First dating of Pilbara petroglyphs

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Abstract. The first attempts at scientific dating of petroglyphs in the Pilbara region of Western Australia are reported. Using microerosion analysis, a calibration curve has been established on the basis of a series of engraved historical dates, which is then used to estimate the ages of several petroglyphs. The results indicate that some of these are of Pleistocene antiquity. The consistency of the preliminary results of this project with observations made elsewhere in Australia and abroad is noted.

THE DATING OF PETROGLYPHS

Rock art occurs in two forms: as the results of additive processes, in the form of pictograms (paintings, stencils, drawings, beeswax figures); and as petroglyphs, i.e. the results of reductive processes (pounding, abrading, engraving, pecking, drilling). This division immediately determines the fundamentally different approaches to rock art dating, or rather, to estimating its antiquity. The substances added to the rock surface in the creation of pictograms provide the analyst with a variety of datable compounds that are of ages closely resembling the time the art was produced. For instance, paint residues may contain remains of organic binders or diluents (blood, saliva, orchid juice etc.) or pigments (charcoal, cochineal, berry juice etc.), as well as a great variety of incidental inclusions (brush fibres, pollen, bark fragments etc.) that contain radiocarbon of adequate quantities to permit accelerator mass spectrometry (Cole and Watchman 1992; but cf. Ridges et al. 2000). The fine-grained mineral detritus removed in the production of petroglyphs is, however, not likely ever to be recovered for analysis (cf. recent attempts by G. Susino to do so). Therefore, in order to date petroglyphs directly we have to resort to analysing a physically related feature that either pre- or post-dates the art (lichen, accretionary skin or crust, biogenic deposit etc.), providing a minimum or maximum age. In the language of Dunnell and Redhead (1988), such a procedure fails to focus on the ‘target event’, which is the creation of the petroglyph. Moreover, most of the methods used are seriously impaired by inherent uncertainties. For instance, dating bulk carbon isotope concentrations in accretionary crusts may be severely misleading, particularly if the crusts are open systems (Bednarik 1979, 1994a; Nelson 1993; Dorn 1997). Thus, the dating of petroglyphs remains one of the most intractable problems in archaeology. Indeed, of the methods proposed for petroglyph dating, only microerosion analysis (Bednarik 1992) seeks to determine Dunnell and Redhead’s (1988) ‘target event’. This paper presents the first application of this technique in Australia, and the first scientific age estimates for Pilbara rock art.

Until the early 1980s, no inherently testable methodology had become available for the age estimation of rock art (Ward and Tuniz 2000). Previous dating claims had generally been based on non-scientific criteria, and in the case of petroglyphs it had been sought to determine the ages from their perceived iconographic content (i.e. what the art was thought to depict), style or technique; from spatial proximity to archaeological evidence (such as occupation debris) and by excavation (usually of purported occupation deposits); or from superimposition, patination and weathering.

Iconographic interpretation, however, is not falsifiable in most instances, and stylistic constructs, while possibly comprising some valid elements, are not a sound basis for dating rock art, as has been demonstrated time and again in various continents (e.g. Macintosh 1977; Bahn and Lorblanchet 1993; Bednarik 1995a, b; Watchman 1995, 1996). Not only are such mental constructs of researchers untestable, they tend to reflect modern Western perception more than historically valid variables inherent in the rock art. They are also taphonomically naive in that they ignore that the surviving vestiges of any rock art are not random samples of living traditions (Bednarik 1994b), and they tend to be formed without adequate recourse to archaeometry. The technique of petroglyph execution, too, is rarely a reliable chronological marker, and should not be cited as a dating criterion without substantial other evidence. Proximity to occupation sites is almost irrelevant in the reliable dating of rock art, because rock art often occurs at ‘focal’ sites within a landscape, as do occupation debris, hence their co-occurrence is more likely to be related to this factor than to contemporaneity. Superimposition of motifs certainly provides sound data for relative sequences, but is not always reliably determined without the use of field microscopy and does not yield actual age estimates, so in rock art dating it is only useful as a supplementary method.

There are two basic approaches to dating rock art by excavation. The petroglyphs, either on a vertical wall or on horizontal bedrock, may have been covered by subsequent sediment deposition (Rosenfeld et al. 1981; Steinbring et al. 1987; Crivelli et al. 1996), or detached and stratified fragments of rock bearing petroglyphs may be excavated in an occupation deposit (Hale and Tindale 1930; Mulvaney 1969: 176; Thackeray et al. 1981; Lorblanchet 1992; Fullagar et al. 1996). In all these cases the dating of the sediment can only provide minimum ages for the petroglyphs, and it is dependent upon the validity of a chain of unfalsifiable deductive arguments relating to the taphonomy of both the excavated sediments and the dated material (e.g. charcoal). Moreover, and especially in the case of rock art on vertical walls or detached fragments, the minimum age secured from the sediment is likely to be very conservative. Also, archaeological claims about the dating of sediments need to be viewed sceptically, as there are numerous cases on record of incorrectly dated sediments related to petroglyphs. For instance at Fariseu, Portugal, a colluvium of probably less then 17 years of age was claimed to be around 25 000 years old (cf. Abreu and Bednarik 2000), and at Jinmium, in the Keep River region of northern Australia, a saprolithic sediment of the Holocene was claimed to be over 170 000 years old (cf. Roberts et al. 1998).

Indeed, of the traditional methods of estimating the ages of petroglyphs, only the study of subsequent patination and weathering promises secure or testable data, and although it was perhaps the first to be considered (Belzoni 1820: 360-61), it has not been applied in a rigorous and systematic fashion up to the present time (but see Trendall 1964). Instead of pursuing the development of a scientific methodology to date petroglyphs, archaeology has for the greater part of two centuries opted for an ‘archaeological methodology’, which consists of non-quantifiable speculations, unexplained perception of invented styles and non-falsifiable propositions. The use of these untestable and thus non-scientific approaches continues to the present time, and is sometimes defended vigorously by archaeologists (Zilhão 1995; Rosenfeld and Smith 1997).

The alternative approach is by ‘direct dating’, the use of direct physical relationship of art and dating criterion, and the presentation of falsifiable propositions concerning this relationship for the purpose of estimating rock art age (Bednarik 1996; for a comprehensive critique of all rock art dating methods, including those contributed by me, see Bednarik 2001).

