Deterioration Analysis of Rock Art Sites

J. Clarke

Introduction

In this paper it is proposed to describe the results of investigations into three different types of rock art sites, and to show how deterioration analysis can be used to understand the processes causing the sites' outward appearances.

The first two examples will be painting sites, in which the environment, combined with very different pigments and painting technqiues, has caused a need for extremely diverse conservation procedures. The third example is a rock engraving site which is rapidly deteriorating due to a combination of man-made changes to the environment and an unstable rock type.

Durable Red Paintings in Arid Environments

Throughout the arid and semi-arid areas of Western Australia there are numerous examples of very durable red pigmented paintings on siliceous rocks. These paintings are often in exposed positions and pre-date the culture present at European contact. The sites cover a wide range of art styles, but all exhibit a number of common parameters. Examples of this art are shown in Figs. 1a and 1b.

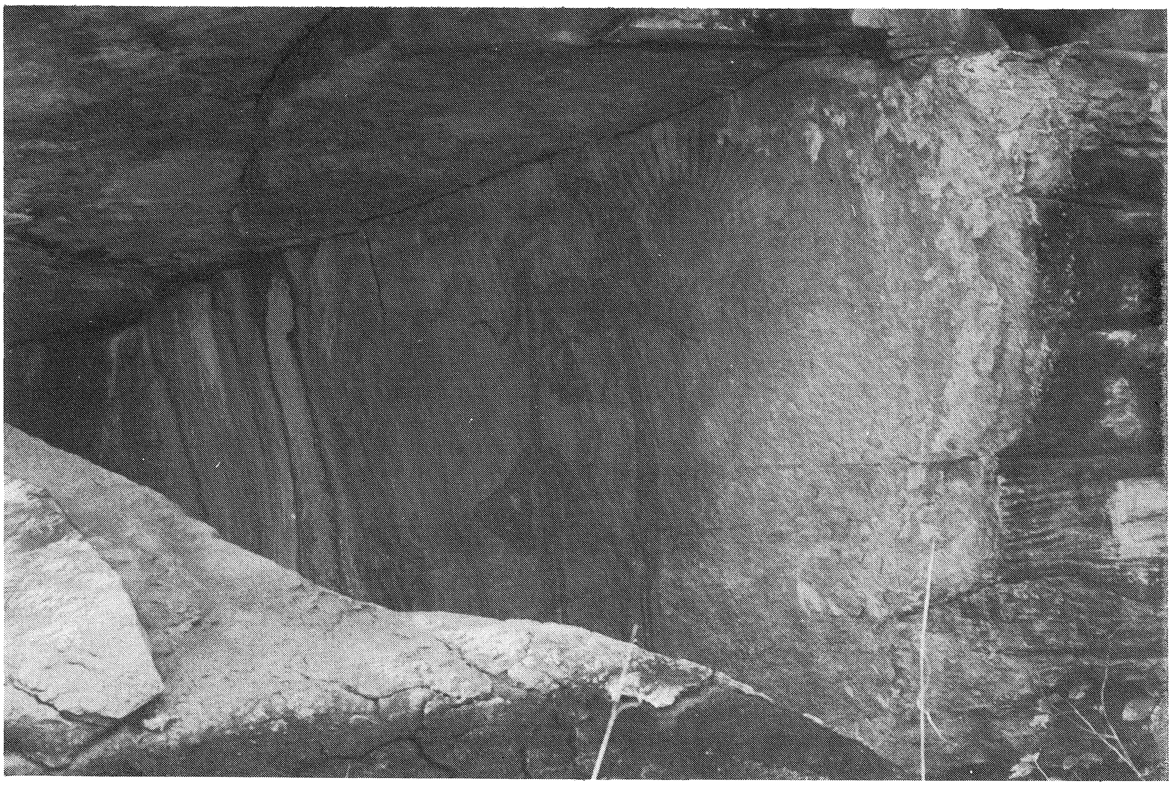

Figure 1a: Red pigmented paintings on a partly exposed quartzite face. Kimberley W.A. These figures are referred to as Bradshaw figures.

Figure 1b: Red pigmented paintings on a fully exposed sandstone face. Some figures appear to have originally been in two colours and now only the red remains.

Rock Type

All sites are on siliceous rocks, the most common being sandstones and quartzites, which consist almost entirely of the mineral quartz (SiO_2), cemented by secondary silica. This forms an extremely stable surface in an arid environment, the rock being chemically inactive and mechanically strong, with low permeability. Rock type is best studied using petrological sections under a microscope, since the composition and internal structure (texture) can be determined, along with the presence of unstable minerals and weathering products. A typical section of one of these sandstones is shown in Fig. 2. There are usually traces of iron oxide present in the surface of the exposed rock.

