Title:

A critical assessment of the potential and limitations of physicochemical analysis to advance knowledge on Levantine rock art.

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Abstract

This paper offers an updated review of the variety of physicochemical analysis applied so far to Levantine rock art (Spain) to characterize de composition of the pigments, as well as the substrate and/or the natural coating covering these particular prehistoric paintings. This paper is part of a broader special issue evaluating the real contribution of scientific approaches to rock art research, assessing how they have improved our understanding of this particular heritage and the new research questions they open. In this context, and with a focus on Levantine rock art, our aim is to explore: 1. the guiding principles behind the different sorts of analysis conducted and published so far; 2. the non-invasive and invasive techniques applied to answer the research questions raised, and 3. if the result published as yet have met the expectations of rock art researchers. We also reflect on the potential, the limitations and the future developments of this sort of studies, as well as on the ethics and desirable protocols of applying invasive techniques to this UNESCO World Heritage listed archaeological remain. While the focus is Levantine rock art, the discussions raised by this paper and the experiences reported in relation to the various techniques used are of global interest, especially when dealing with open-air rock art.

Keywords: max. 6 Levantine rock art, prehistoric art, analytical chemistry, pigments, binders, crusts

1. Introduction

In the 21st century, archaeometric approaches to rock art are changing the way we understand the materiality of this fragile cultural heritage. The application of analytical chemistry to archaeological research has improved substantially over the last half-century and today it is an essential methodological subfield within archaeological science, becoming a critical part of modern archaeological investigation. Not by chance, archaeology is the study of past human societies through the examination of material remains: it is this focus on material evidence that yields the necessity for scientific approaches to the past (Pollard et al., 2007; Nigra et al., 2015**.** In rock art research, new approaches to the materialities of art and the analysis of the different stages involved in the process of production or operative sequence (as described by Fiore, 2007), are improving our understanding of what it means to produce art. In the last few decades there has been a growing increase on the use of analytical chemistry to identify pigment procurement practices and sourcing areas (ex. Onoratini, 1985; Couraud, 1988: 22-23; Hameau at al., 1995; Lorblanchet, 1995; Bello and Carrera, 1997; Smith and Pell, 1997; Mooney, Geiss and Smith, 2002; Stafford et al., 2003, Bonneau et al., 2012, Prieto et al., 2016; etc.); the raw materials used, as well as pigment composition, binders and recipes (Watchman, 1990; Montes and Cabrera, 1994; Lorblanchet, 1995: 146; Clottes, 1997: 38; Smith et al., 1999; Salomon et al., 2008; Iriarte et al., 2009; Reeves, 2013; Gomes et al., 2013 and 2019, Olivares et al., 2013; Roldan et al., 2013; Huntley and Freeman, 2016; Brook et al.. 2018, Sepulveda, 2016 and in press, etc.), technologies of pigment transformation, such as mechanic grinding, heating, shifting, etc. (Bello and Carrera, 1997; Pomies et al., 1999a and b; Guineau at al., 2001: 222; Salomon et al., 2015, etc.) and so forth.

Today it is widely accepted that building a systematic knowledge about the materials, instruments and processes involved in rock art production and exploring their continuities and changes over time we can generate knowledge on the technologies and choices of ancient artists and address questions of social dynamics and productive processes not necessarily visible in the more visual characteristics of rock art. Archaeometric approaches to the study of cultural heritage materials, and in this case to rock art, are also important to understand the conservation history of the art (Brunetti et al., 2010; Madariaga, 2015; Mazzeo, 2017), to identify the factors and the taphonomic processes that have facilitated the survival of this ancient legacy to date, as well as those responsible for the degradation threatening the preservation of this heritage. Such an approach is key to anticipate potential risks and to design appropriate preventive measures. In short, they are necessary to secure and improve the future of this vulnerable and singular heritage.

In this paper, we explore the use of physicochemical analysis for the study of a particular rock art tradition added to the UNESCO World Heritage list in 1998: Levantine rock art (Fig. 1). This cultural legacy, unique to Mediterranean Iberia, is one of the most singular and fragile artistic phenomena we have inherited from the past in this part of the world, illustrating human practices and behaviours rarely visible in other parts of the archaeological record (Domingo, 2012, 2015). With no other parallels or precedents in Europe, LRA is the only European body of figurative art dominated by narrative scenes, with naturalistic men, women and even children engaged in a wide range of economic, social and cultural activities. They include individual and cooperative hunting of deer, goat, wild boar and bull, as well as battle scenes, marches, dances, representations of pregnancy, birth, maternity, death and so forth. The location in the open air exposes the more than a thousand sites with this particular heritage to the elements and to a wide variety of degrading agents (water, microorganisms, insects, animals and, more damaging, human impacts) (for a recent summary see Rodríguez and Domingo, 2018).

This paper aims to provide a general overview on the application of analytical chemistry to archaeological research on this particular art. Our aim is to explore to what extent this sort of analyses is contributing to improve our understanding of this rock art tradition, in line with the questions raised in this special issue on the *Impacts of scientific approaches on rock art research*. To do so, we summarize the main studies published so far, paying attention to the research questions raised by the authors, the guiding principles behind the different sorts of analysis conducted, the non-invasive and invasive techniques applied to answer the research questions and the results achieved. Finally, we will also discuss other new analytical techniques with potential to contribute to our understanding of the technologies of Levantine rock art.

Our final aim is to evaluate to what extent these new interdisciplinary approaches to Levantine rock art are really furthering our knowledge on this particular artistic tradition and if new research questions are opened that we could not even consider before the introduction of these new approaches.

2. Analytical chemistry and Levantine rock art: an overview

In the last twenty years, the expanding use of modern analytical techniques applied to Levantine rock art has allowed archaeological research on this particular art to widen the range of knowledge we have so far. Interest on different aspects of the *chaîne operatoire* of Levantine rock art (from raw material procurement to techniques and materials involved in rock art production and application) traces its roots back to early studies (Obermaier et al. 1938). However, aside from a few exceptions (Ripoll, 1961; Montes and Cabrera, 1994), during the last century these questions were primarily addressed through experimental archaeology and ethnographic analogy, which were essentially used to suggest potential raw materials and binders, as well as possible tools used for paint application (see a synthesis in Domingo, 2005; Santos da Rosa, 2018).

