THE POTENTIAL OF ROCK PATINATION ANALYSIS IN AUSTRALIAN ARCHAEOLOGY – PART 1

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PATINATION AND AUSTRALIAN PETROGYPHS

More than 150 years have passed since Belzoni (1820: 360-361) investigated the numerous petroglyphs on the granite of a Nile cataract and noted the varying tinges of patination. He observed that the unworked rock surface was evenly dark brown, whilst the engraved designs displayed several shades of light brown and seemed to be of differing ages. The possibility of calculating these ages occurred to Belzoni. His speculations are concluded with this comment:

> 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.

The subsequent one and a half centuries have seen the emergence of prehistory as a discipline and its ascent to become a highly sophisticated sphere that draws considerably on other fields. The progress in the direction foreseen by Belzoni has been somewhat sporadic by comparison.

Australian writers have shown little enthusiasm for the concept of using patination as a dating criterion; they remain apprehensive because of the many variables capable of influencing patination processes (e.g. Wright 1968). The question of Australian engraving's [1] antiquity has been surrounded by controversy since at least the days of Basedow (1914).

The scarcity of direct correlation of rock art with dated archaeological evidence (Mulvaney 1975: 188, Stockton 1971: 57) is by no means limited to Australia, it is a worldwide phenomenon as much as are petroglyphs themselves. Direct dating of palaeolithic engravings, by means of their clear association with occupational layers has been possible only in a few cases in Europe: Daleau succeeded at Pair-non-Pair in 1896, after 14 years of investigation, and Amboulange did so 8 years later at the La Gréze Cave. Other instances are the Abbé Lemozi's reindeer from Sainte-Eulalie, and the Aurignacian petroglyphs of the Gargas Cave. However, these were particularly fortunate finds and in general it has been only through much perserverance that overseas workers have been able to allocate chronological lables to much of the Old World's rock art,

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despite initial discouragements. Vaufrey attempted to correlate rock pictures with portable material culture in the Atlas Mountains but his results and those of similar endeavours by various others remained problematic. Rhotert (1938) succeeded in distinguishing three main phases of engraving at Kilwa (Near East) and later made extensive use of patina analysis in his work in (Rhotert 1952). Mori (1965) successfully utilized patination to assist in estabilishing a chronology of Saharan petroglyphs. Goodwin's (1960) study will be reviewed in some detail later. Finally, the accomplishments of Vaufrey's pupil, Anati, in the Val Camonica of Northern Italy (Anati 1960, 1961), the Negev Deserst (Anati 1963) and his less widely known work in Central Arabia (Anati 1968) would all have been impossible without patination studies.

Anati's Negev study is particularly relevant to Australia in that it surveys a region comparable climatically to much of this country. It is also one of the very few overseas investigations of this subject to ever have been quoted by an Australian prehistorian, and even the fact that Anati was misrendered by Edwards (1971: 361) fails to fully diminish the value of this citation. According to Edwards,

> ... 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 2,500 years for a thin, initial surface patination to form in that region.

This passage, to my knowledge one of the only two definite numerical statements on the antiquity of patinae so far published in Australia other than minimum ages derived from radio carbon dating, is a virtual reversal of Anati's (1963: 189) observation:

> In this region we know of no engraved surface from Style IV-B (Iron Age) to Style VII (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 2,500 years to reach an "O" shade, the natural color of patina on the surface of the rock.

Conversely, a similar error has occurred before; Mori (1974: 89-90) has had to restract a statement on patina color (Mori 1965: 63) and substitute "quasi scura quanto" for "tanto scura quanto".

In view of the paucity of detailed research on the antiquity of Australian petroglyphs, and on their cultural association, it seems appropriate to afford this subject maximum space here. Some elementary considerations: a petroglyph cannot predate human occupation of a given region, it is contemporary with the object depicted, and the portrayal of a now extinct animal species (Wright 1968, 1972) must predate its demise. Not only would a petroglyph have to precede any patina that may have formed in the engraved incisions, if these are intersected by a later fracture (such posteriority in time can usually be determined) the patina within the crack will be younger than the petroglyph (Bednarik 1977a: 55). The resulting face may later have been fractured itself, and so forth, and with each such occurrence progressively younger surfaces will be fored and exposed to patination processes. Multi-faceted boulders with greatly varying degrees of patination will be the result. Many engravings are found on rock types which have a tendency to be reduced to such boulders and I have observed instances where engravings occur on several of the facets of such a specimen.

Before we elaborate further on this subject it is advisable to consider the agents capable of fragmenting the inciseed rock. Edwards (1971: 360) suggests "frost action" as a possible factor. In his view, "the resulting cracks allow moisture and dust to penetrate the rock, gradually prising it apart." What Edwards probably has in mind is macrogélivation succeeded by Ollier's (1969) [2] "dirt cracking" but before the demolition of engraved rock pavements is accepted to be a result of congelifraction it should be remembered that this process does not account for the formation of new fissures, it can only be effective where these already exist. If they are less than a few tenths of a millimetre wide, even temperatures as low as -20 degrees celcius will not induce the water to relinquish its liquid state. On the other hand if the openings exceed a few millimetres and are well connected to the surface, frost shattering will not be effective because the expansion attendant on the crystallizing of the ice will force water out rather than exert great pressure on the rock. Some writers suggest rock fatigue reslting from the compression of air sealed off in voids by the ice to be a factor in congelifraction (Tricart 1969), and Schmid (1958) prefers to see relegation as the prime cause for the development of cryoclastics.

In the absence of a permafrost horizon it is unlikely that a pavement of massive rock would suffer any significant frost fracture. The freeze - thaw cycles of small amplitude likely to have been experienced in Australia's recent geological past could have only caused microgélifraction (Tricart 1956, Birot 1960) which affects mainly porous rocks and those of little mechanical strength such as schists and certain limestones whilst it is of little consequence in massive crystalline rocks such as granites or marble.[3] Most Australian petroglyphs, however, have not be graved on a rock of a porosity and structure conducive to frost action and the rock's mode of disintegration does not suggest such a process. Conversely, evidence of cryoturbation seems lacking at known archaelogical deposits in Australia, and angular clastics need not indicate frost action at all.

Some scepticism would also seem tenable as to the ability of dust and water to prise apart rocks. Mineral dust is chemically fairly stable, consisting chiefly of silicate. Water will, however, induce chemical weathering processes most of which involve an increase in bulk within the zone affected and which are prolonged by the geomorphologically sigificant ability of cracks to retain dampness for much longer than the rock's surface.