MICROEROSION ANALYSIS

Microerosion analysis seeks to estimate the actual age of petroglyphs. The rationale of this technique is that, after a new rock surface has been created, be it by natural or anthropic agents, it is subjected to chemical weathering processes. This applies especially in unsheltered locations, and it results in cumulative effects that are a function of time, among other factors. While this is a fairly self-evident principle, the difficulty in using the results of such processes to estimate the age of a rock surface is that our understanding of them, of their effectiveness on different component minerals, and of their susceptibility to environmental factors remains limited (concerning typical rates of solution, cf. Acker and Bricker 1992; Busenberg and Clemency 1976; Lin and Clemency 1981; Oxburgh et al. 1994; Rimstidt and Barnes 1980; Williamson and Rimstidt 1994).

For the time-span we are concerned with in dating petroglyphs (the last 50 000 years), only comparatively erosion-resistant rock types are suitable for microerosion analysis, because those that dissolve too fast are unable to preserve original fracture surfaces for time-spans long enough to be of relevance. Sedimentary rocks, in particular, weather so fast that remnants of the surfaces created at the time a petroglyph was made survive only for very short periods. So far, two different methods have been used. In one, the retreat of the more soluble component of a rock is measured against a component that retreats at an extremely slow rate. For instance the retreat of amorphous silica cement in a heavily metamorphosed quartzite can be measured against the crystalline quartz component, or the alveolar retreat seen in schistose rocks can facilitate rough age estimates. However, the principal technique used so far is the measurement of micro-wanes on fractured crystals (Bednarik 1992, 1993a). The ‘radius’ of wanes (strictly speaking, wanes are not equi-circular in section, but hyperbolic) increases as a linear function of age, as demonstrated by the geometry of the process. In wane formation, be it at the macroscopic or microscopic level (Fig. 1), the ratio $h : r$ is constant for any angle a, irrespective of distance of retreat of the faces and the edge. Ratio $x : z$ is a function of a, and for instance at $a = 60°$, $x = 2z$. Dimension x can be expressed in algebraic fashion:

$$x = \sqrt{\left[\left(\frac{z}{\tan 0.5\alpha}\right)^2 + z^2\right]} \qquad (4)$$

This leads to the prediction of b, the angle expressing the rate of wane development relative to surface retreat:

$$\beta = 2\sin^{-1}\left(\frac{r}{x+h+r}\right) \qquad (5)$$

The relationship wane width A versus age, irrespective of actual retreat, is ultimately determined by the ratio $a : b$, which must be established empirically. It follows that the dimensions A, r, z, and angles a and b in Figure 1 are all related geometrically and algebraically, and that the variables A, r, x, z and h are all proportionally equivalent, and increase linearly with age. Of these, A is most easily measured physically in the field. It is therefore the variable preferably used in micro-wane measurement.

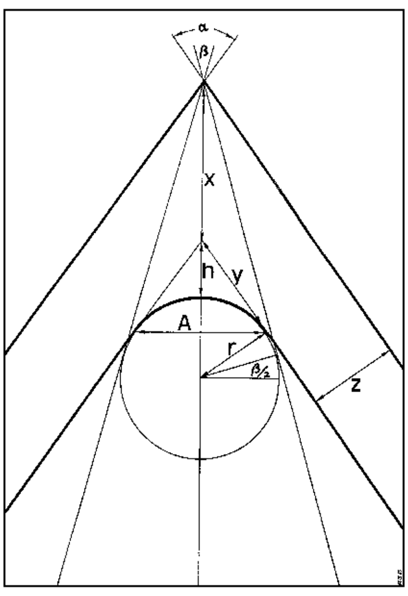

Figure 1. *Diagram depicting the laws of wane formation in a simplified form.*

In the field, the analyst scans the rock surface microscopically to locate crystals that have been truncated (either fractured by impact or truncated by abrasion) by the event to be dated (e.g. the petroglyph production). A statistically significant sample of micro-wane widths along the edges of such truncation surfaces is recorded and placed in a calibration curve. Age estimates are prefixed with a capital E, indicating that the result is erosion derived.

The method is not very precise at this early stage, because it has only a few calibration points in each region where it has been applied. The principal variables in the solution process responsible for microerosion are temperature, pH and moisture availability. The first two are regarded as unimportant. Variations in mean annual temperatures, even as far back as glacial peaks of the Pleistocene, are not thought to have been of a magnitude that would have affected solution rates appreciably. Variations in pH back through time can be assumed to have taken place, but they are just as unlikely to have influenced solution rates. In the case of both amorphous silica and crystalline quartz, there is almost no change in solubility below pH 9, and higher values would certainly not have been experienced in nearly every natural environment. For alumina the effect is negligible in the central region of the pH scale, which coincides with most natural conditions. Precipitation certainly varied in the past, but it can be accounted for it. Significant changes in moisture availability affect component minerals differently, and should thus be detectable by calibration of more than one component mineral. Therefore it is preferable to apply the method to two or more different component minerals of the same surface, such as quartz and feldspar.

While microerosion analysis is not thought to be very accurate, it is probably more reliable than most alternative methods of dating petroglyphs, and it is certainly cheaper, simpler and more robust than most. It requires no laboratory facilities. Results can be determined in the field, which may save considerable effort necessitated by the need to return to a perhaps very remote site to obtain supplementary data. The method provides not a single result, but clusters of age-related values (the micro-wane widths) that can be converted into various statistical expressions — a luxury not available to all other dating methods currently used. Moreover, it is the only such method offering a means of internal checking — that is, of checking the validity of the result without recourse to another method (although luminescence dating has a limited feature of this type, i.e. the possibility of checking whether the uranium and thorium decay chains are in equilibrium). Finally, microerosion analysis involves no removal of samples, or even contact with the rock art, being a purely optical method.

