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The calibrated dating of petroglyphs

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Abstract. One of the most intractable dating problems is without doubt the dating of petroglyphs. In contrast to rock paintings, for which reliable methods of dating are at last becoming available and are producing reasonably consistent and realistic dates, the dating of petroglyphs will continue to demand considerable methodological creativity. This paper considers the calibrated direct dating methods so far applied to this task, finding that they are either unreliable, they provide merely minimum dates, or they have not been widely applied or tested and are still regarded as experimental. The development and current standing of the various methods used are considered, together with their future prospects, with special emphasis on the microerosion method.

Introduction

Commenting in *Australian Archaeology*, Watchman (1992a) is rightly critical of the archaeological misinterpretation and misrepresentation of geological dating results, citing two specific examples relating to the work of D. Dragovich. Similar experiences, both as an editor and in my research work (Bednarik 1993a), lead me to suggest that there is a strong need for a better understanding of dating techniques and results. A major role of the First AASV Symposium on Archaeological Dating is the improvement of interdisciplinary communication in this particular field.

Here I will address the subject of the calibrated direct dating of petroglyphs. Petroglyphs are rock art motifs that were produced by some *reductive* method, such as abrasion, engraving, pounding, bruising, pecking, drilling or etching with corrosive agents. The minute quantities of rock that were removed in the process are generally not recoverable for dating purposes. By contrast, rock paintings, drawings or beeswax figures, which form the second major division of rock art, were produced by an *additive* process, and residues of the material used in their production are often recoverable. In the case of paintings, the paint may consist of one or more components: pigments, binders, diluent, extenders of various types, and a large number of possible incidental inclusions, such as brush fibres, pollen, other plant materials, airborne matter, substances remaining from the grinding or mixing processes, and so forth (Grant 1965; Barnes 1982; Clottes et al. 1990; Loy et al. 1990; Cole and Watchman 1992; Bednarik 1992a). It is obvious that all these materials offer enormous potential for analytical studies which can tell us much about the circumstances of art production, and which in many cases are also datable with presently available methods.

In contrast to the wealth of potential approaches to the analysis and direct dating of rock paintings, the dating of petroglyphs, which are sometimes called engravings or carvings (engravings are, more correctly, one particular form of petroglyph, which is exceedingly rare in Australia but most common in certain other regions, e.g. Franco-Cantabria), remains one of the most difficult problems in the discipline. Because of the lack of a substance that effectively marks the production of a petroglyph, researchers began their quest for a direct dating method by concentrating on mineral accretions that covered the petroglyph at some later time. Such deposits are indisputably younger and their relative physical relationship with the art motif is beyond any doubt (see Bednarik 1981, 1993b). In this way they tried to secure minimum dates for the petroglyph in question, and in some cases also maximum ages. Nevertheless, most petroglyphs in the world are not concealed by datable mineral precipitates, and they are thus not susceptible to these methods. Moreover, it is obvious that a minimum age may be extremely conservative, and may thus be misleading.

What is calibrated dating in archaeology? To calibrate, in this context, means to adjust data systematically to exclude extraneous or error-prone information. Where a dating attempt is based on a continuous process of change that is a function of time, the rate of progress is either assumed to be universal, as in radiocarbon dating, or it can be affected by environmental variables, as in cation-ratio dating. In calibrated dating one adjusts the primary analytical information for these known variables. For instance, we know from isotopic work and from dendrochronological analysis that the best-known archaeological dating method, radiocarbon dating, produces results that need to be adjusted to account for the variable atmospheric production rate of radiocarbon in the past. Calibration may involve combinations of locally different variables, in which case it may be necessary to allow for the specific conditions that apply at each and every site. In such cases it may be necessary to create a calibration curve for each site or environmental area one wishes to sample, by either using results of another, better known and proven method to calibrate against, or by using a number of samples of known age as reference points. Clearly, the latter possibility is preferable, because one does not need to rely on relating one's results to another method, but instead one constructs a chronological framework on relatively safe foundations.