The results of the first physicochemical analysis (Obermaier, 1938; Ripoll, 1961; Montes and Cabrera, 1994) were not very significant or they did not receive the attention deserved at the time. In 1938, Obermaier et al. refer the first spectrographic analysis in the Valltorta-Gasulla complex of sites, one of the most iconic regions containing this rock art tradition. Their only conclusion though was that the colours were fossilised and completely attached to the rock, thus making no progress on our understanding of the pigment nature and composition. Three decades later, in 1961, Ripoll publishes Codina's analysis conducted at la Vacada site (Castellote, Teruel) characterising for the first time the elemental composition of both the pigment (Fe, Al, Mn, traces of Cu and no traces of fatty excipients) and the rock surface (Si, Ca – Sr and Ba-, Mn and Na). More informative was the paper by Montes and Cabrera (1994) identifying for the first time different pigment recipes, the results of which will be further analysed along these lines.

A more systematic analytical approach to Levantine rock art occurs as we enter the 21st century. The geographic spread as well as the often remote and difficult location of this rock art tradition certainly constraint the analysis, since non-invasive portable techniques require carrying the instrumentations for on-site operation. They also need a power source, such as a portable generator, thus limiting the type of equipment to be used. The most frequently and effective portable non-invasive spectroscopic methods used so far for the in situ study of Levantine rock art have been energy dispersive X-ray fluorescence (EDXRF) (Roldan et al., 2006, 2007; 2010, 2014; Hernanz et al., 2014; López et al., 2014 and 2017; Pitarch et al., 2014) and micro/Raman spectroscopy (Hernanz et al., 2006, 2007, 2008, 2010, 2014, Mas et al., 2013; Pitarch et al., 2014; Roldán et al., 2014 and 2018; López et al., 2014 and 2017), besides the common use of portable stereoscopic microscope. Energy dispersive X-ray fluorescence (EDXRF) spectrometry is a powerful, compact and commonly used technique for elemental analysis employed on a large variety of materials in the cultural heritage field, offering new opportunities for non-destructive in situ investigations. Roldán et al. were among the first researchers to apply this kind of technique to Levantine paintings (Roldán et al, 2006, 2007 and 2010) (Fig. 2). This technique is appropriate for the qualitative study of high-Z elements in low Z-matrixes, being able to detect chemical elements heavier than Al or Si. However, it also has some limitations. For example, when analyzing multilayer samples, this technique is not able to discriminate between single layers: it detects all chemical elements the X-ray beam encounters on its path without giving information on their distribution across the stratigraphy. Moreover, since it is an elemental technique, other molecular analytical methods have to be used in conjunction if we aim at identifying the nature of the compounds. Assuming the homogeneity of the bedrock, analyses of the Levantine pigments have been based on the comparison between painted and not painted areas in order to highlight differences in the detection of the elements and their relative counts, as well as to characterize the trace elements related only to the paintings (Fig. 3). However, this approach fails when the painting layers are very thin and/or degraded and differences are indistinguishable, as shown by Roldán et al. (2016).

Raman spectroscopy is widely used in research on cultural heritage artworks, including both conventional micro-Raman and mobile micro/Raman versions of the technique (Bersani and Lottici, 2016). This vibrational spectroscopic method is fast and non-invasive and it allows the unambiguous identification of a wide range of materials: inorganic and organic pigments, crystalline and amorphous compounds, highly heterogeneous matrixes, thanks to the high space resolution. For these reasons, it is a great tool for the analyses of archaeological objects, and it has been widely used in the study of Levantine rock art, for both the analysis of micro-samples using bench-top setups and on site using portable equipment. The inorganic minerals and pigments composing the bedrocks, pictorial layers, accretions such as calcite, gypsum, hematite, calcium oxalates, etc. of the Levantine paintings are easily identifiable using this vibrational spectroscopy (Burgio and Clark, 2001). Nevertheless, the on site use of micro/Raman portable instrument involves some problems, since Raman spectra collected in situ normally exhibit lower signal-to-noise ratio than the spectra collected in-lab by classical benchtop instruments. In addition, they are also severely affected by sunlight, wind, vibrations, dust, etc. As for sunlight, working at night is not suitable in open-air rock shelters due to the presence of numerous insects over the painted panels. This problem could be potentially solved by covering of the objective head. As an example, Hernanz et al. (2014) suggest the use of an opaque foam rubber tube adapted for their specific micro-Raman portable equipment to solve this issue. Hence, heavy objective lenses, gadgets to cover the external objective, optimizing the focusing, power supply, laser power at the focus position, integration time and the number of spectral accumulations, etc. are some of the factors to be adjusted to eliminate technical limitations and problems involve in on-site working setup. Another complication affecting both on site and benchtop Raman analyses is the presence of crusts and layers of fluorescent materials interstratified with the pigments, since they produce a covering background fluorescence signal that masks the detection of any investigated materials. Moreover, it is important to be careful with laser power when examining micro-samples in which the presence of iron oxides and hydroxides is assumed. It is known the effects of the laser power dependence and associated heating in these kind of compounds (De Faria et al., 1997, Shebanova and Lazor, 2003). Spectral changes and transitions phases between the Fe-oxy/hydroxyes can be produced by increasing the laser power, inducing sample degradation. This fact frequently occurs under intense sample illumination and may lead to misinterpreting the Raman spectra.

Portable non-invasive techniques such as these are necessarily the first step of any approach to this fragile cultural heritage, since their non-destructive nature allows the use over extensive surfaces on a virtually infinite number of points, thus providing numerous integrative and representative data. On the contrary, a micro-sample can be representative only of the site where it has been sampled. Furthermore, we have to bear in mind that the number of samples that can be taken is limited, both for ethical and damage reasons (they affect the integrity of the paintings, even when we are now talking about micro-samples). Thus, non-invasive techniques are essential to guide ethically targeted sampling. In addition, when taken, micro-samples should respect the integrity of the motif (sampling from lacunas or borders are preferable) and contribute to deepen the questions arising from previous non-invasive approaches (Fig. 4).

Sampling is also necessary to conduct microstratigraphic analysis and identify the different components and layers, which information is of capital importance to better understand and sequencing the paintings and for their protection (Fig. 5). The samples can be investigated in the laboratory using bench-top instrumentations, by non/destructive analytical methods both in micro- and sub-micro scales. Different phases of this ideal approach have been tackled in the study of Levantine rock art and all the analytical methods and methodological procedures used and published so far are reported in Table 1.

