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Short Contributions

Direct Dating Results from Australian Cave Petroglyphs

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The ^{14}C dates of carbonate precipitates have occasionally been used to estimate the age of rock art. To investigate the prospects of this direct dating method, speleothems physically related to various petroglyph traditions in two South Australian caves were analyzed. It is proposed that one of the principal factors in the isotopic geochemistry of the types of speleothems sometimes occurring together with rock art is their porosity, which can facilitate rejuvenation through the filling of voids by much younger precipitate.

INTRODUCTION

The term “direct dating” of rock art refers to methods of obtaining absolute or relative numerical ages for rock art from a feature or substance that is physically relatable to the rock art. Such a feature may be a component of the paint used in a rock painting, which is thought to be of the same age as the art (a pigment, binder, extender, solvent, or an incidental component, such as pollen, brush fiber, etc.); or the feature analyzed may be younger than the art (e.g., a later crack in the rock dissecting the motif, or a precipitate deposit formed over it), or it may be older than the art (e.g., the surface on which the art is executed, or a lichen thallus dissected by a petroglyph line) (Bednarik, 1981, 1992). The basic requirements of direct dating of rock art are that the physical relationship between the feature being dated and the evidence of art production is indisputable and that the interpretations of any results are falsifiable. Sediments covering rock art, for instance, also relate to it physically; but any inferred chronological relationship between charcoal particles contained in them, and the rock art is not necessarily testable (Bednarik, 1996).

The techniques so far used in attempts to date rock art directly include methods to estimate the ages of accretionary mineral deposits (through their organic carbon content, oxalates, or from assumed rates of cation leaching), those of mud-daubing insect nests (through the thermoluminescence of quartz grains concealed in these), of microerosion phenomena (especially microscopic wanes on edges of mineral grains fractured in the production of petroglyphs), and of organic components of paints (only charcoal pigment used convincingly so far; see Nelson [1993] for critique of analysis of blood residues) (Loy, 1994). However, the first feature used for

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direct dating of rock art was secondary (i.e., reprecipitated) carbonate found as laminar deposits with rock art (a few earlier attempts of direct dating are on record but did not result in tangible knowledge about the age of the art concerned) (Grant, 1965; Denninger, 1971). In the South Australian site Malangine Cave, such laminae were found both under and over petroglyphs, and they yielded the first radiocarbon dates from such speleothems (Bednarik, 1981, 1984).

It was always assumed that this method is subject to various limitations. Speleothems may experience "radiocarbon rejuvenation," for example, where porosity is available for deposition of younger carbonate, as well as through isotope exchange in the presence of moisture. This led to the assumption that such dates are probably conservative, minimum estimates. However, the effectiveness of such rejuvenation processes remained unknown, and other possible sources of contamination were considered but not resolved (Bednarik, 1994). Here I present some new information that may be relevant to further work on this topic.

EARLY WORK

Radiometric analyses relating to the dating of cave petroglyphs in the Mount Gambier Tertiary limestone karst of South Australia have been conducted since 1980. Isotopic geochemistry was begun in the first-discovered site, Malangine Cave, and, as several dozen art sites were later located in some of the region's hundreds of caves, this project has been extended to other suitable localities.

In Malangine Cave, a distinctive sequence of three petroglyph traditions was first identified: (1) finger markings on formerly soft carbonate speleothems, (2) deeply carved "geometric" designs, and, finally, (3) shallow incised motifs. The finger flutings were covered by pearly travertine exudations, and the deep petroglyphs by a lamina of porous calcite skin on which the third tradition was executed. Therefore, the calcite skin must be younger than the deep petroglyphs (2), and older than the shallow incisions (3), while the pearly travertine postdates the finger flutings (1). If the ages of these speleothem deposits could be determined, they would provide minimum or maximum ages for those art traditions they are physically related to (Bednarik, 1984:Figure 3).

The bulk carbon ratios of the two speleothem deposits, laminar calcite skin and pearly travertine, were determined in 1980. Based on a stylistic assumption (that similar designs should belong to the same art tradition), it had been assumed that the pearly travertine deposit is older than the calcite skin (because one design similar to those underlying the skin was found engraved through the pearly travertine), but the radiocarbon results challenged this assumption. The pearly deposit produced ^{14}C age measurements interpreted as 4425 $\pm$ 75 yr B.P. (Hv-10240), while the lamina supplied a result of 5550 $\pm$ 55 yr B.P. (Hv-10241). In 1982, splits of the same two samples were used for uranium-series dating, but the results were obtained by alpha-spectrometry which has since been replaced by the more sensitive and accurate thermal ionization mass spectrometry.

