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# DATING AUSTRALIAN ROCK-MARKINGS: AN INTERDISCIPLINARY CHALLENGE

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**Abstract**. Archaeometry is at the borders of archaeology, epistemologically related to physics, chemistry, geology and other 'hard' sciences. This has led to situations where 'archaeometrists' are often involved in the development of new tools and methodologies, sometimes independently of the needs of the archaeological sciences. Archaeologists, based in the social sciences, tending to be in awe of the tools developed by their 'scientific' colleagues, might uncritically accept the results obtained from scientific analyses, or be over-suspicious of them. Increasingly, however, there is a demand from archaeologists for evaluation of their assumptions and results by means of advanced scientific analyses. These scholars recognise the need for assistance in the characterisation of materials and in dealing with thorny problems of chronology. An approach integrating various disciplinary specialisms is particularly important in the application of sophisticated analytical techniques such as those using ion accelerators. In this overview paper, we review previous work, discuss current developments and problems, assess the potentials and limitations of this interdisciplinary field, and point to the potential of further methods.

Rock-markings[1], unlike stone artefacts and other manifestations of past cultural behaviour recoverable from archaeological contexts, generally have not been accepted as proper subjects of systematic archaeological investigation. The difficulty of obtaining secure temporal contexts for rock-markings has been a significant factor in this perception.

During the last two decades, the possibility of more accurately estimating the archaeological age of rock-markings has been pursued by various scholars in Australia and elsewhere, and a variety of techniques have been applied directly to materials comprising motifs or their immediate contexts. Recently, a major factor has been the development of Accelerator Mass Spectrometry (AMS) for radiocarbon analysis of sub-milligram samples of organic materials taken from rock-markings (Tuniz et al. 1998). AMS also has been used to analyse cosmogenic radionuclides produced on rock-surfaces in the expectation that they would provide a maximum age for petroglyphs[2]. Luminescence techniques, along with such radiometric methods, have become important in the context of the archaeological investigation of the Australian region because its cultural history apparently spans a period beyond the effective limits of radiocarbon analyses (Roberts and Jones 1994).

The results of recent research have been most encouraging and these are explored below. There also have been some spectacular claims of early dates for rock-markings and for pigments used in painting that have gained the attention of journalists and a public eager for speculation about the initial settlement of the continent; some interpretations have been unsustainable and there are warnings here for researchers. Concurrently, it has been stressed that there is a variety of interests in the materials and the results of research, including those of Indigenous Australians. There is need for a critical appraisal both of research design and of interpretation of results, and for a protocol for research that takes into account the concerns of all parties.

## Australian studies of rock-markings

The centrality of the various studies of rock-markings to archaeology and other disciplines in Australia is reflected and reinforced by various recent overview publications of both scholarly and popular orientation (e.g. Layton 1992; Chaloupka 1993; Flood 1997); there have been various regional studies (e.g. Jones 1985; McDonald 1992; Morwood and Hobbs 1995; Officer 1992; Stanbury and Clegg 1990); and a series of topical reviews and conference papers by specialist publishers (e.g. Bahn and Rosenfeld 1991; Pearson and Swartz 1991; McDonald and Haskovec 1992; Morwood and Hobbs 1992; Ward 1992; Faulstich and Taçon 1993; Steinbring and Watchman 1993; Morwood and Smith 1994; Thorn and Brunet 1995; Vinnicombe 1995; Ward and Ward 1995). Chronological approaches to rock-marking studies have been reviewed by Rosenfeld (1987, 1993).

Chronologies of rock-pictures have been developed using various stylistic criteria (e.g. Maynard 1977, 1979). Identifications claimed of extinct fauna (e.g. Basedow 1907; Mountford and Edwards 1962; Calaby and Lewis 1977; Lewis 1988) have suggested Pleistocene dates for carving and painting. Edwards (1971:358-359), following fieldwork in central Australia and identification of an extensive tradition of rock-carving there, argued for the considerable age of markings because of their advanced weathering, well-developed patination and association with elements of the "'Kartan' industry". Analyses of motif and superimposition have been the bases for regional temporal models (e.g. Chaloupka 1984, 1985; Lewis 1988), and have been considered useful starting points for archaeological interpretation; some currently are guiding the application of chronometric methods.

Stylistic analyses have failed to produce a generally accepted model, or even agreement as to what constituted a 'style'; some have been contradicted later by the results of the application of radiometric and other quantitative analyses. The assumptions of methods based on stylistic criteria have been criticised as not being quantifiable, falsifiable, repeatable or objective (Bednarik 1995a; cf. 1995b), as dependent upon the "… apparent iconographic content" of rock-markings (Bednarik 1995c: 71). Rosenfeld and Smith (1997) have defended the use of stylistic methods and argued for the complementary use of the more considered stylistic and chronometric methods for dating rock-markings. Andrée Rosenfeld (2000) has pursued this argument, questioning "… the tendency to prioritise chronometric age determinations on the grounds of their scientific nature", suggesting that the developments in chronometric dating should not lead to the neglect of archaeological methods founded in the stylistic features of representation, and arguing for an approach that uses the strengths of both while recognising their limitations. Stylistic analyses, Michael Morwood (n.d.) has suggested, could help resolve the problem of un-targeted sampling by focussing sampling strategies; chronometric data used to evaluate existing stylistic sequences could provide a contextualising procedure and avoid emphasis upon and sensationalising of old dates.

