetation in the past. This circumstance has been taken into account in the proposed methodology, as explained below.

Although limestone outcrops are found throughout northern Iberia (Hoyos & Herrero, 1989; Farias & Marquínez, 1995; Marquínez & Adrados, 2000), some areas contain particularly dense concentrations of caves, for example, the mountain limestone in the Picos de Europa and the Urgonian limestone in the east of Cantabria. In the Nalón basin, the presence of Devonian and Carboniferous carbonate lithologies has favoured the formation of caves and rock-shelters, in which archaeological deposits and/or parietal representations have been preserved (García-Moreno et al., 2019).

The human occupation of the valley dates back to the Lower Palaeolithic, of which deposits and remains have been found on the river terraces. Evidence of Neanderthal activity and rich cultural manifestations of Upper Palaeolithic hunter-gatherer societies are preserved in the caves. The use of the territory appears to have become increasingly important from the Solutrean onwards. Indeed, the parietal art is an indicator of the important occupations before the Magdalenian, as described below. However, the best documented habitation deposits correspond to the Magdalenian and particularly its recent phase (Corchón et al., 2014a; Álvarez-Alonso & Rodríguez-Asensio, 2014; Rodríguez-Asensio, 2000). As a result, the pre-Magdalenian record offers fewer options for the study of the relationship between decorated caves and inhabited sites, as mentioned above.

Archaeological context

The archaeological basis of the study consists of rock art representations in 16 caves in the Nalón basin: La Peña de Candamo, Las Mestas, Godulfo, La Lluera I and II, Las Caldas, La Viña, Los Murciélagos, Entrefoces, Molín, Santo Adriano, El Conde and the Torneiros group: Camarín de las Ciervas de Los Torneiros, Cueva Grande, Los Torneiros and Cueva Pequeña (Corchón, 2017; Corchón et al., 2017; González-Pumariega et al., 2017a, b, 2018; Fortea, 1981, 1989, 1990, 1992, 1994a, 1999, 2005; Fortea et al., 1999; Fortea & Rodríguez-Otero, 2007; Rodríguez-Asensio, 1992; Rodríguez-Asensio & Barrera-Logares, 2012; González-Sainz et al., 2013; González-Morales, 1990; Fernández-Rey et al., 2005; Arsuaga et al., 2012) (Fig. 2 and Online Resource). The absence of detailed studies has meant that other decorated caves, like Entrecueves and Cueva Fogareda, have not been included. Similarly, a further two caves with engravings were made known in 2021, when the present study had been completed (Juaneda-Gavelas et al., 2018).

With the exception of La Peña de Candamo, the parietal ensembles studied here are 'exterior shrines' with deep engravings, according to the classic definition

Fig. 2 Middle basin of the River Nalón. The locations of the cave art sites included in the present study are shown (A. García-Moreno. Base DEM: ©IGN-CNIG)
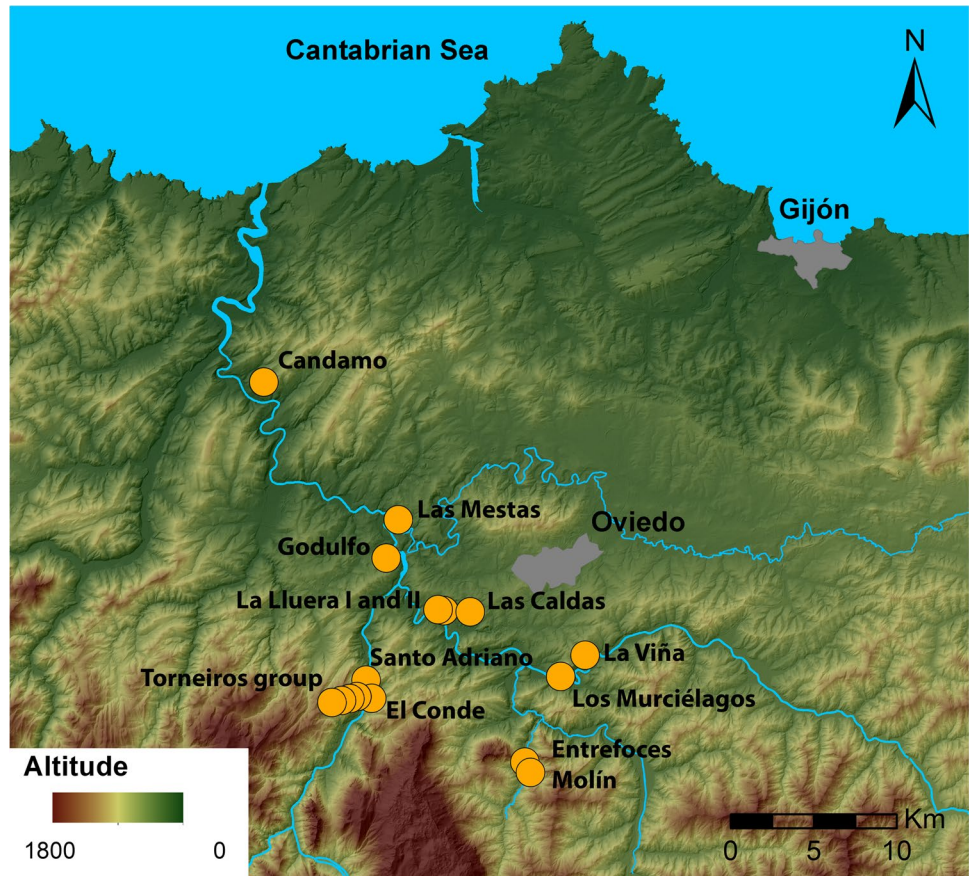

Fig. 3 'Exterior shrine' in La Viña Rock-shelter (Photograph by Marco de la Rasilla)

(Fortea 1994b, 2000–01, 2005; Fortea & Rodríguez-Otero, 2007). They are caves where the engravings are on walls that are directly reached by sunlight or are well illuminated in a zone of semi-shade (Fig. 3). In such cases as La Viña, the location of the engravings in the open-air has caused conservation and interpretation problems, because of alterations to the rock surface. Exterior engravings are characteristic of the Nalón basin and are less common in central and eastern sectors of Cantabrian Spain. Some clear parallels are known in the caves of Chufín,

Hornos de la Peña and Venta Laperra, among few other sites (Fortea, 1994b).

This sample of caves is very heterogeneous regarding the number of representations. It includes 'large sites' with dozens of figures and a complex arrangement of panels, as at La Lluera I, together with caves with a single figure, like Godulfo. Observations of different kinds (stratigraphic, heights of the manual field etc.), especially at La Viña, led F.J. Fortea to define two successive graphic horizons: one non-figurative (H1) with series of deep and generally vertical parallel incisions, and one in which non-figurative motifs persist but which also includes zoomorphs, mainly hinds (H2). Signs are important in some caves (La Lluera II). In the first horizon, the manifestations can be described as graphic motifs, found at La Viña (Fig. 4), El Conde and perhaps Las Caldas. The second horizon is more common in the Nalón basin, with La Lluera I and Santo Adriano the most important sites, and is more closely related to what we usually regard as art.

The chronology of 'exterior shrines' has been debated in recent decades, in relation to the general greater difficulties in dating pre-Magdalenian art (cf. Petrognani & Robert, 2019). Initially, H1 and H2 were attributed respectively to the Aurignacian (even to its ancient phase) and the Gravettian-Solutrean (Fortea, 1994b). The review of

Fig. 4 Central sector of La Viña Rock-shelter. Non-figurative engravings corresponding to Horizon 1, covered by stratigraphy. The lowest line reaches the top of Level VIb, which is the last Gravettian level in the sequence (photograph by Javier Fortea)

Fig. 5 East wall at San Adriano. Representation of a bison corresponding to Horizon 2 (photograph by Javier Fortea)

the parietal ensemble at La Viña, including new topographic surveys, has nuanced the chronology of H1, for which a later date in the recent Aurignacian is now postulated (González-Pumariega et al., 2017a, 2017b; Rasilla et al., 2018). The chronology of H2 has been discussed since the 1990s, when it was proposed that the start of this horizon might be set back to the Aurignacian (González Sainz, 1999, 2000; Garate, 2008; Aguirre & González-Sainz, 2011; González Sainz et al., 2013). However, the recent study at La Viña advocates in favour of an essentially Solutrean chronology for H2, in accordance with Fortea's proposal, although a Gravettian date cannot be ruled out for some representations. Observations based on the stratigraphy at La Lluera I, in connection with flooding episodes and the formation of river terraces in the Nalón valley, also support a Solutrean age for H2, at least at that site (Rodríguez-Asensio et al., 2012). In the present study, we attribute all the parietal ensembles to an archaic or pre-Magdalenian period, owing to the impossibility of greater precision.

The images were normally created with simple lines, without any details. In some cases, greater technical complexity involved lowering the edges of the engraved grooves to achieve a greater sense of volume, as documented at La Lluera I and II. In H2, the depictions may have been associated with red paint, at least at La Viña, possibly to emphasise the engraved lines (Fortea & Rodríguez-Otero, 2007). Zoomorphs in the Nalón H2 (hinds, horses, bovids etc.) aimed

to express the most representative parts of the animals rather than their naturalistic reality (Figs. 5 and 6).

Unlike these 'exterior shrines', the Cave of La Peña de Candamo displays graphic activity in the dark part of the cave. It is the shrine with artistic aggregation in the Nalón

Fig. 6 'Gran Hornacina' in La Lluera I. Representation of a hind drawn with three lines, corresponding to Horizon 2 (photograph by Javier Fortea)

river basin. Half a dozen decorative phases cover practically the whole of the Upper Palaeolithic (Corchón et al., 2017). The wall of the engravings, in the main chamber of the cave, exhibits a full complex parietal stratigraphy that allows the order of the different decorative phases to be reconstructed. This sequence, together with radiocarbon dates and stylistic considerations, is able to differentiate the pre-Magdalenian representations.

The base of the sequence thus consists of animal figures (mostly aurochs and deer) in red and yellow, attributed to the Aurignacian and Gravettian by stylistic comparisons and the parietal stratigraphy. The animals are limited to their silhouettes, with few anatomical details and no use of perspective in the depiction of the limbs. Several T-shaped signs in both colours are assigned to the same periods. The following phase is represented by rows and lines of black dots which have been dated by C14-AMS to the late Gravettian (Corchón et al., 2014b).

Methods

Spatial analysis

As indicated above, studying the location of archaeological sites and their surrounding territories requires a specific methodology that is able to determine the characteristics of the location of each site, in both a qualitative and a quantitative way. The full potential of the theoretical approach proposed in this paper can only be realised with such a systematic methodology (García-Moreno & Fano, 2014).

