FIRST MICROEROSION CALIBRATION CURVE FOR IBERIA

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Abstract: Using microerosion analysis, a calibration curve has been established for northern Portugal on the basis of data secured from historical engravings and two Roman bridges at Vila Real. The data collected are internally consistent but they indicate that the sampled surfaces have been subjected to subsequent damage. This is indicated by distinctive peaks in the micro-wane widths. The calibration curve is significantly below those from Grosio (Italy), Lake Onega (Russia) and Qinghai (China), but well above the values observed in the semi-arid Pilbara region (Australia).

Key-words: Microerosion analysis; granite; Roman structures; inscriptions; calibration; dating.

The dating of petroglyphs

Rock art occurs in two forms: as the results of additive processes, in the form of pictograms (paintings, stencils, drawings, beeswax figures); and as petroglyphs, i.e. the results of reductive processes (pounding, abrading, engraving, pecking, drilling). This division immediately determines the fundamentally different approaches to rock art dating, or rather, to estimating its antiquity. The substances added to the rock surface in the creation of pictograms provide the analyst with a variety of datable compounds that are of ages closely resembling the time the art was produced. For instance, paint residues may contain remains of organic binders or diluents (blood, saliva, orchid juice etc.) or pigments (charcoal, cochineal, berry juice etc.), as well as a great variety of incidental inclusions (brush fibres, pollen, bark fragments etc.) that contain radiocarbon of adequate quantities to permit accelerator mass spectrometry (Cole and Watchman 1992; but cf. Ridges et al. 2000). The fine-grained mineral detritus removed in the production of petroglyphs is, however, not likely ever to be recovered for analysis (cf. recent attempts by G. Susino to do so). Therefore, in order to date petroglyphs directly we have resorted to analysing a physically related feature that either pre- or post-dates the art (lichen, accretionary skin or crust, biogenic deposit etc.), providing a minimum or maximum age. In the language of Dunnell and Redhead (1988), such a procedure fails to focus on the 'target event', which is the creation of the petroglyph. Moreover, most of the methods used are seriously impaired by inherent uncertainties. For instance, dating bulk carbon isotope concentrations in accretionary crusts may be severely misleading, particularly if the crusts are open systems (Bednarik 1979, 1994a; Nelson 1993; Dorn 1997). Thus, the dating of petroglyphs remains one of the most intractable problems in archaeology. Indeed, of the methods proposed for petroglyph dating, only microerosion analysis (Bednarik 1992) seeks to determine Dunnell and Redhead's (1988) 'target event'. This paper presents the first calibration curve for this technique secured in Iberia, which under suitable conditions can facilitate scientific age estimates for petroglyphs in northern Portugal.

Until the early 1980s, no inherently testable methodology had become available for the age estimation of rock art (Ward and Tuniz 2000). Previous dating claims had generally been based on non-scientific criteria, and in the case of petroglyphs it had been sought to determine the ages from their perceived iconographic content (i.e. what the art was thought to depict), style or technique; from spatial proximity to archaeological evidence (such as occupation debris) and by excavation (usually of purported occupation deposits); or from superimposition, patination and weathering.

Iconographic interpretation, however, is not falsifiable in most instances, and stylistic constructs, while possibly comprising some valid elements, are not a sound basis for dating rock art, as has been demonstrated time and again in various continents (e.g. Macintosh 1977; Bahn and Lorblanchet 1993; Bednarik 1995a, 1995b; Watchman 1995, 1996). Not only are such mental constructs of researchers untestable, they tend to reflect modern Western perception more than historically valid variables inherent in the rock art. They are also taphonomically naive in that they ignore that the surviving vestiges of any rock art are not random samples of living traditions (Bednarik 1994b), and these constructs tend to be formed without adequate recourse to archaeometry. The technique of petroglyph execution, too, is rarely a reliable chronological marker, and should not be cited as a dating criterion without substantial other evidence. Proximity to occupation sites is almost irrelevant in the reliable dating of rock art, because rock art often occurs at 'focal' sites within a landscape, as do occupation debris, hence their co-occurrence is more likely to be related to this factor than to contemporaneity. Superimposition of motifs certainly does provide sound data for relative sequences, but is not always reliably determined without the use of field microscopy and does not yield actual age estimates, so in rock art dating it is only useful as a supplementary method.

