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Résumé. *Cet article est au sujet d'un groupe d'Aborigènes de fermes d'élevage et d'un aspect particulier de leurs activités au début de l'époque des rapports européens. Pendant la saison des pluies, les peuples Mirriuwung et Gadjerong, des environs de la frontière entre le Territoire du Nord et l'Australie Occidentale, se rassemblaient et circulaient à l'intérieur de leur pays traditionnel, tout comme ils le faisaient avant l'arrivée de l'homme blanc. Les septuagénaires d'aujourd'hui se rappellent ces temps, concentrant sur les années 1920 et 1930 quand les membres de la famille peignaient dans des abris-sous-roche partout dans leur pays. Cet article présente ces données ethno-historiques, et examine les implications possibles concernant l'antiquité et l'objet de l'art rupestre dans cette région de l'Australie.*

Zusammenfassung. *Dieser Artikel befaßt sich mit einer Gruppe von Aboriginal Leuten und einem besonderen Gesichtspunkt ihrer Aktivitäten während der frühen Periode europäischen Kontaktes. Während der 'nassen Saison' versammelten sich die Mirriuwung und Gadjerong des Grenzgebietes von Northern Territory und West Australien und zogen durch ihr traditionelles Gebiet, ähnlich wie sie das vor dem Kommen der Weißen taten. Leute, die jetzt in ihren Siebzigerjahren sind, erinnern sich dieser Zeiten, und konzentrieren sich auf die 1920er und 1930er Jahre, als Familienmitglieder in den Abris des Gebietes malten. Der Artikel legt diese ethnohistorischen Daten vor und erörtert die möglichen Implikationen für Alter und Zweck der Felskunst in diesem Gebiet von Australien.*

Resumen. *Este artículo trata acerca de un grupo de gente Aborigen sedentaria y de un aspecto particular de sus actividades durante el primer período del contacto Europeo. Durante el tiempo de lluvias las naciones Mirriuwung y Gadjerong, del área fronteriza del Territorio Septentrional y de Australia Occidental, se congregaron y se trasladaron a través de su territorio tradicional, muy a la manera como lo hicieron antes de la llegada del hombre blanco. Gente que ahora está en sus años setenta recuerda estos tiempos, sobre todo de las décadas de los años 1920 y 1930, cuando miembros de la familia pintaban en abrigos rocosos a lo largo de su territorio. Este artículo presenta esta información etno-histórica, y revisa las posibles implicaciones de la antigüedad y propósito del arte rupestre en esta región de Australia.*

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KEYWORDS: ***Petroglyph - AMS radiocarbon dating - Accretion - Côa valley - Portugal***

A REVIEW OF THE THEORY AND ASSUMPTIONS IN THE AMS DATING OF THE FOZ CÔA PETROGLYPHS, PORTUGAL

Alan Watchman

Abstract. The theory and assumptions of the accelerator mass spectrometry (AMS) radiocarbon dating of micro-organisms fossilised in silica skin accretions associated with petroglyphs are explained. Ethical matters related to the dating of the Côa valley petroglyphs, Portugal, are discussed and the six assumptions used in the dating process are reviewed with the aim of clarifying the basis on which the dating results were obtained.

Introduction

Considerable controversy has arisen surrounding the dating of the Côa valley petroglyphs in Portugal. This was generated from the major contradiction between archaeometric determinations and the age estimates made by European prehistorians based on stylistic similarities with presumed Palaeolithic engravings elsewhere in Europe. It appears that theoretical and methodological approaches and assumptions used in the dating of the petroglyphs have been misconstrued to address ethical, political and rock art significance issues (Chippindale 1995; Reevell 1995; Ridges 1995; Salema 1995; Zilhão 1995a, 1995b). While the latter are important issues and warrant further discussion, this paper aims at critically reviewing the method and basic assumptions underlying the scientific dating of the Foz Côa petroglyphs (Watchman 1995a), and seeks to clarify and correct some of the major misunderstandings.

Antiquity is only one criterion that can be used to evaluate significance in determining measures aimed at protecting and conserving rock art, and by adopting significance criteria solely based on the antiquity of rock art, the opponents of the Côa valley dam construction were devastated when the chronometric results gave much younger ages than expected (Bednarik 1995a; Watchman 1995a). However, the recent dating results are now potentially far more important because, if accurate, they signify great stylistic, cultural and scientific values for petroglyphs that resemble engravings found elsewhere in Europe that are ten times older. Before moving on to describe specific aspects that I consider should be reviewed to establish the limitations of the dating of the Côa valley petroglyphs, I would like to answer criticisms about the conduct of the dating project.

ethical behaviour by the dating researchers have been expressed in several forums about the 'supposed scientific dating of the Côa petroglyphs' (Reevell 1995: i). These insinuations apparently stem from an opinion, held by many rock art enthusiasts and widely circulated by opponents of dam construction and of the young dating results, that 'those researchers made explicit their view (prior to dating) that their techniques may be able to demonstrate the recent antiquity of the material and in doing so reduce its cultural value' (Reevell 1995: i).

In refuting these assertions, it can be pointed out that petrographic and scanning electron microscopes, x-ray analyses, and accelerator mass spectrometry can be used in a systematic way to identify and characterise materials in accretions and to radiocarbon-date carbon-bearing substances associated with petroglyphs. There is nothing unusual about the orderly conduct of archaeometric research that could be called 'supposed scientific dating', especially when considerable research data exist for similar siliceous rock surface accretions elsewhere in the world (Clarke 1978; Curtiss et al. 1985; Dolanski 1978; Dorn and Meek 1995; Farr and Adams 1984; Fisk 1971; Hughes and Watchman 1983; Watchman 1985, 1990, 1992, 1994).

