THE USE OF MICROMETEOROLOGICAL STUDIES AS AN AID TO THE CONSERVATION OF ABORIGINAL ROCK ART

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SUMMARY

It is believed that the primary weathering processes on the art at Walga Rock, involves the presence of water. A model based on micrometeorological studies by Lyons[1] has been applied to consider what incidence of condensation there may be on the art. The other source of water damage is recognised as being due to driving rain.

The model is primarily based on the surface energy balance, where each point on the rock face, its heating and cooling trends, are directly related to their respective sky view-factors. The sky view-factor is the real proportion of surface directly exposed to the sky. This model was used to predict rock face temperatures, and in conjunction with climatological data from nearby Cue, was then used to study the incidence of dew-point temperature on the rock face.

The model did not predict condensation on the rock face via the processes of dew formation or fog inception, for either current site conditions or conditions of revegetation. However, the moisture input from vegetation transpiration into the micro-climate is recognised in that it would have some effect on the kaolinitic pigments, the extent of which has not yet been ascertained.

Taking into account the action of driving rain and transpiration, a management proposal has been drawn up. This proposal seeks to minimise rain action, combined with a cautious approach to the questions of humidity and condensation.

Introduction

In recent years the need for conservation of aboriginal paintings has become increasingly recognised. There has been a growing awareness of the important and integral part that rock art plays in Australia's heritage.

Conservation processes are generally individually considered to take into account the specific characteristics of each site. For example, sites located in more arid conditions are generally more stable with regard to aboriginal rock art, and less conservation work is necessary. However, with sites where more marginal climatic conditions prevail, the patterns and processes of weathering must be understood so that the most effective management programmes may be implemented. Whilst weathering is a natural and inevitable process, factors within a micro-environment may either enhance conservation, or hasten deterioration. The application of these programmes must also demonstrate the appropriate respect and sensitivity toward maintaining the natural integrity of the site.

Walga Rock art site suffers weathering processes that have not yet been clearly understood. This paper aims to pinpoint the major variables within the weathering processes, and discuss the relative importance of each of these.
This study aims to identify both the past and present weathering processes, and also future processes that may occur in the advent of an implemented management plan, which would consider the variables that have been discovered during the course of this research.

There are three major data sources incorporated within this study programme and they include the use of climatological data recorded at Cue by the Bureau of Meteorology, field data recorded within the art site itself and the implementation of a micrometeorological model, developed by Lyons[1], which is based upon predictions of the heating and cooling trends on the rock face.

The field data assists in testing the validity of the model, which can then be used in conjunction with the climatological data to predict the temperature trends on the rock face.

Methodology

It has been recognised that the deterioration of the art at Walga Rock is hastened by water[2]. White pigments, being kaolinitic clays, are particularly sensitive to water. The three situations that will lead to hastening of the weathering processes are: (i) water reaching the rock face by means of driving rain; (ii) the condensation of water on the rock face, when the dewpoint temperature has been reached; and (iii) the condensation of water on the rock face via the mechanism of fog inception.

The aim of this paper is to study the micro-environment within the rock shelter to see if it is at all possible that water might condense on the rock face. The effects of change in this micro-environment, brought about by different variables such as vegetation height and transpiration will also be examined.

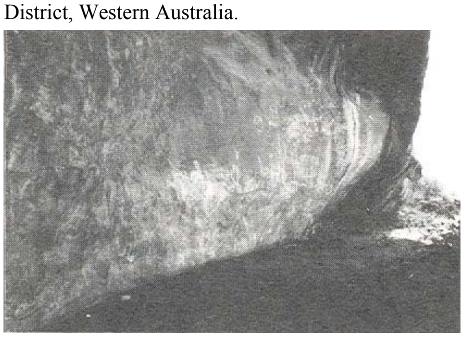
Finally, a management plan is described so that the site conditions can be enhanced to provide a greater control over the weathering variables.

