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Rock art conservation and management: the past, present and future options

Abstract

The primary function of this review is to provide the reader with an overview of the issues that impinge on the conservation management of rock art sites around the world. Because of the author’s familiarity with Australian rock art sites, particularly those in the Kimberley region of Western Australia, the review is somewhat slanted towards Australian issues. The first section covers factors associated with the basic points of documentation, which includes the sites themselves as well as the images painted or engraved on the rock surfaces. Techniques range from the rudimentary methods of sketching and tracing to the use of photogrammetric, photographic, videographic and colourimetric methods of documenting both the nature of the surfaces and the way in which the images have been presented. The involvement of indigenous persons in all the areas of documentation and any subsequent intervention at the site or on the images is considered to be most important. Detailed discussion of the role of controlling visitor access indicates that this is a primary factor influencing the deterioration of rock art sites, whether they are in subterranean environments or in open shelters.

Management of the natural factors of the impact of flora and fauna and human visitation at the sites are discussed and some simple and practical options for cost-effective management are provided. The importance of recording base-line information about the microclimate, in terms of the temperature and relative humidity, are frequently stressed. The roles of bacteria, lichens and moulds are reported, with some guidance as to how the relative importance of these forces of decay varies with the nature of the site. The next section contains a detailed discussion regarding the nature of the pigments that have been used in the execution of the paintings and how these minerals and other products have undergone changes. Not all natural ageing processes lead to the irreversible deterioration of the images. Examples of beneficial weathering are given as illustrations of the need to identify carefully the nature of the materials on the surface, in the substrate and in the immediate microenvironment before reaching any decisions as to the nature of the site. The impact of graffiti and the removal of the same is reviewed in the context of overall visitor and site management. The final section covers the primary role of water as the principal agent of decay of the painted surfaces. This can be in the form of direct dissolution of the rock substrate, erosion, salt efflorescence and the promotion of bacterial and algal activity. The concluding chapter offers some comments on the future directions in the management of rock art sites and the need for continuing research.

Introduction

Any review is fundamentally limited in scope, owing to the deficiencies in the author’s experience of the depth of the complexity of the many issues associated with the conservation of rock art across the globe. Living in a part of the world where some of the most significant rock art exists on our very doorstep, the orientation of this work inevitably draws heavily on experiences associated with Australian Aboriginal rock paintings. The very term of rock art comes with one set of values; that the work is something of a cultural outpouring of expressions of interaction with the immediate physical world. There is an implied element that creative forces other than the basic desire to record images of the present environment may be at work. The term ‘rock paintings’ tends to place a different value on the images, that somehow they are not 'art’ in the traditional European context and are somehow lower valued.

As an Australian conservator who has been privileged to be involved in several research programs involving Aboriginal people, I am mindful of the different ways in which such studies are conducted when the direct descendants of those who created the images are standing beside you. This close contact presents opportunities to learn much more about the images than an analysis of the pigments or the motifs can ever provide. To come to know something of the underlying spiritual power behind the sites and the images that have been created in those locations, is something that leaves you simultaneously humbled and exalted. Other colleagues working with rock art in the Lascaux caves in France [1], where there is no clear connection between the current occupiers of the land and those who made the images all that time ago, are denied the opportunity to have that more direct interaction.

The most profound example of the different ways that Europeans and traditional owners view rock art sites was demonstrated at the 1992 Australian Rock Art Research Conference in Cairns. During a joint presentation by Pat Vinnicombe, an anthropologist working for the Western Australian Aboriginal Affairs Department, and the tribal elder David Mowaljarlai, each gave their understanding of the site. The European description was of a cave shelter containing a series of images of the Wandjina[1], some kangaroos, turtles and snakes, sited amongst an outcrop of rocks on an ancient elevated land platform. The elder told of how the site is sacred to the initiation rites of the local people and demonstrated, through a series of slides, retreating images of how the cave was a point spot in a whole range of hills, which were the focal point of a massive land form that reached back into the sea and the surrounding islands. From the birds-eye view taken from a plane flying at 5,000 metres the audience could gain a sense of the power of the site as the natural focus of all that imagery. Having stated that the site involves incision rites, he took a sharp stone from his pocket and cut open several wounds in his hand and covered them with earth from the site. The red earth stopped the flow of blood and this message was understood by all in the auditorium [2].

For conservators, no matter where they work, the various *Codes of Ethics* are most demanding when dealing with the cultural values pertaining to the conservation management of rock art sites. The images painted on the rocky outcrops, in caves and shelters have often been ravaged by the environmental onslaught of rain, heat and wind for countless millennia. These objects, which cannot be housed in museum galleries, are to be treated with as much respect as images by Michaelangelo or Leonardo da Vinci depicting the moments of Creation or the Last Supper. In the following pages, the author will attempt to present an overview of the issues affecting the conservation of this vital part of our shared heritage through a consideration of the literature published in this field. The subject area is vast and the factors affecting the management of the sites are daunting, but the rewards of coming to know the subject are beyond price.

Documentation

Before any informed decision can be made with regard to the need for conservation intervention at a site, it is vital that detailed recording of the nature of both the supporting rock surfaces and the painted surface is undertaken. Although repeated visits to a remote location involve extra staff time and an additional imposition on the funding bodies, it is a very questionable practice directly to become involved in treating an image without first observing the site over several characteristic seasons.

Characterization of the sites should be carried out in a manner that is compatible with the standards developed by the International Council on Monuments and Sites (ICOMOS) and encapsulated in the Burra Charter, 1979. The Charter applies rigorous standards to the recording of the nature of monuments and sets out the procedures that should be followed if all the relevant information is to be placed on record. The original document should be consulted for details of the practical implication of the code of ethics implied in the conservation work on rock art sites [3].

Colourimetry

The use of Munsell colour charts as the primary method of determining the colour of images is perhaps due to the traditional training in land archaeology that forms the background of many rock art practitioners. Their continued use is very much open to question. Using a calibrated chromameter, a conservator can readily determine that most Munsell colour charts, even when kept in ideal library storage conditions for the past five years, have undergone significant fading in some of the more fugitive colours [4]. Given that many of the charts taken into the field are of a venerable age, their use cannot deliver reliable characterization of colour and so should be regarded with scepticism.

