



KEYWORDS: *Rock art – Age estimation – Direct dating – Reliability – Precision*

ROCK ART 'DATING' METHODOLOGY: A REVIEW

Robert G. Bednarik

Abstract. The age estimation of rock art is a crucial factor in the science of rock art. Many researchers seeking to undertake rock art projects need clarification on the technical jargon and the various controversies in this field. They are looking for direction in designing their research strategies. This paper guides the choice of methods, rating their precision and reliability of results, predicted proximity to actual age, level of intervention and potential contamination, and relative accessibility and ease of application.

Introduction

It seems widely agreed that the age estimation of rock art has been one of archaeology's most intractable problems—and it remains to be so. It has led to various innovative and experimental approaches, beginning with the introduction of 'direct dating' in 1981 and then continuing particularly through the 1980s and 1990s. 'Direct dating' offered a distinct break from previous practices, stipulating a direct physical relationship between rock art and dating criterion and falsifiable propositions concerning that relationship. To illustrate with an example, some of the most credible rock art age claims derive from ^{14}C analyses of charcoal pigment or soot marks, and yet there are numerous potential reasons why such results may not date the rock art in question. A radiocarbon result on charcoal does not refer to the production of the painting. It marks the time the tree in question assimilated atmospheric carbon dioxide, and the carbonisation of the wood also separates the two events. Moreover, charcoal occurs in profusion on the rockshelter floors. Its very low specific gravity causes it to drift to the surface through sediment turbulence, which can be by one of many causes. These factors alone indicate that a charcoal motif may be many millennia younger than the radiocarbon age yielded by its paint residue. Many other aspects prevent such results from dating the motif precisely: past regimes of atmospheric carbon isotopes are unknown, ^{14}C results are statistical expressions that will be wrong at times, and endeavours to calibrate them are problematic (Muzzolini 1999). And yet, ^{14}C analysis is the most-used archaeological dating method—which invites comparisons with others.

In my work as the Convener of the International Federation of Rock Art Organisations (IFRAO), I have for many years received requests from agencies in var-

ious countries involved in the study or management of rock art, asking me to advise them about 'dating' rock art. In some cases, I became directly involved in their projects (e.g. in Rio Grande do Norte [Brazil], Karelia [Russia], various parts of Saudi Arabia and many provinces of China). However, most of these requests only resulted in brief sets of recommendations adapted to specific circumstances. These usually included brief comments on sample removal and rock art conservation. Here, it is endeavoured to present basic but generic evaluations of the various methods used in estimating the age of rock art. Only methods that hold (or may have held at some historical stage) reasonable promise of credibility are included for consideration. Table 1 lists twenty-six methods that have been used in estimating rock art age, together with my rating assessments of their key attributes:

- (1) *Accessibility* of the method to most researchers: methods involving laboratories tend to be complex and expensive.
- (2) The *ease* of applying the method: some methods can be mastered by anyone persistent enough to acquire the relevant knowledge, while others involve intensive specialist attention.
- (3) Avoidance of physical *intervention* in rock art: if no intervention is involved, the method attracts a rating of 3; maximal intervention (sample removal) is rated at 1.
- (4) Closeness of dating criterion to *target* event (sensu Dunnell and Readhead 1988): methods providing only minimum or maximum ages have a rating of 0, while those expected to be closest to true age have a rating of 3.
- (5) Potential *contamination* of sample or criterion characteristics: the highest potential is rated 0, and the lowest potential is rated 3.
- (6) Anticipated *precision* of the result: often at the ex-

No.	'Dating' method	Attributes						
		1 Ac- cess	2 Ease	3 In- terv.	4 Tar- get	5 Con- ta.	6 Pre- cis.	7 Reli- ab.
1	Iconography	3	3	3	1	3	0	1
2	Style	3	3	3	1	3	0	1
3	Archaeological excavation	2	3	3	1	2	1	2
4	¹⁴ C of carbonate	2	2	2	0	0	3	1
5	U-Th of carbonate	2	2	2	0	0	2	0
6	U-Th of ferromanganese accretion	2	1	1	0	0	2	?
7	¹⁴ C of ferromanganese accretion	2	1	1	0	0	3	0
8	¹⁴ C of oxalate deposit	2	1	1	0	1	3	2
9	¹⁴ C of non-carbon paint residue	2	2	1	0	0	3	0
10	¹⁴ C of charcoal paint, soot	2	2	1	2	1	3	2
11	¹⁴ C of sequestered organic object	1	1	1	3	2	3	3
12	¹⁴ C of beeswax	2	2	2	3	2	3	3
13	¹⁴ C of identified OM in paint	1	1	1	2	2	3	3
14	X-ray fluorescence spectrometry	2	2	3	0	0	2	?
15	Amino acid racemisation	1	1	1	1	1	?	?
16	Cosmogenic radiation nuclides	1	1	1	0	0	2	0
17	OSL analysis of insect nests	1	2	2	0	0	2	1
18	¹⁴ C analysis of insect nests	1	2	2	0	0	2	0
19	Lichenometry	3	3	3	0	2	1	3
20	Surface retreat of cement	3	3	3	1	2	1	3
21	Microerosion analysis	3	3	3	3	3	1	3
22	Macroerosion analysis	3	3	2	3	3	1	?
23	Cation ratio of accretions	1	2	2	0	0	0	0
24	Fluvial erosion wear	3	3	3	1	2	1	3
25	Paint drips/grains in soil*	2	3	3	1	1	2	1
26	Digital colourimetry of accretion	3	3	3	3	3	2	3

* Refers to paint drips from pictograms; or grains, dust or rock chips from petroglyphs.

Access. = Accessibility of the method to most researchers

Ease = Ease of application of the method

Interv. = Avoidance of physical intervention in rock art

Target = Closeness of dating criterion to target event

Conta. = Avoidance of contamination of samples

Precis. = Anticipated precision of the result

Reliab. = Anticipated reliability of the result

pense of reliability, the highest rating is 3.

(7) Anticipated *reliability* of the result: often at the expense of precision.