From this table it is obvious that over the first two decades of this new century, researchers have demonstrated an increasing interest in the study of the pigments and their sources, of use to address questions of mobility and social interaction; the nature of the bedrock surface, raw material transformation and recipes, to identify cultural similarities and differences and potential authors, traditions and schools; the stratigraphic analysis of superimpositions, to identify the order of the paintings events; and the conservation histories and futures of Levantine rock art (table 1). While more pigment analysis than those listed in table 1 have been conducted (for ex. Martínez-Valle, 2002: 200, mentions analysis conducted at la Sarga site, Alcoi; or samples we took at el Carche site, Jalance in 2014), unfortunately many of them are still unpublished.

In general terms, while the priority in research on Levantine rock art has been to determine pigment composition, the underlying aims have been to track historical or regional patterns to deduce social and cultural behaviour, and to contribute to better understand the conservation of this art.

Two decades later, it is clear that there is no single technique to answer all these questions, so different analytical methods have to be combined. The identification of carbon-based pigment in a black figure is a good example in that regard. The absence of signals related to specific elements of black inorganic pigments such as Mn, Fe, when performing X-ray fluorescence analyses, provides indirect information on the use of an organic-based pigment (as observed by Roldan et al, 2014), the presence of which can be only confirmed by other analytical techniques, among which Raman spectroscopy is one of the most suitable for the identification of these compounds (Coccato et al, 2015). On the contrary, the latter technique is less efficient for identifying poorly crystallized pigments such as manganese oxides, whose constituent metal is easily detectable by X-ray analysis. This demonstrates that a combination of different techniques may be required to fully understand the processes and materials involved in rock art production and the conservation history of Levantine rock art.

3. RESULTS

3.1 The Levantine Palette: Pigments and Binders

The palette of Spanish Levantine artists includes three main colours: red, black and white (Fig. 6). These colours were used to produce mainly monochrome paintings, though a few bichrome paintings (white over red or various red hues) have been also identified (Cabré 1925; Domingo, 2005, 2008 and 2012; Hernanz et al., 2008), suggesting perhaps that this technique was also common but today is underrepresented for conservation issues. While the reasons behind the choice of these nuances are still unknown, whether resulting from specific social rules or from limited access to mineral or organic raw materials, today analytical research has provided a quite complete identification of their components (table 1). Red pigments are mainly composed by iron based oxides or hydroxides, basic compounds of ochers and earths pigments, among which hematite (α-Fe_2O_3) is the most frequently detected in prehistoric Levantine paintings (Table 1). This mineral is an iron (FeIII) oxide present in rocks and soils and it is the principal pigment in red, brown and purple iron oxide-based pigments, known from all cultures usually in the form of hematite-rich earths and/or ochers. Due to its natural abundance, chemical stability and lightfastness, it has been highly employed since prehistoric times as art pigment (Eastaugh et al, 2008). The colour depends on the phase (oxyde, hydroxide…) and crystal size: the hues range from yellowish to red trough several browns. Nanoparticles of hematite lead to red and purple colours or even black for larger crystals (specularite) or for the cementation or the aggregation of very small crystals, as ferricrete dense masses (Schwertmann, 1993).

Among the first analytical studies, Montes and Cabrera (1994) investigated the post-Palaeolithic rock art of the Murcia region, carrying out a micro-stratigraphic study of the prehistoric representations. A clay matrix with a composition very similar to an ocher, but more compact and unctuous, as they defined *Bol rojo*, was detected in all the red pigment samples. Moreover, Roldán et al. 2006, 2007, 2010 and 2014 identified *in situ* by portable EDXRF spectrometer the use of various Fe-based pigments (red earths and/or ochres) in the production of the red layers of several figures depicted at *Les Coves de la Saltadora* and *Cingle de la Mola Remigia*, both sites belonging to the Valltorta-Gassulla complex of sites (Castelló). The authors concluded that the artists used different raw materials, suggested by the characterization of diverse trace elements found in various red pictograms from the same site. In particular, they detected traces of Mn in some red pigments showing the use of Fe-oxides from different sources as well as the possible intentional addition in one of the figures. Moreover, the identification of traces of As in part of a red deer appeared in agreement with the use of two kinds of red pigments and different phases of execution. On site non-invasive analyses allowed the authors to assume that a complex process of composition lies behind the production of these rock paintings, highlighting possible differences in sources, authors, and execution times.

Furthermore, Hernanz et al., 2006, 2008 and 2010 recognized the use of hematite studying several micro-samples belonging to the rock shelters in the Cuenca region. They distinguished three different granular sizes of the mineral (namely, <1 µm fine, 1–10 µm intermediate and 20–100 µm gross), evidencing a great technology and ability employed by prehistoric artists during the process of rock art production. Moreover, Raman spectroscopic analyses allowed the authors to achieve structural information regarding the crystallinity of hematite by evaluating the half bandwidth of the Raman bands (Hernanz, 2015). In fact, this spectroscopic technique represents an effective method in the identification of Fe-based pigments (Bersani and Lottici, 2016), narrow Raman bands were observed in well-crystallized hematite (Hernanz et al., 2010), whereas band broadening was observed in impure, amorphous or altered hematite containing other iron oxides and hydroxides (De Faria and Lopes, 2007). These changes in the hematite crystal size could be natural or the result of anthropic manipulation (De Faria and Lopes, 2007). Indeed, it is worth mentioning that hematite is a naturally occurred pigment, but thermal and mechanical processes based on the conversion of hydrated Fe-oxide goethite α-FeOOH (or a goethite containing material such as a yellow ochre) into its crystaline form α-Fe_2O_3, can synthesize it (Cornell and Schwertmann, 2003, González et al., 2000; Cavallo et al., 2018). It has been reported that mechanical dry grinding synthesis produces an important reduction in particle size with respect to thermal treatments (González et al, 2000). Furthermore, hematite can be generated by heating goethite at temperatures below 850–900°C, when it undergoes dehydration and crystalization (Pomies et al., 1999; Gialanella et al., 2011). However, heating is not the only agent able to produce hematite since de Faria and Lopes (2007) suggest that biodegradation and weathering can produce the same effect. In addition, the colour changes (from brown-red to deep purple-violet) induced in the hematite by increasing the firing temperature during its thermal synthesis have been attributed to the increase of its grain size; minor colour modifications are observed in natural yellow ochers with high argillaceous content upon firing (Mastrotheodoros, 2010). From an archaeological point of view, the question of whether artists living in prehistoric times have used the red Fe^{3+} oxide in their natural form or after intentional treatments to obtain a desired colour and/or a softer product to be pulverized (Gialanella et al., 2011) is of great interest. Several studies have demonstrated that in most cases, a multi-technical analytical strategy based principally on the use of TEM and XRD techniques can effectively answer these questions (Helwig, 1997, Pomies et al., 1999a and b, Gialanella et al., 2011; Cavallo et al., 2018). As for Levantine rock art, this aspect has not been addressed in depth yet.

