



KEYWORDS: *Colorimetry – Patination – Petroglyph – Western Australia – Saudi Arabia*

EXPERIMENTAL COLORIMETRIC ANALYSIS OF PETROGLYPHS

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Abstract. This paper presents the results of experiments testing the long-suggested possibility that colour gradations in the repatination of petroglyphs might be quantifiable for purposes of age estimation. Colorimetric readings from a series of engraved and repatinated dates found among major petroglyph concentrations in the Pilbara of Western Australia and from petroglyphs at Jabal Qara in southern Saudi Arabia are reported. They show fairly good consistency when plotted by age, raising the possibility of using this method for dating petroglyphs under favourable conditions. The method also has significant applications in rock art conservation and condition monitoring work.

Introduction

Rock patinae have long been recognised as a potential means of estimating the age of petroglyphs (Belzoni 1820), but the difficulties of quantifying and calibrating the processes involved and the variability of their products have fostered the view that these factors are too intractable. Belzoni examined the numerous petroglyphs on Egyptian granite along the Nile and noted the different stages of repatination, compared to the evenly dark-brown accretion on the unworked rock surface. The possibility of estimating the ages of the variously patinated petroglyphs occurred to him:

I beg my readers to pardon my thus speculating on a point which, in my humble capacity, can afford but little instruction; however, as the idea struck me, I lay it before the public (Belzoni 1820: 360–361).

The form of patination Belzoni considered was probably one of various types of ferromanganous accretionary deposits, some of which, such as rock varnish (formerly desert varnish), have been intensively studied by geomorphologists for well over a century. However, the potential use of these precipitates in speculating about the ages of geomorphic exposures, including petroglyphs and other anthropic surfaces, remained sporadic and plagued by confusion. Among the researchers using this approach were Basedow (1914), Rhotert (1938, 1952), Mori (1965), Goodwin (1960) and Anati (1960, 1961, 1963, 1968), to name just a few. Statements about repatination colour or degree tended to be imprecise, subjective and misunderstood. For instance, two Australian writers misrepresented Anati's key observation concerning the age of repatination in the Sinai desert:

In this region we know of no engraved surface from [Iron Age to recent] with a patination identical to that of the original rock surface. This seems to mean that in this area it took a minimum of 2500 years to reach an '0' shade, the natural colour of patina (Anati 1963: 189).

This was rephrased, literally inverting the original statement:

... no engravings have re-weathered to match the natural dark rock surface. As some of them are associated with the Iron Age, Anati believes it takes a minimum of 2500 years for a thin, initial surface patination to form in that region (Edwards 1971: 361).

That version was then adopted and repeated by L. Maynard. A similar error had earlier been published by Mori (1965: 63), who subsequently realised it and corrected himself, substituting '*quasi scura quanto*' (Mori 1974: 89–90) for his earlier statement '*tanto scura quanto*'. Another example of the confusion surrounding the subject is the well-known polemic concerning the repatination of petroglyphs: if a groove has been cut into the weathering rind beneath a ferromanganous accretion, will its repatination occur at an accelerated rate relative to unaltered rock? Does a shallow groove repatinate faster than a deep groove? If the process were endogenous (i.e. its products derived from the substrate) this would be likely, but not in exogenous patinae such as rock varnish or aeolian deposits (Bednarik 2007: 219–225). The role of engraved groove depth remains poorly understood, as does the influence of cation-scavenging micro-organisms and non-organic processes of re-cycling accretionary matter. The use of such phenomena to estimate rock surface ages, including those within a

petroglyph, requires an intimate understanding of the processes active in repatination, and most comments one finds in the existing archaeological literature elicit little confidence in the conclusions drawn from often apparently superficial observations. Indeed, there are numerous instances of evidently false or misleading statements about the nature and significance of such features in the literature, in which surface deposits are incorrectly described, or used as evidence to prop up implausible chronological assertions.

These conundrums indicate the need for some rudimentary understanding of the processes involved in rock patination. Unless the type of surface alteration is identified, such controversies are futile. If the principal component of the patina were rock varnish, repatination would proceed independent of the substrate, but if the process relied largely on the oxidation of resident iron cations, it would be affected by the state of the exposed substrate. To make this judgment it is essential to analyse the patination products responsible for the macroscopic appearance of the surface. This is certainly not beyond the means of the determined researcher (Bednarik 1979: Fig. 2); field microscopy is an essential component of such work (Bednarik 2001: 164–167).

The repatination of petroglyphs

Most altered rock surfaces experience more than one patination process, so what is simplistically called 'patination' is then in fact the macroscopically visible outcome of several factors and their interplay. The word 'patina', in rock art science, defines a visually obvious surface feature that differs from the unaltered rock in colour or chemical composition (Bednarik et al. 2003). It is a collective, almost colloquial term for many phenomena, but they all share one common attribute: they are acquired gradually over time. Hence they are an indication of antiquity, as researchers have appreciated for centuries.