Key attributes of the methods

In a few instances in the last two columns, I had to omit the rating and place a question mark, either because a method has yet to produce any credible results or because I remain undecided about their credibility. The first three methods listed were traditionally used in estimating the ages of rock art before the introduction of 'direct dating'. They rate highly in the first three

attributes as well as the fifth, contamination. They are readily accessible and easy to apply, and they should involve no intervention in the integrity of the rock art or its support context and no chemical or physical contamination. *Iconography* (No. 1 in Table 1) refers to the beliefs of what is depicted in rock art, which may appear credible in some particularly detailed, semi-naturalistic traditions. However, for most rock art, these beliefs reflect untestable propositions that are outside of science and lack authority in the absence of valid ethnographic support. This applies especially to very early traditions because their creators' cogni-

Table 1. Schedule of tentative ratings of methods used to estimate the ages of rock art; highest numbers for 'Attributes' represent the most favourable conditions.

tion and perception probably differed significantly from that of the iconography's modern 'interpreters' (Helvenston 2013), who have not been conditioned to perceive reality how the rock art makers experienced it. Obviously, if readings such as animal species, specific weapons or other objects presumably depicted are most often erroneous (as we know they are, from blind tests; cf. Macintosh 1951, 1952, 1977), the chronological deductions drawn from them are likely false. Therefore, the probability of guessing the correct target date is correspondingly low, and that applies also to its precision and reliability.

Very similar considerations apply to *style* (No. 2 in Table 1), which is an inherently subjective attribute that only exists once it has been defined. Style has led to many disagreements among rock art interpreters, who rely entirely on their culturally conditioned neural processing of sensory input. However, rock artists of the same family may use very different styles (Mulvaney 1996), or artists may use a variety of styles throughout their lifetimes. Distinctive styles, e.g., depicting horses or cattle, can be found in temporally widely separated traditions and, therefore, do not tell us their age. For instance, some stylistic elements featuring in Upper Palaeolithic rock art re-occur in Holocene traditions, such as the Spanish Levantine shelter art, in Greek and Roman times, and in subsequent Historical periods up to the present. Purely stylistic 'analyses' have resulted in roughly 100-year-old petroglyphs being pronounced more than 20,000 years of age (Bednarik 2009a). While styles do exist, they are challenging to define and 'quantify', and the simplistic endeavours to do so in rock art have often failed spectacularly. Their 'visual grammar' needs to be known in order to understand the rules defining them, which is rarely the case (Layton 1991, 2001). The self-referential discourse of rock art interpreters invites no confidence in the age determinations they extract from their assertions about both style and iconography.

In rare cases, rock art concealed by soil sediment has been found by *archaeological excavation* (3). It is then assumed to predate the deposition of the covering stratum, which may be the case but is not necessarily guaranteed. The complex sedimentary histories, especially of such places as rockshelters and caves, provide limited confidence in such claimed relationships, which also depend on hypothetical propositions about the age of the sediment. Such bridging arguments, of varying credibility, have been presented for stratified pigment traces and supposedly related nearby rock paintings (Macintosh 1965; Wakankar 1983; Combier 1984; Linares 1988; Chippindale and Taçon 1998). Petroglyphs of suggested minimum ages based on presumed antiquities of concealing sediment have been reported from several sites (Daleau 1896; Lalanne and Breuil 1911; Lemozi 1920; David 1934; Passemard 1944; Clark 1950; Ampoulange and Pintaud 1955; de Saint Mathurin 1975; Anati 1976: 34, 41; Rosenfeld et

al. 1981; Cannon and Ricks 1986; Steinbring et al. 1987; Crivelli et al. 1996; Steinbring 2013; Rodríguez-Vidal et al. 2014). Another technique of attempting archaeological minimum dating has been to propose that exfoliated and buried fragments of petroglyphs should be considerably older than the sediment they were excavated from (Capitan et al. 1912; Hale and Tindale 1930; Mulvaney 1969: 176; Thackeray et al. 1981; Fullagar et al. 1996, refuted by Roberts et al. 1998; Bednarik et al. 2005). Minimum dating of exfoliated rock painting residues has been less persuasive (O'Connor 1995). Traditional methods of estimating the rock art age also include proximity of 'dated' other archaeological evidence (e.g. nearby human occupation evidence) and comparative technique of rock art production, which are not considered here as they are epistemologically doubtful.

The *radiocarbon age of reprecipitated carbonate* (4), especially calcite, is one of the two analytical criteria used in the first application of direct dating of rock art (Bednarik 1981, 1984). When limestone is dissolved by carbonic acid, approximately one-half of the resulting calcium bicarbonate's carbon derives from the atmosphere (as CO₂) and thus contains ¹⁴C, which then begins to decay. Therefore, reprecipitated secondary carbonates, such as speleothems and travertine, can be radiocarbon-dated. Where the rock art has been executed on such precipitates, it must postdate them; where they formed over the rock art, it predates them by an unknown margin. Hence, the method cannot provide target dates; at best, it yields minimum or maximum ages. The only exception is markings pressed into the travertine because that material remains soft for only a short time and, therefore, roughly coincides in age with the time of its deposition. However, this technique has rarely been used to estimate the rock art age.

The second method applied in the first direct rock art dating was the *U-Th analysis of reprecipitated carbonate* (5). It was immediately found to contradict the much lower ¹⁴C result obtained from the same speleothem sample, and such divergence has since been reported in all studies using the two methods in tandem (Holmgren et al. 1994; Labonne et al. 2002; Plagnes et al. 2003; Taçon et al. 2012; Quiles et al. 2014; Valladas et al. 2017; Tang et al. 2020; Pons-Branchu et al. 2020). This explains the method's low rating, especially for its reliability (Tang and Bednarik 2021; Bednarik 2022). Difficulties are most likely attributable to the removal of uranium by moisture, although the deposition of detrital thorium is also a possible explanation. Improved sampling methods seek to address these complications (e.g. Yanuo et al. 2024).

Similarly, determining *uranium-series isotopes of ferromanganese accretions* (6), such as rock varnish, cannot provide target dates and would probably fail to deliver credible age estimates. *Radiocarbon dating of ferromanganese accretions* (7) has been applied by presuming that organic matter embedded in them is

of the same age as their deposition. Its utility is contradicted by the observation that most rock subsurface zones, such as weathering zones, harbour organics of varying origins, most of which are of different carbon ages than the accretion (Bednarik 1980).

