KEYWORDS: ***Petroglyphs* - *Antiquity* - *Erosion* - *Quartz* – *Microscopy***

8

MICROEROSION ANALYSIS – A RECAP

Robert G. Bednarik

Abstract: The basis of microerosion analysis as a tool in estimating the age of petroglyphs is briefly considered as are some of its applications, in particular, the three 'blind tests' of the method conducted in three European countries. A description of the various advantages of the method as well as its disadvantages shows that the former outweigh the latter. The method's main limitation is inadequate information about presumed variability in solution processes.

The method

The fundamental rationale of microerosion analysis is that, after a new rock-surface has been created, by either natural or anthropic agents, it is subjected to chemical weathering processes. This applies especially in unsheltered locations, and it results in cumulative effects that are a function of time, among other factors. While this is a fairly self-evident principle, the difficulty in using the results of such processes to estimate the age of a rock-surface is that our understanding of them, of their effectiveness on different rock types, and of their susceptibility to environmental factors remains very limited. We know that rock-surfaces retreat with time, be it by solution or physical wear. Empirical engineering data for natural building stone tells us that the amount of retreat differs greatly according to rock type (Schwegler 1995). Rock erosion ranges up to fifty millimetres each one thousand years for poorly cemented sandstone, but can be as little as fifty microns on the non-quartz components of granite, and less again on quartz. This process of weathering has sometimes been called 'micro-erosion' (hyphenated), although its products are certainly visible at the macroscopic level (Smith 1978). In the way I use the term, it has a very different meaning. Unfortunately, some archaeologists have confused these two uses of the same term (e.g. Rosenfeld, cited by Zilhão 1995:891).

With the term '*microerosion'* (one word, unhyphenated), I refer exclusively to processes the effects of which can be seen only at the microscopic level (Busenberg and Clemency 1976; Rimstidt and Barnes 1980; Lin and Clemency 1981; Acker and Bricker 1992; Oxburgh et al. 1994; Williamson and Rimstidt 1994). Hence, for the time-spans we are concerned with in dating petroglyphs, only comparatively erosion-resistant rock types are of interest. In most cases this excludes especially sedimentary rocks. It must also be emphasized that microerosion analysis is not one specific method, but a cluster of possible methods around a basic concept. Two have so far been applied practically: the measurement of micro-wanes on fractured crystals (Bednarik 1992, 1993), and the selective, often alveolar retreat in certain rock types of components that weather at vastly different rates (Bednarik 1995). There is no doubt that various alternative indices of microerosion may also prove to be useful, but, so far, their potential remains entirely unexplored.

My attempts to date petroglyphs began in 1963 when I discovered a petroglyph with dated inscription at the entrance of a cave. During the late 1960s and throughout the 1970s, subsequent to recording hundreds of petroglyph sites in the Pilbara, I investigated many possibilities of deriving information about the age of petroglyphs from a variety of phenomena. Among them were rock-varnish, other accretionary deposits ranging from carbonates to ferromanganese substrates, and weathering alteration zones. One of these phenomena was macro-wanes, the results of progressive rounding of freshly broken rock edges. Cernohouz and Solc (1966) had claimed to be able to estimate the ages of such wanes to within ten- to twenty-percent accuracy on two rock types. After observing similar rounding at the microscopic scale, on individual mineral crystals that had been fractured, it occurred to me that these phenomena were likely to obey the same laws. Late in the 1980s, I managed to explain these fundamental laws geometrically and mathematically, which made it possible to attempt dating by measuring wane sizes. These formulae explained how, under ideal conditions, wane development is related to time. (They explain also many other things in nature, for instance the geometry determining the course of temperature transfer within an object, or the geometry explaining how a solid body melts.)

In the real world, conditions are rarely ideal, so I devised a way to check results. Until we know much more about solution rates of common and suitable component minerals, we need to establish these rates regionally with calibration curves. But instead of relying on a single curve, I introduced the use of two (or more) curves for two (or more) different component minerals. Since it is unlikely that different minerals would all react similarly to past environmental changes, one would expect to detect irregularities because the corresponding values of a sample would appear displaced in the calibration graph. If solution of one component mineral had slowed down or accelerated sufficiently to render the distortion detectable by such a comparatively coarse method, it would be reflected in the misalignment of the corresponding points on the curve. No other dating method currently used in archaeology offers such a self-checking mechanism.

The precision of the method is probably poor at this early stage, because it depends entirely on the number and precision of calibration points, and one has to contend with possible misalignments due to climatic or other environmental factors. Fortunately, the latter seem to be less severe than one would be tempted to think. The principal potential variables in microerosion are thought to be temperature, pH and moisture availability. I regard the first two as unimportant: variations in mean temperatures were probably minor, even as far back as glacial peaks of the Pleistocene; they would not have affected solution rates appreciably. Variations in pH would certainly apply back through time, but in the case of both amorphous silica and quartz, there is almost no change in solubility below pH 9. For alumina it is negligible in the central region of the pH scale, which coincides with most natural conditions. Quartz, then, can serve as a control against which to check the effects of pH changes on other minerals (Rimstidt and Barnes 1980).

