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MAPPING

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3D-PORTABLE DOCUMENTATION TECHNOLOGY FOR ANALYSIS AND PRESERVATION OF SCHEMATIC ROCK ART PANELS:
a case study of the Castrocontrigo calcolithic paintings

MAPEADO DE INVERNADEROS MEDIANTE TELEDETECCIÓN ORIENTADA A OBJETOS:
entre la calidad de la segmentación y precisión de la clasificación

LOS SISTEMAS DE INFORMACIÓN GEOGRÁFICA (SIG) INDUCEN
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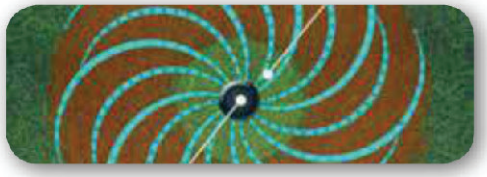
Sumario



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3D-portable documentation technology for analysis and preservation of schematic rock art panels: a case study of the Castrocontrigo calcolithic paintings

Tecnología portátil de documentación 3D para el análisis y preservación de paneles rocosos de arte esquemático: un caso de estudio de las pinturas calcolíticas de Castrocontrigo

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Abstract

The Castrocontrigo rock art, located in the southwestern area of the León province (Spain), is one of the occurrences of Neolithic rock art in northwest Iberia. They comprise a series of schematic panels within two rock shelters characterised by the presence of anthropomorphs, sun-forms and pectiforms that nowadays lack of any preservation directives. Recent forest fires and other human activities have partially damaged the motifs, eventually leading to the possible destruction of this singular place. This paper deals with the digital description and documentation of the two shelters using non-invasive procedures based on structure-light scanner, photogrammetry and digital image enhancement. The acquisition of 3D digital information in combination with the application of image enhancement tools reveal the presence of new motifs in poorly preserved sectors of the studied panels. Although the age of the motifs remains unknown (allegedly between the Chalcolithic and the Iron Age), they provide useful information about the human socio-cultural relationships, suggesting military and/or religious representations. In addition, the distribution of motifs, both in horizontal and vertical panels, suggests the distinction within the social group as well as the existence of power relationships. The generation of photorealistic models from the outcrops aims at the better visualization of the motifs from different angles and perspectives, providing valuable qualitative and quantitative information for archaeologist and historians. Our 3D models aim too at providing effective and wider dissemination of the results ensuring the rock art preservation and awareness to the general public.

Resumen

Las pinturas rupestres de Castrocontrigo, situadas en el suroeste de la provincia de León (España), representan uno de los restos de pinturas de edad Neolítico en el noroeste de la península ibérica. Comprenden una serie de paneles esquemáticos dentro de dos abrigos rocosos caracterizados por la presencia de antropomorfos, soliformes y pectiniformes sin ningún tipo de protección. El reciente incendio y la actividad antrópica han contribuido a dañar parcialmente los motivos, llevando a la destrucción de esta singular estación rupestre. En este artículo se describe la documentación digital de los afloramientos, mediante el uso de técnicas no invasivas con tecnologías portátiles basadas en el escáner de luz estructurada y una fotogrametría detallada, así como el uso y tratamiento de mejora digital de los datos obtenidos. La adquisición de información digital 3D en combinación con la aplicación de herramientas de mejora de la imagen revela la presencia de nuevos motivos, extendiendo la superficie de los paneles lateralmente hacia otras zonas próximas. Aunque la edad de los motivos no se conoce (probablemente entre el Calcolítico y la Edad del Hierro), proporcionan una información útil sobre las relaciones socioculturales de sus autores, sugiriendo un contexto de representación militar y/o religiosa. Además, la distribución de los motivos, ambos en paneles horizontales y verticales, sugiere el establecimiento de una distribución dentro del grupo social, así como la existencia de relaciones de poder. La generación de modelos fotorealísticos de los afloramientos ayuda a la visualización de los motivos desde diferentes ángulos y perspectivas, proporcionando información cualitativa y cuantitativa de valor para arqueólogos e historiadores. Nuestros modelos 3D facilitan una mayor y más efectiva difusión de los resultados, asegurando la preservación y concienciación de su valor por parte de la sociedad.

Keywords: 3D documentation, portable geomatic technology, rock art, Castrocontrigo, León.

Palabras clave: Documentación 3D, tecnología geomática portátil, pinturas rupestres, Castrocontrigo, León.

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1. INTRODUCTION

Rock art represents a global phenomenon characterised by the symbolic representation of human-made ideology. The production of paintings and engravings has had different interpretations associated with cultural, religious or military contexts usually restricted to and preserved in caves or shelters (Breuil, 1935; Laming-Emperaire, 1972; Leroi-Gourhan, 1965; Fiore, 1996; Bradley, 1997; Lewis 2002). Recent archaeological studies suggest that shelters and caves used by humans served for passage and stopover, where the surrounding context plays an important role on selected locations (Pastoors and Weniger 2011; Martínez-García, 2002; Berrocal et al., 2014). However, other researchers point to the idea that these shelters eventually served for human groups to portray their thoughts as a sign of ideological expression (Breuil, 1933, 1935; Conkey, 1997).

The preservation of motifs and panels within these locations is always problematic due to the occurrence of natural processes (i.e. geological factors, vegetation, lichens, humidity, bacterial activity, thermal gradient, etc.) or anthropic deterioration such as graffiti (Walderhaugh and Walderhaugh, 1998; Deacon, 2006; Aurbry et al., 2012; Giesen et al., 2014). Raised concern about the need for conservation has led to a large number of studies, focused on new technologies, providing 3D documentation of different archeological remains. These methods are based on the use of image and range sensors to record surface data from regional scale archaeological landscapes, to local scale architecture and excavations or even to small scale object surveying (Bryan et al., 1999; Hanke, 2000; Brown et al., 2001; Chandler and Fryer, 2005; Lambers and Remondino, 2007; Yastikli, 2007; Lerma et al., 2013; Domingo et al., 2013). These technologies allow the reliable acquisition of high-resolution digital data such as point clouds and orthomosaics that may help for the identification and description of the panels aiming at their documentation and preservation (Ogleby, 1995; Andrés et al., 2002; González-Aguilera et al., 2009; Lerma et al., 2010).

Neolithic rock art in Iberia is widely represented both in Spain and Portugal. The geographical distribution of schematic rock art in northwest Iberia configures a band that extends from Galicia to the western Duero Meseta (Agosta-Martínez, 1968; García et al., 1986 Pérez-Bécares, 1992; Bradley, 1997; Bradley and Fábregas-Valcarce, 1998; Blanco, 2006; Molina Hernández and de Inés Sutil, 2014) including the Batuecas, Siegaverde and Foz Coa world-class paintings and engravings (Breuil, 1918; Cabré, 1922; Alcolea, 1996; Balbín et al., 1996; Bicho et al., 2007; Baptista and Fernandez, 2007). Within this context, the Castrocontrigo Neolithic paintings can be interpreted as an example of the connection between the Atlantic façade domain and the central Spain (Mediterranean) post-paleolithic rock art.

In this work, we have studied two shelters comprising three panels characterised mainly by the presence of anthropomorphs and sun-forms together with other less recognizable abstract representations (i.e. fingerprints, circles, etc.). The location of the shelters is conditioned by geological factors, the lithology and the location of cores and limbs of coalescent folds which are affected by joint systems and conjugate faults (Fig. 1). Recent wildfires, the presence of lichens and humidity, and graffiti have contributed to damage the outcrops, causing the partial destruction of the paints. This paper deals with the 3D-documentation of the panels using a combination of robust and non-invasive geomatic approaches (based on terrestrial laser scanner and photogrammetry) and image enhancement tools for the identification, description and preservation of the rock panels. Image enhancement tools also aimed at the location of new motifs improving the comprehensiveness of the panels.

2. SCHEMATIC ROCK ART CONTEXT IN NORTHWEST SPAIN

The Iberian schematic rock art gathers different types of prehistoric drawings and engravings broadly dated between the early Neolithic and the Iron Age (Pérez-Bécares, 1991, 1992; Esparza, 1990; Gómez-Barrera, 1992; Delibes, 2000; Gómez-Barrera, 2000) and possess a natural, realistic and refined artistic quality. The first archaeological studies carried out by Breuil (1933, 1935) and Agosta-Martínez (1968) considered this type of rock art as the previous mode of communication before writing. However, different interpretations have related them to the conceptualism of ideological manifestations: religious, civil or military origin, among others (Raphael, 1945; Leroi-Gourhan, 1958, 1965; Laming-Emperaire, 1962, 1972; Fiore, 1996; Bradley and Fábregas-Valcarce, 1998).