The name *patina* referred originally to copper carbonate or copper sulphate, the corrosion skin that slowly develops on copper and its alloys (*verdigris*) and implies great age — although the term has earlier roots and derives from the Latin word for a 'shallow dish'. It was extended to other age-related surface alterations, such as the sheen or wear-polish on antique surfaces, or cutaneous alteration of rocks or stone tools that seemed to indicate great age. Such very diverse surface skins could be the result of bleaching or leaching (e.g. of sedimentary silicas; Bednarik 1980), limonite staining (Goodwin 1960), mineral accretion (e.g. by rock varnish; Engel and Sharp 1958), chemical alteration of substrate components (most rock weathering processes are candidates), and abrasion or polish (e.g. by sediment grains or biological agents). While this encompasses a great variety of causes, from the rubbing of animal bodies against a rock to the modification of optical properties through the etching of crystal lattices (as in sedimentary silicas), all

of these processes are slow and gradual, resulting in cumulative products that represent relatively lengthy time spans. The quantification of these products might therefore lead to ways of estimating the ages of the surfaces they have affected.

The term 'patina' thus describes a visually obvious skin on rock surfaces that differs in colour, texture or chemical composition from the unaltered rock, and whose development is a function of time. It can be additive or accretionary, it can be reductive, or it can have involved not a change in bulk, but in the composition or surface characteristics of the substrate. Stating that there is a change in colour with time without saying what caused it, or without quantifying that change and calibrating it with reference to time, is of little consequence to the matter at hand. In a very general sense, rock patinae can conveniently be divided into those involving the deposition of extraneous matter and endogenous alteration products (although some forms, such as the oxalate patina on marble statues, might be attributable to a combination of local and introduced substances; Del Monte and Sabbioni 1987; Lazzarini and Salvadori 1989). However, the form of patination most frequently encountered in the study of petroglyphs consists primarily of iron compounds, and it is the only one considered here. It presents itself as the ubiquitous dark-brown coating of rock surfaces, found particularly in arid and semi-arid regions around the world. In all cases I have analysed it is not the product of just one process, it combines the results of various factors and may incorporate exogenous and endogenous components. Archaeologists frequently assume this to be either an oxidation product or a rock varnish. The latter term should be limited to a very thin (<0.5 mm), often shiny ferromanganous skin that covers even rocks entirely free of its contributing cations (Engel and Sharp 1958), and in whose laminar, stratified deposition microorganisms are implicated (Scheffer et al. 1963). Other deposits of similar composition and appearance occur commonly and should be more properly described as *dunkle Rinden* (Walther 1891).

Microscopic examination of brown-patinated non-varnish surfaces usually presents evidence of a variety of processes (Bednarik 2001). A surprisingly large component is of aeolian nature, especially on felsic facies. Crusts of the *dunkle Rinden*-type comprise of several iron compounds that are subjected to progressive and probably ongoing modification, both morphologically and chemically. Being the most stable form of Fe_2O_3 , haematite content tends to proportionally increase with time, even though it can be reduced to magnetite by high temperature. Its degree of agglomeration or particle size determines its colour — the larger the particles the redder the otherwise brown deposit — but saline solutions also influence the production of red haematite. While the colour of such patinae is thus determined by the combination and state primarily of iron salts, e.g.

through the taphonomy favouring haematite, other cations are also present, particularly manganese, and these crusts tend to incorporate significant clays and aeolian detritus. I have observed quartz, tourmaline and other crystal grains, plant matter and even charcoal fragments in these accretions, caked together most often by iron compounds and amorphous silica. They are subjected to continuous modification by rainwater, which may favour the formation of distinctively 'laced' or 'terraced', reticulate micro-morphologies (Bednarik 2007: Fig. 21). However, despite their macroscopically homogenous appearance, such extraneous deposits are usually quite discontinuous at magnified view, so that at the microscopic level exposed surface can be found on all but the very oldest petroglyphs. Their thickness can vary greatly at that level.

Despite their rather complex microscopic compositions, in the macroscopic sense these deposits appear relatively uniform and it has long been assumed that they seem to form fairly consistently as a function of time. Directional aspect, while being of significance microscopically (both in water-caused migratory precipitation patterns and in the influence of aeolian deposition characteristics), has little macroscopic effect. Comparisons of regional differences show that the ambient pH regime is a principal influence, both in the deposition and the stability through time of these formations. Certainly they are lacking in regions of acid rain (pH 5.6 or lower), or if they did formerly exist in areas now subject to such conditions, they have been mobilised by hydrolysis. Stable deposits of *dunkle Rinden* or rock varnish are limited to regions with an average ambient precipitation pH ≥ 6.8 .