The calibrated methods of direct dating of petroglyphs that have been developed or used in Australia since 1979 fall into three categories: those using the radiocarbon content of a mineral precipitate or its organic inclusions that have been deposited over a petroglyph; those that use radiocarbon dating to calibrate indices produced by other components of a mineral deposit; and one method that uses indices of known age to determine the age of a feature that has been exposed to the same alteration processes.

Reprecipitated carbonates and oxalates

In 1980, having located petroglyphs that were sandwiched between laminar deposits of calcite in a South Australian cave, I attempted to date the rock art through these deposits (Bednarik 1981, 1984, 1985). In this analysis of reprecipitated carbonate, the radiocarbon content of the deposits is determined, providing a conservative minimum age for the rock art it conceals, or a maximum age from the deposit on which the same is executed. Limestone as such is radiocarbon-dead, because it is (nearly always) millions of years old, but when it is dissolved and then re-precipitated, be it in a cave or on open rock surfaces, about one half of its carbon is of biological or atmospheric origin, and thus contains a known proportion of radiocarbon at the time of its reprecipitation (Franke 1951a, 1951b, 1967; Craig 1953; Münnich and Vogel 1959; Geyh and Schillat 1966; Franke and Geyh 1970; Franke et al. 1958; Bednarik 1981). For instance, the well-known flowstone deposits in limestone caves consist of calcite that was dissolved by carbonic acid produced mostly by the carbon dioxide exhaled by mycorrhizal micro-organisms living in the root systems of the vegetation above the cave (Geyh 1969; Hendy 1969, 1971). Speleothems are thus indicators of external climatic conditions at the time of their formation (Franke 1953, 1958; Labeyrie et al. 1967; Geyh 1970; Geyh and Franke 1970; Hendy and Wilson 1968), and are datable by various radiometric methods (Baker et al. 1993).

However, it was known since the earliest work in this field that only very dense, crystalline deposits are reliably datable by the radiocarbon method, because where the crystal lattice is porous, subsequent deposition of more solute would progressively rejuvenate the deposit. For instance, it has been known since the 1950s that stalagmites are better suited for radiocarbon dating than stalactites. Moreover, further work and a series of radiocarbon dates have recently suggested that, in regions of volcanic activity and permeable rock, inorganic sources of carbon dioxide may have contributed more to the formation of speleothems than had been assumed (Bednarik et al. in prep.). Nevertheless, the method has been used with convincing results in southern China, at the rock painting sites Huashan in Guangxi Province, and Cangyuan in Yunnan Province (Bednarik and Li Fushun 1991). It has never been my intention to rely on carbonate speleothem dating alone. In my 1980 project I had envisaged using speleothem dates in tandem with minimum ages derived from exfoliated fragments of speleothem which had become archaeologically stratified (Figure 1, as drawn in 1981). Unfortunately the subsequent excavation of the substantial sediments at the site in question, Malangine Cave near Mount Gambier (South Australia), showed them to be extensively disturbed (Frankel 1986).