The methodology proposed some years ago by one of the present authors (García-Moreno 2010a, 2013a) has been followed, but including some novelties, like those connected with the analysis of accessibility. This methodology is based on the combination of two different datasets: *parameters*, which are obtained by direct observation during fieldwork; and *variables*, which must be calculated using GIS. It is a tried and tested methodology that has been used in recent years by several researchers for the spatial analysis of sites dated in prehistory and antiquity, as well as to develop predictive models (Drinkall, 2014; Danese et al., 2014; Cutler, 2015; Lysandrou & Agapiou, 2016; Ortega-Martínez & Ruiz-Redondo, 2018; Neruda, 2018, Mas et al., 2018, among others).

The fieldwork consisted of documenting the location and setting of the rock art sites in order to complete the information corresponding to each of the parameters included in the present research (Table 1). It did not include the study or revision of the cave art. The data in this regard used in the present research have been taken from the reference literature cited in the 'Archaeological context' section (see

Online Resource). The parameters considered in this paper have been:

(1) *Classification*: distinguishing between caves and rock shelters
(2) *Aspect*: refers to the cardinal orientation of the site
(3) *Absolute altitude*: altitude above modern sea level, expressed in metres
(4) *Relative altitude*: altitude of the site above the valley floor or the lowest point in the surrounding, expressed in metres
(5) *Topography*: it indicates whether a site is located in a valley bottom, mid-slope or on a ridge
(6) *Location*: it refers to the geographic position of a site within a river basin. It differentiates between the main valley (the valley where the main watercourse of the drainage basin flows) and secondary valleys (of tributary rivers flowing into the main watercourse)
(7) *Landscape*: defines the landform of the territory where a site is located, differentiating between open, hilly, steep and gorge
(8) *Hydrology*: it classifies the location of a site based on the topography in the immediate area around the site. It differentiates between riverine valley, river bank, confluence and gorge

To calculate the variables, the software ESRI ArcGIS 10 was used. The cartography was provided by the Spanish National Geographic Institute's Digital Elevation Models, scale 1:25.000. The coordinates indicating the location of each site were taken in the field using a GPS and later adjusted using the Digital Elevation Models and aerial photos provided by the Spanish National Geographic Institute. The modelled variables were regarded as the most relevant for the present study type and objectives:

(1) *Viewshed* measures the surface area visible from the site. The calculation of this variable also provides data about the visual prominence of a site and its importance within the surrounding landscape (García-Moreno, 2013b). Due to the uncertainty in some elements involved in visibility, such as changes to the vegetation, and modelling in general (e.g. Grøn, 2018), this measurement indicates more the general pattern of visibility from a site than the exact spots actually viewed from that site (Frieman & Gillings, 2007). The observation point was set at the cave entrance or in the mid-point of rock shelters. The height of the observer was 0, to avoid overrepresentation due to differences between modern and Palaeolithic ground level. Viewshed was calculated up to a maximum distance of 10 km, considered the distance at which an observer can distinguish what

Table 1 Data corresponding to the studied parameters and variables

Site name	Absolute Alt	Relative Alt	Aspect	Classification	Location	Topography	Landscape	Hydrology	Slope > 30%	% Viewshed	CMWI	Isochrone 1 h%	River
Candamo	188	158	NW	Cave	Main	Mid slope	Hilly	Riverine valley	39.83	2.07	2.74	6.97	Nalón
El Conde	170	15	NW	Rock shelter	Secondary	Valley floor	Hilly	Riverine valley	68.45	0.59	3	6.17	Trubia
Entrefoces	240	3	E	Rock shelter	Secondary	Valley floor	Gorge	Gorge	59.08	0.11	3.34	2.65	Riosa
El Molín	240	3	"	"	"	"	"	"	59.08	0.11	3.34	2.65	Riosa
Godulfo	130	60	E	Cave	Main	Mid slope	Hilly	Riverine valley	44.5	1.12	2.51	9.97	Nalón
La Lluera I	105	3	SW	Cave	Main	Valley floor	Open	River bank	39.90	0.81	2.62	9.13	Nalón
La Lluera II	105	3	"	"	"	"	"	"	39.90	0.81	2.62	9.13	Nalón
La Viña	265	130	SE	Rock shelter	Main	Mid slope	Hilly	Confluence	42.67	3.19	2.61	9.18	Nalón
Las Caldas	153	3	W	Cave	Secondary	Valley floor	Hilly	Riverine valley	38.71	1.44	2.52	11.44	Reguero El Pontón (Nalón)
Las Mestas	90	5	SW	Cave	Main	Valley floor	Hilly	River bank	39.58	0.05	2.45	10.65	Nora
Murciélagos	225	90	SE	Cave	Main	Mid slope	Steep	Riverine valley	56.3	0.69	2.61	9.26	Nalón
Santo Adriano	160	5	S	Rock shelter	Secondary	Valley floor	Gorge	Gorge	65.51	0.06	2.98	6.12	Trubia
Torneiros group													
Torneiros	400	240	S	Cave	Secondary	Mid slope	Steep	Riverine valley	69.3	1.64	3.28	3.43	Reguero de Sabadíe (Trubia)
Cueva Grande	400	240	"	"	"	"	"	"	69.3	1.64	3.28	3.43	Reguero de Sabadíe (Trubia)
Cueva Pequeña	400	240	"	"	"	"	"	"	69.3	1.64	3.28	3.43	Reguero de Sabadíe (Trubia)
Camarín de las Ciervas	400	240	"	"	"	"	"	"	69.3	1.64	3.28	3.43	Reguero de Sabadíe (Trubia)

he or she is looking at (Gillings and Wheatley 2001). The resulting viewshed was divided into three distance ranges: close range (0–2 km), middle range (2–5 km) and long range (5–10 km).

(2) *Slope*: it indicates the gradient of the area where a site is located, where gradient refers to the tangent of a given surface to the horizontal. Slope was calculated as a percentage of inclination for each cell in the digital elevation model (DEM) in a radius of 10 km around each site. Then, each cell was classified into four categories: flat terrain (0–5%), hilly terrain (5–15%), abrupt terrain (15–30%) and steep terrain (> 30%). Finally, the proportion of each category within the 10 km radius was calculated (Garcia-Moreno 2013a).

(3) *Accessibility*: it estimates the areas that are more easily accessible from a site. Rather than demarcating the catchment territory of a site (sensu Higgs et al., 1968), it can approach the areas of preferential movement and human interaction, without excluding further mobility or visits to remote areas (Morgan, 2008). Our main goal is to identify possible differences between the cave art sites regarding accessibility to their immediate surroundings, rather than making an actual calculation of any cost (calories, for example) of traversing a given territory. Therefore, our model in this paper does not aim to accurately represent hunter-gatherers' movement (as in agent-based approaches, for example) but to quantitatively identify those areas in a site's surroundings that could potentially be reached from the site more easily (or directly) than other areas.

This variable results from the combination of two measurements: the accumulated cost of movement and isochrones maps. The accumulated cost of movement measures the 'effort' of crossing a given terrain, depending on the slope

and the distance (Howey, 2007; Herzog, 2020). Effort here is considered an abstract value, rather than a real expense of time and/or energy, to avoid direct anthropological misinterpretations derived from other social factors involved in movement (Whallon, 2006; Grove, 2009; García-Moreno, 2010b; Supernant, 2017). The cost of movement was derived from the tangent of slope, to represent the non-lineal increase of movement upslope (Bell & Lock, 2000). The direction of movement was not considered here, since it was considered that return-to-site trips would balance the movements up and down slope.

In turn, isochrone maps represent the distance covered in ranges of 1-h trips from a starting site. It is based on the slope of the terrain and the distance. A limit of a 2-h range was selected since this is the distance commonly considered to be covered by foragers in their daily raids (Morgan, 2008). For calculating the isochrones, we followed the formula proposed by A. Uriarte (2005).

Isochrones maps were also used to quantify the *cost of movement weighted index* (*CMWI*), an index used to measure the accessibility to the terrain from each site and, therefore, to compare the sites included in the sample. To calculate the *CMWI*, series of isochrones, corresponding to 1 h-walking displacements, were calculated up to a 10 km radius from each site, dividing the territory around each site in ranges. Then, the number of cells in the DEM within each range was calculated and multiplied by the number of hours required to reach that range (Fig. 7), according to the formula:

$$CMWI = \frac{(cells\ in\ 1h\ range\ *\ 1) + (cells\ in\ 2h\ range\ *\ 2) + (cells\ in\ 3h\ range\ *\ 3) \dots}{Total\ number\ of\ cells}$$

The higher the index, the more difficult the access, and vice versa. Additionally, to compare the more immediate setting of each cave, and not only the terrain inside a 10 km radius from each site, the number of cells in the DEM

Fig. 7 Example of calculation of isochrones and cost of movement weighted index (CMWI) for Las Caldas Cave and the Torneiros group. The values indicate the multiplier applied for each isochrone to calculate the CMWI: (×1) 1-h isochrone; (×2) 2-h isochrone; (×3) 3-h isochrone; (×4) 4-h isochrone; (×5) 5-h isochrone
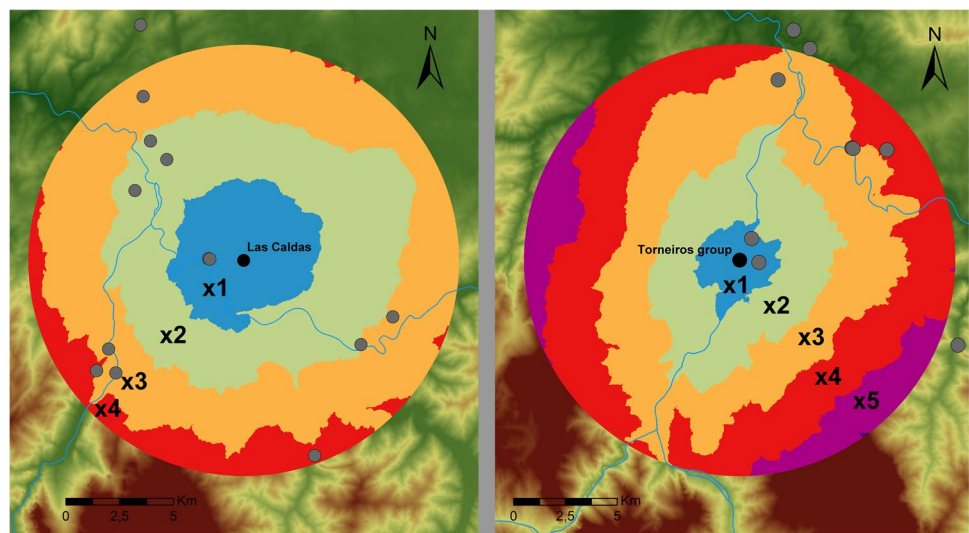
inside the 1-h isochrone was calculated, i.e. the surface area that can be reached within that time from each of the sites included in the study.