This leaves us with precipitation as the major unknown variable. There is no doubt that this would have varied at any site in the past, and it varies between different sites today. However, it is expected that significant changes in moisture availability would affect component minerals differently, and should thus be detectable by calibration. In this respect, the unknown sample – the surface to be dated – provides one of the points one can use to check reliability of the calibration curves, because its values, too, must lie on the same ordinate in the diagram.

Applications

The microerosion method has been used in six blind tests now. At Lake Onega in Karelia, northern Russia, its results confirmed archaeological estimates (Bednarik 1992, 1993). At Grosio, in the Valtellina of northern Italy, it met archaeological expectations precisely, even with the use of only one component mineral: the result is tied to the time of the last retreat of the glacier at the location, and, depending on when this happened (about ten or twelve thousand years ago), provides a particular anthropomorphous petroglyph with an age-estimate of about five- or six-thousand years ago. Subsequent to obtaining this result, I was informed that the figure in question belongs archaeologically to the Neolithic period of northern Italy (about seven- to five-thousand before the present). At three sites in central Bolivia (Inca Huasi, Kalatrancani 3 and Lakatambo 2), microerosion results were obtained from petroglyphs which matched archaeological expectations in all cases.

In the Côa valley of northern Portugal, results from microerosion analysis contradicted archaeological hunches completely, but agreed with the results of other scientific methods, in particular the radiocarbon age-estimates for organic residues encased in silica accretions (Bednarik 1995; Watchman 1995). The archaeological age-estimate of the specific figures we researched is over twenty thousand years; both Watchman and I estimate their age as being less than two- to three-thousand years old. At these sites, microerosion analysis has also assisted in relative sequencing of cumulative petroglyph corpora.

In five of these six blind tests, the alternative dating notions were unknown to me at the time I presented my results; in the Côa case, I knew beforehand that the local archaeologists would reject any result other than their stylistic estimate of over twenty millennia, but elaborate precautions ensured that I could not know the results of the other dating scientists involved in the project.

The second method of microerosion analysis so far tried, based on differential retreat measurements, can probably only provide relative age-estimates. It relates to rock types lacking large enough quartz crystals to provide viable wane measurements; examples are poorly metamorphosed schistose rocks, that is, slates, phyllite and schists. It is based upon the observation that discrete areas of rock-surface, at the microscopic level, dissolve at vastly different rates, depending on their mineralogical composition and re-crystallization state. In the zones of the more readily soluble substrate, depressions develop and become deepened, eventually to form alveolar recesses. The relief between the original floor of the impact pits or abrasion grooves of petroglyphs and the deepest solution holes on the same surfaces provides a rough indication of relative age where figures of different ages occur on the same panel and were similarly exposed to solution agents (Bednarik 1995: Figure 10a). It must be cautioned, however, that this index is not likely to relate to age in a linear fashion. Susceptibility to solution is a function of several variables, among them the area of the surface available to solvent action, and this increases obviously as the relief increases in depth. Hence this is a 'self-accelerating' process, and its index can be used only as a rough guide to age. Nevertheless, it is well suited to help differentiating between figures executed at different times.

Microerosion analysis is now being applied in South Africa and China, with my co-operation, and has been applied by me in India, Russia, Italy, Bolivia and Portugal. It has not been systematically used in Australia so far, and there are no plans to apply it here. There is not sufficient interest in its application to encourage its use in this country, although excellent prospects for the method's successful application certainly do exist in Australia. Petroglyphs occur frequently on suitable rock types and in a great range of ages and environments, for instance in the Pilbara.

Discussion

Microerosion analysis has numerous favourable aspects, even though accuracy is not among them. It is probably more reliable than most alternative methods of dating petroglyphs, and it is certainly cheaper and simpler than most. It requires no laboratory backing; the results can often be determined in the field. Most importantly, it provides not a single result, but clusters of age-related values that can be converted into various statistical expressions. This is a luxury that all other dating methods have to do without. Moreover, it is the only dating method that offers a means of internal checking, that is, of checking the validity of the result without recourse to another method. While there is every reason to check age-estimates with those derived from alternative methods, the problem with this procedure is always that we are not comparing calendar dates, but sets of statistical probabilities, often without a full understanding of the realistic statistical limitations involved (Bednarik 1994). For instance, the results of cation-ratio analyses are calibrated by radiocarbon, which means that any qualifications or error possibilities are correspondingly amplified. Then to compare the result of the cation-ratio analysis with some other dating result involves so many assumptions and qualifications that it seems impossible to express such comparisons in scientifically accurate terms (Bednarik 1996). Hence internal checking does offer considerable benefits.