Micro Climate

The sites show a wide range of micro climates, however there are a number of common features. All sites are in arid climates where evaporation exceeds precipitation by large amounts. Temperatures show wide diurnal variation, registering extremely high daytime temperatures for much of the year. We have recorded rock surface temperatures of $>80^oC$ with air temperatures of $>40^oC$. However, while sub-zero air temperatures can occur in winter, rock temperatures have always been above zero — this combined with very low relative humidity (RH) prevents any frost action. RH is usually low (20-40%); periods of high humidity or precipitation are of very short duration. The sites are all well ventilated and usually exposed to direct sunlight for part of the day. Some are covered with water after heavy rain, but this is a rare event occurring less than once every three years.

Pigment Type

These durable paintings all have red pigments, while in all cases tested there is a range of colour tones, they have been shown to consist primarily of the mineral hematite (Fe_20_3). Pigment identification is usually carried out using one or more of the following methods.

(1) Microscopic examination. This is quick and cheap, but can often be non-diagnostic because of small particle size and difficult sample preparation.

(2) X-Ray Diffraction. This is by far the best method, as it gives a positive mineral identification and is very useful where several phases are involved. We usually use a micro X.R.D. technique, in which the sample is placed on the end of a glass fibre; this results in non-visible damage when collecting samples.

(3) Scanning Electron Microscope. We have recently used a S.E.M. with an X-Ray analyser, and this has also provėd useful on rock chip samples because it is possible to carry out point analysis and thus differentiate between rock and pigment minerals as well as obtain particle size data.

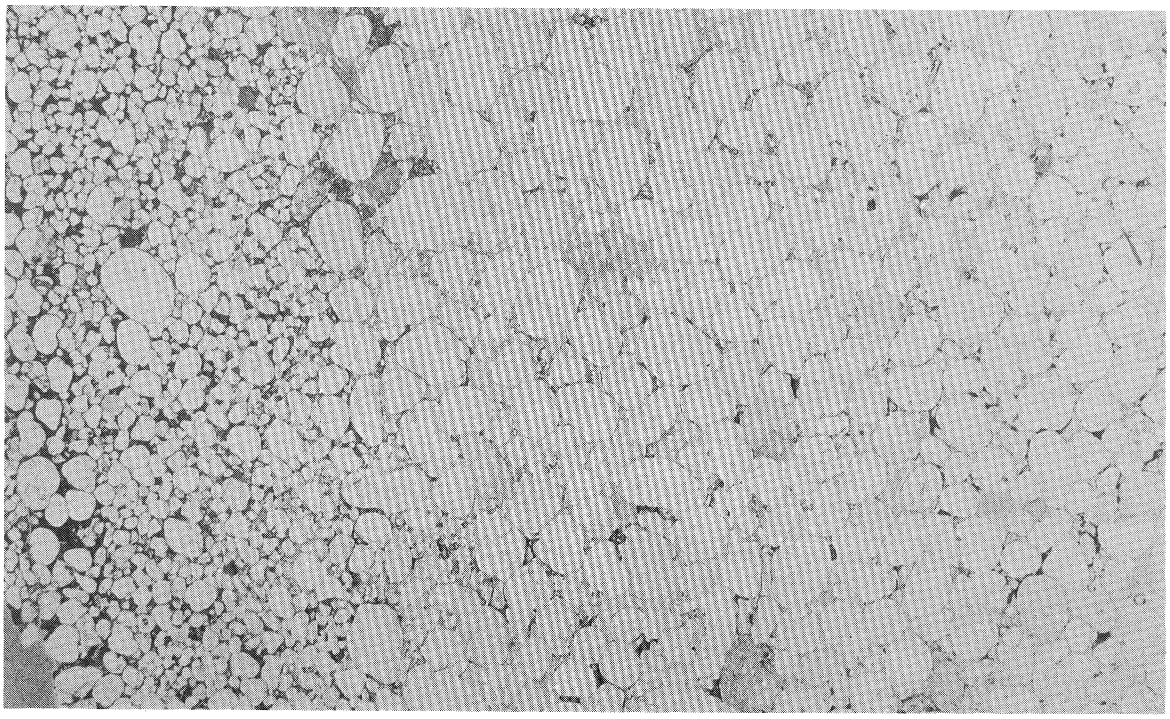

Figure 2: Petrographic section of a sandstone showing the quartz grains tightly cemented with silica, the back-in fillings are iron oxides in the weathering zone of the rock. Plane light. Length of section 30mm.