This paper reports an attempt to test field observations made for centuries, suggesting that anecdotal evidence implying that such patinae accumulate at locally consistent rates may have some validity. About 180 years after Belzoni's pioneering observation, the author attempted to address his question with observations on rock almost identical to that referred to by Belzoni (coarse granite), in a region of very similar climate, the Australian Pilbara (dry, subtropical). He determined from surfaces of historically known ages that an incipient but very discontinuous ferromanganous film becomes evident after a fresh surface has been exposed for 30–40 years. After about 100 years, the deposit reaches a thickness locally of 30–50 μm , or 100–150 μm after 230 years (Bednarik 2002a). It can, however, remain microscopically discontinuous for many millennia, especially on felsic rocks.

Colorimetric analysis

The phenomenon we describe as 'patina' thus needs to be seen as often comprising both extraneous and intrinsic products, and their complex interplay and ongoing modification regimes seem to imply that these phenomena are difficult to assess quantitatively. There are other significant difficulties with using patination and weathering states in estimating ages

of petroglyphs, or in quantifying patina changes for other purposes. To begin with, both weathering and patination processes are variable, depending on petrography, climate, micro-topography, surface geometry, orientation, chemical environment and other factors (Bednarik 1979). Repatination can be affected by numerous factors besides the underlying lithology, among them water presence, epilithic organisms, coarseness of surface texture, and the proximity of cation sources, such as sediments or nearby accretions.

Secondly, there is no simplistic method of quantifying such changes, and attempts to quantify colorimetric indices in rock art research (e.g. by measuring reflective properties of accretionary deposits such as rock varnish or paint residues of pictograms) have not been pursued with much persistence. A notable exception is the work by Mirmehdi et al. (2001), whose pilot study of monitoring and modelling paint residues were conducted in a cave environment. This neglect is in spite of the obvious importance of such work to the dating as well as preservation of rock art. Lambert (1995) describes the use of a chroma meter to measure reflective colours of rock paintings for the purpose of monitoring pigment changes. The same equipment could be used to measure colour properties of petroglyph patinae, but there are several practical problems, as shown by the study of Lau et al. (2007: 57–71). The need to make contact with the rock art is itself unwelcome, especially in the case of fragile pictograms. In using this instrument, a circular perspex baffle with a small opening through which a light dose is fired is rested against the rock surface.

The difficulties with the portable spectrophotometer used by Lau et al. (2007), a BYK-Gardner model 45/0 (Bednarik 2004: 6), are well demonstrated in their report. The instrument (Fig. 1) is not precise above a temperature of 35°C or a relative humidity of 85%, yet both conditions apply most of the time at the sites concerned, in the Dampier Archipelago of Western Australia. Because rock surfaces are usually not flat, the analysts had to try excluding natural daylight, which introduces further potential distortion. It is difficult to safeguard against such contamination, and



Figure 1. The BYK-Gardner model 45/0 portable spectrophotometer used in the study by Lau et al. (2007).

the procedure does not detect it or permit compensation for such distortion. Also, the instrument operates at spectral intervals (20 nm) across a limited spectrum (400–700 nm); i.e. it does not even cover the full range of visible light. But most importantly, its use requires that precisely the same tiny sampling site be re-measured every time, within one millimetre. Yet the baffle surrounding the tool's aperture measures about 12 cm, and it therefore conceals the sampling site during use. It is virtually impossible to have any confidence in the operator's ability to sample precisely the same micro-site many months (or years) after the previous visit. Lau et al. (2007) are silent on this crucial point, and in a release before commencing the project they had indicated that they would use digital photography to re-find sampling sites. It is highly likely that they failed in this, and their results show a complete lack of consistency, being essentially random numbers. It can be reasonably assumed that this is due mainly to the lack of repeatability of their experiments. Their study confirms that the most important factor in long-term colorimetric studies (colorimetry is related to chromatography and spectroscopy) of rock art is the confidence of re-finding precise sampling sites, within a tolerance of well under a hundred microns. Any method that cannot guarantee this has no relevance.

Electronic optical colorimetry as used by Lambert (1995) involves a combination of a spectrometer (e.g. Tristan UV/VIS, 250–850 nm), a standard light source, a reception adaptor from the sample to the spectrometer, dedicated proprietary colorimetric software and a portable computer. This arrangement has to be individually adapted to each and every application, which is far from convenient in the field. Typically such a system can make measurements according to these standards: CIE groups $L^*/a^*/b^*/dL^*/da^*/db^*/dE$ / White, FMC 2, CMC i:l, Hunter-Lab and DIN Yxy / DIN Luv / DIN LCh. In taking measurements, a dark current and a reference or calibration reading are necessary first to determine the standard colour. These values can be stored to file. Measurements are then secured from the production targets. The deviation between the sample and the reference is displayed. Limits for deviation can be pre-set by making a test series. All standards are based on algorithms, which consider the performance of the human eye and are correspondingly complex.