Watchman pioneered the ^{14}C determination of oxalate deposits (8) over or under rock art, particularly layers of paint residue (1990, 1991, 2000, 2024; Watchman and Campbell 1996). Like carbonate, precipitates of oxalic acid also contain organically derived carbon and are thus datable. The issue with using oxalate is understanding the mode of biochemical formation. Care must also be taken to ensure that there has been no rejuvenation through the deposition of interstitial solute in pores, the deposition of organic matter, isotopic exchange or fractionation. Another possibility is to sequester and radiocarbon-date calcium oxalate contained within mineral crusts directly associated with paint residues (Jones et al. 2017).

Many analysts have removed samples of mineral paint residues and radiocarbon-dated them, attempting to establish the ages of such layers of *non-carbon paint* (9) by presuming that the paint's organic content is derived from a binder or diluent. Such results are only meaningful if it is known what substance they refer to because of the natural occurrence of carbon in all rock surface deposits. By contrast, carbonaceous paint, prepared with *charcoal or soot* (10), can provide valid age estimates if we tolerate the potential distortion from incidental organic matter. This could derive from aerosols, lichen, fungal hyphae, bacteria and many other sources (cf. Ridges et al. 2000). However, their contaminating effect would be negligible in paint consisting mostly of charcoal or soot.

The determination of *radiocarbon in sequestered organic objects* (11) found embedded in the paint residue, such as pollen grains, plant fibres, seeds, hairs or other carbon-based items is of greater reliability. This method was introduced by Cole and Watchman (1992; cf. Watchman and Cole 1993) when they detected and isolated a variety of vegetation fibres in rock art paint at sites in northeastern Australia. Some were attributed to binders (orchid juice), others to paint brushes (kapok bush). The extracted fibres were then dated by subjecting them to AMS radiocarbon analysis.

Among the rock art forms most amenable to age estimation are the *beeswax figures* (12) of northern Australia (Nelson et al. 1995; Taçon and Garde 2000). They also provide adequately sized samples. As the wax needs to be applied in relatively fresh condition, ^{14}C dates secured from it are unlikely to differ greatly from the time the wax was applied, and distortion from organic sources is likely insignificant. Sixteen sites of beeswax figures have yielded 137 age estimates (Nelson 2000), and their distribution in time presents a temporal dispersal curve implying a taphonomic threshold of about 800 years bp (Bednarik 2001).

Another promising method seeks to *identify organic matter in paint residues* (13). Ponti and Sinibaldi (2005)

estimated the ages of five rock paintings in southwestern Libya after sequestering proteins, hydrocarbons and terpenoids (possibly bitumen) from paint residues. These substances were then subjected to AMS radiocarbon analysis. The method is difficult to apply, but its results are both relatively reliable and precise within the limits of the dating method.

Since the introduction of highly portable equipment, *x-ray fluorescence spectrometry* (14) has been added to the arsenal of rock art dating scientists (Lytle et al. 2004). It seeks to calibrate the increased Mn+Fe concentrations of rock varnishes as a function of age, deriving calibration from the results of another method, such as microerosion analysis (Macholdt et al. 2019). No physical sampling is involved, but the expected precision of results has been suggested to be modest. Since the notion of linear enrichment of cations is questionable, the method's reliability needs to be verified independently.

The initial attempt by Denninger (1971) to estimate rock art age by *amino acid racemisation* (15) has been refuted by the susceptibility of the reaction to temperature. However, it has been shown subsequently that amino acid residues can be preserved in rock art paintings (McCarthy et al. 1994). The method may still be useful in rock art research, but it needs to be evaluated and appropriately tested. By contrast, the next-listed approach in Table 1 is unlikely to facilitate rock art age estimation. *Cosmogenic radiation nuclides determination* (16) has failed to provide credible dates in archaeology. The cosmic ray-caused nuclides in question are ^3He , ^{10}Be , ^{14}C , ^{21}Ne , ^{26}Al , ^{36}Cl and ^{41}Ca . The method's two applications in archaeology (Williams-Thorpe et al. 1995; Phillips et al. 1997) both provided apparently false results (Bednarik 1998a). This was because the least suitable nuclide was used (^{36}Cl), and the method necessitates the assumption of a rate of erosion retreat, which would effectively exclude the survival of the petroglyphs supposedly dated.

In *optically stimulated luminescence analysis of insect nests* (17), one of three luminescence dating methods is applied to determine when quartz grains extracted from insect structures had last been exposed to light. In various continents, the nests of mud dauber wasps or trackway tunnels of termites are often superimposed over rock paintings or sometimes bear such rock art (Bednarik 2014). These structures then predate or post-date the paintings. However, there is no certainty that each sand grain in the mud pellets carried by a mud wasp has been fully bleached by sunlight, introducing a major potential error source. Also, it is unknown whether the measures taken to exclude the effects of alpha and beta radiation (etching with hydrofluoric acid) had been effective or whether the gamma dose rate is correct in the absence of a surrounding sediment matrix. These and other uncertainties account for the low ratings in Table 1.

The rating of ^{14}C analysis of insect structures (18) is even lower, in view of the considerable uncertainties

about the origin of the organic constituents of these deposits. While the dating method of radiocarbon analysis offers high precision, the closeness of the dating criterion to the target event and reliability are both rated zero, and the level of contamination of results is unknown. The numerous carbonaceous components of the mud used are all different ages, and some, such as micro-charcoal, could be any conceivable age (Watchman 2022). Determining the carbon isotopes in the former mud is akin to carbon-dating the randomly acquired organics found in non-carbon paint residues. It can be expected to yield essentially random numbers.

Considering the 'desperate' nature of some of the methods applied in dating rock art, it is surprising that a reliable, albeit relatively imprecise method such as *lichenometry* (19) has been widely disregarded. Besides a few attempts to apply the method (e.g. Li and Zhu 1993), its only benefit has been in unquantified discussions of thallus sizes vs petroglyph ages (e.g. in the Côa Valley, Portugal). Lichen commonly co-occurs with petroglyphs, and given the potential of using the method in tandem with other methods, this neglect is regrettable. Although lichenometry provides no target dates, it is highly rated in the remaining attributes.