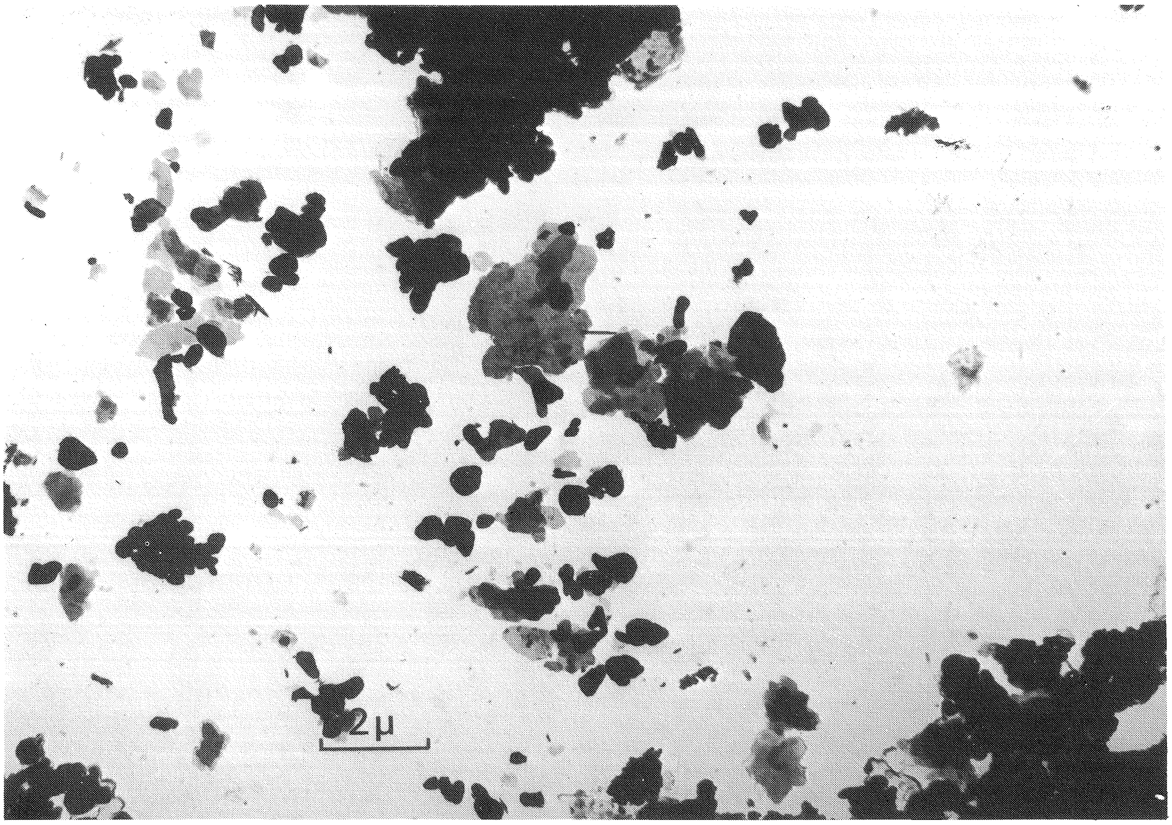

Figure 3: Electron micrograph of the Wilgi Mia ochre x 7000 scale in microns. Showing both the platy (light) and granular (dark) particles with a wide size range including some very small $< 0.5\ \mu m$ particles.

In W.A. we are fortunate to have a major Aboriginal red ochre mine, the working of which continued until well after European settlement. Woodward[1] and Davidson[2] have recorded details. The mine is now known as Wilgie Mia, and the ochre was extensively traded throughout the southern half of the State. We have collected samples from the site and examined the ochre by a range of techniques, the results of this were reported earlier by Clarke[3].

X.R.D. analysis showed that the ochre was mainly hematite with minor ($<$10%) geothite ($Fe_2O_3.H_2O$) and kaolinite ($Al_2O_3.SiO_2.2H_2O$). When examined under a transmission electron microscope (Fig. 3), it can be seen to consist of both granular and platy particles of hematite with a wide range of sizes from 0.5μm to 2μm. A standard sedimentation method gave a much larger median size of 7.4μm – this was due to the extreme difficulty in obtaining defloculation, however, it is probably more typical of the Aboriginal usage where the pigment was ground mechanically with water to make paint.