As noted above, the ferromanganous crusts that we are largely concerned with here are far from homogenous. They exhibit variations in visual as well as other properties (morphological and chemical) at the micro-level, and what is perceived as the colour of a petroglyph is in reality an agglomerate of many colours, even at the sub-millimetre scale. Therefore one would invariably obtain colorimetric readings that merely reflect random averages. But more importantly, the conditions of many relevant projects very probably demand extensive reference to earlier photographic records. This applies particularly to

projects trying to determine long-term changes to rock art or rock patination, as are required for conservation studies (cf. Bednarik 2002b), and they are one of the most important applications of colorimetry. In such circumstances a method is needed that can readily combine measurements from old or pre-existing photographic records with either new photographs, or with digital colorimetric field measurements taken now (Bednarik 2002b). In such research it is necessary to calibrate the photographs against a known standard before they can be subjected to analysis (Bednarik and Seshadri 1995). For that reason alone it is preferable to conduct this work by digital photography rather than direct measurement of reflected light. Moreover, typical rock art fieldwork often occurs in very remote locations, therefore simplicity, portability and compactness of equipment are of utmost importance, and field dependence on sensitive technology should be minimised. Besides, digital cameras and colour calibration devices have already become standard equipment in all rock art research, inevitably taken to the field by any researcher, so their use in colorimetry involves no need for additional field equipment and the considerable associated costs. Other reasons for this preference include the avoidance of physical contact, which is always preferable in rock art-related analytical work, the greater flexibility, and, most of all, the potentially greater precision.

There is only one significant source of imprecision, and it can easily be eliminated. Reflectance glare, be it from the target surface or from the calibration profile device (the colour scale used), will distort the colour correction process and must be avoided. This will be encountered either from shiny, reflective rock surfaces, such as rock varnish, or, more commonly, as glare from the colour scale. Both effects can be avoided, either by shading the target area or by careful angling of the scale to avoid direct reflection of the light source into the camera lens.

Nevertheless, these considerations prompt a decisive preference for the method the author has introduced to quantify the distinctive differences in repatination colour he found in a series of engraved dates. In 2000 he rediscovered a concentration of several dozen engraved names, initials and year numbers among one of the largest petroglyph occurrences in the world, that of the eastern Pilbara (Bednarik 2002a, 2002c). In some cases the surfaces of selected large boulders were extensively covered with such historical inscriptions (Fig. 2). The dates ranged from 1771 (Bednarik 2000) to 1997. Some of them yielded a series of microerosion results that form the basis of the only microerosion calibration curve so far established in Australia (Bednarik 2001, 2002a). In examining the colour gradations among these many dates pounded into deeply patinated boulders, a distinct trend was observed in the repatination products, rendered visually obvious by the distinctive change in colour with increasing age. This is particularly well illustrated



Figure 2. Historical inscriptions and dates adjacent to the peak of Spear Hill petroglyph site 7, eastern Pilbara, Western Australia.

in one inscription from Spear Hill site 7 (Fig. 3), which was created in three temporally separated acts but apparently by one person (Fig. 4 and back cover). The name 'O. Findlay' and the number '1940' bear identical light-brown patination, as do the impact marks below and to the left. The two very recent additions and the impact marks under the number '93' are almost free of patination, even under the microscope. Nevertheless, there is a practically imperceptible difference in weathering even between the '+ 93' and the '+ 98' inscriptions, not detectable by human vision (whose efficiency is entirely limited by the actinic effects of the retinal system), but discernible by colorimetry (the accuracy of which is several times greater, and could be increased further; Bednarik and Seshadri 1995). Not only does this confirm that the whole arrangement is indeed the result of three discrete events in time, it also illustrates the superior precision of digital colorimetry

as an analytical method. A sequential marking such as this inscription is of great value to this study, as is the direct superimposition of the number '1917' over a much earlier anthropomorphous petroglyph at nearby Spear Hill site 9 (Bednarik 2002c).

In an effort to better understand the repatination process, many of the inscriptions in the spear Hill region were studied microscopically, observing the progressive formation of the complex crusts under a binocular microscope. Recalling Belzoni's (1820) idea of quantifying variations in the degree of repatination, the author considered the possibility of sampling and measuring 'bulk colour' (the average reflective properties of a series of given sampling areas of under one square millimetre size) and then plotting the results in a graph. The initial purpose was simply to see how this variable might behave as a function



Figure 3. Spear Hill site 7, eastern Pilbara, Western Australia, seen from the east.

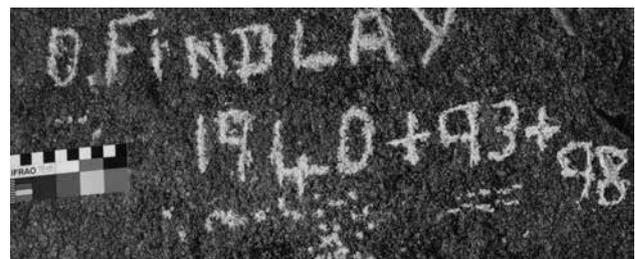


Figure 4. Engraved name and three consecutive dates, showing distinctive colour change over time, at petroglyph site Spear Hill 7. For colour version, see back cover of this issue.

