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New discoveries of pre-Magdalenian cave art in the central area of the Cantabrian region (Spain)

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ABSTRACT

Evidence of the potential occurrence of Palaeolithic red paintings has been found in several caves in Cantabria since the 1980s. Awareness of those references led us to propose a research project aiming at exploring the caves with the most recent methods and techniques of graphic data acquisition and processing to the Government of the Autonomous Community. Encouraged by the discovery of Cueva Auria in 2015, the project started in 2016. In a first stage, seven caves were selected for study with the systematic integrated application of lasergrammetry, photogrammetry, microphotography and multispectral imagery. This high-resolution study has been able to confirm the existence of six new Palaeolithic cave art sites in Cantabria. The preliminary results of the project, programed to last for another two years, are most interesting from a scientific perspective. The new cave art sites, as in the case of Cueva Auria, can be assigned to an archaic phase within Palaeolithic Art, that is to say, to a pre-Magdalenian age. With the exception of El Rejo Cave, where the main panel includes some animal figures, and an imprint of a hand of La Brazada Cave, none of the new assemblages contain either zoomorphic or human representations. Apart from parietal testimonies which could be linked to the human frequentation of the caves and not properly, to the category of graphic expressions (such as stains, small marks, imprints and other coloured traces), these small ensembles constitute an interesting group of cave art sites mainly formed by isolated dots or integrated in geometric compositions, discs, spots, isolated or paired strokes, and, in two cases, by complex rectangular signs. The new discoveries imply a significant increase in the number of Palaeolithic Cave Art sites in the Cantabrian region, which could be related to other assemblages in the same region and other proximate areas. All together, they demonstrate the great variability of the regional parietal record in the Early Upper Palaeolithic. We can be optimistic that further research, applying the systematic approach developed by this project, will continue to improve knowledge of pre-Magdalenian cave art in northern Spain.

1. Introduction

Evidence of red paintings, probably Palaeolithic in age and previously unknown, has been found in several caves in the Autonomous Community of Cantabria in recent years.

The study of the parietal art in Cudón Cave, from 2011 to 2014 (Montes et al., 2015) and Cueva Auria (Peñarrubia) in 2015 and 2016 (Ontañón et al., 2018) are the immediate antecedents of the present project. They both announced the great potential of assemblages like those two sites within Upper Palaeolithic graphic expression; that is to say, sites decorated in early stages of the Last Glacial period without figurative motifs in their iconographic repertory.

The interest in assessing the heritage value of these sites and documenting them with scientific methodology was unquestionable in the field of rock art research, but also in aspects related to conservation and dissemination of archaeological heritage. Their study would improve our knowledge of cave art in the region and also enable public administration to adopt the necessary measures to guarantee their

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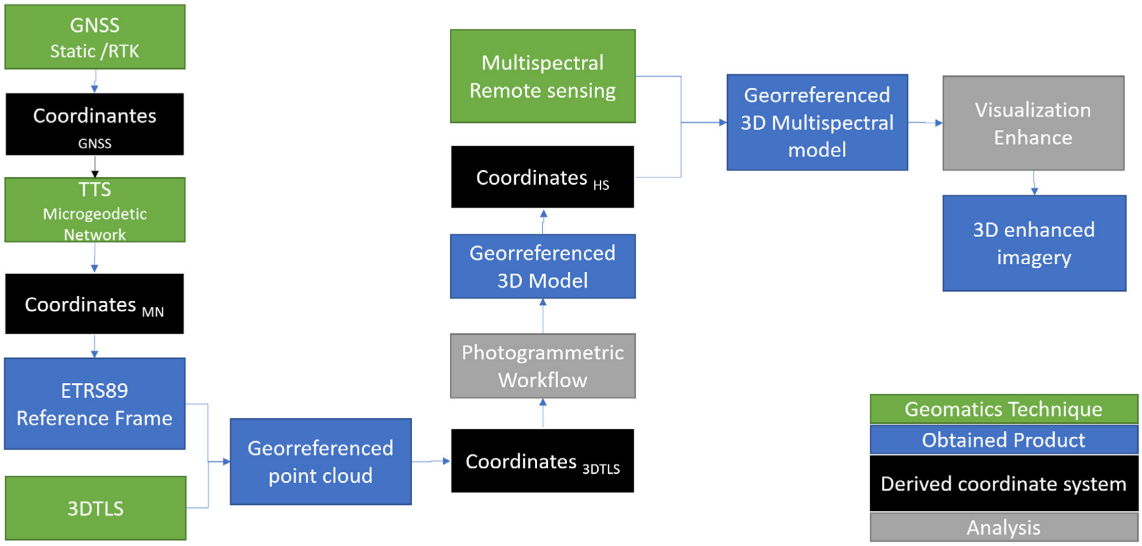


Fig. 1. Geomatics workflow diagram.

conservation and legal protection. The documentation of these heritage sites would also permit them to be discussed in the scientific world and to be made known among the general public. The importance of the project within different aspects of cave art management was therefore undeniable.

The main interest of the project is based on two goals: a) the possibility of obtaining precise information about these unknown sites, determine the origin and nature of the red paintings and include them, depending on the results, in the corpus of caves with prehistoric decoration in the Autonomous Community of Cantabria; and b) acquire precise data for the correct physical and legal protection of the sites.

Suitable tools were needed to achieve those objectives and face the challenge of exploring and documenting caves located sometimes in difficult places, with somewhat dubious parietal manifestations and in a varied, and occasionally deficient, state of conservation. These restrictions have demanded the design of a strict working methodology in order to reduce the time spent on fieldwork as much as possible. This involved the use of powerful tools capable of acquiring the maximum amount of information for later processing in the laboratory. The methodology thus included the application of the latest technology for image capture and processing.

The project therefore aims to study the parietal motifs in the caves in order to obtain the information necessary to discern, with rigorous criteria, which elements really are prehistoric graphic expressions and which are not. This is allowing us to include these assemblages in the scientific discourse and, at the same time, facilitate their technical-administrative cataloguing and the adoption of the relevant management measures.

Thus, in the case of the sites where the heritage value of the parietal evidence is certified, it will be possible to produce the documentation for the physical protection of the caves, their inclusion in the Regional Archaeological Inventory and the initiation of the corresponding process for their designation as recognised cultural properties. This will fulfil the requirements in regional and national legislation and in charters and recommendations of international organisations, like UNESCO, the Council of Europe and IFRAO, which are concerned with this kind of site.

It should be added that, although in some caves the evidence clearly indicates the archaeological value of the parietal motifs, in others there are reasonable doubts and a methodologically complex and detailed study is necessary, including the characterisation of the materials and even sampling for radiometric dating, in order to determine empirically the authenticity of the supposed prehistoric graphic expressions.

In any case, a multidisciplinary study guaranteeing full knowledge of the parietal representations and their geoarchaeological context has been carried out at all the sites.

From the viewpoint of the transfer of knowledge, the project is conceived within an inter-disciplinary approach involving different specialists in research and the management of archaeological heritage who belong to both the institutional and professional spheres. The team is thus formed by members of the Administration of the Autonomous Community of Cantabria and of the Cantabria International Institute of Prehistoric Research (Government of Cantabria-University of Cantabria-Santander), of the international association that manages the Council of Europe Cultural Route 'Prehistoric Rock Art Trails', and of companies specialising in geomatics and archaeology.

2. Materials and methods

To attain the objectives as explained above, a working procedure has been designed for the fieldwork and laboratory work. It consists of a series of steps, using the methods and techniques described below.

1. The site is mapped and georeferenced with a 3D scanner and GPS.
2. The cave is divided into sectors and an order is established for the walls, which are systematically searched and examined with cold electric lighting (LED lights, energy-saving fluorescent lamps and ultraviolet lamps). Exploratory pictures are taken supported by the image-processing software DStretch® (Harman, 2008), which is also employed as a complementary technique in stage 4.
3. The parietal motifs are located precisely on the 3D model of the cave, based on their organisation in panels and graphic units.
4. The photogrammetric documentation of the graphic record in the cave is based on high definition digital photography. This enables a precise three-dimensional record of the motifs within a database that can be used for the later digital processing of the images. This phase of data collecting and processing constitutes the main methodological advance of this work and so, it is described more fully in the following lines (Fig. 1).