All these factors favour microerosion analysis. The valid technical arguments *against* the method are: inadequate calibration curves, its limited accuracy through its inherent coarseness, its application is limited to rock types that preserve crystal surface features and have been continuously exposed to precipitation. These significant limitations are outweighed by the benefits of the method. The microerosion method by micro-wane measurement has been used on petroglyphs in six blind tests: in Russia, Italy and Bolivia (Bednarik 1992, 1993a, 1995b, 1997a, 2000a). Archaeological expectations were matched in all but one case, where the results matched those of other scientific analyses (Bednarik 1995b; Watchman 1995, 1996). Calibration curves are now available from Lake Onega (Russia), Vila Real (Portugal), Grosio (Italy), Qinghai (China; Tang 2000) and eastern Pilbara (Australia). The technique has also been applied in India and South Africa. The method's practical time range on crystalline quartz, from perhaps 50 000 years BP to the present, renders it particularly suitable for rock art, very little of which can be expected to be in excess of that range. The perhaps most effective range (from around 10 000 years to about 1000 years) coincides with the presumed age range of most petroglyphs.

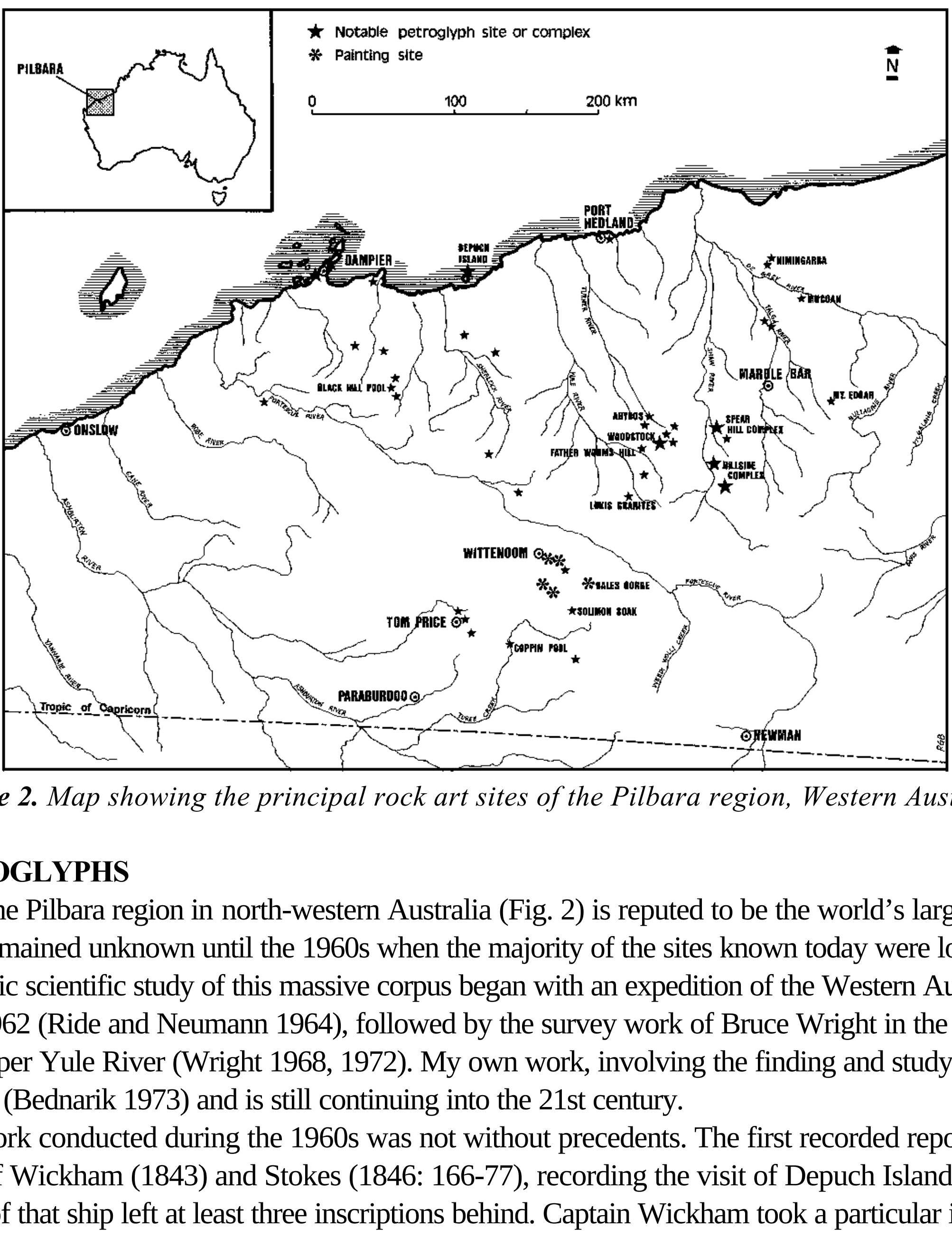

Figure 2. *Map showing the principal rock art sites of the Pilbara region, Western Australia.*

PILBARA PETROGLYPHS

The rock art of the Pilbara region in north-western Australia (Fig. 2) is reputed to be the world's largest concentration of petroglyphs. This remained unknown until the 1960s when the majority of the sites known today were located and first examined. Systematic scientific study of this massive corpus began with an expedition of the Western Australian Museum to Depuch Island in 1962 (Ride and Neumann 1964), followed by the survey work of Bruce Wright in the region from Roeburne to the Upper Yule River (Wright 1968, 1972). My own work, involving the finding and study of hundreds of sites, began in 1967 (Bednarik 1973) and is still continuing into the 21st century.

However, the work conducted during the 1960s was not without precedents. The first recorded reports of any Pilbara rock art are those of Wickham (1843) and Stokes (1846: 166-77), recording the visit of Depuch Island by *H.M.S. Beagle* in 1840. The crew of that ship left at least three inscriptions behind. Captain Wickham took a particular interest in the petroglyphs and his illustrations were republished by Stokes. These authors, however, were probably not the first Europeans to view the rock art. Much earlier, in 1688, buccaneer William Dampier, after whom the Dampier Archipelago is named, visited the north-western coast and may well have seen rock art, but in his very brief account about Australia (under 2500 words) he makes no mention of it. A recent discovery in the eastern Pilbara, however, suggests that a European of the 18th century, presumably living with indigenes, not only saw the rock art but added his own designs (see below).

