The first attempts at scientific dating of petroglyphs in the Pilbara region of Western Australia are reported. Using microanalysis, 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 the petroglyphs are of prehistoric age, and for instance at Windjana (Bednarik 1994a), 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 result of additive processes, in the form of pictograms (paintings, stencils, drawings, peckings, etc.), and as petroglyphs (peckings, etchings, grinding, 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 durable compounds that are of ages closely resembling the time the art was produced. For instance, paint residues present in the form of organic compounds (pollen, saliva, sweat, cell secretion), biological deposits (microbial crusts, lichen, coals), or pigments (charcoal, ochre, bitumen, etc.) are dated by radiocarbon and the carbonized residues may contain remains of organic binders or diluents (blood, saliva, orchid juice etc.) or pigments (charcoal, ochre, bitumen, etc.) as well.

Thus, the dating of petroglyphs remains one of the most intractable problems in archaeology. Indeed, of the methods proposed for petroglyph dating, only microcrystal analysis (Bednarik 1992) seeks to determine Dulland and Redhead's (1988)'event' target, which is the creation of the petroglyph. Moreover, most of the methods used are seriously impeded by inherent uncertainties. For instance, dating bulk carbonate concentrations in accretionary crusts may be severely misleading, particularly if the crusts are open systems (Bednark 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 microcrystal analysis (Bednarik 1992) seeks to determine Dulland and Redhead's (1988)'event' target. This paper presents the first application of this technique in Australia, and for the first scientific age estimates for Pilbara rock art.

Until the early 1990s, no inherently testable methodology had become available for the age estimation of rock art (Ward and Tumam 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), or the age of the rock surface that is the rock surface has been created, be it by natural or anthropic agents, it is subjected to chemical weathering processes. This leads to the prediction of a chain of unfalsifiable deductive arguments relating to the taphonomy of both the excavated sediments and the dated material (charcoal, paint residues). Moreover, as petroglyphs are essentially the results of reductive processes (pounding, abrading, engraving), the dated material (charcoal, paint residues) may contain remains of organic binders or diluents (blood, saliva, orchid juice etc.) or pigments (charcoal, ochre, bitumen, etc.) as well.

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 created by subsequent sediment deposition (Roseinfeld et al. 1981; Steinheinig et al. 1987, Cirelli et al. 1996), or detached and stratified fragments of rock bearing petroglyphs may be excavated in an occupational deposits (Hahn and Tindale 1930; Mulvanny 1969: 176; Thackery et al. 1981; Lohrbach 1992; Folliard 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 (charcoal, paint residues). Moreover, as petroglyphs are essentially the results of reductive processes (pounding, abrading, engraving), the dated material may contain remains of organic binders or diluents (blood, saliva, orchid juice etc.) or pigments (charcoal, ochre, bitumen, etc.) as well.
European of the 18th century, presumably living with indigenes, not only saw the rock art but added his own designs (see under 2500 words) he makes no mention of it. A recent discovery in the eastern Pilbara, however, suggests that a

Much later, Pilbara petroglyphs are briefly mentioned by Richardson (1886), while Withnell (1901) dedicates a page to

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, 1995a, 1995b, 2000a). Archaeological expectations were matched in all but one case, where the results matched those of other scientific analyses (Bednarik 1995b; Watchman 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 microerosion analysis involves no removal of samples, or even contact with the rock art, being a purely optical method.

The relationship wane width \( \Delta \) versus age, irrespective of actual retreat, is ultimately determined by the ratio of the rates of \( \frac{d \Delta}{dt} \) and \( \frac{d h}{dt} \) (Figure 2). 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 it can be accounted for. 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, 1995a, 1995b, 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.

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 remains unknown until the 1960s when the majority of the sites known today were located and first examined. Systematic 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 Robe Bar 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 petroglyphs are those of Wickham (1843) and Stokes (1846. 166-77), recording the visit of Depuch Island by H.M.S. Beagle in 1834. 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 1868, 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

Figure 2. Map showing the principal rock art sites of the Pilbara region, Western Australia.
In July 2000 I managed to locate a large series of engraved dates on one of the four major granite facies of the thinly populated north-west of the continent, there are no rock surfaces of historically known ages available to establish spans. The earlier components of these rich sequences of petroglyphs could well be of Pleistocene age.

Many boulder piles, and even the most cursory examination reveals the presence of many traditions separated by great time hundreds of kilometres long. Drainage of the occasionally cyclonic and always unpredictable rainfall is effected via ecology, there are reliable supplies of permanent water close to the surface, and aquifers are sometimes exposed even in the consequence of full glacial aridity.

A single shell date. Moreover, the Burrup would then have been over 100 km from the sea shore and rather inhospitable — petroglyphs. On the basis of this rather slender evidence, Lorblanchet constructed a chronology of successive petroglyph assemblages from fragments of a trumpet shell (Valinis). Since Wright’s first tentative but inconclusive forays into the question of petroglyphs just on Burrup (Lorblanchet 1986), are perhaps excessive. However, the number of petroglyphs now known 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 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.

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 to the 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 figures in question are now called ‘Woodstock figures’.