Drawings are usually made using different techniques, resources and colours. Although the latter can be variable, analysis of bacterial activity found on rock art paints suggests the control of the authors on the establishment of colour and hue, which in turn may have favoured the paints preservation (González et al., 1999). The strong similarities between the Galician, Portuguese and western Duero basin schematic art suggest the presence of cultural permeability (i.e. acculturation) between the various human settlements that shared common interests and concerns during the Neolithic. The distribution of different settlements and their interactions may have influenced the characteristics (i.e. colours, style, etc.) and location of rock art panels and motifs (Bradley and Fábre-

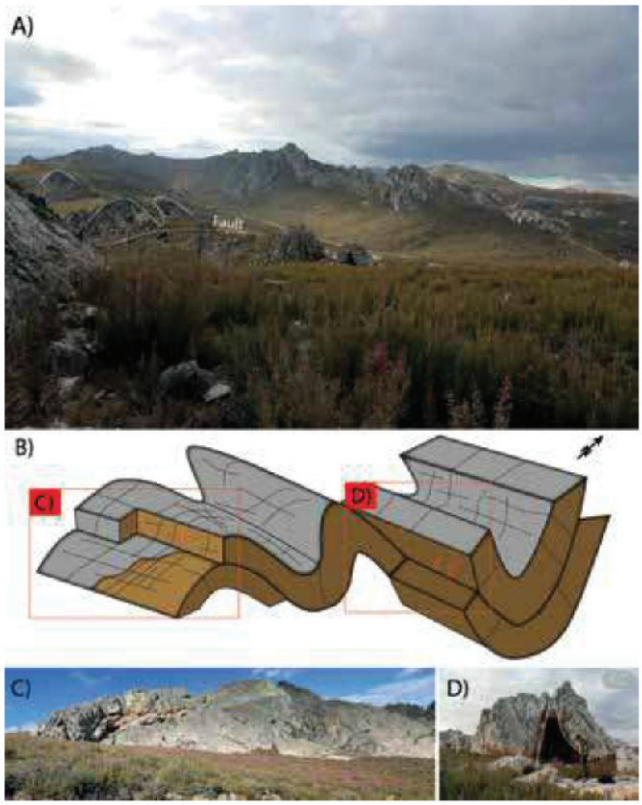

Figure 1. A) Panoramic view of the study area showing a train of folds where shelters occur. B) Schematic representation and geological relationship between folding and faulting configuring the panels location. C) Panoramic view of anticline fold. The shelter is located in the reddish quartzite beds. D) Location of the shelter in the northern limb of an anticline. It is represented by a conjugate system of faults that provide a polish surface where the rock paints are found. The outcrop is affected by jointing and a recent wildfire that strongly affected the paints

gas-Valcarce, 1996;1999); although, the location may have also responded to the suitability of the support rocks as well as to the presence of exotically coloured minerals in the surroundings (García-Arranz, 1990, Bradley and Fábregas-Valcarce, 1999).

Delibes and Del Val (2007), Sanz (2007) and Molina-Hernández and de Inés Sutil (2013) have defined three phases of Iberian Neolithic art based on the observed differences in style. Thus, a first stage is characterized by the representation of zoomorphs, sun-forms and anthropomorphs within the context of an intensive agricultural activity carried out in the valleys. This stage is interpreted to respond to occupation sites characterized by shelters during the Chalcolithic-PreCampaniform. A second phase, Campaniform-Bronze, involved the exploitation of mineral resources such as the Duero basin salt deposits of Villafáfila in Zamora (Delibes y Del Val 2007), when a partial disconnection between the main settlements and the rock art areas occurred. During this stage, rock art motifs are dominantly anthropomorphs (i.e. idols), ocular idols and zoomorphs (Molina-Hernández and de Inés-Sutil, 2013). Finally, between the Middle Bronze and Iron Age, the rise in agricultural activity led to the third final stage, interpreted to be linked to the disconnection between settlements (located near the rivers in areas of fertile soil) and the main rock art panels. During this period, the archaeological record shows a reduction of pictorial motifs and the increase in the number of engravings (anthropomorphs and zoomorphs; Martín-Valls, 1973; Molina-Hernández y de Inés-Sutil, 2013).

The presence of schematic rock art in the province of León is scarce and the style (i.e. drawing or engravings) is defined by the different types of rock in which they occur, mainly low-grade metasedimentary rocks comprising mostly slates that were quite easy to engrave (engravings) and the much harder quartzites and scarce limestones (paintings). In general, panels have been interpreted as sanctuaries or areas dedicated to cultural activities, although their significance is still a matter of debate (Fernández-Manzano, 1996; Bradley and Fábregas-Valcarce, 1998). There are at least six studied neolithic archaeological sites in the León province: Librán, Sasamo, Boudela, Filiel, Andiñuela and Castrocontrigo (Avello-Álvarez and Gutiérrez-González, 1985; Gutiérrez-González and Avello-Álvarez, 1986; Mañanes, 1987; Fernández-Manzano, 1996; Rabanal-Alonso et al., 1999; San Román-Fernández et al., 2004; San Román-Fernández, 2006; Vidal-Encinas et al., 2008; Cadierno-Guerra, 2012, 2014). Pictorial representations comprise a wide variety of zoomorphs, hands, fingerprints, idols and anthropomorphs. The latter are represented by T-types, cruciforms, Pi and Phy, Y-type, etc. (Rabanal-Alonso et al., 1999). They can appear isolated or in small groups together with zoomorphs or other geometric shapes. In the Sasamo site, astral designs such as esteliforms have been described, while the Librán area is characterised by the presence of sun representations. The paintings were made using different instruments (i.e. hands, natural brushes, etc.) and colours (red and black principally) (Gutiérrez-González and Abello, 1985). Refections and superpositions can be observed and are interpreted as indicating that they were made when the drawings were still functional (Rabanal-Alonso et al., 1999).

The study of these archaeological remains suggests that the neolithization process likely occurred before in this part of the Duero Meseta than in the Cantabrian area, further north, and was probably disseminated from the east and south of the Iberian Península (Morales-Molino and García-Antón, 2014). This process would have been influenced by the expansion of agriculture, strongly controlled by the environment (Delibes, 1985; Morales-Molino and García-Antón, 2014).

3. GEOLOGIC CONSTRAINTS IN ROCK ART

Recent archaeological works have pointed out the importance of geological and geomorphological constraints in the location and preservation of rock art panels (Aubry et al., 2012 and references therein). Differences in rock types, structure and composition may have been responsible for the distribution of rock art in northwest Iberia. These differences configured the location of engravings and imagery, which were controlled by the friability, strength and texture of the rocks (Corchón et al. 1989; Bicho et al., 2007 Collado-Giraldo and García-Arranz, 2009; Doce et al., 2012). Thus, the presence of rock art imagery (paintings) is rather scarce in western Iberia when compared with the number of discovered engravings (Agosta-Martínez, 1968; Terés-Navarro 1987; Pérez-Bécares, 1991; Bradley et al., 1994, 1997; Luis 2009b; Molina-Hernández and the Inés-Sutil, 2014).

Rock art (paintings) in western Spain is commonly found in shelters preserved in the Lower Ordovician metasediments - i.e. principally Armorican quartzites -, through a nearly continuous broad band across the boundary between Portugal and Spain (Pérez-Bécares, 1974). The Armorican quartzite is a pure quartz, fine to coarse grained sandstone affected by low-grade metamorphism organized into thick sandy beds interbedded with thin shale layers. Panels are usually found in weather protected surfaces consisting mainly of fold axis, parallel and normal joint surfaces trending NW-SE and NE-SW (normal to the shallow dipping bedding), where the latter produces natural shelters, and occasionally in fault surfaces or inside fold structures where the core has been eroded. Fold cores are regularly affected by a dense network of quartz veins and dikes, a few cm to meters long, often with iron mineralizations. The two studied shelters are located in the core of coalescent upright folds characterized by nearly vertical axial planes (Fig.1). Paintings are always located in surfaces where colours are easy to set, standing out of the rock and providing a volumetric effect. The shelters appear always close to rivers and/or in topographically high areas that dominate the landscape (700-1.200 m.a.s.l.) with good visibility of the surroundings.