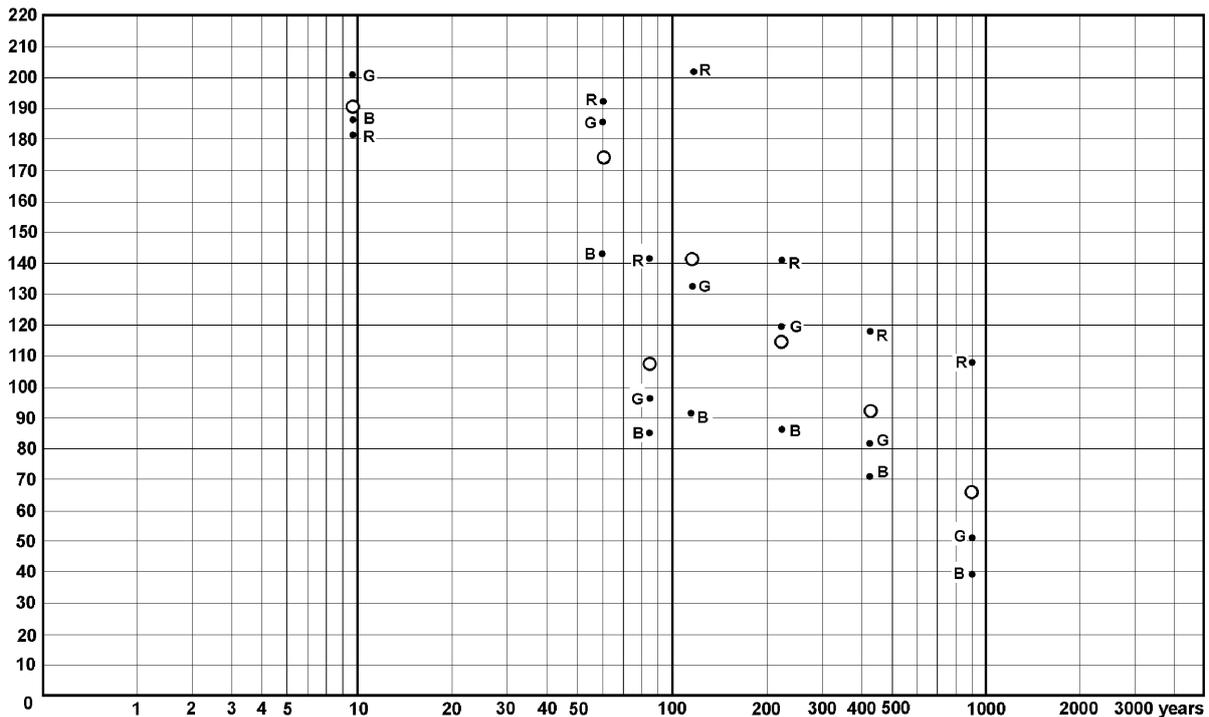


Figure 5. Summarised colorimetric data from five engraved dates at and near the Spear Hill rock art complex, and two recent petroglyphs dated by microerosion analysis, showing their respective RGB values and their means (circles) as a function of age.

of time, which in the case of dated inscriptions it was possible to account for reliably. In the absence of any similar previous work it was resolved to experimentally convert the visual data to digital format for easier handling and quantification. This had the dual benefits of reducing the fieldwork to simple digital photography with a calibration device, and of facilitating colour re-constitution for better precision.

Experimental colorimetric study

At this stage in the development of rock art research it seemed appropriate to pursue experimental assessment of colour analysis, and to determine whether such approaches are or are not likely to yield useful or expedient results. The rationale of this work should initially be directed towards the establishment of appropriate methods and standardisation. Once it had been determined that a digital approach would be used, the next step was to decide appropriate aliquot sizes, aliquot shapes and sample numbers for a comprehensive but not unnecessarily unwieldy procedure. Bearing in mind that there is as yet no dedicated software for processing sample matrices for this kind of analysis, all sample processing had to be done manually in this pilot study. An unnecessarily large aliquot size would exponentially increase the amount of work, without a corresponding improvement in precision. In view of the highly preliminary format of this experimentation the most modest sample sizes promising to suffice for the preliminary identification of trends were opted for.

Trials suggested that thirty-six pixels was the smallest aliquot size offering reasonably representative data from the often quite variable repatination colours at the resolution range used (300–600 dpi), and for ease of handling a square sampling area was preferred over a circular one. Digital photographs were first colour corrected as described previously, using the IFRAO Standard Scale as the reference device and Adobe Photoshop software for colour management (Bednarik and Seshadri 1995). They were then carefully examined to establish the type and range of colour variation present within the pounded areas. In selecting suitable sampling sites any visually obvious patches of dense precipitates from saturated solution, especially iron salts, were avoided, and the most typical and homogenous areas of patina were selected. Test readings were taken in various parts of the target area to establish the broad ranges present. Typically three areas (considered the smallest number to most economically express variability) of smallest variation located in the lighter range of the spectrum were then selected and marked with surrounds of one pixel width. The RGB values of each pixel in each aliquot were determined and tabulated, and in some cases the repeatability of selected readings was ascertained by blind testing.