Since Wright’s 1968 examination and spectacular anthropomorphic 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 therefore began in 1967 (Bednarczuk 1973) and still continuing (Bednarczuk 2000b), differs from 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 anthropomorphic component of the rock art’s antiquity.

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An attempt was made by Lorblanchet (1992) to archaeologically date the petroglyphs at Gum Tree Valley and Skew Peak, the western Burrup Peninsula. He obtained a series of radiocarbon dates ranging in age from 7000 to c. 500 BP. 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.
eastern Pilbara, which provided the means of securing calibration values for this important rock art region (Fig. 4).

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 silcrete 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.

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 granite 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).

<table>
<thead>
<tr>
<th>Date</th>
<th>No. of determinations</th>
<th>Min. width</th>
<th>Max. width</th>
<th>Mean width</th>
</tr>
</thead>
<tbody>
<tr>
<td>1938</td>
<td>15</td>
<td>0.1</td>
<td>0.4</td>
<td>0.233</td>
</tr>
<tr>
<td>1941</td>
<td>8</td>
<td>0.2</td>
<td>0.3</td>
<td>0.237</td>
</tr>
<tr>
<td>1980</td>
<td>Micro-wanes are slightly &lt;0.1 micron</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>Micro-wanes too small to measure effectively</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1964</td>
<td>4</td>
<td>0.2</td>
<td>0.3</td>
<td>0.275</td>
</tr>
<tr>
<td>1941-</td>
<td>32</td>
<td>0.2</td>
<td>0.4</td>
<td>0.259</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1881</td>
<td>8</td>
<td>0.4</td>
<td>0.7</td>
<td>0.537</td>
</tr>
<tr>
<td>1917</td>
<td>8</td>
<td>0.3</td>
<td>0.7</td>
<td>0.412</td>
</tr>
</tbody>
</table>

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

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.
and the world (Bednarik 1994c).

old motif. This observation of the precedence of cupules is consistent at many sites in the region, and elsewhere in Australia

Although the cupules are not datable by the method used here, there can be little doubt that they are the earliest component

Several Karake-style crossed and bisected circles on the north-west side of the boulder appear to be of intermediate age.

continued onto the upper surface of the rock, and there could be taphonomic selection based on relative orientation evident.

are so heavily coated by accretionary deposits that microerosion analysis could not be attempted. They appear to have

highly visible dark boulder. The numerous motifs include female Woodstock figures. One of them, with distinctly S-shaped

quantitative count was attempted.

the same age as the Woodstock figure just mentioned: micro-wane sizes of about 2

years old. The ground area, about 70 cm across (Munsell 5YR-8/4, but very speckled), is significantly younger. It is about

largest circle yielded a mean value of 91.07

(E425 (+426 -212) years old (Table 2).

≈

anthropomorph. The quartz cleavage faces in this petroglyph appeared quite fresh under magnification. Analysis of their

recent reaction to the earlier circle, are significantly younger than the circle.

The immediately adjacent circle was also examined (Munsell 7SR-4/6) and an area of suitable accretion-free quartz edges

were measured. 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

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The ‘E’ in front of the age estimate indicates that it is derived from microerosion analysis.

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

developed on these edges were then measured in accordance with standard microerosion analysis (Bednarik 1992,

parameters within which future datings of Pilbara petroglyphs are to be conducted.

curve. This first determination for the Australian Pilbara is therefore best regarded as preliminary, subject to refinement and

especially the short range of the calibration values it is based on. Second, its reliability could be backed up by a feldspar

One of them, with distinctly S-shaped...
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 1993 age date included in the calibration curve, located at site No. 9, is just marginally superimposed over a non-Woodstock anthropomorph (Fig. 8). The latter involved 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).

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

<table>
<thead>
<tr>
<th>Motif</th>
<th>Wane</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Age, years</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female SH7</td>
<td>No measurements taken</td>
<td></td>
<td></td>
<td></td>
<td>c. E530</td>
<td>-</td>
</tr>
<tr>
<td>Male 65B</td>
<td>10</td>
<td>1</td>
<td>4</td>
<td>2.00</td>
<td>E425</td>
<td>+426, -212</td>
</tr>
<tr>
<td>Anthrop.</td>
<td>12</td>
<td>3</td>
<td>5</td>
<td>4.25</td>
<td>E904</td>
<td>+160, -266</td>
</tr>
<tr>
<td>Female 65B</td>
<td>Micro-wanes range from 10-15 microns</td>
<td></td>
<td></td>
<td></td>
<td>E1217-3191</td>
<td>-</td>
</tr>
</tbody>
</table>

**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 and 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. Crystaline 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 phaneritic 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 of other continents. This possibility is currently under investigation.

7. 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.

8. Crystaline 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.

9. 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...
ACKNOWLEDGMENTS

I thank the most senior traditional custodian of the Woodrock- Alyathorn region, Gordon Pootin, 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 meaning of the motifs. I also wish to thank Sharon Allen, Myfanwy Cotton, and Anthea Manhire, for fruitful discussions in the field; and especially to Nicholas Rothwell, for organising a return trip to the region in November 2000 to collect relevant observations.

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