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Special issue: Conservation of Rock Art. Part I

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FIVE YEARS OF COALITION

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In September 2000 the first issue of this Newsletter was launched. Today the issue No. 10 is being distributed to subscribers all over the world and we are proud of seeing consolidated this project of dissemination of research and best practices on Cultural Heritage.

This newsletter was edited in the framework of "COALITION", a Concerted Action of the European Commission (EC) that started on April 1st, 2000. The objectives of this project were (Saiz-Jimenez 2000):

1. To identify, introduce and enhance the use of molecular biology and biotechnology techniques of interest for the conservation/restoration of Cultural Heritage;

2. To obtain information on the type of microorganisms colonizing different and representative materials, by generating an inventory of the microorganisms associated with the damages of Cultural Heritage, and

3. To disseminate the advantages of using molecular techniques for diagnostic purposes to end users.

In order to reach these objectives several initiatives were carried out, such as setting up a web site, organizing two international workshops (March 2001 and July 2002); organizing of an advanced course for young researchers and professionals in November 2002, publishing the proceedings of an International Congress on Molecular Biology and Cultural Heritage and launching this newsletter, as a mode of communication within the project.

The EC funded project lasted three years although COALITION has continued. At that moment the number of subscribers reached 700 including people in North and South America, Asia, Australia, Northern Africa and most European countries. During its first three years of activity, a total of 31 papers were published in six (two of them double) issues, covering topics as databases of microorganisms related to deterioration of Cultural Heritage, molecular techniques applied to conservation/restoration of Cultural Heritage, or biological problems associated to cultural assets.

An important step for the continuity of this newsletter was the sponsorship of CSIC Thematic Network on Cultural Heritage after COALITION project concluded. This network was launched in October 2001 to coordinate the efforts of several CSIC research groups working on Cultural Heritage. Five research activity areas, with the common interest on Cultural Heritage, are included in the network: Archaeological and Architectonical Heritage; Biology; Physics; Geology and Materials Science (Saiz-Jimenez 2004). From that change of sponsorship, the newsletter is the medium for disseminating CSIC Thematic Network activities and intends to be an international forum for scientists, conservators, restorers and students, fostering interdisciplinary communication.

We intend that this international newsletter could keep on being a place for rendezvous between all knowledge concerning Cultural Heritage and people involved in it.

In order to make easier the accession to the contents of these first ten issues, we have prepared an index of the papers already published that will be distributed jointly with issue 10 of the Newsletter (Figure 1).

Figure 1. Cover of Index

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Saiz-Jimenez, C. (2004). A new step for COALITION. *COALITION* 7: 2-3.

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THE LESSONS OF LASCAUX

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Recently, in some multidisciplinary journals (Holden, 2002, 2003; Allemand, 2003; Allemand and Bahn, 2005; Castellani, 2005) and a few internet web pages appeared reports and letters on the biological threats on Lascaux paintings. This increasing interest in biodeterioration effects of microorganisms on rock art paintings derived from the fungal invasion of Lascaux Cave.

Lascaux Cave suffered works and modifications since 1940, the year of discovery. In fact, an air-conditioning system was installed between 1957 and 1958, replaced in 1972 and thereafter in 2000. It was thought that workmen putting in the new system brought the contamination on their boots (Allemand, 2003). *Fusarium solani* quickly covered the floor of the cave and fungicides and antibiotics were used against it. However, Lascaux has a long history of biological contamination and previously was contaminated by algae (Lefèvre et al. 1964) and the cave treated with formaldehyde and antibiotics. The eradication of microorganisms in Lascaux Cave is a clear example of how man's attempts to control or manage nature provoke further unpredicted changes in cave´s biodiversity.

Microorganisms, particularly bacteria, inhabit all allowable habitats of the biosphere, including subterranean ones. Subsurface habitats are dark, generally low in organic nutrients, relatively constant in temperature, but, in turn, contain numerous microbial communities. Microorganisms occupy all cave niches (rocks, speleothems, moonmilk, waters, etc.) and the conspicuous colonization of paintings, walls, ceiling, and cave soils constitute a biological pool where a wide variety of microorganisms is waiting for an unbalance in the delicate ecological and microclimatic cave conditions for proliferation.

Microorganisms have been found in all Spanish rock art paintings so far studied (Schabereiter-Gurtner et al. 2002 a, b) and they are apparently a "natural" colonisation, as shown in La Garma Cave, visited and sampled shortly after the discovery (Schabereiter-Gurtner et al. 2004). However, most of the identified strains in caves represented unknown and uncultured species.

We must accept that some of the most famous paleolithic paintings are threatened by unknown microorganisms, but under these premises, how a microbiologist can propose countermeasures?. If the microbes and their metabolic activity are unknown how a treatment can be proposed? And if proposed, can be predicted the effects on other microbial communities and the evolution of further biological successions?.

Allemand and Bahn (2005) stated that the best way to protect rock art is to leave it alone, and, at the current level of knowledge, we must admit it would be the safest measure.

Assuming that rock art, all over the world, is subjected to many different threats, and to commemorate the fifth anniversary of the publication of this electronic newsletter, an invitation for contributing was addressed to a number of well-known specialists in rock art. COALITION Nos. 10 and 11, therefore, will include contributions on conservation of rock art in Africa, America, Australia and Europe. The editor acknowledges the collaboration of all colleagues and their availability for preparing this special issue that is expected will be of interest for all professionals involved in cultural heritage studies.

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UNKNOWN MICROBIAL COMMUNITIES ON ROCK ART PAINTINGS. CONSEQUENCES FOR CONSERVATION AND FUTURE PERSPECTIVES.

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Abstract

Rock art containing caves are significantly affected by microbial colonization. Due to the need for preserving these unique paintings, there is an increasing interest in understanding the microbial communities involved in these negative processes. Recent studies on the development of different colonies using advanced molecular techniques are revealing the presence of a high proportion of unidentified microorganisms in caves holding prehistoric paintings. The metabolic capabilities of these microbes are so far unknown. Interestingly, these microorganisms are metabolically active in situ as shown by RNA-based molecular surveys. Understanding the role of the microbial community on these caves is a first requirement to attempt an effective conservation of these prehistoric paintings.

Introduction

Prehistoric paintings are almost the only representations of art by our very first ancestors. Caves containing prehistoric paintings attract the interest of scientists as well as the general public. Massive tourist visits to prehistoric paintings generate a potential risk for the conservation of these caves. Some of the most famous caves, such as Altamira and Lascaux, are currently closed to the public due to accelerated deterioration (Schabereiter-Gurtner et al. 2002; Holden, 2002).