By making repeated visits to the same site at different times of the day and at different seasons, recording large changes in solar penetration of the site, Lambert showed that traditional colour photography was totally unreliable [5]. The use of portable chromameters has been shown as the only really reliable way in which the colours of the painted surfaces can be documented accurately. Owing to the irregular nature of the surfaces onto which most rock paintings have been applied, it is important to have good lighting during recording. The use of a chromameter, with its own independent source of white light, assists in the accurate determination of the colours of the images. Details of the time of day, the season and the date should form a part of the standard documentation of the site. The colour temperature of the light sources used for any illumination should also be noted as it is then possible for other workers to make appropriate corrections for any variations in apparent colours due to the use of portable incandescent floodlights, quartz-halogen globes or fluorescent tubes. Chromameters are also useful tools in determining the colour changes associated with dry surface cleaning of images on granite and to verify that the colour change matches the colour readings of the local dust [6].

[1] Wandjina are larger than life-size anthropomorphic figures, often depicted in vivid white pigments with black eyes. They are images of the powerful spirit beings which bring rain and the life to the people and the region.

Outlining
The practice of outlining images, which are often faint due to the effect of centuries of decay, dust and general deterioration, is to be avoided as it is all too easy to 'see' images that are more in the mind of the researcher than present on the surface. Fortunately, outlines drawn in lead pencil sometimes can be removed from the surfaces simply by using a rubber eraser and gently working the surface [7-9].

Wetting
The use of water to clean surfaces partially, in order to obtain a better image of rock paintings and engravings, generally should be avoided as the pigments and their degradation products are often water-soluble. Given that some sites and images have established a semi-equilibrium state over many centuries, the rapid rehydration of a desiccated surface or a substrate may lead to irreversible physical changes that lead to rapid degradation. Recent reports have given a classic example of how the impact of tourism can have a deleterious effect on the painted and inscribed surfaces of rocks and tombs. Tourists in Egypt's Western Desert are destroying known prehistoric sites in Wadi Sura or 'Valley of Pictures'. Dating from 7000 to 5000 BC the images are being destroyed by salt efflorescence as a result of tourists pouring water over figures to make them more clearly visible. Two to three centimetre sections of paintings had fallen off according to a report in April 2000 [10].

Cleaning
Examination of the images on the rock surfaces is naturally fraught with difficulty when there are encrusting layers of mineral deposits, bird guano, dust, lichen, algae and fungal hyphae, as well as root hairs and other forms of vegetation. Experienced practitioners can physically remove dust, guano deposits, mudwasp nests, termite trails, etc. without any damage to the underlying substrate. This is achieved through methods that range from dust puffers, to camelhair brushes, through blunted spatulas to scalpels. Traditional approaches have involved the use of biocides to 'treat' the surfaces prior to recording, but this often results in long-term damage since the combination of plant exudates may be the only binding medium which holds the ancient images to the rock surfaces [11].

Ambient conditions
During detailed site documentation it is vital to obtain typical data that effectively characterizes the nature of the site and the substrate with regard to the average conditions of moisture, in terms of relative humidity and temperature. Although obtaining long-term meteorological data for many remote sites is difficult, owing to the lack of proximal cities and towns, data from near locations can provide the basic understanding of the general type of climate that exists around the shelter or cave site. Recordings of the amount of direct sunlight penetrating the shelter can also provide a useful tool when analysing the variations in the amount of lichen and other forms of biological activity on the rock surfaces [12] and general deterioration aspects [13].

Recording
The importance of recording and documenting the sites cannot be underestimated, since they are going to remain essentially trans-generational areas of interest and repeated visitation. The use of photogrammetry and the scanning of such data into a digital format allows details of surfaces and pigments to be examined with great precision. Apart from the photographic recording techniques, which still rely on traditional 35 mm slide format, the detailed documentation of the colours of the painted surfaces can be a significant determinant in stylistic comparisons, as well as recording the changing nature of the surface. Traditional recording methods have relied on the use of accurate artists' impressions of the images. It is often the case that the human eye is able to discern more subtle detail than can be recorded on a 35mm slide or by a large format camera, regardless of the quality of the lens. Given that sites are often in physically remote areas where there is no source of power for proper studio lighting for accurate photographic recording, the data conveyed through detailed drawings is often very reliable [14].

Tracing
Simple tracings have been used to document the annual changes in the deterioration patterns on sites in Argentina [15]. The use of wet paper as a recording medium should be avoided since this process erodes limestone in arid regions and permits artistic licence, while detailed tracings using transparent sheeting, such as polyethylene 'cling-film' food wrapping plastic, and felt marking pencils are preferred, with colour photographs as a back-up [8]. Whilst such techniques may seem to be lacking in sophistication, they do avoid the real systematic errors associated with reliance on traditional slide films and lenses which are not corrected for distortion created by commercial lenses. Some authors maintain that tracing remains a more effective recording technique than photography and photogrammetry [9]. During examination of a series of petroglyph sites in Columbia, rescue documentation work and study of the alterations due to lichen infestation and fractures

included photographs and rubbings on good elasticized-fibre paper. The rubbings would subsequently require consolidation to ensure their preservation [16]. One problem with tracing images is that the film medium can often exhibit characteristic anisotropic properties, in some cases shrinking more than 2% in one direction, but remain dimensionally stable in another. This change has been attributed to the manufacturing processes and underlines one of the pitfalls of relying on transparent organic polymer film as a recording medium [17].

Casting

Direct surface replication of endangered sites is a form of site management intervention. Prior to the use of any casting materials on a surface, the physical integrity of the rock should be carefully assessed to ensure that it is not likely to suffer damage when the replicating agent is peeled away. The use of silicon elastomers to make castings of engraved images, threatened by development projects, has been practised in the Sahara, on sites in the Atlas Mountains [18] and in the Burrup Peninsular in the Pilbara region of Western Australia. In the latter case the construction of a liquefied gas plant brought about the urgent need for direct recording of the engraved images, carried out at the request of the traditional owners of the land. Subsequent casting of the images, using standard woven glass fibre-matt and polyester casting resin, and repainting the replicas with acrylic colours brought about a culturally acceptable solution to the problem [19].