Site Description

Walga Rock is situated 45km west of Cue in the upper Murchison Region of Western Australia. Of the 60m long wall which carries an extensive array of rock paintings, this work has been concerned with those paintings within the shelter (see Figure 1). The shelter's dimensions are: 25 metres long, 12 metres high and up to 5 metres deep at the widest point. The paintings within the shelter extend the full length of the shelter, and up to a height of 2.5m. Carbon dating of deposits within the floor of the shelter denotes human occupation back to 9950 ± 750 years B.P.[3]

Predominantly there are two pigments used in the paintings, as have been identified by Clarke[2] - the red pigment, hematite (Fe_20_3) and the white pigment, kaolinite ($Al_2Si_2O_5(OH)_4$). The white kaolinitic clay pigments display much more deterioration than those based on hematite. The reason for this is that the kaolinitic clay is much more susceptible to moisture and changing humidities, due to the hydration of the molecules which causes dimensional changes which can lead to the pigment being dislodged from the rock face. Hematite, on the other hand, is unaffected by the presence of moisture, and bonds very strongly to the rock face.

Fig. 1: Walga Rock shelter, near Cue, Murchison District, Western Australia.



The two forms of moisture which present problems are firstly, water in the liquid phase and secondly, humidity changes. The effects of humidity on stability are far less dramatic than the presence of water itself. Since the magnitude of the effects of humidity changes on weathering are markedly less than those associated with water in the liquid phase, we have concerned ourselves primarily with the latter.

There are four ways by which water may reach the rock face and contribute to the weathering of the paintings. The four modes are: water seepage through the rock face via fissures; rain being driven onto the rock face; the condensation of water on the rock face in the form of dew; and the condensation of water on the rock face through fog inception. Each mode of weathering is assessed below.

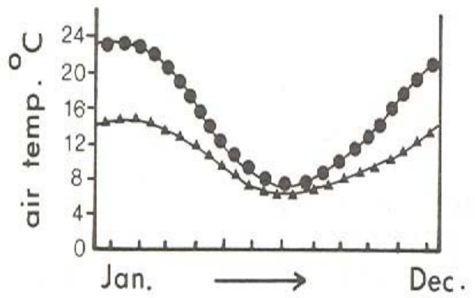


Fig. 2: Minima and dew-point temperatures for Cue. Data courtesy of the Bureau of Meteorology. Dew-point ▲ Minima ●

Water Seepage

The action of water seepage on the rock face is localised and damage minimal. Since Walga Rock is granite and has a negligible porosity, water seepage is only through fissures. The effects of the water seepage occur only at the weathered edge of the shelter, with drainage occurring only after rains.

It is not considered necessary to divert this streaming since the diversion would only transfer the problem and the damage to a more sensitive part of the site.

Driving Rain

A study to determine the incidence of driving rain in this area needs to be done to fully evaluate this problem. It is calculated that rain would have to be driven at an angle of 27° to the vertical, to place water on the rock face at a height of 2m or lower. It is understood from Pigdon[4] that in the 1930's the site was well sheltered by vegetation, and it is since that period that the site has been largely cleared. The clearing process has probably increased the incidence of rain-based weathering. Support for this argument was found during field work when a light rain shower resulted in small amounts of water being driven onto the wall.

Management of this problem may be best served by replanting the area with the original and indigenous species since this would serve to both shelter the site from possible rain, and restore the former integrity of the site. However, vegetation transpiration may then result in the condensation of water on the rock face. This problem is addressed in a subsequent part of the text.

Water Condensation

It is the consideration of water condensation through the mechanisms of dew formation and fog inception that forms the basis of this research programme. We are concerned with both an assessment of current conditions and a projection of future parameters with vegetation regrowth, in our attempt to model the incidence of these forms of condensation.