4. MATERIALS AND METHODS

Traditional analysis of prehistoric rock art has been widely focused on the direct observation of images. However, the combination of new geomatic techniques and digital image treatment can improve the results by providing non-invasive qualitative and quantitative digital

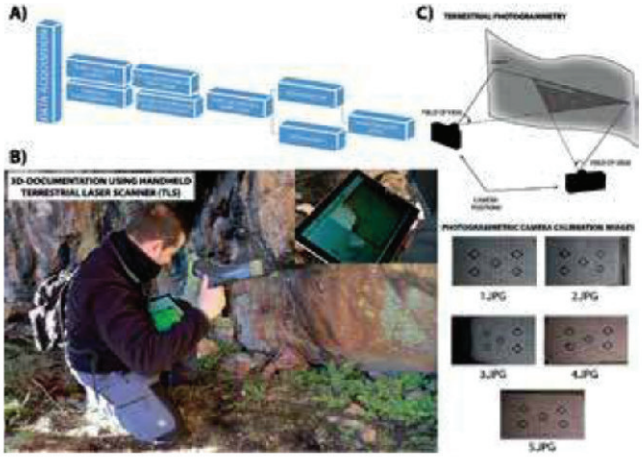

Figure 2. A) General workflow illustrating the TLS and SfM methods of 3D reconstruction. B) Outcrop documentation with Faro handheld scanner Freestyle3D and data recording shown in a tablet. C) Basic principles of terrestrial photogrammetry and camera correction based on detection of the central part of the marks for each pattern, obtaining 5 central points also known standard and 140 secondary's, known as peripheral

information, improving visualization and identifying possible superposition of different paintings or the presence of previously unseen motifs (Fig.2A). The integrated analysis of prehistoric rock art using 2D images and 3D information reduces the possible distortion problems caused by the recording of photographic images. In addition, the 3D resolution reduction -i.e. due to information loss-, during the acquisition of digital information is very minor and can be dismissed (Barnett et al., 2001; Fowles et al., 2003; Wasklewicz et al., 2005; González-Aguilera and Lahoz, 2006; Lambers and Remondino, 2007; González-Aguilera et al. 2011; Domingo et al., 2013). The generation of 3D-photorealistic models retrieves the volumetric sensation and the colours preserved by the jagged relief of the outcrop (Sunday et al. 2011; Domingo et al. 2013). The possibility to observe the panels through different angles and perspectives and the application of light enhancement by using interactive personalized visualization tools contributes to a better analysis, interpretation and description of the pictorial motifs.

4.1. 3D-Documentation

The study area is a mountainous region characterized by a strong topographic relief, where GPS signal may be strongly shadowed and receivers were proven not valuable. In addition, the studied shelters are located at high topographic elevation, and are reduced, inclined flat steeply inclined, even overhanging, rock surfaces, difficult to access, which prevents or make difficult the use of traditional terrestrial laser scanners and/or any other traditional topographic surveying method. Because of this withdrawal, 3D-documentation was acquired using a high-precision portable Faro Freestyle3D handheld structured-light 3D

scanner (SLS), commonly used for industrial purposes (Fig.2B). The small dimensions and weight (< 2 kg) of the equipment enabled the acquisition of high-resolution point clouds in reduced hard-to-reach areas such as rock shelters and rugged rock walls characterized by corners with limited visibility. A calibration prior to documentation was carried out in the laboratory to ensure the best results, considering parameters such as illumination, colour textures, temperature and humidity of the scanned area as well as the variations in reflectance provided by different rock types.

We performed 6 individual handheld scans for each surface resulting in point clouds formed by ca. 109 points with information including the position and the surface colour at each point. The 3D point accuracy was submilimetric (0.2-0.1 mm) when scanned at a distance of 1 m; the maximum volume covered by a single scan was 8 m3. The scans were performed within a distance from the object of ca. 0.30 to 0.60 m. The integrated memory-scan technology present in the used scanning device allowed us to control repeated scans, and to use the location of initial low-resolution data for further re-scanning and point cloud merging. Processing of point clouds was carried out using Faro® software SCENE®. As explained before, due to the strong topography, the use of Global Navigation Satellite Systems (GNSS) and traditional surveying methods were not suitable for georeferencing and scaling the models. Therefore, the laser scan data was used to provide the local scaling for further 2D photogrammetric restoration, adding a valuable high-resolution locally georeferenced point cloud for the subsequent digital models generation.

4.2. Digital photogrammetry

The new Structure from Motion photogrammetry (SfM) approach provides high-resolution photorealistic models by bundle adjustment of photographic images through the recognition of objects or pixel elements by comparison of several images obtained at different angles. This is a low cost, reliable and precise method for generation of dense point clouds and high-quality orthomosaics. During the last few years, photogrammetry works have been used for the documentation and preservation of rock art imagery, often combined with 3D data (González-Aguilera et al., 2006; Lerma et al., 2010; Plets et al., 2012; Lerma et al., 2014; Alexander et al., 2015).

The accuracy and resolution of the photogrammetric works strongly depend on the geometry of the images and the physical characteristics of the sensor (Mikhail et al., 2001; Linder, 2003; Bemis et al., 2014). We used a digital SLR camera CanonEOS5DMarkIII with 20 megapixels (5760x3840 pixels) and CMOS sensor (50 mm). The camera was calibrated using a calibration module in the laboratory and a minimum image overlap of 80% from different perspectives. We used ImageMaster Calib. software by Topcom® using 5 different focusing positions and the following control parameters: focal lens, radial distortion, tangential distortion and location of the principal components of the camera sensor (Fig.2C). The criteria followed for a correct calibration of the camera is based upon the assumption, that during image processing, point residuals are below 0.25 pixel. Afterwards, the camera calibration bundle adjustment of the images taken in the studied panels was performed using Agisoft Photoscan® obtaining point clouds, orthomosaics and digital models of each of them (Fig.3).

4.3. Image enhancement tools

Digital imaging of the studied rock art panels was performed using the digital camera mentioned above. However, to improve image visualization, digital processing of the images was required. In the last 20 years, the analysis of principal components, K-means, Decorrelation Stretch in RGBN images, based on photometric stereo methods have provided reliable results in enhancing the visualization of low contrast or extremely faded characteristics in rock surfaces with archeological paintings (Buchner et al. 2000, McNiven et al. 2000; Bonilla et al., 2002; Remondino and El-Hakim, 2006; Garfinkel et al. 2009; Mudge et al., 2012; Cerrillo-Cuenca et al., 2014). The study of balance, curves, brightness and hue for the identification of faded or deteriorated colours has become a widespread and accurate method for image enhancement (Brady and Gunn, 2012) especially applicable to archaeological sciences.

We used the image enhancement tools based on the decorrelation stretch algorithms implemented by Harman, (2008). This method is based on principal-component (PC) analysis and transformation of spectral information contained in the picture. The method provides contrast exaggeration by correlating the image channels displayed as R, G and B in order to expand the dark-light range of intensities by exaggerating the colour saturation, independently of the light conditions (Gillespie et al., 1986). Furthermore, in order to perform the decorrelation stretch procedure, we have used the shareware DStretch plug-in (Harman, 2008) implemented in JavaTM for ImageJTM, a freeware tool for processing and analysis developed by the US Department of Health and Human Services in 1997 (Schneider et al., 2012). Using this method, the image enhancement artificially highlights different colours by selecting a colour space and using different colour field separation increase or reduction - i.e. filtering different RGB bands -. The software computes intensity variations, adjusting hue and saturation by using different provided command matrices (YDS, YBR, YBK, CRGB, LDS, LAB, LRE and RGB for red and black

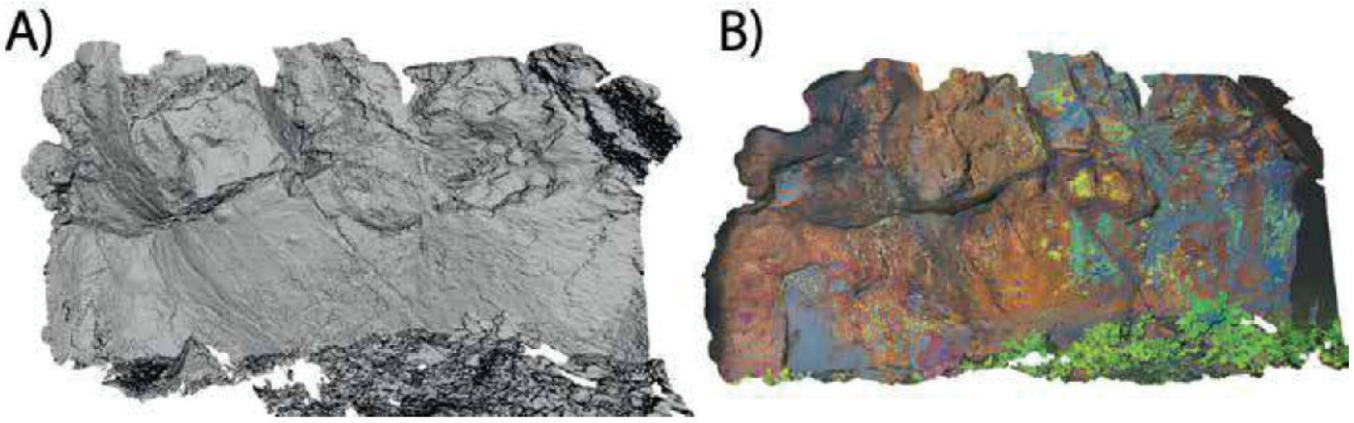

Figure 3. Processing of digital data acquired using photogrammetry A) Digital Model from panel-II and B) orthomosaic acquired using image enhancement

colours used in paints). The image improvement resulted into brining out different elements not directly observable upon direct eye recognisance of the studied panels.