Photogrammetry

Detailed site documentation is often best managed through the processes involving the use of photogrammetric recording techniques, i.e. the use of glass plate negatives and stereophotography using large format cameras. Whilst the quality of the data is very high, the cost of the equipment and the processing of the information is often only justified at sites of national or international significance. The work by Wainwright and colleagues in the Canadian Conservation Institute on the petroglyph site at Peterborough in Ontario provides a very useful summary of the complexities associated with the detailed recording of a large site [20-22]. Among the more practical issues, camera placement and lighting, evaluation of the photogrammetric results and suggestions for future work using the techniques employed in this research can be found in relevant reports [21]. Another place where this technique has been extensively used is in the World Heritage Listed Kakadu National Park in the Northern Territory of Australia, which contains some of the oldest and most extensive rock art galleries in the world. The difficulties in recording this site, how the processes were managed and the details of cameras, film and other equipment needed for the detailed 1:10 or 1:20 reproductions of sites in the park can be found in the papers by Rivett [23, 24]. A large amount of effort during many thousands of hours of site work is involved in projects such as those performed at Cueva de El Ratón in Mexico [25]. Repeated electronic recording of the images allows for quantitative measurements to be used as a tool to assess the extent of change in the rate of decay. It should be noted that there are extra degrees of difficulty associated with recording images on curved sites, since this requires extensive correction to ensure that the images and details are not distorted.

Photography

The principal purpose of producing the International Federation of Rock Art Organisations (IFRAO) Standard Color Scale and distributing 20,000 copies of it world-wide to all rock art specialists underlines one of the key issues associated with photographic recording of sites using traditional colour transparency film. Such recording techniques result in images that fade. It was decided to try to establish a standard for an international system of colour calibration in this field that would prepare the photographic record for computerized colour reconstitution. This is needed to correct the effects of the photographic dyes fading with time. To ensure that the most effective guidelines can be issued for the use of the colour scale, a pilot project of colour reconstitution was conducted in India in December 1994, at the computer centre of the National Museum of Man in Bhopal (Indira Ghandi Rashtrya Manav Sangrahalaya). This resulted in the successful reconstitution by computer of the original colour. The software is available from IFRAO to assist in this process of colour calibration of rock art photographs [26]. The use of infra-red photography to enhance the inherently poor quality of aged images, through absorption of the radiation by the underlying paint and rock substrata, charcoal and materials such as animal fat, can make the images easier to decipher. This technique works well for both incised and painted images and so extends the range of film into a new region [27].

Video and digital recording and manipulation

One of the real limitations of the traditional Video Hi 8 format was the fact that, apart from details of the location of the images on the specific tape, in terms of hours, minutes and seconds, the data had limited use because of the problems associated with editing and archiving video film clips. Apart from the fact that the medium is inherently transitory in nature, the amount of time spent in attempting to master the editing suites often precluded all but the keenest videographer. With the advent of digital video, it is now a routine procedure to take a combination of both still and moving images of sites. Once back in the laboratory it is possible, using standard computer editing tools, to obtain accurate images of the sites and to carry out any necessary colour adjustments, depending on the influence of external lighting factors such as the use of incandescent or other portable lighting sources. Another advantage of digital videographic recording is that the instruments are very sensitive to low light levels, which are often encountered in the field. The massive volume of data collected during surveys of sites and the recording of the images needs to be archived properly. Descriptions of how such information can be managed using video and laser discs has been reported by Seglie *et al.* and Swartz [28, 29].

Archiving, reports and publications

The importance of proper recording of the sites and the images has previously been noted, but a significant aspect that cannot be ignored is the need to have an integrated system of indexing the data, so that it can be readily accessed by future workers. In Queensland, Australia, the Department of the Environment and Heritage has developed a database of all relevant site information, which has enabled some basic assessment of site types, site distributions and effectiveness of site cards to be made. Problems identified include an over-representation of art sites relative to other site types, a geographical bias in sites recorded and a lack of information on site preservation [30].

Site management

Indigenous participation and control

Without the engagement and participation of the traditional owners of the rock art sites, any attempts to study their location, the mineralogy, the stylistic evidence, the hydrology, the pigments and the impact of biological agents of decay will be fraught with difficulty. It is paramount before any programme involving the development of tourism, academic research by anthropologists and historians and investigations by visiting Parliamentary delegations, that the wishes of the local community members should be ascertained. If it is their wish that nothing is done to the site, then that wish should be recognized and acceded to. Research workers educated in Europe, who have not generally grown up in the company of the descendants of those who created the images of interest, may find this attitude strange. However, the situation in Australia, India, Africa and the Americas can be profoundly different from that of Europe, for in these countries it is not unusual to be working with the traditional owners of the sites.

In the South West of Western Australia no traditional Aboriginal inhabitants are said to be alive; however, neighbouring traditional groups have utilized the region for about 100 years. The information and views of these people and the opinions of Aboriginal people from the wider West Pilbara, Ashburton and Gascoyne regions have been sought and have been taken into account in the development of cultural tourism at rock art and other Aboriginal sites. The vulnerability of the art and archaeological deposits are considered as well as the proximity of the cave to other archaeological sites (especially middens). Visitation programmes have been formulated in co-operation with the local tourist bureau and the Western Australian Department of Conservation and Land Management personnel [31].

The problems of private ownership of land incorporating rock art sites has been noted in the Mount Lofty Ranges, close to the city of Adelaide in South Australia. The sites are several hundred kilometres from the Flinders Ranges, the nearest known rock art region. Past isolation can no longer protect them from the increasing human impact of mobile, informed urban tourists and the demand for passive recreation. The existence of minimal legislative protection and limited human and financial resources for management, combined with the absence of archaeological research in this area currently offers little future heritage protection for these sites [32]. However, everything is not totally gloom and doom, for in Queensland, Australia, there are regions where there has been good integration of the views of local Aboriginal people in the conservation management of the sites [33].

