KEYWORDS: ***Petroglyph – Cupule – Kakadu National Park – Radiocarbon – Oxalate***

MINIMUM AGE FOR A PETROGLYPH ON A BOULDER OF SIGNIFICANCE IN SOUTHERN KAKADU NATIONAL PARK, NORTHERN TERRITORY, AUSTRALIA

A. Watchman

Abstract: A remarkable set of carvings has been surveyed and traced on a rounded boulder within a rockshelter in the southern Kakadu National Park region of northern Australia. The oxalate in the coating covering one of the cupules forming the heel of a pecked macropod track has been dated. The age determination indicates that the carving was most probably made prior to 6600 years ago. Another crust at a nearby site associated with a five-pronged 'rake' has also been dated at 3425 radiocarbon years BP. These age determinations are consistent with other measurements and observations for the production of rock carvings across the tropical north of Australia.

Introduction

In 1989 ben Gunn rediscovered a remarkable engraved boulder in a rockshelter in the Coronation Hill region of southern Kakadu National Park (Fig. 1), which he referred to as Fenceline 12 (Fig. 2). This boulder has about 100 petroglyphs, mostly macropod and other animal tracks, some human footprints, partly concealed tracks and also some deep semi-spherical cupules (Fig. 3). A shiny dark mineral coating covers the upper rounded surface of the boulder. Later the same year the late Professor Rhys Jones and Sally Brockwell investigated the boulder as part of a resource assessment commission concerning Coronation Hill in the Stage III area in the upper headwaters of the South Alligator River valley. Jones believed that this site had great significance to the Aboriginal people because of its rarity, location in the region, unusual situation of the carved boulder within a rockshelter, as well as the hardness of the rock and the large number of the petroglyphs (Jones and Brockwell 1990: 36). He coined the expression 'cosmic egg' to reflect the probable enormous significance of this carved egg-shaped boulder, a conclusion that had also been reached by Gunn (1989: 14). The aims of the investigation were to record the carvings and determine the composition of the dark mineral layer covering the petroglyphs to assess whether dateable oxalate minerals were present.

The work at Fenceline site 9 (the site identifier used by Jones and Brockwell 1990 and previously referred to as site 12 by Gunn 1989) and at another nearby site (Fenceline 8, Jones and Brockwell 1990) was undertaken with assistance by the Djarwon Larich-speaking traditional owners, Mr Roy Anderson and Ms Jessie Brown. Mr Anderson is the brother-in-law of the late Mr Peter Djatbula who was the traditional owner of the area around Coronation Hill. It was Djatbula who had given permission for archaeological investigations to be undertaken in the area and had also stated the fact that the now existing ritual or secret, sacred associations had no restrictions on the engraved rock being viewed by women and other non-initiated people. Accordingly, Ms Margaret McGregor, who was at that time the Cultural Resource Officer for the National Parks and Wildlife Service in Jabiru was invited to participate in the fieldwork with Professor Rhys Jones and George Chaloup-ka. Margaret assisted Rhys in the tracing of the engraved boulder. Chaloupka had organised permission from both the Director of the National Parks and Wildlife Service (permit RK463) and the traditional owner Mr Peter McLivett for the collection of samples that would be used for radiocarbon assay.

Sample collections

Samples of oxalate crust that cover the upper surface of the engraved boulder at Fenceline 9 were collected from a single petroglyph and from the adjacent unengraved surface (off-art; Fig. 4). The engraved macropod track (a right foot) measured approximately 10 cm long and 3.5 cm wide near the heel. The relative differences in colour and thickness of the mineral coating gave the appearance that the long toe had been a later addition to a pre-existing cupule. The coating in the heel was darker and thicker than in the toe. Therefore it is likely that there were two episodes of carving separated by a relatively long time period.

An area of mineralised coating (about 0.2 mm thick) in the cupule (heel), measuring 1.5 × 1.4 cm was removed in a three-stage micro-excavation. The surface was lightly scraped using a tungsten carbide dental burr before two layers, each about 0.1 mm thick, were removed. The powders from each layer were collected on aluminium foil and saved for analysis and dating. A small chip was also removed from the edge of the excavated area for use in a cross-section and to determine thickness and lamination chemistry. Mineral