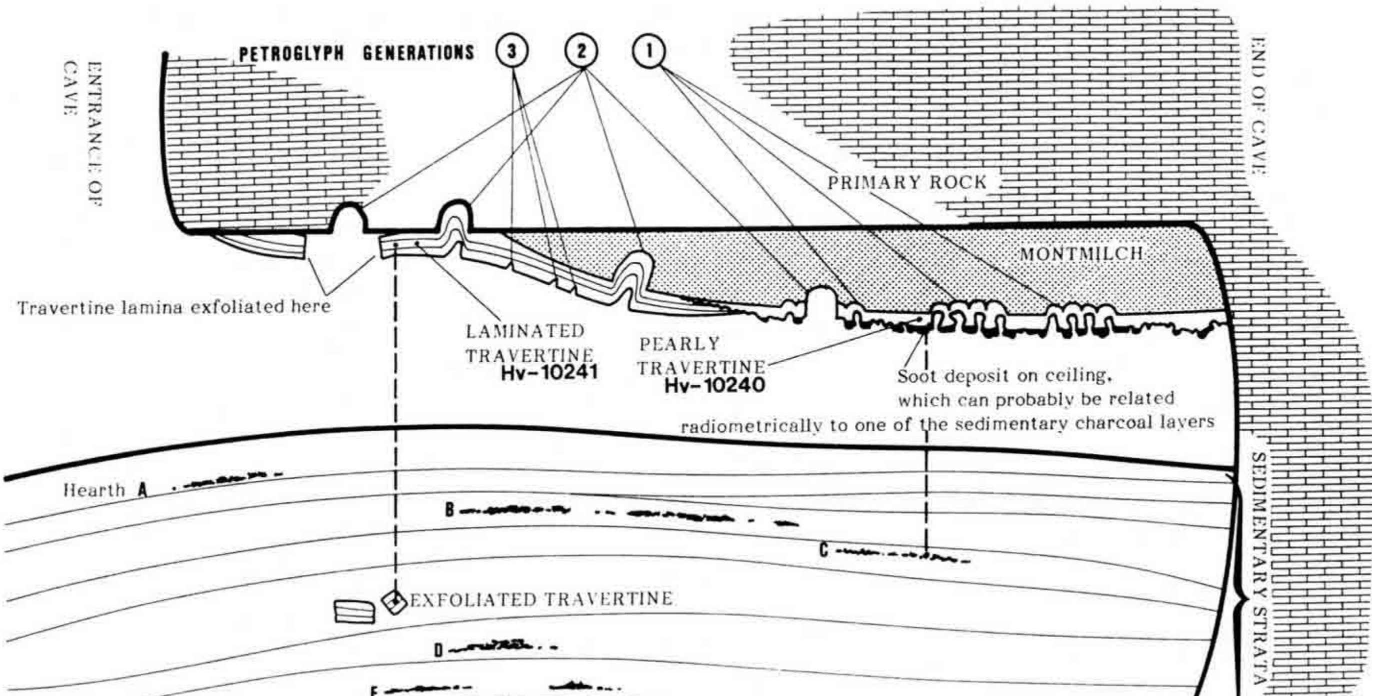

Figure 1. *Schematic illustration of the dating framework envisaged for Malangine Cave in 1981, showing the relationships of relevant features. While the upper half of the diagram illustrates established physical relations, the lower half shows how it was intended to relate the sedimentary and occupational evidence to the rock art sequence. It was hoped that subsequent excavation would assist in combining geomorphological data, sedimentary stratigraphy and petroglyph stratigraphy to construct an integrated chronological model. The three petroglyph generations are finger flutings (1) on former* montmilch, *concealed under a 'pearly travertine' speleothem; deeply carved linear motifs (2), concealed near the entrance by laminated travertine, into which shallow engravings (3) have been incised. The sediment stratigraphy is mereley tentative.*

Carbonate speleothems can also be radiometrically dated through their uranium content, but the effect of rejuvenation through later deposition still applies. Another method based on the radiocarbon content of a mineral precipitate was developed by Watchman (1990), who discovered that rock art is sometimes concealed by oxalates, namely whewellite and weddellite. These are salts of an organic acid and thus contain radiocarbon. Recent reports suggest that the incidence of oxalates at petroglyph sites may be greater than had been expected, and many oxalate deposits in rockshelters had previously been identified as soot or precipitated plant resins. Watchman has produced several tentative minimum ages for rock art from oxalate deposits in northern Australia. He warns, however, that the precise mechanism for the formation of the oxalate remains uncertain and that the method must therefore also be regarded with caution (Watchman 1993).

Watchman (1990) has also reported trace amounts of algal matter and fine particles of carbonised plant remains from laminated silica skins that have in many cases formed over rock art, which might be suitable for radiocarbon dating using accelerator mass spectrometry. However, he notes that the physical extraction of these remains is impracticable (Watchman 1993), and so far no such dates have been reported.