Statistical analysis

The use of multivariate statistical analysis in the study of archaeological data goes back a long way (e.g. Kendall, 1969, 1971). These statistical tools have also often been used in studies on Palaeolithic cave art (e.g. Buisson et al., 1996; Pigeaud, 2005; Rivero & Sauvet, 2014). Because of our objective of determining whether any association exists between the location of the caves and their parietal art, in the first place, the sample has been analysed to discriminate different situations in the total number of representations, the importance of figurative and non-figurative motifs, and the type of figurative depictions (zoomorphs or anthropomorphs).

Multidimensional scaling (MDS) techniques locate objects (decorated caves in our case) on a map using as data a measure of similarity between the objects (Coxon, 1982). Many multivariate statistical methods can be viewed from the same perspective; for example, principal components analysis and factor analysis locate objects on a map using correlations as a measure of similarity.

In this study, a distance-based approach has been used. Our data is a two-dimensional matrix of caves (rows) and types of representations (columns). In the statistical sense, caves have been treated as cases, and types of representations as variables. Caves can be described as similar if they contain the same kinds of representations in similar amounts, and they can be described as different if they contain representations of different figures. To analyse our data, we have, therefore, derived a measure of similarity between any two caves on the basis of the number and types of representations that they contain. Since we have data on 16 caves, this produces a symmetric matrix of 16 rows and 16 columns, each cell in the matrix being the measure of similarity calculated between the 'column cave' and the 'row cave'.

Many measures of similarity can be calculated from the raw data. However, there were large differences in the variability of the representations. For example, the number of horse depictions varied between 0 and 6, while the number of images of hinds varied between 0 and 39. For this reason, and to avoid the analysis being dominated by the objects with a large representation, the variables were standardised to zero mean and unit variance, as is a usual statistical practice.

The measure of similarity between any two caves was the Euclidean distance between standardised variables. This is a measure of distance. If two caves contain about the same number of pictures of the same kind, the distance between them will be small, and if the two caves are very different in the kind of representations and the numbers of them, the distance between the caves will be large.

An appropriate technique for the analysis of distance-based data is multidimensional scaling (MDS). Given a map, one can assess the distance between any two points on it. In fact, a table of distances between points in the map can be generated. MDS works in the opposite direction: given a table of distances between pairs of points, MDS aims to produce a map where the points are located. The map does not need to be two-dimensional; it might have more dimensions. The number of dimensions in which the map is produced is also derived from the distance data. In this particular case, ordinal MDS has been used. This technique relies on the ordering of the similarity data to perform the calculations and has the advantage of avoiding the problem of extreme values in the data. This problem is evident in our dataset (see Online Resource). Two extreme values would be La Peña de Candamo and Godulfo, which contain 145 and 1 representations, respectively.

Stress is a standard measure of goodness of fit in MDS. There are various measures of stress although they all tend to move in the same direction. We have used Stress1. This measure can be used to assess the number of dimensions in which the map is to be drawn, since its value decreases as the number of dimensions increase. Stress1 takes the value zero when the quality of the map is perfect and moves towards unity as the quality of the representation deteriorates. Goodness of fit can be improved by adding extra dimensions to the model, but there is a moment when the addition of extra dimensions has a minimum impact on the stress value, and this indicates that the extra dimension is not needed. Using this procedure, we concluded that a map in four dimensions gives an optimal approximation to the data. The value of Stress1 for a map in a four-dimensional space was 0.013, an excellent fit under J. B. Kruskal's (1964) verbal classification. To assess the proximity of any two points in the four-dimensional space, we have resorted to hierarchical cluster analysis (HCA). To do this, we have performed the calculations using Ward's clustering method.

After analysing the sample from the thematic point of view, the association between the EAC, particularly the variables included in the spatial analysis, and pre-Magdalenian graphic activity was explored. To interpret the statistical maps obtained by MDS, property fitting (Pro-Fit) was applied, a regression-based technique that belongs to the Biplot category. Pro-Fit represents a characteristic of the data in the form of a vector. The value of the property increases in the direction of the vector. This would be the equivalent to North–South and East–West directions in geographical maps. The drawing of the vectors requires a linear regression in which the property of interest acts as dependent variable, and the coordinates of the position of the cave in the space act as regressors. For a clear explanation of

the technique, see Schiffman et al. (1981), and for a mathematical justification of the procedure, see Mar-Molinero & Mingers (2007).

In this study, the properties used are the variables *accessibility* and *visibility* (previously defined), and the variables *figurative* (number of figurative representations), *non-figurative* (number of non-figurative representations), *total* (number of representations) and *zoomorphic* (number of zoomorphic images). Because of the numerical importance of zoomorphs among the figurative representations (see Online Resource), we thought it would be interesting to assess specifically the association between the spatial variables and the depictions of animals. The variables *accessibility* and *visibility* contain data that had not been used for the drawing of the maps. For this reason, the analysis is known as external. Drawing the remaining variables requires the use of data that has been utilised to derive the maps and is known as an internal analysis. As one would expect, the value of the goodness of fit statistic is much higher in the case of internal analysis than in the case of external analysis.

Results

Spatial analysis

Only eleven locations have been considered, since some caves were sometimes very close to one another, only a few metres apart (Entrefoces and El Molín; La Lluera I and La Lluera II; Torneiros group). The degree of precision permitted by the methodology and the type of observations to be made supported grouping these caves and for that reason their results are identical in Table 1. An individualised study of those caves, in terms of their location and their setting, would not have added details to the results.

The distribution of the decorated caves in the river basin is varied. They are at altitudes of 90 to 400 m above sea level, both in rugged areas of steep slopes and in places with more gentle relief (Table 1). In addition, three locations are in the valley of the River Trubia (El Conde, Santo Adriano and Torneiros group), a tributary of the Nalón, while the rest of sites are located within the main Nalón river valley, with the exception of Entrefoces and El Molín, on a small tributary of the River Nalón, the Riosa.

The artists chose caves and rock-shelters with favourable orientations. This is the case of the 'large sites', like Santo Adriano, La Viña and La Lluera I, which respectively face south, south-east and south-west. Only two sites are oriented towards the north: El Conde, with some motifs corresponding to the H1, and La Peña del Candamo, which is not an 'exterior shrine'.

The position of the decorated caves can be differentiated into two general patterns: sites in the valley bottoms

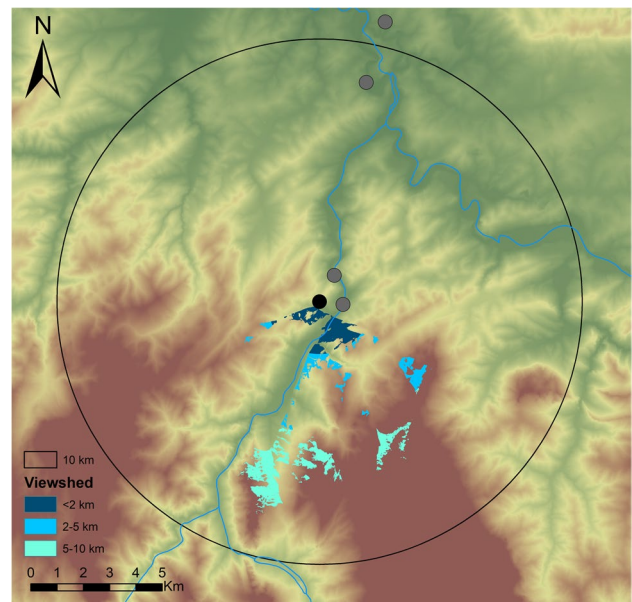**Fig. 8** View from the entrance of Camarín de las Ciervas (Torneiros group)

Fig. 9 Calculation of the viewshed of the Torneiros group, assessing three ranges (< 2 km, 2–5 km, 5–10 km)

with a relative altitude of a few metres, and places in high positions in the landscape. Among the latter, sites like La Peña de Candamo, La Viña and the Torneiros group are high above the valleys and their viewsheds are large (Figs. 8 and 9). The relative altitude of the caves is sometimes considerable, as much as 240 m in locations with very steep slopes, in the case of the Torneiros group. In contrast, at sites next to water-courses, like Entrefoces, Las Mestas and Santo Adriano, the relative altitude is minimal and the viewsheds are very restricted (Figs. 10 and 11).

Nonetheless, visibility does not depend solely on the relative altitude. Sites like La Lluera I and II, on the banks of
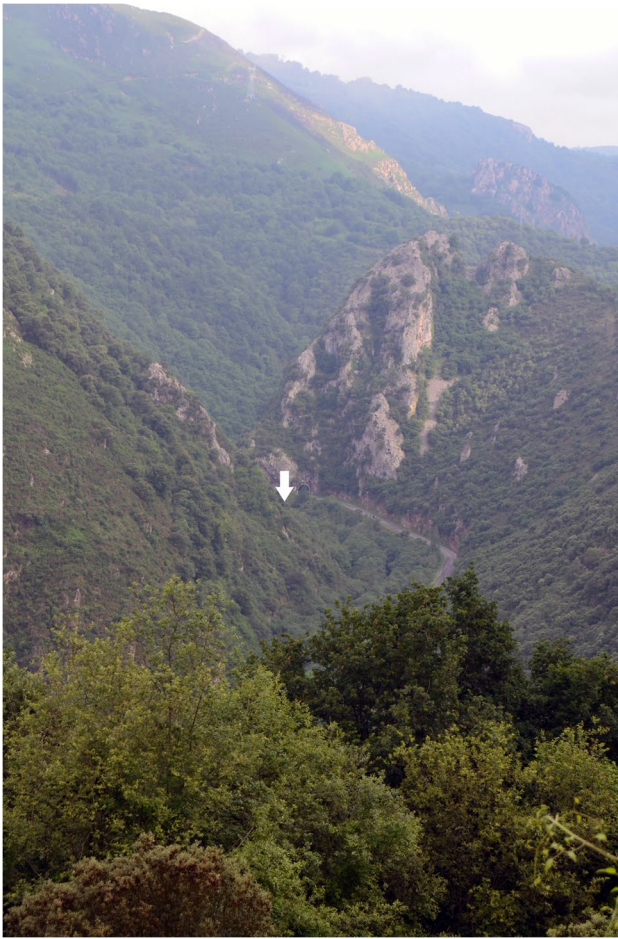
Fig. 10 View of the valley where Santo Adriano is located. The cave is below the road seen in the photograph, a short distance from the course of the River Trubia

Fig. 11 Calculation of the viewshed of Santo Adriano

the River Nalón, enjoy similar viewsheds to sites in high locations, like Godulfo and Murciélagos. In the case of Las Caldas, also located in a valley bottom, it is even larger (Fig. 12). Consequently, visibility depends on a combination of relative altitude and the type of territory where the sites are located. The caves of La Lluera I and II and Las Caldas are situated in open valleys, which translates into high viewsheds, despite their lower relative altitudes.

