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Digital image analysis-based strategies for quantitative monitoring of rock art sites

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ABSTRACT

Approaching rock art as one of many elements of greater, complex natural systems allows for a better understanding of rock art panels as dynamic realities. This stands in contrast to the traditional concept in which rock art is framed as a static set of paintings and/or engravings over a rock surface. The nature of the rock surface, and even other elements related to the supporting rock, such as the network of microfissures or the very composition of the rock, have generally been of secondary interest. Information on the environmental conditions, even at the most basic level, has been absent, as has the nature (or even the mere presence) of the biological communities harboured by the supporting rock. This new, dynamic, concept of rock art, needs to be understood by means of empirical data, in which quantitative and non-contact methods are of particular use. This paper deals with the application of digital image analysis (Principal Component Analysis and digital classification algorithms) as the basis of several research strategies for identifying these elements, measuring their extent, and monitoring the effects of these elements over time. It also presents the advantage of freely available software, minimising the overall cost of the analyses. Some examples were performed in laboratory conditions, and others in subterranean environments such as Roman hypogean tombs and Altamira Cave.

1. Introduction: rock art and complex natural systems

From the very beginning of scientific research on prehistoric rock art, significant effort has been applied to the development of recording techniques. Of course, these techniques were mostly developed with a nearly exclusive focus on only the manifestations of rock art rather than on other issues, and their goals were merely to reproduce the rock art itself. In the 20th century, the goal of improving the visibility of the motifs in order to understand (or at least to see) what was depicted was added, but the physical context of the rock art in terms of the supporting rock, still received little interest. Thus, many of the classical records of rock art consist of a series of drawings or photographs (sometimes scaled, sometimes not) focused on the motifs without any reference to their environment - as if the rupestral representations existed in a void, floating in space like some kind of prehistoric astronauts. Interestingly, in some early examples of rock art recording we can find some kind of interest in depicting the substrate of the artistic manifestations, as is the case of the first recordings of the Portuguese rock art site of Cachão da Rapa, performed as early as 1734 (Contador de Argote, 1734, Santos Júnior, 1933, Rogerio-Candelera et al., 2013).

In contrast to the traditional approaches to rock art which, as mentioned above, usually emphasized the study of the rock art itself (often to the exclusion of many other elements of interest for understanding the organization of the panels and their implications for conservation), systems theory allows for the improvement of the description of the complex network of characteristics and relations that compose a rock art panel, thus supporting a more complete and comprehensive vision in which taphonomy plays a more relevant role. It seems necessary to state here that we understand taphonomy not as defined by Efremov (1940): the study of the transition of life forms from the biosphere to the lithosphere, but in the updated definition of Domínguez-Rodrigo et al. (2011:5), i.e., "the study of the dynamic processes of modification of the original properties of all the components (including those that are missing) of any palaeontological, archaeological or forensic assemblage, comprising its constituent materials and its context."

Rock art constitutes, in our framework, one part of a complex natural system. Fig. 1 synthetically illustrates some of the complex networks of relationships and synergies inherent in these kinds of systems, in which the rock art is one of the many abiotic constituent elements. Nevertheless, in order to avoid misunderstandings it is probably necessary to define rock art here, and for these purposes, our definition can only be operative: "every graphical act, independent of its possible semantic value inside a concrete belief system, produced by means of the application of paint, scratching, engraving, bas-reliefs or full-relief sculptures, with so varied instruments as fingers, burins, flint points or paintbrushes,

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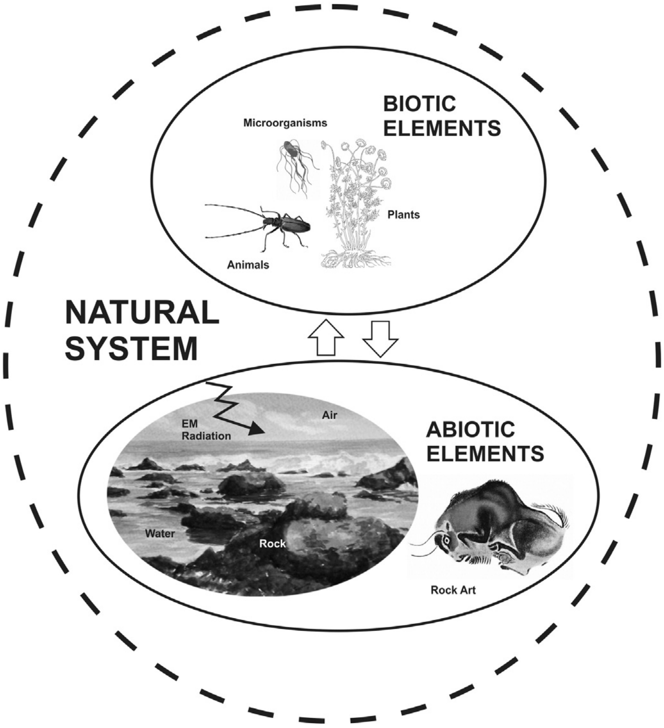

Fig. 1. Some of the elements which compose a complex natural system, including rock art.

effectuated over rocky surfaces (be them hard or soft), without a previous preparation or with a very slight preparation of the supporting rock" (Rogerio-Candelera et al., 2011:2–3).