The mean values were then determined from the resulting matrices and they are plotted in Figure 5, together with the RGB means. As there are seven targets being considered, this figure summarises a total of 756 individual, manually acquired colour

determinations. The targets consisted of five engraved dates, supplemented by two older petroglyphs that had earlier been subjected to microerosion analysis (Bednarik 2002a, 2002c). The purpose of this experiment was to determine whether any trend could be detected in the results.

In Figure 5 the seven samples are arranged by age (in logarithmic fashion, to facilitate depiction on the page), beginning from the left with the youngest. This is from the '+93' marking seen in Figure 4, which is presumed to date from 1993 (located at the peak of Spear Hill site 7, near Pilga Station). Next is the number '1940' from the same inscription. Its readily detectable repatination confirms that an age of about sixty years is realistic. Then follows the number '1917' inscribed at Spear Hill site 9 (about 1 km east of site 7), which was found to be significantly darker (Fig. 6). The lighter inscription '1881' from Spear Hill site 7, western slope, exhibits widely spaced RGB values. Next in age is the number '1771', which forms part of an inscription in the Woodstock – Abydos area some distance to the west. It was included here experimentally because the question of its true antiquity remains untested. Also, it occurs on a basaltic dolerite facies, whereas all other rock markings considered here are on granite (a biotite adamellite of remobilised older granites) and this might conceivably affect repatination processes.

Finally, on the right of Figure 5 are two determinations obtained from clearly older Spear Hill petroglyphs whose approximate age has recently been estimated on the basis of microerosion analyses (Bednarik 2002a, 2002c). Whereas the first five targets could be said to probably represent calendar dates, it may be questioned that samples from targets relying on age estimates are included in this experiment. However, as these are relatively low ages (significantly greater age estimates were obtained from the area's rock art) it is unlikely that they would be substantially wrong. It was considered interesting to obtain an indication of how the trend continues beyond the range historically available in Australia.

There are only indistinct trends evident in Figure 5, reflecting the already visually obvious drift in the targets towards darker chroma as a function of increasing age. The consistent sequence in most samples from the top of R-G-B is only negated by the youngest sample. This is clearly a reflection of the lack of repatination, as are the tightly packed individual determinations in that sample. However, it is when the RGB values are omitted and only their means plotted that a distinctive trend becomes evident at once (Fig. 7). While it could be argued that considering only the mean values ignores what colour data they represent, this would be an invalid objection, because whichever of the colour variables (hue, value or chroma) changed



Figure 6. Anthropomorph with superimposed inscription. The anthropomorph is in the order of 900 years old, based on micro-wanes.

with age, any change would be proportionally reflected in the aggregate value. If it were not for the sample thought to be from 1917, the trend shown by the other six targets would be almost geometrically perfect. There are several potential explanations for this one apparently aberrant result (the most obvious being that the date is false), but until we understand the underlying issues better, it is best to just note the divergence and not try to interpret it. Having undertaken this experiment purely to see what might develop, without any preconceived construct of what the outcome might be, the author (see his scepticism expressed in Bednarik 2001: 118) confesses that he was surprised when he plotted these values on graph paper. He resolved that this is either a monumental

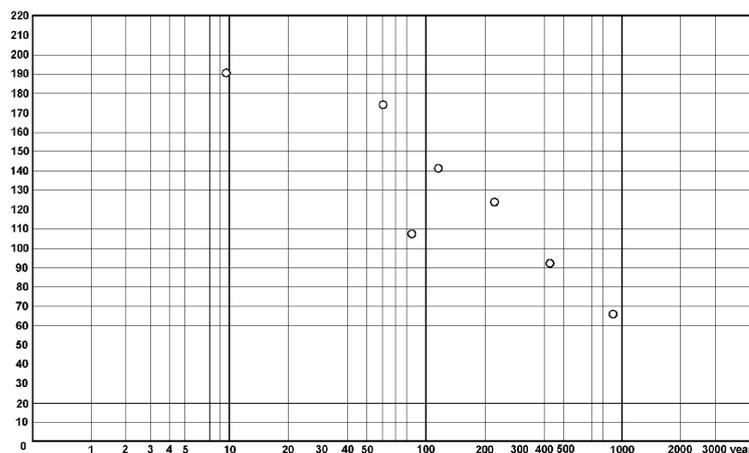


Figure 7. The mean RGB values of the seven target samples from the Spear Hill area, showing a distinct trend with age increasing from left to right.



Figure 8. Central part of the main panel at Ta'ar, Jabal al Kawbab near Himā, southern Saudi Arabia. The central anthropomorph, above the scale, is the motif subjected to both microerosion analysis and colorimetry. The three microerosion sampling points are marked.

fluke of an unbelievably low probability, or the colorimetry of repatinated petroglyphs is indeed a useful analytical method in rock art science.