It is standard scientific procedure to develop an hypothesis about the age of the petroglyphs prior to conducting field work and then, methodically evaluating the observations and analyses, to substantiate or refute that supposition (following Renfrew and Bahn 1991: 61). While I suspected the petroglyphs were not Palaeolithic, I undertook my field work with the aim of finding evidence either to substantiate or refute that age estimate. I set out to date Palaeolithic petroglyphs, but soon realised from my on-site observations and geological experience that they were much younger than 20 000 years old.

lithic (Bahn 1995; Clottes 1995; Rebanda 1995), and prior to examining them for myself, I felt that the petroglyphs would probably be less than 20 000 years old because of reports about their topographic position and the softness of the schistose rocks on which they were made (Bednarik 1995b, 1995c). The petroglyphs were pecked or incised onto relatively soft rocks adjacent to the present river at the bottom of a geomorphologically young, steep-sided valley. The petroglyphs most similar to Palaeolithic engravings, according to the European experts, are about 5 to 6 m vertically above the present river level. Other glyphs are located within 50 m of the river, but none have been found on the upper slopes or on the hill tops.

I also observed that accretions were not very well developed on the petroglyph panels. Black rock varnish that may take hundreds of years to form was only sparsely developed on several pecked rock faces, and brown accretions only covered some of the petroglyph panels at Canada do Inferno and parts of two panels at Penascosa, two of the major petroglyph sites in the valley (Figure 1). There were no indications that the varnish had weathered and been removed from the surfaces. Brown friable deposits were associated with water wash zones and they covered small areas in some petroglyphs and on some of the adjacent rock surfaces. The distribution, softness and thickness of the accretions suggested that the engraved surfaces were relatively recently exposed, because not enough time appeared to have passed for thick rock varnish and silica accretions to have formed. The alternative conclusion was that the accretions on the petroglyph surfaces had been eroded, but there was no evidence on unmodified rocks (without petroglyphs) to support that conclusion, and most of the glyphs' edges were so sharply pecked or incised that they showed no visible signs of weathering and erosion. What geological or anthropogenic process could remove accretions from more than 80% of engraved and natural rock surfaces, but did not affect the petroglyphs? Could both the rock surfaces and glyphs have been cleaned? This seems unlikely, for if the petroglyph panels had been cleaned, then the cleaning would have needed to have been very thorough and widespread because most engraved panels looked in similar condition. There is no evidence that cleaning occurred, and besides, the natural surfaces elsewhere in the valley and the rock faces exposed anthropogenically in quarries and railway cuttings had almost identical appearances to those bearing petroglyphs.

I discussed various issues with representatives of the Electricidade de Portugal (EDP, the company wanting to construct the Côa dam), surrounding their proposed plan to establish an interpretation centre and archaeological park outside the future inundation area. Contrary to some widely held views I suggested that dating the petroglyphs might perhaps provide the stimulus towards gaining international support for their proposed centre and park. I also made two other points in my first preliminary report to EDP about the in-situ conservation of the petroglyphs. I stated that 'in rock art conservation we generally believe that it is best for the engravings to remain where they are because their in-situ conservation has far more heritage value than relocating them to a location out of context with the original setting' (Watchman 1995b: 6). My additional advice to EDP was that 'few rock art sites have been relocated by physically transporting massive slabs of rock, and of those moved unforeseen technical problems have resulted in only a fair result. I caution against hasty measures to remove large blocks of highly foliated and fractured stone' (Watchman 1995b: 7).

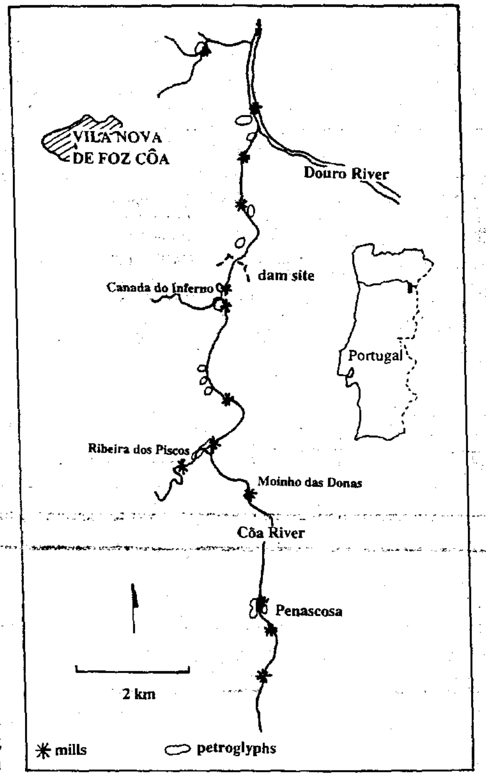

Figure 1. *Distribution of petroglyph sites (open circles) along the Côa River, Portugal, found clustered near water mills built using locally derived stones (except at Moinho das Donas where suitable rock surfaces for engraving do not exist).*

Critical comments about my involvement as a consultant archaeometrist in a political debate seem, in hindsight, to have been derived from the actual dating results rather than directed to my participation in the dating project. The problem was misinterpretation and misuse by the media and other people, of the young dates which were used to create sensational news (Salema 1995). The young chronometric age estimates were inappropriately used by the media to reduce the value of the petroglyphs, when in fact the recent antiquity for stylistically Palaeolithic petroglyphs probably made them even more remarkable (Clottes 1995). The apparently worthless petroglyphs, therefore, inflamed the situation, provoking ill feeling between dam opponents and the archaeometrists. Dam opponents then attempted to discredit the dating methods, results and archaeometrists in order to try to reinstate antiquity and hence value to the petroglyphs. Contrary to the stands favoured by many European archaeologists, age is only one of numerous values that can be used to assess significance of places containing cultural remains (Marquis-Kyle and Walker 1992). I agree with Bednarik (1994, 1995c, 1996), that it was inappropriate to predicate the preservation of the Côa valley petroglyphs on their antiquity.