Much later, Pilbara petroglyphs are briefly mentioned by Richardson (1886), while Withnell (1901) dedicates a page to them. In 1939 the Frobenius Institute of Germany conducted brief expeditions to three localities — Abydos, Port Hedland and Depuch Island — which resulted in some preliminary descriptions (Fox 1939; Petri 1954; Petri and Schulz 1951). Davidson's visit in 1938-39 is reflected in his opinions about similarities with other Australian rock art (Davidson 1952), but the first study of substance was the work of another German researcher, Father E. A. Worms, who conducted field work in 1931 and in the early 1950s (Worms 1954). His observations, especially in the Abydos area, led him to suggest that many anthropomorphous petroglyphs there with certain distinctive features were connected with the Kurangara cult, introduced from the east and originating in Arnhem Land. This deduction is no longer accepted today (McNickle 1985) and the figures in question are now called 'Woodstock figures'.

More detailed reports only began to appear in the 1960s, first of the 1958 study by F. D. McCarthy on Depuch Island (1961), then his subsequent comprehensive survey of the limestone ridge at Port Hedland (1962), where he determined the presence of about 7000 motifs, spread over a distance of more than ten kilometres. Most of these figures were still well preserved when I first saw the site complex six years later, but by the end of the century only a few hundred motifs remained. The massive industrial development at Port Hedland had resulted in the gradual deterioration of that rock art corpus. The destruction of rock art was of an even greater scale on Burrup Peninsula, where I witnessed the loss of many thousands of motifs during the 1960s. The 1962 expedition to Depuch Island by the Western Australian Museum (Ride and Neumann 1964) was in fact prompted by a proposal to construct a deepwater port for loading iron ore on the island. The recommendations of the Museum team effectively led to the abandonment of this plan, and to developing instead the loading facilities at Dampier during the mid-1960s, where no survey work had taken place prior to 1968. Abydos was also visited by Mountford (1968).

The principal limitations of all research efforts up to the mid-1960s were that they usually dealt with individual sites or site complexes and were the result, generally, of rather brief visits; they lacked in-depth consultation of Aboriginal informants, which has severely limited the amount of authentic ethnographic information available about Pilbara rock art; and until Trendall's (1964) work there was no attempt to provide analytical data. Because of this piecemeal approach it was only with the work of Wright (1968, 1972) and myself during the 1960s that the true magnitude of the Pilbara petroglyph corpus began to become apparent. Wright was the first to conduct broadly based inter-site studies over a wide section of the region, and thus to define this distinctive rock art province. Indeed, his quantitatively descriptive study, extending over two years and then intermittently into the early 1970s, has not been bettered to the present time, even though much better funded projects have been undertaken during the subsequent three decades. Wright kept interpretation of the rock art to a minimum and endeavoured to provide comprehensive initial descriptions, particularly of the significant and spectacular anthropomorphous component of the region's rich iconography. Because his recordings were derived from a meticulous photographic record, on which the early component of the art tends to be invisible due to repatination, he only registered the more recent technological traditions in most instances, as had also been the case with all previous research endeavours. Importantly, Wright was the first to conduct in-depth ethnographic research, particularly through the cultivation of personal rapport with indigenous elders in Roebourne.

My own study of Pilbara petroglyphs, commenced in 1967 (Bednarik 1973) and still continuing (Bednarik 2000b), differs from previous work in the region in various aspects. It is a long-term project that initiated archaeological studies in the region (Bednarik 1977), but focused on extracting scientific (1979) and ethnographic information (1998). I soon noticed the occurrence of entirely re-patinated, almost invisible petroglyphs of great antiquity, which had been overlooked by previous investigators. If they occurred by themselves, they were very difficult to find, and if they occurred with much more visible recent figures they had remained undetected, leading me to differentiate artistic traditions of greatly varying, but unknown, age. Motivated by wanting to place the rock art into an archaeological context rendered it essential for me to focus particularly on the question of the art's antiquity, because it can only become an archaeologically meaningful resource if its age is known — at least approximately.

Wright's painstaking site recording program involved close to 100 sites, and my addition of several hundred more sites in the western Pilbara (about 570 sites just on the Burrup Peninsula) demonstrated that the Pilbara contains the largest known assemblage of petroglyphs. Some of the more enthusiastic estimates, such as the suggestion that there are 500 000 petroglyphs just on Burrup (Lorblanchet 1986), are perhaps excessive. However, the number of petroglyphs now known in the Pilbara is at least in the hundreds of thousands, with perhaps in the order of 2000 sites known, many of which number in excess of 1000 motifs.

Once the magnitude of this corpus became apparent it attracted the interest of other researchers, and in particular the Dampier sites became the subject of several studies (Virili 1977; Lorblanchet 1983, 1992; Vinnicombe 1987). These and other research projects were usually connected with industrial developments and were therefore often well funded, but they were also highly biased in favour of specific localities and corporate or governmental preoccupations. Elsewhere in the Pilbara, little further rock art research took place, although there are some exceptions (e.g. Palmer 1975; Maynard 1980; McNickle 1985; Brown 1987). Since Wright's first tentative but inconclusive forays into the question of petroglyph antiquity, no hard evidence has become available. Concerning Burrup rock art, Clarke (1978) stated his opinion that some of it must be in excess of 17 000 years old, based on his assumption that the patina found on it, which he thought to be desert varnish, formed during a very arid phase at about that time. However, much of the patina is not of the varnish type, nor does that kind of accretionary deposit indicate arid conditions.

An attempt was made by Lorblanchet (1992) to archaeologically date the petroglyphs at Gum Tree Valley and Skew Valley on the western Burrup Peninsula. He obtained a series of radiocarbon dates ranging in age from 7000 to c. 500 BP. Only the three youngest dates were secured from charcoal, all others are from marine shells. A date of about 18 500 BP came from fragments of a trumpet shell (*Syrinx aruanus*) found on the present land surface, some distance from the petroglyphs. On the basis of this rather slender evidence, Lorblanchet constructed a chronology of successive petroglyph traditions extending back over 18 000 years (Lorblanchet 1992: Figs. 20, 21), which is unlikely to be valid since it relies on a single shell date. Moreover, the Burrup would then have been over 100 km from the sea shore and rather inhospitable — the consequence of full glacial aridity.