Edwards (1971: 363–4) argued that radiocarbon analyses of strata containing broken carved rocks in an excavation by Mulvaney at Ingaladdi provided an estimate of the minimum age for the carving (also Maynard 1979). Wright (1971: 28), and Maynard and Edwards (1971: 76) speculated on the relationship between a radiocarbon determination made on charcoal taken from the floor beneath the markings known as 'finger flutings' at Koonalda Cave. Rosenfeld systematically used charcoal from associated archaeological strata to argue a *terminus ante quem* for rock-markings at the Early Man shelter near Laura (Rosenfeld et al. 1981; Cole et al. 1995: 12).

In Australia, several relative and chronometric methods[3] have been applied to the problem of dating rock-markings more directly. Bednarik, in the 1960s, pioneered the use of lichenometry; in the 1970s, he used chemical analyses to define separate microscopic layers of ferromanganeous accretions on basalt (Bednarik 1979; cf. 1995c: Fig. 6); the progressive increase in organic content of this microscopic stratigraphy suggested that an open system was present and that attempts to date rock-imagery using these materials would be problematic. Bednarik subsequently explored the use of secondary, reprecipitated, carbonates enveloping a series of three types of rock-markings found on cave walls that he was studying in southeastern South Australia; in 1980, using these mineral reprecipitates, he obtained radiocarbon age-estimates and uranium-series results for the encased rock-markings (Bednarik 1984:figure 3, 1985, 1990, 1994a, 1996). The technique has been applied also to rock-pictures at sites in China (Bednarik 1997: 9-10). This initiative was followed by the work of Watchman (1990a) who used another mineral deposit, oxalate, as a source for radiocarbon analyses; this, and related work, is further considered below.

Robert Bednarik (2000a) provides a review of the application of various radiometric techniques directly to the immediate contexts of *in situ* rock-markings (also Bednarik 1995c, 1996); he has coined the term 'direct dating' in contrast to 'traditional archaeological methods' (1992a, 1998b[4]).

Over the last two decades, various 'direct dating' methods have been applied in Australia to rock-pictures of various types; three have provided the majority of age-estimates: 'Cation-ratio dating' of rock varnishes; luminescence techniques applied to quartz found in wasps' nests; and AMS radiocarbon determination of the organic carbon content of paints.

The use of 'direct dating' techniques has achieved varying degrees of success. The 'cation-ratio' method, substantially applied to rock-carvings in the Olary region of South Australia (Nobbs and Dorn 1988), has been subject to much criticism (and, essentially, was abandoned by Dorn in 1996), as has the application of thermoluminescence (TL) analysis of the archaeological contexts of rock-marking in Northern Australia (see below). McDonald and her co-workers (1990) reported radiocarbon analyses from the application of AMS technology to small samples of charcoal from sites in eastern New South Wales; the results were contradictory and difficult to interpret, and Jo McDonald (2000) explores the reasons for this. Jones and Loy and their co-researchers also used AMS analyses of organic materials from sites in Tasmania and the Northern Territory (Loy *et al*. 1990); interpretation of their results has proved to be problematic.

Critiques of the application of 'direct dating' have been made by Bednarik (e.g. 1996); overviews of methods and the potential of radiometric dating to Australian rock-markings, especially the application of AMS technique, have been provided by Watchman (1989, 1990b, 1993a), and Tuniz and Watchman (1994). Significant research in this field has been conducted elsewhere (e.g. Van Der Merwe *et al*. 1987; Hedges *et al*. 1987; Valladas *et al*. 1992; Clottes and Courtin 1993; Chaffee *et al*. 1993). Consideration of the results of dating research in Australia and Europe – evincing painting having been practiced in the late Pleistocene – has raised questions about human symbolic expression having developed independently in each region of the Old World (Watchman and Jones 1999). Bednarik (e.g. 1995c, 2000a) has argued the need for a critical approach to dating processes and results, and care in their interpretation; he has questioned the worth of 'high-tech' and expensive analytical techniques when simpler approaches, such as the 'microerosion method' (1992b, 2000b), first applied in Russia in 1990 (Bednarik, 1997: 9), might suffice and provide greater accuracy and reliability.

**Developments in the application of chronometric methods to rock-markings: 'cation-ratio dating'**

In a series of papers, Dorn and Nobbs have explored the application of the 'cation-ratio dating method', developed by Dorn in arid south-western USA (Dorn 1983), to a thin patina[5] covering rock-carvings in the arid Olary region of South Australia (Dorn *et al*. 1988; Nobbs 1989; Nobbs 1992). To provide estimates of relative ages, the cation-ratio method relies on the observation of differential mobility of cations, the ratio of the more mobile (potassium and calcium) to the more stable titanium. It is argued that, over time, the proportion of the sum of the formers' values decreases relative to that of the latter, so that a lower cation-ratio indicates an older age for varnishes.