At the present time it is not possible to provide an explanation shedding light on all elements involved on the formation of these fissures. Some aspects are fairly self evident, such as at the main gallery at Mootwingee (Western New South Wales) where a sandstone layer bearing a rich array of petroglyphs is breaking up slowly. Here, the cement of the underlying sandsstone stratum is chemically unstable, its gypsum content subjected to hydration and hydrolysis, and the consequent leaching has facilitated the establishment of a network of stress or expansion cracks. Mass exfoliation of the engraved rock lamina is the result.

Just as the range of Australian petroglyph-bearing minerals encompasses a great variety (including limestone, sandstone, quartzite, schist, slate, basalts, granites, gabbro and dolerite) diversity is also plausible for their modes of disintegration, which in most instances are far from being as readily interpretable as in the Mootwingee example. Still controversial, yet enticing, is the role played by thermal expansion and contraction of rock boulders or slabs. The ability of insolation to effect extensive physical weathering has been questioned repeatedly since Blackwelder (1933) queried its potency. In his much-quoted paper, he drew attention to the largely untested nature of this hypothesis and to the lack of objective proof in its favour. He recommended that insolation be seen as a "possible factor in the mechanical weathering of rocks but one the importance, and even the validity, of which yet remains to be determined." His paper was followed by further experimental work (Griggs 1936).

Whilst the subsequent tendency, which prevailed until recent decades, to view the term insolation as not quite respectable, may be a credit to Blackwelder's authority, it was in my opinion an unwarranted overreaction not invited by the author. His paper in fact suggests a potential explanation for the process by considering the buckling of marble slabs reported by Kessler (1919) and others. Ollier (1969) reminds us that the diurnal temperature range can be considerably greater on a rock surface than of the air temperature. He also questions the relevance of the experiments attempting to simulate natural conditions and describes a number of observations at Mt. Olga, Central Australia, that appear to lend considerable support to the insolation theory (Ollier 1963). Goodwin (1960) certainly does not hesitate to described subspherical boulders in the Karroo of Southern Africa as the result chiefly of insolation, and to some degree lightning.

The products of a process of rock spalling I have observed in North Western Australia warrant detailed description here, not only to further illuminate the insolation issue but also in preparation for my subsequent argument. Dominating the topography of the Dampier Archipelago are the often huge accumulations of dark brown weathered gabbro and granophyre detritus. Termed "boulder screes" by Virili (n.d.) these formations vaguely resemble glacial moraines and could be defined as _Felsenmeere_ provided climatic connotations inherent to this term are ignored.[4] Their barren appearance is a function of their inability to stabilize weathered matter, and the consequent lack of vegetation.

When freshly broken, the gabbro exhibits a blueish to greenish-grey bright color which remains unchanged for quite some years. The spalling of the boulders does not occur at random, it evidently strives to achieve a rounding of the angular blocks: acute edges and projecting portions are detached, invariably revealing a fracture surface of pronounced convexity. The spalls commonly bear one or more ridges on the outer face. Figure 1 is an idealized depiction of this spalling procedure. If continued it will result in a boulder

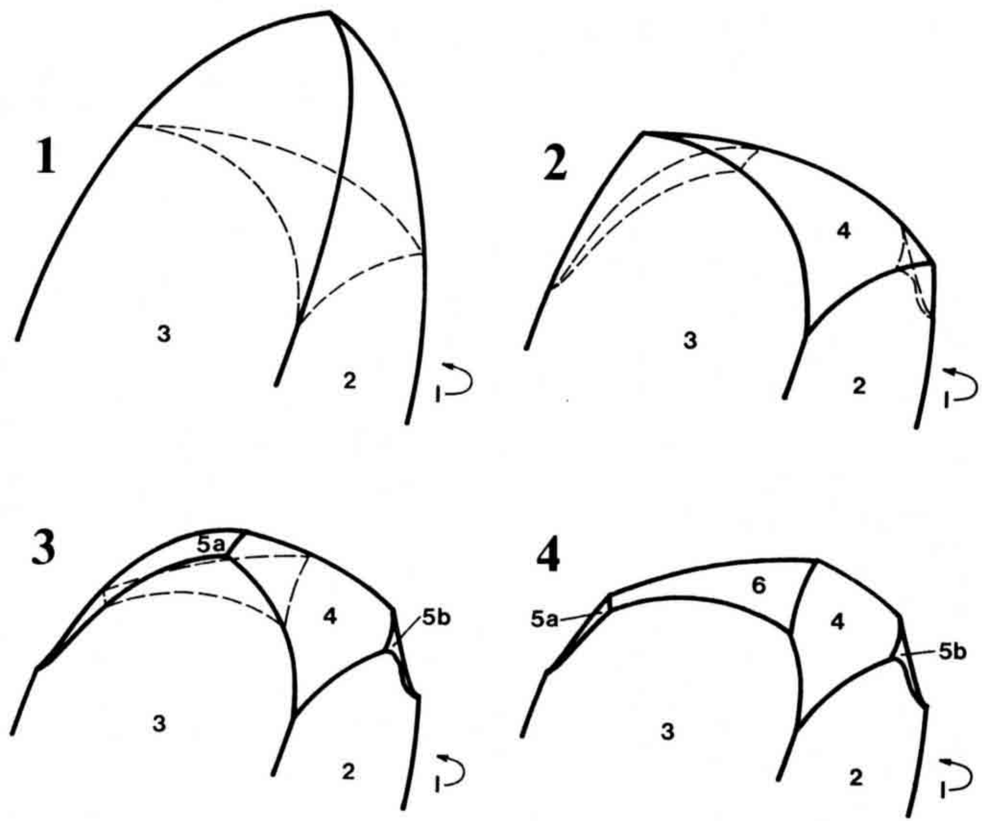


FIG. I

completely bereft of angularity until it falls victim to Kernsprung, enabling the cycle to commence anew.

The fractures do not usually trace existing faults such as unloading or exfoliation planes and are not pre-determined in any way other than by the rock's shape. Fresh fractures always cut clean through differing layers of patina, implying an instantaneous detachment. The number of potential causes is therefore quite limited and they are reviewed here:

1. Mechanical impact: despite the sometimes steep detrital slopes, a very low incidence is suggested by the stable nature of the formations. The bulk of the relatively fresh fractures investigated were neither found in a location where direct impact would be a tenable interpretation, nor were they impact fractures morphologically. Experiments by Laudermilk and Kennard (1938) have shown that rock fragments produced by mechanical shattering often showed a bulb of percussion or radiating lines (as on natural, or cultural, flint flakes). Finally, a boulder is much more likely to be struck at a protuberance of some type whereas the process considered here detaches such features intact.