Behaviour and impact of visitors

Each site and situation of visitor access requires a unique response; it is very dangerous to attempt to apply common solutions to microenvironments that are inherently dissimilar. Despite the complex issues that control access to most cave sites, the Combarelles Cave in France is open to the public. The idea of tourist access to such places of cultural interest must be reconciled with their upkeep and so the cave was modified to facilitate the visits of tourists. This also involved organizing the course of the visits, taking into account specific aspects (climatological, morphological, etc.) of the decorated gallery. The site's future depends on an acceptable compromise being reached between visitor and preservation needs, but the educational experience gained by the tourist has been shown to make them more sensitive to the needs of other sites, which are not so robust [34]. The use of shelters to protect large areas of prostrate petroglyphs and the management of visitors and their viewing of the site has to be carefully researched in order to avoid the pitfalls of creating an aggressive microclimate [35].

Since the foundation of SIARB (Sociedad de Investigación del Arte Rupestre de Bolivia) in 1987 some 300 rock art sites have been registered. The adoption of a *Code of Ethics* in 1989 banned all potentially destructive documentation methods and required that the locations of unprotected rock art sites should not be disclosed in publications such as newspaper articles, popular journals or in other media for the general public. Lectures and exhibitions have been presented in seven Bolivian cities and permanent regional rock art exhibitions installed in two archaeological museums. Teaching aids for children have been developed and three rock art parks have been created; this has lead to reduced damage from visitors. The discovery of an important colonial indigenous rock art site near La Paz has resulted in detailed documentation and the involvement of the local Aymara in responsibility for site management [36].

The best chance for the long-term preservation of rock art in its original setting lies in public education of the potential visitors. An innovative approach to this issue was shown by the Southwest Museum in Los Angeles, who constructed a facsimile of a Chumash rock art site. Although some would argue that the project has not totally succeeded, any movement that leads to an increase in the awareness of the cultural value of such sites has to be lauded [37]. Other simple ways of modifying negative behaviour is to improve the paving through the area. Not only will this bring about a reduction in the amount of dust and general grime being deposited on the images; the improved access has been shown to reduce the amount of damage from uninformed visitors. Once graffiti had been removed with a cocktail of organic solvents it was found that the treatment had no apparent ill effects on the images themselves [14].

The impact of visitors to a site will be dependent on the nature of the rock surface on which the images have been made. Apart from the differences in the inherent reactivity of the rock substrata, i.e. either calcareous, siliceous or granitic, the major differences in behaviour depend on the degree of openness of the sites. When the rock art is located in caves the situation becomes much more complex, as is demonstrated by the experiences in Spain and France [1]. Attempts at minimizing visitation rates by fencing off the caves in Aragon, Spain have shown that this is counter-productive, for it results in increased vandalism. These sites are close to prime tourism areas and public education programmes are managed via visitor centres. A combination of legal protection of the sites, through the creation of National Parks, and public education programs have succeeded in minimizing the detrimental impact of tourism on the sites [38]. In reviewing results of studies carried out after the cave at Altamira, Spain, was closed to the general public in 1977, the conservation team considered the total context of the site. This involved analysis of the geological characteristics, pigment composition, colourimetry, natural microclimate and the microbial flora. The inherent reactivity of the calcareous site was noted as well as the amount of dust, salt efflorescence, algae, fungi and the chemical corrosion of the polychrome surfaces with concomitant detachment of those layers. Controlled visitation is clearly consistent with better long-term preservation [39]. A three-year programme of detailed recording of the variations in temperature and relative humidity in a cave site in Malta has resulted in the development of a comprehensive management strategy. The strategy will allow the fragile site to be managed more effectively, with control of visitor numbers being of paramount concern [40].

With hundreds of thousands of visitors to sites in the Kakadu and Uluru (Ayers Rock) sites in the Australian Northern Territory, it became readily apparent that the lack of previous research on the impact of such high visitation levels was a major factor in inhibiting the development of effective management strategies. This necessitated the development of an experimental methodology that drove the development of the research design [41]. Action plans were implemented to record about 3,000 art sites. At 85% of these some of the basic preservation measures included the management of the run off of surface water and the installation of walkways. For the balance of the sites no preservation measures were taken because some sites are either in pristine condition or are irreversibly damaged. Some require special attention because they are significant to the Aboriginal people, the tourist industry or have special scientific merits. At these art sites, other measures beyond the initial preservation procedures have been implemented. A substantial part of deterioration can be averted with simple, sound management procedures, adapted to local needs. Site-specific problems must be solved by site-specific responses. In some situations, this work has involved stabilization of the images by direct use of consolidants (See section below) [42].

Site interpretation and information

The provision of good signage for the sites, with full interpretation panels showing the details of the analytical work at the location and the meaning of the iconography, does a lot to minimize the amount of vandalism of the art works. Proper story telling of the mythology behind the images helps to provide the visitor with a unique experience. The provision of devices such as visitor books has been demonstrated to be responsible for a marked reduction in the amount of graffiti at the sites. It is a surprise as to how often comments from the book will result in new insights into how the viewing and overall management of the sites can be improved [43, 44].

Site works/construction
Perhaps one of the most difficult sites to manage and provide access to is the site of the Grotte Cosquer in France. Presently the only entry to the cave and the wonderful array of horses, bisons and penguins from 27,000 to 18,500 years BP[2] is by way of a submarine passage, with the entry point being at a depth of 37 metres below sea level. French conservators are examining the possibility of monitoring of the microclimate of the site from the surface. If the ambient positive air pressure were lost in this process, the underwater cave would flood and simultaneously destroy the images. Those working on the site have to balance out the risk of a diving conservator becoming trapped in the black water conditions, when the silt in the narrow passages is stirred up, with the need for gaining more data about the unique nature of this site [45].