Dorn attempted to obtain a chronometric measure by relating cation-ratio results to radiocarbon age-estimates. Dates of up to forty thousand years were claimed for Olary, but it appeared difficult to assess the cation-ratio results, there were problems of reliability and inconsistency, and styles could not be related to assessment of age (Dorn *et al*. 1988). Clarke (1989) and Lanteigne (1991) have questioned the assumptions behind the cation-ratio technique (Dorn 1983), and Watchman, also critical of the assumptions underlying its application to the Karolta rock-carvings, has questioned, based on his field and laboratory research, the ability of the method to provide consistent results (Watchman 1992a, 1992b, 1993b; reply by Dorn and Nobbs 1992). Bednarik (1992b, 1994b, 2000a) has argued that the method is difficult to express in scientifically accurate terms and has expressed concern over an uncritical acceptance of the assumptions on which Dorn based this work. Of the Karolta results, Dorn has reported that "Major uncertainties surround these previously published ages …" (1996a). In 1996, Dorn essentially abandoned as flawed this aspect of the cation-ratio technique (Dorn 1996b).

Dorn applied AMS to the analysis of minute samples of carbon in the layers of rock-varnish on the carved boulders at Olary (Nobbs and Dorn 1993). Some of his rock-varnish samples were found to have contained mixtures of materials, presumably derived from the immediate environment[6]; such a mixture, of course, produces an invalid referent for age-estimation of a carving.

Building on her understanding of rock-varnish processes, Dragovich (1984a, 1984b, 1984c, 1986, 1987) explored the relative dating potential of Dorn's cation-ratio model in the context of western New South Wales rock-carvings (e.g. Dragovich 1988, 1993). Aiming to compare cation-ratios with radiocarbon age-estimates from the same rock-varnish samples, Dragovich also attempted to obtain, from within layers of varnish, organic carbon for AMS analysis; however, in a study of Mootwingee Historic Site materials, despite concerted efforts, she was unable to collect sufficient sample material for adequate AMS determination of radiocarbon (Dragovich 1992:32), raising questions about the validity of such attempts. Watchman (1993c: 41) also found that his laser-induced extraction method (see below) did not produce sufficient carbon dioxide for an AMS determination from a ten-centimetre-square area of rockvarnish. Bednarik has pointed to problems with identification of the origins of materials being collected for analysis (1996, 2000a).

In her review of various aspects of cation-ratio dating as applied to rock-carvings, Deirdre Dragovich (2000) has concluded that the technique's requirement of small sample size make its potential as a relative dating method worthy of further investigation.

Margaret Nobbs and David Moyle (2000) have developed another aspect of the Olary cation-ration based research, the selection of samples for dating.

Except perhaps in the cases where rock-varnish has developed, a suitable method for dating rock-carvings – where materials have been extracted from, rather than added onto, a surface as in the case of paintings, drawings and prints – has been elusive. A chronometric method with particular relevance for rock-carvings, but one that has not been widely applied in Australia, 'microerosion analysis', has been developed by Robert Bednarik; the method and its potential and limitations as a tool in estimating the age of petroglyphs is described in Bednarik (2000b).

**Developments in the application of chronometric methods to rock-markings: luminescence methods**

Thermoluminescence (TL) analysis of suitable materials, often quartz, recovered from excavation contexts associated with rock-markings, has been applied to the task of dating archaeological sites in Australia for several decades (e.g. Adams and Mortlock 1974; Prescott 1982). Luminescence analysis depends upon the 'resetting' of the luminescence 'clock' to zero by exposure to heat or light, and the measurement of the development of luminescence since that time. The most publicised example of its application in Australia is the study by Fullagar, Price and Head (1996) of the Jinmium site in the Keep River area of the north-western Northern Territory; the study methods and results have been subject to criticism from various quarters, most agreeing that the results – implying ages of considerable antiquity for the associated rock-carvings, and even older ones for human occupation of the area – had derived from samples 'contaminated' by more ancient sediments (e.g. Roberts *et al*. 1998; Spooner 1998)[7].

The newer optically-stimulated luminescence (OSL) technique, a development of luminescence analysis and remarkable for its ability to analyse single grains (Murray and Roberts 1997), has the archaeologically important advantages of measuring only the rapidly bleached luminescence signal, thus obviating difficulties associated with assessment of the influence of the residual signal at the time that the 'TL clock' was re-set (e.g. Spooner

1998:178), and being able to be applied directly to the immediate context of rock-markings. OSL has been applied by Roberts and Jones to a series of longstanding chronological questions using sediments from several sites (Roberts and Jones 1994; Roberts *et al*. 1993; 1994a; 1994b; 1996; David *et al*. 1997) in an attempt to explore the period claimed to be beyond accurate radiocarbon age-estimation. In the northern Australian context, age-estimates significantly older than those obtained from other chronometric techniques have been obtained and have prompted considerable debate (e.g. Roberts *et al*. 1993, 1994a; Allen 1994; Allen and Holdaway 1995; Chappell *et al*. 1996). Of particular interest to the current discussion is the application of 'optical dating' to fossil wasp-nests associated with *Wanjina* and *Gwion* figures in a Kimberley site (Roberts *et al*. 1997; 2000).

The OSL and other 'direct dating' techniques, more directly applicable to manifestations of human symbolism left on rocks, appear well placed to assist in an exploration of changes in cultural behaviour over the considerable time-range being revealed in Australia. Roberts has established an OSL facility at La Trobe University (e.g. Roberts et al. 2000).

