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Interactive relighting, digital image enhancement and inclusive diagrammatic representations for the analysis of rock art superimposition: The main Pleito cave (CA, USA)

E. Kotoula*, D.W. Robinson, C. Bedford

School of Forensic & Applied Sciences, University of Central Lancashire, Preston, PR1 2HE, United Kingdom

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This paper deals with the documentation, and virtual visual analysis of pictographs using interactive relighting, digital image enhancement techniques and diagrammatic representations. It discusses areas of interest for the analysis of low surface detail, large and geometrically complex superimposed pictographs. The synergy of reflectance transformation imaging (RTI) and decorrelation stretch (DS) aimed to improve the study of superimposition via the enhanced visualization of the surface morphology, dominant features, paint characteristics and layering. Additionally, diagrammatic representations of the results of the image-based analysis provided a valuable tool for interpretation and integration of the diverse dataset from the ongoing research in the Pleito Cave in California. This method allows revisiting unresolved hypotheses concerning the site by unpacking chemical and visual data in superimposed sequences.

1. Introduction

Digital imaging techniques, including decorrelation stretch (DS), combined with 3D technologies have been applied extensively to rock art (Cerrillo-Cuenca and Sepúlveda, 2015; Defrasne, 2014; Domingo et al., 2015; Cobb, 2016; Fritz et al., 2016; Gunn et al., 2010; McDonald et al., 2016; Poier et al., 2016; Robert et al., 2016; Rogerio-Candelera, 2016, 2015). RTI technology (Malzbender et al., 2001; Mudge et al., 2005) has received less attention for analysis of pictographs, although previous work proved that surface details can be thoroughly studied, unnoticed evidence can be revealed and engravings, reworking, erasure, and sequences of working history can be examined, assisting in defining earlier elements relative to later ones. RTI archaeological applications focused on petroglyphs (Duffy, 2010; Mudge et al., 2006; Riris and Corteletti, 2014), engraved details on stone and (Díaz-Guardamino et al., 2015; Gabov and Bevan, 2011; Jones et al., 2015; Lehoux, 2013; Milner et al., 2016) and painted artefacts (Artal-Isbrand and Klausmeyer, 2015; Beale et al., 2013; Kotoula and Earl, 2015; Kotoula, 2016; Padfield et al., 2005). This paper presents the results of the first application of interactive relighting in synergy with digital image enhancement techniques to the study of pictographs, with an emphasis on the analysis of rock art superimposition. It discusses the problems encountered during data capture, processing and analysis and the way they were addressed. It presents the potential of RTI documentation and analysis of superimposed pictographs, focusing on condition assessment, visualization of surface morphology, dominant features, paint characteristics and layering, as well as the limitations of the technique. Then, it discusses the requirements, evaluates the already available systems and develops a visual grammar for the holistic diagrammatic representation of multimodal diverse rock art dataset based on DOT scripts rendered in GraphViz.

Diagrams facilitate externalization and organization of thoughts, communication, and justification of ideas, insights and enhanced detection of patterns via synthesis of large and diverse datasets by abstract representation. They can be revised, manipulated and interpreted in different meaningful ways via visual perception (Eades, 2014; Goel et al., 2010; Moktefi and Shin, 2013; Tversky, 2014). The combination of schematic representations in a conceptual ordering forms visual narrative and explains sequential information. For archaeology, the Harris Matrix is a set of rules for

* Corresponding author.
E-mail address: e.t.kotoula@hotmail.com (E. Kotoula).

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the generation of diagrams enriched with stratigraphic information (Harris, 1989), used for documentation of analysis and conservation (Barros García, 2009; Watts et al., 2002) and for rock art superposition studies (Chippindale et al., 2000; Mguni, 1997), informed by imaging analysis (Gunn et al., 2010). The recent development of portable technologies for compositional analysis of pigments and digital image enhancement in synergy with colour and texture visualization for the analysis of rock art and superimposed pigment motifs leads to complex multimodal datasets (Robinson et al., 2015), that need to be integrated into the stratigraphic diagrams. The currently available specialized pieces of software, ArchEd (Hundack et al., 1998), Stratify (Herzog, 2004), compatible with Strati5 (Sikora et al., 2016), and Harris Matrix Composer (Traxler and Neubauer, 2008), do not provide useful options for differentiation of painted features, represented by nodes. Hence, it is difficult to incorporate additional information, apart from the stratigraphic relationships between painting features. Many aspects of the paintings, such as pigments and paint application methods used, can be represented diagrammatically via differentiation of nodes in terms of shapes, outline styles and colours. Alternatively, diagrams can be generated from text via scripts programmatically, such as Unified Modelling Language (UML) (Booch et al., 1999) and DOT for GraphViz (Gansner et al., 2015; Khoury, 2013). The former may be problematic in the case of many nodes with complex relationships, which is usually the case in rock art. On the contrary, directed graphs generated by the DOT language scripts in GraphViz, an open source graph visualization software and automatic layout system, provide options for adjusting the representation and placement of subgraphs, nodes, and edges. DOT is a very well documented programming language with an active support community of developers. It has been used for automatic generation of Harris Matrices in excavations such as the case of Gortyna, Crete (Costa, 2007), and have been incorporated in excavation management systems (De Roo et al., 2016; Motz and Carrier, 2013) and CIDOC-CRM mappings (Carver, 2013).