The Côa river valley in Portugal is a large open-air rock art site of controversial age. Some 150 decorated panels have already been found, spread along 17 km. The whole complex would have been submerged under 100 metres of water if construction of the large Foz Côa Dam, begun in 1992, had been allowed to continue. The dam project was halted in 1995 and an archaeological park of 200 square metres is established in this area, which is now legally protected at the highest level as a National Monument. Public access to selected sites is organized through four-wheel drive tours of groups of eight people accompanied by guides appropriately trained in archaeology and rock art studies. Visitor Centres have been set up in restored traditional houses located in the villages around the periphery of the park. In addition, a Museum of Rock Art and Archaeology and associated research facilities is to be established at the site of the now abandoned dam [46].

Routine management activities
The regular clearing of encroaching vegetation is amongst the simplest measures employed in minimizing the damage from tree and other plant roots. It was found that through careful management of researchers on sites in Siberia, the extensive unintentional damage made by rock art recorders, as well as deliberate vandalism by residents of the district's villages, could be reduced to a manageable level [47]. With very steep sites it is important to make access modifications to alleviate anthropogenic damage. The general adage of minimal intervention is generally beneficial to the artworks, but the management of the same often requires significant strength of character, since doing apparently little does is not always fully appreciated by funding bodies.

Site preservation and management

Monitoring and documentation
The approach to site management by staff of the British Columbia Provincial Museum on Sproat Lake, Vancouver Island, Canada, is worthy of emulation. Despite the deterioration of the petroglyphs and damage caused by vandalism, natural weathering and erosion (ground water seepage, fractures, cracks, moss, lichens, microbacterial growth, mud, etc.), staff undertook detailed analysis, which culminated in recommendations for preservation. In 1975, silastic moulds were taken of the zoomorphic designs and the following year mud and plant growth were removed, although the removal of some yellow oil-based paint was only partially successful. Access by both water and road was reduced, and a channel created to divert run-off waters. It is hoped that vandalism will be discouraged by means of public education, and production of replicas (reproductions), which people can touch and from which they can make rubbings [48].

Flora control
The impact of subtle changes in the environment, created through direct planting of local plant species, can also result in significant improvement in the amelioration of the forces of degradation. A site at Mount Cameron West in Tasmania was subject to abrasion by cattle and wind-borne sand. By repairing the breach in the foredune and stabilizing the adjoining extensive sand blow with marram grass, one aspect of the decay was managed. Installing a boundary fence across the sand dune reduced the impact of domestic cattle, but the long-term impact of rising sea levels cannot be addressed at this stage [49]. It is important to note that the removal of nearby vegetation may not necessarily always be beneficial, especially if the local vegetation is responsible for significant transpiration of water from the vicinity of the engravings or the painted areas of the rock surfaces.

[2] Dating by radiocarbon methods involves measurement of the changes in activity of the carbon isotope between the present time and past event; BP equates to *before present* time.

Detailed examination of the local hydrology is an essential precursor to rooting out any vegetation. Experiences with the management of sites in the National Park of the Serra da Capivara, Piaui State, Brazil, have shown that the destruction of old vegetation and its replacement by vegetation more prone to fire adversely affected the rock paintings [50] However, the planting of tall vegetation to provide a sunscreen for the paintings can be used as a passive measure to improve climate control. Conservation management of the multiple sites in the Tassili N'Ajjer, Algeria, partially consists of encouraging the inhabitants to reforest the area, to block desertification. Control of visitation, the implementation of urban planning and the selective reproduction of at-risk sites are key factors in the overall management strategy for this World Heritage listed area [51]. The use of geotextiles to provide a foothold for vegetation to alter the hydration profile of a site in Argentina is another example of the lateral thinking that needs to be adopted to ensure that any physical changes in the environment have no long-term adverse effect on the rock art [52].

Fauna control

Experiences with wandering cattle in remote sites in the West Kimberley region of Western Australia have shown that simple fencing, with five strands of barbed wire, is sufficient to stop the animals rubbing their shoulders on the painted sites at Barralumma in the Napier Ranges [53]. The presence of native animals, such as kangaroos, has a negative impact on the overall level of decay on the sites, since their dried dung can be crumbled by visitors and the dust settles on the art and acts as a nutrient source for bacteria during the wet season [54]. A different problem exists at sites where caves provide human shelter, such as in Brazil where the poor population living in immediate proximity to the images has had a major impact on their rate of deterioration [50].

Lichens and algae

Amongst the most significant agents of decay of rocks are natural organisms, which colonize the rock substrata and are part of the processes that extract minerals from the rocks and bring about their conversion into soil. Several workers have reviewed the impact of algae on the natural weathering of sandstone and have discussed the implications for the management of sites [55, 56]. There is significant debate as to whether lichens should be removed from sites although it is well established that they do cause an increase in the rate of decay of the rocks. The possible use of lichenometry for dating rock art has also been discussed by Florian and Pearson [57]. Recent research has shown that the tracking of the amount of direct sunlight over a site can explain the presence and/or absence of lichens, with the areas experiencing direct light remaining free of this form of colonizing organism [12]. Detailed studies of the effects of lichens on the biodegradation of petroglyphs showed that the activity was dominated by the availability of moisture. The best biocides were those of low solubility, which made it possible to eliminate the crustose lichens on the stone surface relatively safely. Unfortunately, in conditions of high insolation, natural flushing by water and drastic daily and yearly temperature variations, none of the tested biocides or their mixtures provided long-term protection against biodeterioration [11]. The author has observed patchy striations over the massive granite structure called Wave Rock, east of Perth in Western Australia, which are consistent with zinc corrosion products from the galvanized iron fencing above the site, acting as an effective way of eliminating lichens.