These early results seemed to suggest that some radiocarbon values from calcite speleothems may be reliable (for instance, they coincide with extensive occupation evidence in the site from the first half of the Holocene), but that there is the possibility of a rejuvenating effect through later deposition of younger carbonates. The question of the credibility of radiocarbon dates from porous travertines therefore needed to be examined.

RECENT ANALYTICAL WORK

Further analytical work was made possible by the discovery of naturally exfoliating laminar limestone speleothem deposits in Prung-kart Cave, South Australia, located 31 km from Malangine Cave (Figure 1). The cave's finger markings had been made on a soft *Mondmilch* lamina about 1 cm thick that continued to "grow" after this event, with subsequent precipitation covering the markings. However, where the fingers had destroyed the delicate crystal lattice, further "growth" was "retarded" so that the subparallel finger grooves remained well visible on the present surface of the deposit, in the form of narrow grooves. Subsequent climatic or other environmental changes have led to some exfoliation of the laminae, where the relationship of the finger flutings with the successive layers of calcite can be seen clearly (Figure 2). Similar relationships can be observed at several other Mount Gambier sites with cave petroglyphs (39 sites currently known) (Bednarik, 1990).

Pine trees planted above Prung-kart Cave formed extensive lattices of fine rootlets that followed the contact zone between the primary limestone rock forming the cave, and the secondary deposit on it. Desiccation may have led to some stress fracturing in this zone which was exploited by the rootlets. The fracturing caused by these rootlets resulted in the detachment of almost 1 m^2 of the calcite skin, between 15 and 20 mm thick, within which were contained many finger flutings. Severe deterioration was already observed when the markings were discovered in 1984, and after 5 years the surface deposit exfoliated fully. It was then found that, in section, the cutaneous calcite consisted of over a dozen distinctive laminae, of alternatively white and grey layers (Figure 3). Since the dark layers might conceivably contain organic material deposited on the surface at times of high aquifer

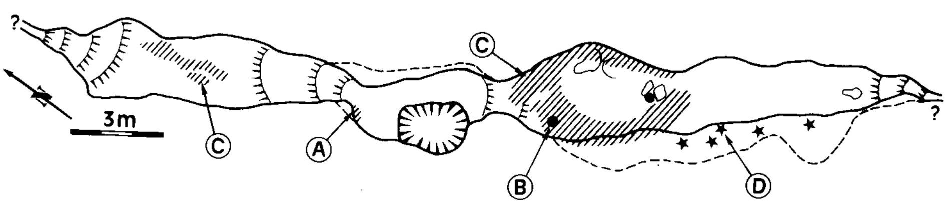

Figure 1. Plan of Prung-kart Cave, southeastern South Australia. The locations are shown of the exfoliating skin in Figure 2(A), of the speleothem collection site (B), of the extent of finger flutings (C), and chert mining (D) in the cave. Due to the narrow entrance, practically all of the cave is in complete darkness.

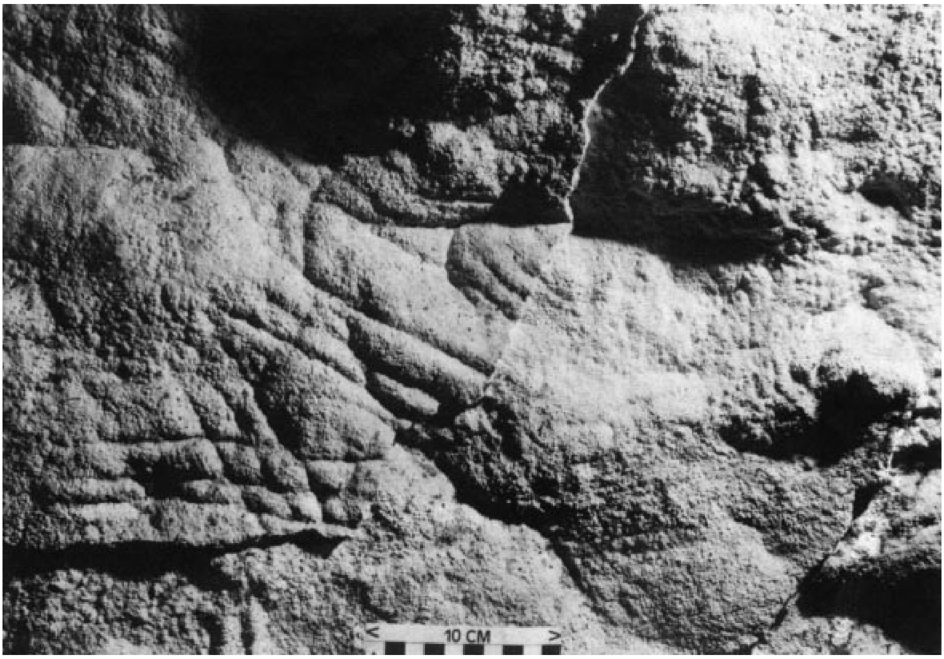

Figure 2. Detail of exfoliating calcite skins in the northwestern branch of Prung-kart Cave, South Australia, showing a set of finger markings sandwiched within layers of the skin.

levels, the possibility of extracting such material from individual layers and using it to check carbonate-derived radiocarbon dates became apparent.