The prehistoric paintings we know today have been naturally preserved due to the stable environmental conditions existing in these caves. However, the affluence of large numbers of visitors result in microclimate changes leading to unpredicted effects with serious negative consequences for the conservation of these unique paintings.

Microorganisms are everywhere and caves are no exception. Microbial colonization of cave walls is significant and wide spread. However, these microbial communities are unknown and consequently of unpredictable long-term effects. Current research initiatives are focusing on deciphering the complex composition of the microbial communities developing on rock art paintings.

The methodology currently available for detecting microorganisms in natural samples can be classified in two major groups, culture-dependent and culture-independent methods (Ward et al. 1990). Culture dependent methods require the growth of microorganisms on culture media. Thus, those microorganisms unable to develop in the medium and incubation conditions provided will never be detected. The major advantage of culturing techniques is that the metabolic capabilities and physiology of the microorganisms can be studied in detail and novel strains or species can be characterized. Culture-independent methods do not need cultivation of microorganisms since they are detected in situ. Although there are several culture-independent strategies available, the more frequently used are the molecular techniques. Molecular techniques rely on the specificity of the nucleic acid sequences for detecting and differentiating microorganisms. Molecular methods allow highly sensitive and unambiguous detection of microorganisms in situ. Generally, the identification of environmentally-extracted DNA fragments is based on the 16S ribosomal RNA (16S rRNA) gene which offers a conserved sequence and the most complete database available today for any type of gene sequences (Woese et al. 1990). The disadvantage of molecular methods is that the physiology of the detected microorganisms can not be easily investigated.

Using these methodologies, microbiologists are currently focused on deciphering the composition of the microbial communities developing on cultural heritage and figuring out their role and consequences for preserving rock art.

Methodology

Molecular methods have been recently introduced into microbiological research in the field of cultural heritage. The basic protocol is outlined in Figure 1 and requires the extraction of nucleic acids from a given sample, followed by amplification of the gene of interest (generally, the 16S rRNA) by PCR, DNA library construction and clone screening, biodiversity analysis through microbial community fingerprinting techniques, DNA sequencing, bioinformatic analysis of sequences, and final identification of microorganisms and their closest phylogenetic relatives.

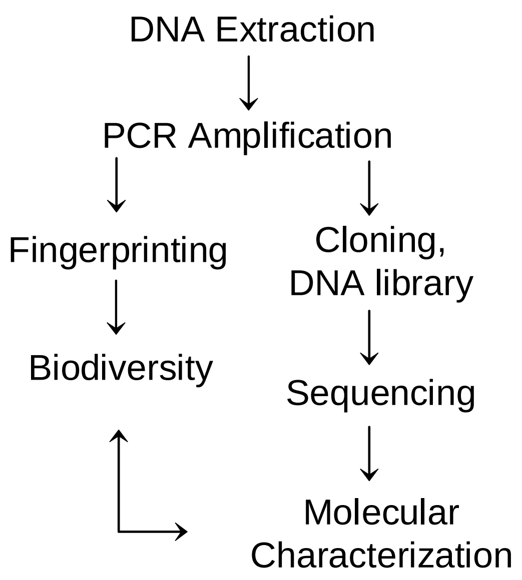

Figure 1. Basic protocol for the molecular analysis of microorganisms. This scheme represents a culture-independent strategy allowing the in situ detection of the microorganisms present in cultural heritage samples

Novel improvements in the molecular analysis of complex microbial communities are being developed within the cultural heritage field (Schabereiter-Gurtner et al. 2001; Gonzalez et al. 2003, 2005a and 2005b) and in other cases imported from other biological scientific areas. Sample or treatment comparison can be performed by analysis of microbial community fingerprinting techniques since each sample can be represented by the molecular fingerprint based on the retrieved 16S rRNA genes. There are several fingerprinting techniques available (SSCP, t-RFLP, DGGE) although the Denaturing Gradient Gel Electrophoresis (DGGE) is the most frequently used in cultural heritage studies (Gonzalez and Saiz-Jimenez, 2004).

Recently, we are introducing the use of RNA-based analysis as a complement to standard, DNA-based molecular studies of microbial communities. While DNA offers information on the presence of microorganisms in a sample, RNA permits the detection of those microorganisms metabolically active. This is because the amount of RNA per cell is proportional to its metabolic activity and RNA is rapidly degraded when not needed (Molin and Givskov, 1999). In our case, these active microorganisms are the ones directly responsible for the development of undesired colonies on the paintings under the current environmental conditions. However, if conditions change over time, the microorganisms present at the studied site can become metabolically active and become actively growing and implicated in transformations or colonizations potentially leading to unpredictable changes in caves and paintings.

The microorganisms present in Altamira Cave were first approached by culturing techniques and the major group of detected microorganisms belonged to the Class Actinobacteria (Groth et al. 1999; Laiz et al. 1999). Culturing strategies although requiring the growth of microorganisms are extremely useful since they allow detailed studies of the metabolic capabilities and physiology of the microorganisms. However, the proportion of microorganisms detected from culture-dependent and –independent methods are generally in disagreement (Laiz et al. 2003). Once a microorganism is cultured, its growth conditions, carbon substrate utilization, participation in nitrogen and sulfur compounds transformation, among other characteristics, can be examined. Thus, the function, environmental role, and potential impact on cultural heritage can be easily analyzed.

Current state-of-the-art

Current studies being carried out in Altamira Cave are revealing the existence of highly complex microbial communities. Molecular studies performed during the analysis of these samples were first based on DNA (Schabereiter-Gurtner et al. 2002). Thus, the number of microorganisms detected was too high to be able to study a significant fraction of them. Recently, we are initiating molecular analysis based on RNA which should indicate us which microorganisms within the total microbial community are showing metabolical activity. This initiative presents two major advantages. First, we are able to detect those microorganisms actually involved in the colonization process in the cave. Second, the fraction of metabolically active microorganisms in a given sample is much lower than the total number of microorganisms. Therefore, we were able to detect the fraction of active microorganisms and so significantly reduce the number of microorganism to be studied in detail in order to approach their effect on the biodeterioration of the cave walls.

Although these molecular tools provide with valuable methods for the detection and identification of microorganisms in complex microbial communities, there is still a long way for understanding the behaviour of these communities and their potential effects on the preservation of prehistoric paintings. The reason is simple but it has a difficult solution. The results revealed the presence of a high proportion of microorganisms showing highest similarity to uncultured microorganism. This is in agreement with the results obtained by other authors in a variety of substrates of cultural heritage interest and greatly slows down the progress in the field. These results imply that we are unable to deduce the potential metabolic capabilities of the unknown microorganisms detected during the studies. As a consequence, it is difficult, and generally impossible, to reach any scientific-based conclusion on the potential biodeterioring effect of the microbial community and specifically of its component microorganisms.

