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MENGA 04

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Menga es una publicación anual del Conjunto Arqueológico Dólmenes de Antequera (Consejería de Educación, Cultura y Deporte de la Junta de Andalucía). Su objetivo es la difusión internacional de trabajos de investigación científicos de calidad relativos a la Prehistoria de Andalucía.

Menga se organiza en cuatro secciones: Dossier, Estudios, Crónica y Recensiones. La sección de Dossier aborda de forma monográfica un tema de investigación de actualidad. La segunda sección tiene un propósito más general y está integrada por trabajos de temática más heterogénea. La tercera sección denominada como Crónica recogerá las actuaciones realizadas por el Conjunto Arqueológico Dólmenes de Antequera en la anualidad anterior. La última sección incluye reseñas de libros y otros eventos (tales como exposiciones científicas, seminarios, congresos, etc.).

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Menga is a yearly journal published by the Dolmens of Antequera Archaeological Site (the Andalusian Regional Government Ministry of Education, Culture and Sport). Its aim is the international dissemination of quality scientific research into Andalusian Prehistory.

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Menga is open to original and unpublished papers that have not been submitted for publication to other journals. All original manuscripts will be submitted to an external and anonymous peer-review process before being accepted for publication. In exceptional cases, the editorial board will consider the publication of Spanish and English translations of already published papers on the basis of their interest and/or the difficulty of access to their content.

Figurilla antropomorfa procedente de Marroquíes Bajos (Jaén).
Foto: Miguel A. Blanco de la Rubia

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ROCK ART AND DIGITAL TECHNOLOGIES: THE APPLICATION OF REFLECTANCE TRANSFORMATION IMAGING (RTI) AND 3D LASER SCANNING TO THE STUDY OF LATE BRONZE AGE IBERIAN STELAE

Marta Díaz-Guardamino y David Wheatley[1]

Abstract:

In spite of a long-standing research tradition, the study of Late Bronze Age Iberian stelae has been severely limited by a very fundamental shortcoming: the inaccuracy of the methods and techniques that have been employed to record, examine and reproduce these stones and their engravings. This paper will describe the recent application of two innovative techniques, namely Reflectance Transformation Imaging and 3D laser scanning, to record various Late Bronze Age stelae found in the South of the Iberian Peninsula. It will then comment on the preliminary results of this undertaking and their implications for current research on Late Bronze Age Iberian stelae. Finally, it will assess the potentials and limitations of these techniques for recording and interpreting Late Bronze Age Iberian stelae in particular, and prehistoric Rock Art in general.

Keywords: Rock Art, Late Bronze Age Stelae, Digital Technologies, Recording Techniques, Polynomial Texture Mapping, Reflectance Transformation Imaging, 3D Laser Scanning.

ARTE RUPESTRE Y TECNOLOGÍAS DIGITALES: LA APLICACIÓN DE REFLECTANCE TRANSFORMATION IMAGING (RTI) Y ESCANEADO LÁSER 3D AL ESTUDIO DE LAS ESTELAS DEL BRONCE FINAL DE LA PENÍNSULA IBÉRICA

Resumen:

A pesar de contar con una larga trayectoria, la investigación dedicada a las estelas decoradas del Bronce Final en la Península Ibérica ha estado seriamente limitada por un aspecto fundamental: la inexactitud de los métodos y técnicas que se han empleado para el registro, examen y reproducción de sus soportes y grabados. Este artículo describe la reciente aplicación de dos técnicas innovadoras (*Reflectance Transformation Imaging* y escaneado láser 3D) para el registro de varias estelas decoradas del Bronce Final documentadas en el sur de la Península Ibéri*ca*. Se ofrecen algunos resultados preliminares y reflexiones en torno a sus implicaciones para la investigación actual dedicada a las estelas del Bronce Final. Para acabar, el artículo valorará el potencial y limitaciones de estas técnicas para el registro e interpretación de las estelas del Bronce Final en particular y del Arte Rupestre prehistórico en general.

Palabras clave: Arte rupestre, estelas del Bronce Final, Tecnologías Digitales, técnicas de registro, Mapeado de Texturas Polinomial, *Reflectance Transformation Imaging*, Escaneado Láser 3D.

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1. IBERIAN LATE BRONZE AGE STELAE AND TRADITIONAL GRAPHIC RECORDING METHODS

"Late Bronze Age (decorated) stelae" is used in this article as a conventional term that encapsulates a variable and complex phenomenon[1]. It refers to a series of stone stelae that are inscribed with engravings reproducing varied, more or less conventionalized, iconographies which may bear broad geographic distributions. These stelae are known in various regions of the Iberian Peninsula but are particularly dense in the Guadalquivir Valley (South) and the South-West of the Central Meseta. Their chronological attribution has been a matter of some debate. Various authors have considered their possible relationship with previous engraving and sculptural traditions (*i.e.* Almagro-Gorbea, 1993; Bueno Ramírez *et al.*, 2005a, 2010; Díaz-Guardamino, 2010: 327-46, 2011). Within this perspective, it has been recently suggested that their 'emergence' as differentiated iconographic traditions could have taken place during the late Middle Bronze Age or early Late Bronze Age (*ca.* 1425/1250 cal. BCE) and their manufacture could have lasted in some regions until the beginning of the Iron Age (*ca.* 800/750 cal. BCE) (Díaz-Guardamino, 2010: 346-61, 2012).

Late Bronze Age (hereafter LBA) decorated stelae are striking visual displays. They have variable sizes but are generally large sized (between *ca.* 0.50-1.60 m), and usually present regularized shapes. Typically, in one of their surfaces, they present a series of engraved, more or less standardized, motifs of variable size that are arranged over the surface of the stone following broadly shared conventions. Their iconography is centred on the 'presentation' of personages, who are generally represented through static bodies adorned or surrounded by various 'things', such as elements of dress and adornment, weapons, and other elements of 'prestige'. In some occasions there are stelae with various personages, which are represented either as static or active beings that may be part of broader narratives. These were conspicuous monuments, for they were set in the landscape, usually nearby older remains, contemporary settlements and/or passageways (for a recent review see: Díaz-Guardamino, 2010).

Research on LBA decorated stelae has a long-lasting history. The first stela known to scholars was published in 1898 by Mario Rosso de Luna (Rosso de Luna, 1898). Since then, more than one hundred articles publishing newly discovered stelae and various books or lengthy book sections dedicated to the topic have been published (Almagro Basch, 1966; Pingel, 1974; Almagro-Gorbea, 1977: 159-94; Gomes and Monteiro, 1977; Barceló, 1989; Galán Domingo, 1993; Celestino Pérez, 2001; Harrison, 2004; Díaz-Guardamino, 2010). Despite this long-standing research tradition, there are many aspects of LBA stelae that remain largely unexplored and/or unknown, such as the contexts in which they were placed, their surrounding landscapes or the social contexts in which they were produced. To a great extent this situation is the result of the research interests that have guided the study of LBA stelae, generally focused on the formal analysis of their iconography. Until now little attention has been placed on innovative questions, such as their landscape dimension or the technological aspects involved in their manufacture, for instance. This situation has also resulted in the application of very traditional methodological standards, which, apart from a few exceptions, are still preponderant.

Already since the late 1990s and early 2000s, other comparable research themes in the Iberian Peninsula, such as Palaeolithic, Levantine or Megalithic Rock Art, have benefited from innovative research questions that have promoted the application of modern techniques such as Geographic Information Systems (*i.e.* Fairén-Jiménez, 2002; Cruz Berrocal, 2004), Photogrammetry (*i.e.* Buchón Moragues *et al.*, 2002), Digital Image Enhancement techniques (*i.e.* Domingo and López Montalvo, 2002; Bueno Ramírez and Balbín Behrmann, 2006), Digital Image Analysis (*i.e.* Montero Ruiz *et al.*, 1998; Rogerio Candelera, 2007) or direct C14 dating of paintings (*i.e.* Carrera Ramírez and Fábregas Valcarce, 2002). Occasionally, research on Early and Middle Bronze Age stelae and statue-menhirs has also included the application of advanced technologies such as Digital Image Enhancement techniques (Teira Mayolini and Ontañón Peredo, 2000; Bueno Ramírez *et al.*, 2005b) and Geographic Information Systems (Fábrega-Álvarez *et al.*, 2011).

1 This term includes the stelae that are typically known as "Warrior stelae", "South-western stelae" or "Extremaduran stelae", as well as the so-called "Diademated stelae" or "Stelae with headdress" attributed to the Late Bronze Age.

Research on LBA stelae profited from the application of quantitative analysis methods for the examination of their iconographic variability in two works during the late 1980s and early 1990s (Barceló, 1989; Galán Domingo, 1993). Yet, since then and until very recently, neither quantitative nor other 'new' methods have been applied for the recording and/or analysis of LBA stelae. Recently, some works have employed Geographic Information Systems to map and assess their spatial setting at different scales (García Sanjuán *et al.*, 2006; Díaz-Guardamino, 2010; Celestino Pérez *et al.*, 2011) or to analyse their spatial relationship with passage ways in a particular region (Celestino Pérez *et al.*, 2011: 142-4; Rodríguez Zamora, 2013).

