Case study

3D digital documentation and image enhancement integration into schematic rock art analysis and preservation: The Castrocontrigo Neolithic rock art (NW Spain)

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A B S T R A C T

The Castrocontrigo rock art, located in the southwestern area of the León province (Spain), is one of the Neolithic rock art occurrences in northwest Iberia. The showings comprise three schematic panels within two rock shelters characterised by the presence of anthropomorphs and sun-forms. This paper deals with the digital description and documentation of the two shelters using non-invasive procedures based on portable white-light scanner, photogrammetry and digital image enhancement. The acquisition of 3D digital information in combination with the application of image enhancement tools aimed to improve visualization and analysis of motif’s degradation by delamination and water runoff. Additionally, enhancement was used to reveal the presence of new motifs in poorly preserved sectors of the studied panels aiming at their conservation. The generation of photorealistic models from the outcrops aims also to better visualization of the motifs from different angles and perspectives, providing valuable qualitative and quantitative information for archaeologist, historians and the general public.

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1. Introduction and research aims

The access to geomatic technologies has provided new and improved techniques for digital documentation and rock art conservation directives. The preservation of cultural heritage archaeological motifs and panels 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 [1–4]. Raised concern about the need for preservation has led to a large number of studies, focused on new technologies, providing 3D reliable 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 [5–12]. These technologies allow the 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 digital documentation and preservation [13–16].

In this work, we have studied two rock 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.). These motifs represent a good example of the connection between the Atlantic façade domain and the central Spain (Mediterranean) post-paleolithic rock art (allegedly between the Chalcolithic and the Iron Age). The location of the shelters is conditioned by geological factors, lithology, bedding attitude and joints (fractures) distribution. 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 presents comprehensive and detailed 3D documentation of the panels using a combination of robust and non-invasive geomatic approaches (based on portable white-light 3D scanning and photogrammetry) and image enhancement tools for the identification, description and preservation of the rock panels. The latter also aimed at the location of new motifs, improving the comprehensiveness of the panels.

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2. Schematic Rock Art 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 [17–21]. Drawings are usually made using different techniques, resources and colours.

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, 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 [22,23]. There are at least six studied Neolithic archaeological sites in the León province, Librán, Sésamo, Boudela, Filiel, Andiñuela and Castrocontrigo [22,24–31]. 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. [27]. They can appear isolated or in small groups together with zoomorphs or other geometric shapes. The paintings were made using different instruments (i.e. hands, natural brushes, etc.) and colours (red and black principally) [24].

3. Materials and methods

Traditional analysis of prehistoric rock art has been widely focused on the direct observation of drawings and/or photographic images. However, the advent and combination of geomatic techniques and digital image treatment can improve the results by providing non-invasive qualitative and quantitative digital information, enhancing visualization and identifying possible superposition of different paintings or the presence of previously unseen motifs. The integrated analysis of prehistoric rock art using 2D images and 3D information reduces the possible distortion problems caused by the recording of drawings and/or photographic images. In addition, the 3D resolution reduction —i.e. due to

![Fig. 1. A. Panoramic view of Panel I and different enhancement settings emphasizing red colours (B–D) according to processing by image enhancement tools following the procedure suggested by Haman [52]. B and C show six human figures, one of them carrying what we interpret as a shield. There are other motifs characterized by fingerprints and circles C. The presence of water runoff and erosion destroying the panel can be seen in D. E. Sketch with the interpretation of the motifs based on observations carried out on B, C and D (red motifs represent newly described motifs, see text for further explanation).](image-url)
information loss—, during the acquisition of digital information is very minor and nowadays can be dismissed [9,12,32–35]. The generation of 3D-photorealistic models also retrieves the volumetric sensation and the colours preserved by the jagged relief of the outcrop [12,36]. The possibility to observe the panels through different angles and perspectives and the application of colour enhancement by comparing the original and enhanced models contributes to a better analysis, interpretation and description of the pictorial motifs.

3.1. Documentation

The study area is a mountainous region characterized by a complex topographic relief, where GPS signal may be strongly shadowed and receivers were proven not valuable due to the limited space for data acquisition. Moreover, the use of traditional topographic techniques is also a time-consuming task—because it is necessary to locate a GPS RTK receptor combined with the use of a Total Station (TS)—, which requires complex post-processing tasks for coordinate transformations, and it is not free of errors. Because of these reasons, we have used a relative coordinates system that, in this case, provides better accuracy. The studied shelters are located at high topographic elevation (ca. 1260 m.a.s.l.), in steeply inclined, even overhanging, rock surfaces, difficult to access, which makes difficult the use of traditional terrestrial laser scanners and/or any other traditional topographic surveying method (TS). 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. The small dimensions and weight (<2 kg) of the equipment enabled the acquisition of high-resolution point clouds in rock shelters and rugged rock walls characterized by corners with limited visibility. The acquired structured-light point cloud served as a reference to constrain the accuracy of the photogrammetric work. A calibration prior to documentation was carried out to ensure the best results, taking into account parameters such as illumination, color textures, temperature and humidity of the scanned area as well as the variations in reflectance provided by different rock types. In addition to portability, SLS scanning shows several advantages to laser scanners: (i) increase accuracy due to the multiple surface readings; (ii) higher scanning speed (about 1 scan/second); and (iii) safety. On the other hand, SLS are sensible to lighting conditions, which eventually can make difficult the scanning under non-appropriate conditions (strong and direct sunlight or shiny surfaces, for example).