At the Turin Rock Art Congress, further criticisms were directed at the archaeometrists on the grounds that they did not consult with Portuguese archaeologists, in particular with those directly involved in protests to stop the dam. In fact, close contact was maintained with Nelson Rebanda, the archaeologist responsible for documenting all archaeological sites in the area affected by the development. Consultation was also undertaken with Goncalves Guimaraes, an archaeologist who had conducted excavations at a Roman site in the Côa valley.

As a consultant to the EDP, my brief was very specific, focusing solely on dating the petroglyphs as one of four independent scientific studies. At my request, the EDP obtained permission to collect samples for dating from the Instituto Portugûes do Património Arquitectónico e Arqueológico (IPPAR) who then had responsibility for the protection of cultural remains in Portugal (Correia 1995; Pereira 1995).

Accretion dating theory

Petroglyph production usually involves removing a dark surface to reveal relatively unweathered rock contrasting in colour with the surrounding patinated or weathered surface. For example, pecking through black rock varnish exposes the underlying pale rock minerals and the colour difference between the recent tool marks and the surrounding rock surface highlights the glyph. In the Côa valley, the dark grey and brown, thinly patinated off-art surfaces contrast with the pale green-grey of the unweathered rocks. Through time the glyphs either weather or accumulate mineral accretions. When rock surface conditions are stable and weathering is minimal, rock varnish, silica skins and other mineral deposits form in the petroglyph depressions. As the accretions have formed after the glyphs were made, it is possible to use the formation age of the accretion to indicate when production of the glyphs occurred.

Dating rock surface accretions is generally based on determining the radiocarbon ages of carbon-bearing substances lying in finely laminated sequences of subaerially deposited materials on- and off-art (Watchman 1993, 1994). Making a petroglyph by removing an accretion-covered surface exposes bare rock, so dating the carbon-bearing substances in the basal laminae of a mineral deposit formed in the peckings (on-art) provides a *terminus ante quem* (date before which), or a minimum-limiting age for the petroglyph. Measuring the age of carbon-bearing substances in the basal laminae of the off-art accretion through which the petroglyph was made provides a *terminus post quem* (date after which) for the petroglyph, because the accretion was present prior to pecking, and this gives a maximum age for the petroglyph.

These theoretical aspects were used in the dating of the Côa valley petroglyphs. Fossilised carbon-bearing substances in silica skins adjacent to pecked animal-like figures (stylistically typical of Palaeolithic engravings according to European prehistorians), were sampled to determine maximum ages, while accretions in peckings and abraded grooves were collected to give minimum-limiting ages for the petroglyphs. The theoretical basis for dating the Côa valley petroglyphs has not been challenged, but the assumptions which follow have been attacked as unverified and naive (Zilhão 1995a).

Assumptions

While I mentioned the assumptions of the dating method in my report I did not explain them in detail, and perhaps this accounts for some of the misunderstandings about my dating results (Watchman 1995a). Prior to sampling, six assumptions were made on the basis of previous research and from preliminary examinations of the Côa valley rock surface accretions: that (1) silica skin accretions existed on the rocks prior to petroglyph production, that (2) micro-organisms living on those surfaces were fossilised in silica skins that formed directly on the unengraved rock, that (3) these fossilised micro-organisms contain carbon-bearing components that can be used for AMS radiocarbon dating, that (4) the silica skins are structurally stable and do not reform, that (5) the petroglyphs were not pecked or incised after their initial production, and that (6) extraneous carbon was not a contaminant. These assumptions are discussed in greater detail below.

1. Silica skins existed prior to petroglyph production

I have no absolute proof that silica skins were present on the rock surfaces prior to petroglyph production, but my field observations and measurements of the distribution and thickness of silica skins suggested that some siliceous coatings were present at the time the glyphs were made. I made two visits to the Côa valley in the course of my dating work. The first inspection on 27 March 1995 was to see if suitable rock surface accretions were present in the petroglyphs and on the adjacent rocks. That visit gave me the opportunity to make preliminary observations about the geographical setting, rock weathering features, nature and distribution of rock surface accretions, and the degree of petroglyph weathering. I also collected two small brown accretion samples from Canada do petroglyph sites in the valley; Figure 1). I visited petroglyph sites within and outside the Côa valley from 17 May until 23 May to sample accretions for dating, and I also inspected accretions formed on rocks in quarries, and on railway and road cuttings.

Before returning to collect samples specifically for dating, I used a scanning electron microscope to examine the texture, thickness, layering and composition of the accretions. I found that these off-art surfaces were covered by silica skins, up to 0.4 mm thick, covered by friable, silty brown accretions (Figure 2). My field observations and later laboratory measurements revealed that accretions in the petroglyphs were less than about 0.12 mm thick. Differences in thickness and distribution of the accretions indicated to me that some of the rock surfaces were covered by silica skins when the petroglyphs were made, and I deliberately sampled the basal silica in these small patches to determine the maximum age for the petroglyphs.

2. Micro-organisms fossilised in silica skins

I have documented the fossilisation and dating of micro-organisms in silica skins at rock art sites in Australia (Watchman 1990, 1992, 1994) and in Canada (Arsenault et al. 1995), and have subsequently found fossilised diatoms in silica skins at other rock art sites (Watchman 1996). At the Côa sites I sampled silt deposited in fractures on the petroglyph panels and found the diatom species *Nitzschia* and *Navicula* mixed with the sediment (Figure 3). When sub-samples of the Côa silica skins were rapidly etched to remove the encapsulating silica I also observed fragments of diatoms (phytoplankton) fossilised in the skins, indicating that these carbon-bearing micro-organisms had been completely encapsulated by silica. I therefore knew that the fossilised micro-organisms would provide carbon suitable for determining when the silica was deposited.

I was aware of the possibility of physical inclusion of modern chasmolithic micro-organisms in the upper parts of the accretions. To eliminate this potential problem I removed a surface layer before collecting the underlying samples for dating. Pretreating these samples using acids and alkalis also reduced contamination from modern micro-organisms.