**Developments in the application of chronometric methods to rock-markings: AMS technique of measuring radiocarbon content**

Conventional radiocarbon analysis has been applied to the archaeological contexts associated with rock-pictures, usually to argue for a minimum age (e.g. Rosenfeld *et al*. 1981), and to provide age-estimates from materials such as carbonates directly overlying and underlying rock-markings (Bednarik 1984). The development of the accelerator mass spectrometry radiocarbon determination (AMS C-14) techniques for measuring radiocarbon content and its availability for application to rock-markings is of particular significance because of its small sample-size requirements allow the immediate contexts of markings to be analysed; results of such research should assist studies of human symbolism and ancient environments, manifestations of which have been captured in the naturally formed layers covering many rock surfaces. The major AMS analysis facility at Lucas Heights is available for determination of organic materials from rock-markings (Tuniz and Watchman 1994; Tuniz 2000), as are facilities for the identification of carbon compounds obtained from rock-markings and for the preparation of AMS targets from carbon samples.

Charcoal, used as a drawing material, could be ideal – because of its high carbon content and stability – for radiocarbon measurement. Charcoal from drawings has been subject to AMS determination in Australia (McDonald *et al*. 1990; David 1992; Armitage *et al*. 1998) and elsewhere (e.g. Van Der Merwe *et al*. 1987; Valladas *et al*. 1990; Clottes 1996; cf. Bednarik 2000a), but charcoal appears to have been used relatively infrequently as a marking medium in Australia, where ochres and other mineral pigments are more common. Paints containing pigments along with a small proportion of particulate charcoal, various organic materials, and accretions associated with rock-markings have been collected for analysis. Results have been reported of AMS radiocarbon determinations made from organic materials in ochres (Loy *et al*. 1990), of pollen (Gillespie *et al*. 1991), and microscopic plant fibres contained within encrustations (Watchman and Cole 1993). Bees' wax, moulded like putty and placed on rock-walls in rows of dots or modelled to form 'figures', as at some tropical northern Australian sites, has proved amenable to AMS radiocarbon determination; the compositions of waxes and processes of their deterioration over time have been studied by Nelson and others (1993; 1995), and their results were useful in tying to a chronometric framework an element of the 'Estuarine Phase' as defined by Chaloupka's stylistic model (1985). Paul Taçon and Murray Garde (2000) describe further applications of AMS analysis to bees' wax markings; the results lead them to an important ethno-archaeological conclusion: Some such markings may represent accumulations of motifs over extended periods rather than a single event with a particular intended composition; they anticipate that application of 'direct dating' techniques, providing accurate and reliable results, will allow clarification of this issue.

Various substances, including blood, fats and urine, have been reported to have been mixed with pigments used to mark rock-walls. Identification of the nature and source of carbon and other organic materials found with rock-markings is necessary in order to ascertain whether materials are integrally associated with the rock-marking events the age of which is to be estimated. Subsequently, it might be necessary to separate various organic fractions to permit one or another micro-organisms to be extracted as the target material for analysis. Following the initial work of McDonald and of Loy and their colleagues, questions have been raised about the anthropogenic origin of the materials analysed and the possibility of contamination of the sample by extraneous materials (McDonald *et al*. 1990; McDonald 2000; Loy *et al*. 1990; Nelson 1993; Loy 1994; Bednarik 1996, 2000a; Gillespie 1997).

At the workshop from which these paper derived, the importance of knowing the significance of the association between the material being analysed and the rock-marking event that this sample is supposed to represent was emphasised by several participants. This matter, and closely related ones of identification of the sample material and the possibility of contamination of the sample, is taken up by participants in these workshop proceedings (discussions by various presenters, and commentators, Iain Davidson and John Clegg).

Multiple samples from single motifs have provided age-estimates significantly different from each other, and have been difficult to interpret, being incompatible with other archaeological results, or with the visual evidence for the relative age of the motifs. Jo McDonald (2000) has explored these conflicts, pointing to micro-contamination factors, concluding that:

> Attempting to date rock-pictures using one sample per motif is methodologically inadequate. Micro-contamination may not be identifiable except by a multiple-sampling procedure, making

> the conclusions based on this dating potentially hazardous … .

Bruno David and his co-authors (2000) also have raised the possibility of contamination of samples. They obtained seven determinations from rock-drawings, whose inconsistencies

> … highlight the need to determine what has been dated. Were organic or inorganic, carbon-bearing contaminants present in the charcoal scrapings sent for analysis? Had these been eliminated during the pre-treatment stage?

If the drawings had been made with more than one piece of charcoal and some charcoal had been taken from non-contemporaneous fire remains, then the age-estimate obtained would not be directly related to the drawing event; indeed, any charcoal used may be thousands of years older or more recent that that event (cf. Bednarik 1996, 2000a).

The possible contamination of samples, selected to define the marking event, by extraneous organic carbon has been identified by Bednarik (1979, 1984), and investigated by Watchman (Watchman and Cole 1993; Watchman 1996, 2000), and Ridges (1995) has described how samples of ochre might include particles of lichen and of bacteria. Malcolm Ridges and his co-workers (2000) show how phototropic micro-organisms, some algae and bacteria, can recycle old organic carbon in an ochre deposit. This process introduces contaminants into the ochre, organic matter derived from the surrounding environment and unrelated to the painting event. A sample taken from any paint made from such pigment materials would be likely to contain a mixture of organic matter derived from non-contemporaneous natural processes, as well as that incorporated culturally into the paint at the time of its use, and thus would give radiocarbon age-estimates that are unrelated to the actual antiquity of the painting event.