Figure 3. *Typical granite boulder pile of the eastern Pilbara. This is Spear Hill site 7, the principal calibration site in this project.*

In the Pilbara, the most likely place to find Pleistocene occupation debris is inland, along river courses, at waterholes, soaks, springs and in rockshelters, especially in areas of relatively impermeable rock, particularly granites, which allow aquifers to remain close to the surface throughout the year. Much of the eastern Pilbara fits this description. Despite its arid ecology, there are reliable supplies of permanent water close to the surface, and aquifers are sometimes exposed even in quite flat areas. Morphologically, the piedmont region is dominated by roughly conical boulder piles which in some areas occur in large groups and are generally of granite facies (Fig. 3). Sub-parallel dolerite dykes occur locally and can be hundreds of kilometres long. Drainage of the occasionally cyclonic and always unpredictable rainfall is effected via substantial river systems, most of which carry little or no water for much of the year. Rock art is found at hundreds of the many boulder piles, and even the most cursory examination reveals the presence of many traditions separated by great time spans. The earlier components of these rich sequences of petroglyphs could well be of Pleistocene age.

ESTABLISHING A CALIBRATION CURVE

Twenty-two years after commencing my research in the Pilbara, my development of the microerosion method in 1989 seemed to render Pilbara petroglyphs datable at last. Unfortunately, in Australia, and most especially in the remote and very thinly populated north-west of the continent, there are no rock surfaces of historically known ages available to establish calibration curves. The great wealth of rock-made structures, quarries, gravestones and glacial abrasions in Eurasia whose age is either known precisely or can be ascertained with reasonable accuracy renders this region far more amenable to this method. In July 2000 I managed to locate a large series of engraved dates on one of the four major granite facies of the eastern Pilbara, which provided the means of securing calibration values for this important rock art region (Fig. 4).

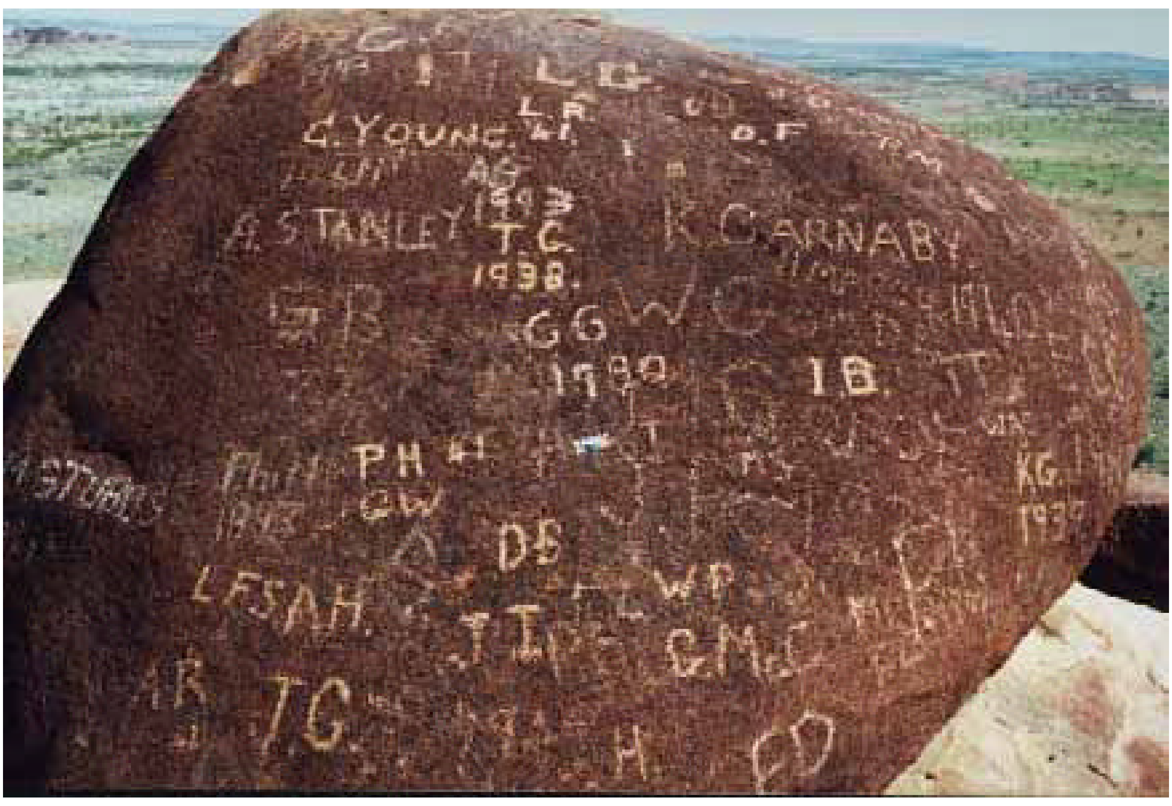

Figure 4. *Large granite boulder at the peak of Spear Hill site 7, bearing numerous inscriptions.*

While surfaces of historical structures (Roman bridges, Buddhist inscriptions) and glacial striae from the end of the last stadial have been utilised in Eurasia, dated inscriptions of the last two centuries seem to be the only available option in Australia. I had already used dated inscriptions very profitably abroad, but in the case of Australia, the exceedingly short time range covered by such dates would introduce a higher level of imprecision. However, the potential imprecision imposed by an arid climate could be considerably greater than that of very short-range calibration values.

The series of dated inscriptions located in the Pilbara includes an apparently authentic example from 1771, which is part of the earliest currently published non-indigenous rock art composition yet found in Australia (Bednarik 2000b; I emphasise that I know of two earlier European inscriptions). It consists of four motifs, two of which show limited evidence of the application of a metal implement prior to completion with a pounding stone (Fig. 5). The panel is still being subjected to further research, and this work may lead to the development of a calibration curve for olivine or pyroxene. It was engraved on a basaltic dolerite, free of quartz and feldspar, and therefore cannot be utilised for microerosion analysis until one of its constituent minerals has been subjected to a calibration study.

Figure 5. *Historical petroglyphs, apparently of 1771, eastern Pilbara.*

The remaining engraved dates recently discovered in the eastern Pilbara and examined for constructing a calibration curve are all located on AGL granite, a well foliated, fine to medium-grained biotite adamellite representing remobilised older granitic rocks. Eight dates ranging from 1881 to 1997 were surveyed with a specially adapted field binocular microscope. Six lie near the peak of Spear Hill site 7, one on the hill's western flank and one on nearby Spear Hill site 9 (McNickle 1985). Six of these inscriptions provided quantifiable micro-wane width readings from 90º fracture edges on crystalline quartz (see Bednarik 1992, 1993a), with samples ranging from four to thirty-two measurements per inscribed date (Table 1).