Rock-Pigment Bond

An electron-probe microanalsyer was used to examine the nature of the interface between the paint and rock on small samples from a number of sites. A typical result is shown in Fig. 4. The reason for the durability is clearly the migration of silica from within the rock, and the deposition of this silica within the pigment layer, bonding it chemically to the rock surface. We have shown by micro X.R.D. that the silica deposited in this layer is in the form of quartz and not the hydrated form, opal.

While silicification of rock and even soil surfaces is a well known phenomenon in arid environments[4] there is as yet no real understanding of how the process works or how long it takes. It is obvious however, that under arid conditions silica is far more mobile than originally thought, or than its limited solubility would indicate. The process probably results from evaporation of ground water from within the rock, at the rock surface. These ground waters are usually quite saline, with gypsum ($CaSO_4.H_2O$) being the most common salt, along with minor sodium and potassium salts. This means that the process must include a separate leaching cycle, by which the more soluble salts are removed from the surface, leaving the silica. The process appears to be self-regulating, as the silica deposition causes the surface to become impermeable and therefore limits further deposition. A sandstone

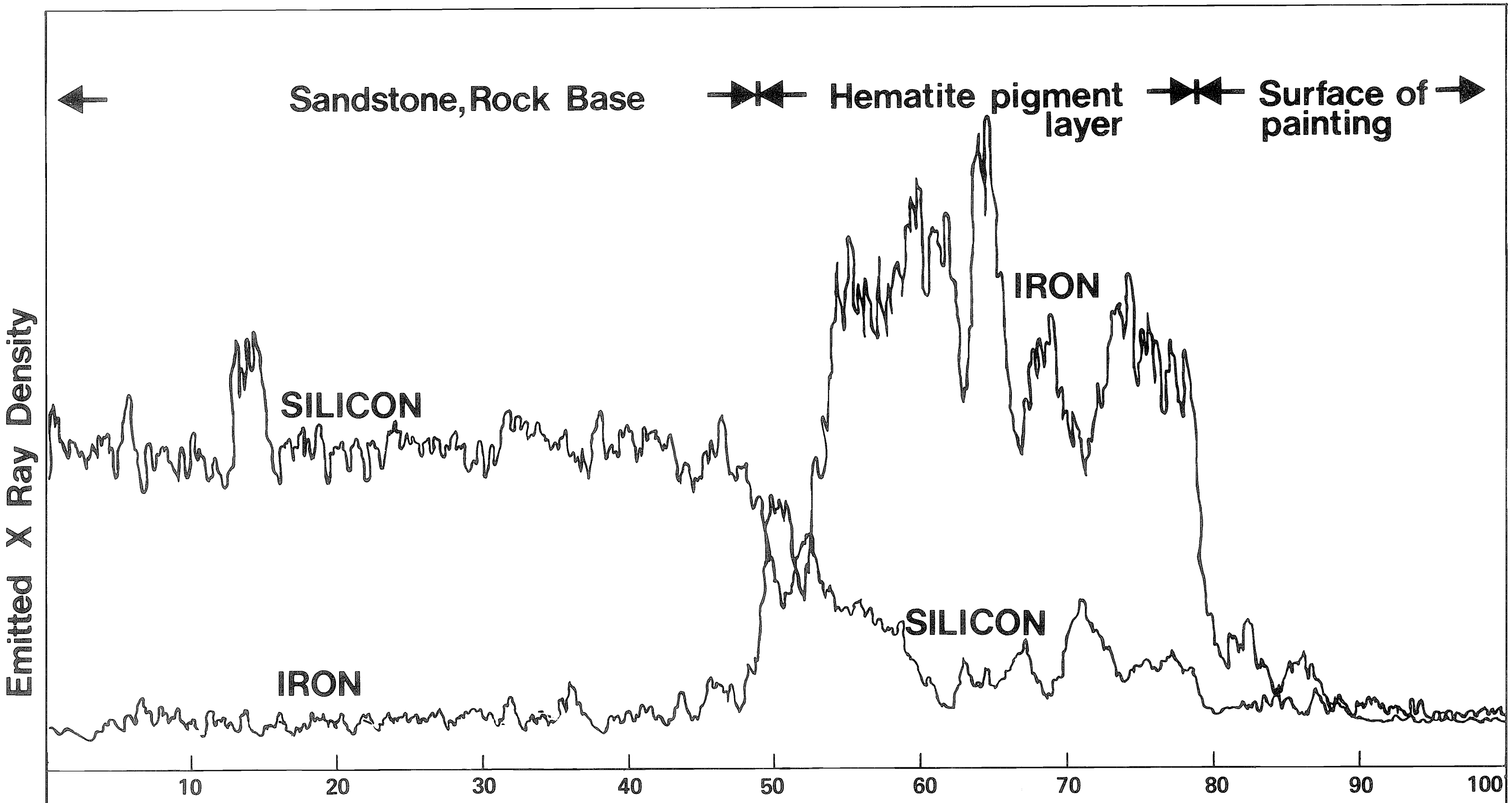

Fig. 4. An electron probe cross sectional scan of an Aboriginal rock painting. Sample is from a snake painting at Mt. Methwin, W.A. The profiles represent the density of the emitted X-Rays as recorded by an analyser. The migration of Silica into the pigment layer is clearly shown.

Figure 5: A typical Wandjina rock art site in Northern Kimberley W.A.

sample from 2cm below a silicified surface had a permeability coefficient (k) of 5.4×10^{-5} m/sec., whereas the permeability through a sample with the surface intact was less than 1×10^{-9} m/sec., which is effectively impermeable.

Discussion

The natural preservation of these red paintings can be attributed to a combination of factors related to the properties of the rock, pigment and environment.