Again, Hernanz et al. (2008) also identified the presence of apatite in mixture with hematite in the pictorial red layer of some figures from *Sierra de las Cuerdas* (Cuenca). Since phosphates were not detected anywhere in the numerous samples of substrata they analysed and the use of bone implements to grind the pigment does not seemed reasonable to them, considering that Fe-oxide is harder than apatite, the authors hypothesized the use of a specific recipe to prepare the red pigment including powdered hematite and calcined bones as filler. In addition, the authors speculated that such use of an apatite-rich recipe was ritual and the identification of the phosphate compound in some samples belonging to a white painted area of the same site has reinforced this thesis. Moreover, the identification of amorphous carbon mixed with hematite in several red figures also suggested the authors the use of another specific pictorial recipe (Hernanz et al., 2006, 2007).

Later, Mas et al. 2013 detected concentrations of calcium phosphates in the rock surface besides their identification in the red pigment layer composed by hematite, analysing two micro-samples coming from two red figures from *Minateda* rock shelters (Alpera, Albacete). This finding moved the authors to consider, on the contrary, the presence of apatite as the degradation of shells of invertebrates and fragments of foraminifera, partially replaced by phosphate and not related to any pictorial recipe, rejecting the thesis of a possible ritual. In addition, the authors recognized for the first time the presence of goethite in mixture with hematite from red samples related to Schematic paintings.

Another uncommon pigment has been identified at a Levantine shelter, but in the red sample belonging to a schematic figure from *Los Chaparros* shelter (Albalate del Arzobispo, Teruel) by Pitarch et al. (2014). This figure was composed by iron oxides (hematite) in mixture with a Mn- oxide, identified as chalcophanite. This result suggested the authors the use of an intentional pictorial recipe by the schematic artists.

Amorphous carbon (charcoal or soot) (Montes and Cabrera, 1994; Hernanz et al., 2010 and 2014; Roldán et al., 2014; López et al., 2014 and 2017) and manganese oxides and hydroxides (Roldán et al., 2006; 2007, 2010; Pitarch et al., 2014) are the principal components identified in black Levantine paintings. Carbonaceous matter can be found in nature as geological deposits of graphite and related materials, or can be produced by firing wood (Coccato et al., 2015). Most natural Mn oxyhydroxides are nanosized and poorly crystalline, especially in soils and sediments, and they exist in various mineralogical forms on the earth's surface (geologists have identified more than 30 $Mn_xO_y(OH)_z$). They can be distinguished according to their chemical composition, oxidation degree-Mn^{2+}, Mn^{3+}, Mn^{4+} or mixed- and crystalline structure and some of them are of black shade (Post, 2013). Based on the studies published so far, in Levantine rock art contexts amorphous carbon from vegetal origin occurred more frequently than Mn-based pigments, contrary to widely held opinions. This finding appears very interesting from the archaeological point of view: it could be related to a better access to vegetal organic raw material to be burned (Byrne et al., 2013) and to be employed as a black pigment to depict (López et al, 2017). This result also suggests that Levantine prehistoric artists did not use to burn bones in the painting procedures to create black pictograms. López et al. (2017) used an archeobotanical and physicochemical multi-analytical approach to identify very broadly the raw materials used by the prehistoric painters in the production of the black carbon-based pigments, studying several samples coming from the *Les Dogues* shelter (Ares del Maestrat, Castelló). Through the identification of plant cells, they recognized the amorphous carbon belonging to angiosperm (any flowering plants) in one figure and conifer charcoal (including cedars, pines, cypresses, junipers, firs, yews, spruces, among others) in another. While the authors claim that the botanical identification of plants used in the preparation of these black pigments could constitute another effective research line on the understanding of plant resource exploitation by Neolithic communities, their own results (limited identification of very large groups of plants) demonstrated that the grinding process had seriously damaged the charcoal structure, thus "rendering the identification of tissues quite difficult" (López et al., 1917:12/27). At this stage, therefore, the extensive development of this invasive approach should be rejected, unless further experimental approaches demonstrate their potential to go beyond the identification of very large plant groups.

Another interesting approach was that of Pitarch et al. (2014) and their analysis of black pigments from Levantine motifs located at *Los Chaparros* shelter (Albalate del Arzobispo, Teruel). They explore the possibility to link the pigments used by the artists with the raw sources available in the surrounding of the rock-shelter. In particular, together with the black sample, they analyzed two additional dark specimens from a black dendrite present in the same rock shelter and another sampled from the *Los Mases de Crivillén* mining area, close to *Los Chaparros*. According to the study, the Levantine black figure was composed by Mn oxides/hydroxides whose raw materials corresponded to those identified in the dendrite mineralization of the site. The exact nature of the Mn compound was not identified. The authors highlighted also the analytical difficulties to determinate the specific nature of the Mn oxides/hydroxides by both Raman spectroscopy and X-Ray diffraction when these compounds are a mixture of various poorly crystalline minerals.

Finally, to complete the Levantine painting palette, it is interesting to note that descriptions and analysis of white pigments are missing. This colour is not as frequently used as red and black in prehistoric paintings, or at least it is not so well preserved (Beltrán, 1993; Domingo, 2005). In the Levantine context, components like α-quartz, anatase, apatite, muscovite, gypsum and illite were detected in white lines of a bicolour pictographs found in the *Marmalo IV* shelter of *Sierra de las Cuerdas* (Cuenca) by Hernanz et al. (2008). The figure showed many white traces highlighting the perception of the muscles of a red bull. Microstratigraphic investigation showed that the white layer was superimposed on the red pigment. A similar pattern has been previously observed in a couple of sites at Valltorta-Gasulla complex of sites (Civil and Centelles), but in these cases it was used to highlight details and adornments in human figures (Cabré, 1925; Domingo, 2005, 2008 and 2012). In the same red bull, significant amount of amorphous carbon black particles underlying the whitish paints were detected. The authors interpreted them as remains of a previous sketch of the figure made by the artists using charcoal of vegetable origin, as occurred in other prehistoric pictographs in France (Clottes et al., 1990). However, a later work showed that the presence of black-coloured particles could result from the metabolic activities of lichen, fungi, and other microorganisms and could not be exclusively related to an anthropic use as pigment (Darchuk et al., 2009; Mas et al., 2013).