Other applications of colorimetry

Since these experiments, the author has provided results of two more colorimetric projects. One addressed the range of colours found in a series of sixteen ochre markings in Mladeč Cave, near Olomouc, Czech Republic, which had been proposed to be of Palaeolithic age. This first application of the method to pictograms suggested that the colour variations among four demonstrably recent (late 19th century) markings as well as among the twelve purported Palaeolithic markings exceeded the differences between the two groups (Bednarik 2006). This confirms the several other indicators that all these pictograms were made recently, and the observed minor variations in colour are probably attributable to the effects of moisture.

Of more relevance in the present context is work conducted at the petroglyph site Najd Sahī, at Jabal al Kawbab near Himā, Najran region, Saudi Arabia (Bednarik and Khan 2002, 2005, 2009). One of the most obvious features on a major vertical panel bearing numerous petroglyphs is that an anthropomorph, one of Anati's (1968) 'oval-headed' figures, is clearly among the most recent motifs present. It is not much more repatinated than the several bullet hole craters that we know were not present on 14 January 1952, when the panel was photographed by G. Ryckmans. Five rock surfaces on this panel were selected for sampling: the very recent anthropomorph, one of the bullet impact marks, a semi-naturalistic 'ostrich' motif, a Thamudic letter on its body and possibly associated with it, and one other anthropomorph that seemed

marginally earlier than the last mentioned two motifs (Bednarik and Khan 2005: Figs 36, 37 and 39, Table 2). (In retrospect, a null-patination value should have been determined, preferably by scraping a small area in the bullet hole included in the study.)

To gain better chronological depth for the colorimetric data, two repatinated petroglyph surfaces of known ages at two nearby rock art sites, Ta'ar and Jabal A'an (or Ain Jamal), were included. An early Islamic four-line inscription at the latter site (Bednarik and Khan 2005: Figs 30 and 31) is epigraphically datable to between 650 and 700 C.E. Three large quartz grains of the sandstone, fractured during the production of the inscription, provided a microerosion calibration value for the Najran area (Bednarik and Khan 2005: Fig. 32). At Ta'ar, one of several prominent anthropomorphs (Fig. 8) also yielded microerosion measurements from micro-

wanans at three sampling points, providing an age estimate of $E2109 + 245/ -534$ years BP. Similar petrography, orientation and exposure at these sites are assumed to have resulted in very similar repatination rates to those at Najd Sahī, therefore these two dated surfaces were experimentally included in a tentative colorimetric curve plotted against time.

The result of this exploratory exercise are summarised in Figure 9, in which the results from the Pilbara sites are compared with those from Saudi Arabia. It is at once clear that the two curves differ significantly, indicating that the repatination process occurs slower in the Arabian desert, as evident from the trend marked in light-grey. While it needs to be emphasised that this is an experimental exercise, it is based on empirical data, and it seems to rather broadly confirm Anati's chronological observation cited in the Introduction. It is possible that the more rapid repatination regime of the Western Australian Pilbara region is related to the ample availability of cations, especially iron, from the ambient geological environment. Practically all air-borne particulate matter there is rich in iron, which seems much less prominent in the Middle East.

Discussion

Before excessive confidence is expressed in these results, some of the qualifying considerations need to be briefly canvassed. For instance, one of the Spear Hill readings does not comply with the general trend. There are several potential explanations for this, but most are readily countered. For instance the engraved date may be simply false, but this is highly unlikely, because if it were located in the trend's curve its age would be too great to be plausible historically. Similarly, it is hard to see how there could have been sufficient differences in contributing variables