Rock varnish

The most spectacular results in petroglyph dating have been obtained only very recently, from microscopic inclusions in accretionary surface deposits. Rock varnish is usually a dark-brown, sometimes black, very thin, often laminated, ferromanganese skin that covers the rock at thousands of petroglyph sites throughout the world. In the arid regions of Australia, many petroglyphs concealed by varnish have long been regarded as being of extremely great age. However, there was little credible evidence for this until the last few years when Dorn and colleagues began detecting small organic particles under the rock varnish within engraved grooves (Dorn et al. 1992; Dorn and Nobbs 1992; Nobbs and Dorn 1993). Using the accelerator mass spectrometry radiocarbon dating method, they determined the radiocarbon content of minute fragments of plant matter from several petroglyph motifs in the Olary region, South Australia (west of Broken Hill), thus obtaining apparent minimum ages for the underlying rock art. Their results suggest that Australian rock art is much older than the celebrated Upper Palaeolithic art in the caves of western Europe (Bednarik 1993c). Dorn's earliest radiocarbon dates are in the 40 000s, and these are, in all probability, minimum ages. The petroglyphs in question may in fact be considerably older.

Dorn's work actually began with his development of another calibrated method, the cation-ratio dating of rock varnish, in the early 1980s. He postulated that cations of the varnish are leached at different rates, and that therefore the time at which leaching began can be estimated. Since the method is based on unknown variables its results have to be calibrated by the radiocarbon method. However, after the method was first applied in Australia (Nobbs and Dorn 1988), its validity was challenged by several researchers (Bednarik 1988; Clarke 1989; Lanteigne 1989, 1991; Reneau and Harrington 1988; Watchman 1989, 1992b), and while it is still being used it is now thought by many to produce questionable results (cf. Bierman and Gillespie 1991; Bierman et al. 1991). There are far too many uncertainties connected with it to rely on it entirely, and it has been effectively replaced by the dating of organic matter in the lower strata of rock varnish. Although Dorn has shown that cation-ratio dates from his work are often compatible with radiocarbon results from the same motifs, and the crucial dates from the Broken Hill region are supported by radiocarbon dates from the same sites, Watchman's attempts to duplicate his results have seriously questioned the method's reliability (Watchman 1992b). Most recently, Watchman has developed his laser-assisted method of dating organic carbon in rock varnish (or other accretions) by combustion (see next paper of this volume).

Microerosion dating

Only one calibrated method has so far been proposed to date the event of petroglyph production itself, rather than the age of some related but inevitably younger (or, sometimes, older) mineral accretion, and it is also the only non-destructive method, and the only archaeological dating method that is capable of generating statistically meaningful solutions by satisfying statistical sampling requirements. This is microerosion dating. During the late 1960s and the 1970s, I examined under the microscope the reasons for the fading of freshly broken rock, noticing that the angular fractures of individual crystals were becoming progressively rounded with age. The result of this process is called a 'wane' in geology, and it was evident that the size of these micro-wanes was related to the age of the surface (Figure 2).

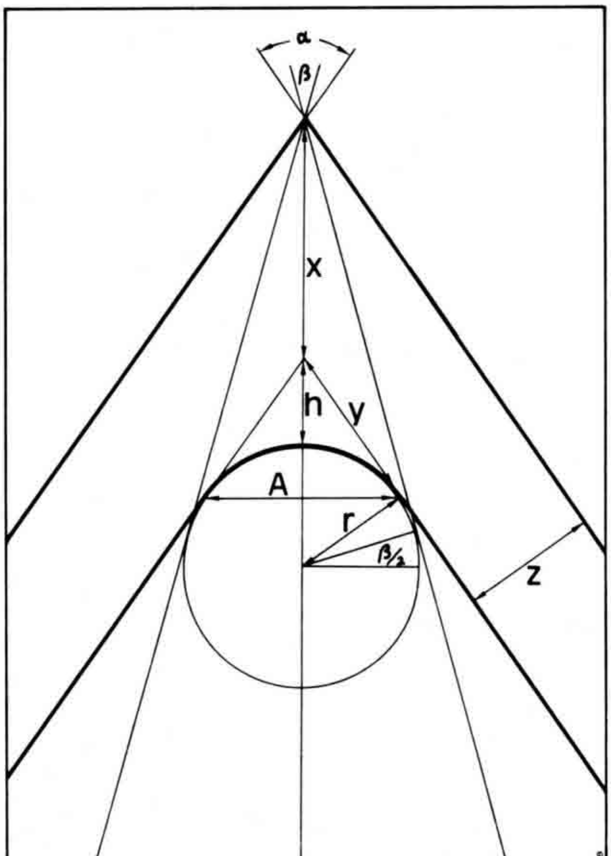

Figure 2. Diagram depicting the laws of wane formation in a simplified fashion.