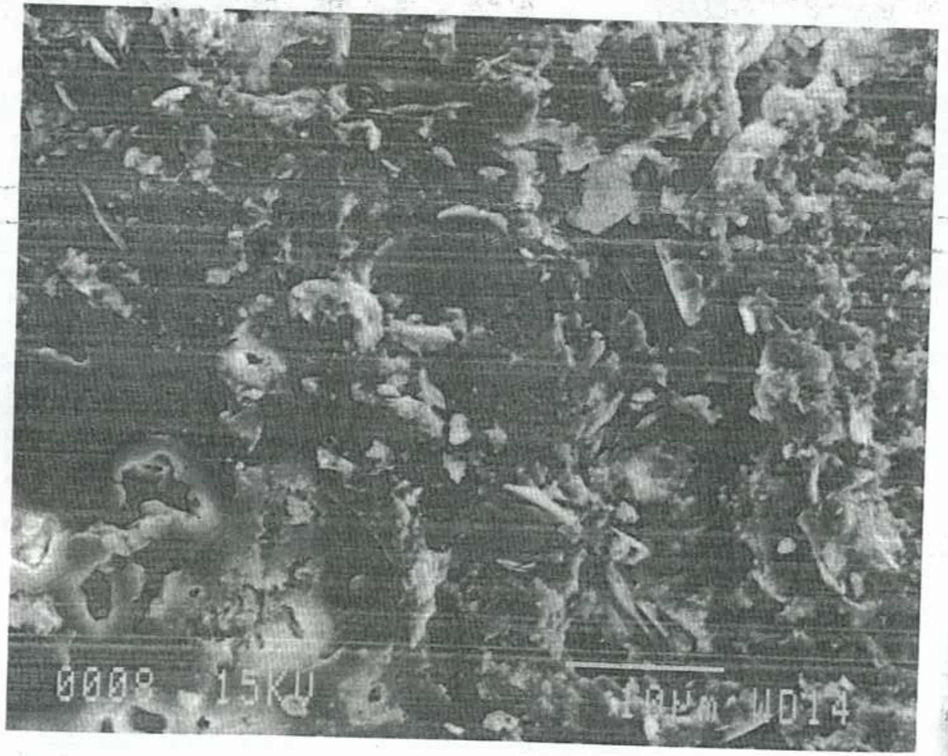

Figure 2. Scanning electron microscope photograph of the junction between basal white amorphous silica (left) and the silty brown accretion containing granules of weathered schist and platy sheets of mica (scale bar is 10 µm long).

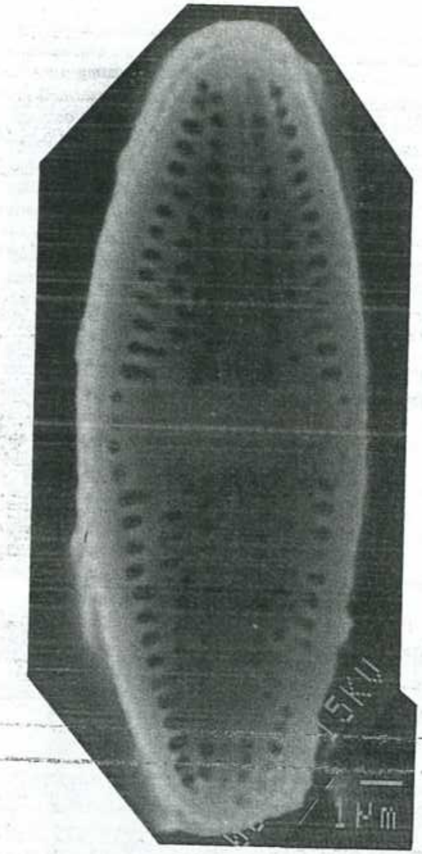

Figure 3. *Scanning electron microscope image of a single* Nitzschia *diatom extracted from the silty brown accretion. Diatoms similar to this and also like* Navicula *were observed in rapidly etched sub-samples of amorphous silica.*

3. Silica accretion components are chemically stable

Fossilisation of micro-organisms in silica gel that becomes a hard skin on drying effectively seals the organic residues from outside influences, and this ensures reliable age determinations for silica formation. The silica, derived from chemical weathering of siliceous minerals in the schist, is chemically deposited from seepage and run-off water on stable rock surfaces (Watchman 1996). Potential effects on the radiocarbon dating of the fossilised micro-organisms include carbon isotope exchange, chemical absorption of extraneous carbon compounds and physical attachment of solid carbon particles derived from non-contemporaneous sources. For carbon isotopic exchange to occur between the fossilised carbon components and extraneous sources of carbon, the most likely scenario is for silica to dissolve and expose the micro-organisms; chemical exchange occurs in solution and then the silica reforms. Given the insolubility of amorphous silica in the acidic aqueous environment at Côa, the mechanisms for dissolution, reconstitution and reprecipitation are extremely hard to imagine. Scanning electron microscope studies did not reveal etch textures indicative of chemical dissolution. The alkalinity of the water would need to increase drastically before the alumina-rich silica dissolved, and then after carbon in the alkaline waters mixed with the micro-organic remains, the solution would either have needed to regain its acidity or have increased in ionic strength to catalyse precipitation of amorphous silica. This scenario makes the involvement of modern tree root and lichen acids as proposed by Zilhão (1995a, 1995b, 1995c) implausible. Percolation of carbon-bearing fluids through the accretions would not lead to carbon isotope exchange because of the protective coating of silica around the fossilised micro-organic compounds. Chemical absorption of extraneous carbon on the silica is therefore also discounted as a possible problem in dating, especially as the silica skin accretions used for dating were pre-treated using acids and alkalis at 60° C before AMS targets were produced. I also did not use a laser-based extraction technique to produce carbon for dating as implied by Zilhão (1995b), but used the micro-excavation technique, and so criticisms pertaining to the laser method also do not apply (Dorn 1995).