2.1. Creation of the georreferenced 3D reference frame

An innovative geomatics method based on the combined use of photogrammetry techniques supported on a rigorous topographic base has been used in the current work.

This combined technique offers greater precision, since it allows:

- Network adjustment permits to run a statistical test to remove bundlers.
- All the scans positions are derived from adjusted point of a local network and it is possible to derive some indicators of the quality.
- Increase the accuracy of the Ground/Control points: 2 mm of a point compared to 5–7 mm of the prism measuring systems of the Topographic Total Stations (TTS).
- Have control points throughout the whole panel to analyze deviations from the photogrammetric model.

In addition, it makes the documentation of caves more sustainable, since it allows:

- The use of 3D Terrestrial Laser Scanner (3DTLS) reduces the time in the cave, and so on the impact on it.
- Avoid the use of pointing elements such as targets, reducing the risk of damaging and the insertion of elements that could cause damage (such as fungus and bacteriae).

The method permits, by using a combination of geomatics methods, to have 3D georeferenced coordinates with millimetric accuracy in the interior of a cave. The workflow is as follows:

1. *Global Navigation Satellite System (GNSS):* The reference frame for georeferencing data was created outside the cave and was measured with a TOPCON model HIPER SR GNSS with integrated receiver GPS + GLONASS for Real Time Kinematic (RTK). The result is a set of 4 or 5 GNSS coordinates with centimeter precision (error below 2 cm).
2. *Microgeodetic Network:* A complex network is created. The least squares solution of a network is similar to that of a traverse. Firstly a Free Network is adjusted; this involves using a pseudoinverse to solve systems that have less than the minimum amount of control as described by Bjerhammar (1973). Later the network is attached to the previously observed GNSS points. The result is a set of Microgeodetic Network coordinates in which the accuracy is known and constitutes the ETRS89 Reference Frame of the site.
3. *3DTLS:* The sites where scanned using a FARO X-130 scanner. This scanner provides an accuracy of 2 mm at 25 m with a reflectance of 85%, which allows to obtain a series of points that can be used in the support of the photogrammetric model, and to ensure that they meet the required metric tolerances (Fig. 2).

Once the information collected in the field, it passes a series of processes to filter noise, register the scan positions and optimize of the model in a single model to obtain a 3D georreferenced model which will be the base of the photogrammetric models

2.2. Photogrammetric workflow

The aim is that the recording made not only preserves the object, but the attributes that describe this and its content (shape, color, texture, etc.) and geometry as well. The objective is to generate enough information for restitution in case of loss.

1. *High Resolution photogrammetry:* The photogrammetric campaigns permitted the digitalization of the decorated panels with a resolution of approximately 50 µm. Stereoscopic coverage is assured throughout the area, overlapping the adjacent sections. The horizontal overlap is 80% and the vertical 50%. In the changes of direction in the line of the flight, the last and first frame overlap is 80%.

The photogrammetric equipment used was Sony A7R Mark II and Sony A7S Mark II with calibrated lenses, LEICA M-8 Infrarred Camera, performing exposure control procedure.

2. *Lighting sources:* In field campaigns, three lights were calibrated in the spectral range where sensors were operational. All of them are suitable in avoiding damage to rock art:
   - Ultraviolet LED light
   - Infrared LED light
   - Visible LED light (Fig. 3)
3. *Radiometric correction:* A colour management method has been carried out with the aim of keeping the colour and its perception constant along the chain of devices or applications in which the information could be used. A Datacolor SpyderCHECKR colour chart was used to record colour on-site and later they were processed as described in its user guide. The radiometry of the processed images has made an effective use of all the bits according to each case, avoiding the appearance of empty digital levels in the case of the 8-bit image (Fig. 4).
4. *Photogrammetric flow diagram:* Once the images are recorded in the field and their color is corrected, the processing is made. In this phase the photogrammetric pictures are aligned by using digital methods. It is needed to extract a set of minimum 12 ground control points in each pannel. The adjustment of the block is carried out simultaneously by bundle adjustment as described in Granshaw (1980). All areas proposed in the project are completely aero-triangulated. As verification of the calculation of the

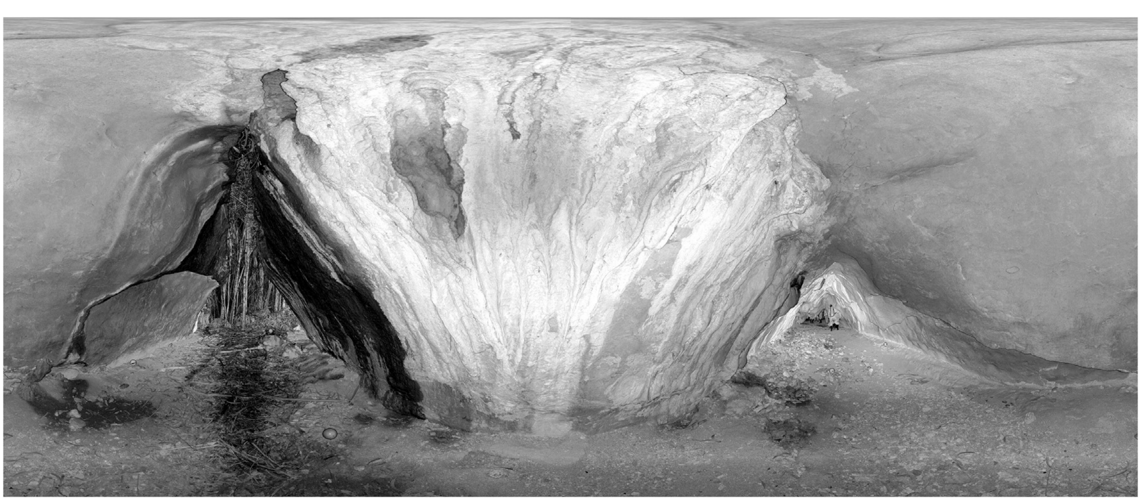


Fig. 2. Planar View of scan position made by the 3DTLS FARO X-130.

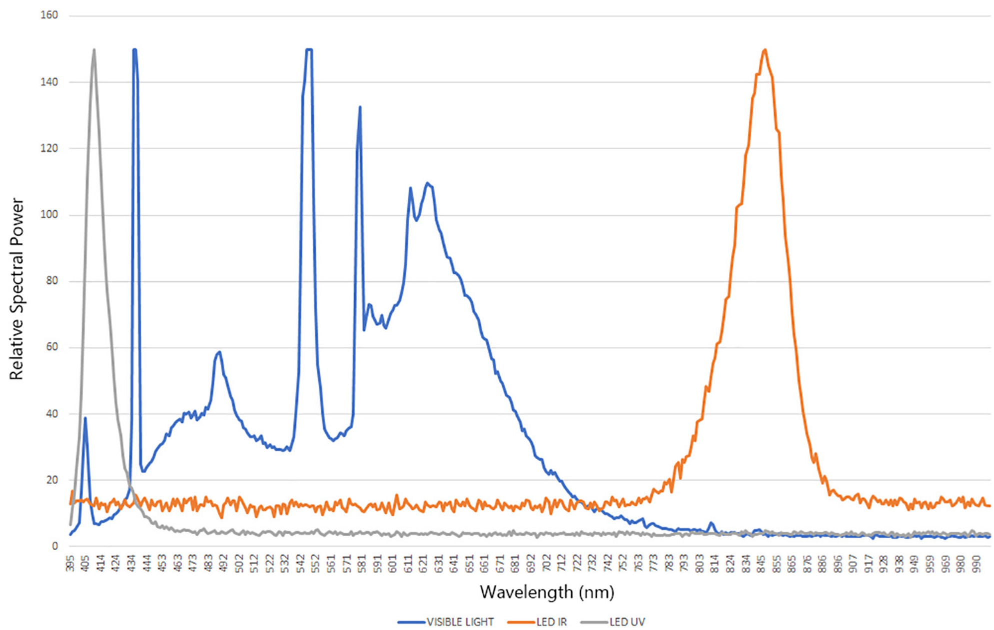


Fig. 3. Spectral signatures of lights at working distance. The vertical axis represents the Relative Spectral Power measured and the horizontal axis the wavelength in nanometers where it was measured.

aerotriangulation, precision control points are included at least 1/3 of the final RMS, for which the existing information in the point cloud is used. The flow chart followed has been (Fig. 5):

2.3. Visualization enhance

In some sites, bands in the ultraviolet (380 nm) and near infrared (850 nm) spectrum have been recorded and integrated with visible information to create a set of multispectral data.