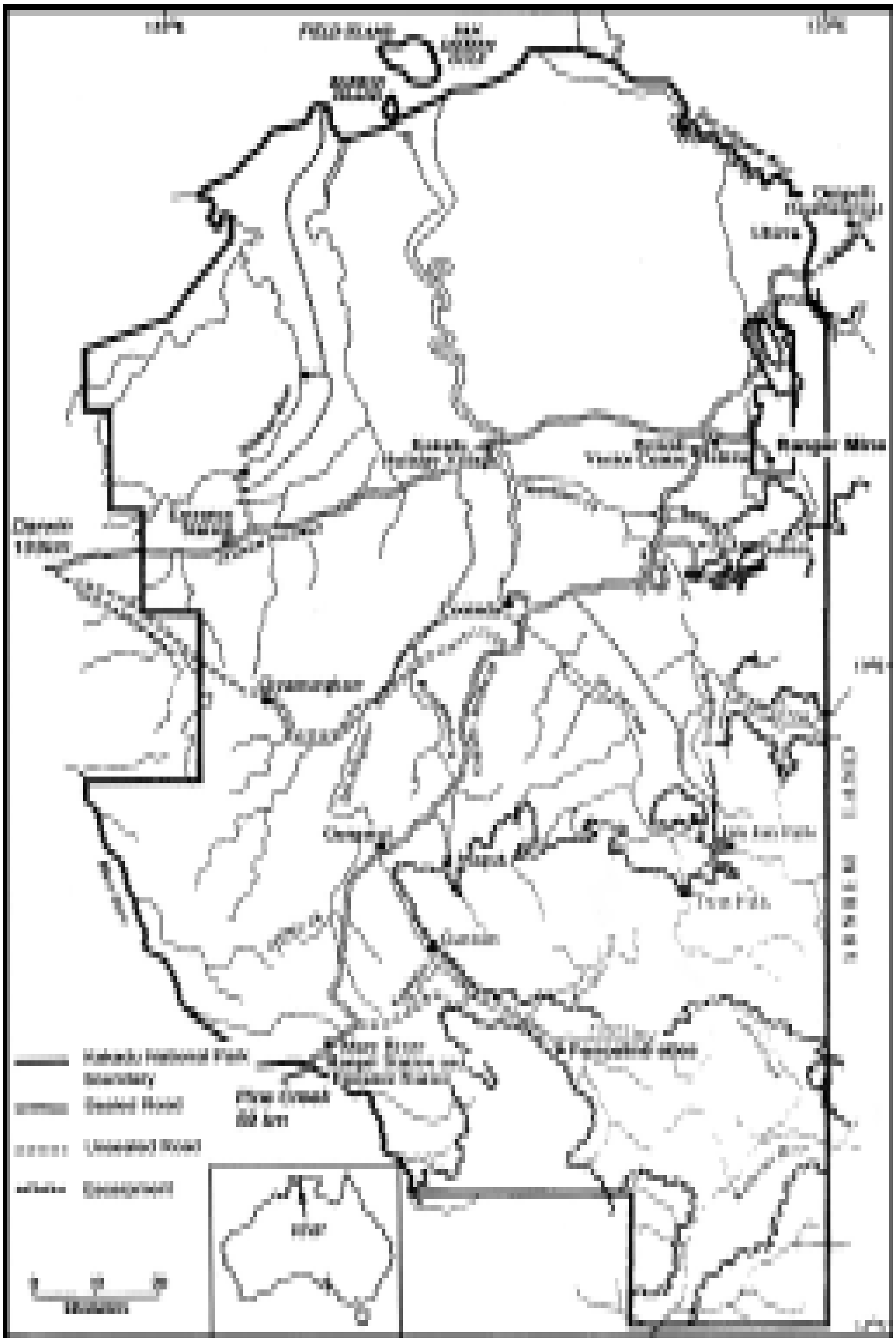


Figure 1. *Map of the South Alligator River valley in Kakadu National Park Stage III showing the locations of the two rock carvings sites.*

coatings were also taken from the shelter walls and from fossilised mud-wasp nests on the vaulted ceiling.

A detailed survey of the rockshelter (Fig. 5) was made including a tracing of the petroglyphs (Fig. 6). A sheltered area of 10 m × 5 m is formed beneath an overhanging roof of sandstone that has a sloping ceiling about 2–3 m high. Inside the alcove is a large spheroidal-ellipsoidal boulder measuring 2.1 m long ×1.45 m wide × 1.17 m tall. On the upper surface is a panel of pecked carvings covering an area 1.57 m × 1.22 m. One of the lower vertical faces has some faded red paintings, including that of a human figure. The boulder lies within the primary dripline and is in shadow throughout the day, enabling micro-organisms to establish colonies on the dusty and occasionally damp upper surface. This moist, shaded and dusty environment facilitates the formation of the shiny brown mineral coating (Watchman and Jones 1998).

Forty-two cupules were traced and 31 measurements made of the widths and depths of the larger ones (Fig. 7). The average width and depth of the pits are 3.92 cm (standard deviation 0.95) and 1.28 cm (std. dev. 0.54), respectively. Twenty-five pairs of macropod tracks were recorded; including one pair of much more elongated tracks than all the others. Nine single right tracks and four individual left tracks were also counted. A fascinating feature of the petroglyphs is the presence in the carved feet of both five-toed (four examples) and four-toed human tracks (three examples) as well as three four-fingered hands. The hands were differentiated from the feet by having splayed fingers compared to the roughly parallel toes of the feet, that do not have heels. The majority, eighteen pairs, of macropod feet (72%) are oriented so that the toes point directly upslope. The remainder either face downwards or across the slope of the boulder. Three of the five-toed feet face directly upslope and one is angled downwards across the slope. The four-toed feet all face upwards. Two of the four-fingered hands face down and the other one faces up.