Date	No. of determinations	Min. width	Max. width	Mean width
1938	15	0.1	0.4	0.233
1941-A	8	0.2	0.3	0.237
1980	Micro-wanes are slightly <0.1 micron			
1997	Micro-wanes too small to measure effectively			
1964	4	0.2	0.3	0.275
1941-B	32	0.2	0.4	0.259
1881	8	0.4	0.7	0.537
1917	8	0.3	0.7	0.412

Table 1: *Microerosion calibration values (in microns) from micro-wanes on eight engraved dates at Spear Hill, Pilbara, for crystalline quartz.*

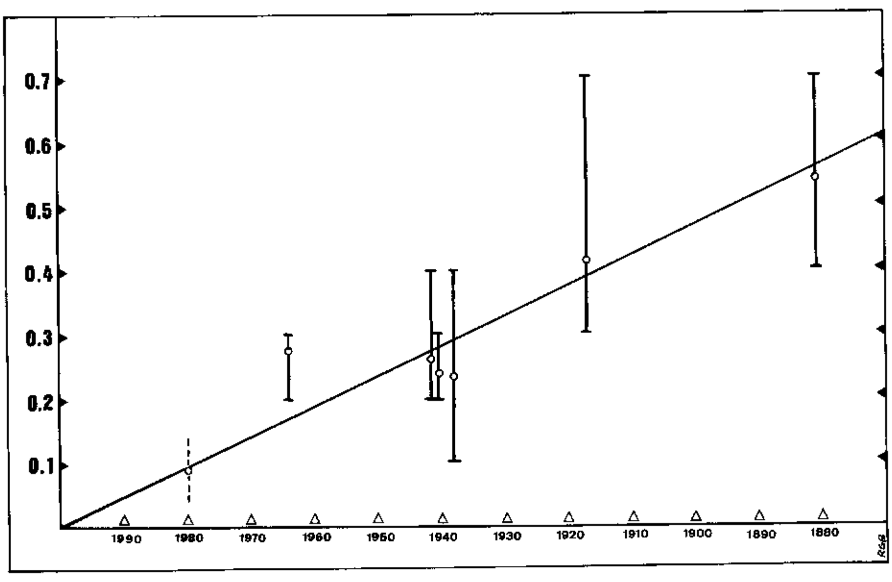

Figure 6. *Microerosion calibration curve for quartz, Spear Hill rock art complex.*

The calibration curve derived from these values (Fig. 6) provides a reasonably distinctive trend, although the values recorded for the 1964 date are not a good fit. However, only four determinations were possible which is statistically inadequate. The remaining values fit well, but the resulting curve differs considerably from those secured previously from temperate to sub-Arctic sites. This was certainly expected, and the difference is not even as great as one might have predicted, considering the much greater difference in precipitation (cf. Bednarik 1992, 1997a). However, erosion rates in an arid climate may well be determined not so much by annual precipitation, but by the relative duration of surface moisture, which is determined by the length of rainfall periods and evaporation rates. In that sense, the Pilbara with its cyclonic precipitation, very low relative air humidity and sparse vegetation is probably close to the end of the spectrum of mineral solution rates in common natural environments. The ubiquitous iron-rich accretions of the entire region, which have previously been interpreted as autochthonous conversion products, are another result of these conditions, being largely, though certainly not entirely, the outcome of inadequate flushing of dissolved minerals.

Two other points need to be emphasised. First, this calibration curve lacks in precision for a number of reasons, especially the short range of the calibration values it is based on. Second, its reliability could be backed up by a feldspar curve. This first determination for the Australian Pilbara is therefore best regarded as preliminary, subject to refinement and testing, and its purpose is merely to explore the time depth represented by Pilbara rock art and to set some of the parameters within which future datings of Pilbara petroglyphs are to be conducted.

THE FIRST DATING OF PILBARA PETROGLYPHS

The Spear Hill calibration curve (Fig. 6) has been applied to selected petroglyphs at three granite boulder piles: Woodstock 65B, Spear Hill 7 and Spear Hill 9 (Fig. 2). In each case, fractured quartz crystals were located that had remained free of accretionary mineral deposits and possessed edge angles between 85º and 95º. The micro-wanes developed on these edges were then measured in accordance with standard microerosion analysis (Bednarik 1992, 1993a). Not every motif on granite is suitable for this kind of analysis, many are so extensively covered by accretionary mineral matter that weathering processes have been retarded. Such surfaces are unsuitable for microerosion analysis. However, the deposits are often sufficiently discontinuous, even on repatinated motifs that are of macroscopically even colour, that microerosion analysis is possible.

The ubiquitous reddish-brown patination of the entire Pilbara region is generally neither an intrinsic alteration product nor entirely an accretion, it is a combination of the two. On the dolerites, the magnetite component takes well under a century for an initial crust of iron oxides and hydroxides to form in situ, but on the granites there is only limited inherent potential for the development of alteration products. The accretionary matter is selectively deposited, sometimes its distribution is determined by aeolian factors, and its microscopic morphology is closely related to whether the support surface is vertical or horizontal. Distinctively 'laced' or 'terraced' morphologies are common. Under adequate magnification (>60×), the accretionary matter reveals a diversity of airborne materials, including widely transported mineral grains and charcoal detritus, and this is caked together mostly by iron salts and amorphous silica. These deposits were found to form fairly consistently as a function of time. An incipient film becomes evident after a surface has been exposed for 30-40 years, and after about 100 years, the patchy deposit reaches a thickness locally of 30-50 microns (µm). The thickness of the laced accretionary deposits in part of the above-mentioned 1771 inscription reaches 100-150 µm, which is crucial in assessing the authenticity of this composition. However, on granite such deposits remain often so discontinuous that fracture surfaces that have remained exposed can usually be found on all but the very oldest motifs.