Complex natural systems are characterised by contingency and also by the irreversibility of the processes, due to their tendency toward increasing entropy as stated by the second law of thermodynamics. Consequently, they are subjected to continuous evolution due to their own elements, or even by the action of other elements that cannot be regarded as parts of the system because of their contingent and limited actions in the systems (impulsive processes, in the words of Brimblecombe, 2005). Vandalism on rock art, or a wildfire, for instance, are two good examples of these kinds of contingent actions.

One of the main implications of this concept of rock art is that none of the parts of the system can survive independently. On the contrary, the relationships and synergies generated are together responsible for the conservation of the broader system. Thus, paradoxically, the same elements that can destroy the rock art can also contribute to conserving it. Maybe one of the most important ways to influence positively in the conservation of the system lie in the discovery of its structure, as the negative impacts of the elements can thus be proactively minimised.

Biodeterioration was defined by Hueck (1965) as any undesirable change in the properties of a material caused by the vital activities of organisms. The different materials can include not only the supporting material in which the organisms grow, but also the very source of C and N for many microorganisms. Thus, microbe-pigment interaction can be the cause for the disappearance of painted rock art in some cases. Not only the organic matter, but even the inorganic pigments used in some rock paintings can be affected, as they can be reduced or oxidized by the metabolic activity of members of the microbial biofilms developing on them. In this sense, the reduction of haematite by bacteria in a rock shelter harbouring prehistoric rock paintings has been reported (Gonzalez et al., 1999). All these biotic elements have a spatial dimension, which is susceptible to be represented graphically, as well as a temporal dimension that it is important to know (Rogerio-Candelera et al., 2011). Digital image analysis currently constitutes the simplest tool to achieve the two goals of understanding what is happening and where it is happening in a rock art panel.

The elaboration of a detailed record of a rock art site is in fact an exercise in cartography, in which the different elements (including the rock art manifestations) can be considered as different expanses expressed in a thematic map. As not all of the processes happen in the same places and at the same moments in time (Margalef, 1982), it is useful to define the spatial extent each of the different elements of the system. Moreover, the preparation of a detailed map is a prerequisite for the assessment of the evolution over time of these systems. Digital image analysis techniques constitute an essential set of tools which maximize the accuracy of representations while minimising contact with the rock art and simplifying the task of documenting the extent of distinct elements over time. In the following sections, we provide several examples of detection, quantification, and monitoring of biogenic or biologically induced elements that affect the conservation of rock, and subsequently the conservation of painted rock art, using digital image analysis (DIA) as our main tool. The chosen case studies were performed over a period of time ranging from eleven years ago to six years ago, so they can also be seen as examples of the evolution over time of this research strategy. In summary, as we have stated in other places (Rogerio-Candelera, 2008, 2009, 2013, 2015), DIA has demonstrated a wide range of capabilities in the detection, distinction, and classification of elements with different features, detection of phases of painting and repainting, and the quantification of surface areas of elements, and the monitoring of processes with a temporal dimension, all of which are of special utility in the study and conservation of rock art.

Economic factors are an important dimension when dealing with cultural resources and cultural heritage, as substantial funding is rarely available. Consequently, most of the software packages used in this study (the most important sets of tools used following this approach) are freely available on the Web, making the method both non-invasive and cost-effective.

2. Digital image analysis techniques

The range of available techniques for digital-image-based analysis is ever expanding. Nevertheless, the approaches presented here are based on two basic techniques: On the one hand, the use of Principal Components Analysis (PCA); on the other hand, the implementation of basic classification techniques like the application of thresholding algorithms for the segmentation into binary of the resulting images. In the present case studies, DIA techniques were applied to digital or digitized images obtained with conventional cameras (both analog and digital) using natural light, LED light sources (LitePad DL, 900 Lux, 6000 K colour temperature) or illuminated by means of a fluorescent UV light source (Omni-Lux, Wood's glass, $\lambda = 400$ nm) to induce fluorescence in the images. When time is a relevant dimension for the research objectives (i.e., for monitoring purposes), the construction of coherent image series plays an important role, as it constitutes the basis for establishing comparisons. Geometry and radiometry of the different images was homogenised by various methods in order to build comparable series. In terms of geometry, the comparability of the images was achieved using projective methods (by means of the Adobe Photoshop [Mark and Billo, 1999] and HyperCube software packages). The comparability of the images in terms of radiometry was achieved by extending the histogram to the maximum and minimum values in several images considered as a series (i.e., using the histogram to match some images to others, be they greyscale or full colour images). Of course that does not constitute an exact reference to radiometry in a strict sense, although the objectives of comparability (the possibility to follow the development of several microbially produced stains over time) were reached in a relatively easy and inexpensive way thanks to this research approach.

2.1. Principal Components Analysis

PCA is a widely known statistical technique for multivariate analysis developed at the beginning of the 20th century after the works of

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