Figure 2. *Photograph of the Fenceline 9 site showing the position of the carved ellipsoidal boulder within the rockshelter.*

Figure 3. *Photograph of the carved boulder at Fenceline 9.*

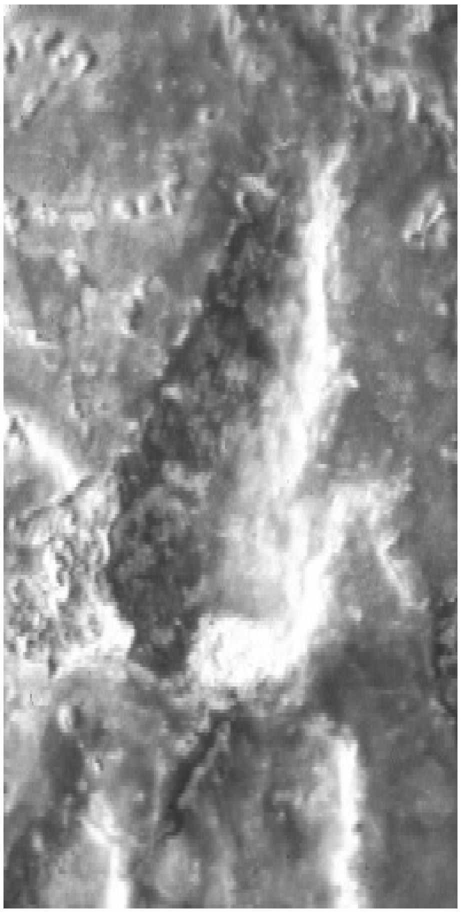
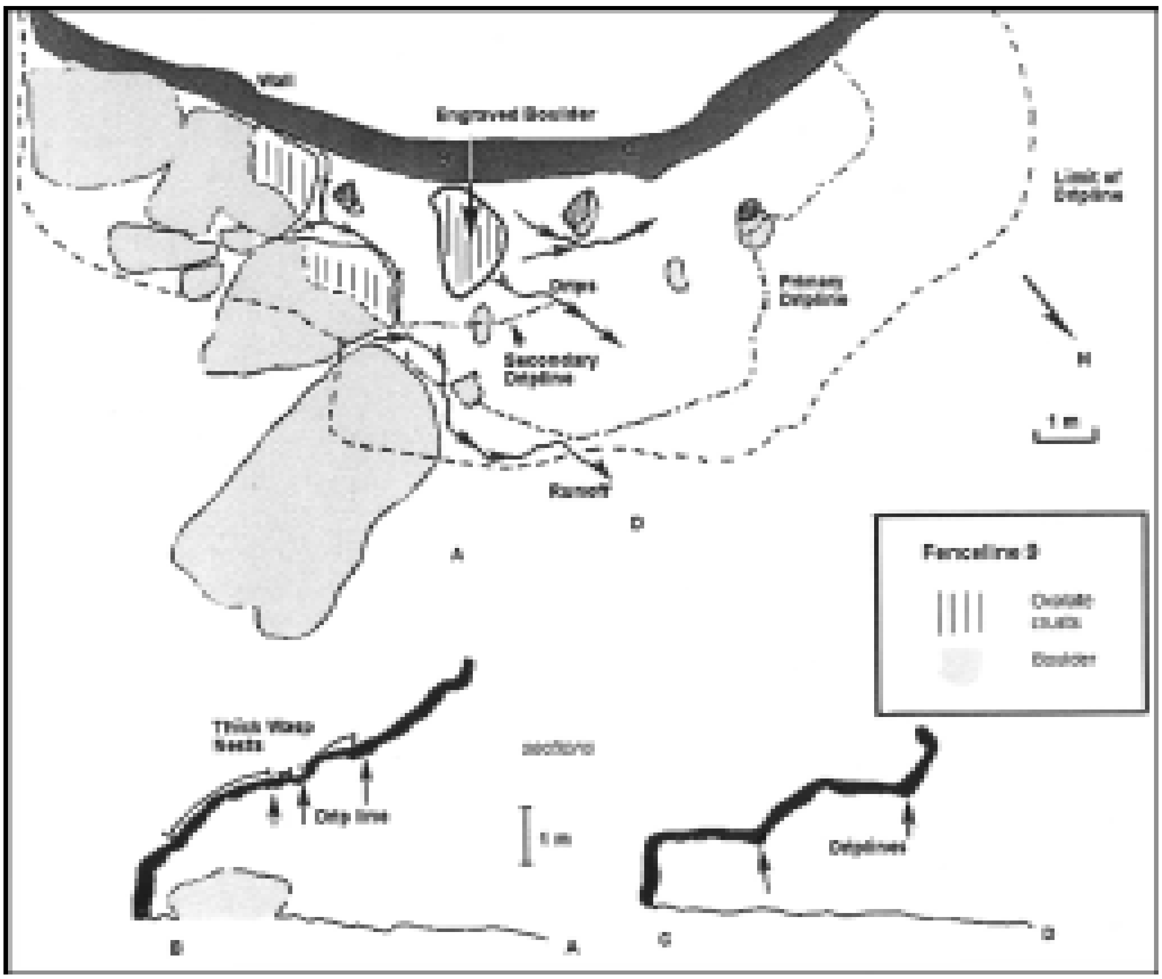


Figure 4 (left). *Photograph of the macropod track on the boulder showing the sampling location on the heel from where the powdered coating was removed.*

Samples were also collected from Fenceline 8, a site located approximately 200 m away (Fig. 8). Fenceline 8 is a small rockshelter with a low overhanging ceiling. The alcove has formed by the collapse of sandstone from the sloping ceiling, probably through the weakening action of intermittent water that flows along bedding and joint planes. Subsequent to the formation of the shelter the occupiable space has gradually filled up with sediment washing in from above and the sides, and rock-falls collapsing from the ceiling.