4. Silica skins are structurally stable and do not reform

It is important to ascertain whether silica skins have exfoliated or dissolved and reformed over short distances because these processes can influence measurements of the age of silica skin formation. While silica skins at many rock art sites are strongly fractured and show signs of micro-exfoliation (Watchman 1996), the skins associated with Côa petroglyphs are highly aluminous and contain small mica impurities. Both these inclusions increase the stability of the skins by reducing internal stresses, thereby making them more robust. I made thorough observations of the textures of silica skins and found layered sequences of silica films typical of regular deposition on physically and chemically stable surfaces.

Evidence from Australian sites where micro-exfoliation of silica skins has occurred reveals radiocarbon dating results that are much older than expected (for example McDonald et al. 1990). This is probably because silica exposed in the micro-exfoliation scars contains carbon that is much older than the nearby unaffected surface. This is not the case at Côa, where the silica skins are harder than other silica skins that I have micro-excavated in Canada, Australia and the United States. Their hardness prevented me from completely removing the basal silica layer, and so the weathering rind and underlying rock were not included in silica samples prepared for dating. I am convinced that the small patches of silica skins I sampled on the Côa have not been unduly affected by micro-exfoliation and reformation of silica.

5. Petroglyphs were not pecked or abraded after their initial production

The Côa valley petroglyphs generally occur either as fine line scratches to outline a figure, a series of peckings that may or may not follow a scratched outline, or as abraded grooves (incised V-shapes). Most of the petroglyphs at Penascosa are in the form of abraded U- and V-shaped grooves while a few are closely spaced peckings. At Ribeira dos Piscos, the two horse-like animals are delineated by closely spaced peckings, but the human head on a nearby panel is finely incised.

At Canada do Inferno, a much more complex series of production techniques was used because either fine scratches, peckings or abrasions were applied separately to different panels, or a combination of techniques used on individual figures (Figure 4). A cow-like animal at site 18 was outlined by fine scratches, then incompletely pecked and partly abraded. Accretions were not observed in any of the depressions on that figure. The goat-like animal, site 21, is only outlined in fine scratches, but the horse-like animals on two nearby panels were only pecked, leaving conical, oblong and inverted pyramid-shaped depressions (possibly indicating the use of three different tools perhaps over an extended time interval). Thin silty brown accretions were found in some of the depressions outlining these animal-like figures.

Although the petroglyphs do not contain evidence suggesting rejuvenation, there is no way that I can be absolutely certain that the accretions in the petroglyphs were not formed in renovated depressions. For dating purposes I therefore assumed that the age of the carbon-bearing substances in accretions from within the petroglyphs would provide a minimum-limiting age, for they represented the age of production of the petroglyphs that were thought on stylistic grounds to be Palaeolithic. If this represents the final episode of a sequence of petroglyph production steps, then the measured radiocarbon age determination is the estimate for the last reworking event. If this is the case, then it raises some important questions. How would rejuvenation of a petroglyph affect stylistic arguments for petroglyph antiquity, especially if the original production scars can no longer be seen? Are stylistic traits then simply represented by the form and technique of execution of the petroglyph, and if so, how reliable are stylistic age estimates using the reworked outlines?

6. Extraneous carbon is not a contaminant

In my first preliminary report to the EDP I emphasised that

> under no circumstances whatsoever should the engraved rock surfaces (particularly the ones mentioned above for sampling) be treated with any organic or inorganic carbon-bearing substance, including the materials for making casts, the production of rubbings, spraying to remove lichen, using soaps or other chemicals to clean chalk and other graffiti until after samples for AMS ^{14}C dating have been removed. Doing so will contaminate the rock surface and lead to false ages for the surface accretions (Watchman 1995b: 4).

On my first inspection I observed that minor graffiti and crude rubbing with sharp objects had recently damaged some parts of several petroglyphs, but that most petroglyphs were unaffected by chalk, pencil or latex casting remains (*contra* Zilhão 1995a, 1995b, 1995c). In looking for the best places to take samples for dating I used binocular magnifying lenses and I avoided those surfaces where even the slightest sign of recent damage

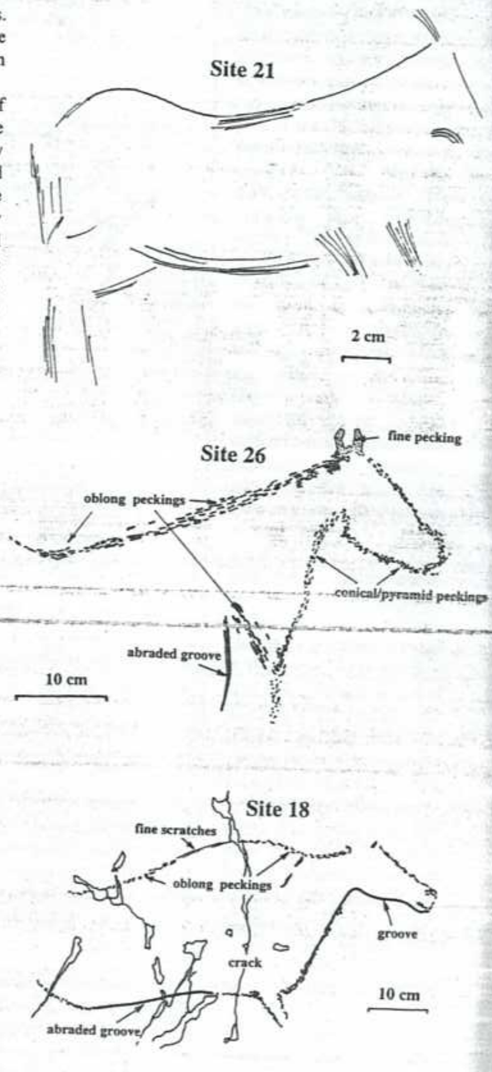

Figure 4. Sketches of three animal-like figures on panels 21, 26 and 18 at Canada do Inferno showing the range of petroglyph production techniques: fine scratches, oblong, conical and pyramidal peckings, and abraded grooves.

or intervention was apparent. I removed the upper surface of accretions before collecting the basal deposits within individual peckings and thus minimised the inclusion of microscopic particles of chalk, pencil or other possible modern contaminating substances.

