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Characterization of the Inkaterra rock shelter paintings exposed to tropical climate (Machupicchu, Peru)

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A B S T R A C T

During last decades, rock shelter paintings have been described as the most magnificent expression of the scenes of ancient daily lives culture in graphic form. In the scientific field, different analytical techniques have been used for the characterization of different pigments present in the pictographs from rock shelter paintings. Example of this are the Inkaterra rock shelter paintings, which are placed in one of the most impressive and unknown natural setting, located in the town of Aguas Calientes, belonging to the lands of the Hotel Machupicchu Pueblo, forming part of Machupicchu Archaeological Park (Peru) and are composed by many different geometric pictographs. In this work, apart from micro-Raman spectroscopy, X-ray Diffraction (XRD) and Scanning Electron Microscopy coupled to Energy Dispersive Spectrometry (SEM-EDS) have been used to ascertain the molecular and elemental composition of the rock substrate as well as of the different pigments used to create the pictographs visible on the Inkaterra rock shelter. In this sense, black, red and orange pigments were analyzed, identifying the use of carbon, hematite and beta-carotene respectively. Thus, thanks to this work it has been demonstrated that the orange color was not present in the original painting, but it is caused due to microbiological colonizations favored by the climate conditions of the area.

1. Introduction

During many centuries rock art has been a form of expression of the human being. This practice is part of the spiritual expression of ancient cultures, which represented and still represents nowadays their magic-religious concepts and daily acts. Before the development of writing, human societies were already able to record, through painting and engraving on stones, a large part of their experiences, thoughts and beliefs. Examples of these are the rock shelter paintings. Rock shelter paintings on cave walls, depicting humans and animals, can be found all around the world. The historical and cultural value of rock paintings is very high, and should be valued as a part of cultural heritage. According to the literature, there exist several works about rock shelter paintings around the world. Examples of that are scientific works developed in Bhimbetka, India [1]; RSA TYN2, in South-Africa [2], Gode Roriso, in Ethiopia [3], Songo, in Mali [4], Taorengaole, in China [5], Lower Pecos Canyonlands, in United States [6], Dalakngalarr 1, in Australia [7], Abrigo Los Chaparros, El Castillo Cave, Hoz de Vicente, Cova dels Rossegadors, Cueva de la Vieja, Cueva del Queso, Abrigo Riquelme, Abrigo Remacha and Minateda, in Spain [8–13], Abri Pataud, Cave of Rouffignac and Lascaux Cave, in France [14–16] and in South-America, Oyola's caves, in Argentina [17], Tangani, Pampa el Muerto, Maderas Enco-Cuerpo1 and Los Pumas mine, in Chile [18] etc.

Sometimes it is difficult to perform and in-depth characterization of the paintings due to restrictions applied by the authorities. Those restrictions are usually related with sample extraction or sampling processes on these kind of paintings. Because of that, scientific researchers are often very limited in their analyses. Thus, the use of portable/handheld non-invasive spectroscopic techniques to conduct this type of analysis in the archaeological and cultural heritage field is usually mandatory [19,20]. However, depending on the accessibility, altitude, etc. variables, the possibility of transport the instrument to the field can be conditioned [21,22].

Among all the different analytical techniques that can be used for the characterization of these paintings, Raman spectroscopy is one of the most used technique, which can provide fast and conclusive information about the nature of the paintings [8,10–12]. Although Raman spectroscopy is the major technique cited in the literature for the analytical studies of rock shelter paintings, other portable and benchtop devices

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are also used [8,10,23]. Sometimes the combination of them is very useful and even mandatory to obtain a complete characterization of the paintings.

Apart from the different techniques, it is important to highlight that, in the different rock shelter paintings sites around the world, there is a lack of works related with rock shelter paintings located in tropical climates. It is known that this kind of climates show a high level of humidity. This kind of atmosphere can exert bad influence on them. One place that matches with these characteristics is Peru. Example of this are the Inkaterra rock shelter paintings, which are placed in one of the most impressive and unknown natural setting, located in the town of Aguas Calientes, belonging to the lands of the Hotel Machupicchu Pueblo, forming part of Machupicchu Archaeological Park (Peru). Machupicchu was declared a Peruvian Historic Sanctuary in 1981 and a UNESCO World Heritage Site in 1983. In 2007, Machupicchu was selected as one of the New Seven Wonders of the World in a worldwide Internet poll. This considerations show the importance of this magnificent ancient place. These all singularities have become Machupicchu one of the most popular destinies all around the world. For this reason, although the Inkaterra rock shelter paintings are not located in the archaeological citadel itself, they are part of the archaeological space. For this reason, scientific studies are an important task in order to analyze, try to understand and consequently obtain key information to preserve the singular cultural heritage that hosts this magnificent archaeological park.