Regarding the use and the identification of the binders, not much information is currently available. The common assumption that Levantine pigments were simple solutions/suspensions instead of complex mixtures, since components such as proteins or lipids, which could act as binders, have never been identified, seems no longer appropriate (Montes and Cabrera, 1994). Ethnoarchaeological research has demonstrated that the use of binders plays a significant role in the long-term conservation of the art in the open air, since paintings produced without binders disappear in a few years or decades depending on their exposure (Domingo et al, 2018: 173). Several recent works (Domingo, 2012; López et al., 2017; Santos da Rosa, 2018) have shown that prehistoric artists should have used some liquid medium (vehicle) and a binder to suspend inorganic pigments in the creations of their paintings, as well as different kind of brushes to apply such paint mixture to the substrate. Natural carbohydrates, lipids and proteins could have been employed as binding media (from honey, blood, milk, plant resin, etc.), in addition to the potential use of inorganic binders as clay minerals (Hernanz et al., 2008). One of the problems regarding their identification arises by the fact that these organic compounds are actually the basic nutriments of microorganism such as fungi, bacteria, lichens, etc. and they could be fixed into calcium oxalates (Rampazzi, 2019). According to the literature, one of the possible origins of the oxalic acid may be related to the chemical degradation of the organic binding media used for painting due to the feeding and metabolic actions of microorganisms (Spades and Russ, 2005; Mas et al., 2013; Pitarch et al., 2014). Thus, it results doubtful they would have persisted intact on the rock surface since prehistoric times; if any residual amounts are still present, it is often not enough to be detected (Spades and Russ, 2005). Moreover, it has been shown that the presence of metal oxalates can also be correlated directly to the degradation of the lipid media itself, as occurred in extensively deteriorated panels or wall paintings (Salvadó et al., 2013; Sotiropoulou et al. 2015, 2018). They have been considered as final decay product related to the binder degradation mechanism that begins from the auto-oxidation of the fatty content of the binding media, such as egg yolk or drying oil (Sotiropoulou et al. 2018). Thus, it cannot be excluded that the occurrence of Ca-oxalates in proximity of pictorial layer could also be due to aging processes of the binder itself, beyond the action of any microorganisms. Or even more, calcium oxalate could also be produced by the decay of the proteinaceous material of the cell membranes of several microorganisms such as bacteria, fungi, etc. (Rampazzi, 2019). Thus, the presence of calcium (or other metallic) oxalates cannot be directly related with the painting technique.

Furthermore, the chemical transformations and aging that the organic residues are expected to have undertaken need to be considered. Generally, lipids of animal and plant origin, as well as plant resins, may survive better than carbohydrates, proteins and nucleotides in archaeological environments due to their lower susceptibility to structural modification and degradation by chemical and microbiological attacks as well as hydrophobicity; degraded lipids in archaeological samples are identified by high concentrations of palmitic (C_{16}:0) and stearic (C_{18}:0) acids (Colombini et al., 2012; Bonaduce et al., 2016). Furthermore, the lack of the organic media detection in the Levantine paint layers can be also related to the limits of the experimental techniques employed for their identification so far. As an example, in situ and laboratory Raman analysis are often frustrated by the fluorescence background signal that frequently occurs during the investigation due to the presence of crusts and layers of fluorescent materials interstratified with the pigments such as naturally fluorescent organic compounds, atomic fluorescence in some minerals, etc. (Smith and Clark, 2004; Hernanz et al, 2014; Bersani and Lottici, 2016). This kind of technical difficulties led the detection of any remaining binders harder. Moreover, among the vibrational spectroscopies, Fourier Transform Infrared spectroscopy (FTIR), both in transmission and reflection configurations, represents an effective and highly suited method in the identification of residual organic matters belonging to the binders, and good results have been also shown elsewhere in rock art micro samples (Rosi et al., 2019; Rosina et al., 2019). Nevertheless, typically liquid/gas chromatographic based-techniques coupled with mass spectrometry, after appropriate sample pre-treatments, represent some of the most commonly and effectively adopted analytical methods in the study of organic materials from archaeological contexts (Pollard et al., 2007; Colombini et al., 2012). Recently, Roldan et al. (2018) have performed a prominent and innovative analytical approach based on the proteomic analyses of some micro-samples belonging to Les Coves de la Saltadora (Coves de Vinromà, Castelló). They used for the first time in Levantine rock art analyses high-throughput sequencing to provide the first description of the bacterial communities colonizing the rock art patina, as well as analyses to determine organic binders. Beyond the identification of the *Firmicutes* bacterial species, that might have a protective effect on the paintings, they also detected casein peptides of animal origin, present both in the pigmented red samples and in one sample taken from a not pigmented area with a reddish patina. The authors conclude that these results could be compatible with the use of animal milk employed as a binding agent in red pigments motifs from *Coves de la Saltadora*. A finding that would be especially significant since, if demonstrated, it would directly relate Levantine rock art to Neolithic populations, closing the debate on the chronology and the lifestyle of the authors. However, they recognize that since it has been also detected in a reddish patina in a not pigmented area, additional and multidisciplinary efforts are needed to confirm whether the casein peptides identified come from modern contaminants or, alternatively, from molecular remains of the binders used. Although they have not still found direct evidence to demonstrate that the discovered casein is not a ubiquitous contemporary contaminant, their results show the potential of the use of proteomics in rock art investigation to contribute to our understanding and knowledge on the technical and socioeconomic aspects of prehistoric Levantine societies.