2. The effects of lightning on rocks have been investigated by various workers, including Laudermilk and Kennard (1938) and Farmer (1939). Lightning spalling can be fairly readily identified and has evidently contributed to the Dampier material, particularly where it is located at an elevated site. Atmospheric electric discharges have a tendency to strike the highest point of a boulder and to produce radial spalls by inducing a "skinning effect". The area of impact will lack crushing but in some minerals surface glazing may result. The vast majority of the spalled rock I have observed at Dampier was, however, not produced by lightning.

3. The exfoliation effect of brush fires will produce a tendency towards the development of spheroid boulder shapes because the sudden exposure to heat detaches surface spalls not unlike those described here, but much thinner. Emery (1944) found that the thickest flakes were generally formed "at the sharpest corners", an observation relevant to the Dampier situation: since the detachment of ridges can be plausibly explained by temperature caused stress, brush fire would be an acceptable fissuring agent here. However, the present lack of vegetation can be safely assumed to have extended for some time into the past, yet the shattering process still continues.

4. Insolation: it would be quite impracticable in the present context to elaborate on the mechanics possibly involved, such as effects of varying expansion coefficients, amplified by anisotropic properties of component minerals, and, more importantly I believe, the influence of temperature absorption characteristics of irregularly shaped rocks. However, insolation would appear to be a logical explanation for the phenomena cited although it must not be seen as a proven fact in this instance.

In summary, the boulder spalling at Dampier is a process operating slowly but continually, resulting in facets of varying ages which can be assembled in a chronological order at a single site, by means of a detailed analysis of scar succession and study of the differing patinae.Where petroglyphs are present they can often be readily incorporated in such a sequence. sequence.

Many engraved galleries are in close proximity to occupational sites which may be stratified. The abundant middens of the Archipelago surely are (Lorblanchet 1977), and some of these deposits would inevitably contain boulder spalls. Since these can be expected to have remained very close to their point of origin it appears feasible to identify their source by re-assembling them. If a few of them could be dated by conventional methods, through their stratigraphical association with datable matter, the patina sequence, itself only a crude means of relative dating, would become valid dating criteria for the site in question. At the same time analysis of what Anati (1960) has termed "stratigraphical relationships of petroglyphs" would be greatly assisted.

The procedures and methods envisaged would most certainly be laborious, and may at first sight seem impracticable or farfetched. Yet in principle they are quite comparable to those employed successfully by overseas scholars. For example, the sequence developed for the 130,000 or so engravings of the Camonica Valley is a result of very exhaustive studies of patinae, superimpositions, chiseling techniques, frequency and relationships of designs, typology of implements illustrated and geographical distributions. Crucial was the "deciphering" of the Naquane Rock (Anati 1961) where 876 figures yielded 50 cases of superimposition, assisting eventually in the identification of five main phases.

Much of the Australian effort in this field is to the credit of one singular scholar. Not content with fathering the now universally accepted typological system of Australian stone implements, McCarthy also pioneered the study of superimpositions amongst the continent's petroglyphs and to this day no substantial further elaboration on his sequence has taken place.Later authors have confirmed its basic premises, but their work has not included sufficient detail to further develop upon, or to seriously challenge, McCartny's hypothesis (see McCarthy 1967 for bibliography).

One cautionary note on McCarthy's system is contained in the Western Australian Museum publication on Depuch Island, a paper that is of much pertinence here. Crawford's (1964) comments are most relevant and Trendall's (1964) contribution, Australia's sole detailed analysis of mineral patina in an archaelogical context, merits more than brief consideration in the present review.

Crawford interprets Trendall's data as correlating a fresh appearance of the engraving with a thin weathering crust, and weathered heavily patinated appearance with a thick weathering zone. This seems an over-simplification of complex relationships that does not do full justice to the significant work done by Crawford and colleagues. To demonstrate that various interpretations are tenable, I have graphically reproduced Trendall's findings (Fig. 2). Whilst it is true that the three samples of heavy engraving patination coincide