The rock must be siliceous and both chemically stable and mechanically strong to create a permanent substrate for the painting. The pigment must be the mineral hematite with suitable small particle sizes to bond to the rock and survive the silicification process. This, in turn, requires an arid environment, permeable substrate and exposure to both evaporate ground water and wash out soluble salts, without biological activity.

Silicification of rocks in situ has long been the goal of stone and rock art conservators. Further study of this natural process may give valuable clues on the controls necessary to develop synthetic silicification processes for preserving rock art.

Kimberley Wandjina Paintings

In contrast to the previously discussed durable red paintings, there is a rock art style in the Kimberley region of W.A. which is rapidly deteriorating. Fig. 5 illustrates a typical site. The paintings are usually in large rock shelters developed in quartzites. They consist of large human and animal figures, painted in a range of coloured pigments on a prepared white background. They are of recent origin with active painting continuing up the 1940's. Some artists are still living in the area, but are no longer rock painting.

Over-painting is common; usually a new white background is applied, and new figures painted. This has resulted in paint up to 5mm thick, with over 40 layers being built up on the surface in places. An example of this is shown in Fig. 6.

Site Parameters

The underlying rock is a strong, stable quartzite, as described earlier. In some cases there are much older durable red paintings with siliceous coatings, next to poorly preserved Wandjina paintings. The main differences are the position of the paintings — the Wandjinas being inside rock shelters and not directly exposed to rain or sunlight. The shelters also moderate the temperature and humidity variations, and provide a suitable environment for animal life such as bats and mud wasps which cause minor damage.

Figure 6: Deterioration of a Wandjina painting in Northern Kimberley. The numerous layers due to over painting are visible.