The sloping upper surface of one of the sandstone slabs that has fallen from the ceiling is carved with five abstract designs resembling the upturned heads of 'rakes', each with five prongs. The rake tines are each approximately 10 cm long. One of the most prominent carvings near the centre of the engraved panel was selected for sampling because it showed evidence of partial flaking of the mineralised coating. This upturned 'rake' petroglyph comprised five tines ranging from 6–8 cm long and spanning 14 cm wide (Fig. 8). An area of mineralised coating was systematically removed in two layers from the spine of the rake between the second and third tines (counted from the left). The samples were from the oldest part of the encrusted surface from within the petroglyph where some of the coating had already exfoliated. Off-art samples of mineral coating from 11 cm away were also collected to determine when the coating started

Figure 5 (below). *Plan and section drawings of the Fenceline 9 site showing the location of the carved boulder within the sandstone rockshelter.*



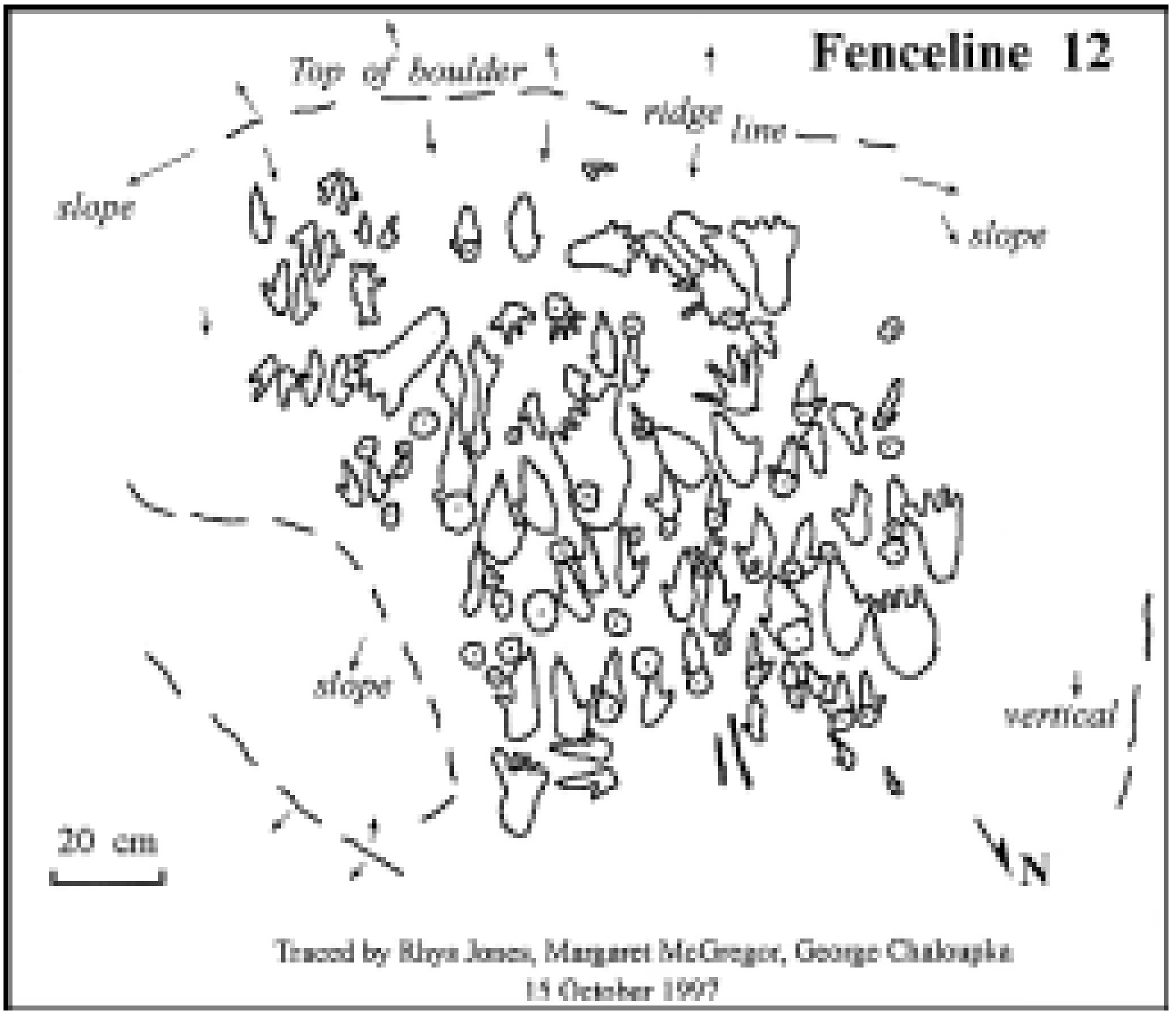


Figure 6. *Reduction of a tracing of the carved surface at Fenceline 9 made by Professor Jones and Margaret McGregor. Note the sampling location from within the cupule forming the heel of the macropod track.*