If modern latex had been used on the panels and trace chemical residues were left on the rock surfaces, then the radiocarbon dates obtained from those contaminated samples would have yielded a modern or post-bomb date reflecting the carbon-14 contents introduced during chemical processing of those substances.

Graphite in the weathering rinds of samples collected from accretions in the petroglyphs and at the geological control site (railway quarry) introduced ^{14}C-free carbon to the silty brown accretionary samples (Figure 5). This form of carbon, with dissimilar age to the fossil carbon enveloped by contemporary silica, therefore diluted the modern ^{14}C activity in the silty brown accretions and made the apparent ages for the accretions in petroglyphs and geological control samples much older than the true age of the contemporary carbon (natural graphite alone will give an apparent, background AMS ^{14}C age of about 50 000 years even though it may be millions of years old, so mixing modern carbon with different proportions of radioactive-'dead' carbon in graphite will give age determinations between modern and the background values). When I presented my results, I indicated those accretions in which I had found graphite (Watchman 1995a, Table 1; note that the calibrated age for FC8 was incorrectly reported in that publication; it also contained graphite).

I identified trace amounts of naturally occurring graphite in the schists and thin weathering rinds beneath the accretions in the petroglyphs and had to take this unexpected source of carbon into consideration when I interpreted the AMS determinations. The silty brown accretions in the petroglyphs and the thin soft weathering rinds containing graphite are optically and geochemically indistinguishable from each other because they essentially contained the same minerals. The silty brown accretions consist of weathered schist components: muscovite, feldspar, quartz and chlorite; and the weathering rind contains these same major minerals plus accessory ilmenite, zircon and graphite, therefore it was not possible in the field to distinguish the base of a silty brown accretion from the underlying brown, graphite-bearing rind. Although the potential impact on the AMS ^{14}C determinations for the silty brown accretions was therefore substantial, the overall affect on the accretionary dating results was less dramatic because chemical tests of silica skins off-art did not reveal graphite. This was because the silica in the skin was deposited from silt-free (and therefore graphite-free) water, and also because the weathering rinds beneath the silica skins were not sampled. Radiocarbon determinations for silica skin samples therefore gave reliable age estimates for silica deposition, providing maximum ages for petroglyph production.

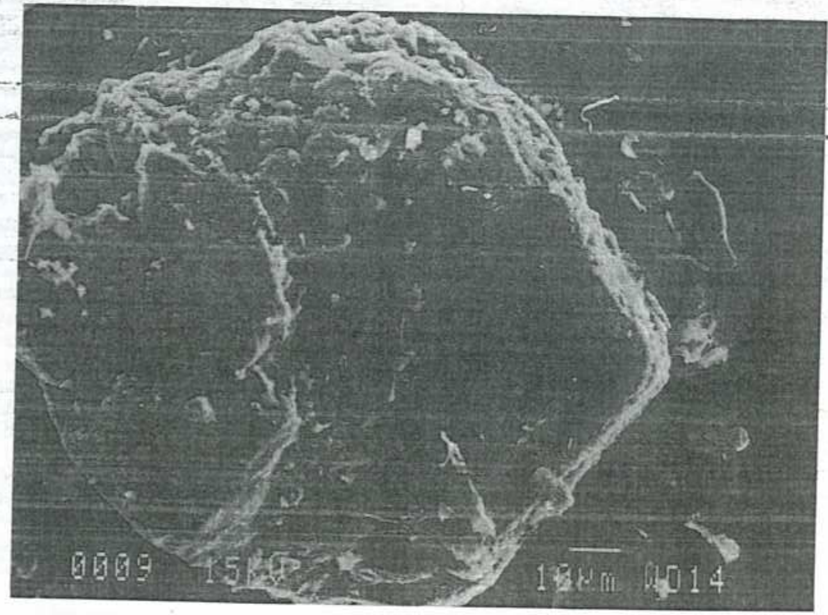

Figure 5. Scanning electron microscope photograph of a small graphite crystal extracted from the weathering rind at Canada do Inferno (scale bar is 10 µm long).

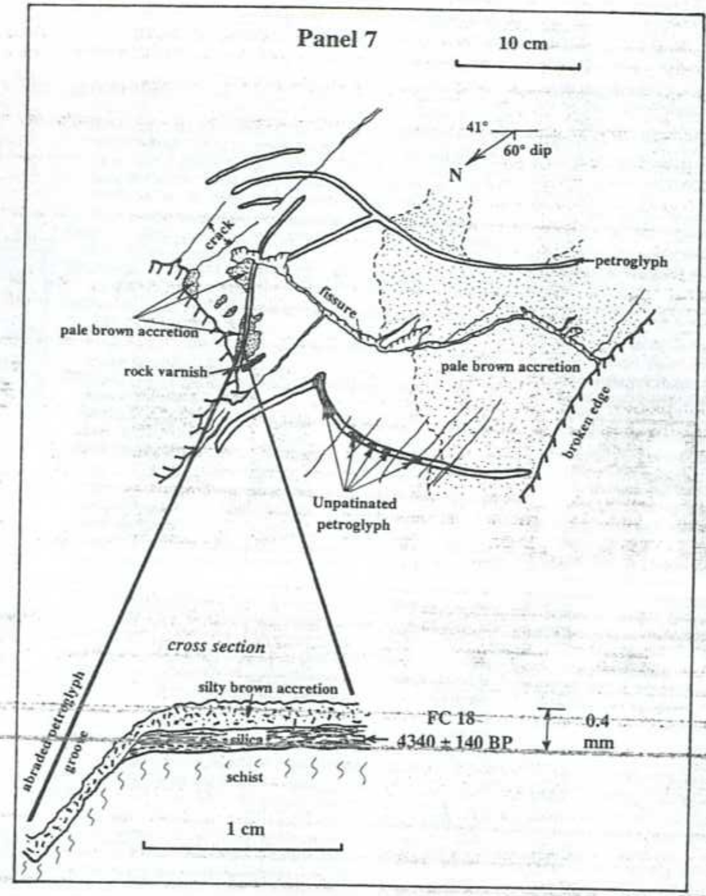

Figure 6. Sketches of the abraded petroglyph and cross section on the sloping schist surface, Panel 7, Penascosa, showing the distribution of accretions, rock varnish and patinated rock surface and animal-like petroglyph. Cross section reveals the stratigraphic sequence of layers and the radiocarbon determination for fossilised micro-organisms in the silica adjacent to the petroglyph groove. Note the silica does not occur in the groove, but has been cut through to make the groove.