Recent research on this topic have shown the presence in Altamira Cave of unsuspected types of microorganisms. The fist example is the presence of Acidobacteria representing up to almost a 25% of the total number of cloned sequences analyzed from the cave. At present, the Phylum Acidobacteria has only three cultured and described representatives (*Acidobacterium capsulatum*, *Geothrix fermentans*, and *Holophaga foetida*) and over a thousand sequences deposited in DNA databases from molecular surveys of microbial communities. The diversity within this phylum is believed to be comparable to the diversity known within the Phylum Proteobacteria, probably the widest and most diverse bacterial phylum known today (Hugenholtz *et al.*, 1998; Quaiser *et al.*, 2003). Therefore, the role of Acidobacteria in Altamira Cave is so far completely unknown and their diversity is greatly above any expected prediction (Zimmerman et al. 2005).

A study being carry out at Altamira Cave have revealed the presence of metabolically active low-temperature Crenarchaeota. The presence of a highly diverse community of these Archaea in Altamira Cave and the fact that they show metabolical activity represent unique findings since they have never been detected in this environment and their activity had not been shown in microbial ecology. DNA-based molecular surveys have shown the presence of low-temperature Crenarchaeota in diverse environments (Hershberger et al. 1996; Schleper et al. 2005). However, at present, there is not a single cultured representative of the low-temperature Crenarchaeota and as a consequence, we are completely unaware of their metabolic capabilities, functional role in their habitats and potential physiology.

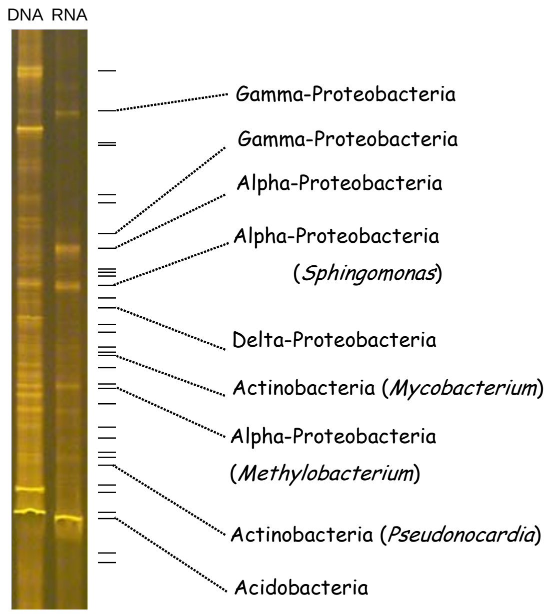

Figure 2. Comparative microbial community fingerprints by DGGE obtained from DNA- and RNA-based molecular approaches from Altamira Cave samples. RNA-based identified microorganisms are indicated

During a molecular survey of differently coloured colonies actively developing on Altamira Cave walls, strict anaerobes have been detected as metabolically active microorganisms on superficial samples taken from these colonies. Among these microorganisms, sulphate-reducing bacteria related to *Desulfovibrio*, or *Thauera* related microbes have been detected from the presence of 16S rRNA in the RNA pool extracted from the analyzed samples. These results clearly suggests the involvement of anaerobic processes in the already complicated microbial interactions going on at these complex microbial communities colonizing the cave walls.

Future perspectives

Molecular tools solve the problem of detecting the biodiversity constituting the total microbial community, the metabolically active microbial community, and the identification of the specific microorganisms composing each of these two populations. However, the presence of a high number of unknown microorganisms requires further investigation. While classical microbiological methods where based on the culture of microorganisms and by the end of last century a requirement of culture-independent methods was getting imposed for the survey of microorganisms in natural environments, now at the turn of a new century the microbiologists are again in need of culturing techniques. Currently, culturing techniques are needed to ascertain the metabolism and physiology of a large number of microorganisms only known by being detected by molecular methods. Consequently, molecular and culturing methods are complementary.

Other strategies might come up in a near future due to the fast pace of scientific progress in these days (Gonzalez, 2003). Assuming a large fraction of the uncultured microorganisms will be difficult to culture and the microbiologists are not able to do so in the next decade, complex approaches based on current metagenomic techniques (e.g., Schleper et al. 2005) or a variety of other molecular techniques still not frequently used in cultural heritage (Gonzalez, 2003) might be solutions to decipher the role and metabolism of some of those unculturable microbes. The complexity involved in the use of genomic approaches might represent something out of the reach for modest cultural heritage budgets, but it is a clear indication that our field of research is at the cutting edge of scientific development.

Perhaps the major consequence of having still a large fraction of unknown microorganisms whose role in their habitats remains to be understood is that, as far as this required knowledge is not in our hands, the best strategy to be followed for prehistoric paintings is to maintain the original conditions which permitted the conservation of rock art for thousands of years.

Acknowledgements

Researches on Altamira Cave were supported by the Spanish Ministries of Culture and Education and Science.

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IBERIAN PALAEOLITHIC ROCK ART

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Geography

Geographically speaking, the boundaries of European Pleistocene rock art are marked by a series of occidental and southern coordinates. The recent discovery of Church Hole, in the south of England, is one of the rare sites located to the north of 48th parallel. The latitudinal stain of this kind of art is located between the 46th parallel and the southern European border, i.e. Strait of Gibraltar.

Longitudinally this stain spreads from Portugal to the Ural mountain chain, but in an uneven way, as 96% of the stations where this kind of art can be found are located in Iberia and France: the 1984 official French computation, partially updated by us, registers 150 stations; there are 6 Italian sites, and only 3 or 4 are scattered within the rest of this immense territory to the Ural mountains.