The surface retreat of cement (20) refers to the retreat of the material surrounding sand grains in arenite rocks, especially siliceous sandstones, due to its greater solubility than the quartz grains embedded in it. Where calibration with known references is possible, relatively reliable age estimates of petroglyph surfaces are feasible, provided they are not older than the time it takes for all grains to exfoliate from a surface created by petroglyph production (Bednarik 2024). Depending on several variables, this can range up to a millennium or two.

Microerosion analysis (21) refers to the measurement of micro-wanes on quartz crystals fractured during the creation of petroglyphs (Bednarik 1992). Its high rating is attributable to several factors: it is one of only a few methods that yield target dates rather than minimum or maximum ages; as an optical method, it involves no physical contact with the rock art, and thus no contamination; and it offers the opportunity of checking the validity of the result without recourse to another method, by cross-checking it with a second mineral component, e.g. feldspar. Microerosion analysis has been applied on all continents (except Antarctica) and subjected to numerous blind tests. It is the principal method the International Centre for Rock Art Dating (ICRAD; Bednarik 2016) uses.

Although based on the same geometrical principles as microerosion analysis, *Macroerosion analysis* (22) has so far yielded no credible results. Černohouz and Solč (1966) reported age estimates from sandstone and basalt, but the difficulty of applying this method to petroglyphs derives from their lack of adequate groove depth. Realistically, it would be limited to grooves deep enough to form distinctive angles of 90° between

the grooves' side walls and the surrounding surfaces. If calibration could be achieved through historically dated rock surfaces nearby, macroerosion analysis might yet provide adequate results.

The determination of *cation ratios of rock surface accretions* (23) to date rock art was a method that held little promise from its beginnings in the 1980s. It was based on the premise that the more soluble cations of rock varnish (K and Ca) would be removed more rapidly than the supposedly more stable Ti component. The numerous flaws of this idea include the great variability of Ti concentrations and anomalies in the Ca and K; and that the method of calibrating the cation ratios, ¹⁴C analysis, yields inherently false data because rock substrates are generally open carbon systems (Bednarik 1979). Moreover, the cations analysed do not occur as pure elements but as various minerals, sometimes combining Ti and one or both of the other two. After Watchman (1992) tried unsuccessfully to replicate some South Australian results, Dorn (e.g. 1996) conceded that cation-ratio dating was not viable.

The appraisal of *fluvial erosion wear* (24) in a quantified format has only been attempted once so far (Bednarik 2009a). In that study, schist petroglyphs shared their high-kinetic river setting with hundreds of rock inscriptions, many of them dated. The latter facilitated the establishment of a chronological framework of the degree of erasure by abrasive fluvial wear that was then applied to the rock art occupying the same flooding zone. It established, together with other evidence, that the rock art, claimed to be Palaeolithic, is of recent times. Most of it is from the early 20th century.

Locating paint drips or rock grains in the sediment (25) below pictograms or petroglyphs, respectively, has been tried unsuccessfully, e.g. by G. J. Susino. Gordon (2013) has attempted to locate such materials at a series of North American sites but reports no results. Not only would rock dust and fragments weather rapidly in the earth, but their radiometric dating would present further impediments. The prospects of this approach are somewhat better for paint remains that dripped onto the floor of deep caves. Their well-protected environments might preserve such remains and even render their stratigraphical dating feasible in favourable conditions.

Contrary to my expectation, *digital colourimetry of ferruginous accretions* (26) can be usefully engaged in estimating the age of petroglyphs. It requires no specific expertise or specialised equipment. This approach was the first advocated for direct dating (by Belzoni 1820). When I tested its utility by sequencing precise colour characteristics of a series of dated inscriptions on some granite tors, I obtained surprisingly consistent results of the gradual colour change of the patina (Bednarik 2009b). Despite its lack of precision, deriving from the considerable variability in the accretionary processes, this method has a high rating in Table 1. All other of its attributes are perfect, justifying Belzoni's confidence.

We thus arrive at Table 2, which presents my sug-

gested ratings of the methods I have considered. These ratings provide only a rough guide, reflecting very different attributes. Individual researchers are likely to favour different attributes, and these preferences are not well reflected in the ratings totals. However, it soon becomes apparent that ratings of 8 or lower apply to methods that should be avoided for various reasons. The traditional methods, the first three listed and used for well over a century, have good ratings. However, it must be noted that the first two show mediocre track records, and the third can only be applied under the most fortunate circumstances. Nevertheless, ratings of 14 or higher identify methods that have either yielded credible results or can be considered promising. One of the lessons provided by Table 2 is that the precision of the results of a method is often at the expense of their reliability, or vice versa.

No.	'Dating' method	Rating
15	Amino acid racemisation	5
16	Cosmogenic radiation nuclides	5
23	Cation ratio of accretions	5
6	U-Th of ferromanganese accretion	6
7	^{14}C of ferromanganese accretion	7
18	^{14}C analysis of insect nests	7
5	U-Th of carbonate	8
9	^{14}C of non-carbon paint residue	8
17	OSL analysis of insect nests	8
14	X-ray fluorescence spectrometry	9
4	^{14}C of carbonate	10
8	^{14}C of oxalate deposit	10
10	^{14}C of charcoal paint, soot	13
13	^{14}C of identified OM in paint	13
25	Paint drips/grains in soil	13
1	Iconography	14
2	Style	14
3	Archaeological excavation	14
11	^{14}C of sequestered organic object	14
19	Lichenometry	15
22	Macroerosion analysis	15
20	Surface retreat of cement	16
24	Fluvial erosion wear	16
12	^{14}C of beeswax	17
21	Microerosion analysis	19
26	Digital colourimetry of accretion	20

Table 2. Tentative ratings of methods used to estimate the ages of rock art.

Discussion

The purpose of this paper, as stated in the introduction, is to provide generic evaluations of various methods that have been used in estimating the age of rock art. This includes the precision of the analytical techniques, the reliability of their results, and

important variables such as the levels of intervention and potential contamination involved. In planning the use of specific dating methods, it is also vital to consider their accessibility to prospective users and their ease of application. Most methods can only provide maximum or minimum ages, which can be of minimal significance (Ward and Tuniz 2000; Bednarik 2014). Only five of the listed twenty-six techniques can deliver target dates (11, 12, 21, 22, 26) in the sense of Dunnell and Readhead (1988), while twelve of them offer no significant indication of how much earlier or later the true age is (4–9, 14, 16–19, 23).