There are two basic approaches to dating rock art by excavation. The petroglyphs, either on a vertical wall or on horizontal bedrock, may have been covered by subsequent sediment deposition (Rosenfeld et al. 1981; Steinbring et al. 1987; Crivelli et al. 1996), or detached and stratified fragments of rock bearing petroglyphs may be excavated in an occupation deposit (Hale and Tindale 1930; Mulvaney 1969: 176; Thackeray et al. 1981; Lorblanchet 1992; Fullagar et al. 1996). In all these cases the dating of the sediment can only provide minimum ages for the petroglyphs, and it is dependent upon the validity of a chain of unfalsifiable deductive arguments relating to the taphonomy of both the excavated sediments and the dated material (e.g. charcoal). Moreover, and especially in the case of rock art on vertical walls or detached fragments, the minimum age secured from the sediment is likely to be very conservative. Also, archaeological claims about the dating of sediments need to be viewed sceptically, as there are numerous cases on record of incorrectly dated sediments related to petroglyphs. For instance at Fariseu, Portugal, a colluvium of probably less then 17 years of age was claimed to be around 25,000 years old (Anonymous 2000; Aubry et al. 2002; cf. Abreu and Bednarik 2000). Similarly at Jinmium, in the Keep River region of northern Australia, a saprolithic sediment of the Holocene was claimed to be over 170 000 years old (Fullagar et al 1996; cf. Roberts et al. 1998).

Indeed, of the traditional methods of estimating the ages of petroglyphs, only the study of subsequent patination and weathering promises secure or testable data, and although it was perhaps the first to be considered (Belzoni 1820: 360-361), it has not been applied in a rigorous and systematic fashion up to the present time (but see Trendall 1964). Instead of pursuing the development of a scientific methodology to date petroglyphs, archaeology has for the greater part of two centuries opted for an 'archaeological methodology', which consists of non-quantifiable speculations, unexplained perception of invented styles and non-falsifiable propositions. The use of these untestable and thus non-scientific approaches continues to the present time, and is sometimes defended vigorously by archaeologists (Zilhão 1995; Rosenfeld and Smith 1997).

The alternative approach is by 'direct dating', the use of direct physical relationship of rock art and dating criterion, and the presentation of falsifiable propositions concerning this relationship for the purpose of estimating rock art age (Bednarik 1996; for a comprehensive critique of all rock art dating methods, including those contributed by me, see Bednarik 2002a). 'Direct dating' of rock art is defined as the estimation of rock art antiquity by direct physical relationship of art and dating criterion, and falsifiable propositions concerning this relationship.

Microerosion analysis

Microerosion analysis seeks to estimate the actual age of petroglyphs. The rationale of this technique is that, after a new rock surface has been created, be it by natural or anthropic agents, it is subjected to chemical weathering processes. This applies especially in un-sheltered 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 component minerals, and of their susceptibility to environmental factors remains limited (concerning typical rates of solution, cf. Acker and Bricker 1992; Busenberg and Clemency 1976; Lin and Clemency 1981; Oxburgh et al. 1994; Rimstidt and Barnes 1980; Williamson and Rimstidt 1994).

For the time-span we are concerned with in dat-ing petroglyphs (usually the last 50,000 years), only comparatively erosion-resistant rock types are suitable for microerosion analysis, because those that dissolve too fast are unable to preserve original fracture surfaces for time-spans long enough to be of relevance. Sedimentary rocks, in particular, weather so fast that remnants of the surfaces created at the time a petroglyph was made survive only for very short periods. So far, two different methods have been used. In one, the retreat of the more soluble component of a rock is measured against a component that retreats at an extremely slow rate. For instance the retreat of amorphous silica cement in a heavily metamorphosed quartzite can be measured against the crystalline quartz component, or the alveolar retreat seen in schistose rocks can facilitate rough age estimates. However, the principal technique used so far is the measurement of micro-wanes on fractured crystals (Bednarik 1992, 1993). The 'radius' of wanes (strictly speaking, wanes are not equi-circular in section, but hyperbolic) increases as a linear function of age, as demonstrated by the geometry of the process. In wane formation, be it at the macroscopic or microscopic level (Fig. 1), the ratio h : r is constant for any angle a, irrespective of distance of retreat of the faces and the edge. Ratio x : z is a function of a, and for instance at a = 60∞, x = 2z. Dimension x can be expressed in algebraic fashion:

$$x = \sqrt{\left[\left(\frac{z}{tan\ 0.5\alpha}\right)^2 + z^2\right]} \qquad (1)$$