Regarding the graphic recording of LBA stelae, there has been a total absence of innovation. The documentation of LBA stelae has been generally focused on the two-dimensional recording of engraved motifs through traditional recording methods. This has been particularly detrimental, for the quality of the primary data is in some cases rather low, not even capable of contributing to traditional research questions, which are typically concentrated on the identification and interpretation of motifs. In some occasions researchers have been faced with two rather different interpretations of the engraved motifs found on the same stela. Attempts to answer more innovative questions such as the techniques employed in their manufacture (*i.e.* Díaz-Guardamino, 2010; Enríquez Navascués and Fernández Algaba, 2010) or the different interventions involved in their present configuration (*i.e.* Harrison, 2004; Díaz-Guardamino, 2010) have been restricted by the limitations of the recording techniques used or/ and the lack of detail with which many of the published reproductions have been undertaken.

Interestingly, most works that have included the publication of new recordings, of either newly documented or already known stelae, do not comment upon the techniques employed for their documentation (*i.e.* Celestino Pérez, 2001; Domínguez de la Concha *et al.*, 2005). This lack of explicitness has also been unfavourable, for it has prevented researchers to be able to assess the quality of the reproductions that have been published. By considering the time in which particular stelae have been studied or the resulting interpretative drawings, it is possible to infer that most of them are either scale drawings, tracings made from photographs or directly drawn from the stela with the use of polyvinyl plastic sheets and permanent markers, all probably aided by the visualization of the stela's surface with oblique light. Nowadays, tracing from digital photographs or direct tracing are usually supported by vector graphics software (such as *Adobe Illustrator* or *Corel Draw*). Direct tracing is commonly used for the graphic recording and reproduction of engraved rock art in Spain (*i.e.* Domínguez García and Aldecoa Quintana, 2007: 18-9; Seoane Veiga, 2009). In the case of LBA stelae, direct tracing seems to be the preferred method among Portuguese scholars, who tend to note the techniques they have employed more frequently (*i.e.* Alves and Reis, 2011: 191; Vilaça *et al.*, 2011: 299).

Traditional recording techniques such as scale drawing, direct tracing or tracing from conventional photographs, all pose relevant limitations. The very process of retrieval and assemblage of primary information (measurements, tracing, photographing) involved in the elaboration of the resulting reproductions is selective and interpretative. At this stage recorders have to make several decisions and, depending on the method employed and on the quantity and quality of the data recorded, namely its richness, the resulting reproduction will have more or less empirical resonance. These recording methods do not provide a lot of accuracy, neither enough information to help constrain interpretations. Additionally, the recording process may be conditioned by environmental circumstances, especially in terms of light and weather, which may influence to a high degree the quality and quantity of the recorded data. This kind of graphic recording techniques and the renderings they produce are two-dimensional by definition. They have inherent problems to capture and reproduce the very essence of these monuments and the engravings they bear, that is, their three-dimensionality. As a consequence, the resulting reproductions are deprived from relevant information, such as the volume of these monuments or the micro-topography of their surfaces. These aspects would potentially provide us with clues about the technologies involved in their production, their subsequent re-use or the effects of weathering on them through time. Finally, we should consider that LBA stelae could have been painted and, until very recently, no technique has been applied to detect possible preserved pigments on their surfaces (but see below).

It is true that, as David Whitley reminds us about the graphic documentation of rock art that "There is simply no way that every empirical fact can be recorded about a site." (Whitley, 2011: 48). As he mentions, there are various general views regarding which aspects are essential to be documented. These general views, and the standard approaches derived from them, are dependent upon broad shared research interests and theoretical orientations. Additionally, the funding available for rock art research also conditions the kind of recording approaches that are considered standard, for many of the innovative technologies enabling richer data recording have been, and at times still are, too expensive to be contemplated as part of the basic methodological approach of most rock art research projects. In conclusion, consensus about standard approaches to recording may vary with time, depending not only on prevailing theoretical orientations and research interests, but also on the availability of certain technologies. As it will be put forward in this paper, new technologies that demonstrate an innovative potential at providing rich and high quality documentation at low cost, such as Reflectance Transformation Imaging, have the potential of triggering the reformulation of Rock Art research interests and the standard approaches to document Rock Art.

During the last decade, interpretative and phenomenological approaches have raised awareness of the importance of documenting and analysing dimensions of Rock Art that had been previously overlooked (*i.e.* Wilson and David, 2002; Jones, 2006; Jones *et al.*, 2011). As a result, current standard approaches for the graphic recording of Rock Art tend to include, when possible, a broader variety of aspects. In the case of the Rock Art panel itself, this includes various interrelated aspects, such as the identification (delineation) of motifs and the techniques employed for their elaboration, the position of motifs on the stone and the spatial relation between each other, including their superimposition, the micro-topography of the stone, the eventual techniques employed in its shaping, its texture and colour, or the geometry of the stone and of the engraved and/or painted motifs (*i.e.* Bueno Ramírez *et al.*, 2008; Fahlander, 2012; Domingo *et al.*, 2013).

Ideally, the documentation of Rock Art, including LBA stelae, should provide a dense and high quality matrix of primary data, capable of enabling other researchers to assess the degree of subjectivity drawn into the interpretative syntheses of the recorders, that is, the renderings that are published as 'final' reproductions. As noted before, we should consider that rock art recording itself is already an interpretative process. Nonetheless, if we compare the process of recording and the process of elaboration of a reproduction to be published, it becomes apparent that the latter synthesises more information, involves more selection regarding the aspects that are held relevant to be reproduced, and therefore, is more subjective than the primary data recorded during fieldwork (*i.e.* photographs aided by oblique light). In this context it is important to note that the richer and the more accurate the recorded primary data are, the more constrained will be the scope of possible interpretations involved in the elaboration of reproductions for publication. Richer primary data will also facilitate the assessment of the robustness of those reproductions by the rest of the community of researchers.

Nowadays there are various techniques capable of producing very rich and accurate documentation, both for painted and engraved Rock Art. Photogrammetry and 3D laser scanning have already been applied to Rock Art for some time (*i.e.* Delluc and Delluc, 1984; Buchón Moragues *et al.*, 2002; Muzquiz Pérez-Seoane and Saura Ramos, 2003; Díaz-Andreu *et al.*, 2006; Chandler *et al.*, 2007; Mañana-Borrazás *et al.*, 2009). They are capable of producing three-dimensional models, which, in the case of 3D laser scanning, have sub-millimetric accuracy. This level of accuracy is especially relevant for documenting rock engravings, for in many occasions carved motifs have millimetric depths and may only be recorded through 3D laser scanning. The software needed for photogrammetry is becoming more affordable with time but laser scanners and their renting are still very expensive. In both cases data processing requires specialized knowledge and is very time consuming. Other innovative technologies are Digital Image Analysis (hereafter DIA) and Reflectance Transformation Imaging. DIA includes the application of remote sensing techniques for the enhancement, among others, of possible existing pigments (Rogerio-Candelera *et al.*, 2011; Rogerio Candelera, 2011). Currently it is being applied by Miguel Ángel Rogerio Candelera for the analysis of two of the stelae that we are addressing in this paper (Mirasiviene and Montoro). Reflectance Transformation Imaging, on the other hand, is a technique developed by HP Labs that is capable of enhancing surface details, enabling their interactive real-time visualization and documentation (Malzbender *et al.*, 2000, 2001). Its implementation and further development for the documentation and communication of cultural heritage has been undertaken by "Cultural Heritage Imaging" (CHI) in collaboration with HP Labs (Mudge *et al.*, 2006). Its introduction in Europe has come through the hand of researchers of the Archaeological Computing Research Group (ACRG) and the Web and Internet Science group (WAIS), at the University of Southampton, in collaboration with HP Labs through various projects[2] (Earl *et al.*, 2010a, b). The application of RTI to Rock Art is still incipient but the initial case studies, which, apart from the examples here described, include cases from Portugal and South East France (Mudge *et al.*, 2006)[3], Sudan[4] (Kleinitz and Pagi, 2012), Libya or the British Isles (Earl *et al.*, 2010a, b), have provided outstanding results (Mudge *et al.*, 2006, 2012).

In this paper we will present the recent application of 3D laser scanning and Highlight Based Reflectance Transformation Imaging for the documentation, visualization, interpretation and representation of various LBA stelae found in the South of Spain (Tab. 1.). It will briefly describe the techniques, their application to these particular case studies, the preliminary results and an assessment of their potential and limitations, not only for LBA stelae but also for Rock Art in general.

2. REFLECTANCE TRANSFORMATION IMAGING (RTI) AND 3D LASER SCANNING: BRIEF DESCRIPTION

Reflectance Transformation Imaging (hereafter RTI) is a technique that uses the transformation of the reflectance properties of any surface through contrast enhancement to improve the perception of its micro-topography by using Polynomial Texture Maps (Malzbender *et al.*, 2000, 2001)[5]. Polynomial Texture Maps are image-based representations of functions of two independent parameters (lu and lv), contained in every pixel, specifying how the red, green and blue bands (RGB) vary according to the direction of a light source. Polynomial Texture Maps are produced by taking multiple photographs of a fixed object from a fixed camera with varying lighting directions[6]. The combination of Polynomial Texture Mapping and RTI provides real-time rendering, interactive visualization of changing lighting conditions and performance of enhancements of the captured reflectance functions, revealing the most subtle details of a surface. In comparison to photometric stereo, another image transformation method aimed at enhancing the three-dimensionality of surfaces, RTI does not involve 3D geometry, making it more affordable in terms of economic costs and processing time (Mudge *et al.*, 2006).