The result of the previous stages is a Georreferenced 3D Multispectral model. This process implemented to the bands has been used for visualization improvement purposes; the aim is to be able to "recover" paintings that are not visible to the naked eye.

1. *Decorrelation adjustment:* As described in Sabins (1986). It is used for image enhancement. It consists of the conversion of the data to the space defined by the main components of the original bands, followed by the equalization of the data according to the new axes, and finally the conversion of the data to the initial space and the combination of the bands with the primary RGB colors. In this way, the points are distributed more evenly in the RGB space, so the image will show a much higher contrast.

The method consists of three phases:

1. Calculation of the principal components of the distribution of values in the original 3D space and transformation of the data to this new space.
2. Application of contrast extension techniques on each of the 3 new axes, not correlated with each other. This is done by equalizing or

Fig. 4. Datacolor SpyderCHECKR.

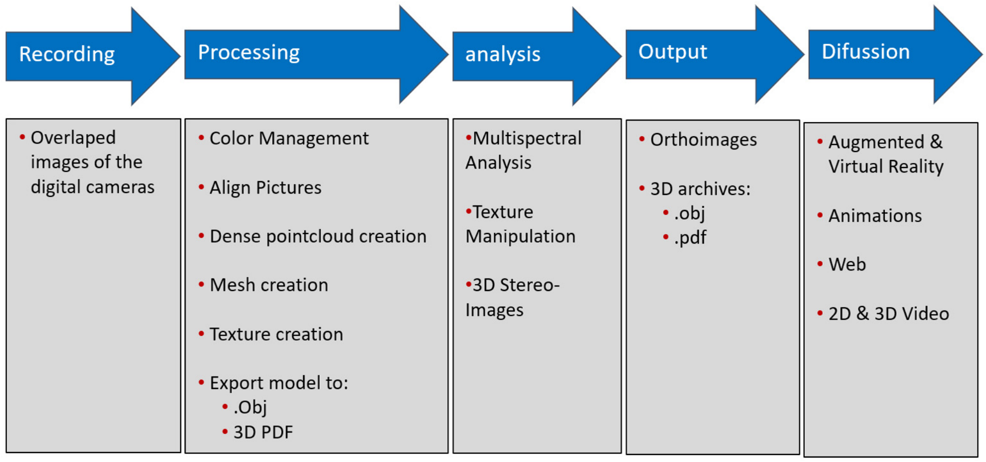


Fig. 5. Photogrammetric Processing Stages.

scaling the new histograms, achieving an expansion of the data in three-dimensional space.

3. Reverse transformation of the data to the original coordinate space (RGB). These operations can be performed through a single linear transformation for each band. Expressing it in matrix form:

$$X_D = X.\ U.\ S.\ U^{-1}$$

where X is the initial data matrix n × 3 (three components, RGB, for each of the n pixels in the image); U is the transformation matrix of the principal components, whose columns are the eigenvectors of the covariance matrix of X; S is a diagonal matrix of scaling, which produces a change of scale of the values in the space of the main components; and XD is the resulting data matrix, also of dimensions n × 3. Each column of X and XD represents a complete band of the image.

2. *Principal Components Analysis (PCA):* Two different Principal components algorithms have been used, one that has been adapted from Richards (1999) and the Karhunen-Loève transformation, as described in Loève (1978), which have been programmed in the IDL (Interactive Data Language) language. Both methods have been carried out using the correlation matrices and all the bands were included in the transformation
3. *Minimal Noise Fraction Transformation (MNF):* The modified MNF transformation as described in Green et al (1988) has been implemented. It is a linear transformation consisting of the following rotations of separate principal component analysis:
   - The first rotation uses the main components of the noise covariance matrix to decorrelate and rescale the noise in the data (a process known as "noise whitening"), resulting in transformed data in which the noise has unit variance and there is no band-to-band correlation.
   - The second rotation uses the main components derived from the data of the original image after the noise of the first rotation has been whitened and rescaled by the noise standard deviation. Since there will be more spectral processing later, the inherent dimensionality of the data will be determined by examining the final eigenvalues and associated images. The data space can be divided into two parts: a part associated with large values and coherent self-images, and a complementary part with eigenvalues close to the unit and images dominated by noise. Using only the coherent portions separates the noise from the data, thereby improving the results of the spectral processing.

   The MNF transformation can also be used to eliminate noise from the data by performing a direct transform, determining which bands contain the coherent images (by examining the images and eigenvalues), and subsequently executing a reverse transform using a spectral subset that includes only the good bands, or soften the bands with higher noise before executing the inverse
4. *Independent Components Analysis (ICA):* Independent Component Analysis (ICA) can be used in multispectral or hyperspectral data sets to transform a set of randomly mixed signals into components that are mutually independent according to Hyvärinen (1998, 1999). The IC transformation is used as a tool for blind separation of sources, where prior information about the mixture is not available. The transformation is based on the assumption that the independent source is not Gaussian, and employs higher order statistics to reveal interesting features in the typical non-Gaussian hyperspectral datasets. The IC transformation can distinguish features of interest even when they occupy only a small part of the pixels in the image.

Compared to the principal component analysis, the Independent Component Analysis offers some unique advantages:

- PC analyzes are an orthogonal decomposition. It is based on the analysis of the covariance matrix, which is based on a Gaussian distribution assumption. The IC analysis is based on the assumption of non-Gaussian distribution of the independent sources.
- The PC analysis uses only second order statistics, while the IC analysis uses higher order statistics. Higher-order statistics are a more robust statistical assumption, revealing interesting features in hyperspectral data sets that are generally non-Gaussian.

  If the characteristic of interest (as, for example, an anomaly) only occupies a small part of all the pixels, which makes the contribution insignificant to the covariance matrix of the whole image, in the PC analysis the characteristic of interest will be considered as noisy bands. In the IC analysis, the characteristics are distinguished from the noisy bands.

  The purpose of the multispectral analysis stage is to create a collection of false colour composition images whose objective is to enhance visualization and to see things that are not visible to the naked eye.

5. Precise output of images is achieved using computer-aided image processing software (basically Adobe Photoshop and Adobe Illustrator).
6. The technical, morphometric and stylistic assessment of the motifs are assessed by applying archaeological documentation techniques.
7. The state of conservation of the cave wall and the parietal record is assessed to detect any potential threats, of both natural and anthropic nature. Proposals are drafted for the protection of the assemblage where it is deemed necessary.

3. Results

The sites documented in each year have been:

2016: La Cantera I (Puente Viesgo), El Rejo (Val de San Vicente), Los Murciélagos (Entrambasaguas), Solviejo (Voto)

2017: Las Graciosas Caves (I and II) (Medio Cudeyo), La Brazada (Ruesga)

2018: La Llosa (Villaescusa), Villegas (Alfoz de Lloredo)

The results of the project have been highly satisfactory. The working methodology applied systematically to the study of these sites has succeeded in documenting the geometry of the caves with great precision and studying their decorated sectors with high definition.

Extremely precise new data have been obtained and it has been possible to confirm the authenticity of most of the assemblages and define the parietal motifs exactly, in the case of both previously unpublished sites (El Rejo, Solviejo, Las Graciosas I and II, Los Murciélagos, La Cantera, La Brazada) and a known assemblage (La Llosa).