5. RESULTS

The Castrocontrigo rock art comprises three panels characterised by the presence of anthropomorphs and, in two of them, sun-forms. Their characteristics, style, and state of conservation are variable and the motifs seem influenced by the location of the outcrops (i.e. within the core of an anticline, on a fault plane, etc.). We describe the results of three different panels; the first one is located at the Peña del Pozo de Rocebros, and the two others, in the same nearby shelter at the Cerro de Llamaluenga, 350 m to the NE of the first one. Ongoing research on the Castrocontrigo rock art showings is also described in Cadierno-Guerra (2014). All the studied panels take advantage of the occurrence of fractures, delamination and rock roughness, which also constrain the distribution of the compositional elements, providing volumetric feeling as suggested by other schematic rock art representations studied in the Albarracín and Sierra Morena areas by Piñón-Varela (1982) and Caballero-Klink (1983).

The new observations in the three panels provide new insights into the quantity and quality of the drawings and aims at the enhancement of the previous description and their future preservation.

Panel-I

According to the information deposited at the "Catálogo de bienes protegidos" (Junta de Castilla y León), these drawings were first discovered by Luis Crespo Cenador in 2000 in the core of a small anticline (Figs.1A and C). The site was declared Site of Cultural Interest under the Spanish regulations (B.O.E., 155, 29/06/1985) and is described as including five male anthropomorphic representations together with one circular-shaped form, all of them drawn in red colour (Ollero-Cuesta, 2000). On the left side of the panel, new motifs were found within the shelter (Fig.4A and B, respectively).

The image enhanced tools allowed the identification of 7 anthropomorphs on the lower left side of the panel and a group of six pectiforms (Fig. 5A and B, respectively).

On the right side of the panel, two of the figures are attached to each other while the others appeared separated (Fig.6A and B). Also, it is worth to notice that the central figure carries what we interpreted as a shield on the right hand, previously described as a weapon (Cadierno Guerra, 2014) or just another human figure by Ollero-Cuesta (2000) (Fig.6E).

The observation and analysis through image enhancement has allowed the identification of new motifs in this panel. On the left side, three more figures can be recognised (Fig.6A, B and E). The presence of oxides and calcite coatings has obscured the paints, and the delamination processes, likely due to thermal gradients (e.g. during wildfires, day-night temperature variations, etc.), have affected the drawings, favoring the destruction of portions of the panel (Fig.6C, D and E). The presence of water runoff has also affected part of the right-side

Figure 4. New lower left panel-I found in the rock shelter: A) original and treated images showing the presence of 7 anthropomorphs. B) Original and treated images where a group of 6 pectiforms can be identified

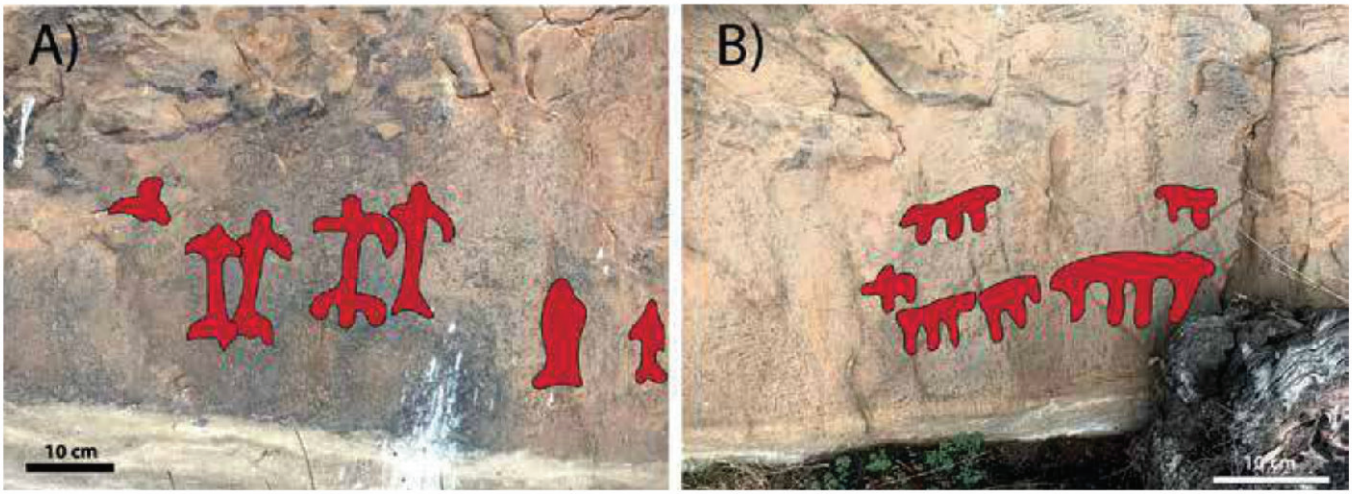

Figure 5. New lower left panel-I interpreted: A) 7 dancing anthropomorphs, some of them partially destroyed. B) A group of 6 pectiforms can be identified on the lower part of the same panel

portion of the panel possibly destroying other existing figures (Fig.6C, D and E). The figures approximately maintain the same dimensions (10 to ~15 cm), although differences between them are observed which may reflect a status pattern or the work of different artists. On the right side of the panel, at least, two more new figures can be identified. They also correspond to male human figures with the same size (10 and 15 cm). The thickness and roundness of the paint stroke suggest that the motifs were made by hand.

Panel-II

Both panels II and III are located at the same shelter in the so-called Cerro de la Llamaluenga and share the same discovery history than the nearby Panel-I paintings (Ollero-Cuesta, 2000; Cadierno-Guerra, 2014). The description of both panels will be done separately in the following paragraphs.

In Panel II, drawings appear on a polished fault plane within the northern limb of a minor anticline with its core eroded and used as a tepee-shaped shelter (Fig.1A, B and D). In the central part of the panel representations consist of three human figures (two of them identified as males, phy-type) in the upper part and a sun-form as described by Cadierno-Guerra (2014). The digital treatment by image enhancement carried out in this study has revealed new paints. In particular, two anthropomorphs and another sun-form (Fig.7).

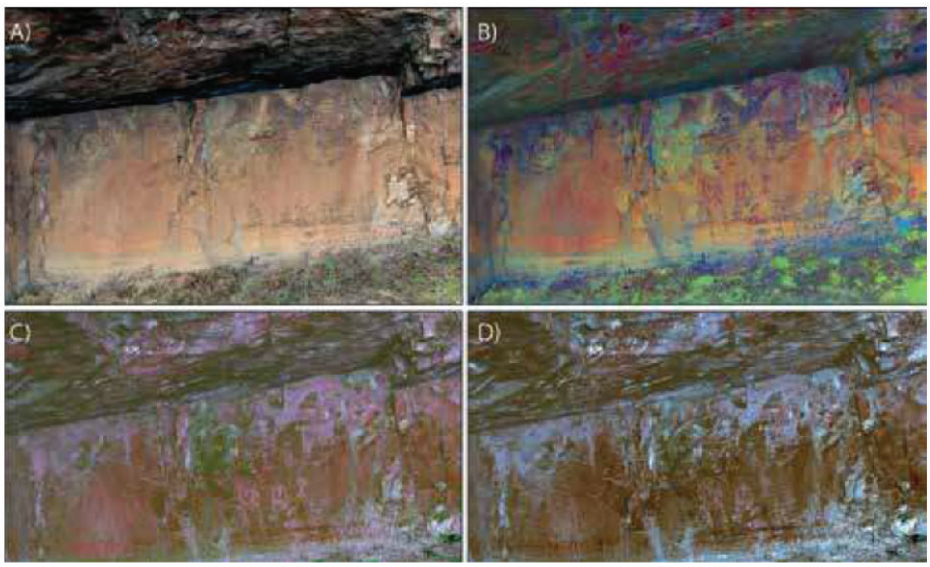

Figure 6. A) Panoramic view of Panel-I and different enhancement settings emphasizing red colours (B, C and D) according to processing by image enhancement tools following the procedure suggested by Haman (2008). B and C) show six human figures, one of them carrying a shield. There are other motifs characterised by fingerprints and circles C). The presence of water runoff and erosion destroying the panel can be seen in D). E) Interpretation based on observations carried out on B, C and D

In the upper left side of the panel, the color digital enhancement has revealed new, non-previously documented four figures and a sun-form (Fig.8). They are poorly preserved, but human shapes and the sun-form are still recognizable. A red circular motif is also observed, but it is difficult to determine whether it is natural or rock art.