Woodstock 65B

Woodstock site 65B is located near the abandoned Abydos homestead, on AGM granite, a fine to coarse, even-grained biotite adamellite, biotite granodiosite and, less commonly, biotite tonalite, well foliated and often gneissic. The hill is a typical conical boulder pile, rising about 80 m above the pediplain. It bears an estimated 2000 petroglyphs, which are scattered in several concentrations around its slopes, with a notable occurrence of very elaborate and detailed anthropomorphs found near the summit. Large boulders form a distinctive shoulder on the western slope, creating an area of level ground where petroglyphs of very different ages occur in close proximity, even on the same panels. They include circle motifs of a quite specific genre thought to be of the Pleistocene near the southern coast of Australia (Bednarik 1990). The upper surface of a small elongate boulder bears several deep impact scars (Munsell 10R-4.5/7) and an almost fully repatinated pounded circle, together with faint linear marks that may also be of former circles. Twenty quartz micro-wane widths (A) were measured in one of the impact scars (Table 2), yielding a mean value of 17.25 µm (range 10-30 µm). On the newly constructed calibration curve (Fig. 6), this corresponds to an estimated age of E3670 (+2713 -1543) years BP. The 'E' in front of the age estimate indicates that it is derived from microerosion analysis.

The immediately adjacent circle was also examined (Munsell 7.5R-4/6) and an area of suitable accretion-free quartz edges was located. Measurements of their micro-wanes yielded a mean width of 125.74 µm (range 110-180 µm, N = 14), which corresponds to E26 753 (+11 545 -3349) BP. Thus, the lightly-patinated impact scars, which seem to be a more recent reaction to the earlier circle, are significantly younger than the circle.

Two metres to the south of this boulder, a well-rounded large boulder bears an only faintly patinated male anthropomorph. The quartz cleavage faces in this petroglyph appeared quite fresh under magnification. Analysis of their ≈90º edges produced a mean value of 2.0 µm (range 1-4 µm, N = 10). Consequently this typical Woodstock figure is only E425 (+426 -212) years old (Table 2).

Some 10 m to the east of this motif is a large flat boulder, about 6 m long. Most of its horizontal upper surface has experienced massive laminar exfoliation of 3-5 cm thickness, but near its northern end, one square metre of patinated crust is still present. It bears the remains of a design of which four circles and an elongate, bisected outline in the Karake style (Aslin and Bednarik 1984) remain visible (Fig. 7). This is heavily weathered (Munsell 10R-4/5, on 10R-3/5 background), and there is a patch of abraded area on the surviving panel. Fourteen micro-wane widths measured on the east side of the largest circle yielded a mean value of 91.07 µm (range 75-125 µm), suggesting that the design is E19 376 (+7219 -3419) years old. The ground area, about 70 cm across (Munsell 5YR-8/4, but very speckled), is significantly younger. It is about the same age as the Woodstock figure just mentioned: micro-wane sizes of about 2 µm are consistent, although no quantitative count was attempted.

Figure 7. *Circle petroglyphs of the Karake style, estimated to be just under 20 000 years old.*

Some of the most prominent petroglyphs at site 65B occur about 30 m north of the locality so far considered, on a highly visible dark boulder. The numerous motifs include female Woodstock figures. One of them, with distinctly S-shaped torso, exhibits wane widths of 10-15 µm, and is therefore between about E2130 and E3190 years old. The south-west wall of the large boulder bears at least 82 cupules, typically of 25-40 mm diameter and 5-10 mm deep. Unfortunately they are so heavily coated by accretionary deposits that microerosion analysis could not be attempted. They appear to have continued onto the upper surface of the rock, and there could be taphonomic selection based on relative orientation evident. Several Karake-style crossed and bisected circles on the north-west side of the boulder appear to be of intermediate age. Although the cupules are not datable by the method used here, there can be little doubt that they are the earliest component of the rock art present. Their alveolar erosion patterns are well in excess of the condition observed in the c. 27 000-year-old motif. This observation of the precedence of cupules is consistent at many sites in the region, and elsewhere in Australia and the world (Bednarik 1994c).

Figure 8. Pounded date '1917' superimposed over anthropomorphous petroglyph of about 920 years age.

Spear Hill complex

Two petroglyphs were examined at sites of the Spear Hill complex (for a detailed description of this extensive complex of about forty boulder piles, see McNickle 1985). The '1917' date included in the calibration curve, located at site No. 9, is just marginally superimposed over a non-Woodstock anthropomorph (Fig. 8). The latter provided a series of twelve micro-wane width measurements with a mean value of 4.25 µm (range 3.0-5.0 µm). This corresponds to an estimated age of E904 (+160 -266) years BP. At the western base of site 7, a prominent group of three female anthropomorphs includes one particularly recent example. Although no quantitative data were collected from it, it appears to be about three times as old as the nearby '1881' date, having been made about E350 years ago (Table 2).

Motif	Wanes	Min. *A*	Max. *A*	Mean *A*	Age, years	Tolerance
Female SH7	No measurements taken				c. E350	-
Male 65B	10	1	4	2.00	E425	+426, -212
Anthrop. SH9	12	3	5	4.25	E904	+160, -266
Female 65B	Micro-wanes range from 10-15 microns				E2127-3191	-
Scar 65B	20	10	30	17.25	E3670	+2713, -1543
Circle 65B	14	75	125	91.07	E19 376	+7219, -3419
Circle 65B	14	110	180	125.74	E26 753	+11 545, -3349

***Table 2:** Quartz microerosion data from seven petroglyphs, at Woodstock 65B and Spear Hill 7 and 9, eastern Pilbara. Micro-wane dimensions in microns.*

DISCUSSION

Although Pilbara petroglyphs, long thought to be of great antiquity, have attracted European interest for at least 160 years, until now their age has remained entirely conjectural. This paper has, however, demonstrated a standardised method capable of routinely yielding credible age estimates for individual motifs in the granite-dominated eastern Pilbara. This development was facilitated by exploiting geochemistry and micro-geomorphology to date rock art directly, based on the theory of micro-wane formation (Bednarik 1992). The discovery of engraved historical dates (Bednarik 2000b) has now made it possible to create the first microerosion calibration curve for the Pilbara (Fig. 6) and use it to estimate the ages of older petroglyphs (Fig. 9). The motifs analysed comprise a fairly random selection, although there was perhaps some bias in favour of very young and very old examples, to acquire an initial appreciation of the time depth represented by a few of the rock art sites in the Pilbara, the world's greatest concentration of petroglyphs.