In addition to the numerous dots, discs and colour stains (which reach a high degree of compositional complexity at sites such as La Graciosa II), magnificent quadrangular signs have been identified in Solviejo and La Llosa, and splendid zoomorphic figures in the entrance of El Rejo.

However, at Villegas, it has not been possible to ratify the anthropic origin of some colour stains, and the study of a large ceiling with engravings of uncertain chronology is still in progress using some of the image processing techniques described above. The study of the large densely-engraved panel in La Llosa is equally still in progress.

As a result, the project has been able to add six new assemblages to the corpus of caves with Palaeolithic art in Cantabria and considerably improve the documentation of sites that were already known.

In both cases, from a methodological point of view, the results of the project are of great interest in that they have been achieved through the systematic application of a standardised working procedure that includes some of the latest techniques for capturing and processing digital images.

Five examples will be given of the results obtained in the caves studied in this project.

3.1. Solviejo Cave: complex rectangular sign

Most of the representations identified and studied in this cave using the described methodology are red paintings, although some yellow and black figures have also been recognised (Montes et al., 2017). They are all in the first passage, not far from the entrance, where the slope of the cave floor leads to a large shaft into the lower levels of the Solviejo-Rayo de Sol cave system.

The most significant motif is a large sign, badly affected by the growth of white calcite that partially masks it. Although it can be appreciated as a large area of colour by the naked eye, digital image processing has been able to define it in greater detail.

It is a rectangular sign with slightly concave longer sides (the lower side and especially the upper side) and with pointed upper corners. The figure combines linear painting for its outline with colour wash for its interior. A narrow fringe along its edge seems to be sub-divided with short straight vertical lines. It is 36 cm high (28 cm in the centre) by 81 cm wide, and it is 110 cm above the floor (Fig. 6).

3.2. La Llosa Cave: complex rectangular sign

The graphic expressions in this small cave are located in two areas, one near the entrance consisting of a single large engraved figure, and the other in the final chamber, where several red and purple paintings (quadrangular signs, rows of dots and stains) and a palimpsest of more recent engravings have been documented.

The painted motifs are badly deteriorated by natural processes such as the loss of pigment and the growth of calcite but include a large figure that was originally identified as a quadruped (González et al., 2000). The application of the techniques described in the working methodology has been able to determine that in reality it is a large horizontal rectangular sign, of the type known as 'tectiforms', with pointed upper corners. Its left half contains four wide vertical stripes, while the right half is crossed by a diagonal line drawn as a series of large dots.

This sign is 23.5 cm high and 96 cm wide and is 160 cm above the modern floor (Fig. 7).

3.3. Los Murciélagos Cave: large stains of colour creating a geometric form

The decorated panels are in three different parts of this cave, not too far from the entrance. The outermost panel, on the right-hand wall at the end of the first passage, is the most complex and the most poorly–conserved one. The motifs are very difficult to see with the naked eye and those that can be glimpsed seem to be natural pigments from the limestone bedrock. They are located on the lower part of the wall and were painted with a red ochre colour wash. Several large stains with a geometric shape, possibly the remains of signs, can be differentiated.

After the images were processed, the following graphic units were appreciable:

A possible irregular rectangular sign is divided into two parts with the right-hand side the larger part. It is in a concavity in the wall, is 20 cm high by 84 cm wide, and 15 cm above the modern cave floor.

An oval-shaped stain of colour, in an oblique position, has two small v-shaped protuberances in its upper part. It is on the edge of a small triangular hollow and is 12 cm high by 11 cm wide, 47 cm above the floor.

An approximately pentagonal stain of colour has a central corner pointing downwards and a small protuberance in the middle of the lower side. It is beneath a very noticeable natural hollow. 30 cm high by 35 cm wide, it is 33 cm above the floor (Fig. 8).

3.4. La Brazada Cave: handprint

This motif is 51 m from the entrance, in a small sub-circular chamber separate from the low entrance passage. It is the innermost motif in the cave, isolated from the rest of the pictorial assemblage, which consists of dots, short lines and red and purple stains, as well as two possible signs: a staff and a triangular geometric motif.

It probably represents a right hand in a vertical position. The palm is seen most clearly, with the rounded base at the wrist, the ulnar edge and a straight wide upper part corresponding to the inter-digital zone. It is located on the edge of a small line of the wall, and is 18 cm high by 11 cm wide, 215 cm above the floor. This means that it would have been painted with the arm outstretched upwards, with the palm placed directly on the wall. The thumb is missing and the other fingers are not appreciated clearly. It should be noted that the representation is affected by the loss of pigment, although it is visible at a distance as a stain of colour. It cannot easily be appreciated with the naked eye. Indeed, it was only definitively identified as a handprint after the photographs were processed with the techniques described above (Fig. 9).

3.5. El Rejo Cave: complete figure of an adult stag

This cave contains a small assemblage of red paintings, most of which are in a panel almost 2 m long and about 1 m high, on the right-hand wall at the end of the entrance chamber. It is a very complex and poorly-conserved panel, especially in the anterior part, where it is only possible to distinguish remains of pigment and some red dots. No clear figure can be seen with the naked eye. However, in the lower central part, the techniques for the capture and processing of images succeeded