Accretion dating results

When sampling off-art surfaces I found that silty brown accretions were deposited over white amorphous silica. I also collected accretions consisting only of the silty brown type in petroglyphs. The same white amorphous silica deposits were not found in any of the petroglyphs, and this indicated that silica skins had not formed in the peckings or grooves. These two types of accretion represent two depositional episodes: a precipitate of silica derived from chemical weathering followed by a deposit of mechanically liberated rock weathering components.

When it became evident that the silty brown accretions also contained graphite from the underlying weathering rinds two options became available: either to disregard all the AMS determinations by saying they were contaminated, or to re-examine the geochemistry of the silica to find out if graphite had also contaminated the skins adjacent to the petroglyphs. Digestion of sub-samples of amorphous silica did not yield graphite, therefore the AMS determinations using fossilised micro-organisms in the silica were reliable. Age determinations for FC7, 6 and 25, sequentially micro-excavated from a panel at Penascosa, also gave stratigraphically conformable age measurements. The lower silica layer (FC7, 3490 ± 90 years uncalibrated BP) was older than the layer above (FC6, 2060 ± 50 years uncalibrated BP), and this was older than the overlying silty brown accretion (FC27, modern). These AMS determinations from the fossilised micro-organisms indicated that silica had been deposited on that rock surface from at least 3500 years ago until about 2000 years ago. Fossilised micro-organisms in amorphous silica adjacent to an abraded petroglyph at Panel 7, Penascosa, were dated as well (Figure 6). The age of 4340 ± 140 years BP (FC18, uncalibrated) for carbon in the silica near the base of the deposit, off-art, indicated that the petroglyph was made after that time because only a silty brown accretion (dated as modern) was present in the abraded groove.

If the petroglyphs were actually Palaeolithic in age, then deposits of white amorphous silica should have been present in the peckings and grooves, unless the silica had formed preferentially on non-pecked surfaces or the silica from the petroglyphs had been selectively re-moved by later renovations.

Depressions on rock surfaces are usually the first places where accretions start to form because they act as small basins that localise sedimentation, so it seems highly unlikely that silica skins were only formed off-art and not in the petroglyphs. It is also hard to imagine that all the white amorphous silica was removed from all the petroglyphs in the Côa valley, leaving only amorphous silica in skins on the immediately adjacent areas (see assumption 5 above). As white amorphous silica does not occur in any of the petroglyphs, but only silty brown accretions, the petroglyphs were made after silica deposition ceased.

Could the age of the petroglyphs still be determined, knowing only that the radiocarbon determinations for fossilised micro-organisms gave reliable results? Yes, because similar silty brown accretions on the one hundred-year-old railway quarry rock face had also been dated. Even though the initial AMS determinations for the railway quarry accretions were also contaminated by graphite from the underlying schist, the results still provided a chronological control. If silty brown accretions, about 0.1 mm thick, took one hundred years to form on the railway quarry rock face, then the petroglyphs could be bracketed in time (assuming similar rates of formation of silty brown accretions elsewhere in the valley). The petroglyphs did not contain amorphous silica, so they were younger than about 2000 years (the age of the upper silica layer), but they had silty brown accretions similar in thickness and composition to those on the one hundred-year-old railway quarry rock face, hence they were made between about 2000 and 100 years ago.

The maximum age for the petroglyphs could be narrowed further by using information provided by Goncalves Guimaraes, an archaeologist, who with his colleague, Dr Maria da Graca Peixoto, had excavated and studied the Roman sites in the Côa valley. They found evidence suggesting that from about the fourth century A.D., or even slightly earlier, veteran Roman legionaries began intensive agriculture on the sides of the Côa valley (Guimaraes pers. comm.).

It was then possible to combine this independent archaeological evidence with the geological observations of petroglyph surfaces and topographic locations, to speculate as to why there was such a drastic change in the composition of the accretions and their depositional history, from silica to silt. A significant climatic change might also explain the formation of layered accretions, but the most likely hypothesis is based on the diversification of land use practices. Prior to cultivation of the hill slopes by the Romans, about 1700 years ago, the valley was used for pastoral activities and chemical weathering of the rocks was dominant. Chemical dissolution of silica from the minerals in the schist produced silica-rich solutions that eventually ran across some rock surfaces to form silica skins. After Roman settlement, and following intensive hill slope cultivation, physical weathering and erosion of the exposed soils and rocks in the almond and olive orchards created streams of silt that washed over

orchards on the Côa valley hill slopes is used to reduce evaporation loss of moisture and this appears to have started only after Roman settlement in the valley). Intensive hill slope cultivation associated with olive and almond production drastically changed the environment and increased erosion and deposition of silt and sand in river terraces and bars, and this explains why silt follows silica in the off-art accretion micro-stratigraphy. As silt and not silica occurs in the petroglyphs, the petroglyphs are younger than the last phase of amorphous silica deposition.

Conclusion

While there will always be sceptics concerned with the reliability of rock art dating, especially when existing notions of age are contested by new dating methods, the theory, method, assumptions, evidence and arguments that I have explained here should clarify some of the previous misunderstandings about the scientific dating of rock art. The Côa dating experience has many implications for archaeology, but for me the most significant aspect is that from now on there should be greater awareness of the theory, assumptions and potential problems in dating petroglyphs. An additional implication is the need to reassess rock art significance criteria, not only incorporating antiquity but also scientific, stylistic, archaeological, cultural and other values.