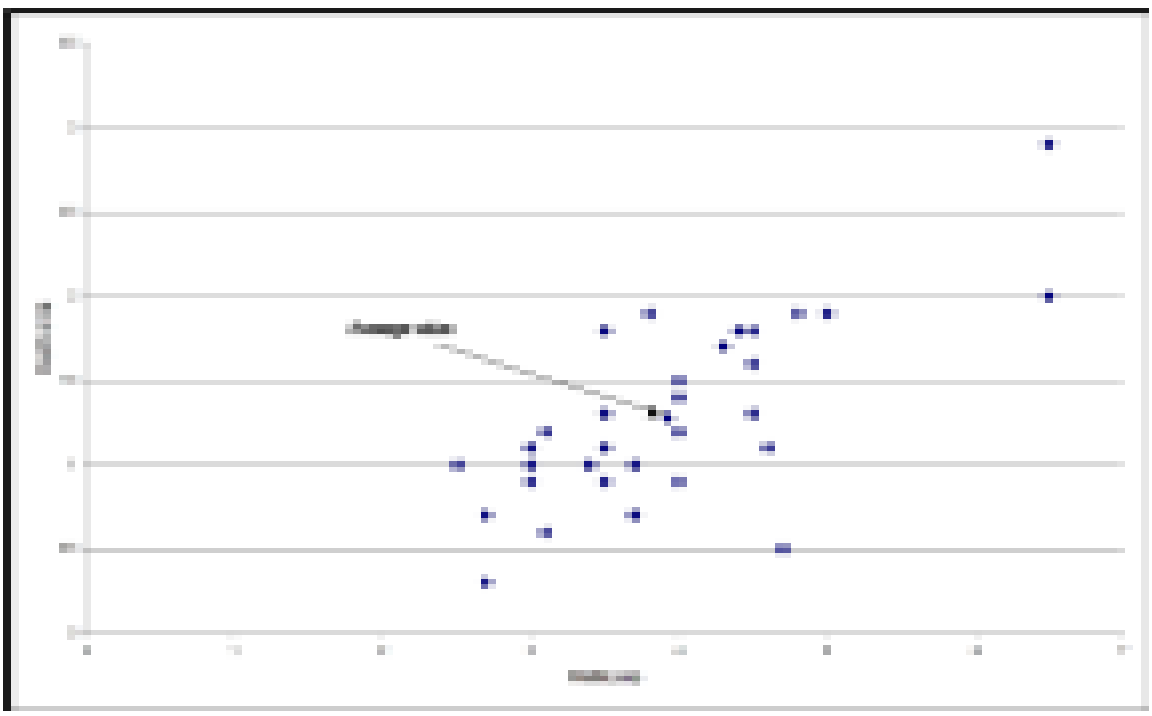


Figure 7. *Plot showing the relationship between width and depth of the cupules on the carved boulder, Fenceline 9, southern Kakadu National Park.*

Figure 8. *Photograph of the 'rake' petroglyph at Fenceline 8 showing the location of the sample removed for dating (the measuring tape is extended 13 cm).*

to form on that surface. A small flake of the coating was removed from the start of the third tine and this was later cross-sectioned for analysis.

A small sample of crystalline material was also collected from a narrow dried trail of urine, possibly from a wallaby or other animal that sat on the top of the boulder at Fenceline 9. The aim in taking that sample was to identify the substance and to find out whether carbon from urine could become incorporated into the oxalate-rich coating on the rock surface. Mud wasp nests adhering to the ceiling of the shelter above the carved boulder were also sampled. Several of these had relatively thick accumulations of laminated mineral coatings indicating substantial age since the nests were built. They were not associated with any paintings and so were taken for research purposes only, and future comparative analyses of luminescence and radiocarbon age determinations. All samples were analysed petrographically, mineralogically and geochemically prior to the dating of the oxalate minerals by accelerator mass spectrometry radiocarbon (AMS ^{14}C).

Analytical methods

The encrusted rock surface samples were examined by petrographic, scanning electron microscopy energy dispersive x-ray analysis (SEM/EDXA and element mapping, to determine the major element chemical components), and general area x-ray diffractometry (GADDS, to determine the mineralogy) in the Advanced Analytical Centre, James Cook University.

For radiocarbon analysis it was presumed in the field that the shiny dark rock surface coating contained oxalate salts because previous work in western Arnhem Land had indicated the presence of these datable components (Watchman 1990, 1991; Watchman and Jones 1998). The simplest way to remove the coating is by the micro-excavation technique (described in Watchman 2002). In the general method layers of the mineral coating can be removed in approximately 0.1 mm thick intervals from the present surface down to the underlying hard rock. Sequential removal of layers of coating allows for the measurement of a series of radiocarbon age determinations, and a degree of reliability and confidence in the results can be obtained from this micro-stratigraphic sequence (Watchman et al. 2000). An age determination for formation of the oxalate salt in the lowest layer provides an estimate for the minimum age of the petroglyph.