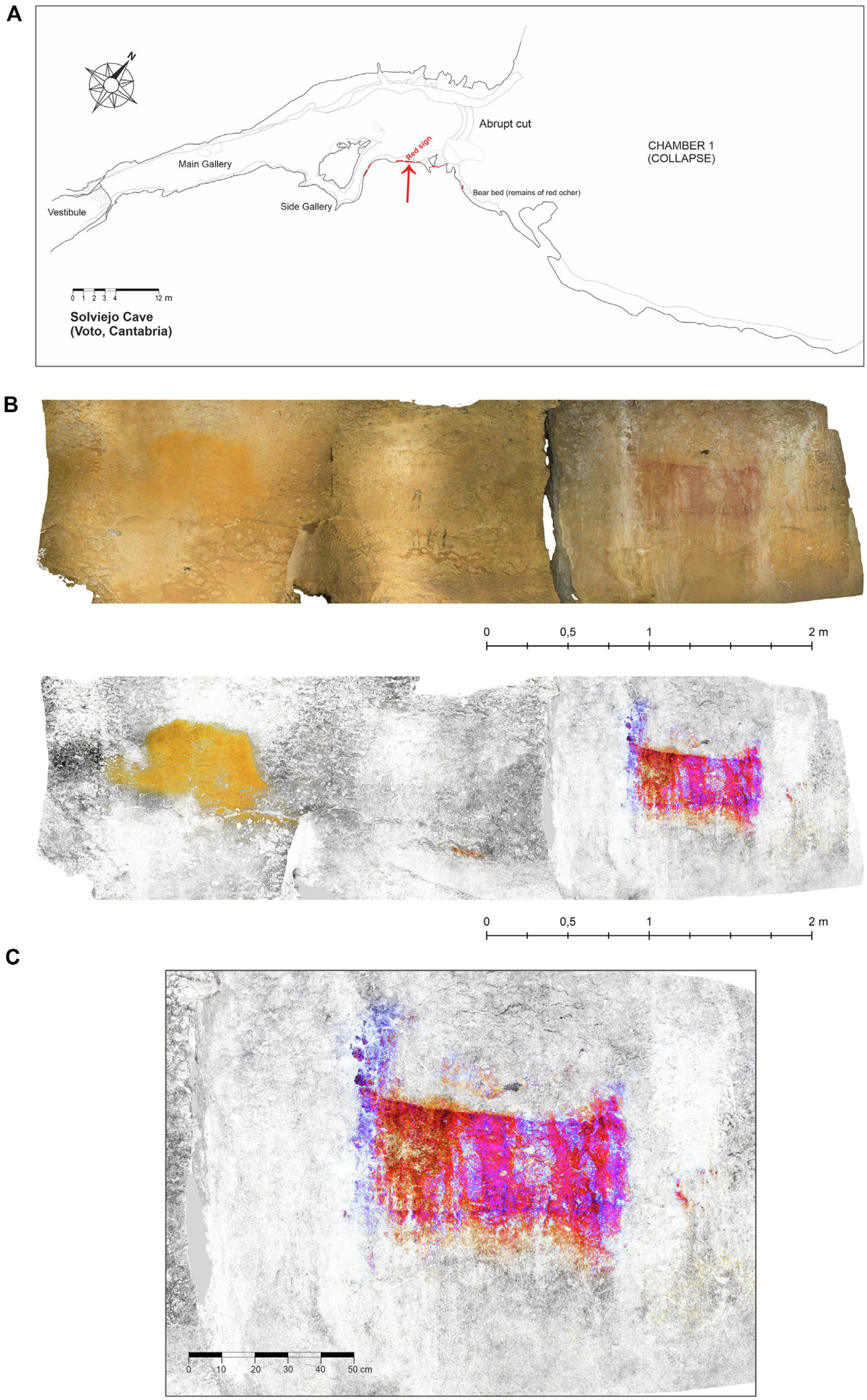


Fig. 6. a. Solviejo Cave. Plan of the cave with the location of the cave art panels. b. Solviejo Cave - Panel 10-3-4. Top: Visible true orthoimage of the rock-art panel. Bottom: Isolation of color pigments over greylevel orthoimage. c. Solviejo Cave– Panel 10-3-4. Tracing of the geometric sign painted in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

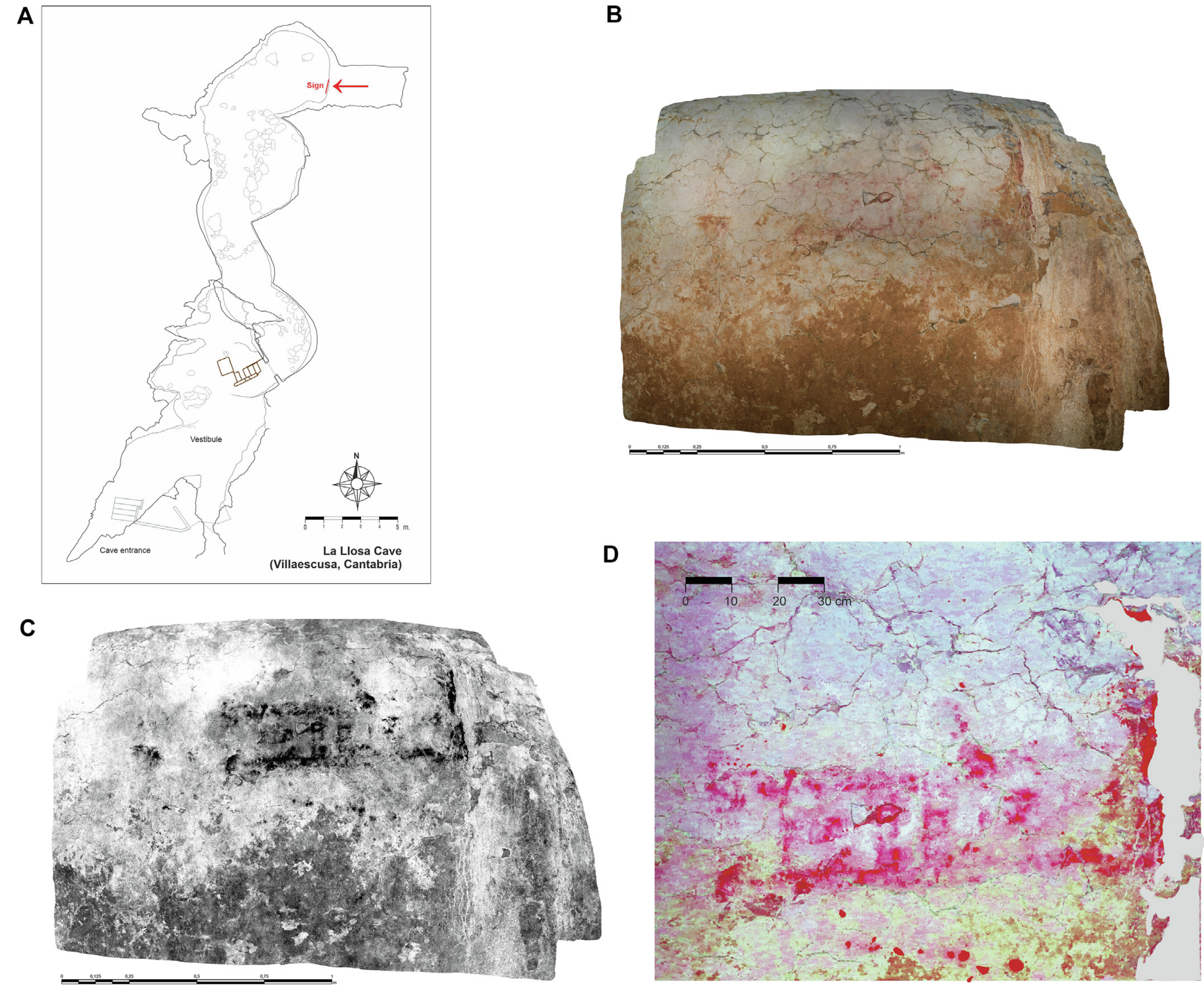


Fig. 7. a. La Llosa Cave. Plan of the cave with the location of the cave art panels. bc. La Llosa Cave- Panel 4. b: Visible true orthoimage of the rock-art panel. c: Pigment absortion signal. The image was obtained by decorrelating the Green band of the camera. d. La Llosa Cave – Panel 4. Tracing of the red geometric sign. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in positively and precisely identifying a complete figure of a stag.

The animal faces right and was painted carefully. Its neck is outstretched and its head is raised slightly. The two antlers were represented, although the anterior one is hardly visible, and the posterior one is very curved and massive, with three oblique lines that represent the tines. Behind the antlers, an oblique line represents the right ear. The cervical-dorsal line is slightly sinuous, the belly is convex and the well-defined tail is small and characteristic of the species. The four limbs are represented with double lines. The hind legs are in correct perspective whereas the fore legs are very simply represented by two straight parallel and oblique lines that are noticeably shorter than the hind legs. The figure was painted with single lines to represent the outline of the body and the antlers. Colour wash was used to fill the fore-quarters of the animal, its neck and head, and anatomical details were indicated by blurring the pigment.

It is 65 cm long from its muzzle to its tail, and measures 37 m from the tip of its antler to the end of the fore-leg (Fig. 10).

4. Discussion

The working procedure designed and employed by this project, whose most relevant methodological contribution is the combination of techniques in a coherent workflow, has signified a great improvement in our ability to obtain and interpret spatial and graphic data related to rock art. In the first place, it makes visible parietal motifs that cannot be perceived with the naked eye or conventional photographic techniques. Second, it objectifies the process of obtaining and working with the information. Third, it provides high definition, measurable and comparable data, which is essential in the process of scientific research. It is therefore a powerful methodology to achieve the full application of state of the art technologies to rock art studies.

The use of this methodology has allowed us to fulfil the project's objectives and find some answers, even if they are only provisional whilst awaiting new advances, to the questions asked of the archaeological record. The results will be summarised very briefly.

Viewed as a whole, the cave art documented in these sites displays technical, formal and stylistic homogeneity.

Only paintings have been studied, mostly in red apart from sienna in Cueva de Solviejo, which is an unusual colour but not unknown in pre-Magdalenian assemblages (for example, in the caves of La Pasiega, El Castillo, El Pendo, Pondra and Covalanas).