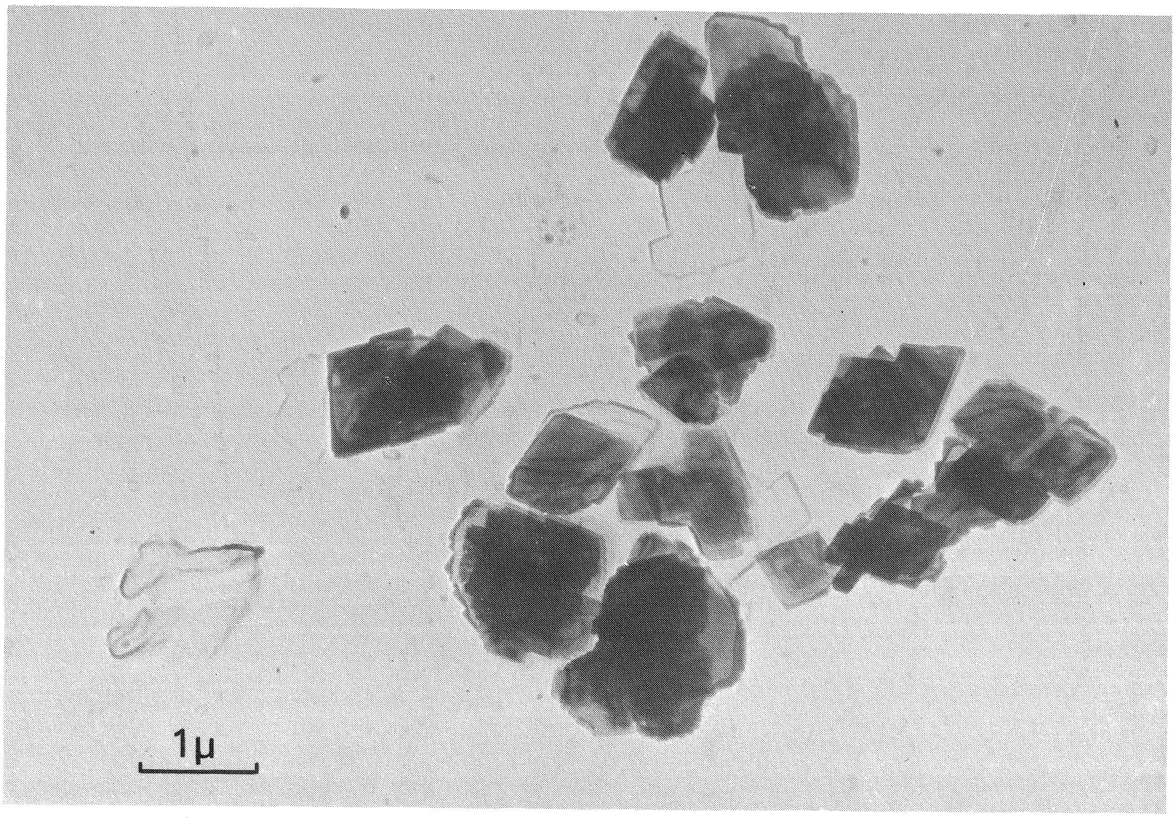

Figure 7: Electron micrograph of the white pigment, huntite. X 15000 scale in microns, showing the uniform size and shape of the particles.

Pigment Types

The artists have aimed at visually spectacular effects, and this has affected pigment choice. In bulk, the most important pigment is the white background, which is causing most paint flaking. However, the coloured pigments have also been examined, and included charcoal, ground and mixed with the white pigment, a range of iron oxides from pure red hematite to earthy mixtures of geothite, and clay minerals giving yellows and brown. We have used both microscopic examination and X.R.D. to find that many pigments are crudely mixed and contain sand and organic debris.

The White Pigment

Two Aboriginal women were able to take us to a source of the white pigment[3] and showed us how it was prepared. With material from this site, as well as flakes from deteriorating paintings, the following results were obtained. The pigment is a pure white, soft, powdery, poorly coherent mineral which disperses easily in water. X.R.D. patterns showed it to be the rare mineral huntite ($Mg_3Ca(CO_3)_4$). This mineral was discovered by X.R.D. in 1957[5] and has been shown[6, 7] to have been used as a pigment by Roman and Egyptian cultures.

The pH of a 1:2.5 water suspension was 9.75, which is alkaline in respect to the rock (6.50) and red-brown pigment (6.20). Electron microscope examination confirmed that, like all known huntites, this one has uniform particles of 1 to 2µm rhombohedral crystals (Fig. 7). These particles disperse easily in water with no sign of floculation, allowing thick suspensions to be formed. Upon drying, this comprised a very low density mass (bulk density of $0.6 gm.cm^{-2}$, compared to $2.89 gm.cm^{-2}$ for the pure mineral).

Durability of the White Pigment

The properties of the pigment outlined above combine to make it very unstable. The alkalinity results in chemical reactions with the rock and other pigments. The particle size allows thick, poorly coherent paint layers to be applied. These layers have an extensive network of capillaries which draw water into the paint with enough violence to cause disruption and flaking of the paint surface. This disruption is caused by air trapped within the paint layers being compressed by the water which is drawn in by the capillaries. Differential movement of the various pigment types under changing weather conditions causes interlayer failures.

We have used an accelerated weathering chamber repeatedly changing temperature and relative humidity, to obtain failures due to flaking, in a simple layer of white pigment on quartzite[3].

Summary

We have shown in this case that the deterioration of the Wandjina paintings can be related to the properties of the main pigment used. Future conservation will depend on either modifying these properties by chemical treatment of the pigment, or by creating a stable moisture-free environment for the art sites. In another paper in this publication[8] we outline one possible treatment to improve the durability by preventing capillary action.