Bacteria

The impact of bacteria cannot be underestimated for the viability of sites. Whilst the number of papers directly reporting the impact of bacteria on the pigments is limited, other references relating to conservation of mural paintings and burial sites are of direct relevance, particularly for cave sites [58]. Where sites are more exposed to direct contact with the air, there are generally much higher levels of fungi and treatment has involved the use of paraformaldehyde and mists of formaldehyde [59]. The need to take special precautions on entering a sealed cave site is demonstrated by the observation that the decomposition of the original buried bodies produces low molecular weight alkyl amines, which have apparently acted as natural biocides [58]. A number of autotrophic and heterotrophic microflora basic to siliceous-calcareous mortars have special biochemical aptitudes, for example the solubility of calcium carbonates and phosphates, the solubility of aluminosilicates and the creation of organic acids and minerals [60]. The impact of water, in terms of the re-activation of dormant bacteria, has been demonstrated to be a major determinant in the rate of acid attack on pigments such as huntite ($Mg_3Ca(CO_3)_4$) when the monsoonal rains come to normally arid regions [61].

Structural Instability

An often-overlooked factor controlling the management of a rock art site is the inherent stability of the basic substrata that support the images. Where underground recovery of minerals, like coal mining, is occurring in the region, then significant subsidence can take place many years after the activity has ceased. In some instances, general geological activity of minor earth tremors can be greatly magnified in the presence of cavernous spaces underground and this can lead to collapse of the rock on which the images have been created [62].

Graffiti and graffiti removal

The techniques used in the removal of graffiti include manual brushing and mechanical removal with scalpels, the rolling poultice method, static poultices and use of air abrasive equipment. Scratched graffiti can be masked under a filler of microscopic glass beads mixed with modern pigments, an intervention easy for future researchers to detect [63]. The use of low pressure air abrasive units offers a lot of promise [64] since traditional methods involving toxic volatile organic solvents tend to create 'lakes' of paint residues, which are difficult to avoid, even with the use of poultices [65]. Work at the Font de Gaume cave in France saw the removal of graffiti and traces of smoke cleaned off using cotton wool pads and/or sheets of paper impregnated with an alkaline solution, which dissolved fats and removed stains. The area was rinsed afterwards with water [59]. Although it is not a treatment of a permanent nature, the practice of using a mixture of water and ground dirt from the base of the rock as a temporary mask on the areas where solvents have been utilized, considerably reduces the visual impact of such activities. It has been noted that the removal of graffiti does lead to reduced rates of repeated attack by vandals [66]. The use of dilute hydrogen peroxide and weak solutions of aqueous ammonia gently to lift accreted matrices of graffiti and termite deposits has been shown to be effective [59, 67]. An unusual form of graffiti occurs when preceding workers have attempted to 'add value' to a site by outlining faint images with charcoal or other pigments. Through judicious use of the techniques outlined above, it is possible to restore the original outline of the images [68].

Materials, deterioration, conservation and research

Pigments

The analysis of the minerals found in the pigments and binders of the painted images may seem to be an essentially academic exercise and the preserve of scholars, but for the conservator, this data is of paramount significance. Since the nature of the bonding of the pigments to the substrate is inherently dependent on the mutual compatibility of the two materials, an understanding of the mineralogy of the pigments will assist the practitioner in ascertaining what the most appropriate form of site management should be. When iron minerals such as haematite (Fe_2O_3) are used in conjunction with a granitic rock, there is a good chance that the images will be inherently more stable than a calcareous pigment, such as huntite ($Mg_3Ca(CO_3)_4$), on a dolomite ($CaMg(CO_3)_2$) and both sites are subject to driving rain. Once the nature of the pigments is known, it is then possible to conduct standard solution chemical simulations to determine the most likely degradation scenario. In tropical environments, when the rain is often associated with electrical storms, the pH of the rain is definitely more acidic than pH 4 and so calcareous pigments are more at risk from acid dissolution. Although this is in part due to the presence of the carbonate anion in their structure, the iron oxides and hydroxy-oxides such as haematite, goethite and lepidocrocite are known to be acid-sensitive, but the dissolution kinetics of the reactions are often slow [69].

A large proportion of the literature associated with the weathering of outdoor monuments is directly relevant to the deterioration of rock art, since the substrates behave in a similar fashion. It should be noted that the nature of the pigments themselves could bring about unexpected reactions and cause transformations from one mineral to another. A case in point was found in the West Kimberley region of Western Australia where the calcium oxalate mineral whewellite ($CaC_2O_4.H_2O$) was found as an apparent pigment [70]. Although no sources of the mineral existed within a thousand kilometres of the site, the presence of the mineral forming coherent images indicated that the material had originally been intentionally applied to the surface of the rock. Isomorphous chemical transformation of the huntite original pigment into the oxalate mineral is believed to be the underlying process involved. The origins of the oxalates are discussed and the potential for using carbon-14 for dating prehistoric paintings has been noted by Watchman [71]. Similar chemical transformations have occurred in semi-arid conditions where calcite ($CaCO_3$) and kaolin ($Al_2Si_2O_5(OH)_4$) have been changed into hydroxy phosphates and a calcium substituted hydroxy silicate through interaction with water containing soluble ions from degraded avian guano [6]. The presence of particular minerals on a rock art site can also be an indicator of the importance of trade patterns in ancient times, since it is known that Aboriginal people often traded ochres over distances of several hundreds of kilometres.

During extensive examination of pigments on Australian sites, there has been no evidence that organic binders or fixatives have been used [72]. Sites used by prehistoric North American Indians for kiva murals and rock painting generally used naturally occurring minerals with clays and charcoal. Whilst it has been supposed that some binders such as milk casein, acacia gum, egg, water, blood, plant and vegetable oils or animal fats may have been used, there is little evidence that survives [73, 74].

Silica skins
Quartzite and sandstone are generally regarded as being much less reactive than substrates such as limestone, but the combination of microbial activity, acidic monsoon rain and high ambient temperatures can lead to significant mobilization of silica. The flow of the 'siliceous acid' solutions over painted rock surfaces leads to the formation of protective silica skins of hydrated amorphous silicon dioxide, commonly less than 1 mm thick, which generally form on stable quartzite and sandstone surfaces. This occasionally results in a thin translucent protective film over rock art that reduces damage by graffiti and securely binds the ochre to the rock face. Dating of the skins and of the carbon in whewellite ($CaC_2O_4.H_2O$) indicates changes in the atmospheric environment over the last few thousand years that have affected the composition of the salts [75-77]. Mobilization of silica to form a protective covering over images painted with haematite (Fe_2O_3) have even been reported in Canada [78].