This leads to the prediction of b, the angle expressing the rate of wane development relative to surface retreat:

$$\beta = 2\ sin^{-1}\left(\frac{r}{x + h + r}\right) \qquad (2)$$

The relationship wane width A versus age, irrespective of actual retreat, is ultimately determined by the ratio a : b, which must be established empirically. It follows that the dimensions A, r, z, and angles a and b in Figure 1 are all related geometrically and algebraically, and that the variables A, r, x, z and h are all proportionally equivalent, and increase linearly with age. Of these, A is most easily measured physically in the field. It is therefore the variable preferably used in micro-wane measurement.

In considering these variables it must be appreciated that at the level of electron microscopy, the solution does not occur in the neat fashion observed at the much lower magnification of optical microscopy. Its progress is much more diffuse, appearing as alveolar decay producing very coarse surface textures. This observation is not relevant to the surface geometry at magnifications of 20x to 160x, generally the range within which microerosion is conducted. At that range of magnification, the diffuse solution surface is not detectable.

In the field, the analyst scans the rock surface microscopically to locate crystals that have been truncated (either fractured by impact or truncated by abrasion) by the event to be dated (e.g. the petroglyph production). A statistically significant sample of micro-wane widths along the edges of such truncation surfaces is recorded and placed in a calibration curve. Age estimates are prefixed with a capital E, indicating that the result is erosion derived.

The method is not very precise at this early stage, because it has only a few calibration points in each region where it has been applied. The principal variables in the solution process responsible for microerosion are temperature, pH and moisture availability. The first two are regarded as unimportant. Variations in mean annual temperatures, even as far back as glacial peaks of the Pleistocene, are not thought to have been of a magnitude that would have affected solution rates appreciably. Variations in pH back through time can be assumed to have taken place, but they are just as unlikely to have influenced solution rates. In the case of both amorphous silica and crystalline quartz, there is almost no change in solubility below pH 9, and higher values would certainly not have been experienced in nearly every natural environment. For alumina the effect is neg-ligible in the central region of the pH scale, which coin-cides with most natural conditions. Precipitation certainly varied in the past, but it can be accounted for it. Signifi-cant changes in moisture availability affect component minerals differently, and should thus be detect-able by calibration of more than one component mineral. Therefore it is preferable to apply the method to two or more different component minerals of the same surface, such as quartz and feldspar.

While microerosion analysis is thus not thought to be very accurate, it is probably more reliable than most alternative methods of dating petroglyphs, and it is certainly cheaper, simpler and more robust than most. It requires no laboratory facilities. Results can be determined in the field, which may save considerable effort necessitated by the need to return to a perhaps very remote site to obtain supplementary data. The method provides not a single result, but clusters of age-related values (the micro-wane widths) that can be converted into various statistical expressions – a luxury not available to all other dating methods currently used. Moreover, it is the only such method offering a means of internal checking — that is, of checking the validity of the result without recourse to another method (although luminescence dating has a limited feature of this type, i.e. the possibility of checking whether the uranium and thorium decay chains are in equilibrium). Finally, microerosion analysis involves no removal of samples, or even contact with the rock art, being a purely optical method.

All these factors favour microerosion analysis. The valid technical arguments against the method are: inadequate calibration curves, its limited accuracy through its inherent coarseness, its application is limited to rock types that preserve crystal surface features and have been continuously exposed to precipitation. These significant limitations are outweighed by the benefits of the method. The microerosion method by micro-wane measurement has been used on petroglyphs in six blind tests: in Russia, Portugal, Italy and Bolivia (Bednarik 1992, 1993, 1995b, 1997, 2000a). Archae-ological expectations were matched in all but one case, where the results matched those of other scientific analyses (Bednarik 1995b; Watchman 1995, 1996). Calibration curves are now available from Lake Onega (Russia), Grosio (Italy), Qinghai (China; Tang 2000), the Nafud Desert of Saudi Arabia and eastern Pilbara (Australia; Bednarik 2002b). The technique has also been applied in India, Portugal, South Africa and Bolivia. The method's practical time range on crystalline quartz, from perhaps 50,000 years BP to the present, renders it particularly suitable for rock art, very little of which can be expected to be in excess of that range. The perhaps most effective range (from around 10,000 years to about 1000 years) coincides with the presumed age range of most petroglyphs.