There are some dangers in this type of general review, with details of individual methods necessarily scant and possibly selective; and the likelihood of potential subjectivity or arbitrariness in some of the scores. It needs to be appreciated that patterns in the results can be more useful than one-off dates. As always, extraordinary results require extraordinary evidence.

A somewhat more complex side to the issue of choice of method is not considered here. It concerns the detailed conditions at the site, such as its lithology, exposure and susceptibility to weathering processes, types of accretions, environmental conditions, previous degradation, research logistics and conditions posed by the relevant management agency. Numerous factors determine which methods could be used at a particular site. These aspects occur in a near-infinite number of combinations; therefore, no two sites are alike in the choice of potential dating method(s). The researcher needs to have some understanding of all of them. Here, the intention is to help prospective rock art dating teams with initial considerations and to formulate a standard response to enquiries asking for advice concerning the strategies for designing rock art dating projects.

Nevertheless, a very simple rule-of-thumb could have prevented many of the mis-datings of petroglyphs we have witnessed over the years. It is based on the work of replicating them (e.g. Bednarik 1998b: 30–31; Kumar and Krishna 2014), which has shown the enormous differences in time taken to create them, depending on the rock's aggregate hardness¹. For instance, it takes roughly one thousand times as long to produce a 12-mm-deep cupule on metamorphosed arenite (hardness 7 on the Mohs scale) than it takes on deeply weathered siliceous sandstone (hardness

¹ Aggregate or composite hardness is intended to be a measure of how resistant the rock is to deformation when a compressive force is applied to it. It expresses scratch or abrasion resistance, which is measured by the Rosiwal scale (greatly superior to the Mohs scale). Indentation hardness is another determining factor, measured by the Brinell scale or determined by the Vickers test. The brittleness factor also influences the effect on the production coefficient. Moreover, the rock's strength, ductility and toughness contribute to aggregate hardness. Finally, it must be appreciated that most rocks are made up of discrete minerals, all with their hardness variables.

<6). *The relative susceptibility of any petroglyph to erasure by natural means is proportional to the time it takes to create it* (Bednarik 2010: 110). All petroglyphs will ultimately be erased by weathering, be it by aeolian, fluvial, marine or biological agents. If it took three orders of magnitude longer to make, it would also take that much longer to erase than an identical motif on the softer rock. The significance of this simple rule is that it renders the longevity of a petroglyph predictable because we can establish how long it takes to make—by replication. Therefore, it is essential that researchers trying to determine the age of such rock art familiarise themselves with the characteristics of the rock on which it occurs, such as its aggregate hardness. To illustrate the implications with a practical example, it means that on a panel of schist exposed to precipitation, a petroglyph cannot be 20,000 years old because schist retreats by weathering at a rate of 1–10 mm per millennium. Well over 20 mm of rock would have eroded in that period, and the petroglyph would have long been lost.

Clearly, this rule does not date petroglyphs, but it does place their age into a realistic probability framework. It requires no in-depth research, but understanding the respective lithology would have prevented many misunderstandings or embarrassments. In various instances, it would have identified numerical results that were simply off the scale. A similar rule might also be possible for rock paintings. However, here the diagnostic information would relate to the paint ingredients' characteristics of adhesion, penetration and durability, as well as the environmental setting. Nevertheless, a significantly better empirical understanding of the effects of these factors would be required than is currently available. Therefore, the rough estimation of rock painting age by some minimal rule remains elusive.

Summary

This paper was written in response to requests by rock art researchers and cultural heritage managers for advice on which methods to use in determining the antiquity of rock art. It presents a table of methods used, listing how accessible they are to most researchers and how easy they are to apply, as well as the vital attribute of how closely the result would match the true age of rock art. Ratings are also provided for how well the method avoids physical intervention and the potentiality of contamination reflected in its result. Finally, the anticipated precision and reliability of each method's results are also rated. This is intended to provide some initial guidance in the perplexing domain of rock art age estimation. Such estimations benefit greatly from independent verification of results, be it by the same or another method. Examples are Watchman and Jones' (2002) confirmation of the radiocarbon determination of a beeswax figure previously analysed by Nelson et al. (1995) or the various age estimates for Côa petroglyphs in Portugal. It must be emphasised that all methods applied to rock art

dating remain experimental—but some more so than others. In a century from now, our present efforts may seem inconsequential, but to gain that insight, they will have been necessary.

Acknowledgments

I thank the paper's peer reviewers, Dr Alan Watchman, Dr Noelene Cole and Dr Graeme Ward, for their constructive comments.