Consolidation of decaying images
Although the range of consolidants used in normal laboratory-based conservation is considerable, the number of materials that can withstand the rigours of the outdoor environment is much fewer. One real concern with materials such as the methyl methacrylate Paraloid B72 (Röhm and Haas) or the acrylic emulsion, Primal AC33 (Röhm and Haas), is that bacteria and the combined effects of high ambient temperatures may bring about decay of otherwise stable polymers and so result in only a temporary stabilization of the sites. It is nevertheless appropriate to undertake repositioning of fragments using either water or dry brushing techniques followed by consolidants [79-81]. In cases where the pigment, such as haematite, is stable but the underlying granite is exfoliating, it has been shown that the use of silicone resins to stabilize paintings on exposed rock surfaces has lasted for more than twenty years [82] One complication of rock art conservation management in Australia occurs when re-painting of the sites, as has been the tradition over countless millennia, results in apparent rapid deterioration of the images. In one instance Calcimine, a modern manufactured white pigment, was used in conjunction with traditional ochres in the Kakadu National Park. The problems of stabilizing the flaking images demonstrate the complexities of the deterioration processes and the effective use of modern synthetic resins to stabilize the same [81].

Environments and microenvironments
Without a detailed knowledge of the microenvironment of a rock shelter or cave, any attempts at conservation management are most unlikely to succeed. It is vital to obtain data on the temperature and humidity inside and outside the site in order to gauge the extent of natural buffering, which results in smaller diurnal fluctuations in temperature and relative humidity. Data from sites close to the ocean, inland and in the tropical areas indicates that the heat capacity of the moisture in the air has a major effect on the rate of change in relative humidity and temperature, as well as on the absolute value of humidity, that is the water vapour pressure. Data on the localized wind speed and direction and the amount of direct light should also be logged since, without this information, the task of interpretation of the microenvironment is fraught with difficulty [54, 58, 83-87].

Deterioration agents and mechanisms
Significant progress on the understanding of the major forces of deterioration on open-air sites was made in work in Algeria. Detailed analysis of data supplied by geomorphological and bio-climatic studies forms the underlying strategy for determining the interrelationships between man and nature. The micromorphological features of the walls underpin the study of the relations between the images and the host rocks supports; while details of the petrography, microbiology, chemical and physical analyses form the framework of the study of deterioration [87]. Without detailed knowledge of the way in which the pigments are interacting with the local substrates, any attempts at conservation intervention are likely to result in only temporary success, with the long-term results leading to flaking and further general deterioration. The major causes of rock art deterioration in Kakadu National Park, Northern Territory of Australia, were shown to be primarily water followed by damage from mud wasps, termites, algae, and humans. The steps taken to protect the sites against these dangers include the extensive use of silicone driplines [88]. Return visits to sites in the Wheatbelt of Western Australia have shown that ten years after the intervention of driplines, the changed pattern of water flow apparently has slowed the rate of deterioration to an indiscernible rate [66].

Characterization of the minerals that form the efflorescences on, and subflorescences behind rock surfaces is essential if the correct conservation decisions are to be made. The dominant minerals that are usually found contain sulphate ions, presumably from lightning storms over the tropical north, and the acidic rain interacts with the rock to produce crusts containing gypsum ($CaSO_4.H_2O$), anhydrite ($CaSO_4$), polyhalite ($K_2Ca_2Mg(SO_4)_4.2H_2O$) and mohrite ($(NH_4)_2Fe\ (SO_4)_2.6H_2O$), while niter ($KNO_3$) and hydroxylapatite

($Ca_5(PO_4)_3(OH)$) have been found in smaller amounts. The plethora of species indicates the underlying complexities of the chemistry of the degradation processes [75]

Role of water

The role of water cannot be underestimated in the overall conservation management of rock art sites. Whether the water is in the form of vapour, direct condensate, running water, ice or snow, the interactions of the rocks and the pigments are invariably dependent on the solution chemistry of the local microenvironment. In colder climes, site management strategies can include covering the area with soil to minimize the impact of frost and ice. This method was tried with success at the Cranbrook site in British Columbia, Canada [89]. The negative impact on cave sites of moisture from human visitation is best demonstrated by the experiences at Lascaux. The cave, when opened to the public in 1948, was in perfect condition; however, the influx of moist air and the elevation of carbon dioxide from human respiration because of intense visitation caused the once vivid colours to fade. Bacteria, algae and fungi grew over some of the paintings. The cave was closed to the public in 1963 and disinfected with formaldehyde aerosol to kill streptomycin, penicillin and kanamycin. The temperature, humidity, and carbon dioxide content are monitored daily in the various galleries, since seasonally variable parameters are not the same in each section. An air conditioner condenses excess humidity and expels it outside. The pressure of tourism resulted in the creation of a series of life-size reproductions, comprising photographs and painted facsimiles of the main paintings on photogrammetrically accurate artificial galleries, which are displayed next to the cave 'Lascaux II,' and in the National Museum of Antiquities at Saint-Germain-en-Laye, near Paris [1, 90].

In Spain, ornamented prehistoric caves automatically come under the protection of the 1985 Law on the Spanish Historic Heritage. With the caves at Altamira, the first attempts at conservation saw the installation of a wooden door that enabled all visits to the site to be accompanied by appropriate personnel. Increasing tourism demanded that the cave walls be consolidated and the floor lowered which lead to cement retaining walls and roofing being installed. The consequent changes in temperature and relative humidity caused paint in the room of the paintings to fade. In the 1960s and 1970s, the influx of visitors became massive. Repeated attempts to reduce attendance were made, monitoring systems installed, a temporary closure was decreed in 1977 and after a series of studies a new regime adopted with benefits to the site, which is being managed by the Centro de Investigaciones y Museo de Altamira [91]. The management of free water flowing over or through a site can be as direct as the re-establishment of the original drainage levels through the use of a stone socle. After more than five years of monitoring the deterioration of a site in Argentina, the conservators were able to demonstrate that the changed hydration pattern would reduce the rate of deterioration [16].