Establishing a calibration curve

Twenty-five years after commencing my research into rock art dating in 1964, my development of the microerosion method in 1989 seemed to render many petroglyphs datable. Although their range is severely limited by the preconditions inherent in this method, there are still vast numbers of petroglyphs that could yield sound microerosion datings, especially in Eurasia. This is because of the great wealth there of rock-made structures, quarries, gravestones, statues, inscriptions and glacial abrasions whose age is either known precisely or can be ascertained with reasonable accuracy. In Australia, for instance, known dated inscriptions begin only with 1771 (Bednarik 2000b) and other rock surfaces of known ages are only available for the last two centuries. Similar limitations are obviously imposed in the remaining continents, though to a lesser extent.

In the case of northern Portugal it was decided to exploit the region's rich supply of Roman structures of, and inscriptions on, granites. In Vila Real, two granite bridges were examined, one to the north of the town, the second in its centre, over the Rio Corgo canyon. Both are still in use. At the first, only preliminary observations were made although it was considered suitable for analysis, offering micro-wanes in the order of 30–40 microns at 85–95° on its square parapet topping. Fifty values were secured from the rounded wall top of the second structure. They are discussed below.

In addition, one of the several Roman-period inscriptions at and near the Sanctuary of Panóias, a few kilometres east of Vila Real, was also selected for analysis. It is known as Inscription No. 2, is located on the east face of Rock No. 3, and is partly in Greek script. It reads:

Υψιστϖ Σερα
πιδι, συν κα–νθο
ρω και μυστο
ριοιζ, (τον ιερον αφιερωσε[ν])
G(aius) C(ai filius)? Calp(urnius) Rufinus V(ir) C(larissimus)

This has been interpreted by Argote (1732–34) as 'Ao altissimo (deus) Serapis, por favor da sorte e dos mistérios (en quem está- iniciado), G. C. Calpurnius Rufinus, atendido, como foi, no voto que fizera, (dedicou este monumento)': 'To the high (god) Serapis, pleading for luck and the mysteries (who is - initiated), G. C. Calpurnius Rufinus, assisted, as it was, in the vote that had been done (he dedicated this monument)'. Colmenero (1999) interprets the text as 'Illustrious Caio Calpurnio Rufino, son of Caio, consecrated, with a lake and the mysteries, a temple to the highest god Serapis' (to see the Cult of Serapis continuing)'. Calpurnio Rufino is in fact named in no less than four more inscriptions at the site and appears to have been a prolific producer of such dedications.

The probably gneissic granite of the Panóias site is particularly high in feldspar, its quartz crystals being irregularly shaped and coarse. The quartz accounts for approximately 15%, the mica for 5–7% and it is peeling away in unweathered flakes. The feldspar weathers quite irregularly and exhibits poor micro-wane formation, being thus unsuitable for microerosion analysis. Six values were secured from quartz within the inscription and are listed as cluster 4 in Table 1. On the same surface, micro-wanes of 6–10 microns width were also noted but not tabulated, they are clearly the result of more recent damage to the inscriptions. This may well be related to a drainage gutter cut into the rock, intended to divert rainwater from the inscription. Also, at a flat area on the northern end of Rock No. 3, which features chiselled flat steps and rectangular holes, a slightly elevated area has extensive wear from foot traffic, including a well-developed polished patch. Distinctive micro-wanes of 30–40 microns wane widths were observed but not recorded, occurring only in depressions. This would seem to date from Roman times, although clearly more recent wear is also present.

The main body of microerosion data secured from Vila Real granites, however, comes from the bridge near the town centre. It is listed as clusters 1–3 in Table 1, but these are clusters only in the quantitative sense, not in the locational sense. All fifty readings were obtained from one area measuring a few square millimetres, but were found to be grouped in three distinctive suites. They are solid evidence of subsequent damage that occurred just under 1000 years ago, and then again around four centuries ago (Figure 2)

Cluster	No. of determinations	Min. width	Max. width	Mean width
1	32	32	42	37.5
2	6	18	22	19.6
3	12	6	10	8.0
4	6	30	38	34.0

Table 1. Microerosion calibration values (in microns) from micro-wanes on a Roman bridge (clusters 1–3) and inscription (4), Vila Real, Portugal, for crystalline quartz.