Moreover, the viewshed and the location itself are good indicators of the visual prominence of a decorated cave in its setting, i.e. its visibility in the landscape. This may be a good indicator for understanding the role a site may have played in settlement patterns and social organisation, since prominent localities may have acted as landmarks in the landscape (García-Moreno, 2013b). Therefore, La Viña and the Torneiros group are good examples of sites with a noticeable visual presence. The same might be said of La Peña de Candamo, which is on the middle slopes

of a conical hill that would have been a landmark in the Palaeolithic landscape (Fano & García-Moreno, 2017b).

In contrast, some caves lack this prominence and are practically concealed in the valley bottom. Santo Adriano and Las Mestas are clear examples of this situation as they are barely visible from their immediate surroundings (Fig. 10). Other sites enjoy greater visibility (Las Caldas and La Lluera I and II) but their low altitude means that their visual prominence is limited. Finally, the characteristics of certain locations should be taken into account. These are the ravines in which Entrefoces and El Molín are situated, near the course of the River Riosa, and Santo Adriano, a few metres from the River Trubia. These caves lack visual prominence but are located in strategic places on the route towards the main river in the basin.

Regarding the accessibility of the territory in which the decorated caves are located when considering the cost of movement weighted index (CMWI), differences between sites emerge (Table 1). Caves in areas of more difficult access have high indices, and vice versa. However, since the CMWI is based on an area comprised within a 10 km radius from each site, the characteristics of the nearest territory around a site are underestimated. For the comparative analysis of the immediate surroundings of the caves, the number of cells in the DEM inside the 1-h isochrones has been calculated, i.e. the surface area that can be reached in that time from each of the caves in the study. In this case, the higher values indicate a larger percentage of the territory inside the 1-h isochrone, and therefore, the

Fig. 12 Relationship between relative altitude and the viewshed of the cave art sites
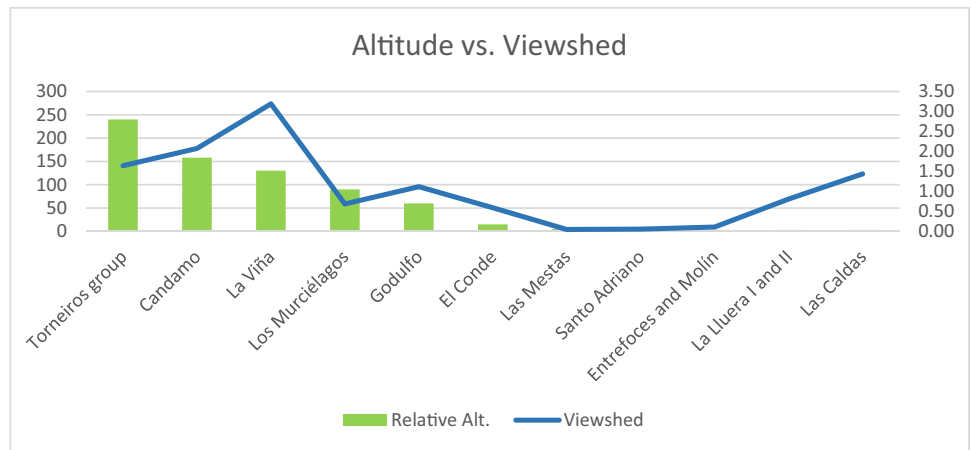
higher the index, the more the territory that is accessible in a 1-h walk from the cave (Table 1 and Fig. 7).

The results reveal significant differences between the caves regarding accessibility to their immediate surroundings. Las Caldas and Las Mestas, both located on open valleys, show the highest values. At the other extreme are the sites located in the steepest landscapes (Entrefoces, Molín and the Torneiros group), where mobility is more difficult and the territory that can be covered in 1 h is considerably smaller (Fig. 7). The sites of Santo Adriano and El Conde show discreet values despite being located in a relatively

open valley, especially in the case of El Conde. This could be interpreted as a result of their location in the secondary valley of the River Trubia, separated from the main basin by a narrow gorge, reinforcing the idea that the Trubia valley constitutes somehow a self-enclosed area.

Statistical analysis

The projection of the four-dimensional map into the first and the second dimensions can be seen in Fig. 13. These two dimensions explain most of the variability of the data and

Fig. 13 Projection of the ordinal MDS map into the first dimension (horizontal axis) and the second dimension (vertical axis) with cluster information and property fitting vectors
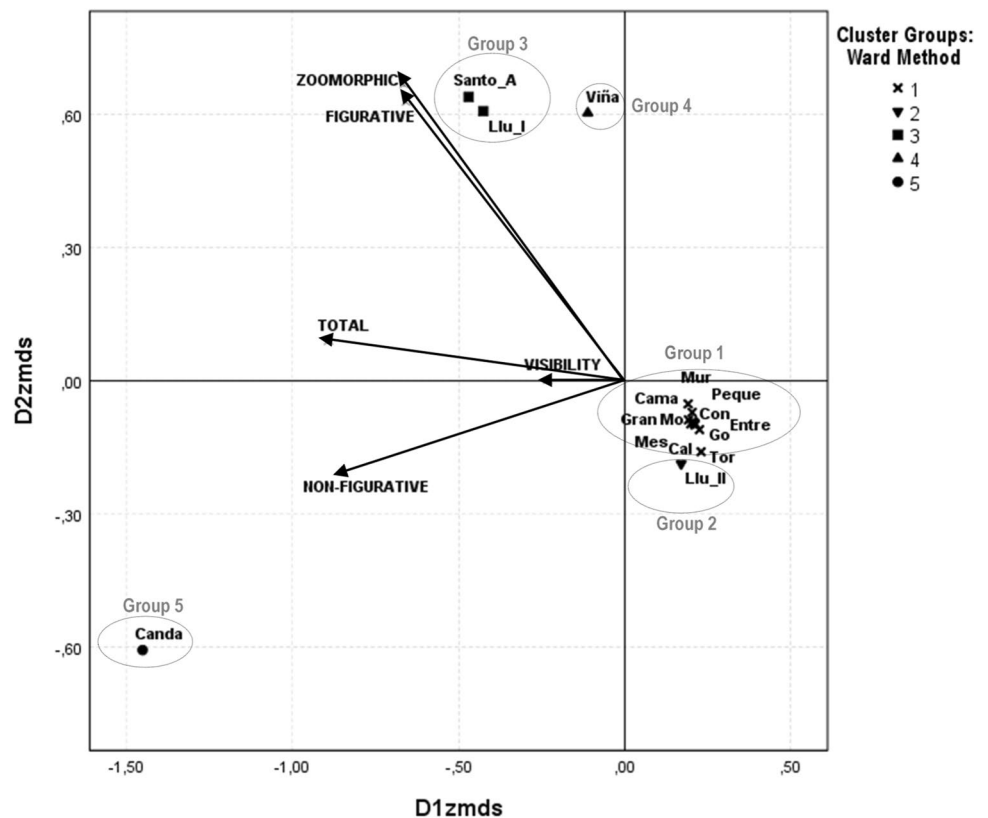
discriminate the sites according to the total number of representations (Dimension 1) and their characteristics in terms of figurative and non-figurative representations (Dimension 2). Caves with a large number of representations are located towards the left-hand side of Fig. 13, while caves that contain a small number of representations are located towards the right-hand side of this figure. Caves containing a large number of figurative representations are located towards the top of Fig. 13, while caves with a small number of figurative representations are located towards the bottom of this image. It should be recalled that their position on the map was estimated by methods that take into account the order of the data and not the magnitude, to avoid the impact of outliers.

Sites appear to group neatly into three groups, but we must remember that we are dealing with projections, and that two points may appear close to each other in the projection while being distant in the space. This is why we have resorted to HCA. We have used as variables the coordinates of the caves in the four-dimensional space. As indicated before, Ward's clustering method has been used, since it maximises homogeneity within groups and heterogeneity between groups. The dendrogram can be seen in Fig. 14.

The number of clusters identified from the dendrogram is a matter of judgement. The three-cluster solution that initially we identified from Fig. 13 is supported by the examination of the dendrogram in Fig. 14. However, the dendrogram also suggests that there are differences between La Viña and the subgroup formed by La Lluera I and Santo

Adriano. This is clear if the projections are represented on a map that contains Dimension 4 (see Fig. 15). This dimension is associated with *visibility* — see below about its explanatory power. At the top of this figure, we see La Viña, the one with the highest visibility, and at the bottom of this image, we find the sites La Lluera I and Santo Adriano, both associated with less visibility. Finally, the projections of the map that contain Dimension 3 (not given here) reveal that La Lluera II is a special site, as indicated in the 'Archaeological context' section. We have, therefore, chosen to identify five groups of sites. Information on cave membership has been added to Figs. 13 and 15.

In summary, to describe a cave, we need to concentrate on the total number of representations (Dimension 1), on whether these representations are dominated by the figurative or by the non-figurative type (Dimension 2), on whether the cave contains human (vulva) representations or not (Dimension 3), and on the level of visibility of the cave (Dimension 4).

Regarding the potential association between the decoration and the spatial variables, Table 2 shows the values of the standardised regression coefficients, or directional cosines, used to draw the Pro-Fit vectors in Figs. 13 and 15. Additionally, Table 2 includes the value of the Adjusted-R^2 statistic to assess the goodness of fit and the *F*-statistic that measures overall adequacy of the regression.