In this work, thanks to the use of micro-Raman spectroscopy, X-ray Diffraction (XRD) and Scanning Electron Microscopy coupled to Energy Dispersive Spectrometry (SEM-EDS), both the molecular and elemental composition of the rock substrate and the one of the different pigments (black, red and orange) used to create the pictographs visible on the Inkaterra rock shelter were studied.

2. Materials and methods

2.1. Inkaterra rock shelter paintings

The paintings are located in the town of Aguas Calientes, on the grounds of the Machu Picchu Pueblo Hotel, in the Machupicchu district (Urubamba province, Peru). It is part of the Machupicchu Historic Sanctuary. Taking as reference the hydrological system of the area, it is located on the left bank of the Alccamayo creek, an affluent of the right bank of the Vilcanota river. The site is at an altitude of 2150 m above sea level. Observing the rock shelter (see Fig. 1), there is a clear predominance of geometric motifs. All the evidence consists of pictographs whose support is a vertical granite cliff, about 15 m high and 10 to 15 m wide. The facade of the cliff is flat but with irregularities due to natural fractures in the rock. The central motif represents a set of concentric circles of alternating black and orange colors: three black circles and four orange circles, including inner and outer circles (see Fig. 1A). Moreover, there are also blackish (see Fig. 1B) and reddish geometric pictographs (see Fig. 1C and D). These observations have strong implications for the chronology of the archaeological occupation in the region. It is also important to mention that the pictographs could not be formal relationship with Inka designs, suggesting a different cultural association.

2.2. Climate conditions

The site has a temperate and very humid climate depending on the season of the year, with an average annual rainfall of around 1900 mm and an average annual temperature of 18–24 °C [24]. From January to March it is the rainy season in the area, while from April to August it is the dry and sunny season [24]. The rainy months represents the 80% of the annual volume of rainfall, ranging from 1800 to 2000 mm and the Relative Humidity can reach until 80–90% [24]. These conditions are typical from the "cloudy jungle".

2.3. Sampling

Due to the restrictions for sampling and thanks to the use of an small portable microscope, in the painted rock substrate small fragments spontaneously detached were observed and consequently collected (some square microns in area), not damaging in this sense the rock shelter painting. In Fig. S1 from Supplementary Material, it can be observed the sampling moment, using the portable microscope. It is important to highlight that the taken samples were never collected from areas with perfect adhesion to the rock substrate (only those that were already detached from the shelter).

2.4. Instrumental

XRD analyses of the rock substrate were performed with a powder diffractometer PANalytical Xpert PRO, equipped with a copper tube ($\lambda_{CuK\alpha media} = 1.5418$ Å, $\lambda_{CuK\alpha 1} = 1.54060$ Å, $\lambda_{CuK\alpha 2} = 1.54439$ Å), vertical goniometer (Bragg-Brentano geometry), programmable divergence aperture, automatic interchange of samples, secondary monochromator from graphite and PixCel detector. The measurement conditions were 40 kV and 40 mA, with an angular range (2θ) scanned between 5 and 70°. For the data treatment of the diffractograms and the identification of the mineral phases present, the specific software X'pert HighScore (PANalytical) in combination with the specific powder diffraction file database (International Centre for Diffraction Data - ICDD, Pennsylvania, USA) was used.

For the micro-Raman analyses, the inVia Renishaw confocal Raman spectrometer (Renishaw, Gloucestershire, UK) coupled to a DMLM Leica microscope with 5×, 20×, 50×, and 100× long working distance lens was used. Different excitation lasers (785 and 514 nm; nominal laser power 350 mW and 50 mW, respectively) and different magnification lenses (50× and 100×, mainly) were used to perform the measurements. The spectrometer was daily calibrated by using the 520 cm^{-1} Raman band of a silicon chip. Lasers were set at low power (not more

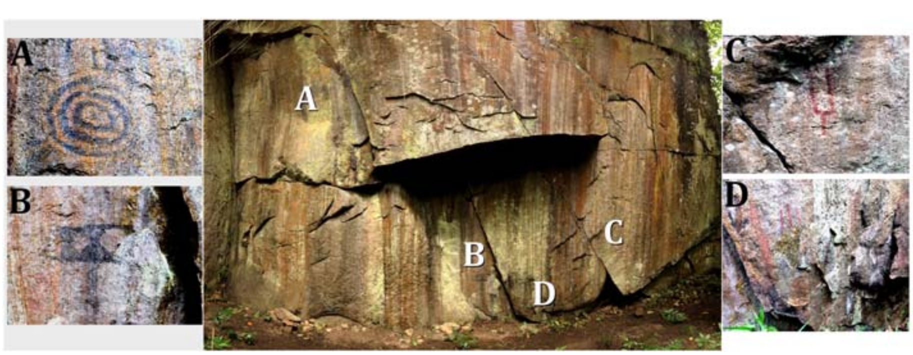

Fig. 1. Inkaterra rock shelter paintings showing: A) concentric circles in black and orange colors, B) blackish geometric pictographs, C) and D) reddish geometric pictographs.(For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)