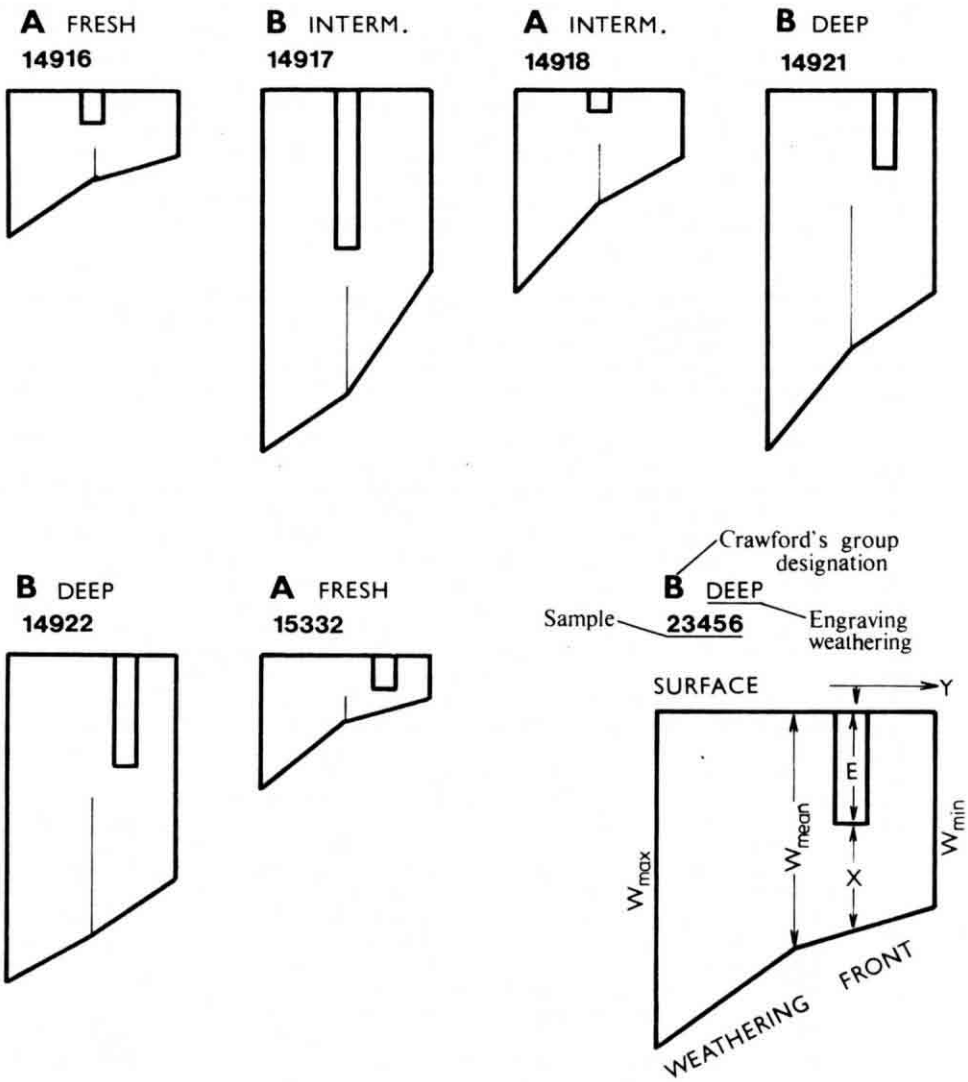

A FRESH
14916
B INTERM.
14917
A INTERM.
14918
B DEEP
14921
B DEEP
14922
A FRESH
15332
Crawford's group designation
B DEEP
Sample
23456
Engraving weathering
SURFACE
Y
E
X
W_{max}
W_{mean}
W_{min}
WEATHERING FRONT

FIG. 2

with those of deeply weathered rock they also correspond with the deeply engraved. Furthermore Fig. 2 readily demonstrates the concurrence of heavy engraving patination and greater distance between the engraved groove's bottom and the weathering front.[5] The last mentioned dimension steadily increases as a function of time, whilst it is probable that engraved groove depth decreases (although necessarily at a far slower rate), unless we postulate a complete absence of abrasive (aeolian) or other erosion. This argument introduces the possibility that of the oldest designs only the deeply engraved remain discernable, whilst those of shallow depth have become unintelligible (Bednarik 1977a: 56). Of course this is a purely hypothetical consideration, as it cannot be verified or refuted.

The main issue here, however, is the question: what factors control the formation of patina in the engraved groove? To be more specific, and leaving aside outside influences and those pertaining to the unaltered rock's composition: can the distance groove - weathering front influence the speed of patina reformation? Does the color of the new patina reflect its age reliably?

Believing to discern two clusters of weathering zone thicknesses Crawford has divided his six Depuch Island samples into two groups: group B includes the three with subcutaneous zones in the order of 6 mm thickness, A those around 2 mm and for this second group the author considers it probable "that the color variations seen in the engravings accurately reflect degrees of weathering" (Crawford 1964: 50). However, maximum weathering depth of the third sample is Fig. 2 is greater than minimum weathering depth of the second, suggesting an overlapping of Crawford's groups, and Trendall's proviso that the number of speciments in small must be regarded as paramount. I would venture to suggest that samples of intermediate thickness are readily available from the region surveyed. If they were indeed absent I would regard this as a possible manifestation of a massive climatic fluctuation that had either accelerated the rate of weathering, or decreased the frequency of rock shattering. The presence of the varying thicknesses of patina could be interpreted as evidence of varying antiquities of the rock surfaces involved, and the latter as having been caused by processes closely resembling the rock fracturing at Dampier: most probably by thermal expansion and contraction.

An interesting point made by Crawford (1964) is his comment on superimpositions. He convincingly argues that it would be more difficult to superimpose an outline figure over an existing pecked intaglio representation than vice versa. It would also seem an unlikely conduct in view of the abundant rock surface available but on the other hand it could be held that prehistoric peoples in all parts of the world are notorious for ignoring the presence of earlier designs when executing their own rock art.

There is considerable disagreement between various writers when discussing the suitability of patina study for dating purposes. Whilst few deny that the weathering process itself can be assumed to progress at a reasonably constant rate it is often felt that the variables affecting it are too numerous, or of a nature preventing quantitative assessment of their influence on the formation of a weathered crust.

The radiocarbon method has found such broad acceptance amongst archaelogists that it is used for calibration purposes of other dating methods today, and yet, it is based on a process that is subjected to so many variables. The issues of constancy of cosmic radiation, of the "atom bomb effect", the "Suess effect", and even of the true half life of C14 have all contributed to question the accuracy of this method, as have consideration of deviations in solar activity, climate and earth magnetism. Errors of 20-30 per cent have been alloted to some older samples and our inability to effectively limit the possible error with absolute certainty (Aitken 1961: 98), combined with the inherent problem of vastly increased contamination effect on very ancient material (Aitken 1961: 97) have prompted in some a view that the relationship between a "radiocarbon date" and the true age of a sample cannot be determined reliably at present (cf. Stuiver and Suess 1966). Nevertheless, the method is quite reliable and accurate when compared with others: thermoluminescence dating of pottery and formerly heated minerals; dating by measuring fluorine and nitrogen contents, collagen residues or racemisation products of osteal remains; fission track or palaeo-magnetic dating all suffer from a lack of precision and their results can sometimes do little more than distinguish between ancient and recent material. Mineral weathering analysis could have the potential of providing far better results if the processes involved were understood and variables accounted for. Yet this potential has been left almost untapped in Australia (- and little used elsewhere). This is not surprising if one considers, for instance, that reference to the work of Cernohouz and Solc (1966) is completely lacking in our archaeological literature. These writer's investigation of rock weathering rates resulted in the establishment of two methods to calculate the absolute ages for the surfaces on two types of rock in Bohemia with an asserted accuracy of plus or minus 10 to 20 percent. Even with a precision of only one half of that claimed the method would yield results eclipsing those offered by almost all other dating media exploited at present.

What clearly emerges from the preceding is a need to appreciate the modes of rock weathering and the outside influences capable of affecting their pattern, to ascertain the dating potential of their products.

ON THE NATURE OF SCHUTZRINDEN

In its lithological sense patina is a term loosely describing visually obvious surface laminae covering rocks. It differs in color and chemical composition from the unaltered rock matrix, is the outcome of widely differing processes and - most importantly for our purposes - is a function of time.

Goodwin (1960) has listed five types of mineral patination and this system, having found acceptance in the literature (e.g. Michels 1973) is followed here. Linck (1901, 1930), adopting the <u>Schutzrinden</u> of Walther (1891) distinguishes basically between <u>Wuestenlack</u> and <u>dunklen Rinden</u>, incorporating in these all coatings of primarily ferro-manganese nature.

1. <u>Formation of a crust</u> by the leaching out of certain minerals, and their reprecipitation on the rock surface is the result of a form of chemical weathering. Some writers consider such surface rinds to be the product of impregnation from without (accretion), rather than secretion following

capillary migration of dissolved minerals (Butzer and Hansen 1968: 204) but their endogenous nature is accepted in general.