Whewellite ($CaC_2O_4.H_2O$) and weddellite ($CaC_2O_4.2H_2O$) are two oxalate minerals formed by the reaction between oxalic acid produced by microbes that live on the exposed damp and dusty surface. The micro-organisms use carbon from the atmosphere, and the oxalic acid they produce reacts with gypsum or other sulphate and calcium-rich minerals deposited from atmospheric dust fallout and salt crystallisation on the rock (Watchman 1990, 1991). These oxalate minerals form under slightly different conditions, depending on temperature and moisture (Watchman et al. 2001). The formation of oxalate in the northern Australian rockshelters is by a mechanism other than that identified in Italy (Del Monte et al. 1987) and in the Lower Pecos River area of the U.S.A. (Russ et al. 1995 1996), where lichens produce oxalate. Recent research (Watchman et al. in press) from the Kimberley region has shown that the rapid chemical oxidation of oxalate ions by permanganate does not fractionate the carbon isotopes, and provides reliable age estimates for the crystallisation of oxalate minerals. This research follows previous work by Vogel (1954), Gillespie (1997) and Hedges et al. (1998) demonstrating the veracity of the chemical method for the rapid extraction of carbon from oxalate salts.

The carbon was selectively removed from within the carbon-bearing mineral coating (whewellite) using chemical oxidation (Watchman 2001a, 2001b). Chemical oxidation is the preferred preparation method when an encrustation has been removed in a series of micro-excavations and the powdered coating can be handled directly. The powder is immersed in warm (< 80°C) dilute (0.1 M) sulphuric acid in a flask located within an extraction line (previously evacuated to remove atmospheric carbon dioxide) through which pure nitrogen gas flows. Potassium permanganate solution (0.1 M) is dripped into the flask to decompose the oxalate ions in a rapid reaction into carbon dioxide, which is collected in a Vycor tube immersed in liquid nitrogen.

The carbon dioxide gas released during the mineral decomposition is captured in a pre-treated Vycor glass tube. The tube is coated on the inside with a zinc mirror that is formed by heating a small zinc pellet to 725°C under vacuum for two hours. Fine iron powder is also weighed into the Zn-coated tube prior to collecting the gas.

To make graphite for AMS radiocarbon dating, the sealed tube containing the iron powder, Zn film and carbon dioxide gas is heated for two hours at 625°C and then at 700°C for eight hours. This method produces graphite-coated iron, which is pressed into an aluminium stub as the target in the ion source of the accelerator. Radiocarbon measurements were made at the Australian Nuclear Science and Technology Organisation, Sydney (Tuniz and Watchman 1994).

Sample description	ANSTO Lab. Number	Mass of coating powder	AMS 14C determination (Years BP)
Fenceline-9 Mud wasp nest on ceiling	OZD 224	0.04745	modern
Fenceline-9 Mud wasp nest on ceiling	OZD225	0.1156	3170 ± 120
Fenceline-9, off-art, base layer	OZD219	0.03078	4565 ± 70
Fenceline-9, base of crust in macropod track heel	OZD268	0.01040	6625 ± 100
Fenceline-8, base layer in 'rake' petroglyph	OZD266	0.01930	3425 ± 45
Fenceline-8, surface layer, 'rake'	OZD267	0.02095	680 ± 65
Fenceline-8 off-art, base layer	OZD269	0.01930	3100 ± 100

Table 1. *Identification and weights of samples used for radiocarbon assay and their age determinations. The percentage of oxalate minerals in the powder is not known.*

Results

Urea was the single component of the crystalline material associated with the dried wallaby urine. When water is added to this substance, ammonia and carbon dioxide are liberated leaving no discernible trace of carbon on the surface. In the damp tropical environment of the site it is unlikely that carbon in urine from animals is incorporated into mineral encrustations. This is important because the carbon isotopes in urine could have been fractionated by the animal's metabolism resulting in contributions to the carbon in oxalate that were not in equilibrium with the environment at the time. Mixing of carbon isotopes of different sources and isotopic ratios in this way could have affected the age determination.

Mineralogical analysis of the coatings at both Fenceline sites confirmed the presence of whewellite and also identified quartz and gypsum as other major components. One sample from Fenceline 9, the engraved boulder, indicated the presence of trichloroethane. This synthetic compound is a constituent of polyvinylchloride, a chemical associated with artificially prepared plastic films. Subsequent investigations and enquiries as to the origin of this foreign material on the boulder revealed that an employee of the National Parks Service had made a casting so that a replica could be made and displayed at a tourist location near the road between Jabiru and Adelaide River. Further observations revealed that the foreign carbon-bearing compound was only adhering to the surface and had not penetrated into the coating. Contamination of the samples collected for dating was therefore not a problem, and testing of the chemical treatment and dating process confirmed that the rapid oxidation of oxalate was not affected by the presence on the surface of this foreign substance.

Element mapping of the cross-sections revealed variations in the relative abundances of the major components. Sulphur, associated with sulphate minerals (gypsum and bassanite) occurs in a prominent layer near the present surface and in four thin laminations near the base of the Fenceline 9 cross-section. Calcium is also enriched in these locations as expected. Silicon, representing quartz, occurs in a lens on the present surface. Generally the encrustation is extremely fine-grained and laminated parallel to the base, indicating that clay-sized particles had settled and accumulated on the surface without any major bioturbation.

The Fenceline 8 coating is also well laminated and extremely fine-grained, except for a layer just beneath the present surface where silt-sized quartz grains are concentrated. The silty band is covered by fine-grained clay similar in composition to the underlying layers. A thin, discontinuous fine lamination rich in iron is present in the middle of the section, possibly indicating an episode of painting using ochre. Both sections indicate the uniformity of the layering and the relative consistency of minerals and chemistry throughout the coatings. This is an important consideration in the dating of the oxalate within the excavated layers because the analyses reveal fine stratified accumulation of homogeneous material.