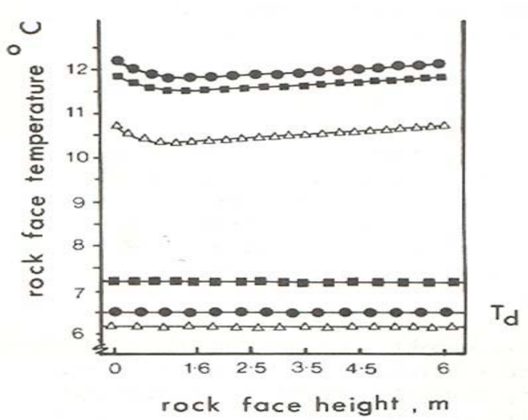


Fig. 3: Predicted minimum temperatures : a vertical temperature profile of the rock face for the months of June ■, July Δ and August ●, with their corresponding dew-point temperatures.

Modelling

Lyons' has developed a computer model based on the surface energy balance, where predictions can be made of the heating and cooling rates of various surfaces: in this case the rock face. Predictions for Walga Rock are made to cover the whole diurnal range for each month of the year. This was done by modifying the model to suit site conditions.

The method of collating a year's predicted data initially involved recording in the field. Rock face temperatures were taken over several days, and then one of these diurnal ranges was extracted and compared with predicted data from an initial model run. This enabled the model to be finely tuned, to produce a close match of actual and predicted data, leading to extrapolation of data for each month of the year.

The criteria under which the days' field data was selected to compare with the model's data, were conditions of optimal cooling, where relatively lower minimum rock face temperatures were reached: through clear skies and minimal wind conditions.

A further explanation of the field data collection and the mathematical bases of the model, are contained in the full report[5].

Once the model had been developed to an acceptable level, the predicted data could be compared with long-term Bureau statistics for the Meteorological Station at Cue, to ascertain the likelihood of condensation occurring on the rock face through dew-fall.

Average Conditions Over 12 Months

The temperature at which dew forms from moisture in the air is called the dew-point. Analysing the Bureau's data for Cue, Figure 2 demonstrates the times of the year where the minimum air temperature and the dew-point temperature is in close proximity to each other. The months of June, July and August are the most susceptible for dew-fall to occur. It must be remembered that this comparison is for air temperature minima, and not rock face temperature minima. The mechanism for dew-fall is such that if a surface temperature drops to the dew-point temperature of the surrounding air, then dew will condense on that surface.

Figure 3 demonstrates the predicted minimum rock face temperatures for June, July and August, and the proximity to their relative dew-point temperatures. The data in Figure 3 clearly demonstrates that under average conditions dew will not form on the rock face, which leads to an investigation into extreme temperature conditions to see if they can give rise to water condensation.

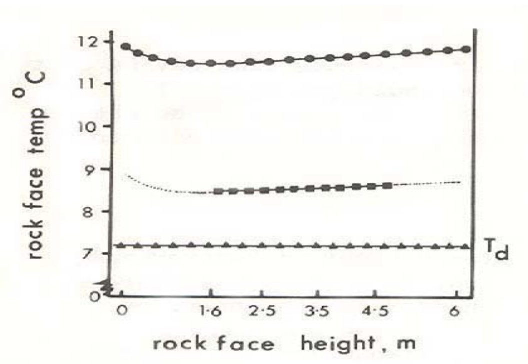


Fig. 4: Predicted rock face minimum temperatures, outlier extreme conditions ■ recorded at Cue on 7, 8, 9 June 1983. The predicted vertical rock face temperature profile under extreme conditions, is lower than normal●, but still well above the dew-point▲ .

Rock Face Minima - Extreme Conditions

Some extreme daily minimum air temperatures were recorded at nearby Cue in 1983, on June 7, 8 and 9, with respective temperatures of 3°°, 1°° and 4°C. The model was altered to run a series of predictions for these conditions. Figure 4 shows the predicted rock face minimum temperatures for June for both the normal conditions and under the extreme conditions. The data indicates that dew-point may not be reached even under the extreme cold temperatures noted above.