Surprisingly, very few studies of Pleito have addressed the complex superimposed paintings at the site. Drawing upon historical records, Lee (1979) famously hypothesized that the exotic blues and greens were stolen from coastal Franciscan Missions by Native refugees following a revolt by the Chumash in 1824. Similarly using ethnohistoric records, Whitley (2000: 121) interpreted some of the compositions as representing ‘exploding shamans’, or self-portraits of the bodily transformation shamans undergo during trance experiences. Superimposition is one of the most valuable aspects of rock art as it provides crucial relative data to determine sequencing of image making and change through time. Methods that enable us to gain as much information as possible from superimposed rock art provide means to address questions concerning time depth. When it comes to painted rock art, including information on texture, colour, and pigment composition allow for a multivariate analysis of change through time in addition to stylistic change. Both previous interpretations of Pleito are based upon ethnohistorical documents from the 1800s–1900s and do not include superimposition analysis of paintings nor in situ analytical work on the paint itself. Here, we show how integrating RTI with in situ analytical work provides a powerful tool to address questions of sequence and pigment source, thus enhancing our understanding of the site itself.

2. Materials

The Pleito cave pictographs (CA-KER-77) located in the Wind Wolves Preserve in South Central California, USA, are characterized by the variety of shapes of polychrome multi-layered compositions, that indicate the high levels of skill and knowledge of pigment preparation and application and by extension the importance of the cave (Robinson et al., 2015; Robinson, 2013a). Within the Main Cave, the extensive colour palette includes varieties of reds, yellows, oranges, whites/creams, greens, and blues: combined with the intensity of overpainting, Pleito stands out as one of the most complex painted indigenous sites in the Americas (Robinson et al., 2015; Grant, 1965). Prior to interactive relighting and diagrammatic representation, a variety of techniques has been recently applied, such as analysis of pigments using X-ray fluorescence, FTIR and Raman spectroscopy, 3D digitization with laser scanning, digital image enhancement and study of superimposed pigment motifs with layer separation techniques (Bedford et al., 2016; Robinson et al., 2015). This study presents examples from pictorial elements located on the ceiling of the Main Cave (Panels B, C, D, E and J), with an emphasis on Panel C (Fig. 1).

3. Methods

3.1. RTI data acquisition, processing, and viewing

Data acquisition was completed using the Highlight-based method (Cultural Heritage Imaging, 2013a; Duffy et al., 2013). Setting up the scene was more complicated than in typical outdoors RTI data capture because of the scale, dimensions and geometric complexity of the cave. The necessity to avoid any contact with the painted surface leaves limited space for humans and equipment. The geometric complexity of the cave introduced problems not only in setting up the scene but also during capture. Unlike typical RTI data acquisition sessions, where the series of raking and oblique light images form a complete hemisphere around the subject, in Pleito cave certain lighting positions are not accessible. As a result, the hemispherical coverage varies across the RTI datasets captured. After the acquisition of 49 RTI datasets and before processing using the RTIBuilder (Cultural Heritage Imaging, 2011), datasets were aligned using digital image processing software in order to improve the quality of the *.rti and *.ptm files and avoid blurry views due to the unstable floor of the cave. In addition, after the promising results of Decorrelation Stretch (DS) in Pleito cave and elsewhere, RTI datasets were preprocessed, using the DS plugin and Image J batch processing tools (Ferreira and Rasband, 2012; Harman, 2008). The DS RTI dataset were processed following the mainstream methodology, resulting in DS RTI files. The RTI files were viewed individually in RTIViewer (Cultural Heritage Imaging, 2013b) and analysed in a comparative mode in CHER-Ob (Shi et al., 2016) (Fig. 2).

3.2. Identification of pictorial elements

Different DS colour enhancement modes, applied to orthophotos of the panels, were created and used as slices in an Image J 2D stack. The scrollbar provided easy navigation between the different DS filters and the wand tool assisted the selection of pictorial elements based on their colour. The ROI Manager utility facilitated saving, renaming (in accordance with the naming convention) and adjusting the attributes, such as colour, of each pictorial element. Two or more pictorial elements formed a group of composite selection in cases of symmetrical and continuous lines or elements with great similarity. Hence, it is possible to achieve a detailed representation which includes every paint feature, while minimizing the number of pictorial elements. After the selection of all paint features, the measure and list ROI Manager functionality was used, leading to an.xls sheet which presents the assigned name and colour of each selection, its location in the stack, as well as its area and perimeter values (Fig. 3).