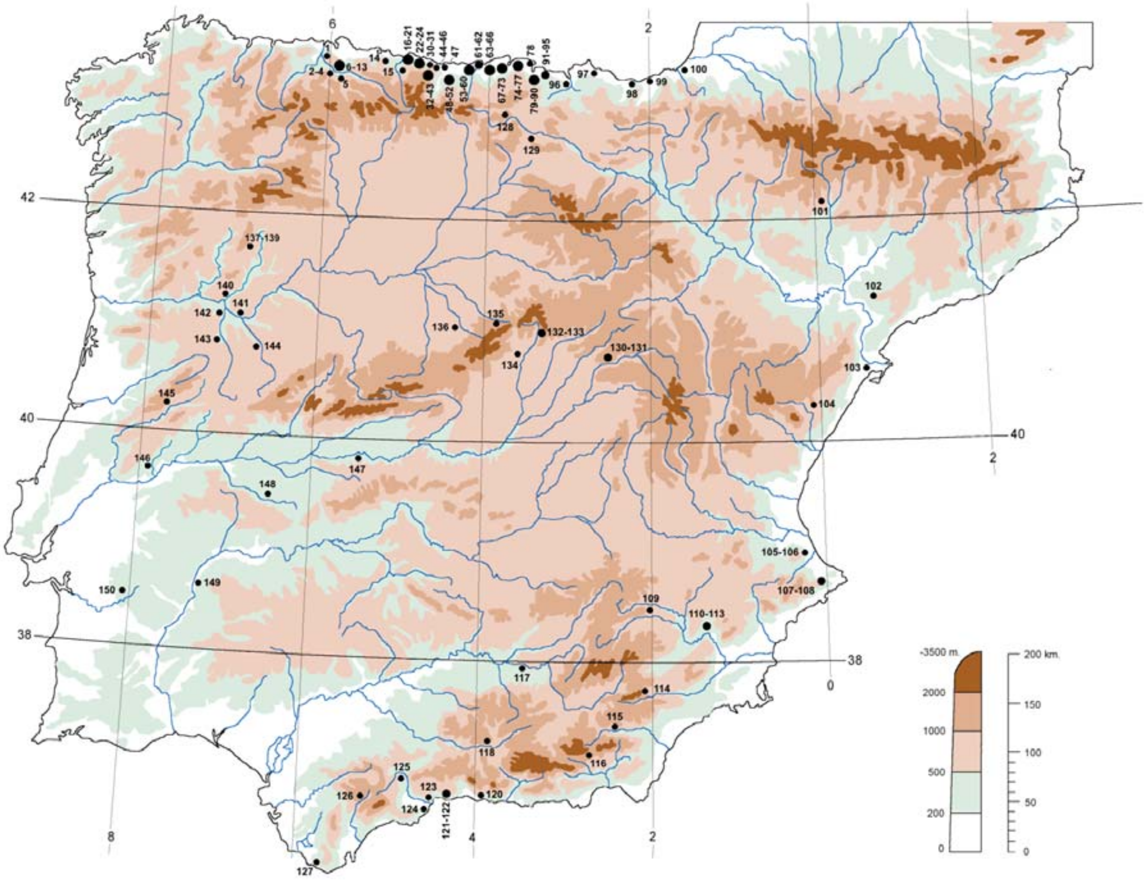

Figure 1. Distribution of the Palaeolithic Rock Art in the Iberian Peninsula. 1: Candamo. 2-4: El Conde, Sto. Adriano, Los Torneiros. 5: Entrefoces. 6-13: Godulfo, Las Mestas, La Lluera I, La Lluera II, Las Caldas, Entrecueves, Los Murciélagos, La Viña. 14: El Sidrón. 15: El Buxu. 16-21: Tito Bustillo, La Lloseta, La Cuevona, Les Pedroses, San Antonio. 22-29: Samoreli, Tempranas, El Tebellín, Cueto de la Mina, La Riera, Trescalabres, Balmori, Quintanal. 30-31: El Covarón, La Herrería, 32-43: Covaciella, Soberaos, El Bosque, Berodia, Falo, Peña del Alba, Los Canes, Traúno, Coimbre, Llonín, Subores, La Loja. 44-46: Mazaculos I, Mazaculos II, El Pindal. 47: La Fuente del Salín. 48-52: Porquerizo, Traslacueva, Chufín, Micolón, Los Marranos, La Meaza. 53-60: Las Aguas, Altamira, El Linar, La Clotilde, Sovilla, Santián, Cualventi, Hornos de la Peña. 61-62: Las Brujas, Cudón. 63-66: El Castillo, Las Monedas, Las Chimeneas, La Pasiega. 67-73: El Pendo, El Juyo, La Llosa, La Garma, Moros de San Vítores, El Caldero, El Salitre. 74-77: El Otero, Los Emboscados, El Patatal, Cobrantes. 78: Peña del Perro. 79-90: Covalanas , La Haza, El Mirón, La Luz, Cullalvera, Sotarriza, Venta de la Perra, Arco A, B y C, Morro del Horidillo, Pondra. 91-95: Urdiales, El Cuco, La Lastrilla, Juan Gómez, Cueva Grande de Otañes. 96: Arenaza. 97: Santimamiñe. 98: Ekain. 99: Altxerri. 100: Alquerdi. 101: La Fuente del Trucho. 102: La Taverna. 103: Moleta de Cartagena. 104: En Meliá. 105-106: Parpalló, Les Maravelles. 107-108: Fosca, Reinós. 109: El Niño. 110-113: Jorge, Las Cabras, Arco I, Arco II. 114: Cueva de Ambrosio. 115: Almaceta. 116: Piedras Blancas. 117: El Morrón. 118: Malalmuerzo. 120: Nerja. 121-122: La Victoria, El Higuerón o Tesoro. 123: Navarro. 124: El Toro. 125: Doña Trinidad de Ardales. 126: La Pileta. 127: El Moro. 128: Cueva Palomera. 129: Penches. 130-131: La Hoz, Los Casares. 132-133: El Turismo, El Reno. 134: El Reguerillo. 135: La Griega. 136: Domingo García. 137-139: Sampaio, Pousadouro, Fraga Escrevida.140: Ribeira da Sardinha. 141: Mazouco. 142: Bajo Côa. 143: Medio Côa. 144: Siega Verde. 145: Zêzere. 146: Ocreza. 147: La Mina de Ibor. 148: Maltravieso. 149: Molino Manzánez. 150: Escoural

Iberia is full of testimonies of this kind of art. Their locations are scattered all over its peninsular geography, both in its current Atlantic climatic environment and in its coastal and interior Mediterranean variants. The lines that provide essential structure to their distribution adapt both to the rivers, which connect Atlantic and Mediterranean coasts to the massifs of the borders of the great interior Plateau, and to the major waterways and their tributary rivers, which cross the Peninsula longitudinally.

In Figure 1 the distribution of the 150 Iberian sites, which have been attributed without any doubt, to this kind of art is shown. The computation is restrictive, as it could be slightly increased if we had followed less strict criteria and furthermore, nº 142 of the Côa river has been counted as only one unit, when actually we are talking about a group formed by 24 different rocks placed in the open air, distributed along 13 kilometres of the downstream course of this river and the Duero river; slightly less numerous are those rocks of the Siega Verde group (nº 144), in river Agueda, or those of Domingo García (nº 136) in the Eresma.