On the assumption that the mathematical model is valid, it has been shown that dew will not condense on the rock face under normal or extreme conditions, under the current site situation. The effect of vegetation must now be examined, since it has a major influence on rock face temperature and dew-point involving both sheltering capacity and the vegetation transpiration.

The Effects of Vegetation Heights on Rock Face Temperatures

If the area in front of the cave is revegetated, there are two outcomes influencing the rock face temperatures. Firstly, the heating of the rock face, currently assisted by direct sunlight, would be lessened due to shading, and as a body's cooling rate is proportional to its magnitude in temperature, the cooling rate would be lowered. Secondly, the night-time long wave emission by the rock face, which lowers the rock face temperature, would be partially blocked by the vegetation, and hence this too would lessen the cooling rate.

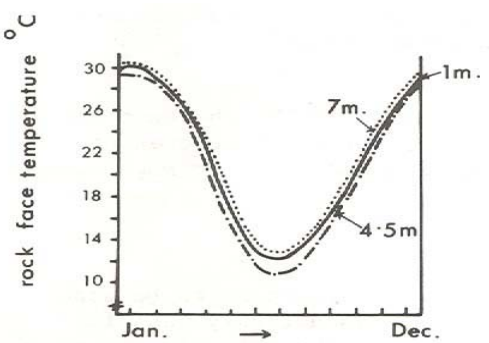


Figure. 5: Predicted data: monthly rock face minimum temperatures, at rock face height of 0.0m, for vegetation heights of 1.0, 4.5 and 7.0 metres.

The overall outcome is to lower the diurnal temperature range - thus cooler rock face maxima and warmer rock face minima are experienced. Figure 5 represents the rock face minimum temperature at ground level at vegetation heights of 1.0m (current), 4.5m and 7.0m. The temperature differences for each vegetation height are not as great for higher points on the rock face. Figure 6 shows rock face maxima at 1.6m height on the rock face for differing vegetation heights. Comparison of the data for the two heights of rock face shows that the vegetation has a minimal effect on rock temperatures at ground level but has a major effect at the 1.6m level.

Transpiration from Differing Vegetation Heights

Condensation may be formed on the rock face by dew formation and by fog inception. Both phenomena will affect the deterioration of the rock art and they are discussed below since they influence the implementation of the proposed revegetation programme.

Dew Formation

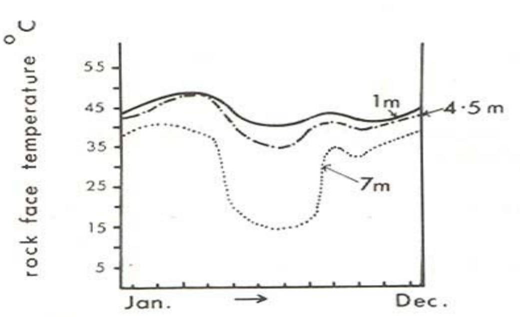


Fig. 6: Maximum rock face temperatures at 1.6m on the rock face for vegetation heights of 1.0, 4.5 and 7.0 metres.

With no specific local data available on leaf area indices and transpiration rates of plants, representative figures were chosen using vegetation transpiration rates suggested by Attiwill and Clayton-Green[6], * and a suggested leaf-area index. The transpiration rates can be calculated using their data and expressed as kg water $day^{-1}m^{3}$ vegetation. The results show that $1m^2$ leaf-area yields 2.64kg water day^{-1}, and that $1m^2$ leaf-area is the equivalent of $5m^3$ vegetation. The above data was then used to assess whether transpiration could induce condensation through dew-fall.

To do this, parameter time periods were chosen to represent the air residence time and moisture build-up: hr and 24 hrs. Without researching local conditions at length, it can only be said that the real value may lie somewhere in between these two parameters. Further assumptions made in the calculations were that there is a uniform mixing of air within the cave and that all the transpired moisture would maintain the appropriate air residence time within the shelter. It was also assumed that there is no mixing of air whatsoever across the boundary of the cave and the external environment within that air residence time. The results of the calculations for the amount of water required to achieve dew-point on the rock surface are shown for each month in Figure 7. The amount of vegetation required to achieve the mass of transpired water is shown in Figures 8 and 9 for the two extremes of air residence times of 24 hours and half an hour respectively.