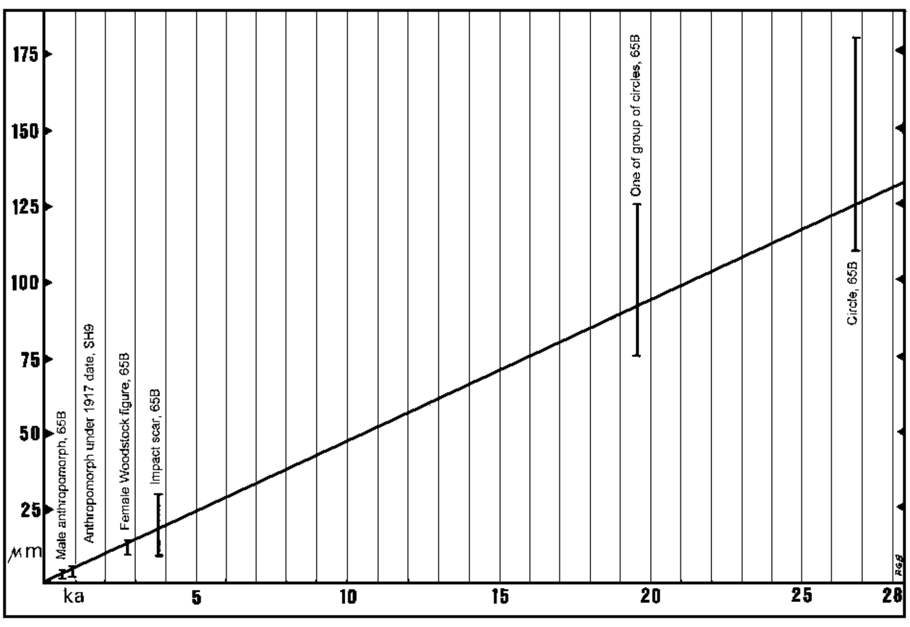

***Figure 9.** Age estimates of six petroglyphs of the eastern Pilbara, based on microerosion indices.*

Given the tendency of archaeologists to misinterpret or over-interpret dating evidence (Bednarik 1996; Watchman 1999), the data presented in Figure 9 require qualification:

1. They do not constitute secure and precise datings. Substantial tolerances are attached to each age, reflecting the spread of the primary data. The true ages of the motifs dated do not necessarily lie within the tolerance values, although this is highly probable.
2. The reliability of each result is largely dependent on the number of micro-wane measurements made.
3. The calibration curve the age estimates listed in Table 2 are based on is tentative and may need to be refined, although there is little prospect for such refinement in Australia. It may come from comparative data from similar arid regions in other continents. This possibility is currently under investigation.
4. To obtain reliable ages by microerosion analysis two or more calibration curves from two or more minerals are desirable. Therefore, a calibration curve for feldspar should be established for the Pilbara to render the ages in Table 2 more reliable and precise.
5. Crystalline quartz occurs in different forms. While their solution characteristics are unlikely to differ sufficiently to affect the rather coarse resolution of the method described above, this assumption should be tested by analysing surfaces of known age but different quartz types.
6. Much Pilbara rock art occurs on plutonic or extrusive igneous rocks such as gabbro, dolerite and basalt, making analysis of the microerosion behaviour of pyroxene, augite and olivine very useful for an expansion of the dating program described above. I plan to attempt this shortly.
7. The preliminary dates in Table 2 cannot be used to interpret archaeological traditions, occupation duration, or any of the other types of archaeological constructs often extracted from rock art. The few determinations now available tell us nothing about population densities, artistic trends, 'styles' etc. The rock art of the Pilbara may yield much older dates in due course, for instance from cupules.

It is likely that adverse climatic conditions during the Last Glacial Maximum, 20 000 - 15 000 BP, depopulated ecologically marginal regions, such as much of the Pilbara. This does appear to be reflected in its rock art, which indicates a lengthy period of very little, perhaps no, petroglyph production during the final Pleistocene, from the LGM to the establishment of present sea level in the early Holocene. The few age estimates presented here support such a scenario, but it requires extensive testing, through excavation and rock art dating. Hundreds of randomly selected rock art motifs need to be dated. Fortunately, the methodology described here could secure fairly reliable age estimations from numerous motifs and sites during quite brief periods of fieldwork.

This analysis has clearly demonstrated the presence of Pleistocene rock art in the Pilbara. Indeed, it suggests that petroglyphs of such antiquity occur commonly, because deeply repatinated, entirely non-iconographic motifs such as cupules and some linear arrangements account for >20 % of the region's rock art motifs. The ubiquity of Pleistocene rock art in the Pilbara has long been suspected, but until now the antiquity of the many thousands of known motifs was purely speculative. This research suggests that the Pilbara comprises not only the largest regional concentration of petroglyphs, it may also possess the world's largest surviving corpus of Pleistocene art, far larger than that in the caves of south-west Europe and older than any rock art known in the Americas or Africa. Older rock art does occur in Asia (Bednarik 1994c), but little is known about its extent. In Australia, Pleistocene rock art occurs in caves along the southern coast (Bednarik 1990) and in various northern and central regions (Bednarik 1993b), but these occurrences do not rival those in the Pilbara numerically. Finally, while rock paintings do occur in the Pilbara, they are rare and none is likely to be of Pleistocene age.

I suspect that the Pleistocene rock art tradition of Australia was brought to the continent by seafarers who arrived most probably from Timor or Roti (Bednarik 1997b, 1999; Bednarik and Kuckenburg 1999), about 60 000 years ago. It derives from earlier, but very similar rock art traditions of the Acheulian in southern Asia (Bednarik 1993c, 1994c), and resembles that of Europe's Mousterian (Peyrony 1934: 33-36, Fig 33). While Pilbara rock art does not document the beginnings of palaeoart, it is a manifestation of a magnitude unequalled elsewhere. I hope that this paper leads to a balanced reconsideration of its importance and protection.

ACKNOWLEDGMENTS

I thank the most senior traditional custodian of the Woodstock-Abydos region, Gordon Pontroy, for giving me permission to study and record the principal corpus of rock art considered in this paper, and for sharing with me some of his knowledge about the traditional meanings of the petroglyphs at site 65B. Thanks are also due to Julie Drew, Dr Jörg Hansen, Horst Jessen, Megan Lewis, Wolfgang Lösel and Dr Anthony Manhire, for fruitful discussions in the field; and especially to Nicholas Rothwell, for organising a return trip to the region in November 2000 to complete relevant observations.

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This paper was first published in *Records of the Western Australian Museum* 20: 414–429 (2002).

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