The motifs´ stroke in Panel-II is thinner when compared with Panel-I, indicating that they were likely performed with an object used as a paintbrush. The size of the antrophomorphs and the sun-forms shows more variabi-

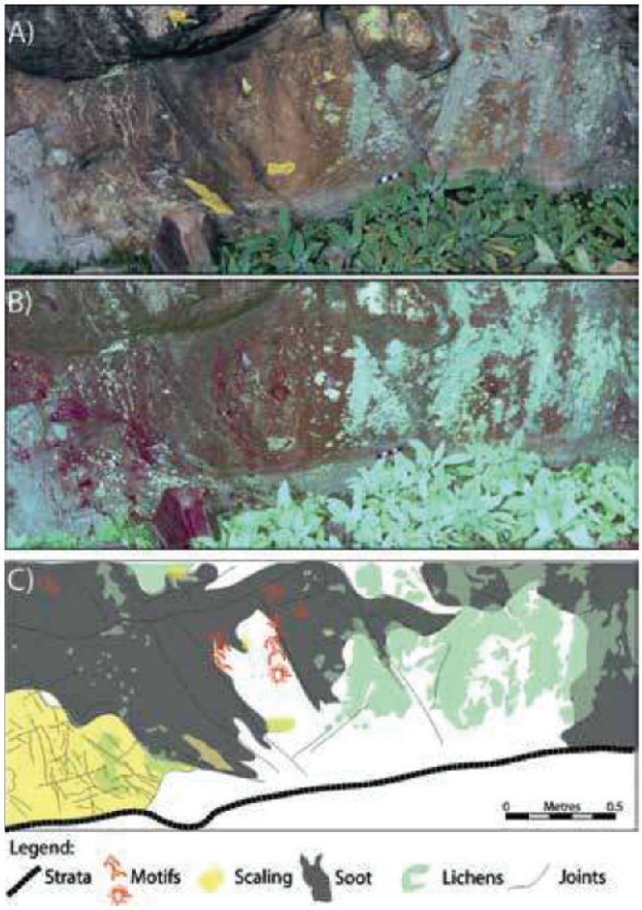

Figure 7. A) Panoramic view of Panel-II and image treated for emphasizing red colours (B) according to processing by image enhancement tools following the procedure suggested by Haman (2008). C) Interpretation based on observations carried out on B). Five anthropomorphs and two sun-forms can be distinguished despite the presence of a smoked surface affecting the panel. Another sun-form is observed in the upper left side of the panel (see text for further explanation)

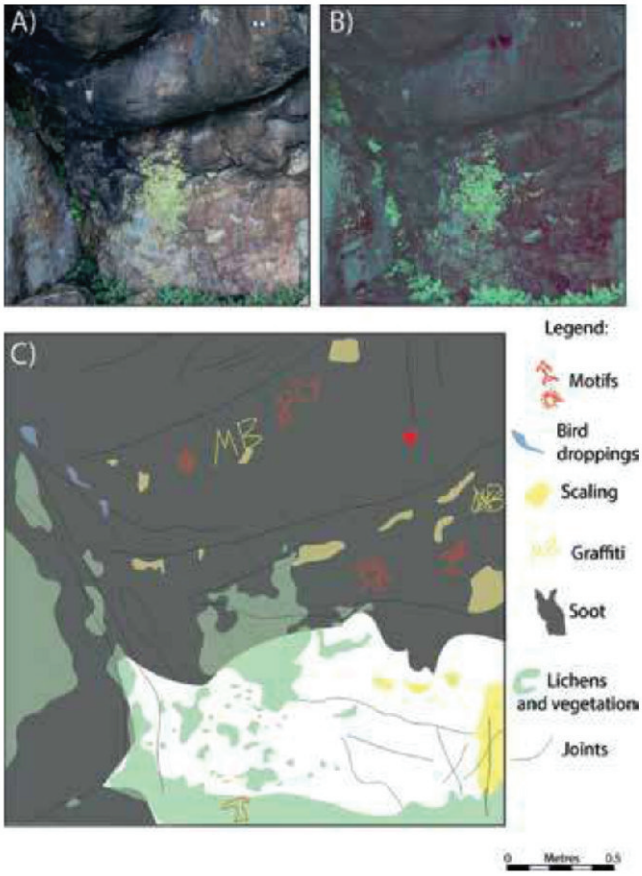

Figure 8. Represents the upper left part of Panel-II. A) Shows the panoramic view of the outcrop. B) The enhancement treatment of the image showing the location of motifs, and recent damages such as graffiti, birds shit or lichens. The area is strongly affected by recent fires destroying some figures that can still be noticed. C) Interpretation of the panel showing the presence of four anthropomorphs, a sun-form, and a circle

lity (10-20 cm) than in Panel-I. They were painted in red-brownish colours. The outcrop has been strongly damaged by delamination caused by thermal gradient, strongly increased during recent wildfires, biological destruction by lichens and bird droppings, human activity and water runoff that caused the precipitation of Fe-oxides in large portions of the panels (Fig.8).

Panel-III

The third panel is located in another surface in the same shelter than the previous Panel-II (Fig.1A, D), oriented approximately normal to it. It also takes advantage of a polished fault surface affected by the same damage that Panel I. In this panel, only one motif has been identified, which represents a phy-shaped anthropomorph (~10 cm size male) painted in red (Fig.9). The thickness of the stroke is similar to Panel-I figures, suggesting that was carried out using the hands.

6. THE CASTROCONTRIGO ROCK ART: A CONNECTION BETWEEN ATLANTIC AND DUERO MESETA CULTURAL DRIFT

The Castrocontrigo paints represent a remarkable example of the post-palaeolithic schematic Iberian rock art. The 3D documentation using terrestrial laser scanner and photogrammetry combined with image enhancement tools has improved recognition and visualization of the paints, helping the interpretation of the rock art panels. We report schematic rock art comprising a group of anthropomorphs (mainly male representations with handle hands) and sun-forms, all reproduced in red colour. The size of the motifs varies between 10-15 cm and the thickness of the stroke as

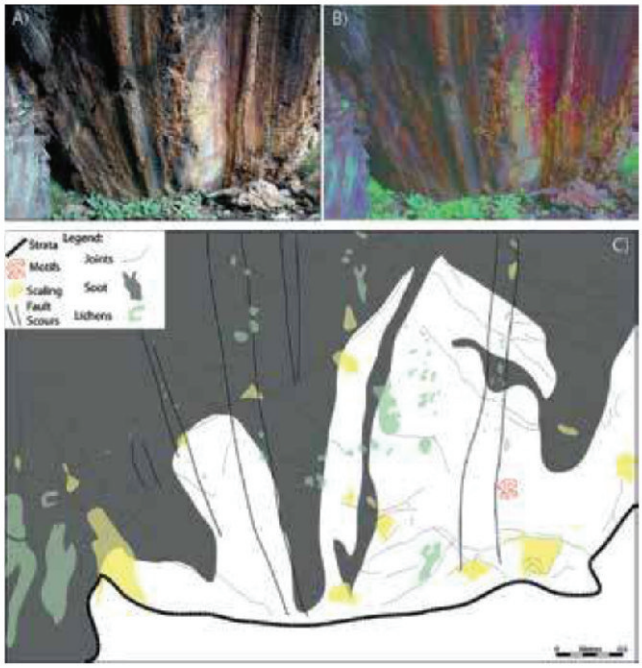

Figure 9. A) Outcrop view showing the location of the polish fault plane comprising Panel-III. B) Enhancement of red colours using image enhancement tools. C) Interpretation of the panel showing the presence of a single anthropomorph

well, indicating differences between them: size variations may respond to a status level, kinship relationships, etc.; the thickness variations observed can provide information about the technique used for the motifs creation. Thus, handmade paints are thick and rounded while paintbrush elements are thinner and more linear.

The unique representation of male motifs suggests the presence of social segmentation between male and women. These differences have been previously suggested based on observations carried out in other localities, interpreted to be used for rituals (Solomon, 1997; Hays-Gilpin, 2012), although other types of segmentation related with age or social differences may also exist (Turne, 1974). For example, the identification of a figure interpreted to be carrying a shield or a weapon in Panel-I may indicate a military ritual that could be related to ceremonial performances reserved for warriors. Another type of social segmentation is interpreted to be represented in Panel-II (Fig.5), where the presence of anthropomorphs around a sun-form suggests another type of ritual, probably related to any astronomical ceremony, and may be a sign of social distinction. This pattern has been interpreted as belonging to the representation of seasonal ceremonies or rituals focused on the sun and maybe other astronomical features in Neolithic nearby examples of the León province (Sasamo, Rabanal-Alonso, 1999).