3.2 Bedrock, Crusts and Conservation

A full understanding of the materials used in Levantine rock art paintings is also basic to identify pathologies and conditions not only threatening rock art conservation today but also those that have operated over time to either preserve or destroy this art since it was created. In fact, it is the first step for devising strategies to contribute to the future preservation of this World Heritage. Rock art sites include pigments and binder, but also different sorts of patinas and crusts, usually covering both the painted and not painted surfaces, that we need to understand properly if we aim at progressing in rock art conservation (table1). They are the result of a double process of weathering of the rock substrate and sedimentation due to bioactivity and dust accumulation. If weathering is more active than sedimentation, there is a loss of the surface material and any potential paint would be loss over time. On the contrary, if the biomineralization process is more active than erosion, some new layers of minerals will develop on the paint, protecting them from any erosive process. This is, probably, the main reason explaining how so ancient and fragile layers of paint survived thousands of years in almost open air conditions. Beyond the analysis of the pigments, analytical approaches to rock art also include the analysis of the bedrock, as well as the patinas and alteration products that appear at the rock-pigment-atmosphere interfaces (Roldán, 2013). In fact, rock art located in the open air is constantly threatened by the effect of spontaneous and changeable external environmental conditions (temperature, water, humidity, sunlight, microorganisms, etc.), besides to the aging of its constitutive components. All these factors provoke significant changes in the structure of the bedrock, including physical-mechanical damage in the form of cracks, fractures, loss of cohesion, flaking, pulverizing, etc., that mostly depend on the type of minerals and their intrinsic properties (e.g. mineralogy, texture and structure). Consequently, a comprehensive study of the physicochemical and weathering (from environmental, mechanical, geological and biological causes) phenomena involved in the alteration mechanisms upon which the rock panels are continuously suffering from, allow to monitor and to predict their long-term behaviour. This way, the aim is to minimize and retard their deterioration with the exploration of the most appropriate conservation strategies (Hernanz et al., 2006, 2007, 2008 and 2010, Alloza et al., 2009, del Hollo-Meléndez et al., 2019).

The starting point is the examination and characterization of the bedrock used as substrate. While constraint by regional geology, the identification of the constitutive rock minerals and their arrangement (petrography) is important to estimate their deterioration processes and potential pathologies, and it is also crucial in the research of their best conservation measures, as occurs for example when exploring potential consolidating agents and their compatibility with the bedrock (Charola et al., 2007; Otero et al., 2017; Sierra-Fernández et al., 2017; Barreda and Zalbidea, 2019). Three different typologies of bedrock surfaces have been identified in relation to Levantine rock art: limestone (mainly composed by calcite, $CaCO_3$) (Obermaier, 1938; Roldán et al., 2006, 2007, 2010, 2014; Alloza et al., 2009; Hernanz et al., 2010, López et al., 2014, 2017), dolostone (based on dolomite, $(Mg,Ca)CO_3$) (Montes and Cabrera, 1994), and sandstone (principally constituted of α-quartz, SiO_2) (Ripoll, 1961; Hernanz et al., 2006; 2007; 2008). In some shelters, calcite and dolomite were identified together (Mas et al., 2013; Hernanz et al., 2014; Pitarch et al., 2014).

Moreover, gypsum ($CaSO_4 \cdot 2H_2O$) and other sulfate salts were identified several times in the pores of the bedrock surfaces as well as of the painting layers of different sites (Hernanz et al., 2006, 2007; 2008; 2010; 2014; Roldán et al., 2006, 2007, 2010; Mas et al., 2013; Pitarch et al., 2014). In particular, their presence was associated with the occurrence of flakes and spallation formations found in various rock shelters, damaging the appreciation both of the painted figures and the rock support. Flake formations are considered as a direct product of the salt weathering processes of the bedrock (Benito et al., 1993; Doehne, 2002; Roldán, 2013). Salts are known to damage porous materials due to the physical stress related to their crystallization in the pores: when water contacts the pore network of a stone, it may carry various salts (Scherer, 2004). Flake accretions were detected both in limestone (Hernanz et al., 2010; 2014) and sandstone (Hernanz et al., 2006, 2007; 2008; 2014) bedrocks in Levantine rock art sites by Hernanz et al. Regardless of the type of substrate, the authors suggested that water from rain, soil moisture, wet areas, etc., dissolves the sulfates, which penetrate into the bedrock due to its porosity. Evaporation in the proximity of the rock surface of the shelters generated gypsum crystals in the pores of the bedrock and close to the surface. The development of flakes can be also produced by the expansion of clay minerals (if they are part of the rock-matrix) when adsorbing water (Vendrell-Saz, M. et al., 1996), even if this aspect has not been explored by the authors. In both cases, humidity–dryness cycles considerably affect bedrock flaking processes. For these reasons, the authors suggested the protection of the painting panels from humidity to preserve and retard the degradation of the rock support from this type of alteration processes. It has been demonstrated that this kind of weathering phenomenon highly depends on the environmental and climate conditions under which the shelters are continuously exposed (temperature, sunlight, moisture, rain etc.) and on the nature of the bedrock itself (mineralogical composition, texture, porosity, capillarity etc.) (Doehne, 2002; Benito et al., 1993). However, it should be reported the option of a contextual biological origin of these sulphate salts (especially in the case of gypsum ($CaSO_4 \cdot 2H_2O$), baryte ($BaSO_4$) and celestite ($SrSO_4$)), as well as superficial carbonates, even such aspect has never been taken into account by the authors. In fact, bio-mineralization could be an effective and further formation path of these superficial inorganic materials, as widely shown in the literature, and the presence of different kinds of microorganisms have been detected in most of the analysed sites (table 1) (Adamo and Violante, 2000; Rodríguez-Navarro et al., 2012; Ngwenya, 2016). It is worth mentioning that limestone and sandstone rocks are both vulnerable to decay, but the synergic effect of both environmental parameters and the specific chemical nature of the rock supports can promote different degradation pathways. As an example, they are both responsive to environmental pollutions even if generally, calcareous stones are more susceptible to deterioration than purely siliceous ones (Sabbioni, 2003; Turkington and Thomas, 2005; Artesani et al., 2020). In particular, any alterations of the chemical equilibrium of the system H_2O-CO_2-$CaCO_3$ in limestones (or any high carbonate content rocks) can induce their dissolution/precipitation. Carbon dioxide dissolves in water with the consequent formation of carbonic acid (H_2CO_3), which is at the base of the dissolution of calcite ($CaCO_3$). High levels of CO_2 in rainwater promote the dissolution pathways. Moreover, sulphur species contained in the air (dry deposition) or dissolved in rainwater (wet deposition) can affect that equilibrium, leading the subsequent conversion of the calcite to gypsum, $CaSO_4 \cdot 2(H_2O)$, that often is the responsible of the creation of black crusts (Garcia-Vallès et al., 1998; Sabbioni, 2003; Turkington and Thomas, 2005; Charola et al., 2007; Artesani et al., 2020).