Prof. Robert G. Bednarik¹

¹College of History and Culture, Hebei Normal University, Shijiazhuang, China

robertbednarik@hotmail.com

REFERENCES

- AMPOULANGE, U. and R. C. PINTAUD 1955. Une nouvelle gravure de la grotte de La Grèze (Dordogne). *Bulletin de la Société Préhistorique Française* 52: 249–251.
- ANATI, E. 1976. *Evolution and style in Camunian rock art*. *Archivi* 6, Capo di Ponte.
- BEDNARIK, R. G. 1979. *The potential of rock patination analysis in Australian archaeology—part 1*. *The Artefact* 4: 14–38.
- BEDNARIK, R. G. 1981. The introduction of direct rock art dating in 1980. <http://www.ifrao.com/wp-content/uploads/2014/06/Dating-1980.pdf>.
- BEDNARIK, R. G. 1984. Die Bedeutung der paläolithischen Fingerlinientradition. *Anthropologie* 23: 73–79.
- BEDNARIK, R. G. 1992. A new method to date petroglyphs. *Archaeometry* 34: 279–291.
- BEDNARIK, R. G. 1998a. Cosmogenic radiation nuclides in archaeology: a response to Phillips et al. *Antiquity* 72: 811–815.
- BEDNARIK, R. G. 1998b. The technology of petroglyphs. *Rock Art Research* 15(1): 23–35.
- BEDNARIK, R. G. 2001. The taphonomy of beeswax figures. *Rock Art Research* 18(1): 91–95.
- BEDNARIK, R. G. 2009a. Fluvial erosion of inscriptions and petroglyphs at Siega Verde, Spain. *Journal of Archaeological Science* 36(10): 2365–2373.
- BEDNARIK, R. G. 2009b. Experimental colourimetric analysis of petroglyphs. *Rock Art Research* 26(1): 55–64.
- BEDNARIK, R. G. 2010. Australian rock art of the Pleistocene. *Rock Art Research* 27(1): 95–120.
- BEDNARIK, R. G. 2014. Mud-wasp nests and rock art. *Rock Art Research* 31(2): 225–231.
- BEDNARIK, R. G. 2016. The International Centre of Rock Art Dating and Conservation (ICRAD). *Rock Art Research* 33(1): 111–112.
- BEDNARIK, R. G. 2022. The dating of rock art and bone by the uranium–thorium method. *Rock Art Research* 39(2): 195–204.
- BEDNARIK, R. G. 2024. Rock inscriptions in Western Australia. *Rock Art Research* 41(2): 208–219.
- BEDNARIK, R. G., G. KUMAR, A. WATCHMAN and R. G. ROBERTS 2005. Preliminary results of the EIP Project: the status at the end of 2004. *Rock Art Research* 22(2): 147–197.
- BELZONI, G. 1820. *Narrative of the operations and recent discoveries within the pyramids, temples, tombs and excavations in Egypt and Nubia*, Vol. 1. London.
- CANNON, W. J. and M. J. RICKS 1986. The Lake County, Oregon, rock art inventory: implications for prehistoric settlement and land use patterns. *Contributions to the*

- Archaeology of Oregon 3: 1–23.
- CAPITAN, L., H. BREUIL and D. PEYRONY 1912. Les gravures sur cascade stalagmitique de la grotte de la Mairie à Teyat (Dordogne). *Congrès International d'Anthropologie et d'Archéologie Préhistorique*, 16^e session, pp. 498–514. Geneva.
- ČERNOHOÚZ, J. and I. SOLČ 1966. Use of sandstone wanes and weathered basaltic crust in absolute chronology. *Nature* 212: 806–807.
- CHIPPINDALE, C. and P. S. C. TAÇON 1998. The many ways of dating Arnhem Land rock art, north Australia. In C. Chippindale and P. S. C. Taçon (eds), *The archaeology of rock-art*, pp. 90–111. Cambridge University Press, Cambridge.
- CLARK, J. D. 1950. The newly discovered Nachikufu culture of northern Rhodesia and the possible origin of certain elements of the South African Smithfield culture. *South African Archaeological Bulletin* 5: 86–98.
- COLE, N. and A. WATCHMAN 1992. Painting with plants: investigating fibres in Aboriginal rock paintings at Laura, north Queensland. *Rock Art Research* 9(1): 27–30.
- COMBIER, J. 1984. Grotte de la Tête-du-Lion. In *L'Art des cavernes*, pp. 595–599. Ministère de la Culture, Paris.
- CRIVELLI MONTERO, E. A. and M. M. FERNÁNDEZ 1996. Palaeoindian bedrock petroglyphs at Epullán Grande Cave, northern Patagonia, Argentina. *Rock Art Research* 13(2): 112–117.
- DALEAU, F. 1896. Les gravures sur roche de la caverne de Pair-non-Pair. *Actes de la Société Archeologique de Bordeaux* 21: 235.
- DAVID, P. 1934. Abri de la Chaire à Calvin. *Congrès Préhistoire de France*, 11^e session, pp. 372–378. Périgueux.
- DENNINGER, E. 1971. The use of paper chromatography to determine the age of albuminous binders and its application to rock paintings. Rock paintings in southern Africa, supplement to the *South African Journal of Science*, Special Issue, 2: 80–84.
- DORN, R. I. 1996. Uncertainties in ¹⁴C ages for petroglyphs from the Olary province, South Australia. *Archaeology in Oceania* 31: 214–215.
- DUNNELL, R. C. and M. L. READHEAD 1988. The relation of dating and chronology: comments on Chatters and Hoover (1986) and Butler and Stein (1988). *Quaternary Research* 30: 232–233.