The calibration curve derived from these values illustrates a predictable trend. It is distinctly lower than that obtained at Rupe Magna, a major petroglyph site near Grosio, Valtellina, northern Italy; and that from the Besov Nos site on the east shore of Lake Onega in Karelia, Russia. It is, nevertheless, significantly above the curve from the Spear Hill petroglyph complex in the arid to semi-arid eastern Pilbara, Western Australia. This is the trend that would be expected, although I would have predicted slightly higher values. This calibration curve should be suitable for age estimations of fractured or ground quartz crystals on exposed rock panels in the region of Vila Real. It remains debatable how relevant it might be for the Côa valley, which is about 50 to 60 kilometres ESE of Vila Real. This is because no studies have ever been undertaken to test the spatial variability of microerosion values and the geographical range of calibration curves.

Discussion

Given the tendency of archaeologists to misinterpret or over-interpret rock art dating evidence (Bednarik 1996, 2002a; Watchman 1999), the data presented in Figure 2 require qualification:

1. This calibration curve does not constitute a basis for precise datings. Substantial tolerances are attached to each microerosion determination, including those for calibration, reflecting the spread of the primary data.

2. The reliability of each result is largely dependent on the number of micro-wane measurements made.

3. The calibration curve is tentative and may need to be refined. For instance, to obtain reliable ages by microerosion analysis, two or more calibration curves from two or more minerals are desirable. Therefore, a calibration curve for feldspar should be established for Vila Real to render the ages in Table 1 more precise.

4. Crystalline quartz occurs in different forms. While their solution characteristics are unlikely to differ sufficiently to affect the rather coarse resolution of the method described here, this assumption should be tested by analysing surfaces of known age but different quartz types.

The data presented here were acquired in only two days of fieldwork. Considerably more research needs to be conducted in the area before the obtained calibration curve should be regarded as satisfactory. At this stage it is only adequate for providing a rough indication of antiquity, but as with all microerosion results, reliability is much greater than in other methods. The processes being quantified are variable, but they are never reversible – as some other indices used in petroglyph dating are (Bednarik 2002a). Microerosion analysis provides results of certainly low precision, but it is the most robust and most reliable method we have for estimating the ages of petroglyphs. With the results reported here, we now have a preliminary calibration curve for the Vila Real region. It remains to be determined over what geographical area it might be applicable, but it certainly provides an initial basis for dating petroglyphs in the immediate region.

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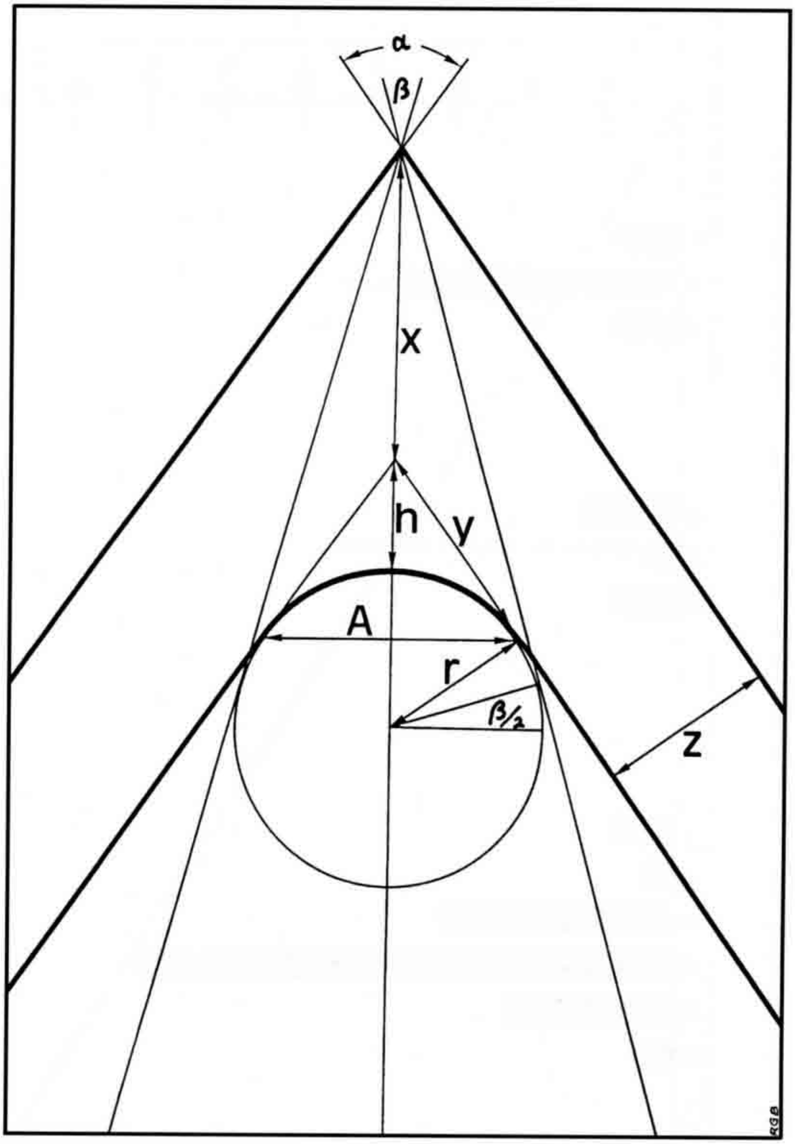