Watchman has found few organic materials within paints; instead, he has targeted micro-organisms trapped within the encrustations of silica skins and oxalate crusts deposited over and underlying paintings, and overlying carved surfaces. He has found bacterial and fatty acids in such laminae, and has used these to derive maximum and minimum age-estimates for each rock-marking event (Watchman 1992c, 1993c). Watchman (1996) has provided a useful review of the methods and assumptions used in AMS analysis of micro-organisms obtained from silica skin accretions associated with petroglyphs, particularly addressing possible sources of contamination, including old organic dust, and has shown that investigation of cross-sections, and micro-analysis of laminae, can serve to obviate many problems. Watchman and his colleagues have demonstrated the application of these methods at several sites in northern Australia (Watchman 1993d; Campbell and Mardaga-Campbell 1993; Cole *et al*. 1995; Watchman and Hatte 1996; cf. Watchman 1998; Campbell *et al*. 1997; Watchman *et al*. 1997). Alan Watchman (2000) reviews the nature of the main encrustations, stressing that knowledge of the nature, source, chemical form and distribution of carbon within laminae is necessary when choosing extraction procedures and to indicate the confidence that can be placed in the resulting radiocarbon determination. Noelene Cole (2000), John Campbell (2000) Bruno David (2000) and others describe applications of these techniques at particular painting complexes in northern Queensland.

The related matter of the collection of very small samples from rock-markings is technically difficult. Drawing upon his considerable research experience into surface accretions, particularly oxalate crusts, at sites across northern Australia (1987, 1990a, 1991, 1992d), Watchman has developed a laser technique to sample organic materials from a particular layer – that might be argued to represent a relatively short time-span – covering a rock-marking (assumed to represent a single event); such a lamination might be less than one hundredth of a millimetre thick. The Focussed Laser Extraction of Carbon-bearing Substances process (FLECS[8]) uses a finely-focussed laser to induce combustion or decomposition of carbon-bearing material associated with a rock-marking event to obviate potential contamination introduced by physical or chemical extraction; the resultant carbon-dioxide is then used to prepare a graphite target suitable for ionisation by AMS (Watchman *et al*. 1993a; Watchman 1993c). Polarised-light microscopy, Fourier Transform Infrared Spectroscopy (FTIR), X-ray diffraction (XRD) and scanning electron microscope energy dispersive X-ray analysis (SEM/EDXA) can be used to identify the mineral composition of the various layers of the extracted sample, and so contribute to an understanding of the formation of the surface accretions. Watchman might also use gas chromatography (GC) and gas chromatography–mass spectrometry (GC-MS) to identify organic compounds in crusts[9]. Micro-excavation techniques have been developed for situations in which the FLECS method might be unsuitable (Watchman 1996: 25, 2000); Gillespie (1997: 436) has advocated permanganate oxidation as a more selective method for obtaining oxalate carbon rather than total combustion of all organic carbon present in a layer[10].

Ruth Ann Armitage and her colleague (2000) discuss the plasma-chemistry technique for dating samples obtained from rock-markings. A radio-frequency generated, low-temperature, low-pressure oxygen plasma is used in their laboratory at Texas A&M University to combust the organic component of the sample, leaving intact the substrate rock. This technique allows the extraction of any organic material present in the pictograph. Pretreatments are necessary to remove humic acid and other possible contaminants. The resulting carbon dioxide is collected and sent to the Lucas Heights laboratories for graphitisation and measurement. Prior cleaning of the system with oxygen plasma minimises contamination.

As well as problems concerned with sampling, identification, and extraction of suitable materials for radiocarbon analysis, there are matters relating specifically to the use of the AMS analytical method as applied to rock-markings that need to be considered. Some of these are common to conventional (counting of gamma spectra) methods as well as AMS determination, including differential production, distribution and absorption of the radiocarbon isotopes; others are particular to AMS. Claudio Tuniz (2000) describes these. Additional fractionation effects, altering the ratios of carbon isotopes, and caused by natural chemical or physical processes, may be introduced by chemical processing of samples and during AMS analysis, but can be corrected by processing and measuring against known standard materials. Contamination by modern carbon, a factor in AMS measurements due to the small mass of the sample, can be assessed during processing by reference to a similar mass of blank material, and a correction applied. Achievement of high-quality AMS measurements depends both on the precision of the isotopic ratio measurement and the application of well-known corrections (as described by Ewan Lawson and Michael Hotchkis [2000]). In an extreme situation, for samples that are both old and small, the number of available carbon-14 atoms may limit the precision. In summary, Tuniz stresses that the major contribution of AMS determination of radiocarbon to rock-marking research is due to a thousand-fold reduction in sample size making possible more accurate dating of the original material by minimising potential contamination and by extracting only a reliable fraction of the sample.

The matters of precision, sensitivity and accuracy in radiocarbon measurement processes are taken up by Lawson and Hotchkis in (2000).

**Collection of materials for analysis**

More accurate age-estimates will be provided by achieving understandings of the sources of sample fractions and the successful isolation of these, more secure relationship of samples to the marking event, and the minimisation of contamination in extracting samples and during radiocarbon determination.

As in other areas of archaeological research, it is necessary to give proper consideration to the bases of the collection of materials for analysis. Multiple sampling of motifs will provide greater confidence in results or identify problems for further investigation. However, while it might be desirable to collect many samples from each example of a variety of rock-marking motifs (according to the topic being studied), other factors will balance this primary concern. These include cost, aesthetic considerations, and the concerns of the custodians of Indigenous heritage. The first is plain; AMS analyses are comparatively expensive and an infinite number of determinations is unlikely to be available to the researcher. The second factor concerns the possibility of visual disfigurement of a marking despite the small area needed to comprise a useful sample.