The study of rock art representations involves the analysis and description of size, composition and location (contexts), adding specific significance to common structures (anthropomorphs, zoomorphs, etc.). Also, the panel's organization, according to Domingo (2013) can provide useful information to understand the distribution and significance of the motifs. The Castrocontrigo panels show horizontal and vertical aligneaments. Panel-I defines a horizontal allocation of motifs, where according to Domingo (2013) the space is not divided and the representation may reflect juxtaposed different social status (Fig.4). Therefore, the panel may be interpreted as to describe the importance of military groups, or other kind of rather closed groups, having access to a reserved ritual. In contrast, Panel-II defines a vertical aligneament, where space is divided, and status differences appear superimposed, not juxtaposed (Domingo, 2013). This latter type of motifs may reflect inequality, indicating two different scales of importance: the sun-forms receive major importance while the human representation is secondary in the panel as suggested by the position around the sun structure. These power relationships have been proposed to represent the centre of the social and economic transformations, which contributed to the social development of post-paleolithic cultures (Berrocal and Vicent-García, 2007). The previous interpretations may be hindered by the fact that the vertical and horizontal aligneaments observed in the Castrocontrigo motifs could also respond to the availability of space, which is in turn controlled by geological constraints as reported previously and in similar studies by Aurby et al., (2012), such as the thickness of the jointed strata, the dimensions of the polish surface along fault planes, etc.

Overall, the Castrocontrigo rock paints can be included in a group of schematic rock art that shares close similarities with other rock paints of northwestern Iberia (Agosta-Martínez, 1968; de Blas Cortina and Fernández, 1985; Romanillo et al., 1986; Gómez-Barrera, 1991; Corchón et al., 1991; Bradley, 1997; Bradley and Fábregas-Valcarce, 1999; Gómez-Barrera, 2005; Pérez-Bécares et al., 2009, etc). The style, size, colours, and location (i.e. in shelters) indicate the close relation with the Atlantic façade post-paleolithic art, which may reflect the permeability and cultural transmission occurred with other Neolithic Iberian cultures coevally present to the East and Southeast.

The use of digital technologies for 3D documentation such as laser scanner and photogrammetry is a widespread tool that has improved the study and description of rock art panels (Robson-Brown et al., 2001; Barnett et al., 2005; González-Aguilera et al., 2006, 2011; Lerma et al., 2010; Domingo et al., 2013). Two sets of 3D photorealistic digital models have been carried out, with and without image enhancement in order to show the capabilities of the method and to provide a usable resource for other researchers and/or the general public (i.e. Cerrillo-Cuenca and Sepúlveda, 2015). These 3D digital models can be consulted in the Supplementary Material Section 3D Models. The combination of the afore-

mentioned methods enhances the classical description of rock art and, in addition, helps to provide accurate and reliable information about their preservation state, including the weathering conditions of rock shelters, the presence of oxides coatings obliterating the paints or other anthropic destruction by graffiti or engravings (Aubry et al., 2012). This information is vital for carrying out a precise restoration and conservation planning of the rock art. Moreover, the acquisition of photorealistic models provides new possibilities for people awareness and archaeological tourism that can integrate 3D digital models in areas where panels are difficult to visualise or access.

7. CONCLUSIONS

The Castrocontrigo schematic rock art in northwest Spain comprises drawings located in small shelters associated with geologic structures (i.e. joints and fault planes). Elevated zones and passageways through the mountains characterise these shelters with good visibility, where social and cultural ceremonies or other rituals would have been carried out. The applied geomatic and digital methods used in this work has allowed the recognition of new schematic motifs within the studied panels, enhancing the characterization and study of them, and providing useful information about the existing conservation problems. Moreover, the acquisition of photorealistic 3D digital models ensures a better visualization and preserves useful information from possible destruction of the panels. The studied paints can be related with other similar motifs found along the western boundary of the Duero basin, providing new ideas about the connection between the Atlantic façade post-paleolithic cultures and the central Meseta, within the context of schematic rock art in northwest Spain.

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REFERENCES

Agosta-Martínez, P. (1968). La pintura rupestre esquemática en España. Memorias del Seminario de Prehistoria y Arqueología, I. Universidad de Salamanca. Salamanca.

Alcolea, J. J. (1996). Los Conjuntos Rupestres Paleolíticos al Aire Libre del Valle del Duero: El Yacimiento de Siega Verde (Salamanca). Unpublished doctoral dissertation, Universidad de Alcalá de Henares.

Alexander, C., Pinz, A., and Reinbacher, C. (2015). Multi-scale 3D rock art recording. Digital Applications in Archaeology and Cultural Heritage, 2(2), 181-195.

Andrés, A. N., Pozuelo, F. B., Marimón, J. R. and de Mesa Gisbert, A. (2012). Generation of virtual models of cultural heritage. Journal of Cultural Heritage, 13(1), 103-106.

Aubry, T., Luís, L. and Dimuccio, L.A. (2012). Nature vs. Culture: present-day spatial distribution and preservation of open-air rock art in the Côa and Douro River Valleys (Portugal). Journal of Archaeological Science, 39(4), 848-866.

Avello-Álvarez, J.L. and Gutiérrez-González, J.A. (1986). Avance al estudio de las pinturas rupestres esquemáticas de Sasamo, Vega de Espinareda (León). I Congreso Internacional de Arte Rupestre, Zaragoza-Caspe.

Balbín, R., Alcolea, J. J., and Santonja, M. (1996). Arte Rupestre Paleol´itico al Aire Libre de la Cuenca del Duero: Siega Verde y Foz Coa. Fundacion Rei Afonso Henriques, Zamora.

Barnett, T., Chalmers, A., Díaz-Andreu, M., Ellis, G., Longhurst, P., Sharpe, K. and Trinks, I. (2005). 3D laser scanning for recording and monitoring rock art erosion. International newsletter on rock art., 41, 25-29.

Baptista, A. M., and Fernandes, A. P. B. (2007). Rock art and the Côa Valley Archaeological Park: a case study in the preservation of Portugal's prehistoric parietal heritage. Palaeolithic Cave Art at Creswell Crags in European Context, edited by P. Petit, P. Bahn, and S. Rippol, Oxford University Press, Oxford, 263-279.

Berrocal, M. C. and Garcia, J. V. (2007). Rock art as an archaeological and social indicator: The neolithization of the Iberian Peninsula. Journal of Anthropological Archaeology, 26(4), 676-697.

Berrocal, M.C., López, M.S., González, A.U. and López-Sáez, J.A. (2014). Landscape construction and long-term economic practices: an example from the Spanish Mediterranean Uplands through rock art archaeology. Journal of Archaeological Method and Theory, 21(3), 589-615.

Bicho, N., Carvalho, A. F., González-Sainz, C., Sanchidrián, J. L., Villaverde, V., and Straus, L. G. (2007). The Upper Paleolithic Rock Art of Iberia. Journal of Archaeological Method and Theory, 14(1), 81-151.

Blanco, J.C.S., (2006). Una aproximación a la puesta en valor del arte esquemático y su paisaje. La sierra de la Culebra (Zamora). Arqueología y Territorio, 3. 1-16.

Bonilla, V.V., Domingo, I. and López-Montalvo, E. (2002). Las figuras levantinas del Abric i La Sarga: Aproximación a su estilo y composición. In La Sarga: Arte rupestre y territo-

rio: [Catálogo de la exposición] (pp. 101-126).

Bradley, R., Boado, F. C., and Valcarce, R. F. (1994). Rock art research as landscape archaeology: A pilot study in Galicia, north□west Spain. World Archaeology, 25(3), 374-390.

Bradley, R. and Fábregas-Valcarce, R. (1996). Petroglifos gallegos y arte esquemático: una propuesta de trabajo. Homenaje al Profesor M. Fernández Miranda. Complutum Extra, 103-110.

Bradley, R. 1997: Rock Art and the Prehistory of Atlantic Europe: Signing the Land (London).

Bradley, R., and Fábregas-Valcarce, R. (1998). Crossing the border: Contrasting styles of rock art in the prehistory of north-west Iberia. Oxford Journal of Archaeology, 18 (3), 287-308.

Bradley, R., and Fábregas-Valcarce, R. (1999). La" ley de la frontera": grupos rupestres galaico y esquemático y Prehistoria del Noroeste de la Península Ibérica. Trabajos de Prehistoria, 56(1), 103-114.

Brady, L.M. and Gunn, R.G. (2012). Digital enhancement of deteriorated and superimposed pigment art: methods and case studies. A companion to rock art, 625-643.

Breuil, H. (1918). La vallée peinte des Batuecas (Salamanca). L'Anthropologie, 29, 1-27.

Breuil, H. (1933). Les Peintures Rupestres Schématiques de la Péninsule Ibérique IL Bassin du Guadiana. Fondation Singer-Polignac. Imprimerie de Lagny. Pans.

Breuil, H. (1935). Les Peintures Rupestres Schématiques de la Péninsule Ibérique. IV Sud-Est et Est de VEspagne. Fondation Singer-Polignac. Imprimerie de Lagny. Paris

Brown, K. R., Chalmers, A., Saigol, T., Green, C. and D'errico, F. (2001). An automated laser scan survey of the Upper Palaeolithic rock shelter of Cap Blanc. Journal of Archaeological Science, 28(3), 283-289.

Bryan, P. G., Corner, I. and Stevens, D. (1999). Digital rectification techniques for architectural and archaeological presentation. The photogrammetric record, 16(93), 399-415.