For this reason, besides physicochemical analyses, it could be very useful for conservative purposes to constantly monitor the environmental parameters such as moisture, air pollutants, temperature, sunlight, etc. in order to contextualize the analytical results, if possible, also in relation to the climate conditions to which the shelters are subjected. Pitarch et al. (2014), analysing the bedrock surface of the *Los Chaparros* shelter (Albalate del Arzobispo, Teruel), constitute by calcite and dolomite, detected also gypsum ($CaSO_4 \cdot 2H_2O$) and its anhydrous form anhydrite ($CaSO_4$). Mas et al. (2013) also identified this anhydrous compound on the limestone surface of the bedrock of the *Abrigo del Barranco de la Mortaja*, in *Minateda* rock shelters (Albacete). In both cases, the authors referred the presence of this phase of calcium sulfate to the gypsum dehydration process. According to literature, gypsum and anhydrite are the most abundant sulfate minerals in nature, which solubility and thermodynamic stability are greatly affected by changes in the physical and chemical parameters that occur within common geological environment (Klimchouk, 1996).

Thus, a deep knowledge of the rock substrate as well as the environmental conditions under which the rock shelters are exposed could be a key factor to understand the chemical processes that occurred and could be still ongoing on the rock surface.

Furthermore, patinas containing calcium oxalates covering open-air rock surfaces were also identified in most of the Levantine sites analysed (Hernanz et al., 2006, 2007, 2008, 2010, 2014; Mas et al., 2013; López et al., 2014, 2017; Pitarch et al., 2014). Their presence is a widespread decay phenomenon found on stone materials and other substrates (walls, paintings, mortars, glass, etc.), representing one of the most assessed weathering processes (Di Turo et al, 2016; Rampazzi, 2019; Artesani et al., 2020).

Calcium oxalates occur in nature in three different crystalline forms: the monohydrate, whewellite ($CaC_2O_4 \cdot H_2O$), the dihydrate weddellite ($CaC_2O_4 \cdot (2+x)H_2O$, $x \leq 0.5$) and the trihydrate, caoxite ($CaC_2O_4 \cdot 3H_2O$). Only the mono/hydrated forms are generally identified in the films. According to literature, the exact variables affecting the prevalence formation of one phase rather than the other are not completely understood: although the most stable form at environmental temperature is the monohydrate, they often are identified together and their distribution is variable and not reproducible (Rampazzi, 2019). Crusts calcium oxalates are recurrently found on the surface of rocks, monuments and buildings and regarding their origin, various possible hypotheses are proposed, as recently summarized by Rampazzi (2019). They could have biological origin, and in this case, the patina is the result of the extensive microorganism colonization due to their metabolic actions; chemical origin, and in this second case the production of the films is considered the final steps of transformation of organic media/binders applied to the stone. Other authors also suggest that the source of oxalic acid derives from the atmosphere, present in the rain (Watchman, 1991), air pollutions (Saiz-Jimenez, 1989), etc.

In Levantine rock shelters, both whewellite and weddellite were recognized together in most of the cases (table 1) and their patinas of variable thickness and pigmentation generally cover all the surfaces of the painted figures and bedrocks of the rock panels. They were also detected in the composition of one flake sample, together with gypsum (Hernanz et al., 2006, 2007), belonging to the painting panel of *Cueva del Tío Modesto* shelter, in *Sierra de las Cuerdas* (Cuenca). In addition, in several cases, they were identified interstratified in the painting layers that appear bracketed between two strata of oxalates films (Hernanz et al., 2006, 2007, 2010, 2014; Roldán et al., 2014). In agreement with the analytical investigations, the origin of these accretions of hydrated forms of calcium oxalate on rock surfaces was attributed to the action of microorganisms, as the result of the biological activity of fungi, lichens and bacteria that live and have lived on and within the stone. Fungal hyphae encrusted with small calcium oxalate crystals were recognized by Hernanz et al. using scanning electron microscopy (SEM) in some micro samples from various rock shelters in *Sierra de las Cuerdas* (Cuenca) (Hernanz et al., 2006, 2007, 2008), in proximities to which they also detected colonies of the lichen *Verrucaria nigrescens*. The finding of carotenoids (Hernanz et al., 2008), organic compounds characterized by yellowish-orange colour and associated with lichens or bacteria, provided further evidence of the biogenic origin of the crusts. Furthermore, in one sample, the same authors suggested that the fungal hyphae degradation activity is still ongoing since whewellite was recognized up to more than 100 microns inside the rock substratum (Hernanz et al, 2007). Based on the literature, the microorganisms colonize the stone and during their metabolic activities, they could secrete the oxalic acid, a chelating organic acid. This latter in turn reacts and dissolves the Ca-based compounds of the surroundings coming from the bedrock, such as calcite/dolomite, or from the rock surface, like gypsum, leading to fixation of calcium ions in excess and to the precipitation of calcium oxalates (Rampazzi, 2019). When the patinas are associated with the paintings, it cannot be excluded that the occurring calcium oxalates might be also related to the digestion by microorganisms of the organic binder, or to the own degradation process of this latter, independently from their feeding actions (as explained in section 3.1). There is a common assumption that oxalate patinas associated with prehistoric rock art are produced naturally. However, differences of the Ca-oxalates crust characteristics in terms of colour, thickness, location in the rock shelters, could suggest that they might be also formed via various pathways and/or by multiple origins, in which chemical and biological mechanisms could act simultaneously, as occurred on other types of heritage surfaces (Garcia-Vallès et al., 1998). Regardless of their possible origin, from a conservative point of view, the presence of patinas and crusts (that can be formed by calcium oxalates, gypsum, calcite etc.) is strategic. They are characterized by poor solubility in water and high stability against environmental agents and, these factors lead them to be natural protection for the prehistoric paintings, as evidenced also by Hernanz et al. (2007). Although these patinas make the painting pictographs opaque, less visible and appreciable, they have allowed the painting layers to remain quite undamaged over time (fig. 6, middle image). These crusts in fact have resisted to the weathering during thousands of years, as well as in most of the case, they have also been robust to the action of oxalate degrading bacteria that oxidize calcium oxalate into calcium carbonate (Sahin, 2003). This is the case highlighted by Roldan et al, 2018, thanks to the omic analytical approach performed on the patinas of several samples coming from *Les Coves de la Saltadora,* Valltorta-Gassulla Region (Castelló). The analyses showed the presence of different kinds of bacteria: some belonging to the genus of *Bacillus*, producers of oxalic acid, which also generate the calcium oxalates patina on the surfaces. Others from the genus of *Flavobacteria,* known to deteriorate the oxalate patinas as a consequence of calcium carbonates solubilization (Di Bonaventura et al., 1999). From the identification of frequencies and ratios of microbial oxalate producers and degraders that act as protectants or destabilizers, respectively, the authors displayed that in well-preserved samples the ratio *Bacilli*: *Flavobacteria* was high, suggesting that the bacterial communities in *Coves de la Saltadora* play a predominantly protective role. This kind of analyses have highlighted that microbiome determination can highly contribute to depict informed conservation strategies for Levantine rock art.