STELA NAME	DIMENSIONS OF THE DECORATED FACE		RECORDING METHOD		PREVIOUS STUDIES AND PUBLICATIONS
	HEIGHT (CM)	WIDTH (CM)	RTI	3D LS	
ALMADÉN DE LA PLATA 2	76	53	*	-	García Sanjuán *et al.* 2006
MIRASIVIENE	181	24	*	*	-
MONTORO	150	85	*	*	Rosas, 2005
SETEFILLA	170	45	*	-	Bonsor and Thouvenot, 1928; Almagro Basch, 1974; Celestino, 2001

Table 1 . List of the decorated stelae that we have recorded through the application of 3D Laser Scanning and/or Reflectance Transformation Imaging.

2 AHRC funded RTISAD project (http://acrg.soton.ac.uk/projects/rtisad/#about), which has been given continuation through further AHRC funding (http://acrg.soton.ac.uk/projects/ahrc-rti-project/).

3 See also: http://culturalheritageimaging.org/What_We_Do/Fields/rock_art/index.html

4 Project "Musawwarat Graffiti Archive. Exploring Pictures in Place", http://musawwaratgraffiti.mpiwg-berlin.mpg.de/

5 See also: http://www.hpl.hp.com/research/ptm/se.html and http://www.hpl.hp.com/research/ptm/ri.html

6 See also: http://www.hpl.hp.com/research/ptm/

The adoption of RTI for the documentation and visualization of cultural heritage has experienced a degree of delay due to restrictions of existing PTM capture methods until very recently. In order to perform RTI it is necessary to know the position of the light. The initial approach to retrieve this information included the use of a physical structure, typically with the shape of a 'dome', with fixed light sources of known location. While effective, this method imposed various limitations for its application to large surfaces and its implementation in fieldwork. As an alternative, CHI and Tom Malzbender, from HP Labs, have developed a new method for capturing PTMs called Highlight Based RTI (Mudge *et al.*, 2006; see also Earl *et al.*, 2010b). In this case, instead of using a physical structure with fixed light sources, this method resorts on a glossy sphere (*i.e.* a blackball) that is positioned within the field of view of the camera. The direction of the light will be then estimated from its highlight location on the sphere assuming a distant camera. This method increases the flexibility of RTI and lowers its costs considerably, as the equipment needed to capture PTMs is reduced to the following: an SLR camera, a light source (it can be a flash or a continuous light, *i.e.* a conventional torch), remote triggers for camera and flash, a blackball, a measuring tape, string and tripod/s[7].

After the images have been captured, ideally saved both in RAW and JPEG formats, a graphics editing software (*i.e. Adobe Photoshop*) is employed to prepare the images for RTI building, including the correction of white balance. Once this stage is fulfilled, there are two alternative RTI/PTM Builders offered for free by CHI and HP Labs respectively[8]. RTI/PTM processing is reasonably straightforward and fast. Once complete, we will be able to view interactively and scrutinize the resulting PTM file through any of the viewers provided for free by CHI or HP Labs[9]. These viewers offer the possibility of employing various methods to transform the reflectance properties of the surface and maximize its perception, revealing, in this manner, subtle details that may not be visible to the naked eye. Two of the transformation methods that afford more potential for the examination of Rock Art engravings are Diffuse Gain and Specular Enhancement (Malzbender *et al.*, 2000). Both are based on the estimation and use of each per-pixel surface normals. Diffuse gain increases the reflectance properties of the surface by maintaining the estimated normals fixed and increasing the curvature of the reflectance function of each pixel. Specular enhancement estimates the lighting direction that maximizes pixel brightness and then uses these normals to relight the surface by adding synthetic specular highlights (Plate 1).

3D laser scanning is a non-contact active technology aimed at capturing data of the shape of real-world objects for the creation of three dimensional models of them. 3D laser scanners capture three-dimensional data through the emission of a laser beam. There are various methods to calculate the location of a point surface targeted by a laser beam. Most commonly

Plate 1. Detail of the stela of Montoro (Córdoba, Spain): (A) Default image, without mathematical enhancement; (B) Image with Diffuse Gain enhancement; (C) Image with Specular enhancement. All images have identical light directions and intensities.

7 For more information on how to capture PTMs with this method: http://culturalheritageimaging.org/What_We_Offer/Downloads/Capture/index.html

8 http://culturalheritageimaging.org/What_We_Offer/Downloads/Process/index.html
http://www.hpl.hp.com/research/ptm/HighlightBasedPtms/PTMBuilderSoftwareLicense.htm

9 http://culturalheritageimaging.org/What_We_Offer/Downloads/View/index.html
http://www.hpl.hp.com/research/ptm/downloads/agreement.html

used for Rock Art and small objects in Cultural Heritage are triangulation based scanners. In this case, after the laser beam has reached the surface point that is being targeted, it is reflected and acquired by an integrated CCD camera. The scanner calculates the coordinates of the measured point by triangulation, using the readings of distance and angle provided by the path covered by the laser beam through its emission and reflection between the laser emitter, the point hit on the object surface and the sensor of the CCD camera. In this manner, each scan produces a series of point clouds that are used to create three-dimensional polygon models (also called unstructured meshes), which are then managed and processed through specific software (*i.e. MeshLab*).

There are varied software systems for processing and editing unstructured 3D triangular meshes. Particularly relevant for Cultural Heritage in general and for Archaeology in particular is *MeshLab*, an open-source software created at the University of Pisa (2005), and maintained by the Institute of Information Science and Technologies of the Italian National Research Council (CNR) with the support of the *3D-CoForm* project[10]. *MeshLab* provides tools for editing, cleaning and merging the individual scans, remeshing, rendering and converting 3D models. Mesh models are very large datasets. Their processing can take a lot of time and requires powerful computers.

One of the most remarkable advantages of 3D laser scanning is that it offers a very accurate 3D geometry. The most common triangulation based laser scanners provide sub-millimetric accuracy, an operating range between 0.1 m and 25 m, fast measuring speed and capture. However, one of the most obvious drawbacks of 3D laser scanning is its high cost in terms of equipment (laser scanner, powerful PCs) and also in terms of time investment given that, while the process of scanning itself may be fast, the post-processing is usually time-consuming.

3. THE APPLICATION OF RTI AND 3D LASER SCANNING TO THE STUDY OF LATE BRONZE AGE STELAE

3.1. BACKGROUND

We have applied RTI and 3D Laser Scanning within the framework of two fieldwork projects aimed at providing enhanced contextual data and visual recording of two decorated stelae found some years ago in the Cortijo of Mirasiviene (Lora del Río, Sevilla, Spain) and the Cortijo of Torre de Villaverde (Montoro, Córdoba, Spain)[11]. These aims are derived from research questions that we are exploring within broader lines of enquiry. These include aspects such as the technological and social dimensions of LBA stelae production, the roles played by these monuments and the places where they were set in prehistoric societies, and their life-histories. In this context, the recording of the stelae of Mirasiviene and Montoro was a good occasion for testing the potential of new technologies to overcome the limitations of traditional recording techniques and to provide us with richer primary data to explore the production and biographies of these monuments.

The experience accumulated by the ACRG in the application of 3D laser scanning and RTI to a variety of cultural heritage media and the results derived from it (see above), led us to consider the application of both methods in combination to test its applicability and potential for the study of LBA stelae. Two of the main reasons for combining them were, on the one hand, the sub-millimetric accuracy of 3D laser scanning, which until now has not been paralleled by any other technique, and, on the other, the potential of RTI to enhance the visualization and interpretation of subtle details (*i.e.* engraved motifs) of the surface of stelae.

The stelae of Mirasiviene and Montoro were discovered by locals some years ago and are currently under study within the already mentioned projects. We under-

10 http://meshlab.sourceforge.net/

11 These fieldwork projects are being codirected by the authors, jointly with Dr. Leonardo García Sanjuán (University of Sevilla, Spain), in collaboration with José Antonio Lozano Rodríguez, researcher of the "Instituto Andaluz de Ciencias de la Tierra" (CSIC-Universidad de Granada, Spain) and Miguel Ángel Rogerio Candelera, researcher of the "Instituto de Recursos Naturales y Agrobiología de Sevilla" (CSIC, Spain). The projects are titled "La estela 'de guerrero' de Mirasiviene y su contexto arqueológico (Lora del Río, Sevilla): Documentación gráfica, caracterización petrológica y prospección de superficie" and "La estela prehistórica de Montoro y su contexto arqueológico (Montoro, Córdoba): Documentación gráfica, caracterización petrológica y prospección de superficie".