***Figure 3.** The expedition vessel of the Moscow Academy of Sciences, the* Neptun, *being unloaded at Besov Nos, Lake Onega, during my research there.*

I commented on wane formation at the time (Bednarik 1979), but remained unable to find a way of relating the erosion process quantitatively to age. After realising in 1988 that cation-ratio dating was not going to deliver its promises, and becoming concerned that the endeavours to find a method of petroglyph dating were becoming increasingly technology orientated (thereby threatening a widening in the technological gap affecting rock art researchers in developing countries; cf. Bednarik 1992b), I returned to my much earlier work with simple phenomena. After examining the process of wane formation geometrically and mathematically, I realised that a basic law of nature is involved which seems to govern many traditionally ignored phenomena besides geological ablation: for instance, the rounding of the corners of a dissolving or melting angular object (Figure 2). Having succeeded in quantifying the fundamental laws and formulating the theory of wane formation in 1989, I began looking for a suitable site to try a practical application. One of several conditions it had to meet was that it had to be on a mechanically resistant, composite rock containing quartz together with a mineral of higher solubility.

An opportunity offered itself in 1990, when I was travelling widely in Russia and Siberia as a guest of the Academy of Sciences of the then USSR (Figure 3). I conducted microscopic work at most of the known petroglyph sites of Karelia (Bednarik 1992c), focusing in the end on the twenty-two sites on the east shore of Lake Onega, of which I have microscopically examined all except two sites. I selected the best known motif of the region, the so-called 'Demon' at the site Besov Nos, to see whether the method has any future. I knew that the figure was regarded as one of the oldest in the region, and it offers an important feature: superimposed over it is a Russian Orthodox cross with inscription and halo, about 500 years old (Figures 4 and 5).

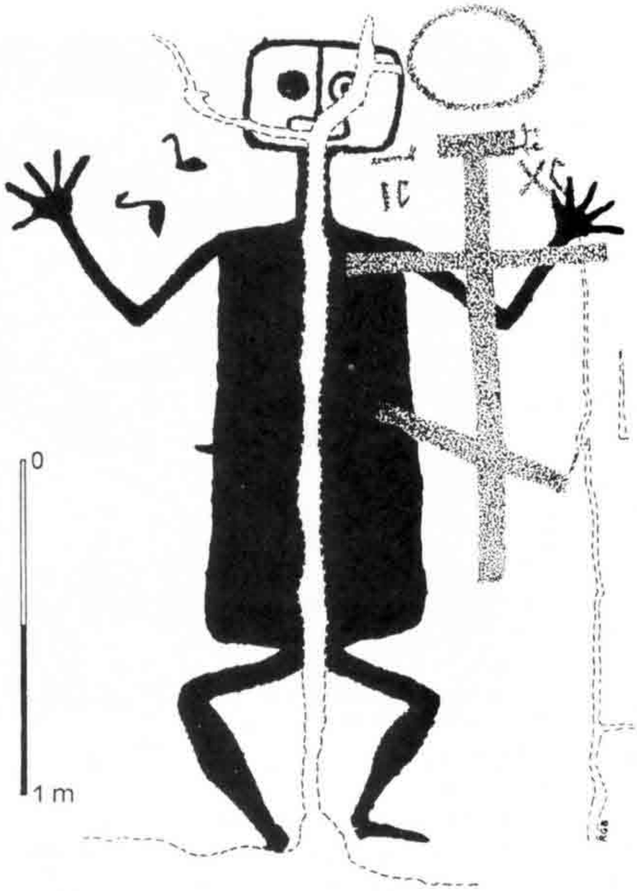

***Figure 4.** Recording of the main motif at Besov Nos, Karelia, and some adjacent figures. The large anthropomorph is thought to be among the oldest in the region. The central crack predates the petroglyph and has been artificially enlarged.*

Figure 5. *Partial view of the 'Demon' at Besov Nos, with the superimposed Russian Orthodox cross.*