*Transpiration rate chosen from E. Microcarpa for moderate stress am/pm to 5.95mm1 kg^{-1}dry wt s^{-1}.

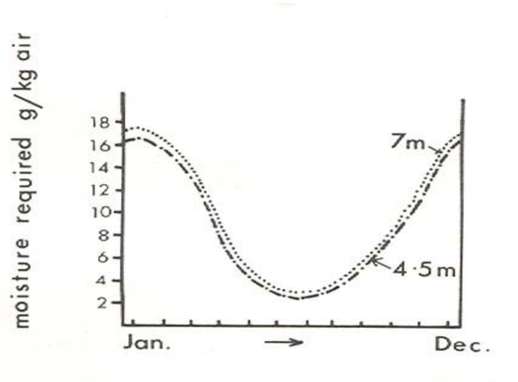


Fig. 7: The required gm H_20/kg air for each month, if condensation is to be reached on the rock face by the dew-point rising and enveloping the minimum rock face temperature at 1.6m: for 4.5m and 7.0m heights of vegetation.

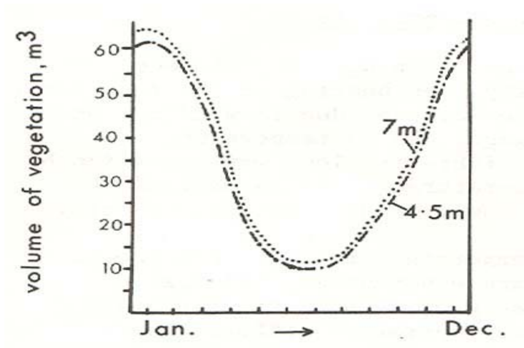
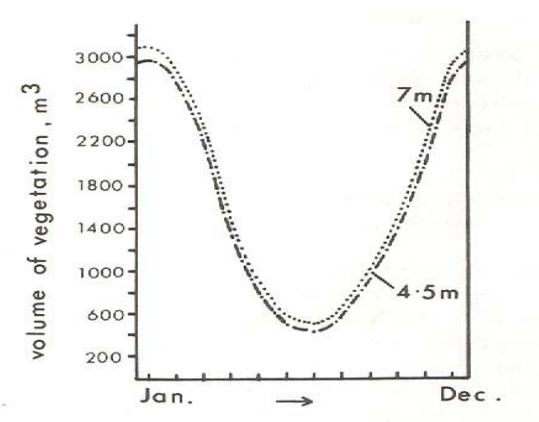


Fig. 8: The volume of vegetation required for an air residence time of 24 hours, transpiring at the given rates needed to raise the dew-point temperature to envelope the minimum rock face temperature at



1.6m; for vegetation heights of 4.5m and 7.0m.

Fig. 9: The volume of vegetation required for an air residence time of ½ hour, transpiring at the given rates to cause the dew-point temperature to meet the rock face temperature at 1.6m; for vegetation heights of 4.5m and 7.0m.

The huge volume of vegetation required for a ½ hour air residence time shows the system to be unrealistic, which leads to the conclusion that dew would not form within these small air residence times as a result of planting trees and shrubs at Walga Rock.

The volume of vegetation required for a 24 hour air residence time may be quite realistic, but it is questionable as to whether dew could actually fall. Monteith's[8] studies indicate that wind speeds of over $0.5ms^{-1}$ at a 2m height are required to facilitate dew-fall, and these wind speeds are not conducive to the long air residence times within this shelter.