12 A preliminary study of the stela of Montoro was published some years ago by Esperanza Rosas (ROSAS ALCÁNTARA, E. (2004): "En torno a la estela decorada hallada en Montoro", Boletín de la Asociación Provincial de Museos Locales de Córdoba, 5, pp. 1 24-34.), but it still lack a comprehensive examination of its engravings and the site where it was found.

took their recording during our fieldwork season in September 2012. They were located, respectively, in the buildings of the Cortijo of Mirasiviene and in the Archaeological Museum of Montoro (Museo Arqueológico Municipal de Montoro). The capture of PTMs and the 3D laser scanning work best when undertaken under controlled light conditions. In the case of Montoro this was not a problem, for the stela is part of the permanent exhibition of the Archaeological Museum of Montoro. In the case of Mirasiviene, on the other hand, the stela was initially located outdoors and we decided to displace it to an indoor room of the cortijo to avoid eventual problems with the interference of natural light.

After processing the PTMs of the stelae of Mirasiviene and Montoro it became clear that RTI offered a great potential to examine and interpret the engravings of LBA stelae. RTI provided such a detailed reading of their surfaces that, if applied to other cases, it could potentially clarify unclear or debated aspects of already known stelae, and provide data about previously unexplored aspects, such as the engraving techniques employed in their manufacture or their life-histories. With these aims in mind, we decided to apply Highlight Based RTI to the stelae of Setefilla and Almadén de la Plata 2, which are part of the permanent exhibition of the Archaeological Museum of Sevilla (Museo Arqueológico Provincial de Sevilla).

The stela of Setefilla (Lora del Río, Sevilla, Spain) was initially detected by George Edward Bonsor and Raymond Thouvenot during their archaeological excavations in the necropolis of the eponymous site (Bonsor and Thouvenot, 1928: 35-7), which is located only 3 km towards the West of the site where the stela of Mirasiviene was found. Bonsor and Thouvenot briefly inform about its discovery and location, and provide a preliminary interpretation of its decoration (Bonsor and Thouvenot, 1928: Fig. 25). Some years later, Martín Almagro Basch undertakes a more detailed study and reproduction of the stela that only differs in some details from the sketch published by Bonsor and Thouvenot (Almagro Basch, 1974: 11-5 and fig. 5). Finally, in 2001 Sebastián Celestino publishes a new interpretation of the stela, based on a new recording, which differs from the previously published reproductions in some substantial aspects (Celestino Pérez, 2001: 417-8). Apart from exploring the engravings of this stela in order to clarify their interpretation, it was relevant for us to examine the engraving techniques involved in their manufacture, for the proximity of this stela to Mirasiviene and the similarity of their iconographic structures could be relevant when considering their social context of production (Plate 2).

The stela of Almadén de la Plata 2 (Sevilla, Spain) was discovered in the mid-2000s during the exploration of the find-spot of another LBA stela (Almadén de la Plata 1) (García Sanjuán *et al.*, 2006). Its graphic study was carried out through a series of high-quality studio photographs which already showed many of the relevant details that were not visible to the naked eye (see the image included in the half-title page for one example). Still, there were areas of its surface whose interpretation remained unclear and, therefore, were not drawn in the final interpretative reproduction. The application of RTI would, eventually, aid us in the clarification of its interpretation (Plates 3 and 4).

3.2. IMPLEMENTATION

3.2.1. Highlight Based Reflectance Transformation Imaging (RTI)

We have applied *Highlight Based RTI* to four decorated stelae, namely the stelae of Mirasiviene, Montoro, Setefilla and Almadén de la Plata 2 (Table 1, Plates 1-4, 6-7). Given that this was the first time that this technique has been applied to decorated stelae, we have undertaken more than one RTI for each stela. Each finished RTI file entails a capture session of around 20-30 minutes long in which, in our case, between 90-150 images were taken. These are more captures than the regular number of photographs taken to build an RTI, but we decided to increase their number, with light from more directions, as suggested in MacDonald (2011: 162), to compensate the space restrictions we had to face. The recommended practice for performing the capture of PTMs is to have a regular distance between the photographed subject, on the one hand, and the camera and flash on the other. The distance of the latter (camera and light source) should be between 3 and 4 times the maximal length of the surface that is being captured. In this manner it is guaranteed that the reflection qualities of the entire surface are recorded under equal conditions. In our cases we had to conduct the capture sessions in rooms that either restricted the possibility of photographing the

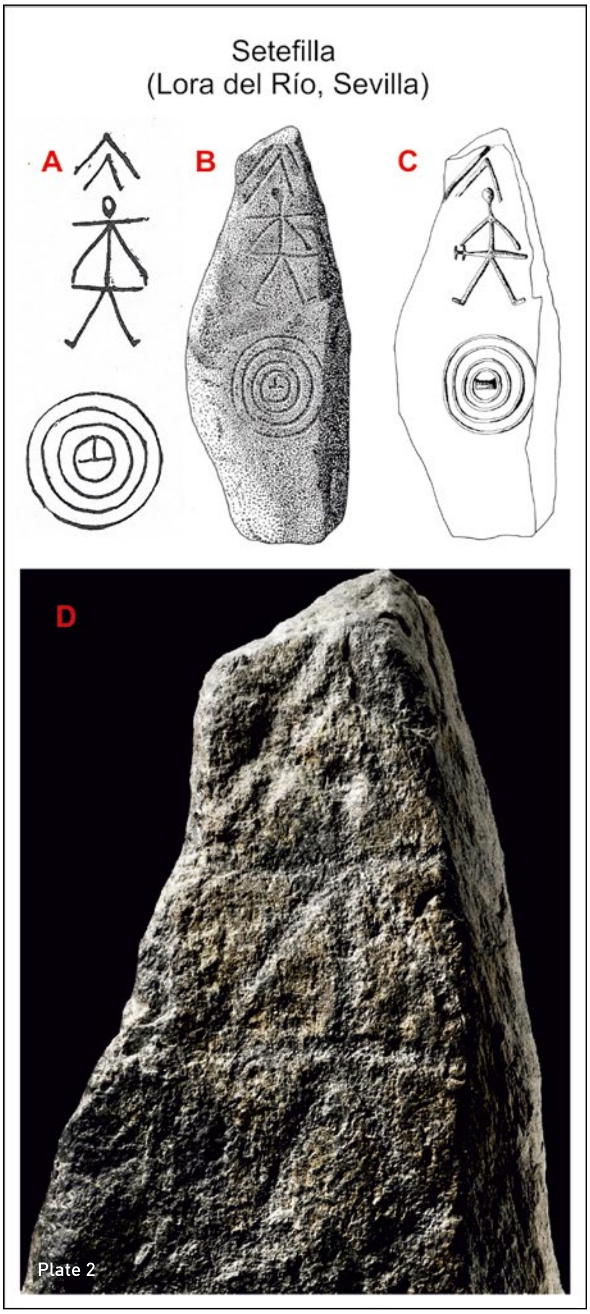

Plate 2. Stela of Setefilla (Lora del Río, Sevilla, Spain): (A) Preliminary reproduction published by G. E. Bonsor and P. Thouvenot in 1928; (B) Reproduction published by M. Almagro Basch in 1974; (C) Reproduction published by S. Celestino in 2001; (D) Detail of the engravings of the upper part of the stela with applied Diffuse Gain enhancement.

Plate 3. Image of the stela of Almadén de la Plata 2 (Almadén de la Plata, Sevilla, Spain) with Diffuse Gain enhancement.

Plate 4. Detail of the stela of Almadén de la Plata 2 (Almadén de la Plata, Sevilla): (A) Default image, without mathematical enhancement; (B) Image with Diffuse Gain enhancement; (C) Image with Specular enhancement. All images have identical light directions and intensities.

stela from some angles or limited the maximal distance of the camera and the flash from the subject. We have undertaken some partial RTIs, but most of the RTIs are intended to capture the whole stela. The results in the cases of Montoro, Mirasiviene and Almadén are very good, for it was possible to capture the information required from most of their surfaces. In the case of Setefilla there were spatial restrictions in various angles (areas around 0º/360º and 180º) and, as a result, the RTIs are not so informative regarding some parts of its surface, especially the upper part of the stela.

To undertake the capture of PTMs we have used the following equipment:

- Camera: Canon EOS 5D with sensor resolution 3744 x 5616 (21.1 megapixels) and EF 24-70mm f/2.8L USM zoom lens (Mirasiviene and Montoro) and Nikon D300 with sensor resolution 2848 x 4288 (12.3 megapixels) and Nikon 18-70 mm f/3.5-4.5 lens (Almadén de la Plata 2 and Setefilla).
- Tripod.
- Light source: Flash connected to the camera through radio remote triggers.
- Blackball.
- Measuring tape and/or string.

Given the weight of the image capture files, which ranged between 25 MB and 5 MB, for raw and jpeg files respectively, we could process the PTMs in our fieldwork laptop, which has a 2.66GHz processor, 4GB of RAM and a 250GB hard drive. As it can be seen in Table 2, the sum of the images required to build one PTM may weigh up to 2.2 GB (.jpg & .cr2), as in the case of Mirasiviene, while its finished PTM weights 0.09 GB[13].