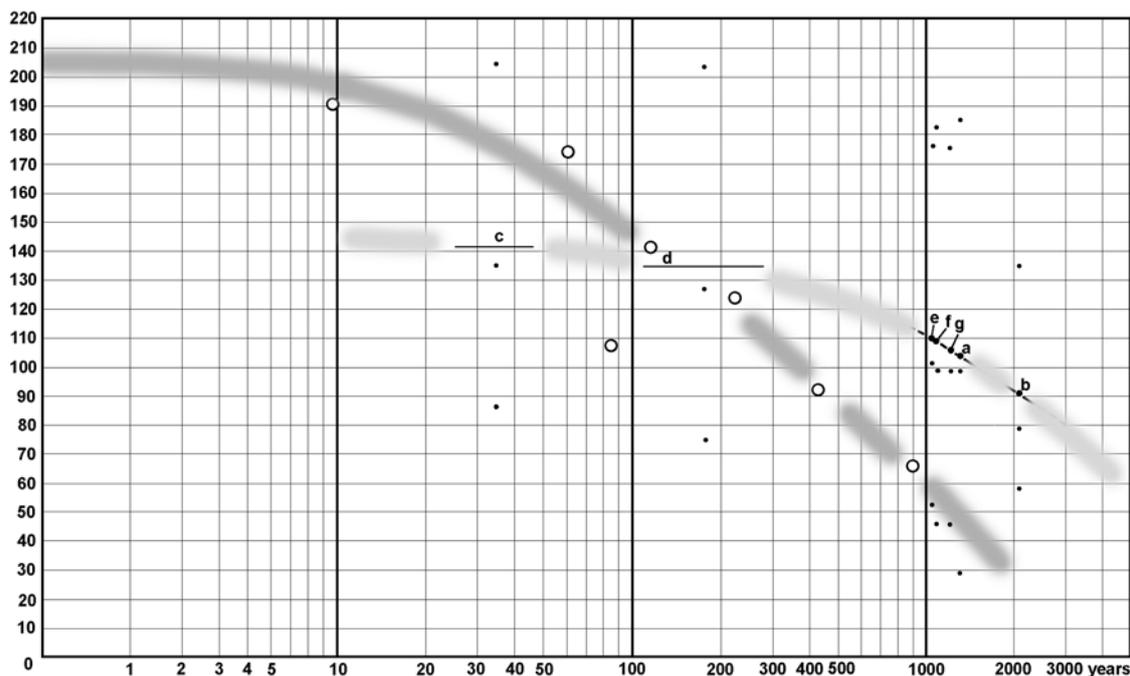


Figure 9. Composite of the colorimetric results from the three Spear Hill sites, shown in the trend indicated in dark-grey, and from the three Jawal Kawbab sites in light-grey. The motifs from the Arabian sites are, from left: c – bullet impact, d – recent anthropomorph, e – ‘ostrich’, f – Thamudic letter, g – large anthropomorph (all Najd Sahī; a – inscription at Jabal A’an, b – anthropomorph at Ta’ar. The respective RGB values of the Arabian samples are indicated by small dots.

(exposure, orientation etc.), although the ambient chemical environment, for instance, could potentially explain the apparent discrepancy. There are other counterpoints that could be raised, and at this early stage in the development of this methodology it is perhaps prudent to remember that the work reported here is experimental and needs to be augmented through much more intensive research.

In keeping with the preliminary and provisional nature of these trials, one should therefore abstain from incorporating these results in the kinds of hypothetical scenarios that would facilitate their over-interpretation. They are merely presented here to encourage analytical explorations in this promising direction. It is self-evident that this work has implications for estimating the antiquity of patinated petroglyphs (Bednarik 2002a, 2002c), and this issue will be pursued in due course. There are, however, more immediately practical applications of this implied methodology, especially in rock art conservation. Such applications had been anticipated in the establishment of a colour calibration device and of colour reconstitution (Bednarik and Seshadri 1995). Indeed, this has already led to the first practical use of colorimetry in quantifying deterioration of similar mineral crusts (Bednarik 2002b), which offers a valuable tool to the rock art conservator. This application of colorimetry is certainly not experimental; it provides solid empirical evidence, and as is evident from the above, it is within the means of any rock art researcher to use.

However, the following points also need to be considered. This experiment was not concerned with precision or practical applicability, but with exploring the methodology and with finding means of defining the parameters that would be essential for developing it into a standard method. Now that it has been demonstrated that this is a useful research tool, the next step is crucial, and needs to be taken before this tool becomes corrupted by misuse. This next step is to refine the method in every possible respect, to subject it to testing procedures, and to determine protocols appropriate for its routine use. This includes the need to review the questions of aliquot size, of sample size (to determine statistically optimal conditions), of the most effective field procedures, and particularly of standardising and greatly streamlining the data processing of colour determinations. Existing proprietary software may be adapted for this purpose, replacing the otherwise very laborious procedure. Indeed, it is perfectly feasible to create software, as a plug-in for colour management programs, that instantly yields readings of pre-set aliquots by simply pointing a sampler at the centres of chosen targets. That same software could be programmed to perform the required calculations automatically. Such a tool would be a great help in making this method *significantly* user-friendlier. The procedures used in the prototype studies reported here were so cumbersome that this factor alone would deter most potential users.

It follows from this that better and simpler procedures will hopefully be developed in due course. They may differ from the described pilot projects; they should be more precise and more amenable to standardisation. For instance it may be determined that trends in hue, value and/or chroma provide more representative data than mean RGB values. What has been described here is embryonic and preliminary. Belzoni's (1820) idea of quantifying patination variations in petroglyphs has certainly been shared by many rock art researchers since, but no sustained attempt had so far been made to test it. To some degree this reflects the general state of the art of petroglyph age estimation: after lengthy neglect of this field of research it is at last being taken seriously. Nevertheless, due to 'ideological' currents in the discipline, the question of rock art 'dating' still remains in its infancy (Bednarik 2002d). Catching up with the rest of science will require decades of effort, and the work reported here is just one very small increment in this process. It resembles the task of rock art science in catching up with fields such as forensic science, a field rock art research is closely related to.

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Final MS received 17 October 2008.

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