Discussion

The engraved boulder is an exceptional cultural feature as it is the only known concentration of rock carvings in western Arnhem Land and it is the only occurrence of an intensively pecked boulder in northern Australia. It is also a rare occurrence of a pecked boulder within a rockshelter. Other engraved feet, tracks and cupules at rock art sites across northern Australia are not localised on a boulder, but form panels on rock walls or on small slabs within shelters. A painted and pecked macropod track has also been dated using this approach in the Victoria River district (Watchman et al. 2000a). Intensely pecked cupules are found in the Keep River area (Watchman et al. 2000b), but these are small and shallow, and generally distributed on rock walls outside of shelters. Deep cupules are found elsewhere in Australia (Taçon et al. 1997), and in Arnhem Land, for example in the west (Chaloupka 1993; Brandl 1973), and in the east (Betty Meehan pers. comm. 2003).

Pecked cupules are present throughout the world having been made by people in various parts of the world at different times (Flood 1997: 148). The oldest age claimed for this form of 'rock art' is for cupules at sites in central India which are said to be earlier than 100 ka (Flood 1997); the current research focus of the Early Indian Petroglyph Project team (Kumar et al. 2003).

Petroglyphs of tracks of animals and humans are widespread across the continent, particularly in the arid regions of northern South Australia and western New South Wales. A typical occurrence of such carvings on Panaramittee Station in the north-eastern part of South Australia was used as the type-site for the 'Panaramittee style' (Maynard 1976: 193). A thin veneer of manganese-rich rock varnish, a feature not found at the Fenceline boulder site, usually covers the art of the 'Panaramittee style' on exposed rock surfaces. The boulder at the Fenceline 9 site is the most complex and tightly packed display of animal and human tracks and cupules, which has yet been found in Australia. On any criteria the carved boulder is a remarkable rock art feature.

It has been at least four thousand years since the start of coating formation on the rock in an off-art situation and approximately 6600 years since the oxalate began to form in the cupule that forms the heel of the macropod track at Fenceline 9. At first these two age determinations appear to be conflicting, but the surface of the boulder is more exposed to abrasion and weathering because of visits by people and animals than the better protected surface within the depression. Field observations also indicated that the toe of the track was lighter in colour, thinner and probably made after the heel. The coating in the toe is therefore younger than on the surrounding rock surface and in the heel. Older mineral accumulations in the cupule are more likely because any dust that settles within the depression becomes bonded to the rock. The deposit within the cupule is thicker than on the surrounding rock surface providing support for the relative age differences.

The age for the onset of coating formation within the cupule that forms the heel of the macropod track is similar to other mid-Holocene age determinations obtained for cupules in the Keep River region near the border with Western Australia (Watchman et al. 2000b). There seems to have been either a mid-Holocene period of oxalate formation or cupule production that commenced at that time during an interval of continuous oxalate formation. The start of specific and favourable environmental conditions for oxalate formation in the region has not been well established although an indication of much older oxalate has been obtained from the Nourlangie region, farther to the north (Watchman and Campbell 1996).

The 'rake' carving at Fenceline 8 is younger than the cupule at Fenceline 9. Again the relative age difference between oxalate off-art and within the carving indicates the advantage that the depression had in trapping dust and forming oxalate, compared with a sloping and more exposed smooth surface. The age for oxalate on the surface of the coating (from within the upper 0.1 mm layer; 680 years) and that from the base of the same encrustation (3100 years) gives confidence in their micro-stratigraphic correlation. If conditions for oxalate formation within rockshel-ters in the Kakadu region have been continuous for more than 15 000 years (Watchman and Campbell 1996), then it would indicate (assuming no re-pecking) that the cupule on the engraved boulder was most probably made about 6600 years ago and the 'rake' petroglyphs were made more recently.

Acknowledgments

I especially thank Rhys Jones who suggested that I visit the site and attempt to date the carvings. Rhys was also prominent in arranging finances for the research. I also thank Roy Anderson, Jessie Brown, Margaret McGregor, Greg Ryan, Kate Lucas, Peter McLivett (a traditional owner). Special thanks go to George Chaloupka and the Director of National Parks and Wildlife Service for the permit (RK-463) to collect samples. George Chaloupka also obtained relevant permits and negotiated with traditional Aboriginal owners for the work in Kakadu Stage III. The Director of the Museum and Galleries of the NT provided a vehicle for the fieldwork. Dr Graeme Ward, Dr Mary Edmunds and other members of the research staff of the Australian Institute of Aboriginal and Torres Strait Islander Studies provided informed guidance for which I am most grateful. The Institute also provided financial support (R95/5074). Support for my work is from an Australian Research Council Fellowship.

Professor Alan Watchman
Department of Archaeology and Natural History

Research School of Pacific and Asian Studies
The Australian National University
Canberra, ACT 0200
Australia
E-mail: *Alan.Watchman@anu.edu.au*

REFERENCES

Birdingal T. G., R. Jones, B. Meehan, A. Watchman and N. White in prep. A minimum 9 ka bp age for a pecked cupule site in Ritharrngu country, eastern Arnhem Land.