3.2.2. 3D Laser Scanning

We have laser scanned the stelae of Mirasiviene and Montoro (Table 1). To undertake this task we have used a Konica Minolta VIVID 910 3D, a triangulation based laser scanner. This scanner may be accurate to X=±0.22mm, Y=±0.16mm and Z=±0.10mm to the Z reference plane when using the "tele" light-receiving lens (focal distance f=25mm) in "fine" mode. We wanted to test the level of accuracy provided by laser scanners to record subtle details of stelae surfaces, such as traces left by the preparation of the surface of the stone and its engraving or very slight engravings, for instance. Therefore, in both cases we undertook a complete middle resolution scan of them (using the "middle" light-receiving lens, with focal distance f=14 mm), which, in the case of Mirasiviene, came up to a total of 94 scans of an average of 200.000 vertices, and a high resolution scan of the engraved face, which in the case of Mirasiviene entailed 57 more scans with an average of 300.000 vertices each (Table 2 and Plate 5).

The processing of laser scanning products is very time-consuming and requires adequate hardware. The initial processing entails importing the raw data from the laser scanner as point clouds (.cdm) and their conversion into unstructured meshes (.obj) that are edited and cleaned. The next step includes the alignment or merging of the individual scans in order to obtain a complete mesh that is them remeshed into more simplified meshes that complete the 3D model. As indicated above, this task can be undertaken with *MeshLab*, an open-source, comprehensive and user friendly software. Table 2 specifies the summed size of every scan taken to build a middle resolution 3D model of the stela of Mirasiviene, whose final size

STELA OF MIRASIVIENE	NUMBER OF CAPTURES	RESOLUTION	SIZE OF CAPTURE FILES TOTAL SUM	RESULTING FILE TOTAL SIZE
RTI (1 PTM)	90	21 Megapixels	2.2 GB (.jpg & .cr2)	0.09 GB
3D LS	94	Medium Lens Fine mode	2.9 GB (.cdm & .obj)	1 .8-2 GB
3D LS	57+39	Tele + Medium Lenses Fine mode	4.4 GB (.cdm & .obj)	2.8-3 GB

Table 2. Table that summarizes information about the files (*i.e.* number, size) involved in the operations of image and scan capture and PTM and scan processing.

13 The resulting RTI files will be incorporated into an RTI digital infrastructure funded by JISC and the AHRC (see note 2).

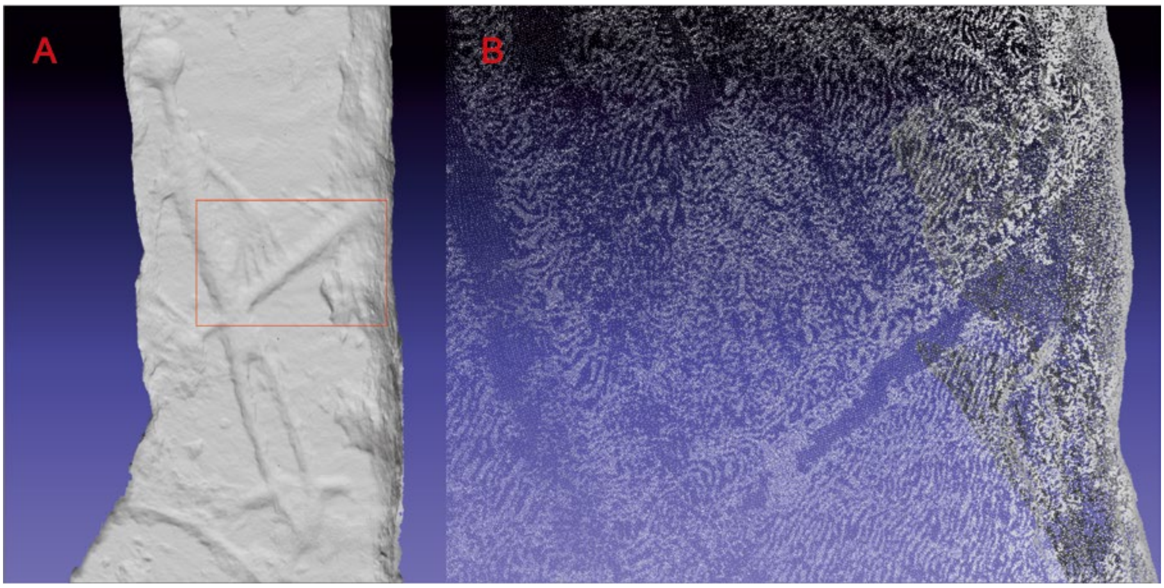

Plate 5. Stela of Mirasiviene (Lora del Río, Sevilla): (A) Partial view of the 3D high resolution model of the stela (Poisson mesh); (B) Sample area corresponding to the square indicated in (A) that displays the point cloud in which the Poisson mesh is based.

before simplification reaches 2GB. When merging the high resolution scans from the front face of the stela with the middle resolution scans form the other three faces, the total sum surpasses 4GB, while the resulting 3D model, before simplification into a Poisson mesh, for instance, weights almost 3GB.

3.3. PRELIMINARY RESULTS

RTI has provided us with outstanding results that will be soon detailed in forthcoming publications. Nonetheless, we can already mention some preliminary results that give us an idea of the potential of this technology for the study of decorated stelae and, more generally, for the recording and interpretation of engraved rock art.

By using PTM, RTI affords robust primary data that are empirically based on the reflectance properties of object surfaces. This establishes a neat difference between RTI products and the use of photographs with conventional texture maps that are applied contrast enhancement filters provided by common graphics editing programs (*i.e. Adobe Photoshop*). Furthermore, RTI enables the interactive visualization of surface details and the application of various transformations or 'rendering modes' that provide enhanced visualizations of the micro-topography of engraved rocks. By producing this versatile and rich matrix of information, RTI greatly facilitates our interpretation of the cues offered by the rock's surface, for its current relief may be the product of natural processes, in which weathering should be considered, and/or the result of various human interventions, intentional or unintentional, that may have been involved in the shaping of its present form.

The application of RTI to our case studies has provided us with relevant information on two main questions. On the one hand, it has aided us in the clarification of aspects that remained unclear or debated in the stelae of Setefilla and Almadén de la Plata 2. On the other hand, it has produced relevant information about the technological dimension of stelae production. In the case of Setefilla (Plate 2) the application of enhancement filters has rendered images that facilitate the interpretation of, among others, the anthropomorphic figure represented in its upper part and the elements associated to it. As it has been previously noted, the stela of Setefilla has been studied in detail at least twice, and the interpretations of its engraved motifs have diverged greatly (Almagro Basch, 1974; Celestino Pérez, 2001). The RTI image that we include here only provides a small fraction of the information delivered by its RTI file. Still, it offers some valuable visual cues that demonstrate the potential of RTI to assess previous renderings and advance the interpretation of these engravings. Among others, this particular RTI capture of Setefilla suggests that the reproduction of Almagro Basch (Plate 2: B) seems to be the most faithful. It also indicates the existence of two aspects that had gone previously unnoticed and which seem to be confirmed through the further visualization of its RTI file. On the one hand, there is a connection between the engraved line that delineates the interior of what has been interpreted as a 'helmet' and the horizontal line that crosses the neck of the anthropomorphic figure, completing the depiction of a triangular figure, possible 'helmet', that encloses the head. On the other hand, there is a small round cupule under the right arm of the human figure, a motif that acquires relevance when considered in relation to comparable cupules documented in other stelae of the Guadalquivir valley such as Écija 1, Ategua and Mirasiviene (Plate 6, Almagro Basch, 1974; Díaz-Guardamino, 2010: Figure 200).

Regarding Almadén de la Plata 2 (García Sanjuán *et al.*, 2006), one of the areas whose interpretation remained unclear in its initial study is located in the centre, underneath the arms of both anthropomorphic figures. RTI provides a clearer and more detailed graphic rendering than previous regular photographs (Plates 3 and 4). Additionally, it seems to become clear that the existing 'cupmark' on the right arm of the 'warrior' could be the result of intentional engraving, possibly the representation of a bracelet bearing resemblance to the one figured on the stela of Ategua (Almagro Basch, 1974). Overall, if we compare the result provided by existing high-quality studio photographs (see half-title page) with the results offered by RTI as seen in Plates 3 and 4, the added information provided by RTI becomes noticeable.

RTI has also provided us with relevant information about the practices involved in the production of decorated stelae. In the case of Mirasiviene, for instance, different rendering modes with equal (Plate 6) or variable light directions (Plate 7) afford detailed reproductions of the micro-topography that enable the identification of differentiated traces that, most probably, were the product of varied engraving techniques. This level of detail can also be grasped in the stela of Montoro (Plate 1). The RTI files of Almadén and Setefilla deliver less detail but still enough information to offer a general characterization of the engraving techniques employed in their manufacture. As Plates 2 and 4 show, the motifs of Setefilla are composed of wide lines made through shallow pecking, while the engravings of Almadén de la Plata 2 seem to have been made with a combination of pecking, incision and abrading. The information provided by the multiple renderings produced through the RTI viewer can be used to create interpretative reproductions (line drawings) through their use as layers within vector graphics software (*i.e. Corel Draw*) (Figure 1). This process is time consuming and entails a degree of subjectivity, aspects that may be overcome in the near future by a new open source tool that is currently being developed by CHI named *CARE*, which will enable the production of scientific illustrations through algorithmic rendering (Mudge *et al.*, 2012).