We performed 6 individual handheld scans for each studied surface resulting in point clouds formed by approx. 10^8 points when merged together. The information includes the relative position and the surface colour at each point. The 3D point cloud accuracy obtained with the SLS was a millimetre when scanned at a distance less of 1 m; the maximum area covered by a single scan was 8 m². 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 perform 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®, point interpolation was performed during processing, enhancing the model resolution up to c. 0.2 mm. The portable scan data was further used to provide the local scaling of the 2D–3D photogrammetric restoration, adding a valuable high-resolution locally georeferenced point cloud for the subsequent digital models generation.

3.2. Photogrammetry

The new Structure from Motion photogrammetry (SfM) range image approach [37], based on the acquisition of 3D information from correlation of 2D images, 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. Therefore, SfM refers to the phenomenon by which observers can build 3D structures from the projected 2D motion field of a moving object. 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 [16,38–40]. The accuracy and resolution of the photogrammetric works strongly depend on the geometry of the images and the physical characteristics of the sensor [41–43]. We used a digital SLR camera Canon EOS 5D MarkIII with 20 megapixels (5760 × 3840 pixels) and CMOS sensor (50 mm). Several bull’s eyes were used to mark the position of reference points (control points) that aimed to constrain the point clouds accuracy by using the same reference points acquired with the portable white-light scanner. The photogrammetric point cloud accuracy was within millimetres (see Supplementary Material Quality Report). The camera was calibrated using a calibration module 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. 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.

3.3. Image enhancement tools

Digital imaging and enhancement of the studied rock art panels was performed using the RAW images obtained with the digital camera aforementioned. Thus, we ensured the high-quality and high-resolution of the enhanced images for the analysis and recognition of new motifs. Several images were merged into a single mosaic and the lens correction was carried out to dismiss the distortion effect. Final images were exported into a high-resolution .jpg file format for further treatment of the image. 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 [44–50]. 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 [51] especially applicable to archaeological sciences.

We used the image enhancement tools based on the decorrelation stretch algorithms implemented by Harman [52]. 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 augmenting the colour saturation, independently of the light conditions [53]. Furthermore, in order to perform the decorrelation stretch procedure, we have used the shareware DStretch plug-in [52] implemented in Java® for ImageJ™, a freeware tool for processing and analysis firstly developed by the US Department of Health and Human Services in 1997 [54]. 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 colours used in paints). The image improvement resulted into sharpening the recognised motifs and bringing out different elements.

![Image](https://example.com/image.png)

**Fig. 3.** Upper left part of Panel II. A. Standard photographic image of the complete panel. B. Colour enhanced image showing the location of motifs, and recent damages such as graffiti, bird’s droppings or lichens. The area is strongly affected by recent fires, almost destroying some figures that can still be barely noticed. C. Interpretation of the panel showing the presence of four anthropomorphs, a sun-form, and a circle (see text for further explanation).
not observable upon direct eye observation of the studied panels.

4. 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 nature and size of the motifs seem to be influenced by the location of the outcrops. We describe the results of three different panels: the first one is located at the Peña del Pozo de Roce-bros, 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 Caderno-Guerra [31]. 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.

The new observations in the three panels provide new insights into the quantity and quality of the drawings and aims at the enhancement of previous descriptions and their future preservation. Digital 3D models of the studied shelters depicting the geometry of the surfaces with merged colour enhanced images can be found in the Supplementary Material Panels.

4.1. 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. 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 [55]. Two of the figures are attached to each other while the others appeared separated (Fig. 1A 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 [31] or just another human figure by Ollero-Cuesta [55] (Fig. 1).

The observation and analysis through image enhancement has allowed the identification of new motifs in this panel. On the left side, three more partially erased figures can be recognised (Fig. 1A, 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.), has affected the drawings,favoring the destruction of portions of the panel (Fig. 1C–E). The presence of water runoff has also bleached part of the right side portion of the panel possibly destroying other existing figures (Fig. 1C–E). 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. A 3D representation of the panel can be found in the Supplementary Material Panels/Panel 1.

4.2. Panels II and III

Both panels II and III are located within the same shelter, at the so-called Cerro de la Llamaluenga and share the same discovery history than the nearby Panel I paintings [31,55]. 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. 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 [31]. The digital treatment by image enhancement carried out in this study has revealed new paints. In particular, two faded anthropomorphs and another sun-form (Fig. 2).

In the upper left side of the panel, the colour digital enhancement has revealed new, non-previously documented four figures and a sun-form (Fig. 3 and Supplementary Material Panels/Panel II). 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 anthropomorphs and the sun-forms shows more variability (10–20 cm) than in Panel I. They were painted in red-brownish colours. The outcrop has been strongly damaged by scaling and delamination caused by thermal gradient, strongly increased during recent wildfires, biological destruction by lichens and bird droppings, human activity and water runoff that has covered large portions of the panels with Fe-oxides (Fig. 3).

Panel III is located in another surface in the same shelter than the previous Panel II, oriented approximately normal to it. It also takes advantage of a polished fault surface affected by the same damage that Panel II. In this panel, only one motif has been identified, which represents a phy-shaped anthropomorph (~10 cm size male) painted in red (Fig. 4). The thickness of the stroke is similar to Panel I figures, suggesting that was carried out using the hands. A 3D representation is shown in the Supplementary Material Panels/Panel III.

5. Conclusions

The Castrocontrigo schematic rock art in northwest Spain comprises drawings located in small shelters. The geomatic and digital methods used in this work has allowed the recognition of new schematic motifs located in small shelters in the area of Castrocontrigo (NW Spain). The SLS technology has been proven as an extremely useful tool for documentation of rock art located in inaccessible sites, providing point clouds that compete in resolution with less portable laser scans. Within the studied panels, the 3D documentation and image enhancement analysis has improved the characterization and study of the motifs, 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.

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Appendix A. Supplementary data

Supplementary data can be found, in the online version, at http://dx.doi.org/10.1016/j.jculher.2017.01.008.

References