- FULLAGAR, R. L. K., D. M. PRICE and L. M. HEAD 1996. Early human occupation of northern Australia: archaeology and thermoluminescence dating of Jinmium rock-shelter, Northern Territory. *Antiquity* 70: 751–73.
- GORDON, B. 2013. Dating rock art: two new methods for pictographs and petroglyphs. In J. Clottes (ed.), *Pleistocene art of the world*, *Palethnology* 2013(5): 221–222.
- HALE, H. M. and N. B. TINDALE 1930. Notes on some human remains in the lower Murray valley, South Australia. *Records of the South Australian Museum* 4: 145–218.
- HELVENSTON, P. A. 2013. Differences between oral and literate cultures: what we know about Upper Paleolithic minds. In R. G. Bednarik (ed.), *The psychology of human behaviour*, pp. 59–110. Nova Press, New York.
- HOLMGREN, K., S.-E. LAURITZEN and G. POSSNERT 1994. ²³⁰Th/²³⁴U and ¹⁴C dating of a late Pleistocene stalagmite in Lobatse II cave, Botswana. *Quaternary Science Reviews* 13: 111–119.
- JONES, T., V. A. LEVCHENKO, P. L. KING, U. TROITZSCH, D. WESLEY, A. A. WILLIAMS and A. NAYINGULL 2017. Radiocarbon age constraints for a Pleistocene–Holocene transition rock art style: the northern running figures of the East Alligator River region, western Arnhem Land, Australia. *Journal of Archaeological Science: Reports* 11: 80–89.
- KUMAR, G. and R. KRISHNA 2014. Understanding the technology of the Daraki-Chattan cupules: the cupule replication project. *Rock Art Research* 31(2): 177–186.
- LABONNE, M., C. HILLAIRES-MARCEL, B. GHALEB and J. L. GOY 2002. Multi-isotopic age assessment of dirty speleothem calcite: an example from Altamira Cave, Spain. *Quaternary Science Reviews* 21: 1099–1110.
- LALANNE, G. and H. BREUIL 1911. L'abri sculpté du Cap-Blanc à Laussel, Dordogne. *L'Anthropologie* 21: 385–402.
- LAYTON, R. 1991. Figure, motif and symbol in the hunter-gatherer rock art of Europe and Australia. In P. Bahn and R. Rosenfeld (eds), *Rock art and prehistory*, pp. 23–38. Monograph 10, Oxbow Books, Oxford.
- LAYTON, R. 2001. Ethnographic study and symbolic analysis. In D. S. Whitley (ed.), *Handbook of rock art research*, pp. 311–331. Altamira Press, Walnut Creek, California.
- LEMOZI, A. 1920. Peintures et gravures paléolithiques découvertes dans les grottes des communes d'Espagnac, de Sainte-Eulalie et de Cabrerets. *Bulletin de la Société Préhistorique Française* 17: 256–263.
- LI X. and ZHU C. 1993. *Helanshan yu Beishan yanhua* (The rock art in Mt Helan and Mt North). Ningxia Renmin, Yinchuan.
- LINARES MALAGA, E. 1988. Arte mobiliario con tradición rupestre en el sur del Perú. *Rock Art Research* 5(1): 54–66.
- LYTLE, F., D. FERRIS-ROWLEY, P. ROWLEY, X. KRETSCHMER, M. DELGADO and N. PINGITORE 2004. Determination of the age of petroglyphs at the Land Hill Site by x-ray fluorescence analysis. Paper presented at annual meeting of the Nevada Archaeological Association, Winnemucca, NV, 17 April 2004.
- MACHOLDT, D. S., K. P. JOCHUM, A. AL-AMRI and A. O. MEINRAT 2019. Rock varnish on petroglyphs from the Hima region, southwestern Saudi Arabia: chemical composition, growth rates, and tentative ages. *The Holocene* 29: 1–19; doi: org/10.1177/0959683619846979.
- MACINTOSH, N. W. G. 1951. Archaeology of Tandandjal Cave, south-west Arnhem Land. *Oceania* 21(3): 178–204.
- MACINTOSH, N. W. G. 1952. Paintings in Beswick Cave, Northern Territory. *Oceania* 22(4): 256–274.
- MACINTOSH, N. W. G. 1965. Dingo and horned anthropomorph in an Aboriginal rock shelter. *Oceania* 36: 85–101.
- MACINTOSH, N. W. G. 1977. Beswick Creek Cave two decades later: a reappraisal. In P. J. Ucko (ed.), *Form in indigenous art: schematisation in the art of Aboriginal Australia and prehistoric Europe*, pp. 191–197. Prehistory and Material Culture Series 13, Australian Institute of Aboriginal Studies, Canberra.
- MCCARTHY, D. L. PAYEN and P. ENNIS 1994. Use of amino acid racemization methods on rock paintings at Motte Rimrock Reserve. *American Indian Rock Art* 13: 17–22.
- MULVANEY, J. D. 1969. *The prehistory of Australia*. Thames and Hudson, London.
- MULVANEY, K. 1996. What to do on a rainy day. Reminiscences of Mirriuwung and Gadjerong artists. *Rock Art Research* 13(1): 3–20.
- MURRAY-WALLACE, C. V. 1993. A review of the application of the amino acid racemisation reaction to archaeological dating. *The Artefact* 16: 19–26.
- MUZZOLINI, A. 1999. La notation des dates au 14 C. *Cahiers de l'AARS* 16: 18–24.
- NELSON, D. E. (ed.) 2000. *The beeswax art of northern Australia*. Compact disk, Simon Fraser University, Burnaby, Canada.
- NELSON, D. E., G. CHALOUKPA, C. CHIPPINDALE, M. S. ALDERSON and J. R. SOUTHERN 1995. Radiocarbon dates for