Goodwin (1960: 304) reports that a weathered crust can yield excellent and consistent information for relevant dating. He cites a number of instances where it has been employed successfully in seperating lithic artefact assemblages of differing antiquities from sites in Southern Africa. Petroglyphs, too, were investigated by him (Goodwin 1936) and the number of useful deductions he derives from the study of a single area (the Vosburg series consists of a mere one hundred engravings) is remarkable. His comments agree closely with those of Wright (1968).

Weathering processes are the responses of materials from the lithosphere when exposed to conditions determined by atmosphere, hydrosphere (ollier 1969) and biosphere (Reiche 1950, Carroll 1970). Chemical weathering is almost universally conditional upon the presence of water - even oxidation of minerals by gaseous oxygen is thought to require water as an intermediary agent (Keller 1957). As atmospheric water travels through permeable rock, by means of gravity, capillarity or heat, it supplies carbon dioxide, hydrogen ions and moisture, to remove rock mineral cations. Chemical weathering is usually by means of quite complex processes which are frequently made more intricate by the ability of many of their own products to accelerate them. Altered minerals are eitner accommodated in residue weathering products (more stable than the parent matter and not necessarily remaining in situ) or are removed in solution. The intensity or rate of chemical weathering is largely related to the amount of water available, which could be of a gravitational, capillary or hygroscopic (as thin film on grains) nature. Although water naturally avaliable will range in its pH from 3 to 9 most of the weathering takes place in the acid to neutral condition. Rainwater, far from being distilled as is assumed commonly, has a pH that is variable seasonally and regionally and largely the result of carbon dioxide absorption. The ions also present in southeast Australia (S, Cl, Na, K, Mg and Ca) are all common additions. The course of chemical weathering frequently commences with solution, and may include hydration, hydrolysis, oxidation and reduction, ion-exchange (including chelation) and carbonation.

In general the dunklen Rinden have not attracted as much specific interest as desert varnish despite their far greater frequency of occurrence. To compensate for the scarcity of certain detailed data suitable for an initial assessment of this phenomenon's potential to archaelogy I embarked upon a research programme of my own. A weathered crust or rind can be produced by sedimentary rocks but it is more conspicuous on those of igneous nature, especially if they are rich in mafic component minerals.

One of the localities examined in the course of my still continuing investigations, south of Craigieburn (near Melbourne) abounds with basaltic regolith. Exploration covering an area of almost 15 hectares included the mechanical excavation, or removal by explosives, of some 1051 cubic metres of sediment and rock, and the survey of several thousand patinated boulders of assorted sizes thus recovered. Methods ranging from granulomorphometric work, detailed abrasion pH studies, chemical and sedimentary analyses, to experimental drilling and core drilling were employed. Since it is neither appropriate nor possible to accommodate an account of these studies and the techniques used in the present context I shall limit my comments to the results relevant here.[6]

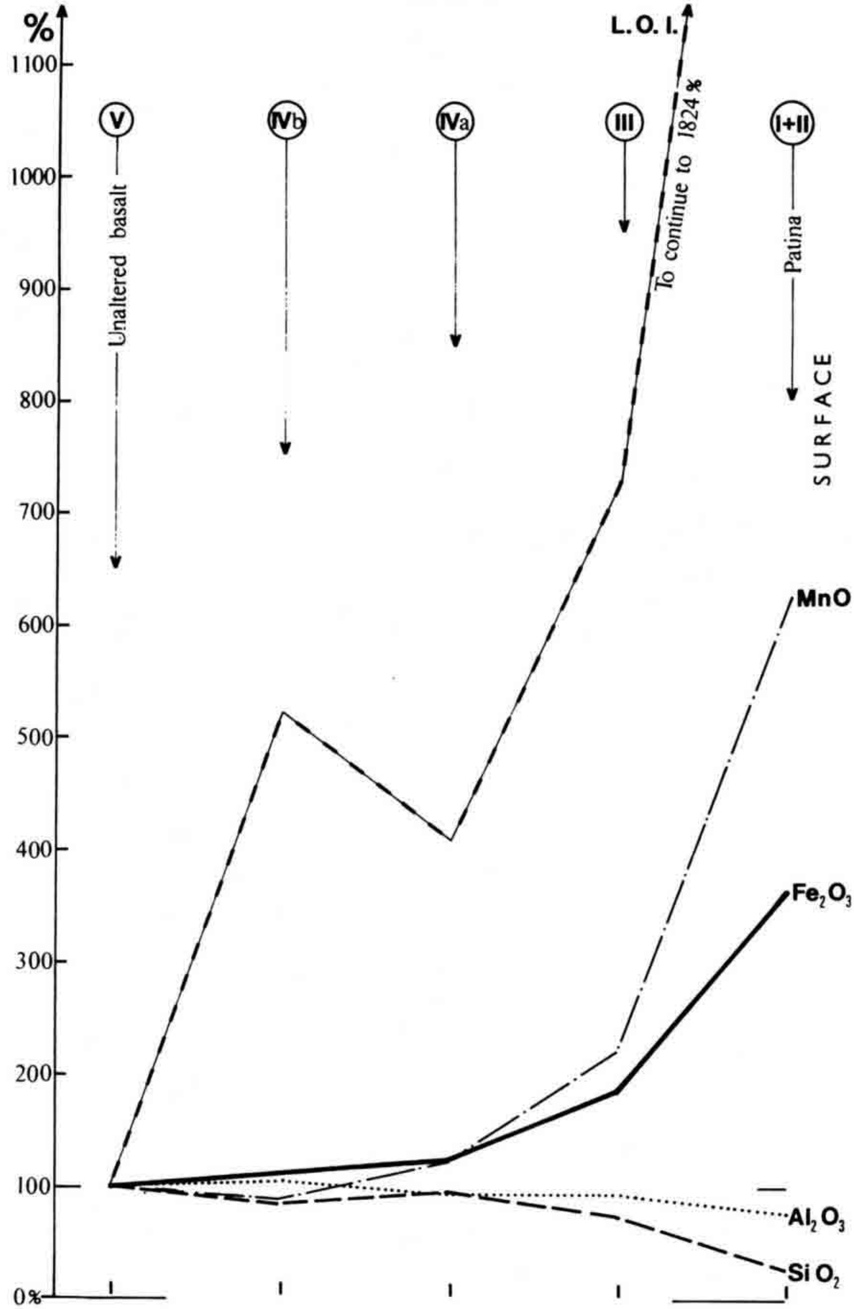
Nearly all of Victoria's Newer Volcanics date from the Upper Pliocene and the Pleistocene, and their easten regions have yielded the oldest absolute dates available as far as I am aware. The geographically nearest published radiometric age is of a sample from near Lancefield which gave a potassium-argon date of 4.21 mill. years (plus or minus 0.05) (Aziz-ur-Rahman and McDougall 1973). Craigieburn's olivine basalt originates from Tulloch Hill (Hanks 1955) and occurs as loose boulders of up to several cubic metres in volume that have been subjected extensively to saprolitization. They are mostly covered by less than one metre of poorly stratified silt containing occasional layers of magnetic "pisolites".