RTI produces very rich information about very subtle details of the surface, added to texture and colour, but it does not provide us with 3D geometry. Here is where 3D laser scanning is incomparable, especially when our recording needs to reach sub-millimetric accuracy. We have applied both, high and middle resolution 3D laser scanning, to test the capabilities of this technology in the recording of LBA stelae. If we compare the resulting 3D models of the stela of Mirasiviene, it becomes clear that we need higher resolutions to be able to record rock engravings properly (Plate 8). High resolution scanning (Plate 8: (A)) produces very accurate models that fulfil very well our needs for the recording of 3D geometry accurately. Furthermore, 3D models can be manipulated in many different ways for different purposes beyond providing accurate renderings. They enable taking measurements and drawing sections, which may be necessary to assess the engraving techniques employed in the manufacture of stelae. Nevertheless, one of the main drawbacks of 3D models is that the textures and colours they may be given are not as versatile and empirically robust in terms of the reflectance properties of the surface as the renderings offered by RTI. This is one of the reasons why, at times, the interpretation of engraved rock art through 3D models is severely limited.

4. RTI AND 3D LASER SCANNING: POTENTIAL AND LIMITATIONS FOR THE STUDY OF ROCK ART

3D laser scanning is, in terms of accuracy, the ideal method to record the 3D geometry of engraved rock art. Nonetheless, as it has been put forward previously, its applicability is severely restricted due to the high economic cost it entails and also to the time needed for post-processing. 3D models also pose

Figure 1

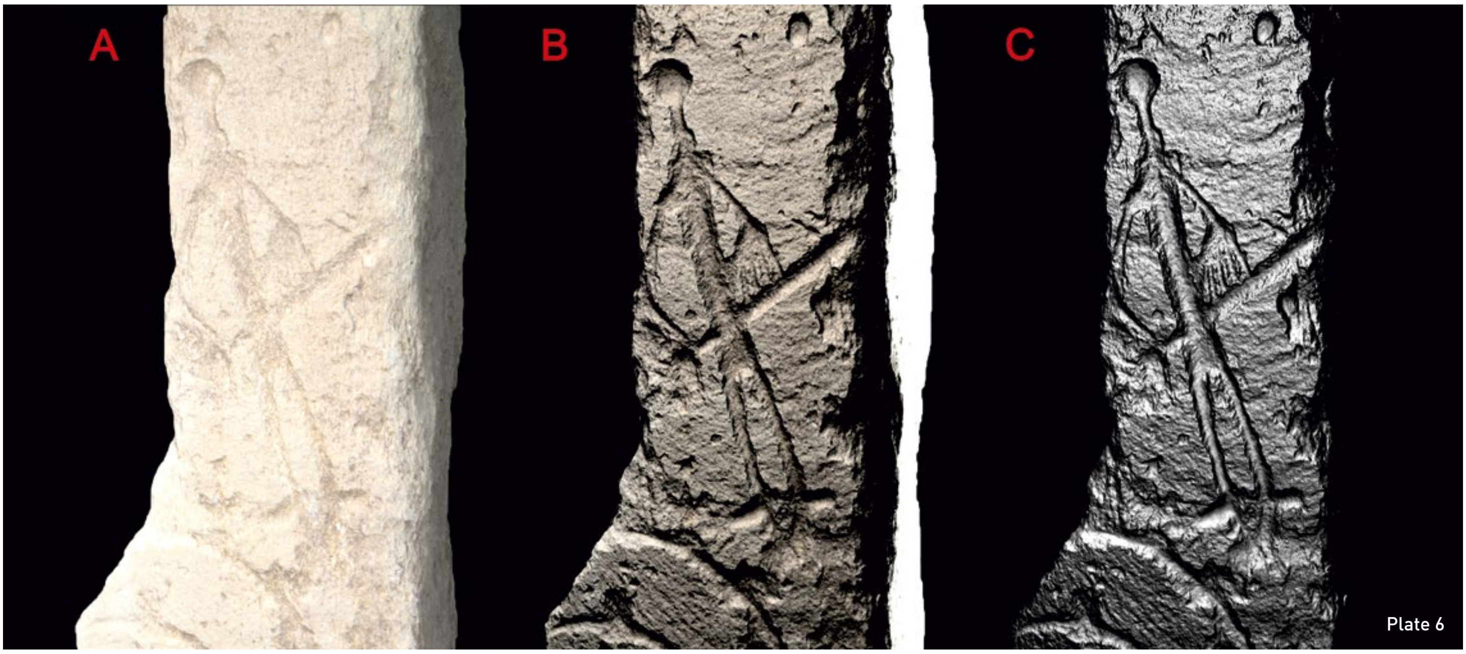

Plate 6

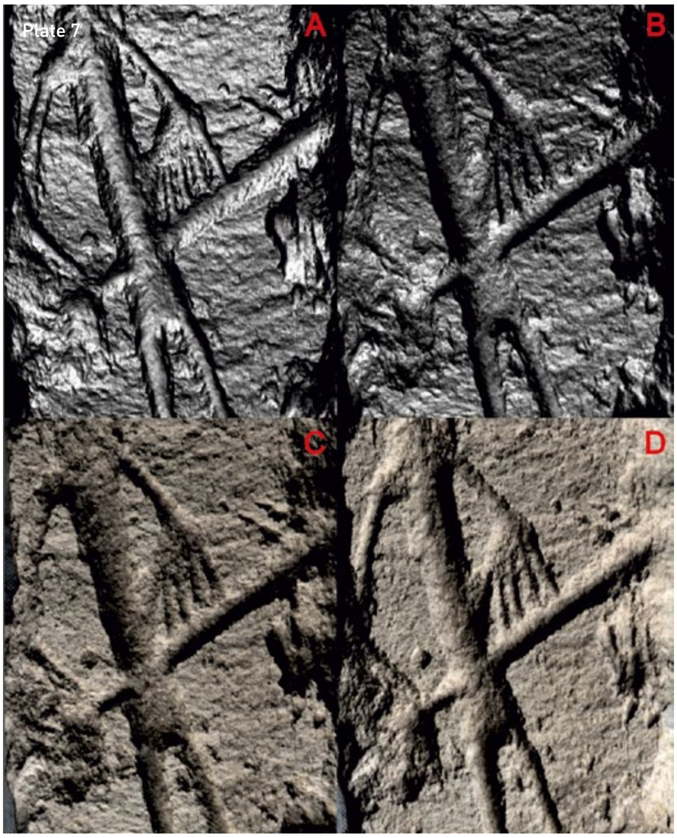

Plate 7

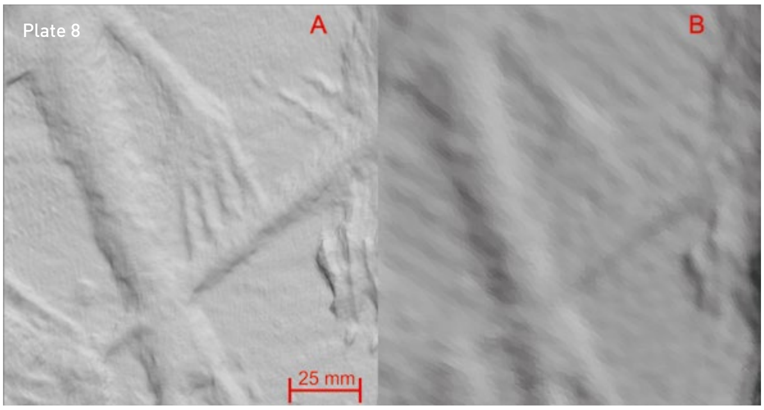

Plate 8

Figure 1. Detail of the interpretative schematic drawing of the stela of Mirasiviene (Lora del Río, Sevilla, Spain), in which varied aspects involved in its production and subsequent life-history are differentiated.

Plate 6. Detail of the stela of Mirasiviene (Lora del Río, Sevilla, Spain): (A) Default image, without mathematical enhancement; (B) Image with Diffuse Gain enhancement; (C) Image with Specular enhancement. All images have identical light directions and intensities.

Plate 7. Detail of the stela of Mirasiviene (Lora del Río, Sevilla, Spain): (A and B) Images with Specular enhancement and different light directions; (C and D) Images with Diffuse Gain enhancement and different light directions.

Plate 8. Detail of the high-resolution (left) and medium-resolution (right) 3D models of the stela of Mirasiviene (Lora del Río, Sevilla, Spain).

important limitations for the interpretation of engraved rock art as well as for the transferability of the resulting renderings.

RTI provides an affordable opportunity to overcome some of the limitations posed by 3D models, for it affords an inexpensive, flexible and robust complement for exploring and interpreting the surfaces of decorated stelae or rock art panels. Its main drawback is, nevertheless, its inability to provide 3D geometry.

These two methods should not be viewed as alternatives, for they provide different products that complement each other perfectly (Earl *et al.*, 2010b). Researchers are already exploring varied alternatives for combining RTI with 3D technologies[14]. The ideal would be to get at 3D models with sub-millimetric accuracy that can be 'textured' with PTMs and manipulated in the same way as 3D models and PTMs are (Mudge *et al.*, 2006, 2012). Recent research by Lindsay MacDonald has demonstrated how high quality 3D data can be derived from the same sets of images used for RTI using, in this case, photometric stereo methods (MacDonald, 2011).