They were produced with simple albeit varied techniques, such as

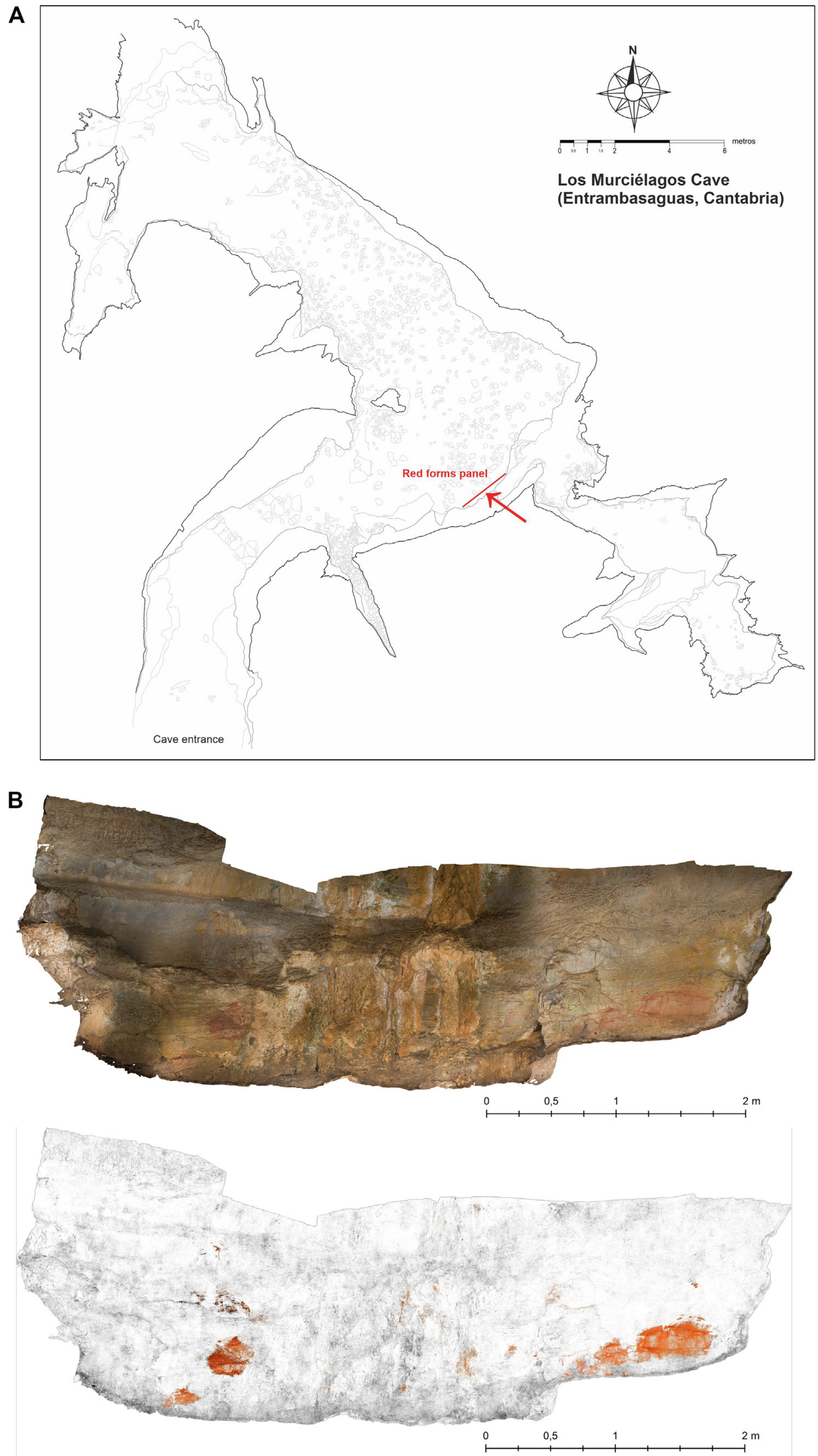


Fig. 8. a. Los Murciélagos Cave. Plan of the cave with the location of the cave art panels. b. Los Murciélagos Cave– Panel 1. Top: Visible true orthoimage of the rock-art panel. Bottom: Isolation of color pigments over greylevel orthoimage. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

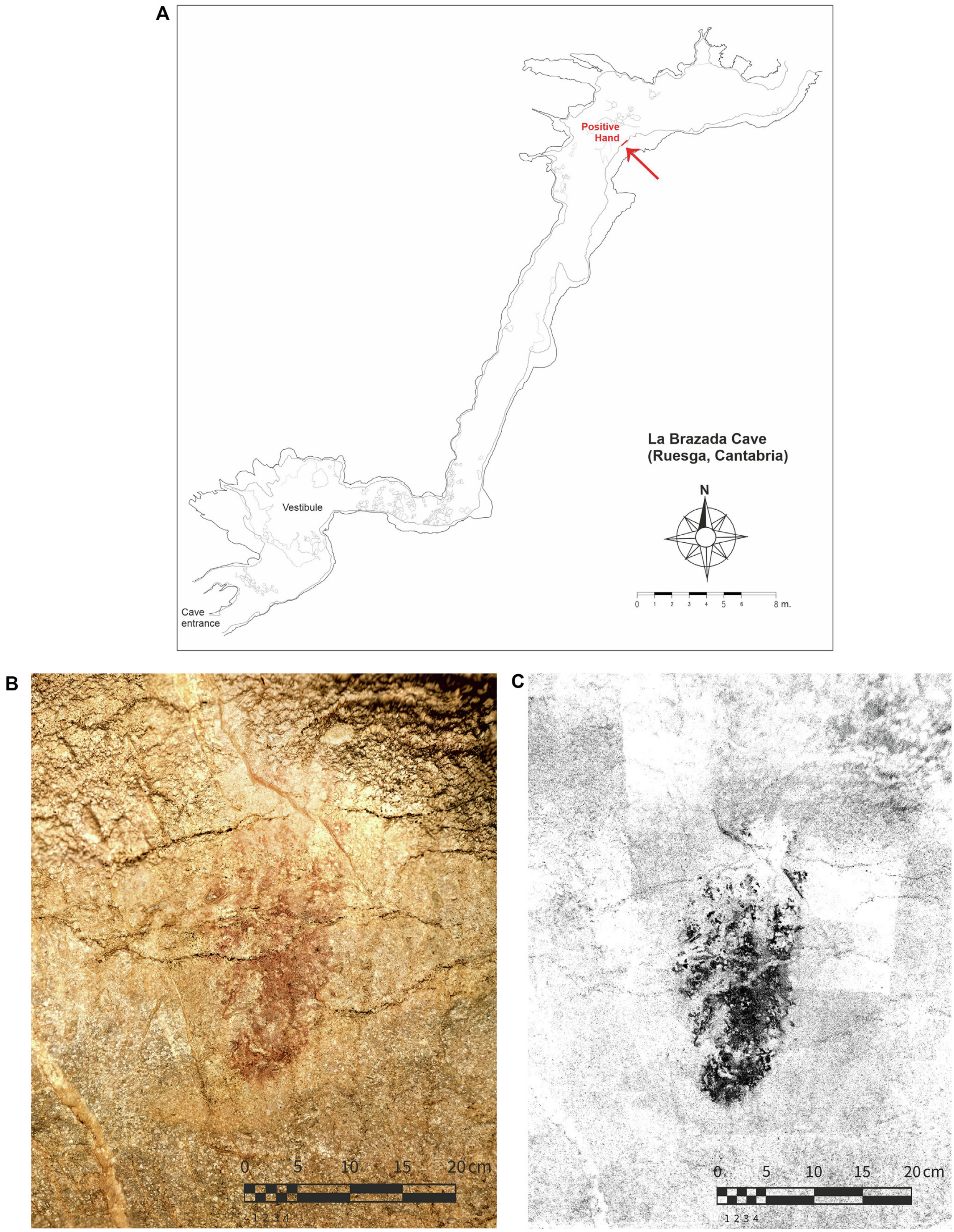


Fig. 9. a. La Brazada Cave. Plan of the cave with the location of the cave art panels. bc. La Brazada Cave– Handprint. b: Visible true orthoimage of the rock-art panel. c: Pigment absorption signal. The image was obtained by extracting the second Principal Component band.