Thus, once we have a look at our inventory, our attention is attracted to the fact that two thirds of the Iberian total is located in the Atlantic area, essentially to the north of the main massif, the Cantabrian Chain, from its foot to the coast. Partly, this concentration could be explained by the biomass diversity and the variety of resources that could be exploited within a small area, which could favour human establishment and population sustainability. Until a few decades ago, the rest of the peninsular map appeared much emptier, with fewer locations. Regions such as País Valenciano or Murcia start to provide their first testimonies and in Andalucía, a relatively large number of new ones are added to the veteran caves of La Pileta (nº 126) or Trinidad de Ardales (nº 125). But it is in the large basins of the Duero, Tajo and Guadiana rivers where, apart from the findings in caves, other examples have been found, which have increased the insight that we had of this artistic phenomenon. To sum up, the peninsular map starts to fill, though it does not seem likely that it will become as full as in its most northern area.

Topography, technique and themes

Topography

This kind of art has four topographic emplacements: in the darkness of caves, sometimes at the very back, as in the case of Cullalvera (nº 79-90), after a one kilometre walk with many difficult passageways; at the cave's entrance up to the penumbra area, as in La Lluera I (nº 6-13) or Los Torneiros (nº 2-4); on the walls of rock shelters, as in La Viña or Cueva Ambrosio (nº 6-13 and 114); finally, on open air rocks, found in a completely open landscape. This is the case of Sampaio, Pousadouro, Fraga Escrevida, Ribeira de Sardinha (nº 137-139 and 140), Mazouco (nº 141), rocks from the middle and lower Côa river (nº 142 and 143), Siega Verde (nº 144) and Domingo García (nº 136) in the basins of the Duero river and its tributaries; it is also the case of the sites in the rivers Ocreza and Zézere (nº 145 and 146) in the Tajo basin; of Molino Manzánez (nº 149) in that of the Guadiana river or Piedras Blancas (nº 116) in Andalucía. These large open-air areas with palaeolithic art are specifically Iberian, this uniqueness would not be refuted by the only open-air station, which up to the date, has been found in France, Fornols Haut, in the Mediterranean region of Aude. On the other hand, the unexpected discovery of these new areas, whose number will increase after the new approach to our analysis that they have caused, will allow us to say that Palaeolithic art is not a synonym of cave art.

Regarding light, these topographic locations are grouped into two categories: interior ones, in darkness, and exterior ones, more or less illuminated by the sun. According to this division, the first category would reach two thirds of the total as a result of the Cantabrian weight. But this simple calculus is perhaps biased as, among the exterior category ones, open-air site discovery is more problematic and hazardous than that of panels sheltered by cave shades, and rock shelter or cave entrances. From our point of view, there are two reasons for this: the approach which has lead the research lately, which did not presume the existence of open air palaeolithic rock art sites, and the lithographic characteristics of the rocks: under these conditions, we cannot expect the same success as regards conservation if the testimony is engraved in strong Palaeozoic non-calcareous rocks, or even, though to a lesser extent, in limestone from the same period, versus Mesozoic and subsequent periods carbonated rocks. Surprises have arisen from the first kind of rocks of the Iberian interior, but it is possible that artistic expression may had been developed on any other type of rock formations and lithography imposed its conditions.

Figure 2. Llonín cave

Techniques

The techniques employed in this kind of art are engraving and painting. The first has fine lines, mainly inside the cave, or deep ones in naturally illuminated sites. In the latter, rabbets and curved edges in the groove lips may cause three-dimensional effects like those of a relief (deep engraving leads to relief), as in La Lluera I, but in Iberia there are no bas and mid reliefs as in France, carved in the rock to represent human figures or animals, sometimes in a scale close to the natural one of the model. Paint was used for linear strokes or, more accurately, to give movement to the coloured mass. Figures are monochrome or bichrome, but in more complex testimonies, as for example in Altamira (nº 53-60), paint was mixed, washed and smoothed to give polychrome effects, masterly achieved with only a two basic colour palette: black from vegetal coal, burnt bone or manganese, and different shades of iron oxides, which they knew how to modify by heat. Inside the caves, depending on the epoch, engraving was associated with painting to delimitate the contours or to outline the internal minimal details of the represented subject. Colour was applied following different methods, including aerography.

Themes

The themes of this kind of art are reduced into four categories: animal figures, human figures, signs and unfinished shapes or undetermined lines. During the Palaeolithic period two expressive branches coexist: the naturalistic animal figure, and the geometrical abstraction of signs, classified as the most impressive example from an intellectual approach to Palaeolithic art.

Interior and exterior art themes do not vary in their substance. If their inspiration sources and the intellectual background, which support both kinds of art, had been different from one another, the themes would have been the best ground to express such differences, but this is not the case. Thematic coincidence exists because, supporting palaeolithic art there is a thought which is sufficiently unified and shared so that it involves, to classify and explain them, both interior and exterior geographies. It is not surprising, as other kinds of art, such as the Australian Aboriginal Art, whose tradition was maintained up to the late 19th century, was the expression of a country.

Figure 3. Tito Bustillo cave

This does not mean that open-air art, that illuminated in shelter or cave entrances and that of interior darkness are interchangeable. One is visible because of its actual location; another coincides with dwelling areas, it was part of daily routine and, as time went by it lost its meaning: in fact, in some places, as successive occupation levels were used, they came to cover up what was represented on the walls, as happens in La Viña or Cueva Ambrosio. The last one is interior, sometimes voluntarily hidden, though in large sites it is enormous, made to be seen and in no way meant to be secret. Even though we perceive a global thought interested in both the exterior and interior worlds, it does not mean their arts functions were the same.

Figure 4. Lluera I cave

Chronology and styles

Chronology

Until the use of the direct dating technique, which provides absolute dates (numeric could be a better qualifying adjective), mobile or rock art chronology was based on the different indirect dating methods, which constitute relative chronology.

Chronological potentiality of these methods is incomparably bigger for mobile art, as items are commonly found in stratigraphies contextually associated to different products of technical activity, whose dating can be found out relatively easily, and transferred to the mobile item. But, these methods are difficult to apply to rock art due to its nature. It is very rare to find cases where a correlation (of diverse nature) between rock art examples and their immediate or close archaeological context has been established. Normally, context is merely reduced to figuration and wall support. The order of the different superimposed figures establishes a basic chronological scheme: obviously, most recent examples are on top of older ones. To face all these deficiencies, traditional chronology looked for the homologies that could be established between rock figuration samples and other mobile art samples whose date was known: examples of these are the engraved scapula found in some levels occupied in Altamira or El Castillo (nº 63-66), which were reproduced in the engraved figures on panels in both caves and, exactly reproduced in Llonín (nº 32-43). This is also the case of the characteristic forms and representation conventions we can see in objects from the Magdalenian period, and which we can easily recognise on many French and Iberian rock walls.