Another key aspect related to the presence of patinas refers to their occurrence when they are interstratified between the painting layers. Microstratigraphic analyses are essential for this purpose in order to visualize and distinguish the various components of the paints: crusts, depicted pictograms and their possible superimpositions, and bedrocks (fig. 6, middle and bottom images). If two pigment layers are divided by calcium oxalate (or another biogenic patina), a time sequence of events on the rock surface may have occurred. In this way, when achievable, it is possible to delineate a chronological sequence of production of the prehistoric motifs, as suggested by Hernanz et al. for *Cueva del tio Modesto* rock shelter, in *Sierra de la Cuerdas* (Cuenca) (Hernanz et al, 2006, 2007). An initial microorganism’s colonization of the surface left the innermost oxalate layer, where the prehistoric artists found the first perfect area to depict. Therefore, a second oxalate layer produced by a new microbial colonization covered the motifs. Subsequent weathering processes can affect the external surface. Furthermore, the layering of carbon-based patinas revealed useful also for dating purposes, using AMS ^{14}C technique (Ruiz et al, 2006, 2012; Hernanz et al, 2007). Establishing the chronology of open-air rock art still represents one of the main challenges in rock art studies. The paint layer must include some organic matters containing carbon for dating goals. If they were present originally, organic materials must be available and persisted nowadays without exchanging carbon. Moreover, ethical consideration based on the size of samples required to carry out AMS ^{14}C dating may be prohibitive under the present experimental requirements. To overcome these limitations, based on the stratigraphic relationship between painted figures and accretions, patinas have been used as an alternative to pigments for radiocarbon dating, requiring no organic material be present in the paintings, in order to obtain *ante quem* and *post quem* dating values of these layers between which the painted motifs are sandwiched. However, this method is not exempt from questions and issues (Bednarik, 2002; Cole and Watchman, 2005; Domingo, 2008: 29; Ruiz et al, 2012). It is based on the presumption that all of the mineralized carbon was derived contemporaneously from the atmosphere by biological processes and that it did not fractionate or change the relative abundances of the three-carbon isotopes (in particular ^{14}C) between the atmosphere and the patina. Moreover, the relationship between the measured age of formation of the crusts and the painting layer event is indirect and it presumes that patinas have formed at regular intervals over a long interval (Cole and Watchman, 2005). Furthermore, once deposited, the calcium-rich patinas are not necessarily closed carbon systems, but they may be involved in further alteration processes: rejuvenation through deposition of younger solute, accumulation of organic material from different sources and isotopic exchange or fractionation (Bednarik, 2002). Additional issues are also related to the difficulties occurred during the sampling process in order to sample selectively the layers interested in avoiding any contamination due to other layers and/or components present in them.

4. Conclusions

Analytical approaches to Levantine rock art are changing the way we understand the materials, instruments and processes involved in rock art production and preservation, and their change over time, through multidisciplinary research. To rock art this means moving from traditional descriptive analysis of the motifs to reconstruct the creative process or operative sequence (from raw material procurement to rock art production and past and present consumption), as well as to understand how it has survived over millennia.

While literature on analytical methods used in this particular rock art tradition is still scarce when compared to European Palaeolithic art (ex. Onoratini, 1985; Lorblanchet, 1995; Clottes, 1997; Pomies et al., 1999; Smith et al., 1999; Guineau at al., 2001; Salomon et al., 2008 and 2015; Iriarte et al., 2009; Olivares et al., 2013; Roldán et al, 2013, etc.), when globally evaluated the analysis conducted so far (including both non-invasive and invasive techniques) are starting to provide interesting results to understand the palette and the practices of Levantine artists. Any stage of the process of production involves socio-cultural decisions and therefore is stylistic in itself (Domingo and Fiore, 2014). Local procurement practices have been detected at *Los Chaparros* site by identifying the pigment sources (Pitarch et al., 2014). The use of different sources has been also deduced through the presence of different trace elements (Mn, As, Pb) at *Coves de la Saltadora* site (Roldán et al. 2007 and 2010) and *Cingle de la Mola Remigia* (Roldán et al., 2014), suggesting the participation of different authors, different painting events and even potential diachronic retouching, and thus complex processes of composition. We now know that hematite is the most used material to produce red paintings, while black paintings are produced either from black charcoal or manganese oxides. However, information on white pigments is still missing. We also know that Levantine pigments show different degrees of grain size maybe related to different processing practices, though this aspect requires further analysis to advance knowledge on the technologies of Levantine rock art production. Different pigment recipes are beginning to be identified (Roldán et al. 2010; Hernanz et al., 2008), while unquestionable information on binders and instruments is still missing. With the available data we observe that the variety of mixtures identified in Palaeolithic rock art, seems to disappear in LRA, despite differences in colour hues. Moreover, it is not possible to link yet specific raw materials or recipes to specific styles or regions. Considering the fragility of this cultural legacy and the distinction as both Bien de Interés Cultural by the Spanish Heritage Act and World Heritage by UNESCO, the utilization of non-invasive techniques should be prioritized as a first step. Here after the synergistic and combined use of several analytical methods is the best strategy to study highly heterogeneous matrices, such as those found in rock paintings. The results achieved using portable instrumentations will be necessary to guide sampling that is still required since microstratigraphic studies represent another essential step to advance knowledge on this tradition. Importantly, sampling should be always guided by ethical principles and as such it should only be conducted if research questions cannot be answer with any other methods. As summarized in this paper analytical approaches are also important for conservation purposes: to identify crusts, degradation, microorganisms, and so forth, and ensure compatibility of any introduced materials for rock art conservation. These conservation practices should be guided by policies securing a balance between preservation of scientific and heritage values, giving careful consideration to the fact that any materials introduced (pigments and consolidating materials) or removed (crusts) could impact archaeological approaches to past technologies and practices. Thus, multitechnical, multidisciplinary and collaborative approaches are the key to advance knowledge on rock art production and conservation minimizing impacts on the different values of this and other rock art traditions worldwide.

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