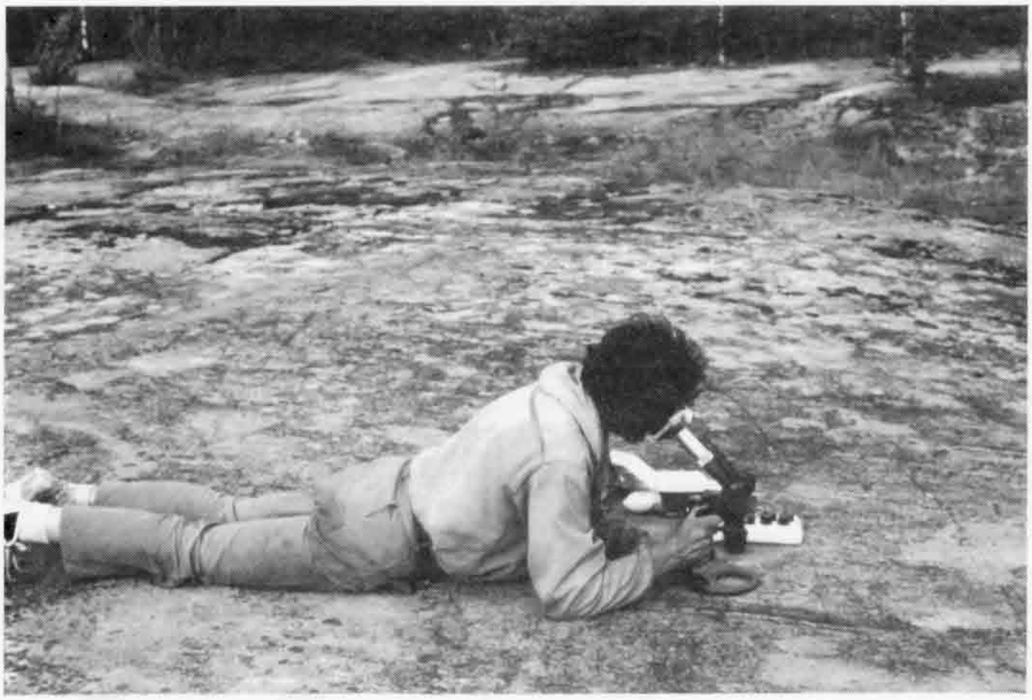

Figure 6. *Examining microerosion at the large petroglyph pavement of Staraya Zalavruga, Karelia.*

A few metres away are two engraved dates of the 1930s. Finally, there are literally millions of glacial striations on all the granite pavements of the region. In selecting the six most recent striations I could find at Besov Nos, I made the encouraging observation that the apparent relative degree of microerosion among superimposed marks corresponds to their relative age (Figure 6). These marks would be expected to date from the last advance of the final Würm or Weichsel glaciers, which withdrew about 9000 years ago, so I assumed the striations to be perhaps around 10 000 years old. Since in addition I had freshly broken rock at my disposal, there were in all four reference points for calibration. After scanning the various surfaces at Besov Nos with the microscope to collect the raw data for two calibration curves, one for the quartz component and one for the plagioclase feldspar of the gneissic granite, the micro-wane indices derived from the petroglyph were placed in the curves. This provided an age estimate of marginally over E4000 years BP (the E indicates that the date is erosion derived) (Bednarik 1992d, 1993d). The estimate is in agreement with the archaeologically proposed age of the petroglyph (Savvateyev 1984; for details, see Bednarik 1993e).

Microerosion dating requires that remains of the surface that was actually exposed at the time the petroglyph was created (or last re-worked) have been preserved intact. This requirement renders most sedimentary rocks unsuitable because they weather too rapidly. The method's prospects of providing meaningful results are greatly enhanced by the presence of several discrete mineral components in a rock, because they can generate multiple calibration curves. Other requirements are that the rock must not have been covered by sediment, water or accretionary deposits, that the various calibration surfaces are similarly exposed to sun and rain (horizontal pavements or elevated boulders are ideal; see Figure 6) and that an adequate number of calibration points is available at the site. Once the method has become better established, the last-mentioned requirement can be relaxed because previously determined calibration curves from other environments may then be consulted, and the influence of the three principal variables in the microerosion of the common minerals will be much better understood (Bednarik 1993f).