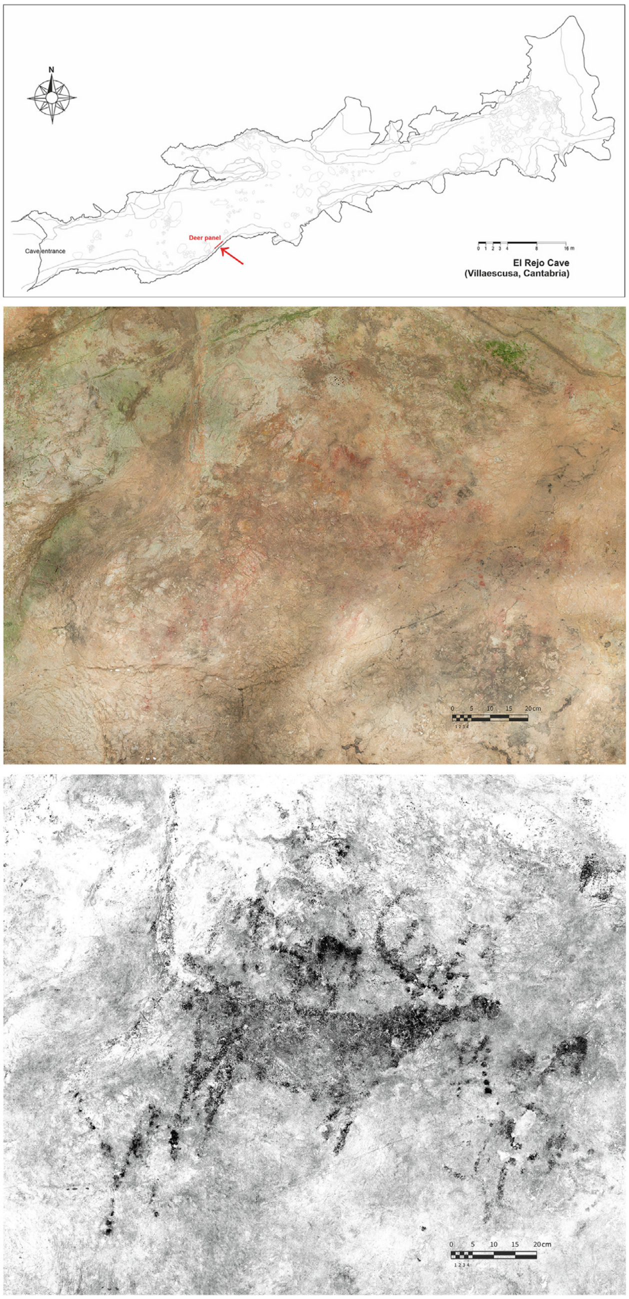
A
B
C


Fig. 10. a. El Rejo Cave. Plan of the cave with the location of the cave art panels. bc. El Rejo Cave – Panel 1-2. b: Visible true orthoimage of the rock-art panel. c: Pigment absorption signal. The image was obtained by extracting the second Independent Component Analysis band.

spraying, linear marks, colour wash or by applying the pigment with the hand stained with semi-liquid or viscous pigment, or as in La Brazada, with some kind of pad.

Complex geometric motifs dominates the repertoire in all cases, except for El Rejo, where a magnificent figure of a stag has been identified, and La Brazada, with the isolated handprint. Given their scarcity, it is worth mentioning the parallels of other positive handprints in Cantabria, such as three at La Lastrilla cave (Molinero and Arozamena, 1993), or three more at Fuente del Salín cave (Moure et al., 1984–1985), as well as the two newly known at Altamira. In this sense, it would be interesting to mention the latest compilation of Iberian Palaeolithic handprints coordinated by H. Collado (2018). Nor should we disregard the possibility that positive hands could respond to later artistic cycles, as seems to be inferred in other cave paintings (Abrigo de Carlos Álvarez en Soria; Cueva del Bubu y Montderes en Huesca; Cueva del Clarillo en Quesada, Cueva de los Ladrones en Cádiz o Risquillo de Berzonaca en Cáceres) (P. Utrilla pers. comm.).

Assemblages formed exclusively by signs are relatively common in northern Spain and are generally attributed to pre-Magdalenian periods (Montes et al., 2015).

The following motifs have been differentiated among the geometric figures:

- Closed motifs: rectangles, pointed oval, fusiform.
- Open motifs: simple (isolated and paired strokes) and complex compositions (parallel vertical lines, groups of dots)
- Others: stains, isolated dots.

These types of motifs appear at several sites in pre-Magdalenian phases in the central part of northern Spain, such as Cudón, El Calero II, Las Aguas and El Cuco (Montes et al., 2015), Cofresnedo (Ruiz Cobo and Smith, 2003) and Mazaculos I (Gómez et al., 1991) (Fig. 11).

One of the most interesting figures is the motif of a rectangle with protuberances, as seen in Solviejo, one in red and the other in sienna (Montes et al., 2017), and a very similar representation in La Llosa (González et al., 2000; Ontañón et al., u.r.). Rectangular or pentagonal signs filled with colour wash are relatively common in archaic phases of the Palaeolithic artistic cycle. They are often quite large but rarely reach 80 cm in width, as in one of the figures documented in Solviejo. Four examples with a straight protuberance upwards are known in a side-chamber in Cudón (Montes et al., 2015). In Mazaculos I, a large example is in a prominent position, with concave longer sides (Gómez et al., 1991). In Las Aguas, a rectangle is open on one side (Lasheras et al., 2010). In La Llosa a rectangle is partially filled and Los Murciélagos contains a rectangle and a pentagon. In Cofresnedo, a simple open rectangle has a concave upper side (Ruiz Cobo and Smith, 2003) and in El Cuco or Sobera there is a simple rectangle Muñoz Fernández et al. (2007). Other smaller rectangles are represented with colour wash, as in Covalanas (García et al., 2003) (Fig. 12).

In all these examples, except for Covalanas, the rectangles were painted in red, both with simple outlines and with colour wash (which are the most frequent), are of appreciable size and often the largest figures in the assemblages, except, with certain nuances, in Cudón and Cofresnedo, and they occupy predominant positions and are clearly visible at a distance, so that they stand out over the other motifs in the assemblages. The two quadrangular signs in Solviejo are unusually large. Although all the geometric motifs of this type catalogued in northern Spain tend to be quite large, the ones in Solviejo are over 80 cm long and are the largest currently known in the Iberian Peninsula.

Other figures in the caves, such as short lines, isolated dots and stains, all in red ochre, are very simple and not very diagnostic, except in the case of dotted lines such as those in Cueva Auria, Solviejo and Cierro de la Cueva. These are very characteristic of pre-Magdalenian pictorial assemblages in northern Spain.

While no absolute dates have yet been obtained, thematic and morpho-technical comparisons with other decorated sites in northern Spain suggest that these sites can generally be attributed to pre-Magdalenian phases within the Palaeolithic artistic cycle.

5. Conclusions

The project of the *Study of Assemblages of Red Paintings possibly of Palaeolithic chronology in the Autonomous Community of Cantabria*, commenced in 2016, has so far been able to document six new Palaeolithic cave art sites in the region of Cantabria.

These are homogeneous assemblages, apparently belonging to a single period. With the available data, long diachronicity in the decoration of these caves cannot be proposed, with the possible exception of La Llosa. This is therefore an iconographic group formed by