Port Hedland Rock Engraving Site

A well known rock art site at Port Hedland, in the Pilbara region of W.A. is deteriorating at a very rapid rate. We have investigated the causes of this deterioration which has been reported by Clarke[9].

The site consists of a low ridge of limestone with thousands of engravings on the outcropping flat and gently sloping surfaces over an area of 17,000 sq.m.

Site Parameters

The rock is an oolitic calcarenite, which is a lithified Pleistocene off-shore bar. A petrological section, Fig. 8 shows that the rock consists of loosely cemented oolites[10] with silica or carbonate sand cores and concentric layers of carbonate, ranging from 0.3 to 1.0mm in diameter. The oolites are cemented by finely crystalline calcite ($CaCO_3$), The rock is porous (porosity 15 – 20%) and permeable (permeability coefficient of 1.4×10^{-5} m/sec.). This results in a mechanically weak rock (uniaxial compressive strength of 11.3 Mpa with failure in the inter-oolite cement).

The climate is arid with a coastal marine influence causing high relative humidity and salt inputs. Rainfall average is 277 mm on 27 rain days, most of which is the result of summer tropical downpours of brief duration.

There has been considerable industrial development in the vicinity of the site since the mid 1960's with a major iron ore export, harbour and associated facilities.

Site Deterioration

Unfortunately, the chemical and physical properties of the rock which made it easy for the Aboriginies to engrave, are also making the site deteriorate by natural weathering and human activities. Limestone is soluble in water and is slowly dissolved away. The rate of solution weathering varies, depending on the pH of rainfall, rock structure, temperature and immersion time. The Hedland site is in a low rainfall area; individual rain showers are heavy and of short duration, and temperatures are high. This results in a low natural solution rate. The present rate has been increased by the industrial development causing more acidic

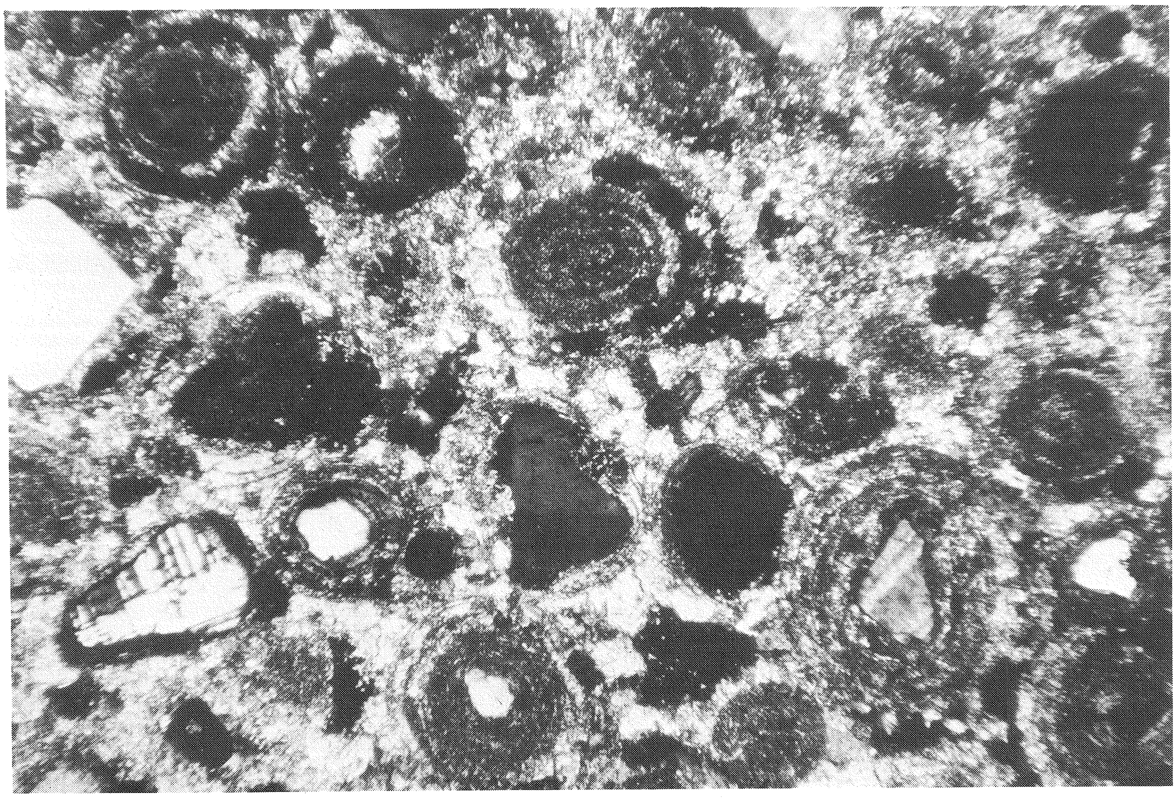

Figure 8: Petrographic section of oolitic calcarenite, Port Hedland, showing the oolites developed around detrital grains and inter-oolite calcite cement, black areas are voids. Cross polarised light. Length of section, 3mm.