I have distinguished five discernable successive laminae on the fully matured weathering crusts (Fig. 3) but it should be noted that the chemical analyses of these are inevitably of contaminated samples (cf. Engel and Sharp 1958: 498) and some authors have attempted to correct their findings by assuming a degree of contamination and amending their results accordingly.

The general course of the weathering process at Craigieburn as I perceive it, is: upon moisture replenishment the weathering front becomes operative, both through introduced agents and the activation of substances already present. Cations are removed and migrate towards the surface but the nature of these movements remained unexplained until pH variations in the weathered layers were probed. The abrasion pH of the fresh basalt averages 8.71 and the reading decreases steadily to reach pH 6.19 in the outermost zones (Fig. 4). Whilst the solubility of iron increases about 100,000 fold (!) over that range of pH alumina is almost insoluble within the entire range encountered at the site, (alumina becomes highly soluble below pH 4 and above pH 10) and both amorphous silica and quartz are of quite moderate solubility (it would increase dramatically around pH 9, due to the ionization of H2 Si04). If we consider a few further facts my thesis on the principal causes for the formation of the crust begins to emerge: the soil pH at the site ranges from 5.1 to 7.7 (mean of 36 field grid tests, each of nine readings, is pH 6.79); patination tends to be better developed where alkalinity is prevalent; and the fully hydrated outermost patina zones (which should be related to the soil rather than the "dry" material) have a stable pH of only 5.45. Thus, precipitation of most of the iron salts upon contact with the soil is inevitable. Differential dehydration (evaporation or transpiration) rates in soil and rock would assist the process, and the influences of organic and micro-electrochemical factors in this context would require scrutiny. It should be recalled that algae - well known for their abillity to exploit and fix metal ions - have been identified in Victorian soils a depths of up to 1m (Phillipson 1935).

As the crust matures its subcutaneous, leached layer increases in thickness whilst it remains protected by the case hardened veneer from mechanical erosion. Soil movement merely manages to polish the surface of projecting portions. The next stage, disintegration, is launched by the collapse of layer II which could be caused either by its impermeability to water, by erosion of layer I where it had taken over some of the protective

FIG. 3


%
1100
1000
900
800
700
600
500
400
300
200
100
0%
L.O.I.
To continue to 1824 %
V
IVb
IVa
III
I+II
Unaltered basalt
Patina
SURFACE
MnO
Fe_2O_3
Al_2O_3
SiO_2

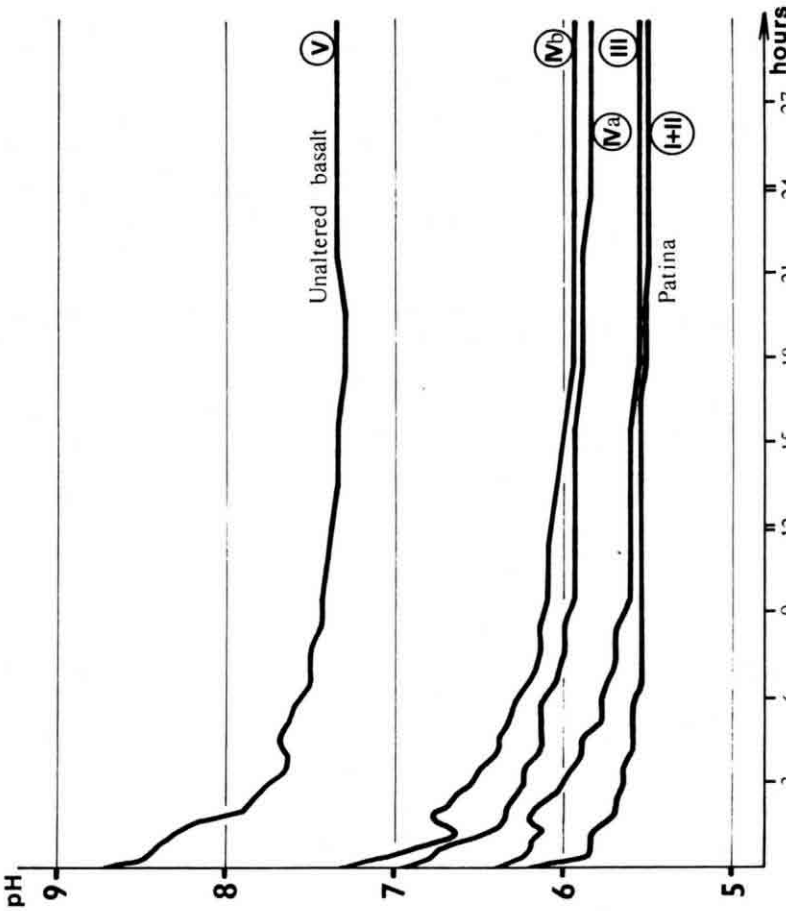

pH
9
8
7
6
5
hours
3
6
9
12
15
18
21
24
27
Unaltered basalt
Patina
V
IVb
IVa
III
I+II

FIG. 4

role, or by other agencies still. Layers III and IV are lost through granular disintegration at a rate demonstrated by the relief difference commonly measuring up to 10 mm on samples, between the retreating surface and the surviving remnants of Schutzrinde, with pronounced undercutting around the latter's margins.

The removal of iron, manganese and other matter continues at the weathering front, and at some stage a sufficient deposit will have formed at the surface to initiate consolidation: another cycle of patina formation has commenced.

This sequence of weathering processes, best described as cyclic cutaneous exfoliation does not normally progress in the orderly fashion outlined. It may be disrupted, locally delayed or hastened by a multitude of factors and it is quite common for different stages to be represented on a single boulder facet. Where conditions are unfavourable for the establishment of the hard veneer the cycles become obscure altogether.

It is the influence the rock surface's contour has on the rate of weathering that is the described processes' most significant peculiarity here. Where proceeding relative to a flat surface chemical alteration will advance quite uniformly, convexity of the surface will induce an acceleration. Where a ridge or corner has been established by two adjoining facets in size of the angle they form is related inversely to the depth of weathering. As a result, the projecting portions of a basalt block will be worn away more rapidly by erosion of weathered zones than flat or concave portions. The final outcome of such a process will be a degree of rounding compatible to the boulder's antiquity. Although my observations suggest cyclic cutaneous exfoliation to be a dominant source of edge blunting in subterranean basalt, at least in some (e.g. waterlogged) situations, it should be stressed that they are not in full agreement with some more established concepts of basalt weathering (c.f. Carroll 1970. Her list of 27 papers on the subject, although very comprehensive is not complete, amongst others it does not record the earliest analytical work on basalt weathering known to me, Ebelman's study of 1845).