- beeswax figures in the prehistoric rock art of northern Australia. *Archaeometry* 37: 151–56.
- O'CONNOR, S. 1995. Carpenter's Gap Rockshelter 1: 40,000 years of Aboriginal occupation in the Napier Ranges, Kimberley, WA. *Australian Archaeology* 40: 58–59.
- PASSEMARD, E. 1944. La caverne d'Isturitz en pays basque. *Préhistoire* 13: 1–95.
- PHILLIPS, F. M., M. FLINSCH, D. ELMORE and P. SHARMA 1997. Maximum ages of the Côa valley (Portugal) engravings measured with chlorine-36. *Antiquity* 71: 100–104.
- PLAGNES, V., C. CAUSSE, M. FONTUGNE, H. VALLADAS, J.-M. CHAZINE and L.-H. FAGE 2003. Cross dating (Th/U-¹⁴C) of calcite covering prehistoric paintings in Borneo, *Quaternary Research* 60(2): 172–179.
- PONS-BRANCHU, E., J. L. SANCHIDRIÁN, M. FONTUGNE, M. A. MEDINA-ALCAIDE, A. QUILES, F. THIEL and H. VALLADAS 2020. U-series dating at Nerja Cave reveal open system. Questioning the Neanderthal origin of Spanish rock art. *Journal of Archaeological Science* 117: 105–120.
- PONTI, R. and M. SINIBALDI 2005. Direct dating of painted rock art in the Libyan Sahara. *Sahara* 16: 162–165.
- QUILES A., C. FRITZ, M. A. MEDINA, E. PONS-BRANCHU, J. L. SANCHIDRIÁN, G. TOSELLO and H. VALLADAS 2014. Chronologies croisées (C-14 et U/Th) pour l'étude de l'art préhistorique dans la grotte de Nerja: méthodologie. In M. A. Medina-Alcaide, A. Romero Alonso, R. M. Ruiz-Márquez and J. L. Sanchidrián Torti (eds), *Sobre rocas y huesos: las sociedades prehistóricas y sus manifestaciones plásticas*, pp. 420–427. Fundación Cueva de Nerja, Córdoba.
- RIDGES, M., I. DAVIDSON and D. TUCKER 2000. The organic environment of paintings on rock. In G. K. Ward and C. Tuniz (eds), *Advances in dating Australian rock-markings*, pp. 61–70. Occasional AURA Publication 10, Australian Rock Art Research Association, Melbourne.
- ROBERTS, R. G., M. BIRD, J. OLLEY, R. GALBRAITH, E. LAWSON, G. LASLETT, H. YOSHIDA, R. JONES, R. FULLAGAR, G. JACOBSEN and Q. HUA 1998. Optical and radiocarbon dating at Jinnium rock shelter in northern Australia. *Nature* 393: 358–362.
- RODRÍGUEZ-VIDAL, J., F. D'ERRICO, F. G. PACHECO, R. BLASCO, J. ROSELL, R. P. JENNINGS, A. QUEFFELEC, G. FINLAYSON, D. A. FA, J. M. GUTIÉRREZ LÓPEZ, J. S. CARRIÓN, J. J. NEGRO, S. FINLAYSON, L. M. CÁCERES, M. A. BERNAL, S. FERNÁNDEZ JIMÉNEZ and C. FINLAYSON 2014. A rock engraving made by Neanderthals in Gibraltar. *Proceedings of the National Academy of Science, U.S.A.* 111(37): 13301–13306, doi: 10.1073/pnas.1411529111.
- ROSENFELD, A., D. HORTON and J. WINTER 1981. *Early Man in north Queensland*. Terra Australis No. 6, Australian National University, Canberra.
- SAINT MATHURIN, S. de 1975. Reliefs magdaléniens d'Angles-sur-l'Anglin (Vienne). *Antiquités Nationales* 7: 24–31.
- STEINBRING, J. 2013. A brief note on archaeological superposition at the Hensler Petroglyph Site (47DO461), Dodge County, Wisconsin, U.S.A. *Rock Art Research* 30(1): 118–120.
- STEINBRING, J., E. DANZIGER and R. CALLAGHAN 1987. Middle Archaic petroglyphs in northern North America. *Rock Art Research* 4(1): 3–16.
- TAÇON, P. S. C., M. AUBERT, GANG L., YANG D., LIU H., S. K. MAY, S. FALLON, JI X., D. CURNOE and A. I. R. HERRIES 2012. Uranium-series age estimates for rock art in south-west China. *Journal of Archaeological Science* 39: 492–499.
- TAÇON, P. S. C. and M. GARDE 2000. Dating beeswax figures on rock art: the view from central Arnhem Land. In G. K. Ward and C. Tuniz (eds), *Advances in dating Australian rock-markings*, pp. 71–75. Occasional AURA Publication 10, Australian Rock Art Research Association, Inc., Melbourne.
- TANG H., G. KUMAR, JIN A. and R. G. BEDNARIK 2020. Rock art of Heilongjiang Province, China. *Journal of Archaeological Science: Reports* 31: 102348.
- TANG H. and R. G. BEDNARIK 2021. Rock art dating by ²³⁰Th/²³⁴U analysis: an appraisal of Chinese case studies. *Archaeological and Anthropological Sciences* 13(1): 1–10; doi: 10.1007/s12520-020-01266-0.
- THACKERAY, A. I., J. F. THACKERAY, P. B. BEAUMONT and J. C. VOGEL 1981. Dated rock engravings from Wonderwork Cave, South Africa. *Science* 214: 64–67.
- VALLADAS, H., E. PONS-BRANCHU, J. P. DUMOULIN, A. QUILES, J. L. SANCHIDRIÁN and M. A. MEDINA-ALCAIDE 2017. U/Th and 14C crossdating of parietal calcite deposits: application to Nerja Cave (Andalusia, Spain) and future perspectives. *Radiocarbon* 59: 1955–1967.
- WARD, G. K. and C. TUNIZ (eds) 2000. *Advances in dating Australian rock-markings*. Occasional AURA Publication 10, Australian Rock Art Research Association, Melbourne.
- WAKANKAR, V. S. 1983. The oldest works of art? *Science Today* 20: 43–48.
- WATCHMAN, A. 1990. A summary of occurrences of oxalate-rich crusts in Australia. *Rock Art Research* 7: 44–50.
- WATCHMAN, A. 1991. Age and composition of oxalate-rich crusts in the Northern Territory, Australia. *Studies in Conservation* 36: 24–32.
- WATCHMAN, A. 1992. Investigating the cation-ratio calibration curve: evidence from South Australia. *Rock Art Research* 9: 106–110.
- WATCHMAN, A. 2000. Micro-excavation and laser extraction methods for dating carbon in silica skins and oxalate crusts. In G. K. Ward and C. Tuniz (eds), *Advances in dating Australian rock-markings*, pp. 35–39. Occasional AURA Publication 10, Australian Rock Art Research Association, Melbourne.
- WATCHMAN, A. L. 2022. Dating mud-wasp nests associated with rock art. *Rock Art Research* 39(1): 114–120.
- WATCHMAN, A. 2024. A review of the dating of oxalate biofilms associated with rock art. In G. Kumar (ed.), *Study of palaeoart of the world: a quest for understanding the evolution of human constructs of reality*, pp. 183–203. Pathak Publisher and Distributors, New Delhi.
- WATCHMAN, A. and J. CAMPBELL 1996. Micro-stratigraphic analyses of laminated oxalate crusts in northern Australia. In M. Realini and L. Toniolo (eds), *The oxalate films in the conservation of works of art. Proceedings of the Second International Symposium, Milan, March 1996*, pp. 409–422. Centro CNR Gino Bozza, Bologna.
- WATCHMAN, A. and N. COLE 1993. Accelerator radiocarbon dating of plant-fibre binders in rock paintings from northeastern Australia. *Antiquity* 67: 355–358.
- WATCHMAN, A. L. and R. JONES 2002. An independent confirmation of the 4 ka antiquity of a beeswax figure in western Arnhem Land, northern Australia. *Archaeometry* 44(1): 145–153.
- WILLIAMS-THORPE, O., D. G. JENKINS, J. JENKINS and J. S. WATSON 1995. Chlorine-36 dating and the bluestones of Stonehenge. *Antiquity* 69: 1019–1020.
- YANUO J., YUE L., ZEJI L., R. GRÜN and QINGFENG S. 2024. U-series in situ dating of secondary carbonates associated with rock paintings using LA-MC-ICPMS. *Quaternary Geochronology* 82: 101552.