In the meantime, the application of RTI would bring several advantages to stelae and, more generally, to rock art research. It is a cheap and easy-to-implement technique. It provides better documentation than standard recording methods and it facilitates its dissemination among researchers and the general public, as it is based on freeware. Ultimately, RTI affords robust primary data and the tools to enhance its interpretation, promoting the exploration of innovative questions, such as the technology of engraved rock art, which may have far-reaching effects on the theory and practice of future rock art research.

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BIBLIOGRAPHY

ALMAGRO-GORBEA, M. (1977): *El Bronce Final y el período Orientalizante en Extremadura*, Consejo Superior de Investigaciones Científicas. Instituto Español de Prehistoria, Madrid.

ALMAGRO-GORBEA, M. (1993): "Les Steles Anthropomorphes de la Péninsule Ibérique", *Les représentations humaines du Néolithique à L`age du Fer. 115e Congrès National des Societés savantes. Avignon. 1990*, (Briard, J. and Duval, A., eds.), Éd. du Comité des travaux historiques et scientifiques, París: pp. 123-39.

ALMAGRO BASCH, M. (1966): *Las estelas decoradas del Suroeste Peninsular*, Consejo Superior de Investigaciones Científicas, Madrid.

ALMAGRO BASCH, M. (1974): "Nuevas estelas decoradas de la Península Ibérica", *Misceláneа Arqueológica. 25 Aniversario de los Cursos Internacionales de Prehistoria y Arqueología de Ampurias (1947-1971)*, n.p., Barcelona: pp. 5-39.

ALVES, L. B. and REIS, M. (2011): "Memoriais de pedra, símbolos de identidade. As estelas

14 Current work by Lindsay W. MacDonald (University College London) and George Bevan (Queen´s University) is being developed in this area (Graeme Earle, pers.com.).

decoradas de Cervos (Montalegre)", *Estelas e Estátuas-menir: da Pré à Proto-história*, (Vilaça, R., ed.), Câmara Municipal do Sabugal, Sabugal +, Centro de Estudos Arqueológicos das Universidades de Coimbra e Porto (CEAUCP) and the Instituto de Arqueología do DHAA da FLUC, Sabugal: pp. 187-216.

BARCELÓ, J. A. (1989): *Arqueología, Lógica y Estadística: un análisis de las Estelas de la Edad del Bronce en la Península Ibérica*, PhD Thesis, Universitat Autónoma de Barcelona, Barcelona.

BONSOR, G. E. and THOUVENOT, R. (1928): *Nécropole ibérique de Setefilla. Lora del Río (Sevilla). Fouilles de 1926-1927*, Bourdeaux, Paris.

BUCHÓN MORAGUES, F. F., HERRÁEZ BOQUERA, J. A., LERMA GARCÍA, J. L., PONS CRESPO, R. and GALÍNDEZ, M. (2002): "Estudio fotogramétrico del abrigo de Cova Ribasals o Civil para la generación de la cartografía temática local y su análisis mediante Sistemas de Información Geográfica", *XIV Congreso Internacional de Ingeniería Gráfica. Santander 5-7 de Junio de 2002*, Publicación en Actas del congreso. Available from: http://www.cuevascastellon.uji.es/articulos/est_fotogrametrico_civil.pdf [last accessed 25/03/2013], Santander.

BUENO RAMÍREZ, P. and BALBÍN BEHRMANN, R. (2006): "Arte megalítico en la Península Ibérica: Contextos materiales y simbólicos para el arte esquemático", *Actas del Congreso de Arte rupestre esquemático en la Península Ibérica: Comarca de los Vélez, 5-7 de Mayo 2004*, (Martínez García, J. and Hernández Pérez, M., eds.), n.p., Vélez-Blanco: pp. 57-84.

BUENO RAMÍREZ, P., BALBÍN BEHRMANN, R. and BARROSO BERMEJO, R. (2005a): "Hiérarchisation et métallurgie : statues armées dans la Péninsule Ibérique", *L´Anthropologie*, 109, pp. 577-640.

BUENO RAMÍREZ, P., BALBÍN BEHRMANN, R. and BARROSO BERMEJO, R. (2005b): "La estela armada de Soalar. Valle de Baztán (Navarra)", *Trabajos de Arqueología Navarra*, 18, pp. 5-39.

BUENO RAMÍREZ, P., BALBÍN BEHRMANN, R. and BARROSO BERMEJO, R. (2008): "Models of integration of rock art and megalith builders in the international Tagus", *Graphical Markers and Megalith Builders in the International Tagus, Iberian Peninsula*, (Bueno Ramírez, P., Barroso Bermejo, R. and Balbín Behrmann, R., eds.), BAR International Series 1765, Oxford: pp. 5-15.

BUENO RAMÍREZ, P., BARROSO BERMEJO, R. and BALBÍN BEHRMANN, R. (2010): "Metal and the Symbols of the Ancestors in Northern Iberia.", *Conceptualizing Space and Place. On the Role of Agency, Memory and Identity in the Construction of Space from the Upper Paleolithic to the Iron Age in Europe*, (Bettencourt, A. M. S., Sanches, M. d. J., Alves, L. and Fábregas Valcarce, R., eds.), Archaeopress, Oxford: pp. 71-87.

CARRERA RAMÍREZ, F. and FÁBREGAS VALCARCE, R. (2002): "Datación radiocarbónica de pinturas megalíticas del Noroeste peninsular", *Trabajos de Prehistoria*, 59(1), pp. 157-66.

CELESTINO PÉREZ, S. (2001): *Estelas de guerrero y estelas diademadas. La precolonización y formación del mundo tartésico*, Bellaterra, Barcelona.

CELESTINO PÉREZ, S., MAYORAL HERRERA, V., SALGADO CARMONA, J. Á. and CAZORLA MARTÍN, R. (2011): "Stelae Iconography and Landscape in South-west Iberia", *Atlantic Europe in the First Millennium BC: Crossing the Divide*, (Moore, T. and Armada, X.-L., eds.), Oxford, Oxford University Press: pp. 135-52.

CHANDLER, J. H., BRYAN, P. and FRYER, J. G. (2007): "The Development And Application Of A Simple Methodology For Recording Rock Art Using Consumer-Grade Digital Cameras", *The Photogrammetric Record*, 22(117), pp. 10-21.

CRUZ BERROCAL, M. (2004): *Paisaje y arte rupestre: ensayo de contextualización geográfica de la pintura levantina*, PhD Thesis, Universidad Complutense de Madrid, Madrid.

DELLUC, B. and DELLUC, G. (1984): "Lascaux II: a faithful copy", *Antiquity*, 58(224), pp. 194-6.

DÍAZ-ANDREU, M., BROOKE, C., RAINSBURY, M. and ROSSER, N. (2006): "The spiral that vanished: the application of non-contact recording techniques to an elusive rock art motif at Castlerigg stone circle in Cumbria", *Journal of Archaeological Science*, 33(11), pp. 1580-7.

DÍAZ-GUARDAMINO, M. (2010): *Las estelas decoradas en la Prehistoria de la Península Ibérica*, PhD Thesis, Universidad Complutense de Madrid, Madrid.

DÍAZ-GUARDAMINO, M. (2011): "Iconografia, lugares y relaciones sociales: reflexiones en torno a las estelas y estatuas-menhir atribuidas a la Edad del Bronce en la Península Ibérica", *Estelas e Estátuas-menir: da Pré à Proto-história. Actas das IV Jornadas Raianas (Sabugal, 2009)*, (Vilaça, R., ed.), Câmara Municipal do Sabugal, Sabugal, Centro de Estudos Arqueológicos das Universidades de Coimbra e Porto (CEAUCP) and the Instituto de Arqueología do DHAA da FLUC, Sabugal: pp. 63-88.

DÍAZ-GUARDAMINO, M. (2012): "Estelas decoradas del Bronce Final en la Península Ibérica: datos para su articulación cronológica", *Sidereum Ana II, El río Guadiana en el Bronce Final*, (Jiménez Ávila, J., ed.), Instituto de Arqueología de Mérida, Mérida: pp. 389-415.

DOMINGO, I. and LÓPEZ MONTALVO, E. (2002): "Metodología: el proceso de obtención de calcos o reproducciones", *La Cova dels Calvalls en el*

Barranc de la Valltorta, (Martínez, R. M. and Villaverde, V., eds.), Monografías del Instituto de Arte Rupestre, Museu de la Valltorta, Tírig: pp. 75-81.

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), pp. 1879-89.

DOMÍNGUEZ DE LA CONCHA, C., GONZÁLEZ BORNAY, J. M. and DE HOZ BRAVO, J. (2005): *Catálogo de estelas decoradas del Museo Arqueológico Provincial de Badajoz (Siglos VIII-V a.C.)*, Consejería de Cultura, Junta de Extremadura, Badajoz.