Černohouz and Šolc (1966) have described a method for determining the ages of blunted edges on sandstone by using two constants a and b, the angle of the edge (φ), and the distance of retreat at the edge, in centimetres (h):

$$(1) \qquad h = \frac{a\ t\ \sqrt{(2)}}{1+b\ \sqrt{(t)}} \cot \frac{\varphi}{2}$$

Time t in millenia can be obtained.

The surface retreat does not occur as the simple curvature shown by Ollier (1969, Fig. 149), it consists of a hyperbola in section. Dimension h is therefore measured from a hypothetical intersection of two asymptotes, the block facets that were extant only at the commencement of erosion. Despite this obvious limitation of the Czech's methods my own observations tend to reinforce optimism for its usefulness to age estimation. The same cannot be said in respect of the second technique proposed by Černohouz and Šolc: dating of basalt was attempted by using the thickness of its weathering crust (i.e. the sum of all weathering laminae present). Chemical alteration does indeed progress at a reasonably uniform rate in rock of a homogeneous composition, but if weathering was to proceed as cyclic cutaneous exfoliation it would be completely futile to afford the weathering zone thickness any significance since it would be nothing more but the manifestation of a single chapter of a lengthy and constant process.

What remains to be reported from the Craigieburn site is the fate of the disintegrated patina. Some of it appears to enjoy considerable longevity, as the magnetic particles colloquially known as buckshot gravel. Upon detachment the crust breaks into fragments that are then rounded by transportation, and subjected to chemical reduction. In any granule, the maghemite's ferrous content is higher nearest to the surface. By contrast, the iron of an in situ layer I crust is of purely ferric nature and always hydrated near its surface. The longevity of the granules (Gill 1953: 74) and their cumulative propensity should suffice to explain their uniformity in appearance which contrasts with the sparsely distributed, very much younger intermediate forms, and freshly eroded crust fragments.

If the mechanics of buckshot gravel formation seem somewhat irrelevant to the topics of this paper one should recall that its size has been suggested to be a crude indication of its geological age (Gill 1953, 1964; Gibbons and Gill 1964) and that of its soil matrix. Provided the magnetic granules are indeed an epigenetic product primarily of laterization (Baker and Gill 1957: 59, Baker 1962: 42) such speculations would seem well founded. If my interpretation as modified residue of weathering rinds is accepted for any portion of these gravels, it would effectively invalidate the claim for their potential as dating criteria. Their average size at any locality may reflect nothing more than sorting, or differing modes of distintegration.[7] Content of ferrous oxide could be suggested to be a characteristic related to age but magnetic properties may merely indicate the content of "free" alumina (cf. Hanlon 1944: 100), or be allied to the degree of water saturation.

What clearly emerges from my work on basalt, is that any endeavour to attribute to its weathering crust much utility for dating purposes would be in vain. The very nature of its patina renders it unsuitable for anything exceeding a broad comparison of differing color values or hues, within the engraved depressions of moreless adjacent petroglyphs. I have not yet completed sufficient work on other rock types to present any detail here, but some are obviously far more expedient for qualitative patina evaluation as an archaelogist's instrument, than basalts. Trendall's (1964) assumption that a weathered rind of 5 mm thickness takes well over one million years to form, at least on the Depuch Island dolerite, has been described as an "extreme view" (Edwards 1971), possibly because of its seemingly intuitive manner. I, too, consider the "Felsenmeere" in Northwestern Australia (and also in Central Australia) in their present state to be features of great antiquity, and their patina to be of outstanding durability. A situation of low and very sporadic precipitation, enhanced by instant and complete drainage may concur here with a favorable combination of minerals to produce a patina best capable of assisting in the assessment of engravings.

The evidence suggesting considerable antiquity for some of Australia's petroglyphs includes the stone plaques from Devil's Lair (Dortch 1976) and the Montmilch markings in Koonalda Cave (Maynard and Edwards 1971) and elsewhere. Less direct proof are the supposed portrayals of several animal species now extinct in a region (or extinct altogether) of which at least some appear to have been identified correctly.

The stratigraphical context of the few engraved rock fragments secured from rock shelter deposits can only offer minimum ages. Since it appears unlikely that such carvings had been executed on already badly fractured and decomposed rock, their true age could in fact be very substantially higher. It is also relevant to note that dated early historical markings are usually devoid of any repatination (- except in alkaline environments, e.g. where exposed to sea spray). Examples are the three Beagle inscriptions at Depuch Island (dating from 1840), or Giles' incisions at Mootwingee (1860/61).

The patina studies envisaged for the future will, however, become increasingly precarious if many current practices of recording engravings are continued at random. The custom of abrading weathered petroglyphs to improve color contrast for photographic purposes has already been denounced by Edwards (1971: 361). This not only destroys the patina it also tends to obliterate the design's purport as it merely superimposes the recorder's intepretation.

The present paper demonstrates that both objections apply also to the common practice of chalking the engraved lines. The repatination occurs in conditions of a delicate natural pH balance and the processes involved are sensitive to any influence inducing a variation in pH. Just as the patina retarding effect of birdlime is a result of its acidity (around pH 5.9) the chalk's pH of 8.3 will accelerate the deposition of patina forming matter. Using chalk dust instead may be preferable but would still not warrant the absence of undesirable influences. Anati prefers a method using very dilute gouache to bring out contrasts.

If the objective is to preserve the patina chemically intact casts should also be avoided. If taking a moulding is considered essential a petrologist well versed in the chemistry of rock weathering should be consulted. It must in any event only be attempted on very compact and firm rock and, despite the convenience in comparison to the method employing plaster of paris, the high alkalinity of latex (around pH 10.6, depending on its solvent component) should be seen as a deterrent for using this second medium. Accordingly, when selecting a recording technique, preference should always be given to photography with oblique lighting, copying with a grid, or tracing.

2. Another of Goodwin's (1960) patina types is desert varnish, a coating that will affect not only minerals containing the elements needed for its establishment, but in fact any stone with a mechanically adequately stable surface. It has been reported most frequently from arid regions, one of several characteristics this form of case hardening has in common with a weathered rind. Iron oxides are well represented in desert varnish too but its high manganese dioxide content is distinctive, as are its surface sheen and the thinness of the deposited lamina.