Buchner, A.P., Hathout, S. and Russell B. (2000). Digital enhancement of a prehistoric rock painting from Hazlet, Saskatchewan. In 1999 International Rock Art Congress Proceedings, vol. 1, edited by P. Whitehead and L. Loendorf, pp. 19–24.

Caballero-Klink, A. (1983). La pintura rupestre esquemática de la vertiente septentrional de Sierra Morena (Provincia de Ciudad-Real) y su contexto arqueológico. Estudios y monografías 9. Museo de Ciudad Real. Ciudad Real.

Cabré. J. (1922). El Hombre Prehistórico de Las Hurdes. (Las pinturas rupestres de Las Batuecas). Coleccionismo, 116. Madrid, págs. 142-160.

Cadierno-Guerra., F. (2012). Las pinturas rupestres de Peña Piñera. Nuevos descubrimientos. Actas de las segundas jornadas de jóvenes investigadores del valle del Duero. León. 103-107.

Cadierno-Guerra., F. (2014). Las pinturas esquemáticas en la provincia de León: desde los primeros descubrimientos a la actualidad. Medina-Alcaide, M. Á., Alonso, A. J. R., Ruiz-Márquez, R. M., and Torti, J.L.S., eds. In: Sobre rocas y huesos: las sociedades prehistóricas y sus manifestaciones plásticas. 205-215.

Cerrillo-Cuenca, E., Ortiz-Coder, P. and Martínez-del-Pozo, J. Á. (2014). Computer vision methods and rock art: towards a digital detection of pigments. Archaeological and Anthropological Sciences, 6(3), 227-239.

Chandler, J.H. and Fryer, J. G. (2005). Recording aboriginal rock art using cheap digital cameras and digital photogrammetry.

Collado-Giraldo, H. and García-Arranz, J.J. (2010). Pintura rupestre esquemática sobre granito en la provincia de cáceres: los ejemplos de la Cueva Larga del Pradillo y Los Canchalejos de Belén (Trujillo). Zephyrus, 64, 15.

Conkey, M.W. (1997). Mobilizing ideologies: Paleolithic "art," gender trouble, and thinking about alternatives. In Women in Human Evolution, ed. Lori Hager, London. Routledge, 172–207.

Corchón, S., Lucas, R., González Tablas, F. and Bécares, J. (1991). El arte rupestre prehistórico en la región castellano-leonesa. Zephyrus xli–xlii, 7-18.

De Blas Cortina, M.Á. and Fernández, E.C. (1985). La cova del Demo (Boal): una estación de arte rupestre esquemático en el occidente asturiano. Boletín del Seminario de Estudios de Arte y Arqueología: BSAA, (51), 47-82.

Deacon, J. (2006). Rock art conservation and tourism. Journal of Archaeological Method and Theory, 13(4), 376-396.

Delibes, G. (2000): Del Bronce al Hierro en el Valle Medio del Duero. Zephyrus. Salamanca. pp. 293 – 309.

Delibes, G. (1985). Paleolítico, Neolítico y Calcolítico, Historia de Castilla y León, Valladolid, 8-52.

Delibes, G. and del Val, J.M. (2011). La explotación de la sal al término de la Edad del Cobre en la Meseta central española: ¿Fuente de riqueza e instrumento de poder de los Jefes Ciempozuelos? Veleia, (24-25).

Doce, E.G., Sánchez, P.J.C., García, J.F.F., Magdaleno, P.Z. and Plaza, S.L. (2012). Una referencia en el paisaje. Canchales graníticos y procesos de Neolitización en el Valle Amblés (Ávila). Rubricatum: revista del Museu de Gavà, (5), 507-516.

Domingo, I., Villaverde, V., López-Montalvo, E., Lerma, J.L. and Cabrelles, M. (2013). Latest developments in rock art recording: towards an integral documentation of Levantine rock art sites combining 2D and 3D recording techniques. Journal of Archaeological Science, 40(4), 1879-1889.

Esparza, A. (1990): Sobre el ritual funerario de Cogotas I. BSAA, LVI, pp. 106-143.

Fernández-Manzano, J. (1996). Calcolítico y Edad del Bronce

en la provincia de León. Historia de León a través de la Arqueología, 29-40.

Fiore, D. (1996). El arte rupestre como producto complejo de procesos ideológicos y económicos: una propuesta de análisis. Espacio Tiempo y Forma. Serie I, Prehistoria y Arqueología, (9).

Fowles, P. S., Larson, J. H., Dean, C. and Solajic, M. (2003). The laser recording and virtual restoration of a wooden sculpture of Buddha. Journal of cultural heritage, 4, 367-371.

García, M., Ortega, A. I., Martín, M. Á., Hortolà, P. and Zuluaga, M. C. (2001). Arte rupestre de estilo paleolítico del Portalón de Cueva Mayor de la Sierra de Atapuerca (Ibeas de Juarros, Burgos):¿cronología paleolítica o contemporánea?. Trabajos de prehistoria, 58(1), 153-169.

García-Arranz, J.J. (1990). La pintura rupestre esquemática en la comarca de Las Villuercas (Cáceres). Institución Cultural" El Brocense". Diput. Prov. De Cáceres.

Garfinkel, A.P., Austin, D. R., Earle, D. and Williams, H. (2009). Myth, Ritual and Rock Art: Coso Decorated Animal-humans and the Animal Master. Rock Art Research: The Journal of the Australian Rock Art Research Association (AURA), 26(2), 179.

Giesen, M. J., Ung, A., Warke, P. A., Christgen, B., Mazel, A. D. and Graham, D. W. (2014). Condition assessment and preservation of open-air rock art panels during environmental change. Journal of Cultural Heritage, 15(1), 49-56.

Gómez-Barrera, J.A. (1991). Contribución al estudio de los grabados rupestres postpaleolíticos de la Península Ibérica: las manifestaciones del Alto Duero.Espacio, tiempo y forma. Serie I, Prehistoria y arqueología, (4), 241-268.

Gómez-Barrera, J.A. (1992). Manifestaciones de la facies esquemática en el centro y norte de la Península Ibérica.

Gómez-Barrera, J.A. (2000): Arte Rupestre Esquemático en la Meseta Castellano-Leonesa. I Congreso da Pre-historia Recente da Península Ibé- rica. Oporto, pp. 503-527.

Gómez-Barrera, J.A. (2005). La pintura rupestre esquemática como acción social de los grupos agroganaderos en la meseta castellano-leonesa.Cuadernos de Arte Rupestre, 2005(2).

González, I., Laiz, L., Hermosin, B., Caballero, B., Incerti, C. and Sáiz-Jiménez, C. (1999). Bacteria isolated from rock art paintings: the case of Atlanterra shelter (south Spain). Journal of microbiological methods, 36(1), 123-127.

González-Aguilera, D. and Lahoz, J.G. (2006). sv3DVision: didactical photogrammetric software for single image-based modeling. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 36(6), 8.

González-Aguilera, D., Rodríguez-Gonzálvez, P. and Gómez-Lahoz, J. (2009). An automatic procedure for co-registration of terrestrial laser scanners and digital cameras. ISPRS Journal of Photogrammetry and Remote Sensing, 64(3), 308-316.

González-Aguilera, D., Muñoz-Nieto, A., Rodriguez-Gonzalvez, P. and Menéndez, M. (2011). New tools for rock art modelling: automated sensor integration in Pindal Cave. Journal of archaeological science, 38(1), 120-128.

Gutiérrez-González, J.A. and Abello, J.L., (1985). Pinturas rupestres esquemáticas de Sasamo, Vega de Espinareda (León). Centro de Investigaciones y museo de Altamira. Monografía, 12. Santander.

Gutiérrez-González, J. A. and Avello Álvarez, J. L. (1986). Las pinturas rupestres esquemáticas de Sésamo, Vega de Espinareda (León). Ministerio de Cultura.

Gillespie, A.R., Kahle, A.B. and Walker, R.E. (1986). Colour enhancement of highly correlated images. I. Decorrelation and HSI contrast stretches. Remote Sensing of Environment, 20(3), 209-235.

Hanke, K. (2000). The photogrammetric contribution to archaeological documentation of prehistory. International Archives of Photogrammetry and Remote Sensing, 33(B5/1; PART 5), 355-357.

Harman, J. (2008). Using decorrelation stretch to enhance rock art images. Online paper at (http://www.dstretch.com/AlgorithmDescription.html). Updated paper originally presented at American Rock Art Research Association Annual Meeting 2005, accessed January 2014

Hays‐Gilpin, K. (2012). Gender and Prehistoric Rock Art. A Companion to Gender Prehistory, 121-141.