After a site inspection by senior representatives of the local Aboriginal community (Bednarik, 1989) and approval by the Aboriginal Heritage Branch of South Australia, calcite samples were removed and analyzed. Two initial analyses were of the inner and outer portion of the entire skin. The outermost portion produced an age of 1150 ± 80 yr B.P. (ANU-6963B), the innermost was 2590 ± 80 yr B.P. (ANU-6963A). The second result was recalculated as ANU-6963, at 2660 ± 70 yr B.P., by basing the calculation on a measured $\delta^{13}C$ of −0.8 ± 0.1‰, not the estimate normally used in routine calculations (−5.0 ± 2.0‰). The black matter occurring in layers yielded only minimal traces of organic matter, insufficient for conventional radiocarbon dating (AMS dating to be attempted in future).

The measured deviation of ^{13}C from that of standard marine limestone carbon is lower than was estimated, and much lower than in atmospheric CO_2. The obvious source as an alternative to the biologically derived CO_2 that is usually active in calcite solution are gaseous emissions in regions of general volcanic activity, where the limestone is readily permeable. The Mount Gambier region has experienced considerable recent volcanic activity, peaking apparently during the mid-Holocene (Blackburn, 1966; Sheard, 1983; Prescott, 1994) but continuing into the late Holo-

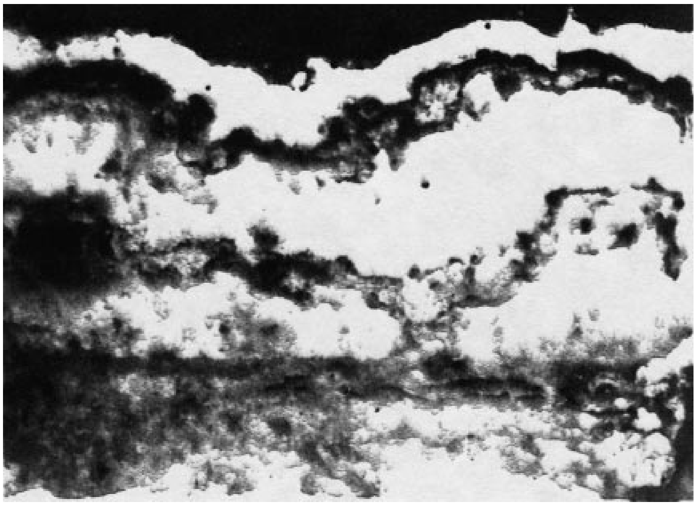

Figure 3. Magnified section of the outermost layers of calcite skin sample from the southeastern branch of Prung-kart Cave. The alternate white and grey strata are clearly visible (photograph by A. Watchman).

cene; and its Oligocene and lower Miocene limestones are highly porous (Bednarik [1991] reports up to 50.8% porosity by volume). Moreover, the aquifer level is frequently close to the surface, which may conceivably facilitate the trapping of CO_2 in caves (see Bednarik [1988] for data concerning air residency characteristics). For comparison, the measured $\delta\,^{13}C$ of two samples of speleothem in Malangine Cave was $+0.2‰$ (Hv-10240) and $-4.8‰$ (Hv-10241) (Bednarik, 1981), which suggests considerable fluctuation in the region's past atmospheric carbon regime.

DISCUSSION

These results raise more questions than they answer, but they are useful in reminding us of the problems with determining the age of rock art. In principle, the direct dating of rock art by means of determining the radiocarbon content of mineral layers "sandwiching" the art should be a straightforward procedure. The physical relationship between the art and the calcite strata is indisputable. The solution process of calcite in caves demands that almost 50% of the carbon of reprecipitated carbonate is derived from biological carbon dioxide (mostly exhaled by mycorrhizal microorganisms), which is closely related to the age of the speleothem. However, the chronological relationship of the real age of the art and the carbon isotope data derived from the strata sandwiching it is a very different matter (this, conversely, applies also to oxalate dating) (Watchman, 1990). Ideally, the radiocarbon isotope concentration would refer to the time the microorganisms absorbed atmospheric carbon, but there is an obvious time lag between that event and the precipitation of the speleothem, accounted for by the travel of the solution through

Table I. Analytical data referred to in the text.