The weathering processes in northern latitudes can be relatively rapid, owing to the impact of frozen water on micro-cracks in the rock surfaces. One advantage of the ultra-cold conditions on the Churchill River in northern Manitoba, Canada, was the ability to use the frozen river as a stable camera platform [27, 92]. The effects of very high winds at high altitudes in the Andes have been studied, and the desiccation and abrasion from the impact of drying winds and the changes that occur with the moist wind all have a major bearing in the choice of conservation treatments that are sustainable [93].

Biological

An unusual example of the impact of animals on sites is seen at the National Park of Serra da Capivara in north-eastern Brazil, created in 1979, and now a World Heritage site. Their specific conservation problems included climatic changes after excavation and the increase in insect infestations following the extermination of anteaters and armadillos [94].

Pollution

In Sweden the effects of air pollution, especially of sulphation of the rock surfaces, has been noted and the general improvement in air quality in Northern Europe that is anticipated to result from consumer and voter demand, would result in a net improvement for the general conditions of exposed rock art sites [95].

Future directions

Having reviewed the massive amount of material that exists in the literature regarding the conservation of rock art around the globe, I am more than a little concerned that there seems to have been a reduction in the activities of conservators working in the field. At the last twentieth-century ICOM-CC meeting in Lyon, France, in 1999 no papers were presented on rock art conservation for the past triennium. Although there are major conferences devoted to rock art at various locations around the globe, it is perhaps a reflection that research funding agencies have all undergone a major review of their grants that there seems to be little institutional support for this vital part of the preservation of our shared cultural heritage. On a more positive note, with the improvements in experimental methods such as accelerator mass spectrometry for isotopic analyses to determine if the carbonaceous materials in the minerals are of biological or anthropogenic origins, there is hope for the future improvement in the understanding of the processes of rock art decay. Once we know what is controlling the deterioration, we shall all be in a better position to assist in the preservation of this wonderfully rich resource.

It is vital that a holistic approach to conservation management be taken if we are to continue to develop effective strategies that will bring about improved preservation of the world's rock art sites. Rather than relying solely on any one of the suite of microclimate studies, pigment identifications, stylistic evidence, micro flora characterisation and hydraulic data, it is essential that training programs in conservation provide the new workers with a solid grounding in how the dozens of parameters all interact to bring about the life and ultimate decay of the images which have recorded humankind's activities over the past millennia. If course co-ordinators adopt a policy of engagement with indigenous owners or descendants of the traditional owners of sites, it should be possible to overcome some of the more problematic issues of site management. In the past, decisions have been made out of ignorance, but with improved communication and awareness of cultural differences and sensitivities it should be possible to bring about a common sense of caring for the sites and the images on the rock surfaces. Recognition by national research bodies and granting foundations of the need for multi-disciplinary studies will improve the chances of finding new solutions to the perennial issue of determining what controls the decay processes. Such changes will also provide long-term career paths for practitioners, which can only auger well for the future.

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Rock art conservation and management: the past, present and future options

Fig. 1 Napier Range, West Kimberley region of Western Australia, detail of images with temperature probe in location, supported by sprung wooden pole (photo: Philip Haydock).

Fig. 2 Napier Range, West Kimberley region of Western Australia, detail of microclimate studies with photographic recording by Philip Haydock (photo: Ian MacLeod).

Fig. 3 General view from rock art shelter across the plains towards Leopold Ranges, West Kimberley region of Western Australia (photo: Ian MacLeod).

Fig. 4 Site in Napier Ranges, West Kimberley region of Western Australia, showing multiple repainting episodes with emu, bush plums, Wandjina, snake and fish images (photo: Ian MacLeod).

Fig. 5 Detail of crocodile image, Napier Ranges, West Kimberley region of Western Australia, huntite support with haematite and charcoal, image approx. 350 mm wide (photo Ian MacLeod).

Fig. 6 Napier Ranges, West Kimberley region of Western Australia, overall view of site in Figs. 1 and 2 (photo: Ian MacLeod).

Fig. 7 Napier Ranges, West Kimberley region of Western Australia, general view of with boab and eucalyptus vegetation (photo: Ian MacLeod).

Fig. 8 View of Walga Rock site near Cue, Western Australia, showing guano flow lines in the left and centre of the images (photo: Philip Haydock).

Fig. 9 Detail of rock art site, Walga Rock, under the influence of water borne materials from avian guano deposits, which stabilized the images (photo: Philip Haydock).

The following are the additional captions from which you and the printers can select the final images.

Fig 1a Napier Range, West Kimberley region of Western Australia, zoomorphic image comprising huntite, haematite (feet) and charcoal outline. Photo: Philip Haydock

Fig 2a Napier Range, West Kimberley region of Western Australia, Wandjina figure adjacent to zoomorphic image, showing thermocouple in position against the painted surface. Photo: Philip Haydock

Fig 3a Napier Range, West Kimberley region of Western Australia showing crocodile image and very large Wandjina, partially hidden behind the thermocouple wire and wooden prop. Photo: Philip Haydock

Fig 4a Napier Range, West Kimberley region of Western Australia, detail of microclimate studies with photographic recording by Philip Haydock (photo: Ian MacLeod).
Note that this is the same image as in figure 2

Fig 5a Napier Range, West Kimberley region of Western Australia, detail of microclimate studies with photographic recording by Philip Haydock, showing Wandjina figures and multiple repainting episodes (photo: Ian MacLeod

Fig 6a Typical rock art shelter in the Napier Range, West Kimberley region of Western Australia. The large flat stone in the foreground has been used for grinding pigments. Photo by Ian MacLeod

Fig 7a General view of the heavily degraded images on calcareous substrates, Napier Range, West Kimberley region of Western Australia. Photo Ian MacLeod