^{14}C method has been rendering its services to archaeological dating since the middle of the 20^{th} Century, but it could not be applied to rock art, because it caused inadmissible destruction, as so much material is needed for this dating method. A technical novelty, the accelerated mass spectrometry (AMS), produced acceptable damage as a result of taking a few milligrams of the picture sample, to obtain, after the depuration of gangue, few micrograms of datable carbon. The direct dating world was open. The title of a symposium published in 1993: *Rock Art Studies: the Post-Stylistic Era or Where do we go from here?* was expressive enough about the old dating methods becoming obsolete and the new expectations that were opened. At the same time, laboratories made an effort to purify the samples more and more, so that pollution due to different causes could be avoided. Engraving dating remained outside of ^{14}C method, but other methods could provide more precise numeric dates than those of relative chronology: among them, thermoluminescence (TL), electronic spin resonance (ESR) or uranium series (U/Th) were applied in Iberia, and other methods which we do not summarise here due to their mere tentative essay nature. According to the physic principles they are based on, their chronological scales are different from those of the ^{14}C method, so the conversion of all of them to the same referential scale expressed in solar years is necessary. This represents a problem for ^{14}C method as it cannot be calibrated by dendrochronology. Among all different dating methods, the most common ones are those based on ^{14}C disintegration: their results have coincided or slightly revised the estimations deduced from relative chronology but other results are irreconcilable. According to the experts, other techniques bring about doubts and have to be regarded as provisional.

Stiles

Change is a temporal marker for form. To place the variations of the representative forms in their corresponding date leads us to the history of style and to ask ourselves about its evolution.

Until the last decades of the 20th century, the most favoured style classification was that of A. Leroi-Gourhan, based on the relationship that could be established between mobile art and most reliably dated wall panels. According to him, four styles have followed one another along Upper Palaeolithic that could be interpreted as four stages in a linear course. This course could have commenced during the first modern human culture in Europe, the Aurignacian period, and could have continued along the following cultures: Gravetian, Solutrean and Magdalenian cultures. The characteristics of each of these styles were described, as well as their chronological frame. This chronological and stylistic organisation was considered a paradigm for the interpretation of the findings that were to come, but in the history of knowledge every paradigm is born to be revised: that is the essence of its greatness.

The finding of the French Chauvet cave meant a great impact because of its exceptionality in every aspect. AMS dating of some of its impressive figures between 32.410 and 30.340 years BP questioned directly the chronological value of style: nobody had ever dated so sophisticated an art in such an early date, that contradicted the idea of a continuous and linear evolution with regional particularities; on the contrary, anticipations, peaks, extinctions and recurrences should have been found within a diversified geographical frame. Other AMS dating of simple figures from the cave of San Román de Candamo in Asturias were found to be even older: 32.310 and 33.910 years BP; but, after a more complex study, their date was found to be much more recent. Direct dating methods, that measure time with numeric results, have not solved all the problems; but they are welcomed for the weighted exercise of the method.

Nowadays, it is not believed that Palaeolithic art can be enclosed in a unified block produced during more than 20.000 years according to a characteristic pattern, recognisable on a general scale above regional particularities. For its dating we apply the best part of indirect methods (its context and a thorough morpho-technical analysis) and direct ones, but after a rigorous confrontation and evaluation of both results: if one of them is rejected, the reasons have to be explained very well. Style markers are looked for in figure deformation and in the expressive conventions of modelling, their inner planes and movement. Thus, the styles of Covalanas, Castillo, Altamira, Parpalló, etc, are described and their geographical frame is defined, outlining vast chrono-stylistic classifications for the future. Actually, the method is the same as before, but with more limited expectations. Nevertheless, the most important chronological frame is already established, and it covers a time immensity, which goes from 33. 000 to 11.000 years BP. Independently of the surprise of a site being older or more recent than thought, and oversimplifying, the enigmatic body deformations, many representative conventions and a greater "expressionist" touch in lines are characteristics of older times; to sum up, we are facing a great stylistic and territorial variety. A more "academic" and naturalistic unification in the vast Franco-Iberian areas corresponded to the peak of the Magdalenian period.

Figure 5. Pileta cave

The meanings

During the first half of the 20th century the hypothesis that Palaeolithic art was the result of magic motivation within a totemic social context was extended. S. Reinach, H. Breuil and H. Bégouen were its main supporters. This conclusion was reached after comparing this type of art to that of primitive peoples studied by Ethnology, particularly that of Australian aboriginal culture. Ethnographical comparisons became abusive, so by the middle of the century this hypothesis became to be severely criticised. It was then when the structuralist point of view of A. Laming-Empéraire and, above all that of A. Leroi-Gourhan, rejected ethnographic comparisons and pointed out the need to go back to art itself; that is, to the cave or the shelter, to the panels and their figurations, to see whether they responded to a previous iconographic plan. Leroi-Gourhan concluded that there was actually such a plan, that both, animals and symbols, were classified in sexual character categories, and that Palaeolithic art was the expression of a dualistic view of the universe, present in the opposition of two principles, masculine and feminine, and a third one: animals. Important aspects in Leroi-Gourhan's literature were deservedly criticised; the mildest but most extended ones were centred on the adjective: sexual, forgetting its basis was dualism but also that this dualism was not present without a third one: according to the basic formula A-B+C. On the positive side we have to highlight his notion of bestiary, the scarce potential of magic as a global explanation; his criticism towards ethnographic comparisons; his regarding the cave as a whole where an iconographic programme was adapted to the possibilities offered by an already finished architecture; and furthermore, that the election of the themes was not made at random, but it was the result of a series of rules that were already becoming present.

Sauvet and Wlodarzyk have deepened this research through the application of statistical and algorithmic analyses to 416 poli-thematic panels and they have underlined that only few associations were made, though the combinatory possibilities were immense. Motives are classified into five categories: 1, horse, bison and goat; 2, anthropomorphic figures; 3, mammoth, rhinoceros, reindeer and bear; 4, fish, lion and "others"; 5, deer, hind and aurochs. But the first group plays the dominant hierarchic role (this group is not very far from Leroi-Gourhan's formula A-B+C) and it is the pivotal point of the associations. Group 2 has a very close placement to the central one and the rest show a peripheral independence. These regularities allow the construction of formal models that explain three quarters of the panels and also show that their thematic constitution was the result of some election, probably regulated by semantic considerations, and which was relatively stable during the Upper Palaeolithic. Though the individual properties of the themes and associative classes contradict Leroi-Gourhan's literature in some aspects, it is none the less true that his approach is nowadays validated and has many possibilities: the establishment of the elements of a formal grammar for rock art.