According to the principles of contemporary research ethics, no investigation of Indigenous Australian cultural heritage should be undertaken without the support of the Indigenous persons and appropriate Indigenous community responsible for that cultural heritage (e.g. Ward 1998; AIATSIS 1999, in press). The necessity for appropriate consultation and negotiation, preferably with relevant persons at the site where samples are to be collected, has been emphasised by Ken Isaacson (2000). In our observations, professional Australian researchers are very prepared to involve Indigenous cultural heritage managers in their research and negotiate the bases of that research; this is an area in which the matter of informed consent is of great significance if the research is to be conducted ethically, and it is highly desirable that a proper written protocol be drawn up to protect all parties involved in the research process. In terms of desirable process[11] for this type of research, it is likely to be necessary to stage the field research (see below).

These and other aspects of the research process were explored by various presenters at the workshop, and emphasised during subsequent discussions (refer to account by the commentator, John Clegg [2000]).

Sampling is complicated where there has been remarking over time (and such re-marking might not be visible to the naked eye, or until samples are returned to the laboratory). The work of John Campbell and Alan Watchman (2000) at Walkunder Arch has demonstrated that evidence for multiple sequential re-marking can be found in a few millimetres of material collected[12].

This might be a spectacular representation of detailed research, but its significance needs to be evaluated also within a wider perspective. Samples such as these, comprising multiple layers of organic materials and pigment and thus revealing multiple painting events, and of minute areal extent thus minimising adverse impact upon a motif, also are comparable to limited-area, 'telephone box', excavations, long known by archaeologists to provide, at best, limited, and often misleading information about earlier occupations. They might evince existence of earlier painting events, but demonstrate nothing of the extent of a marking or of motif or technique. Only further, multiple, sampling will provide such evidence; but would this be required to be of such an extent as to be ethically unacceptable, as well as prohibitively costly in terms of analytical resources?

Nevertheless, recent developments have given the researcher some advantages. Application of micro-excavation techniques have introduced a not inconsiderable benefit: The ability to *sample minimally* can lessen damage to the rock-marking, an important aesthetic and ethical consideration; this point was emphasised by Bednarik (1979, 1992c), and Watchman (1993c). On the other hand, a sample must be sufficient to provide the required quantity of carbon-bearing material for analysis, otherwise the rock-marking is affected for no good purpose, and must be re-visited and re-sampled for a valid result to be obtained, with the attendant inconvenience, expense and greater adverse impact. Watchman (1993c: 41) wrote:

> The size of the rock surface sample collected for dating depends to a large extent on the percentages and compositions of the carbon-containing substances in the coating. As the chemistry of a coating is not known until after analysis, it is a sound practice to collect and analyse a sample of the accretion from the same rock face as the art before dating the encrusted art.

The protocol implied here, and made explicit by John Clegg in discussions at the Dating Workshop, has been explored in the paper by Claire Smith (2000) and is in the process of being implemented in the field.

The dilemma between the desirability of a large number of samples and the various and costly contraindications is likely to remain with the dating researcher for some time. What extent of data collection is required to obtain not only an accurate age-estimate for each stratum of painting but one which is meaningful in terms of the research questions being posed? And how will we know? David Lambert (2000) has suggested that a means for exploring these questions might be found in the salvage use of sites of rock-markings that have been disturbed or might be the subject of destructive action. Such a project would require the readiness of researchers to work promptly with cultural heritage managers, both the State authority and the local Indigenous custodians.

These problems of materials collection – in view of the very limited sampling likely to be practicable in the foreseeable future – are no less restricting than the analytical and technical problems explored by various contributors. They should prompt extreme caution in the interpretation of the cultural meanings of any age-estimates. Under present circumstances, any claims beyond those of the level of “a rock-marking event happened here at a time within the range of X to Y (radiocarbon) years ago” might be unwarranted or misleading.

## Archaeology and archaeometry: terminology and various complexities

Archaeometric dating means different things to different users. For some, the ‘dating’ process might include every procedure from sample selection to publication of a reasoned estimate of the age of a particular event; for others it means the unseen – perhaps mysterious – application of a ‘black box’ technology in a ‘dating laboratory’ to a piece of charcoal that produces a number that can be uncritically re-reported as a ‘date’. Radiocarbon determination applied to organic materials obtained directly from paints[13], or the immediate contexts of rock-paintings (as opposed to age-estimates made on materials from excavation contexts the strata of which have to be argued to be ‘associated’ with nearby imagery) is among the techniques that have been termed ‘direct dating’.

There can be problems with the use of the term ‘direct dating’ as there are with the expression ‘radiocarbon dating’. Its uncritical use can lead to sloppy thinking, ill-conceived research, and a littering of the literature with unsubstantiatable and possibly (mostly we do not know their value) inaccurate and misleading results, euphemistically called ‘dates’. This much should be clear from the review of potential difficulties with the applications of various techniques made here, and has been cautioned for some time by others (e.g. Bednarik 1996, 2000a). It is desirable to recall that we are dealing with *estimates* of ages. In discussions of age-estimates or of the process of obtaining age-estimates for various rock-marking events, it is useful to distinguish the various procedures, to use appropriate terminology, and to be aware of the necessary qualifications obtaining to results; it is our observation that some archaeological users of chronometric data need reminding of these aspects (Ward 1995).