Molina Hernández, F.J.M. and de Inés Sutil, P. (2014). El arte rupestre esquemático y el poblamiento durante la Prehistoria reciente en Zamora y Salamanca. In Investigaciones Arqueológicas en el valle del Duero: Del Paleolítico a la Antigüedad Tardía. Glyphos Publicaciones, 101-117

Lambers, K. and Remondino, F. (2008). Optical 3D measurement techniques in archaeology: recent developments and applications.

Laming-Emperaire, A. (1962). La signification de l'art rupestre paléolithique: méthode et applications. Doctoral Thesis. París. 424pp.

Laming-Emperaire, A. (1972). Art rupestre et organisation sociale. In Santander Symposium (pp. 65-82). Madrid: UISPP.

Lerma, J. L., Navarro, S., Cabrelles, M., and Villaverde, V. (2010). Terrestrial laser scanning and close range photogrammetry for 3D archaeological documentation: the Upper Palaeolithic Cave of Parpalló as a case study.Journal of Archaeological Science, 37(3), 499-507.

Lerma, J. L., Cabrelles, M., Navarro, S., and Seguí, A. E. (2013). Modelado fotorrealístico 3D a partir de procesos fotogramétricos: láser escáner versus imagen digital. Cuadernos de arte rupestre, 6, 85-90.

Lerma, J.L., Navarro, S., Seguí, A.E. and Cabrelles, M. (2014). Range‐Based Versus Automated Markerless Image‐Ba-

sed Techniques For Rock Art Documentation. The Photogrammetric Record, 29(145), 30-48.

Leroi-Gourhan, A. (1958). L'art pariétal: langage de la préhistoire. Editions Jérôme Millon.

Leroi-Gourhan, A. (1965). Préhistoire de l´Art Occidental. París : Mazenod.

Lewis-Williams, J. D. (2002). A cosmos in stone: interpreting religion and society through rock art (Vol. 1). Rowman Altamira.

Mañanes, T., (1987). Arqueología de la cuenca leonesa del río Sil (Laciana, Bierzo, Cabrera). Valladolid, 112pp.

Martín-Valls, R. (1973). Hallazgos arqueológicos en la provincia de Zamora. Boletín del Seminario de Estudios de Arte y Arqueología: BSAA, (39), 403-414.

Martínez-García, J. (2002). Pintura rupestre esquemática: el panel, espacio social. Trabajos de prehistoria, 59(1), 65-87.

McNiven, M.A., Kim, L., Krueger, E.W., Orth, J.D., Cao, H. and Wong, T.W. (2000). Regulated interactions between dynamin and the actin-binding protein cortactin modulate cell shape. The Journal of cell biology, 151(1), 187-198.

Morales-Molino, C. and García-Antón, M. (2014). Vegetation and fire history since the last glacial maximum in an inland area of the western Mediterranean Basin (Northern Iberian Plateau, NW Spain). Quaternary Research, 81(1), 63-77.

Mudge, M., Schroer, C., Noble, T., Matthews, N., Rusinkiewicz, S., Toler-Franklin, C. (2012) Robust and scientifically reliable rock art documentation from digital photographs. In: McDonald J, Veth P (eds) A companion to rock art. Wiley, New York, pp 644–659.

Ogleby, C.L. (1995). Digital technology in the documentation and management of rock art. Preservation of rock art, 80-87.

Ollero-Cuesta, F.J. (1985) Pintura rupestre de la peña del pozo rocebros. Inventario arqueológico de la Junta de Castilla y León. Available online at: http://servicios.jcyl.es/pweb/downloadDocumento.do?numbien=4584&numdoc=68983.

Pastoors, A. and Weniger, G. C. (2011). Close-Range sensing for generating 3D objects in Prehistoric Archaeology. In Proceedings of the ISPRS WGII/5 Workshop. 18, 19. 11pp.

Pérez-Bécares, J. (1974): Nuevas pinturas en Las Batuecas: El Covacho del Pallón. Zephyrus, XXV. Salamanca. Pp: 281-294.

Pérez-Bécares, J. (1991): La pintura rupestre esquemática en la provincia de Salamanca. Museo de Salamanca. Salamanca.

Pérez-Bécares, J. (1992): El arte esquemático en la provincia de Salamanca. La pintura rupestre esquemática. Actas del I Congreso de Salamanca, Salamanca, pp: 209-228.

Pérez-Bécares, J., De la Higuera, M.C.R., Fuentes, A. G. and Civieta, C. (2009). Pinturas rupestres esquemáticas del Bonete del Cura (Ciudad Rodrigo, Salamanca). Zephyrvs, 30.

Piñón-Varela, F. (1982). Las pinturas rupestres de Albarracín. Colección Monografías del Museo y Centro de Investigación de Altamira. Ministerio de Cultura Publicaciones. 244pp.

Plets, G., Gheyle, W., Verhoeven, G., De Reu, J., Bourgeois, J., Verhegge, J. and Stichelbaut, B. (2012). Three-dimensional recording of archaeological remains in the Altai Mountains. Antiquity, 86(333), 884-897.

Rabanal-Alonso, M.A., García-Martínez, S.M., De Quirós F.,-Campos, A.N., Sánchez-Lafuente, J. and González Alonso, E. (1999). La Historia de León, Prehistoria y Edad Antigua. Tomo-I. Universidad de León, 416 pp.

Raphael, M. (1945). Prehistoric cave paintings (Vol. 4). Pantheon Books.

Remondino, F. and El-Hakim, S. (2006). Image-based 3D modeling: a review. The Photogrammetric Record 21(115): 269–291.

Romanillo, J. A. M. and García-Soto, E. (1986). Los grabados en la Cueva de San García (Santo Domingo de Silos, Burgos). Numantia: Arqueología en Castilla y León, (2), 193-206.

San Román-Fernández, F., Bernardo de Quizós, F., Fernández-rodríguez, C., Neira Campos, A. (2004). Memoria del estudio de las pinturas rupestres esquemáticas de Librán y San Pedro Mallo. Inédito. Delegación de Patrimonio de León.

San Román-Fernández, F. (2006). Librán y San Pedro Mallo: nuevas estaciones de arte rupestre esquemático en la provincia de León. In: Martínez-García J., Hernández Pérez M.S., eds. Actas del congreso de arte rupestre esquemático en la península ibérica: comarca de los Velez.

Sanz. S. (2007). Cuestiones sobre el poblamiento y los modos de vida en el neolítico interior de la península ibérica. Cuadernos de prehistoria y arqueología, (33), 7-30.

Sastre, F.J.G.T. and Del Brío, R.G. (2009). Las pinturas rupestres de las Peñas del Gato. Zephyrvs, 34.

Sauvet, G., Sainz, C.G., Sanchidrián, J.L. and Villaverde, V. (2014). Europe: Prehistoric Rock Art. In Encyclopedia of Global Archaeology (pp. 2599-2612). Springer New York.

Schneider, C. A., Rasband, W. S. and Eliceiri, K. W. (2012). NIH Image to ImageJ: 25 years of image analysis. Nat methods, 9(7), 671-675.

Solomon, A. (1997). Landscape, form and process: some implications for San rock art research. Natal Museum Journal of Humanities, 9, 57-73.

Straus, L.G. (1987). The Paleolithic cave art of Vasco□Cantabrian Spain.Oxford Journal of Archaeology, 6(2), 149-163.

Sunday E., Popelka-Filcoff, R.S., Darling, J.A. and Glascock, M. D. (2011). Hematite sources and archaeological ochres from Hohokam and O'odham sites in central Arizona: an experiment in type identification and characterization.

Journal of Archaeological Science, 38(11), 3019-3028.

Teres-Navarro, E. (1987). Pinturas rupestres en El Raso de Candeleda. Rev. Arqueología, 73, 60-61.

Turner, B.L. (1974). Prehistoric intensive agriculture in the Maya Lowlands. Science 185:118-124.

Valladas, H., Cachier, H., Maurice, P., de Quirost, F. B., Clottes, J., Valdes, V.C., Uzquiano, P. and Arnold, M. (1992). Direct radiocarbon dates for prehistoric paintings at the Altamira, El Castillo and Niaux caves. Nature 357, 68–70.

Vidal-Encinas, J. M. V., Rodríguez, C. F., Marcos, M. E. P. and Prieto, M. N. F. (2008). Los hombres mesolíticos de La Braña-Arintero (Valdelugueros, León): un hallazgo funerario excepcional en la vertiente meridional de la cordillera cantábrica. Férvedes: Revista de investigación, (5), 153-164.

Walderhaug, O. and Walderhaug, E. M. (1998). Weathering of Norwegian rock art—a critical review—. Norwegian Archaeological Review, 31(2), 119-139.

Wasklewicz, T., Staley, D., Volker, H., and Whitley, D. S. (2005). Terrestrial 3D laser scanning: A new method for recording rock art. INORA, 41, 16-25.

Yastikli, N. (2007). Documentation of cultural heritage using digital photogrammetry and laser scanning. Journal of Cultural Heritage, 8(4), 423-427.

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