Figure 6. Quinta da Barca open site, rock 3

Recently, the shamanic hypothesis of J. Lewis Williams and J. Clottes has been popularised, based on neuro-scientific aspects, and again, in ethnographic comparisons. The cave walls could be like a veil between the real world from this other world inhabited by spiritual animals, whose favours could be asked by the shaman in a trance.

The loss of oral tradition and the way in which we still understand rock art seriously limit the expectations of a global explanation. There is still a lot we do not know about many of the elements that are involved in figuration. As Leroi-Gourhan said, figuration reflects an ideological situation in which religious, social and aesthetic issues are intimately linked. But, in one way or the other, though always in a simple way, they refer to vision of the universe sustained by myth. This kind of art, as with that of traditional archaism societies, points to a mechanism particular to human beings: the representation of the Universe by means of symbols seen from our point of view.

The legacy of a fragile heritage

Iberia contains 48% of the examples of

European Palaeolithic art, which is one of the main arts produced during human history. Its fragility is great, not only because of the effects of natural agents but mainly because of human interference. It is not enough that these examples have been declared Cultural Interest Goods of Spanish Historic Heritage by article 40.2, Law 13/1985, of June the 25th, and that their conservation is also present in regional legislation of their corresponding heritage; a social pedagogy is necessary. It is very positive that a magazine like *Coalition* has shown interest in it.


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CONSERVATION OF AUSTRALIAN ROCK ART

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Abstract
The current state of rock art conservation in Australia is not as robust as in the past. Threats of nearby development now determine the course of rock art conservation and management actions. The reactive and expedient use of resources to investigate potential threats to rock art now replaces proactive research, management and conservation. This paper presents several examples where a threatened crisis in rock art protection results in the conduct of a short-term scientific investigation perhaps followed by conservation action. Also identified are the damages resulting from fire and lichen, and the loss of an international conservation-training course.

Introduction
Since the 1980s, Australia has led the world in rock art conservation by carrying out research, undertaking international training courses, and making the public aware of the measures needed to reduce threats and minimize damage. However, over the last few years, interest in rock art has been decreasing and fewer researchers and academics are embarking on new initiatives. It seems that the cultural heritage managers and funding decision makers are able to manage and preserve rock art without conducting research, undertaking monitoring programs or training staff. The public is not particularly interested in rock art unless there is a threat to a major gallery of paintings or an expanse of petroglyphs, and this has happened in several cases recently. Politicians only become enthusiastic about rock art when major issues affect their potential to attract votes. This report focuses on examples of the Jabiluka project and the Burrup Peninsula proposed commercial developments which illustrate the plight of rock art, and provides insights into the status of Australian rock art conservation.

Jabiluka
In 1971, the discovery of uranium at Jabiluka in the Northern Territory was one of three major uranium discoveries at that time. Two of the ore bodies have since been mined; Ranger and Nabarlek. In the late 1990s a plan was proposed for the development of the Jabiluka ore deposit, but fierce opposition from traditional owners (Mirrar) and environmental groups forced a senate inquiry. That investigation recommended that the mine not proceed on environmental and cultural grounds, and the project was put on standby mode.

A World Heritage Committee Independent Scientific Panel visited Kakadu National Park (the listed property adjacent to the proposed mine development) and examined Jabiluka's potential impacts on Kakadu's natural and cultural values. Their report recommended that further information be gathered on the impacts of the mining project. One of the concerns raised by the committee was the potential impact of dust on the adjacent rock art and in the nearby heritage area from the infrastructure developments, the mining, ore handling and processing, and vehicle routes. Vibrations from blasting were also considered a threat to the stability of the nearby rock art sites.

In 2001 intense lobbying of governments and the mining company, and the prevention of any scientific investigation on Mirrar land, together with a fall in the price of uranium eventually led to a moratorium on the development of Jabiluka for a period of 10 years. The scientific investigation into the potential dust problem was never undertaken. No rock art conservation or management studies have been conducted or are planned. The crisis is over and rock art no longer plays any role in the Jabiluka project.

Burrup Peninsula
The Burrup Peninsula (Murujuga) is part of the Dampier Archipelago on the north-western coast of Australia. This vast remote semi-arid region contains great iron ore deposits. In addition, off shore there are the gas and oil reserves of the North West Shelf and Timor

Sea. Open-cut mines were developed in the 1960s and railway lines were built to transport the iron ore to deep water ports.

Depuch Island was selected as a suitable port location and the Western Australian Museum conducted an impact study of the island. After finding an extensive array of petroglyphs the Museum recommended that development of the site not proceed. Instead loading facilities were built at Dampier despite the presence of much more rock art in the vicinity of the Dampier facilities than on Depuch Island.

Figure 1. Example of rock carving on the Burrup Peninsula. Courtesy Robert Bednarik

In the 1980s and following the discovery of the North West Shelf natural gas reserves a treatment plant and loading facilities were built on a small part of the Burrup Peninsula. During that development some petroglyphs were destroyed and others moved to a fenced compound. Little conservation work was undertaken and limited recordings were made. No scientific investigations of weathering and deterioration were carried out.

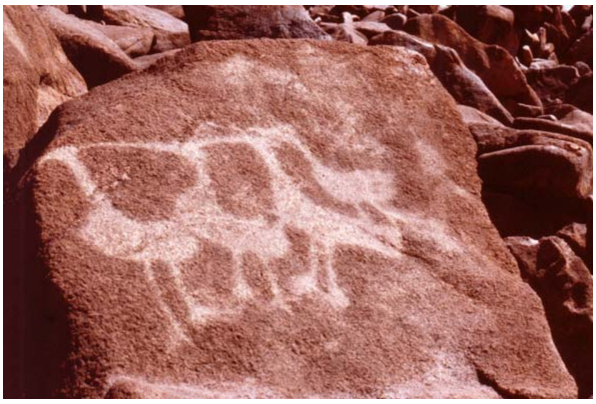

Figure 2. Rock art of the Burrup Peninsula. Courtesy Robert Bednarik

The Burrup Peninsula contains hundreds of thousands of figures and may be the largest concentration of petroglyphs in the world and yet it does not have World Heritage status. An inventory of the rock art has not been compiled. There has been no regular monitoring of rock art sites and no ongoing research. Federal and State governments have not been concerned about the stability or protection of the petroglyphs, and there is no plan of management for the region (Bednarik, 2002).

The reason that the rock art is now in public focus is because further gas and chemical plants are planned for construction and the rock art will once again be impacted. The chemical plants will produce nitrogen and sulphur oxides, and ammonia gas emissions and these artificial by-products may enhance the deterioration of the petroglyphs. In 2004 a study of the chemical effects on the surface of the rock art was commenced (MacLeod, 2005), but the planned development is likely to proceed for economic reasons.