Discussion of microerosion dating

The most obvious drawback of the microerosion dating method is its possible sensitivity to past environmental changes. The environmental variables to be considered are primarily pH, temperature and precipitation. Changes in these may have accelerated or decelerated erosion processes, and this would distort the apparent age. However, the method of using multiple calibration curves which consider different minerals certainly affords protection against distortions from environmental variables, because different minerals are unlikely to react to such variables in quite the same way. Moreover, the susceptibility of, say, quartz ablation to pH variations is negligible up to pH 9, so this mineral provides a good reference standard in relation to pH changes. Mean temperature oscillations in the Holocene would not seem to have been great enough to affect the accuracy of microerosion analysis (they are thought to be only in the order of a few degrees in the mean annual temperatures). Effects of the variations in precipitation, which certainly mark past climates, can be countered by using two, or even more, calibration curves from as many component minerals.

In practical application it can be assumed that the environmental distortions, which one would inevitably expect to have occurred, were not of a sufficient magnitude to be apparent if the indices of the various calibration samples appear on the same respective ordinates within the curves. If one or more of the samples are not so aligned, then distortion is apparent. This does not automatically negate a result, it may be possible to determine the source of the distortion and make an appropriate allowance, or alternatively, if the distortion is small, one can introduce adequate tolerance limits by allowing for either extreme 'worst possible scenario' and thus still secure a valid dating (albeit one with a larger error).

The use of multiple calibration curves provides the microerosion dating method with a feature which no other archaeological dating method can offer: an internal checking device. Most dating methods can be checked only by using another method or another sample, a procedure that inevitably introduces statistical uncertainties. In comparing, say, two radiocarbon dates, we are never considering two calendar dates, but two sets of statistical probabilities (cf. Lanteigne 1991). Some dating methods being used have been calibrated by another calibrated method (e.g. cation-ratio dating of rock varnish), which may render the associated statistical difficulties quite unmanageable and the results increasingly uncertain. These difficulties are well illustrated by Dorn's continual re-calculating and re-calibrating of his own cation-ratio results (Dorn and Nobbs 1992; Nobbs and Dorn 1993), which render both his method and results highly contentious and indeed suspect. By contrast, microerosion dating with its 'self-checking' mechanism provides calibration curves in which environmentally caused distortions are immediately identifiable if they are large enough to affect the results. It is certainly not a very accurate method at this early stage, and much work is required to improve procedures and the understanding of erosion processes under different conditions, but in terms of reliability it is hard to fault: the physical process it is based on is non-reversible, the underlying theory is fully explained and can be expressed accurately in mathematical form, and the low cost, accessibility and simplicity more than compensate for its initial lack of precision which is only due to our very limited knowledge about actual erosion rates.

The permanent limitation of the method is its dependence on certain preconditions: the presence of at least remnants of the surface to be dated (many rocks, especially sandstones, are susceptible to granular massexfoliation, and thus unsuitable), the presence of more than one component mineral, and the guarantee that the surface has never been concealed. Interestingly, the method is most applicable in those field conditions where alternative methods are entirely unsuitable, notably where accretionary deposits are lacking. The method would be valid at tens of thousands of petroglyph sites, none of which are datable by any other currently used method, and if only a fraction of them were reliably dated, a chronological framework for the rock art of the world could be established. It is clear that other methods should be used to complement microerosion dating.

Application of the microerosion method is not limited to petroglyphs, any geomorphic surface of the appropriate attributes is theoretically datable by it. This would include stone implements made of composite rocks (e.g. ground axes of such materials as rhyolite, mortars and pestles, etc.), provided they were always exposed to weathering. However, the effects of microerosion would render it impossible to estimate wane widths beyond a certain age, and in the case of quartz (the most common resistant component) it is believed that this point would be reached at several tens of thousands of years. This presents no problem in the case of petroglyph dating, because the number of petroglyphs world-wide that is likely to be outside this age range is minute.

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