Fog Inception

Having 'removed' the problems of driving rain through vegetation cover and shown that condensation through dew-point formation, as a result of increased transpiration, is unlikely, the final point to consider is fog inception. A fog comprises condensed water droplets in the air, when dew-point is reached in the air. When this happens all surfaces within the area become saturated due to the fog's inception regardless of their temperature. This phenomenon was recorded on site on May 15, 1986. However, it was noted that the rock face was the only surface that wasn't saturated. Within several metres from the rock face, the fog thinned out, preventing water condensation on the rock face. This may be due to the thermal capacity of the rock, warming the ambient air, combined with the possibility that there is insufficient air movement in fog conditions, to assist in the placement of water on the rock face in this situation.

It may then be concluded that neither dew formation nor fog inception would present a major problem, due to the lack of mechanisms enhancing the placement of water on the rock face. It is recognised, however, that the question remains as to what degree the humidity of the air may affect the condition of the paintings. There is no control that may be exercised over the incidence of fog, nor its effects regarding humidity, though in relation to revegetation there currently exists. The effects of revegetation were then modelled and shown to be most unlikely to lead to condensation on the rock surface by dew formation or fog inception.

Management Proposal

The management proposal revolves around a revegetation programme to be undertaken around the vicinity of the rock art wall. This is not only justified on scientific grounds, but it will also help to restore the integrity of the site.

The first proposal includes a revegetation programme that should b undertaken to offer the paintings, particularly in the shelter, some protection from driving rain. Large trees, indigenous to the site with a mature height of 7-8 m should be planted marginally exterior to the drip line. An understorey of vegetation should be arranged so as to suit the second type of protection plan. The placement of the understorey vegetation should be arranged so that a side-profile of the vegetation should appear s though a solid wall (particularly to lower cooling rates of the rock surface) and the aerial view should demonstrate a staggered pattern to maximise the ventilation of the shelter as shown in Figure 10.

The lowering of the day-time heating rates and the night-time cooling rates is achieved by the reduction of the degree of direct sunlight on the wall, and a blockage of the long-wave remissions from the rock face at night.

The ventilation is required to minimise the air residence times within the shelter and to guard against the build-up of humidity.

It is important that this revegetation should not take place in the immediate vicinity of the rock wall, as this may create a fire hazard. Clarke's studies[9] have shown the magnitude of rock surface heating from fires and as such, a fire could destroy most of the painted surface.

Conclusion

The weathering problem, demonstrated by the deterioration of the kaolinitic-clay based paint, is accentuated by the presence of water. Two mechanisms by which water may find itself on the rock face are by driving rain and water condensation. A model developed by Lyons[1] has been used to assess temperatures within the micro-environment. In conjunction with the comparative use of climatological data from nearby Cue, the model was unable to predict dew-point temperatures on the rock face at any stage, with the site environment as it currently exists. The effects of revegetation were then modelled and shown to be most unlikely to lead to condensation on the rock surface by dew formation or fog inception.

The model's findings are accepted with reasonable confidence and it seems that the primary weathering mechanisms may be through driving rain. A suggested management plan has been drawn up that should protect the art from rain, and yet minimise the effect of humidity. It is noted that any management plan must be assessed continuously and that further monitoring of the air is essential.

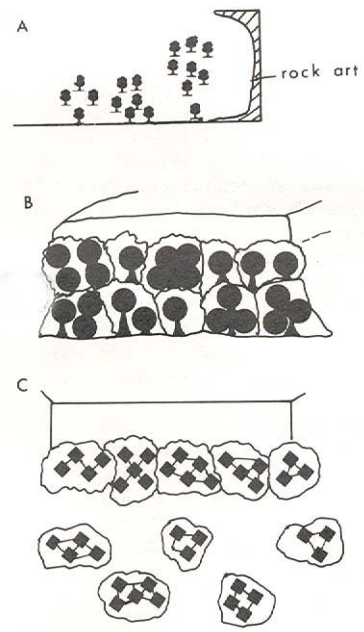


Fig. 10: a) cross-sectional view of proposed planting in front of rock art.

Fig. 10: b) side view – looking into the shelter.

Fig. 10: c) aerial view – note the arrangement for the vegetation.

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