Figure 3. Recent rock carving on the Burrup Peninsula. Courtesy Robert Bednarik

The scope of the research involves modelling the predicted and known ground level ambient concentrations and the deposition rates of nitrogen dioxide, sulphur dioxide and ammonia from the existing and proposed industrial and shipping sources. The mineralogy and chemistry of the rock types will be studied with the aim of determining the natural and possible accelerated weathering rates. Other topics of study include the examination of colour and physical changes to the engravings, the microclimate, atmospheric deposition and microbiological activity. A report is expected from the research management committee in 2007.

Part of the scientific study is being undertaken by research teams that do not have prior experience with rock art conservation. Some conservation scientists are involved in managing the project and this should ensure that appropriate recommendations are made. The major concern is that more petroglyphs will be physically and chemically damaged to the extent that they will be lost from the cultural heritage record.

Wildfires

As in many dry countries, the damage caused by wildfires not only affects infrastructure and people's lives, but also rock art. During recent years in Australia, and particularly along the east coast wildfires have wreaked considerable damage to property and natural areas. In January 2000, a wildfire swept across the Australian Capital Territory and burnt many homes in Canberra. The fire also severely damaged the Rendezvous Creek rock art location in Namadgi National Park (Watchman et al., 1995; Watchman, 2003). A wooden viewing platform had been built within a domed granite tor to protect the archaeological deposit and to minimize dust from tourist traffic. The localized heat from the burning of the platform generated severe stresses within the existing weathered surface and large areas of adjacent rock spalled off.

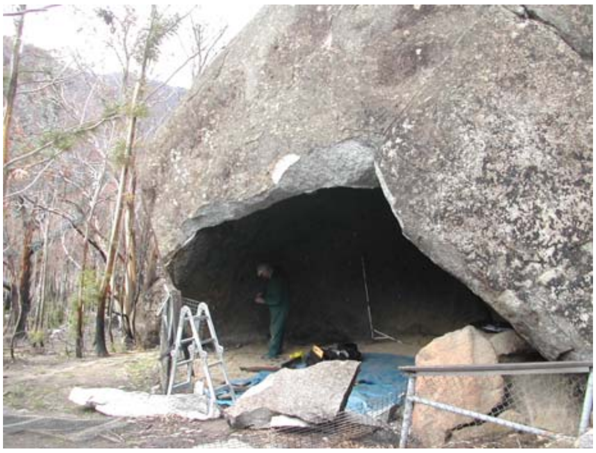

Figure 4. Entrance to the Rendezvous Creek rock shelter showing the large spalled blocks that collapsed during the intense burning of the wooden viewing platform (shown by the blue plastic sheet)

Additional cracking occurred and new strains initiated in the granite. Most of the paintings were relatively unaffected because they were at the back of the shelter and distant from the burning platform. The managers are focusing on erecting in the shelter another wooden structure similar to the previous one, but other options include building a metal viewing platform and closing the site to tourists because of potential instability. The regular monitoring of the walls and ceilings of the shelter is now part of the current management strategy.

Dust

An additional problem at that site and many others is the gradual accumulation of dust from natural sources, such as wind blown particles, and animal and occasional human foot traffic (Watchman, 2002). Often indigenous people painted those stable rock surfaces and now a dust film partly obscures the paintings. The cleaning of the surfaces is not generally undertaken, and it has only previously been carried out once before (Haskovec, 1990). The removal of the accumulating dust on the Rendezvous Creek paintings is not a conservation or management priority. Dust removal is also not a high priority at other locations.

Figure 5. View of the dark dusty surface at Rendezvous Creek rock shelter showing the red and partly obscured white paintings

One success story occurred at the Split Rock site in north Queensland where conservation science established that dust particles from the unpaved road nearby were settling on rock paintings (Watchman, 1998). A result of that research and because of pressure on the government the laying of asphalt paving over several kilometers of road either side of the rock art site eliminated the dust problem.

Current Research

While some rock art research is underway in Australia there is not as much as in the past. The Burrup Peninsula case is one major project. Bruce Ford, a graduate of the joint Getty Conservation Institute and University of Canberra Rock Art Conservation course (Stanley Price, 1990, 1991), is studying the growth rate of lichen in rock shelters and investigating novel ways to control their spread (Ford, 2005). His work in a remote rock shelter without any paintings in Namadgi National Park is another scientific study into ways to conserve Australian rock art, but there are few other current projects.

A major research project into the nature of organic substances and the formation of oxalate rich coatings at rock art sites in Australia has now ended with the termination of a fellowship to this author. That research, over five years provided extensive insights into the existence of natural oxalate rich coatings formed through microbiological pathways (Watchman, 2001a,b, 2004; Watchman et al., 2005). It also provided many age determinations for rock paintings, cupules and tracks, not only in Australia (Cole and Watchman, in press), but in Africa (Mazel and Watchman, 1997, 2003) and Mexico (Watchman et al., in preparation). Flowing out of the research were various contributions to understanding the stability and condition of paintings and rock carvings. Such important outcomes have affected management and conservation decisions at numerous rock art sites in Australia and elsewhere.

Figure 6. Nursery Swamp rock shelter showing the monitoring equipment used to determine environmental factors in relation to the growth of lichen

Training

An end of an era in the training of conservators in Australia occurred with the closing of the University of Canberra's postgraduate program. This disappointing event resulted from financial decisions by the university which considered the course uneconomic. The qualified conservators who graduated from the internationally recognized course always found employment at museums and galleries around the world. The university never acknowledged the high quality of professional training and the excellent reputation of the course and for purely revenue to cost reasons closed the Cultural Heritage Science unit. In 1989, the university had organized and taught the first and only international rock-art conservation course, and another short program of training was under consideration. Abandoning those plans now leaves Australia without any established rock art conservation-training forum.

Conclusions

The dismal state of rock art conservation in Australia reflects a change in attitude by politicians, park managers, granting bodies and the public. Reactive management is in vogue and not proactive research, conservation and planning. This approach saves money. Specialist advice becomes politically or economically expedient and only for development projects where rock art is under threat. A major problem will arise in the future when the current rock art specialists retire without adequate replacements. We will then return to the situation in the 1980s when there was a shortage of knowledge and specialists in rock art conservation in Australia. The void, which is occurring, will require a new generation to take up the challenges of conserving Australia's rock art heritage.

Acknowledgements

I thank Robert Bednarik for providing the Burrup Peninsula photographs. Please visit the web site and sign the petition to save the Dampier rock art:
http://mc2.vicnet.au/home/dampier/web/index.html

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