It can be seen in Table 2 that the values of the Adjusted-R^2 are very high in the case of *total*, *non-figurative*, *figurative*

Fig. 14 Dendrogram for hierarchical cluster analysis using Ward's method
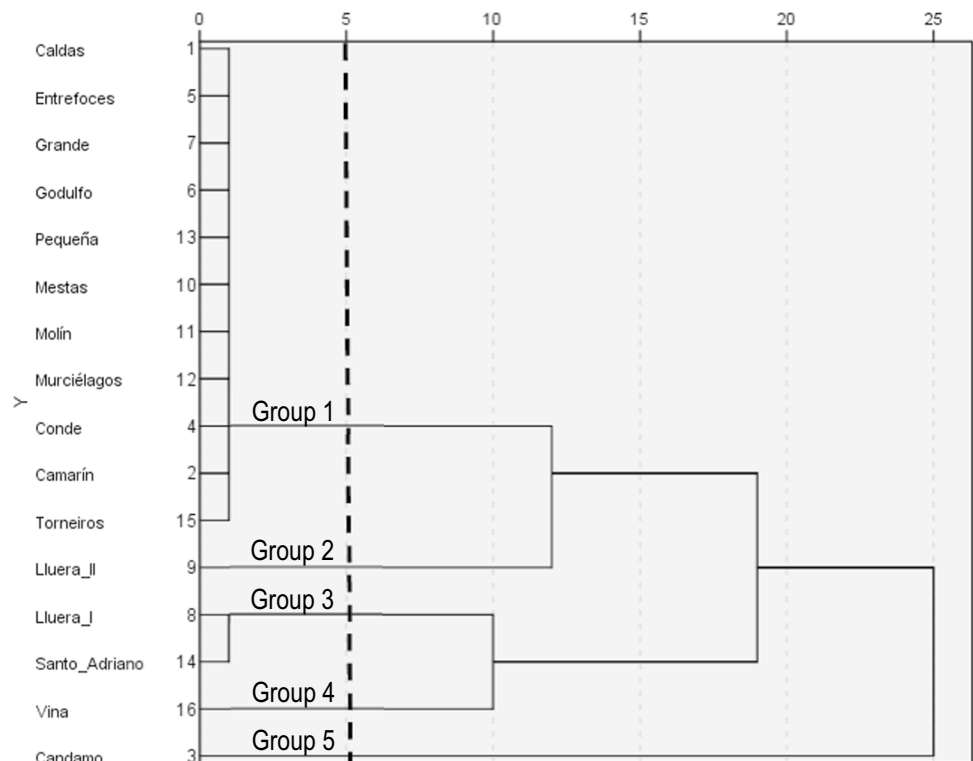
Fig. 15 Projection of the ordinal MDS map into the second dimension (horizontal axis) and the fourth dimension (vertical axis) with cluster information and property fitting vectors
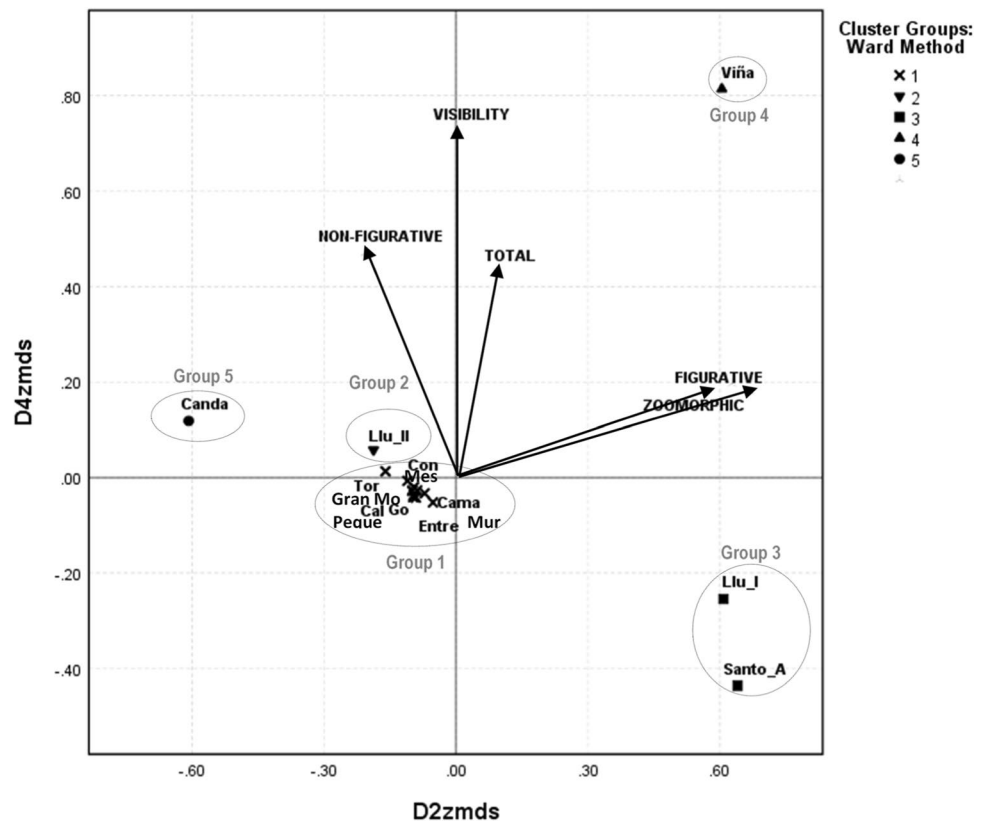

Table 2 Directional cosines and quality of fit for property fitting (Pro-Fit)

Variable	Directional cosines Pro-Fit				Adjusted-R^2	F-statistic[a] (p-value)
	Dimension 1	Dimension 2	Dimension 3	Dimension 4		
Visibility	−0.232	0.000	0.111	0.726	0.444	3.998* (0.031)
Accessibility	−0.118	0.175	−0.236	0.159	−0.193	0.394 (0.809)
Zoomorphic	−0.665	0.667	0.001	0.179	0.891	31.668** (<0.01)
Figurative	−0.658	0.627	−0.231	0.196	0.888	30.632** (<0.01)
Non-figurative	−0.849	−0.206	0.062	0.469	0.983	215.245** (<0.01)
Total representations	−0.892	0.088	−0.043	0.428	0.984	227.104** (<0.01)

[a]Model global significance F-test

*Significant

**Highly significant

and *zoomorphic*, indicating that these variables have strong explanatory power in the interpretation of the maps in Figs. 13 and 15. *Visibility* has a medium explanatory power in the configuration of the caves in the maps. The value of its Adjusted-R^2 coefficient is not high, 0.444, but it is significantly different from zero, as shown by the F-statistic for this variable. In fact, except for *accessibility*, the F-statistic is always significantly different from zero, indicating that the Pro-Fit vectors obtained give a good description of the relationship between variables and caves. *Accessibility*, on the other hand, is unrelated to the results of the ordinal MDS configuration, with a negative value of the Adjusted-R^2 statistics. Given this result, no Pro-Fit vector associated with *accessibility* has been drawn in Figs. 13 and 15.

The length of the Pro-Fit vector reflects the explanatory power of the variable in the interpretation of the configuration. We see in Fig. 13 that the magnitude of vectors associated with the variables *total*, *non-figurative*, *figurative* and *zoomorphic* are long, indicating that these variables are well represented in Dimension 1 and Dimension 2, while the Pro-Fit vector associated with *visibility* is shorter, in line with the lower explanatory power of this variable in both dimensions. Analogously, we see in Fig. 15 that the magnitude of vector associated with *visibility* is long, indicating that this variable is well represented in Dimension 4.

The angle formed by any two pairs of Pro-Fit vectors reflects the correlation that exists between the variables that they model. For instance, in Figs. 13 and 15, we can see a very small angle between the vectors *figurative* and *zoomorphic*, indicating the logical association between these two variables. The vectors associated with the *total* number of representations and with *visibility* are also at a very acute angle, indicating a good correlation between them.

Similarly, it may also be possible to discriminate between figurative and non-figurative ensembles in their association with visibility. In Fig. 15, the combination of *visibility* and type of representation — *figurative* vs *non-figurative* — is shown in an explicit way, indicating a closer association between *visibility* and *non-figurative* representations than the association that exists between *visibility* and *figurative*. In Fig. 15, we see that the angle between *visibility* and *non-figurative* representations is clearly more acute than the angle between *visibility* and *figurative* representations.

Discussion and main conclusions

The analysis of the location and physical characteristics of the setting of a series of decorated caves has succeeded in defining the EAC of pre-Magdalenian art in the Nalón basin. After the distribution pattern of the sites with parietal representations was determined, by fieldwork and GIS, the spatial information was integrated with data from the study of the art in order to observe statistically quantifiable trends.

The technique of multidimensional scaling (MDS) was employed in order to visualise our findings. In addition, the MDS analysis was supplemented with other multivariate statistical analysis tools, such as hierarchical cluster analysis (HCA) and property fitting. Initially, the sample of decorated caves was analysed to differentiate situations regarding the total number of representations, relative abundance of figurative and non-figurative representations, and the type of figurative representations. Then, the potential relationship between the EAC and the graphic activity was explored. We have addressed several questions: (i) is there a relationship between the visibility of the cave and the number of representations? (ii) is there a relationship between the visibility of the cave and the figurative or non-figurative nature of representations? and (iii) is there a relationship between the accessibility of the cave and the number and type of representations?

The EAC shows that pre-Magdalenian graphic expression in the Nalón basin and in particular the artistic phenomenon of 'exterior shrines' with deep engravings did not require a special type of location although sites with favourable orientations appear to have been chosen. In accordance with previous non-systematic observations (e.g. Fortea, 2005), the position of the decorated caves does not correspond to a homogeneous distribution pattern; there are parietal art sites near water-courses but also on steep slopes high above the valley bottom. The location of the new engravings published in 2021 does not modify this observation (Juaneda-Gavelas et al., 2018).

This heterogeneity results in significant differences in the accessibility of the sites. The rugged nature of some settings, as in the case of the Torneiros group, determines much more difficult access than that of sites in more open areas of the river basin. However, the statistical study of the data has shown that no correlation exists between accessibility and the number or type of representations in the caves. In this way, the easier or more difficult access to the locations of the caves with art did not condition the type of graphic expression in them. Except for La Peña de Candamo, the panels are in open places, with few difficulties in their access, in contrast with the cave art sites that entailed more demanding explorations through the cave systems in terms of both technology and time (e.g. Intxaurbe et al., 2021).

The visibility analysis also reveals a diverse panorama with great contrasts. Inconspicuous places, practically concealed in the valley bottom, were sometimes chosen, as were more visible sites in high locations. In this case, we have found that visibility is clearly associated with the total number of representations, and particularly with the number of non-figurative representations in caves. That is to say, greater visibility is associated with sites with more graphic representations, especially non-figurative motifs. However, this particular association between high visibility and non-figurative depictions should be nuanced. Issues of the conservation and interpretation of exterior engravings, mentioned above, particularly affect the identification of figurative representations. Therefore, differential conservation may be emphasising non-figurative decoration in connection with visibility.

Caves with low visual prominence are sometimes located in strategic points on the routes towards the main river in the basin. The decoration in sites like Santo Adriano, which is only a narrow fissure produced by erosion,

may be connected with this circumstance, as those sites were located in places that must have been frequently visited. In this way, the greater 'socialisation' of some locations may have favoured their decoration, regardless of their visual prominence. As Professor Fortea (2005) remarked, the whole middle course of the Nalón valley was imbued symbolically, without any preferential areas for the transmission of the narrative inherent in graphic activity. This is probably a 'symbolic territory' (cf. Honoré et al., 2019), not limited to the Nalón valley although it was in that river basin that different places in the landscape convincingly show a reality (traditions, beliefs, meanings, wishes…) shared by the hunter-gatherer societies living in northern Iberian in pre-Magdalenian times.