Despite considerable efforts the mechanisms involved in the development of desert varnish remain largely obscure. Early investigators tended to look for non-organic agents; Loew (1876), one of the first to study the spectacular Mojave Desert deposits, considered them to originate from carbonates, precipitated from a shallow ocean and later desiccated to oxides. Merrill (1898) and Walther (1924: 169-182) advocated comparable views. Blake (1905) postulates that there would not be a sufficient quantity of varnish producing ions in each coated pebble to account for the phenomenon, thereby suggesting that it must be at least partially of exogenous origin. White (1924) suspected pollen to be the responsible factor, mistakenly believing them to be rich in Fe and Mn. Scheffer et al. (1963) have advanced a theory that involves the mobilization of heavy metal ions by members of an edaphon composed chiefly of cyanophycae. They were obviously unaware of an Australian paper, by Francis (1920), who had already recognized the involvement of algae in the formation of one variety of the varnish. His results are confirmed by Laudermilk's (1931) investigation, again of samples from the Mojave Desert, whose results list the same chemical components as do those of Scheffer et al. but proportions differ considerably. Laudermilk himself remarks on the high silica content, and it is likely that his method of recovering the samples, by mechanical flaking, is responsible for some contamination. On the other hand the chemical extraction method of Scheffer and colleagues could be even more selective, in my opinion it would have recovered silica only as caked-in substance introduced essentially by aeolian action.

Although a substantial time investment is involved, patination layers were separated mechanically in all my own work. Engel and Sharp (1958) provide a detailed account of the techniques they used to extract their samples. Their paper is by far the most comprehensive contribution on the chemistry of desert varnish and they stress the importance of the manganese content, the "most enriched constituent". However, they conclude that modes of depositing Mn onto a rock surface are not clearly understood, but the following possibilities are presented: increased akalinity, abundance of free oxygen, organic agents, or evaporation.

Three phenomena closely resembling desert varnish are briefly examined: During archaelogical reconnaissance in the north of Western Australia extensive bush fires were witnessed in the Hamersley Ranges and the ravaged area was entered a few days later. At some of the surface occupation sites discarded stone implements had acquired a glossy appearance, some even showed fresh heat discoloration. The lithic remains salvaged from the Tom Price sites (Bednarik 1973, 1977a) include some glazed specimens. One of these, item 3-1172 (Bednarik 1977b) is a partially worn Hamersley adze of banded chert. Its distal half is dark, almost black, and has a distinct glaze which is especially well developed on the steep, finely retouched working edge. No crazing or other heat fracture is discernable.

It appears to me that the stone's silica has reacted with the alkali metal oxides of the plant ashes to produce a true glaze. This deduction finds support in comments by Zeuner (1960: 316), who reports observing a glaze on flints retrieved from the burnt down Bristol University Museum. Amazingly, on several of these specimens the inventory number in Indian ink was preserved under the glaze which suggests that the patination must have happened more or less instantaneously.

Granular surface deposits of hematite in an environment rich in silica, in south eastern Western Australia, are coated with a layer of highly reflective case hardening resembling desert varnish, but the glossy surface is restricted exclusively to the ironstone. It seems to successfully retard hydration and brings to mind a vague explanation for the origin of desert varnish offered by Zeuner (1960: 319): the mineral is repeatedly subjected to sudden thunderstorms after it has been exposed to the intense solar radiation of an arid region. The colloidal silica "gets wedded to the iron, and moves to the surface on drying".

Finally, the polishing effects of snow and soil movements on a weathering crust should find mention in this context, in appreciation of the often close resemblance of their results to desert varnish.

Having considered the processes involved in the formation of the varnish, its potential for archaeology is examined now. Godwin (1960:303) quotes Clark's observations on the apparently well pronounced degrees of glazing on artefacts from the Victoria Falls. He cautions that the chronological place of any particular flake could not be "gauged on the evidence of desert varnish alone without considering technology".

Hunt (1954) believes the coating to be mainly the product of past climate. He elaborates on situations where the older of two generations of petroglyphs is stained and concludes with this chronology:

> First, there occured extensive deposition of desert varnish, and this predated an occupation that may predate pottery. This occupation was followed by deposition of more varnish, and this deposition was followed by the occupation known as Developmental Pueblo - A.D. 500 to 900.

Hunt suggests the younger varnish to represent a pluvial period more or less at the beginning of the Christian Era, and the older to the possibly as ancient as late Wisconsin.

After Engel and Sharp (<u>op. cit.</u>) described their observation of apparently very recently formed lacquer Hunt (1961) convincingly defended his view. He concludes that there is overwhelming support for a minimum antiquity of 2,000 years for most desert varnish deposits.

The abstract of a paper delivered by Blackwelder at a meeting of the Geological Society of America (Blackwelder 1948) and a later treatise by the same author (Blackwelder 1954: 14) assemble corroborative evidence: " ... the coating forms so slowly that a geological epoch, rather than centuries, is required for full development". Blackwelder's observations on Egyptian monuments correspond with Hunt's findings: a deposit of 2,000 years is scarcely perceptible, 5,000 years will only result in slight lacquer formation, and its full development may require some 20,000 to 50,000 years.

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The present paper does not incorporate a concluding chapter. This will be included in a subsequent article dealing with the remaining three of Goodwin's patina types, as well as various other aspects summarizing the potential of patina analysis for archaeological purposes.

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NOTES

1. This term is used here solely to conform with estabished terminology. The majority of Australian petroglyphs are essentially sgraffiti rather than just engravings.

2. Ollier's (1969: 18) reference to his own 1965 paper must be incorrect as this does not contain any reference to "dirt cracking".

3. This fact is well demonstrated by the observation that Wurmian cave deposits in formerly periglacial regions of Central Europe are extremely rich of cryoclastics if located in particular rock types, such as an Upper Triassic limestone (Bednarik 1970), but deposits of similar age in the same district are all but devoid of detritus where the cave walls are of metamorphosed limestone or augite (Bednarik, in prep.). A similar situation has been demonstrated elsewhere (Bordes, pers. comm.).

4. The term "scree" should be reserved for the material of talus slopes (cf. Ollier 1969: 215). There is also a tendency to restrict its geomorphological use to frost derived clastics.

5. "Weathering front", in this context, is not related to the term introduced by Mabbutt (1961). It denominates the contour of the deepest visually discernable alteration in the present paper.

6. These are envisaged to be the subject of a future paper, together with other work.

7. This is not to suggest that all buckshot gravels are of the same origin. On the contrary I believe them to be superficially similar products of divers processes of which I distinguish at least three.

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