rainfall[11]. The rock structure is such that the water only has to remove the more reactive inter-oolite cement so that mechanical processes, such as wind and water, can remove the oolites. Salts crystallising within porous rocks result in rapid disintegration, due to crystal growth and, more importantly, hydration pressure as salts take up water due to changing humidities. The proximity of the site to both sea and industry, combined with the arid environment, has led to a build up of soluble salts — mainly halite ($NaC1$) and gypsum ($CaS0_4.2H_20$). Once salt weathering has broken the weak inter-oolite cement, mechanical processes soon remove the loose material.

Over the years vegetation has built up on the site, causing the break-up of surface blocks and soil build up which speeds the weathering rate. Rubbish and vandalism have also accumulated on the site. Industrial pollution is now the most important single weathering agent; in 10 years more damage has been done than in the previous 100 years of natural weathering. The pollution is in two forms, the most obvious is dust from nearby iron ore stock piles. This dust is mainly fine particles of hematite (Fe_20_3) which adhere strongly to the rock surface, and have caused the rock to change from pinkish grey (5YR 6/2) to dark reddish brown (5YR 3/2) on the Munsell system. The dust settles in the bottom of engraved lines protecting them from erosion while the edges are rapidly eroded, causing the engraved line to lose its sharp profile and disappear. The other effect of pollution is not obvious but is probably even more serious. This is the atmospheric pollution which causes a drop in rainwater pH and the introduction of soluble salts, such as sulphates and nitrates, which accelerate the natural salt weathering. This effect is well documented in all industrial countries and is detailed by Winkler[11].

There is also deterioration through abrasion caused by people who visit the site, and this is the result of the limestone's poor mechanical strength. The surface oolites are selectively dislodged from high points by visitors walking over the site causing a loss of contrast in engraved lines.

Summary

In this case the combination of a rock type with poor durability and a man-modified environment has caused a rapid increase in the natural weathering rate and subsequent loss of rock art. In another paper in this publication we outline the procedures now being used to overcome these problems.[8]

References

1 Woodward, H.P. (1914). A geological Reconnaissance of a Portion of the Murchison Goldfields. *Bull, Geol. Surv. W. Australia, 57,* 71-89.

2 Davidson, D.S. (1952). Notes on the Pictographs and Petroglyphs of Western Australia and a Discussion on their Affinities with Appearances Elsewhere on the Continent, *Proc. Amer. Phil. Soc., 96,* 82-84.

3 Clarke, J.D. (1976). Two Aboriginal Rock Art Pigments from Western Australia, their Properties, Use and Durability. *Studies in Conservation, 21*, 134-142.

4 Stephens, C.G. (1971). Laterite and Silcrete in Australia: a Study of the Genetic Relationships of Laterite and Silcrete and their Companion Materials, and their Collective Significance in the Formation of the Australian Continent. *Geoderma, 5*, 17-25.

5 Graf, D.L. and Badley W.F. (1962). The Crystal Structure of Huntite, $Mg_3Ca(CO_3)_4$ *Acta Cryst, 15,* 238.

6 Riederer, J. (1974). Recently Identified Egyptian Pigments *Archaeometry, 16,* 102-109.

7 Barbieri, M. Calderoni G. Cortesi C. and Fornaseri M. (1974). Huntite, a mineral used in Antiquity. *Archaeometry, 16,* 211-220.

8 Clarke, J. (1978). Conservation and Restoration of Painting and Engraving Sites in Western Australia. *Conservation of Rock Art*, I.C.C.M. Canberra, 89.

9 Clarke, J.D. (1975). Conservation requirements of an Aboriginal engraving site at Port Hedland, Pilbara, Western Australia. *Conservation in Archaeology and the Applied Arts 1975. Stockholm Congress*, I.I.C. London 79-86.

10 Pettijohn, F.J. (1957). *Sedimentary Rocks*, New York.

11 Winkler, E.M. 1973. *Stone: Properties and Durability in Mans Environment.* Springer Verlag, New York.