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Résumé. *Les concepts théoriques et présomptions sur lesquels est basée la datation au radiocarbone par AMS de micro-organismes fossilisés dans les accrétions siliceuses associées aux pétroglyphes sont expliqués. Des questions éthiques concernant la datation des pétroglyphes de la vallée de la Côa (Portugal) sont discutées et dans le but de clarifier le fondement des résultcts obtenus, les six présomptions sur lesquelles est fondé le processus de datation sont passées en revue.*

Zusammenfassung. *Die Theorie und Annahmen der Accelerator Masse Spektrometrie (AMS) Radiokohlenstoff Datierung von fossilen Mikroorganismen in mit Petroglyphen zusammen vorkommender Silikathaut werden erklärt. Ethische Fragen bezüglich der Datierung der Côa Tal Petroglyphen in Portugal werden besprochen, und die in dem Datierungsprozess verwendeten sechs Annahmen werden mit dem Ziel, die Grundlage der Datierungsergebnisse zu klären, erörtert.*

Resumen. *La teoría y suposiciones del accelerator mass spectrometry (AMS) para la datación de radiocarbono de microorganismos fosilizados en acrecentamientos cutáneos de sílica asociados con petroglifos son explicados. Cuestiones*

valle de Côa, Portugal, son discutidas y las seis suposiciones usadas en el proceso de datación son revisadas con el propósito de clarificar la base sobre la cual los resultados de datación fueron obtenidos.

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RAR 13-367

AURA INCORPORATED

After more than twelve years, the Australian Rock Art Research Association has finally become an incorporated association, mainly in response to the establishment of a World Wide Web home page (*RAR* 12: 130). This un-moderated Internet site has raised the possibility of individual office bearers becoming legally liable for its contents.

The association has been incorporated on 26 April 1996 in the state of Victoria under the Victorian Associations Incorporation Act 1981. This effectively removes any ambiguity about the legal liability of office holders, arising from the Internet site or from any other circumstances. It also clarifies AURA's corporate status. Henceforth, the full name of AURA is *Australian Rock Art Research Association Incorpo-*

KEYWORDS: ***Rock painting - White pigment - Analysis - Olary region - South Australia***

ANALYSIS OF WHITE PIGMENTS FROM THE OLARY REGION, SOUTH AUSTRALIA

E. J. Mawk, M. F. Nobbs and M. W. Rowe

Abstract. This paper sets forth morphological and chemical characterisation studies of four white pigmented rock paintings in the Olary region of South Australia. Two of the pigments were found to contain clay of micaceous composition, similar to other white pigments found in other parts of Australia. Two others, however, also contained substantial amounts of calcium sulphate, either gypsum or anhydrite, not reported before as a pigment in Australia. Unpainted rock samples near Antro showed no evidence of calcium sulphate, so a natural origin is unlikely for its presence in the pigment samples. But at Cathedral Rock, unpainted rock near the paintings also contained prominent calcium sulphate, so it is unlikely that it was added as a pigment at that location. None of the pigments contain bird excreta, in spite of the visual similarity between some of the paint residues and piles of bird excreta seen near the painted sites.

Introduction

The Olary region is in the semi-arid zone of the south-easternmost corner of north-east South Australia. The annual rainfall is 210 mm and is patchy and unreliable. The evaporation rate is 2400 - 2600 mm per annum. Summer temperatures are high, often over 40°C and winters are cold with frequent frosts. The region supports sheep grazing at the present time.

At the time of European contact (c. 1850), the region was an abutment of at least four Aboriginal tribal territories (Tindale 1974). Given the aridity and the uncertainty of water supplies and food resources — plant and animal — it is unlikely that Aboriginal people visited the area in drought years. From the presence of a large number of painting sites and rich archaeological evidence of past occupation — stone artefacts, stone structures, animal hides etc. — it appears that different groups came to the district in good seasons for the purpose of social interaction, religious observance and trade and exchange, retreating to their larger territories when food and water resources ran out. It is likely that painting ceased soon after European contact as the region was then overrun by introduced grazing animals.

There are twenty-six known Aboriginal rock art sites in the district, confined to the northern edge of the Olary uplands where granite and granitised rocks form low rounded hills. While visiting the Olary area in September 1994, we (MFN and MWR) noticed that white pigments in the region looked similar to bird excreta often seen deposited on nearby rocks, so we also sampled it to <1 mm diameter, white pigment samples from four painting shelter sites in the Olary region of South Australia for morphological and chemical characterisation studies: (1) Plumbago 2 (Camel Hump); (2) Plumbago 3 (Spine); (3) Antro; and (4) Cathedral Rock. A map of the region, noting the rock art sites studied, is shown in Figure 1.

Larger samples, two from Camel Hump (one white and one red) and one white pigment from Cathedral Rock, were taken for radiocarbon dating using the plasma-chemical extraction procedure developed at Texas A&M University and accelerator mass spectrometry (e.g. Chaffee et al. 1993; Ilger et al. 1995). An example of a white-pigmented painting that we sampled is shown in Figure 2. This rock painting panel is at Plumbago 2, Camel Hump. This report describes the results of analysis of four white pigment samples and the bird excretion.

Earlier analysis of white pigments from pre-Historic rock paintings in northern Australia at the Kakadu National Park indicated that the majority of white pigments there were clays of the kaolin type, although a number of samples also contained mica, in particular muscovite (Clarke and North 1991a, 1991b). The mineral huntite ([Ca, Mg]CO_3) was found to be used extensively in rock art pigments in northern Western Australia (Clarke 1976). Ford et al. (1994) found evidence for calcite, huntite and whewellite in white pigments in the Kimberley region of Western Australia. They also detected gypsum in several pigment samples, but only as a minor component, and decided it was likely due to contamination of the pigment