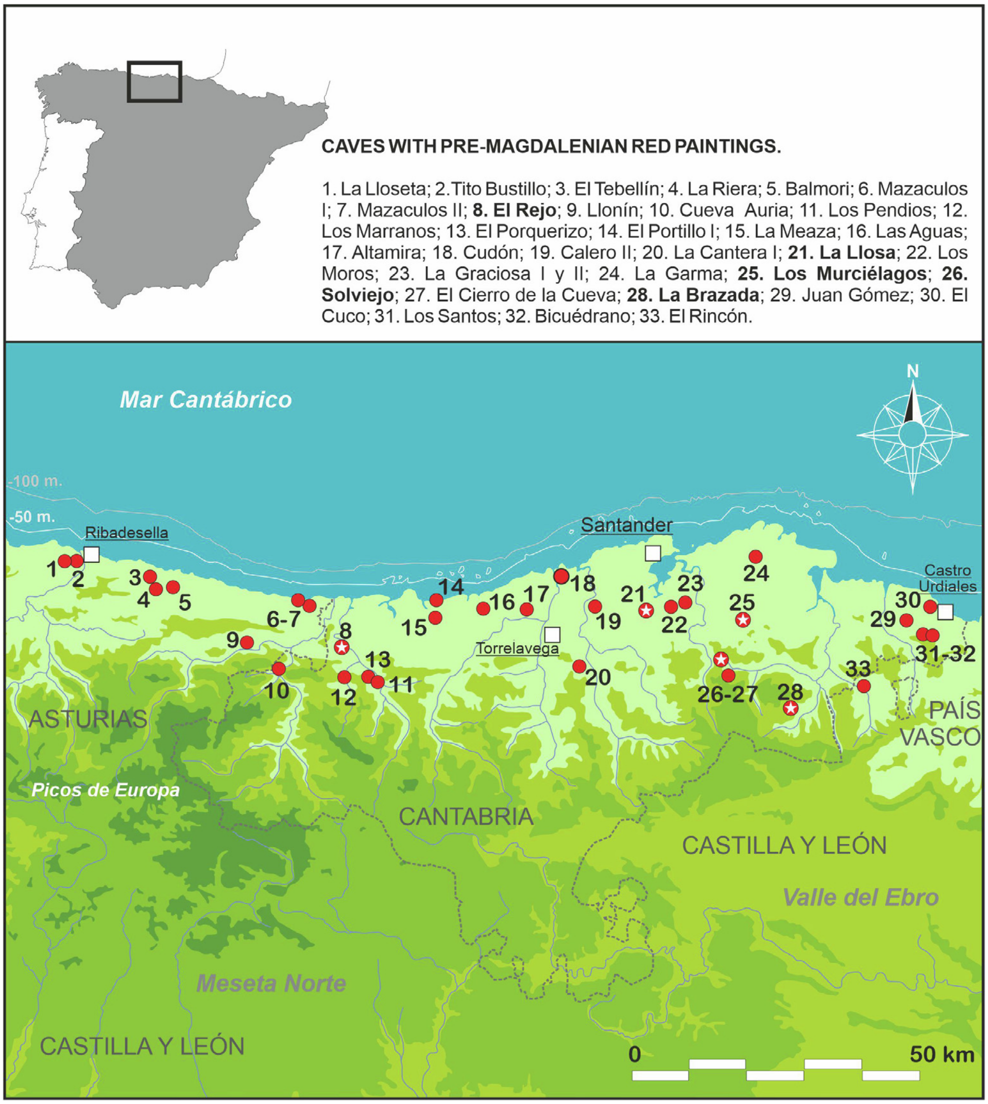


Fig. 11. Map showing the location of the caves mentioned in the study and other pre-Magdalenian cave art sites of the Cantabrian region.

individual parietal assemblages, the result of a single decorative event or several episodes within a short period of time. They can all be assigned provisionally to early stages of the Upper Palaeolithic. Some evidence would suggest more precisely the Gravettian period.

No other anthropic activity associated with the decoration has been observed in any of the sites.

It is interesting to underscore the thematic speciality of the project, as it has opened new perspectives in Palaeolithic art research. It has studied in detail parietal assemblages that until a short time ago were scarcely taken into account in comparison with other cave art sites with figurative representations. Indeed, this kind of graphic record was little known owing to the simple and unattractive nature of the motifs, many of which are also in a deficient state of conservation. However, the study of these assemblages, through the application of state of the art technologies to acquire and process images, is leading to progress in understanding graphic activity in the earliest and least documented phases of Palaeolithic rock art in northern Spain.

In sum, it can be stated that this project is achieving very interesting results from both the substantive point of view, because of its contribution to knowledge of the archaeological record, and the methodological perspective, as its results are due to the systematic application of a standardised working procedure that includes some of the latest techniques in obtaining and working with digital images, as applied to cave art research.

It is therefore an excellent example of inter-disciplinary work in the interaction between geomatics and archaeological techniques, as well as of innovation and development in both fields. The results can be regarded as important both for archaeological research *per se* and for the conservation of archaeological heritage. In a wider sense, they are significant for all aspects of heritage management, from the generation of knowledge to its transfer to society.

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Declaration of Competing Interest

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

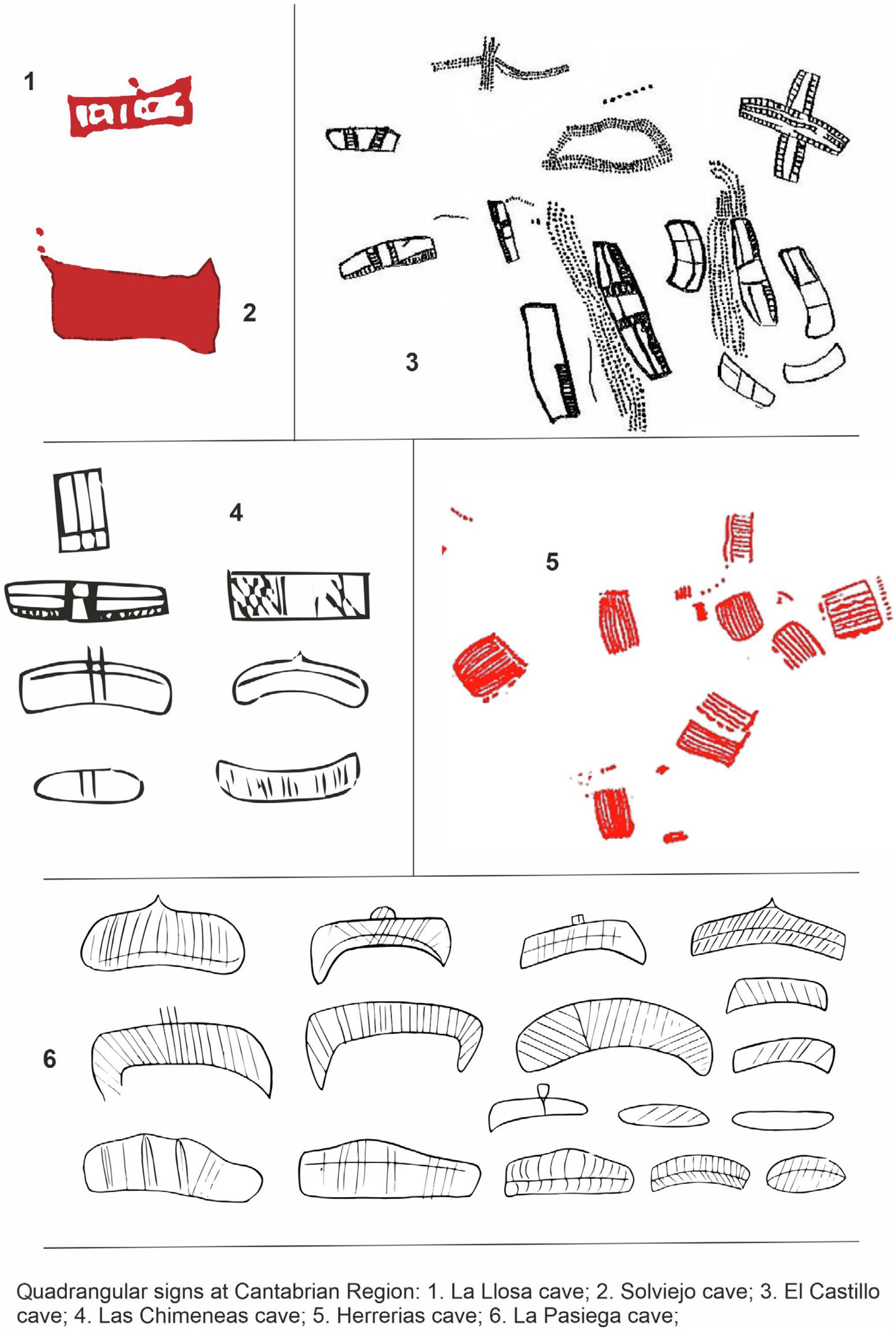

Fig. 12. Comparative with other quadrangular signs in "classic" Paleolithic cave art sites of the Cantabrian region.

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