The results obtained in the present study have shown the interest of the approach to continue advancing in the comprehension of Palaeolithic rock art and, particularly, to answer questions like those posed by the present study. Just as in the case of the IAC, the detailed understanding of the EAC can provide some clues to help understand this cultural phenomenon. The proposed approach has already provided interesting data in its application to habitation sites (Fano et al., 2016), as it succeeded in relating the characteristics of their location with social information derived from the multi-disciplinary study of the archaeological record. It has now proved to be a powerful tool for the analysis of parietal art from a different perspective.

This investigation has suggested new working hypotheses of special interest in connection with the accessibility and visibility of pre-Magdalenian cave art sites and these can be tested in other areas of study. Indeed, the wealth of prehistoric art in northern Iberian and other parts of Europe offers diverse options for the development of this avenue of research. It should be stressed that a significantly larger sample of decorated sites would increase the variability of the data and add greater robustness to the results. Some important points, like those described in the 'Introduction' section, still remain to be explored: decorated versus inhabited caves, or variability in the size of the parietal ensembles. They can be addressed with a large and diverse artistic record associated with a denser population that is known in the Nalón basin during the archaic period before the Magdalenian.

Declarations

References

Aguirre M, González-Sainz C (2011) Placa con grabado figurativo del Graventiense de Antoliñako Koba (Gautegiz-Arteaga, Bizkaia). Implicaciones en la caracterización de las primeras etapas de la actividad gráfica en la región cantábrica. Kobie 30:43–62

Alonso JL, Pulgar JA, Pedreira D (2007) El relieve de la Cordillera Cantábrica. Enseñanzas de las Ciencias de la Tierra 2007(152):151–163

Álvarez-Alonso D, Rodríguez-Asensio JA (2014) Las primeras ocupaciones humanas en el occidente cantábrico: el Paleolítico inferior y medio en Asturias. In Álvarez-Alonso, D. (Ed.), Los grupos

cazadores-recolectores paleolíticos del occidente cantábrico. Estudios en homenaje a Francisco Jordá Cerdá en el centenario de su nacimiento. 1914–2014, pp. 103–132. UNED, Gijón

Arias P (2009) Rites in the dark? An evaluation of the current evidence for ritual areas at Magdalenian cave sites. World Archaeol 41(2):262–294. https://doi.org/10.1080/00438240902843964

Arias P, Ontañón R (2012) La Garma (Spain): long-term human activity in a Karst System. In: Bergsvik KA, Skeates R (eds), Caves in Context. The Cultural Significance of Caves and Rockshelters in Europe. Oxbow Books, Oxford, pp 101–117. https://doi.org/10.2307/j.ctvh1djk4

Arsuaga JL, Adán GE, Arbizu MA, Fernández M, Criado A, Girón M (2012) Grafismo rupestre paleolítico del Valle de Tuñon (Santo Adriano, Asturias): Cueva Pequeña y Camarín de las Ciervas de los Torneiros. In: Arias P, Corchón MS, Menéndez M, Rodríguez-Asensio JA (eds), El Paleolítico Superior Cantábrico. Actas de la Primera Mesa Redonda. San Román de Candamo (Asturias), 26-28 de abril de 2007. IIIPC, Santander, pp 217–224

Bahn PG (2016) Images of the Ice Age. Oxford University Press, Oxford

Barton C, Clark G, Cohen A (1994) Art as information: explaining Upper Palaeolithic art in western Europe. World Archaeol 26(2):185–207. https://doi.org/10.1080/00438243.1994.9980272

Bell T, Lock G (2000) Topographic and cultural influences on walking the ridgeway in later prehistoric times. In: Lock G (ed), Beyond the Map: Archaeology and Spatial Technologies. IOS Press, Amsterdam, pp 85–100

Bertrand G (1971) Morphoestructures cantabriques: Picos de Europa, Montaña de León y Palencia (Espagne du nordouest). Revue Geographique des Pyrénées et du Sudouest 42(1):49–70

Bourdier C, Fuentes O, Pinçon G, Baleux F (2017) Methodological contribution to the integrated study of European Palaeolithic rock art: the issue of the audience and the perceptibility of Roc-aux-Sorciers rock art (Angles-sur-l'Anglin, France). Quat Int 430:114–129. https://doi.org/10.1016/j.quaint.2016.12.009

Buisson D, Fritz C, Kandel D, Pinçon G, Sauvet G, Tosello G (1996) Les contours découpés de têtes de chevaux et leur contribution à la connaissance du Magdalénien moyen. Antiquités Nationales 28:99–128

Clottes J (1993) Contexte archéologique interne. L'art pariétal Paléolithique. Techniques et méthodes d'étude. CTHS, Paris, pp 49–58

Clottes J (Dir.) (2001) La Grotte Chauvet. L'art des origines. Seuil, Paris

Conkey MW (1978) Style and information in cultural evolution: toward a predictive model for the Paleolithic. In: Redman CL (ed), Social Archaeology: Beyond Subsistence and Dating. Academic Press, pp 61–86

Conkey M (1980) The identification of Prehistoric hunter-gatherer aggregation sites: the case of Altamira. Curr Anthropol 21(5):609–630

Conkey M (1992) Les sites d'agrégation et la répartition de l´art mobilier, ou: y a-t-il des sites d´agrégation magdaléniens? In: Rigaud J-P, Laville H, Vandermeersch B (eds), Le peuplement Magdalénien. Paléogéographie physique et humaine. Éditions du CTHS, París, pp 19–25

Corchón MªS (2017) La cueva de Las Caldas (Priorio, Oviedo). Ocupaciones solutrenses, análisis espaciales y arte parietal. Universidad de Salamanca, Salamanca

Corchón MªS, Fano MA, Garate D, García-Moreno A, Rivero O, Ortega P (2014) La ocupación del valle del Nalón durante el periodo 13,2–11,5 ky BP: el contexto magdaleniense de la Peña de Candamo (Asturias). In: Corchón MªS, Menéndez M (eds), Cien años de arte rupestre paleolítico. Centenario del descubrimiento de la Cueva de la Peña de Candamo (1914–2014), pp 221–244. Universidad de Salamanca, Salamanca

Corchón MªS, Garate D, Valladas H, Rivero O, Pons-Branchu E, Ortega P, Hernando C (2014b) Back to the point: new datings for La Peña de Candamo Cave Art (Asturias). Zephyrus, LXXIII, 67–81. https://doi.org/10.14201/zephyrus2014b736781

Corchón MªS, Garate D, Rivero O (eds) (2017) La Caverna de la Peña de Candamo (Asturias) 100 años después de su descubrimiento. Universidad de Salamanca, Salamanca

Coxon APM (1982) The user's guide to multidimensional scaling: with special reference to the MDS (X) library of computer programs. Heinemann Educational Books, London

Cutler HJ (2015) Understanding late middle Palaeolithic Neandertal landscape-use during short-term occupations in Britain. Doctoral dissertation. University of Cambridge https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.708600

Danese M, Masini N, Biscione M, Lasaponara R (2014) Predictive modeling for preventive archaeology: overview and case study. Open Geosciences 6(1):42–55. https://doi.org/10.2478/s13533-012-0160-5

de Beaune SA (2000) Les techniques d'éclairage paléolithiques: un bilan. Paléo 12:19–27

de la Rasilla M, Duarte E (2018) Casualidad o estrategia? Las aguas termales y minero-medicinales en la configuración de los yacimientos con arte rupestre paleolítico de Asturias y su correlato cantábrico. Nailos: Estudios Interdisciplinares de Arqueología 5:17–41

de la Rasilla M, Duarte E, Cañaveras JC, Santos G, Carrión Y, Tormo C, Sánchez-Moral S, Marín-Arroyo AB, Jones JR, Agudo L, Gutiérrez-Zugasti I, Suárez P, López-Tacón C, Badal E, González-Pumariega M (2018) El Abrigo de La Viña (La Manzaneda, Oviedo) 2013–2016. Excavaciones Arqueológicas en Asturias 2013–2016(8):107–120

Drinkall H (2014) Expanding our horizons: an exploration of hominin landscape use in the Lower Palaeolithic of Britain and the question of upland home bases or lowland living sites. Doctoral dissertation. Durham University http://etheses.dur.ac.uk/10660/

Fano MA (2001) Habitability of the prehistoric settlements: proposal for the study of one of the elements involved and first results for the Cantabrian Mesolithic (Northern of Spain). Journal of Iberian Archaeology 3:25–34

Fano MA, García-Moreno A, Chauvin A, Clemente-Conte I, Costamagno S, Elorrieta-Baigorri I, Pascual NE, Tarriño A (2016) Contribution of landscape analysis to the characterisation of Palaeolithic sites. A case study from El Horno Cave (northern Spain). Quat Int 412(Part A):82–98. https://doi.org/10.1016/j.quaint.2015.10.105

Fano MA, García-Moreno A (2017) La Cueva de Las Caldas (Priorio, Oviedo) en su paisaje. In: MªS Corchón (ed), La cueva de Las Caldas (Priorio, Oviedo), Ocupaciones solutrenses, análisis espaciales y arte parietal. Universidad de Salamanca, Salamanca, pp 369–378

Fano MA, García-Moreno A (2017b) La cueva de La Peña de Candamo (Asturias) en su territorio. In: Corchón MªS et al. (eds), La Caverna de la Peña de Candamo (Asturias). 100 años después de su descubrimiento, pp. 59-67. Universidad de Salamanca, Salamanca

Farias P, Marquínez J (1995) El relieve. In: Aramburu C, Bastida F (eds), Geología de Asturias. Trea, Gijón, pp 163–172

Fernández-Rey A, Adán GE, Arbizu M, Arsuaga JL (2005) Grafismo rupestre paleolítico de la cueva del Conde (Tuñón, Santo Adriano, Asturias). Zephyrus 58:67–88

Ferrier C, Debard E, Kervazo B, Brodard A, Guibert P, Baffier D, Feruglio F, Gély B, Geneste JM, Maksud F (2014) Les parois chauffées de la grotte Chauvet-Pont d'Arc (Ardèche, France): caractérisation et chronologie. Paléo 25:59–78

Forgia V, Sineo L (2021) Within the symbolic world of the prehistoric hunters: A GIS-based and 3D model analysis of sites with complexes of linear incisions in western Sicily. Digital Applications

in Archaeology and Cultural Heritage 20(1). https://doi.org/10.1016/j.daach.2021.e00175

Fortea FJ (1981) Investigaciones en la cuenca media del Nalón, Asturias (España). Noticia y primeros resultados. Zephyrus 32–33:5–16