Estimations of age of samples from rock-markings may be based on analyses made, for example, by radiocarbon or luminescence scientists with great sensitivity, precision and even accuracy (Lawson and Hotchkis 2000); analysts will present statistically valid data based on decay phenomena, but they are merely estimates of the age of organics or quartz luminescence and will not necessarily relate directly to the date of significant cultural event that is the subject of research. From any sample, the radiocarbon laboratory’s analysis of its residual radiocarbon content produces a result expressed in counts per unit time (of atoms in accelerator mass spectrometry; of radiations resulting from isotopic decay events assessed by conventional counting techniques). The counting period is variable, but the resulting estimate can be averaged over the time (usually counts per minute) to produce a qualified estimate of the radiocarbon content of the sample. This determination is expressed in two parts: an estimate of the count and an estimate of the standard error that necessarily qualifies this counting estimate. This laboratory radiocarbon estimate then requires evaluation in terms of various other factors such as fractionation effects (discussed by Tuniz 2000). Eventually, it can be interpreted for the user in terms of an estimate of the number of solar years ‘before present’ (by convention A.D. 1950) since the event that produced the radiocarbon in the sample. This laboratory age-estimate is scaled against an estimate of the ‘half-life’ of the carbon-14 isotope, either the old ‘Libby’ estimate of 5568 years or the newer estimate of 5573 years.

But the statistical uncertainty – ‘error’ – factor accompanying a laboratory’s expression of the age-estimate or the age range is not the only source of potential problems that might qualify the result, and many of these other factors are more the responsibility of the fieldworker and should be discussed in detail with the dating scientist. The researcher seeking to ‘date’ a rock-marking must be aware of a variety of intervening factors and decide that various sources of potential error have been eliminated or minimised before claiming responsibility for a ‘date’ for a particular historical event.

The researcher must evaluate critically factors associated with the selection of targets, the methods of sampling, the meaning of the data provided by the physiochemical analyses, and the significance of the resultant data for dating of the behavioural event being investigated. What is required is a considered event-oriented research process rather than an uncritical ‘date’-oriented one.

To emphasise the point that there is no such thing as a simple ‘direct date’, it is worth considering the complexity of the development of the mineral crusts and skins – microscopically visible in cross-section – formed on a rock-surface at its interface with the atmosphere, that cover or underlie many rock-markings in tropical Australia (Hughes and Watchman 1983; Watchman 1987, 1990a, 1991; Watchman *et al*. 1993b; Gillespie 1997). These encrustations, which have provided sources of the majority of samples of organic materials so far analysed, may be comprised of many layers of alternating crust and pigment due to periodic re-painting (Clarke 1978; Mowaljarlai *et al*. 1988; Clarke and Randolph 1992; Watchman 1992e; Sale 1995), with underlying markings invisible until overlying pigment is removed; furthermore, each layer of encrustation might be of a different composition (Watchman 1987) and from a variety of potential sources, with no one process likely to be responsible for the formation of an oxalate, for example (Watchman 1990a). Because of the multiple layering, it is inappropriate to take a sample of pigments and organics that might include all layers or that might include material from an adjacent layer, and expect to 'date' the last, visible image – this merely would produce an 'average' result for the series of layers. Because many of these encrustations have been shown to be mineralogically complex, reflecting not only geological bases, but also environmental and climatic changes, as well as anthropogenic events, any dating analysis might be complicated by a variety of factors. Factors influencing the rate and nature of salt and dust accumulation include local variations in microclimatic conditions within a rock-shelter (Watchman and Campbell 1996:419), and the oxalate salts might contain atmospheric carbon dioxide that has derived from a complex pathway captured by biological action by bacteria or algae. Watchman and Campbell (1996:415) wrote of the composition of organics in crusts, that the most likely source of oxalic acid, and therefore oxalate crystallisation, is considered to be the growth of algal colonies on the periodically damp surfaces.

While the carbon encapsulated in each of the layers of encrustations could be used in AMS analyses, and the development and application of various micro-excavation technique have, to a large extent, lessened the problem of precise sampling, and the methods have been demonstrated to produce consistent and credible results, it is clear that the various processes of crust formation need to be investigated and understood before a valid result can be obtained.

## Further research possibilities

During the presentations and discussions at the workshop several new areas of research application were identified.

Miniaturisation of samples analysable by AMS is developing significant possibilities for Australian Archaeology. Separation of reliable fractions from within the original organic samples can minimise contamination of the target materials from modern organics. This is leading to the extension of the datable time span, beyond the forty-thousand-year (40 ka) limit assumed so far as the limit for radiocarbon analysis of archaeological materials in Australia. The fact that the intrinsic accelerator background is 60 to 70 ka supports the idea that there is potential for this extension.

New materials can be dated. A pertinent example is the traces of pollen in the mud-wasp nests taken from Kimberley sites and analysed by OSL using the quartz contained in the nest material; such pollen has the potential to be used in AMS analysis. This would be a new way to corroborate OSL results used to demonstrate the antiquity of colonisation of Australian by Indigenous peoples.