ASL Sample	Mass (g)	Lab No.	δ ^{13}C (‰)	^{14}C (%) Modern	d ^{14}C (‰)	D ^{14}C, (‰)	^{14}C Age, (Years B.P.)
142018	51.28	Hv-10240	+0.2	57.7 ± 0.5	—	—	4425 ± 75
142035	ca. 400	Hv-10241	−4.8	50.1 ± 0.3	—	—	5550 ± 55
188004 (a)	118.5	ANU-6963A	−5.0 ± 2.0	—	−245.8 ± 6.0	−276.0 ± 6.5	2590 ± 80
188004 (aa)	Recal-culated	ANU-6963	−0.8 ± 0.1	—	−245.8 ± 6.0	−282.2 ± 5.7	2660 ± 70
188004 (b)	Split	ANU-6963B	−5.0 ± 2.0	—	−97.4 ± 8.3	−133.5 ± 8.8	1150 ± 80
188013	65.8	ANU-8457	−1.1 ± 0.1	—	−272.4 ± 5.9	−307.2 ± 5.6	2950 ± 70

Notes: Before processing, surface material was removed from all bulk samples in the laboratory. There was no chemical pretreatment.

the rock overlying the cave. In the case of the Mount Gambier karst, this factor may be unimportant, due to the generally very thin cave roofs and the high porosity of the limestone.

Another difficulty is more serious. The Prung-kart speleothems remain porous, as are most of those found in the Mount Gambier region, and they would be susceptible to rejuvenation even today. Without independent calibration (e.g., through organic matter deposited in the layers) it remains unknown how much of the deposit's crystal lattice actually predates the rock art. We know that those layers found above the art must postdate it entirely, but we also know that a certain proportion of the calcite beneath the art may have been deposited later than the event of art production. This proportion remains an unknown factor, suggesting that what we derive from radiocarbon analysis are actually minimum values of real age. The type of carbonate speleothem best suited for radiocarbon dating are densely crystalline stalagmites (Bednarik, 1981). No stalagmites are known that conceal rock art, anywhere in the world, although many paintings and petroglyphs occur *on* stalagmites (particularly in western Europe and the Caribbean). Stalactites occur rarely over rock art (e.g., in Kriton Cave, Victoria, and a few European sites), but they are less suitable, while the porous travertine skins most frequently found with rock art provides radiocarbon dates that can only be used with various qualifications.

Moreover, if a part of the CO_2 in the solution process was not atmospheric, but of volcanic origin, as could be implied by the Prung-kart data, the dating results are likely to overestimate the age of the calcite formation by an unknown factor. That factor would have been determined by air residency rates at the site in question, and by the isotopic composition of the CO_2 at the time. To render the issue even more complex, the CO_2 may well have been derived from both sources (volcanic and biological), and the relative proportions would have fluctuated through time in accordance with many factors, such as volcanic activity, aquifer level, ambient climate, vegetation regimes, and so forth. It is therefore unlikely that reliable dating of rock art can be obtained by this method alone. To complicate the matter even more, plant communities are themselves susceptible to atmospheric CO_2 values (Robinson, 1994), and so indirectly to climate. They have a significant effect on the $\delta^{13}C$ value of the reprecipitated carbonate: values of between -12 and $-10‰$ apply to respiratory CO_2 derived from C3 plants (shrub communities), while the $\delta^{13}C$ compositions of carbonate in equilibrium with CO_2 respired from C4 plants (grasses) range from -3 to $+1‰$ (Cole and Monger, 1994). This introduces yet another variable, the effect of which is an unknown factor and questions the utility of our results in terms of bracketing the age of the finger flutings.

The dates secured from Prung-kart Cave are certainly “direct dates,” but they provide no secure dating of the petroglyphs to which they are related. One is tempted to place the art in the second half of the Holocene, because this might account for both possible origins of the CO_2. Such a tentative age would confirm Bednarik’s (1990) view that some Australian finger flutings are of the Holocene, while most are of Pleistocene antiquity, and it might add some weight to Spate’s (1993) suggestion that the avoidance of dark caves by Aborigines of recent millennia, implied by ethnography, may not have been universal. However, in view of the difficulties mentioned and the possibility of “rejuvenation,” it seems prudent to remain cautious and to regard the results reported here as preliminary as all other “datings” of rock art, anywhere in the world, ought to be regarded. In particular, it should be noted that in direct rock art dating, several methods provide *more reliable* results than does carbon isotope analysis of essentially unidentified substances (Bednarik, 1996).

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