Fortea FJ (1989) Cuevas de La Lluera. Avance al estudio de sus artes parietales. In: González-Morales MR (ed), Cien años después de Sautuola. Estudios en homenaje a Marcelino Sanz de Sautuola en el Centenario de su muerte. Diputación Regional de Cantabria, Santander, pp 187–202

Fortea FJ (1990) Abrigo de la Viña. Informe de las campañas 1980–86. Excavaciones arqueológicas en Asturias 1983–86(1):55–68

Fortea FJ (1992) Abrigo de la Viña. Informe de las campañas 1987–90. Excavaciones arqueológicas en Asturias 1987–90(2):19–28

Fortea FJ (1994a) Abrigo de la Viña. Informe y primera valoración de las campañas 1991 a 1994. Excavaciones arqueológicas en Asturias 1991–94(3):19–32

Fortea FJ (1994b) Los "santuarios" exteriores en el Paleolítico cantábrico. Complutum 5:203–220

Fortea FJ (1999) Abrigo de la Viña. Informe y primera valoración de las campañas 1995 a 1998. Excavaciones arqueológicas en Asturias 1995–98(4):31–41

Fortea FJ (2000–01) Los comienzos del arte paleolítico en Asturias: aportaciones desde una arqueología contextual no postestilística. Zephyrus 53–54:77–216

Fortea FJ (2005) Los grabados exteriores de Santo Adriano (Tuñón, Santo Adriano, Asturias). Munibe 57(3):23–52

Fortea FJ, Rodríguez-Asensio JA, Ríos González S (1999) La grotte de Los Torneiros (Castañedo del Monte, Tuñón, Asturies, Espagne). INORA 24:8–11

Fortea FJ, Rodríguez-Otero V (2007) Los grabados exteriores de la cuenca media del Nalón. In: La Prehistoria en Asturias. Prensa Asturiana/La Nueva España, Oviedo, pp 167–194

Frieman C, Gillings M (2007) Seeing is perceiving? World Archaeol 39(1):4–16. https://doi.org/10.1080/00438240601133816

Fuentes O, Lucas C, Robert E (2019) An approach to Palaeolithic networks: the question of symbolic territories and their interpretation through Magdalenian art. Quat Int 503(Part B):233–247. https://doi.org/10.1016/j.quaint.2017.12.017

Garate D (2008) Las pinturas zoomorfas punteadas del Paleolítico superior cantábrico: hacia una cronología dilatada de una tradición gráfica homogénea. Trabajos de Prehistoria 65(2):29–47. https://doi.org/10.3989/tp.2008.08002

Garate D (2014) Altamira and Paleolithic cave art of Northern Spain. In: Smith C (ed), Encyclopedia of Global Archaeology 1. Springer, pp 158–163

García-Codron JC (2004) El marco del poblamiento paleolítico: unidad y diversidad de los espacios cantábricos. In Fano MA (ed), Las sociedades del Paleolítico en la Región Cantábrica, pp 11–28. Diputación Foral de Bizkaia (Kobie. Anejos 8), Bilbao

García-Moreno A (2010a) Patrones de asentamiento y ocupación del territorio en el Cantábrico oriental a finales del Pleistoceno. Una aproximación mediante SIG. Doctoral dissertation, Universidad de Cantabria, http://hdl.handle.net/10803/10612

Garcia-Moreno A (2010b) Haciendo humanos a los humanos. Una reflexión crítica sobre la aplicación de las teorías del forrajeo óptimo a las sociedades de cazadores-recolectores. RAMPAS (Revista Atlántico-Mediterránea de Prehistoria y Arqueología Social) 12:25–34

García-Moreno A (2013a) GIS-based methodology for Palaeolithic site location preferences analysis. A case study from Late Palaeolithic Cantabria (Northern Iberian Peninsula). J Archaeol Sci 40(1):217–226. https://doi.org/10.1016/j.jas.2012.08.023

García-Moreno A (2013b) To see or to be seen is that the question? An evaluation of palaeolithic sites' visual presence and their role in social organization. J Anthropol Archaeol 32(4):647–658. https://doi.org/10.1016/j.jaa.2013.03.003

García-Moreno A (2016) Antros, santuarios y pioneros: las condiciones de habitabilidad en los comienzos de la investigación del paleolítico cantábrico. *Sautuola*, XXI, 285–293

García-Moreno A, Fano MA, Garate D (2013) Integrating spatial analyses into foraging societies land use strategies. A case study from the Nalón river basin (Asturias, North of Spain). In: Earl G et al. (eds), Archaeology in the Digital Era. Volume II. e-Papers from the 40th Conference on Computer Applications and Quantitative Methods in Archaeology. Southampton, 26-30 March 2012, pp. 670-677. Amsterdam University Press, Amsterdam

García-Moreno A, Fano MA (2014) Palaeolithic sites beyond the archaeological deposits. In: García-Moreno A, García-Sánchez J, Maximiano A, Ríos J (eds), Debating Spatial Archaeology. Proceedings of the International Workshop on Landscape and Spatial Analysis in Archaeology. Santander, June 8th–9th, 2012. IIIPC, Santander, pp 231–241

García-Moreno O, Álvarez-Lao DJ, Arbizu-Senosiain MA, Dopico-Rodríguez EV, García-Vázquez E et al (2019) The little big history of the Nalón River, Asturias, Spain. In: Benjamin C et al (eds), The Routledge Companion to Big History. Routledge, London, pp 300–319

Genuite K, Delannoy J-J, Bahain J-J, Gresse M, Jaillet S, Philippe A, Pons-Branchu E, Revil A, Voinchet P (2021) Dating the landscape evolution around the Chauvet-Pont d'Arc cave. Sci Rep 11:8944. https://doi.org/10.1038/s41598-021-88240-5

Gillings M, Wheatley D (2001) Seeing is not believing: unresolved issues in archaeological visibility analysis. In: Slapšak B (ed), On the good use of geographical information systems in archaeological landscape studies. Proceedings of the COST G2 Working Group 2 round table (18/12/98 - 22/12/98), pp 25-36. Office for Official Publications of the European Communities, Luxembourg

González-Echegaray J, González-Sainz C (1994) Conjuntos rupestres paleolíticos de la cornisa cantábrica. Complutum 5:21–43

González Morales MR (1990) El abrigo de Entrefoces (1980–1983). Excavaciones Arqueológicas en Asturias 1983–86(1):29–36

González-Pumariega M, Polledo M, Mallo M (2018) Los grabados parietales de la cueva de Las Mestas (Tahoces, Las Regueras, Asturias). Nailos: Estudios Interdisciplinares de Arqueología 5:149–170

González-Pumariega M, de la Rasilla M, Santamaría D, Duarte E, Santos G (2017a) Abrigo de La Viña (La Manzaneda, Oviedo, Asturias). Estudio de sus grabados parietales. Trabajos de Prehistoria 74(2):238–256. https://doi.org/10.3989/tp.2017a.12193

González-Pumariega M, de la Rasilla M, Santamaría D, Duarte E, Santos G (2017b) La Viña rock shelter (La Manzaneda, Oviedo, Asturias): Relation between stratigraphy and parietal engravings. Quat Int 432(Part B):77–85. https://doi.org/10.1016/j.quaint.2015.07.011

González-Sainz C (1999) Sobre la organización cronológica de las manifestaciones gráficas del Paleolítico superior. Perplejidades y algunos apuntes desde la región cantábrica. Edades. Revista de Historia 6:123–144

González-Sainz C (2000) Representaciones arcaicas de bisonte en la región cantábrica. Spal 9:257–277

González-Sainz C, Ruiz-Redondo A, González-Morales MR (2013) Manifestaciones parietales paleolíticas de la cueva de El Molín y del abrigo de Entrefoces (La Foz de Morcín, Asturias). In: de la Rasilla M (Coord.), F. Javier Fortea Pérez: Universitatis Ovetensis Magister. Estudios en homenaje, pp 375–399. Universidad de Oviedo & Ménsula Ediciones

Grove M (2009) Hunter–gatherer movement patterns: causes and constraints. J Anthropol Archaeol 28(2):222–233. https://doi.org/10.1016/j.jaa.2009.01.003

Grøn O (2018) Some problems with modelling the positions of pre-historic hunter-gatherers settlements on the basis of landscape topography. J Archaeol Sci Rep 20:192–199. https://doi.org/10.1016/j.jasrep.2018.04.034

Herzog I (2020) Spatial analysis based on cost functions. In: Gillings M, Hacigüzeller P, Lock G (eds), Archaeological spatial analysis: a methodological guide. Routledge, London / New York, pp 333–358

Higgs ES, Vita-Finzi C, Harris DR, Fagg AE (1968) The climate, environment and industries of Stone Age Greece: part III. Proc Prehist Soc 33:1–29. https://doi.org/10.1017/S0079497X00014018

Honoré E, Lucas C, Petrognani S, Robert E (2019) Discussing the relevance and scope of "Symbolic territories" for Prehistory. Quaternary International 503(Part B):189–190. https://doi.org/10.1016/j.quaint.2019.03.004

Hoyos M, Herrero N (1989) El karst de la Cornisa Cantábrica. In Durán JJ, López-Martínez J (eds), El karst en España, pp. 109–120. Sociedad Española de Geomorfología (monografía 4), Madrid

Howey M (2007) Using multi-criteria cost surface analysis to explore past regional landscape: a case study of ritual activity and social interaction in Michigan, AD 1200–1600. J Archaeol Sci 34(11):1830–1846. https://doi.org/10.1016/j.jas.2007.01.002

Intxaurbe I, Rivero O, Medina-Alcaide MA, Arriolabengoa M, Ríos-Garaizar J, Salazar S, Ruiz-López JF, Ortega-Martínez P, Garate D (2020) Hidden images in Atxurra Cave (Northern Spain): a new proposal for visibility analyses of Palaeolithic rock art in subterranean environments. Quat Int 566–567:163–170. https://doi.org/10.1016/j.quaint.2020.04.027

Intxaurbe I, Arriolabengoa M, Medina-Alcaide MA, Rivero O, Ríos-Garaizar J, Salazar S, Líbano I, Garate D (2021) Quantifying accessibility to Palaeolithic rock art: Methodological proposal for the study of human transit in Atxurra Cave (Northern Spain). J Archaeol Sci 125:105271. https://doi.org/10.1016/j.jas.2020.105271

Jordá-Pardo FJ, Álvarez-Alonso D, Iriarte-Chiapusso, MªJ (2014) Una aproximación geoarqueológica al hábitat humano pleistoceno del occidente cantábrico (Asturias, Norte de España). In: Álvarez-Alonso D (ed), Los grupos cazadores-recolectores paleolíticos del occidente cantábrico. Estudios en homenaje a Francisco Jordá Cerdá en el centenario de su nacimiento, 1914–2014, pp 67–102. UNED, Gijón