Figure 1. Diagram depicting the laws of wane formation in a simplified form.

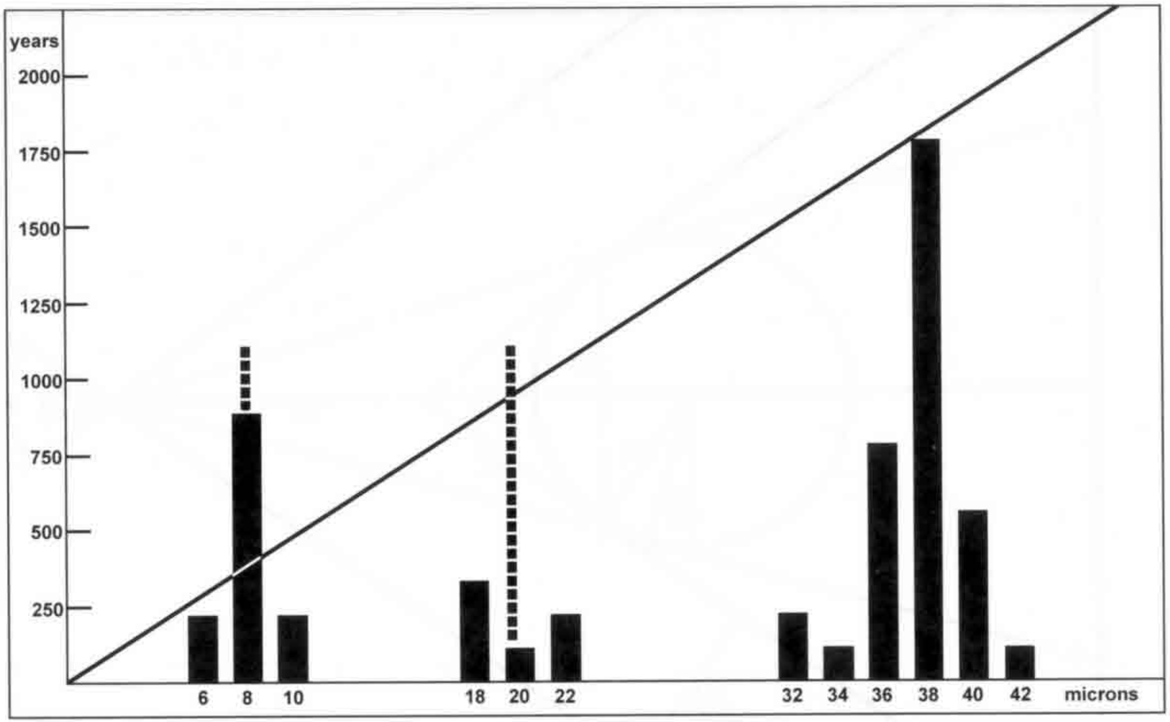

Figure 2. Histogram of microerosion values obtained from quartz in granite of Roman bridge in Vila Real, Portugal, with calibration curve based on the oldest cluster indicated.