New archives can be revealed, such as the micro-stratigraphic sequences in surface accretions on rocks that allow the identification of ancient pictographs hidden within oxalate encrustations. Microscopic samples of organic materials present beneath rock-varnish can be analysed to provide minimum ages for rock-carvings.

Other long-lived radionuclides, such as $^{10}$Be (1.5 Ma) and $^{36}$Cl (301 ka), produced *in situ* on rock-surfaces can be analysed by AMS to determine the age of the surfaces, and setting an upper limit for the age of ancient human markings.

## Conclusion

A variety of methods have been developed to determine the chronology of ancient rock-markings, and the application of 'direct dating' techniques over recent decades has shown considerable promise. Despite the sampling and analytical complexities, the costs of achieving ethical fieldwork and a desirable number of analytical data, it is unarguable that these methods are leading to great progress in the dating of Indigenous Australian rock-markings and of ancient rock-imagery in other parts of the world. At the Workshop held at Lucas Heights, during three days of February 1996, archaeologists, archaeometrists, and other analytical scientists discussed these matters and many related aspects of dating.

We stress that dating of rock-markings provides reliable results only if there is a close interaction among archaeologists, geochemists, environmental scientists, archaeochronologists, and Indigenous custodians in all phases of the research, in sample-collection, analysis and interpretation. Elsewhere, we have outlined protocols, emphasising research processes and research ethics, that we consider will enhance communication across the various disciplines and interests involved with attempts to date rock-markings, and reinforce the values inherent in an interdisciplinary approach to such research.

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1 Rosenfeld (1993:71), in her seminal review of evidence of the age of rock imagery in Australia, has used the term ‘markings’ to differentiate from ‘rock-art’ “… other rock-markings such as finger flutings, handstencils, abraded grooves and battered rock ridges” (cf. Forge 1991). However, *pace* Rosenfeld and Forge, problems of what is ‘art’, and of recognizing emic and etic approaches, and wishing to avoid imposing upon the original markers or owners any interpretation of their behaviour without detailed research and other considerations, and wishing to stress an ethnographic rather than an ‘art appreciation’ perception of the materials in question (cf. Mowaljarlai *et al*. 1988; Ward 1992), we find the neutral terms ‘image’/’imagery’ and ‘pictures’, and especially ‘mark’ / ‘markings’, to refer to all categories of carvings, drawings, paintings, and modelling of bees’ wax, made into and onto rock surfaces, or any modification of such a surface, attractive in their generality and relative lack of assumption. Clegg (1978:42,57) has defined as a ‘mark’ any a modification of a natural situation that ‘is *probably* a human artefact’ (emphasis added; also usage of Layton 1992:141; Sale 1996); there would be instances, however, when the anthropogenic origin of markings should be argued rather than inferred, and this matter, as we are aware, is complex within Indigenous Australia.

2 An example is the use of $^{36}Cl$ analysis made for sites in the Côa valley, Portugal (Phillips *et al*. 1997), but an application severely challenged (Bednarik 1998a:811).

3 Re the terms ‘relative’ and ‘chronometric’: the latter is favoured over ‘absolute’ because of the potentially misleading connotations of the unquestionable ‘absolute’; as well, chronometric values are usually compared with, guaged against, calibrated by other criteria.

4 Bednarik (1992b:279) described ‘direct dating’ as the means for estimating age by “… the investigation of features related to the art itself, which either date it (e.g. pigment), predate it (e.g. the rock art’s medium, or the particular surface it was executed on), or postdate it (e.g. later cracks dissecting a motif, or precipitates deposited over the art)”; ‘direct dating’ “… refers to methods of obtaining absolute or relative numerical ages for rock art from a feature or substance that is physically related to the rock art” (1998b:411).

5 Ranging between five and two hundred microns; known as ‘rock-varnish’ or ‘desert-varnish’.

6 Questions of the integrity of Dorn’s AMS-analysed varnish organics were raised by Beck and others (1998; Malakoff 1988; cf. Dorn 1998); Malakoff (1999) later reported that a faculty panel established by the Arizona State University had concluded that “the evidence did not support allegations that Dorn had added coal or charcoal to rock varish samples”, and that studies showed that these materials were found together naturally.

7 Richard Fullagar has expressed the view that conflicting opinions of the optical and thermoluminescence age estimates persist, and that the dating of initial human occupation at Jinmium is not yet resolved (cf. Roberts 1998; Price 1998a, 1998b; also Head 1996).

8 Acronymania? ‘Laser’, in turn, derives from Light Amplification by Stimulated Emission of Radiation.

9 Alan Watchman, personal communication, February 1999.

10 Gillespie (1997:436) also defined conditions necessary for successful analysis: If direct radiocarbon dating of the abundant rock art-work in Australia is to be done, other organic residues must be found which: a. can be unequivocally tied to the event of painting the rock, b. contain carbon contemporary with that event, c. can be extracted, purified, identified, and d. are present in sufficient quantity for this to be reliably done. Bednarik (1996) advocated identification at the molecular or object level.

11 AIATSIS 1999:27-39, in press.

[12] See reproduction on cover of the 2000 volume of Occasional AURA Publications of photomicrograph of 2.11 mm micro-section of a series of rock surface accretions from the Walkunder Arch Cave (Cape York Peninsula); caption of Plate 1 in Campbell (2000).

[13] A 'paint' usually comprises non-organic pigments, a diluent and binders, and, typically, other, adventitious inclusions, including organic materials.