DOMÍNGUEZ GARCÍA, A. and ALDECOA QUINTANA, A. (2007): *Corpus de Arte Rupestre en Extremadura*, Junta de Extremadura, Mérida.

EARL, G., BEALE, G., MARTINEZ, K. and PAGI, H. (2010a): "Polynomial Texture Mapping and Related Imaging Technologies for the Recording, Analysis and Presentation of Archaeological Materials", *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVIII, Part 5. Commission V Symposium, Newcastle upon Tyne, UK. 2010*, pp. 218-23.

EARL, G. P., MARTÍNEZ, K. and MALZBENDER, T. (2010b): "Archaeological applications of Polynomial Texture Mapping: Analysis, Conservation and Representation", *Journal of Archaeological Science*, 37(8), pp. 2040-50.

ENRÍQUEZ NAVASCUÉS, J. J. and FERNÁNDEZ ALGABA, M. (2010): "Notas sobre las técnicas de grabado y de composición formal de las estelas diademadas y de guerreros", *Cuadernos de Arqueología de la Universidad de Navarra*, 18, pp. 149-75.

FÁBREGA-ÁLVAREZ, P., FONTE, J. and GONZÁLEZ GARCÍA, F. J. (2011): "Las sendas de la memoria. Sentido, espacio y reutilización de las estatuas-menhir", *Trabajos de Prehistoria*, 68(2), pp. 313-30.

FAHLANDER, F. (2012): "Articulating stone. The material practice of petroglyphing", *Encountering Imagery: Materialities, Perceptions, Relations*, (Back Danielsson, I.-M., Fahlander, F. and Sjöstrand, Y., eds.), Stockholm University, Stockholm: pp. 97-116.

FAIRÉN-JIMÉNEZ, S. (2002): *El paisaje de las primeras comunidades productoras en la cuenca del río Serpis (País Valenciano)*, Fundación Municipal "José María Soler", Villena.

GALÁN DOMINGO, E. (1993): *Estelas, paisaje y territorio en el bronce final del suroeste de la Península Ibérica*, Universidad Complutense de Madrid, Madrid.

GARCÍA SANJUÁN, L., WHEATLEY, D. W., FÁBREGA ÁLVAREZ, P., HERNÁNDEZ ARNERO, M. J. and POLVORINOS DEL RÍO, A. (2006): "Las estelas de guerrero de Almadén de la Plata (Sevilla). Morfología, Tecnología y Contexto", *Trabajos de Prehistoria*, 63(2), pp. 135-52.

GOMES, M. V. and MONTEIRO, J. P. (1977): "Las estelas decoradas do Pomar (Beja-Portugal). Estudio comparado", *Trabajos de Prehistoria*, 34, pp. 165-212.

HARRISON, R. J. (2004): *Symbols and Warriors. Images of the European Bronze Age*, Western Academics & Specialist Press Ltd., Bristol.

JONES, A., FREEDMAN, D., O'CONNOR, B., LAMDIN-WHYMARK, H., TIPPING, R. and WATSON, A. (2011): *An Animate Landscape. Rock Art and the Prehistory of Kilmartin, Argyll, Scotland*, Oxbow Books, Oxford.

JONES, A. M. (2006): "Animated Images", *Journal of Material Culture*, 11(1-2), pp. 211-25.

KLEINITZ, C. and PAGI, H. (2012): "Illuminating Africa's past: using Reflectance Transformation Imaging techniques in documenting ancient graffiti at Musawwarat es Sufra", *Computer Applications and Quantitative Methods in Archaeology, CAA2012. Book of Abstracts. https://www.ocs.soton.ac.uk/index.php/CAA/2012/paper/view/758.*

MACDONALD, L. W. (2011): "Visualising an Egyptian Artefact in 3D: Comparing RTI with Laser Scanning", *EVA LONDON 2012. Electronic Visualisation and the Arts. London, UK, 6 - 8 July 11*, (Dunn, S., Bowen, J. and Ng, K. C., eds.), Electronic Workshops in Computing (eWiC), London: pp. 155-62.

MALZBENDER, T., GELB, D. and WOLTERS, H. (2001): "Polynomial Texture Maps", *SIGGRAPH '01: Proceedings of the 28th annual conference on Computer graphics and interactive techniques*, ACM Press, New York: pp. 519-28.

MALZBENDER, T., GELB, D., WOLTERS, H. and ZUCKERMAN, B. (2000): "Enhancement of Shape Perception by Surface Reflectance Transformation", *HP Labs Technical Reports*, 38R1.

MAÑANA-BORRAZÁS, P., BLANCO-ROTEA, R. and RODRÍGUEZ PAZ, A. (2009): "La documentación geométrica de elementos patrimoniales con láser escáner terrestre. La experiencia del Lapa en Galicia", *Cuadernos de Estudios Gallegos*, 56(122), pp. 33-65.

MONTERO RUIZ, I., RODRÍGUEZ ALCALDE, Á. L., VICENT GARCÍA, J. M. and CRUZ BERROCAL, M. (1998): "Técnicas digitales para la elaboración de calcos de Arte Rupestre", *Trabajos de Prehistoria*, 55(1), pp. 155-69.

MUDGE, M., MALZBENDER, T., SCHROER, C. and LUM, M. (2006): "New Reflection Transformation Imaging Methods for Rock Art and Multiple-Viewpoint Display", *Proceedings of the 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST2006)*, (Ioannides, M., Arnold, D., Niccoluchi, F. and Mania, K., eds.), Eurographics Association, pp. 195-200.

MUDGE, M., SCHROER, C., NOBLE, T., MATTHEWS, N., RUSINKIEWICZ, S. and TOLER-FRANKLIN, C. (2012): "Robust and Scientifically Reliable Rock Art Documentation from Digital Photographs", *A Companion to Rock Art*, (McDonald, J. and Veth, P., eds.), John Wiley & Sons, Ltd, pp. 644-59.

MUZQUIZ PÉREZ-SEOANE, M. and SAURA RAMOS, P. A. (2003): "El facsímil del techo de los bisontes de Altamira", *Redescubrir Altamira*, (Lasheras Corruchaga, J. A., ed.), Turner, Madrid: pp. 219-42.

PINGEL, V. (1974): "Bemerkungen zu den ritzverzierten Stelen und zur beginnenden Eisenzeit im Südwesten der Iberischen Halbinsel", *Hamburger Beiträge zur Archäologie*, 4, pp. 1-19.

RODRÍGUEZ ZAMORA, V. (2013): *La distribución espacial de las Estelas de "Guerrero" en el Valle del Guadalquivir y Sierra Morena: Una aproximación desde los SIGs*, Unpublished Master's Dissertation, Universidad de Sevilla, Sevilla.

ROGERIO-CANDELERA, M. A., JURADO, V., LAIZ, L. and SAIZ-JIMENEZ, C. (2011): "Laboratory and in situ assays of digital image analysis based protocols for biodeteriorated rock and mural paintings recording", *Journal of Archaeological Science*, 38(10), pp. 2571-8.

ROGERIO-CANDELERA, M. A. (2007): *Una propuesta no invasiva para la documentacion integral de arte rupestre*, Instituto de Recursos Naturales y Agrobiologia de Sevilla, CSIC, Sevilla.

ROGERIO-CANDELERA, M. A. (2011): *Técnicas de análisis digital de imágenes para la documentación integral de la pintura rupestre*, PhD Thesis, Universidad de Sevilla, Sevilla.

ROSAS ALCÁNTARA, E. (2004): "En torno a la estela decorada hallada en Montoro", *Boletín de la Asociación Provincial de Museos Locales de Córdoba*, 5, pp. 124-34.

ROSSO DE LUNA, M. (1898): "Lápida sepulcral de Solana de Cabañas, en el partido de Logrosán (Cáceres)", *Boletín de la Real Academia de la Historia*, 32-33, pp. 179-82.

SEOANE VEIGA, Y. (2009): *Propuesta metodológica para el registro del Arte Rupestre de Galicia*, Consejo Superior de Investigaciones Científicas, Santiago de Compostela.

TEIRA MAYOLINI, L. C. and ONTAÑÓN PEREDO, R. (2000): "Revisión de los grabados rupestres del Collado de Sejos (Polaciones)", *Actuaciones arqueológicas en Cantabria 1984-1999*, (Ontañón Peredo, R., ed.), Gobierno de Cantabria, Consejería de Cultura, Santander: pp. 285-7.

VILAÇA, R., SANTOS, A. T. and GOMES, S. M. (2011): "As estelas de Pedra da Atalaia (Celorico da Beira, Guarda)", *Estelas e Estátuas-menhir da Pré à Proto-história*, (Vilaça, R., ed.), Câmara Municipal do Sabugal, Sabugal +, Centro de Estudos Arqueológicos das Universidades de Coimbra e Porto (CEAUCP) and the Instituto de Arqueología do DHAA da FLUC, Sabugal: pp. 293-318.

WHITLEY, D. S. (2011): *Introduction to Rock Art Research*, Left Coast Press, Walnut Creek.

WILSON, M. and DAVID, B. (2002): "Introduction", *Inscribed Landscapes. Marking and Making Place*, (David, B. and Wilson, M., eds.), University of Hawai'i Press, Honolulu: pp. 1-9.