Finally, microerosion analysis has the advantage of demanding from the analyst intensive field work at the study site. Microscopic scanning of motifs demands lengthy study and usually prompts observations of many details that would otherwise not be noted. These may include microscopic traces of various types, such as biological corrosion, aeolian erosion, glacial abrasion, frost damage, fire damage, local conversion of specific minerals, abrasion wear from pigment crayons or other sources, vandalism or retouch – all of which relate chronologically to the petroglyph. Their relative time-frame is often readily apparent from superimpositions, they happened either before or after the petroglyph was executed, and they can tell us about the history of the rock-panel. In my experience, such telltales can be very useful in placing the carvings into a preliminary chronological framework, which is less precise but often more reliable than any chronometric 'dating information'.

The valid arguments *against* microerosion dating are that we have inadequate calibration curves for it, or that we have insufficient data on solution processes or their variability. This is not surprising, bearing in mind that the method remains experimental and has attracted no support from funding agencies. This state will not change in Australia if there is no change in the dynamics of funding and research priorities. Microerosion has been specifically developed for researchers with minimal access to advanced technology and funding, hence it will continue to be ignored by centralized institutions, at least in Australia. It seems justified to predict that the microerosion method will be further developed abroad rather than here. In all probability it will be refined by an international network of researchers, particularly in non-Western countries, and will provide the healthy methodological competition that is required in dating of rock imagery.

Acknowledgments

The support of the Australian Institute of Aboriginal and Torres Strait Islander Studies and the Australian Institute of Nuclear Science and Engineering enabling my participation in this workshop is greatly appreciated. In particular, I thank Graeme Ward for his organizational role, and for his endeavours in achieving a timely publication of the workshop proceedings.

REFERENCES

Acker, J. and O.P. Bricker 1992. The influence of pH on biotite dissolution and alteration kinetics at low temperature. *Geochimica et Cosmochimica Acta 56*:3073-3092

Bednarik, R G. 1992. A new method to date petroglyphs. *Archaeometry 34*:279-291

Bednarik, R G. 1993. Geoarchaeological dating of petroglyphs at Lake Onega, Russia. *Geoarchaeology 8*:443-463

Bednarik, R G. 1994. Conceptual pitfalls in Palaeolithic rock art dating. *Préhistorie, Anthropologie Méditerre Anénnes 3*:95-102

Bednarik, R G. 1995. The age of the Côa valley petroglyphs in Portugal. *Rock Art Research* 12:86-103

Bednarik, R G. 1996. Only time will tell: a review of the methodology of direct rock art dating. *Archaeometry 38*:1-13

Busenberg, E. and C.V. Clemency 1976. The dissolution kinetics of feldspar at 25°C and at 1 atm CO_2 partial pressure. *Geochimica et Cosmochimica Acta 40*:41-50

Cernohouz, J. and I. Solc. 1966. Use of sandstone wanes and weathered basaltic crust in absolute chronology. *Nature 212*:806-807

Lin, F. and C.V. Clemency 1981. The kinetics of dissolution of muscovites at 25°C and 1 atm CO_2 partial pressure. *Geochimica et Cosmochimica Acta 45*:571-576

Oxburgh, R., J.I. Drever and Y.-T. Sun 1994. Mechanism of plagioclase dissolution in acid solution at 25°C. *Geochimica et Cosmochimica Acta 58*:661-669

Rimstidt, J.D. and H.L. Barnes 1980. The kinetics of silica-water reactions. *Geochimica et Cosmochimica Acta 44*:1683-1699

Schwegler, U. 1995. Datierung von Felszeichnungen und Schalensteinen. *Mitteilungen der Anisa 16*:99-123

Smith, D. I. 1978. The micro erosion meter: its application to the weathering of rock surfaces. Pp.44-53 of *Conservation of rock art. Proceedings of the International Workshop on the Conservation of Rock Art, Perth, September 1977*, edited by C. Pearson. Institute for the Conservation of Cultural Material, Sydney

Watchman, A. 1995. Recent petroglyphs, Foz Côa, Portugal. *Rock Art Research 12*:104-108

Williamson, M.A. and J.D. Rimstidt 1994. The kinetics and electrochemical rate-determining step of aqueous pyrite oxidation. *Geochimica et Cosmochimica Acta 58*:5443-5454

Zilhão, J. 1995. The age of the Côa valley (Portugal) rock-art: validation of archaeological dating to the Palaeolithic and refutation of 'scientific' dating to historic or proto-historic times. *Antiquity 69*:883-901