Jouteau A, Feruglio V, Bourdier C, Camus H, Ferrier C, Santos F, Jaubert J (2019) Choosing rock art locations: geological parameters and social behaviours. The example of Cussac Cave (Dordogne, France). J Archaeol Sci 105:81–96. https://doi.org/10.1016/j.jas.2019.03.008

Juaneda-Gavelas A, Smith P, Ceballos A, Muñoz E, Milkova M (2018) Los grabados figurativos parietales de las cuevas de Sofoxó I y Las Mestas II y la ocupación prehistórica en el valle del Nora (Asturias). *Sautuola*, XXIII, 391–407

Kendall DG (1969) Incidence matrices, interval graphs and seriation in archaeology. Pac J Math 28(3):565–570

Kendall DG (1971) Abundance matrices and seriation in archaeology. Probab Theory Relat Fields 17(2):104–112. https://doi.org/10.1007/BF00538862

Kruskal JB (1964) Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika 29(1):1–27. https://doi.org/10.1007/BF02289565

Laming-Emperaire A (1962) La signification de l'Art rupestre Paléolithique. A. & J. Picard, Paris

Langley MC (2013) Storied landscapes makes us (Modern) Human: landscape socialisation in the Palaeolithic and consequences for the archaeological record. J Anthropol Archaeol 32:614–629. https://doi.org/10.1016/j.jaa.2013.10.001

Leroi-Gourhan A (1958a) La fonction de signes dans l'art pariétal paléolithique. Bulletin de la Société Préhistorique Française 55(5–6):307–321

Leroi-Gourhan A (1958b) Répartition et groupement des animaux dans l'art pariétal paléolithique. Bulletin de la Société Préhistorique Française 55(9):515–528

Leroi-Gourhan A (1965) Préhistoire de l'art occidental. Éditions d'Art Lucien Mazenod, Paris

Lysandrou V, Agapiou A (2016) Cities of the dead: approaching the lost landscape of Hellenistic and Roman necropoleis of Cyprus. Archaeol Anthropol Sci 8(4):867–877. https://doi.org/10.1007/s12520-015-0267-y

Mar-Molinero C, Mingers J (2007) An evaluation of the limitations of, and alternatives to, the Co-Plot methodology. Journal of the Operational Research Society 58(7):874–886. https://doi.org/10.1057/palgrave.jors.2602228

Marquínez J, Adrados L (2000) La geología y el relieve de los Picos de Europa. Naturalia Cantabricae 1:3–19

Mas B, Allué E, Sánchez de la Torre M, Parque O, Tejero JM, Mangado X, Fullola JM (2018) Settlement patterns during the Magdalenian in the south-eastern Pyrenees, Iberian Peninsula. A territorial study base on GIS. J Archaeol Sci Rep 22:237–247. https://doi.org/10.1016/j.jasrep.2018.10.002

Maximiano A, Barcia C, Arias P, Ontañón R (2015) Luces en la oscuridad: soft computing y arte rupestre en el sitio magdaleniense de la Galería Inferior de La Garma (Omoño, Cantabria, España). In: Maximiano A, Cerrillo E (eds), Arqueología y tecnologías de información espacial: una perspectiva ibero-americana. Universidad de Cantabria, Santander, pp 50–74

Medina-Alcaide MA (2020) Lighting the darkness of the caves with Paleolithic Art: an integral and interdisciplinary vision of the internal archaeological context and the wood charcoals. Doctoral dissertation, Universidad del País Vasco

Medina-Alcaide MA, Garate D, Ruiz-Redondo A, Sanchidrán-Torti JL (2018) Beyond art: the internal archaeological context in Paleolithic decorated caves. J Anthropol Archaeol 49:114–128. https://doi.org/10.1016/j.jaa.2017.12.005

Medina-Alcaide MA, Garate D, Intxaurbe I, Sanchidrián JL, Rivero O, Ferrier C, Mesa MD, Pereña J, Líbano I (2021) The conquest of the dark spaces: an experimental approach to lighting systems in Paleolithic caves. PLoS ONE 16(6):e0250497. https://doi.org/10.1371/journal.pone.0250497

Morgan C (2008) Reconstructing prehistoric hunter-gatherer foraging radii: a case study from California's Southern Sierra Nevada. J Archaeol Sci 35(2):247–258. https://doi.org/10.1016/j.jas.2007.02.025

Moro Abadía O (2015) The reception of Palaeolithic art at the turn of the 20th century: between Archaeology and Art History. J Art Historiography, 12, https://arthistoriography.files.wordpress.com/2015/06/moro-abadia.pdf

Moro Abadía O, Palacio-Pérez E (2015) Rethinking the structural analysis of Palaeolithic art: new perspectives on Leroi-Gourhan's structuralism. Camb Archaeol J 25(3):657–672. https://doi.org/10.1017/S0959774315000086

Neruda P (2018) Settlement strategies of Palaeolithic and Mesolithic societies in north Moravia and Czech Silesia (Czech Republic). Památky Archeologické 109:5–36

Ochoa B (2017) Espacio gráfico, visibilidad y tránsito cavernario. El uso de las cavidades con arte paleolítico en la Región cantábrica. BAR International Series 2875. BAR Publishing, Oxford

Ochoa B, García-Diez M (2018) The use of cave art through graphic space, visibility and cave transit: a new methodology. J Anthropol Archaeol 49:129–145. https://doi.org/10.1016/j.jaa.2017.12.008

Ortega-Martínez P, Ruiz-Redondo A (2018) An approach for understanding site location preferences on Pas River Basin during Late Magdalenian. Landscape analysis of Las Monedas cave. J Archaeol Sci Rep 19:804–810. https://doi.org/10.1016/j.jasrep.2017.08.003

Palacio-Pérez E (2010) Cave art and the theory of art: the origins of the religious interpretation of palaeolithic graphic expression. Oxf J Archaeol 29(1):1–14. https://doi.org/10.1111/j.1468-0092.2009.00337.x

Palacio-Pérez E (2013) The origins of the concept of 'Palaeolithic art': theoretical roots of an idea. J Archaeol Method Theory 20(4):682–714. https://doi.org/10.1007/s10816-012-9135-6

Palacio-Pérez E (2017) El arte paleolítico. Historia de una idea, Nadir Ediciones, Santander

Pastoors A, Lenssen-Erz T, Breuckmann B, Ciqae T, Kxunta U, Rieke-Zapp D, Thao T (2016) Experience based reading of Pleistocene human footprints in Pech-Merle. Quat Int 430(Part A):155–162. https://doi.org/10.1016/j.quaint.2016.02.056

Pastoors A, Weniger, G.-Chr (2011) Cave art in context: methods for the analysis of the spatial organization of cave sites. J Archaeol Res 19(4):377–400. https://doi.org/10.1007/s10814-011-9050-5

Petrognani S, Robert E (2019) Symbolic territories in pre-Magdalenian art? Quat Int 503(Part B):210–220. https://doi.org/10.1016/j.quaint.2017.08.036

Pigeaud R (2005) A propos des représentations de chevaux de la grotte Mayenne-Sciences (Thorigné-en-Charnie, Mayenne). Singularités stylistiques et formes d'usage dans "l'art de la silhouette" anté-magdalénien. In Jaubert J, Barbaza M (eds), Territoires, déplacements, mobilité, échanges durant la Préhistoire. Terres et hommes du sud, pp 235–263. CTHS, Paris

Rivero O, Sauvet G (2014) Defining Magdalenian cultural groups in Franco-Cantabria by the formal analysis of portable art works. Antiquity 88:64–80. https://doi.org/10.1017/S0003598X00050225

Rodríguez-Asensio JA (1992) Excavaciones arqueológicas en la cueva de La Lluera II. San Juan de Priorio. Excavaciones Arqueológicas en Asturias 1987–1990(2):29–32

Rodríguez-Asensio JA (2000) El Paleolítico Antiguo en Asturias. Spal 9:109–123

Rodríguez-Asensio JA, Barrera-Logares JM (2012) La Lluera II (San Juan de Priorio, Oviedo, Asturias, España): estudio integral de un santuario complementario solutrense. Espacio, Tiempo y Forma. Serie I, Nueva Época. Prehistoria y Arqueología 5:517–525

Rodríguez-Asensio JA, Barrera-Logares JM, Aguilar-Huergo E (2012) Cueva de La Lluera I (San Juan de Priorio, Oviedo, Asturias, España): estratigrafía solutrense. Espacio, Tiempo y Forma. Serie I, Nueva Época. Prehistoria y Arqueología 5:235–248

Rouzaud F (1978) La paléospéléologie. L'homme et le milieu souterrain pyrénéen au Paléolithique supérieur. École des hautes études en sciences sociales, Toulouse

Sauvet G, Wlodarczyk A (1992) Structural interpretation of statistical data from Palaeolithic cave art. In: Goldsmith AS, Garvie S, Selin D, Smith J (eds), Ancient images, ancient thought. The archaelogy of ideology. The University of Calgary, Calgary, pp 223–234

Sauvet G, Wlodarczyk A (1995) Eléments d'une grammaire formelle de l'art pariétal paléolithique. L'Anthropologie 99(2–3):193–211

Schiffman SS, Reynolds ML, Young FW (1981) Multidimensional scaling: theory, methods, and applications. Academic Press, London

Straus LG (1987) Upper Paleolithic ibex hunting in Southwest Europe. J Archaeol Sci 14:163–178. https://doi.org/10.1016/0305-4403(87)90004-5

Supernant K (2017) Modeling Métis mobility? Evaluating least cost paths and indigenous landscapes in the Canadian west. J Archaeol Sci 84:63–73. https://doi.org/10.1016/j.jas.2017.05.006

Tilley C (1994) A Phenomenology of Landscape: places, paths and monuments. Berg Publishers, Oxford

Uriarte A (2005) Arqueología del Paisaje y Sistemas de Información Geográfica: una aplicación en el estudio de las sociedades protohistóricas de la Cuenca del Guadiana Menor (Andalucia oriental). In: Blanco A et al. (eds), Encuentro de jóvenes investigadores sobre Bronce Final y Edad del Hierro en la Península Ibérica. Universidad de Salamanca, Salamanca, pp 603–621

Vialou D (1986) L'art des grottes en Ariège magdalénienne. Gallia préhistorique, vol suppl. 22. CNRS, Paris

Villeneuve SN (2008) Looking at caves from the bottom-up: a visual and contextual analysis of four Paleolithic painted caves in Southwest France (Dordogne). Dissertation, University of Victoria https://dspace.library.uvic.ca/handle/1828/2875

Whallon R (2006) Social networks and information: non-"utilitarian" mobility among hunter-gatherers. J Anthropol Archaeol 25(2):259–270. https://doi.org/10.1016/j.jaa.2005.11.004