Brandl, E. J. 1973. *Australian Aboriginal paintings in western and central Arnhem Land: temporal sequences and elements of style in Cadell River and Deaf Adder Creek art*. Australian Aboriginal Studies, Canberra.

Chaloupka, G. 1993. *Journey in time. The world's longest continuing art tradition*. Reed International Books, Sydney.

Flood, J. 1997. *Rock art of the Dreamtime: images of ancient Australia*. Angus and Robertson, HarperCollins Publishers, Sydney.

Gunn, R. G. 1989. Aboriginal rock art in Bulajang (Sickness Country), Kakadu National Park: a third survey, Unpubl. report, Aboriginal Sacred Sites Protection Agency, Darwin.

Jones, R. and S. Brockwell 1990. *Archaeological report on the Kakadu conservation zone*. Resource Assessment Commission, Australian Government Publishing Service, Canberra.

Gillespie, R. 1997. On human blood, rock art and calcium oxalate: further studies on organic carbon content and radiocarbon age of materials relating to Australian rock art. *Antiquity* 71: 430–7.

Hedges, R. E. M., C. Bronk Ramsey, G. J. van Klinken, P. B. Petitt, C., Nielsen-Marsh, A. Etchegoyen, J. O. Fernandez Niello, M. T. Boschin and A. M. Llamazares 1998. Methodological issues in the AMS 14C dating of rock paintings. *Radiocarbon* 40: 35–44.

Kumar, G., R. G. Bednarik, A. Watchman, R. G. Roberts, E. Lawson and C. Patterson 2003. 2002 progress report of the EIP Project. *Rock Art Research* 20: 70–1.

Maynard, L. 1976. An archaeological approach to the study of Australian rock art. Unpubl. master's thesis, University of Sydney, Sydney.

Russ, J., R. L. Palma, D. H. Loyd, T. W. Boutton and M. A. Coy 1996. Origin of the whewellite-rich rock crust in the Lower Pecos region of southwest Texas and its significance to paleoclimate reconstructions. *Quaternary Research* 46: 27–36.

Russ, J., R. L. Palma, D. H. Loyd, D. W. Farwell and H. G. M. Edwards 1995. Analysis of the rock accretions in the Lower Pecos region of southwest Texas. *Geoarchaeology* 10: 43–63.

Taçon, P. S. C., R. Fullagar, S. Ouzman and K. Mulvaney 1997. Cupule petroglyphs from Jinmium-Granilpi (northern Australia) and beyond: exploration of a widespread and enigmatic class of rock markings. *Antiquity* 71: 942–965.

Tuniz, C. and A. Watchman 1994. The ANTARES AMS spectrometer. Accelerators and lasers for dating rock art in Australia. *Rock Art Research* 11: 71–4.

Vogel, A. I. 1954. *A textbook of macro and semimicro qualitative inorganic analysis*. Longmans, London.

Watchman, A. 1990. A summary of oxalate-rich crusts in Australia. *Rock Art Research* 7: 44–50.

Watchman, A. 1991. Age and composition of oxalate-rich crusts in the Northern Territory, Australia. *Studies in Conservation* 36 (1): 24–32.

Watchman, A. 2001a. Dating oxalate minerals in rock surface deposits. In M. Jones and P. Sheppard (eds), *Australasian connections and new directions,* pp. 401–411. Proceedings of the 7th Australasian Archaeometry Conference, Research in Anthropology and Linguistics 5, Department of Anthropology, The University of Auckland.

Watchman, A. 2001b. Micro-excavation and laser extraction methods for dating carbon in silica skins and oxalate crusts. In G. K. Ward and C. Tuniz (eds), *Advances in dating Australian rock-markings: papers from the First Australian Rock-Picture Dating Workshop, Lucas Heights, February 1996*, pp. 35–39. Occasional Publication 10, Australian Rock Art Research Association, Melbourne.

Watchman, A. L. and J. B. Campbell 1996. Micro-stratigraphic analyses of laminated oxalate crusts in northern Australia. *Proceedings, 22nd International Symposium: the oxalate films in the conservation of works of art,* pp. 409–422. Editeam, Bologna.

Watchman, A. L., B. David, I. McNiven and J. Flood 2000a. Micro-archaeology of engraved and painted rock surface crusts at Yiwaralarlay (The Lightning Brothers site), Northern Territory, Australia. *Journal of Archaeological Science* 27: 315–25.

Watchman, A. and R. Jones 1998. Dating rock images in the tropical monsoon region of northern Australia. *Australian Aboriginal Studies* 2: 64–70.

Watchman, A. L., S. O'Connor and R. Jones in press. Dating oxalate minerals near the radiocarbon limit. *Journal of Archaeological Science*.

Watchman, A. L., P. Taçon, R. Fullagar and L. Head 2000b. Minimum ages for pecked rock markings from Jinmium, northwestern Australia. *Archaeology in Oceania* 35: 110.

Watchman, A., I. Ward, R. Jones and S. O'Connor 2001. Spatial and compositional variations within finely laminated mineral crusts at Carpenter's Gap, an archaeological site in tropical Australia. *Geoarchaeology* 16: 803–24.

RAR 21-700