The Micro Erosion Meter: Its Application to the Weathering of Rock Surfaces

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Introduction

Geomorphologists with their core interest in the explanation of landscape morphology have for many years been concerned with the rate of erosion of rock surfaces. In general, the literature on this subject has attempted to estimate rates of erosion by indirect methods. Such estimates are frequently based upon the study of the weathering products rather than upon the actual erosion of the rock surface itself. For example, the literature on limestone erosion has, over the past 15 years or so, attempted to estimate the solutional erosion loss by measuring the calcium and magnesium bicarbonate content of the run-off waters. Measurements of this kind, especially when combined with the necessary hydrological detail, yield information regarding the overall erosion rate. Such rates are frequently expressed in terms of millimetres of lowering per thousand years, see Atkinson and Smith[1]. However, such estimates are of limited value to a prehistorian interested in the weathering of a specific area of sculpted rock art. The estimates themselves are open to criticism in that the emphasis is often on solutional loss and the methods frequently fail to separate out the contributions from the erosion of surface rock from what is essentially sub-surface erosion. Further, the erosion loss at the micro-scale will undoubtedly show very considerable variations, grooves in the rock surface can be expected to erode at differing rates to positive relief features.

Attempts to measure the erosion of rock surfaces by direct measurement at specific point locations at the micro-scale are few. No particular technique appears to have been successful enough to become widely established.

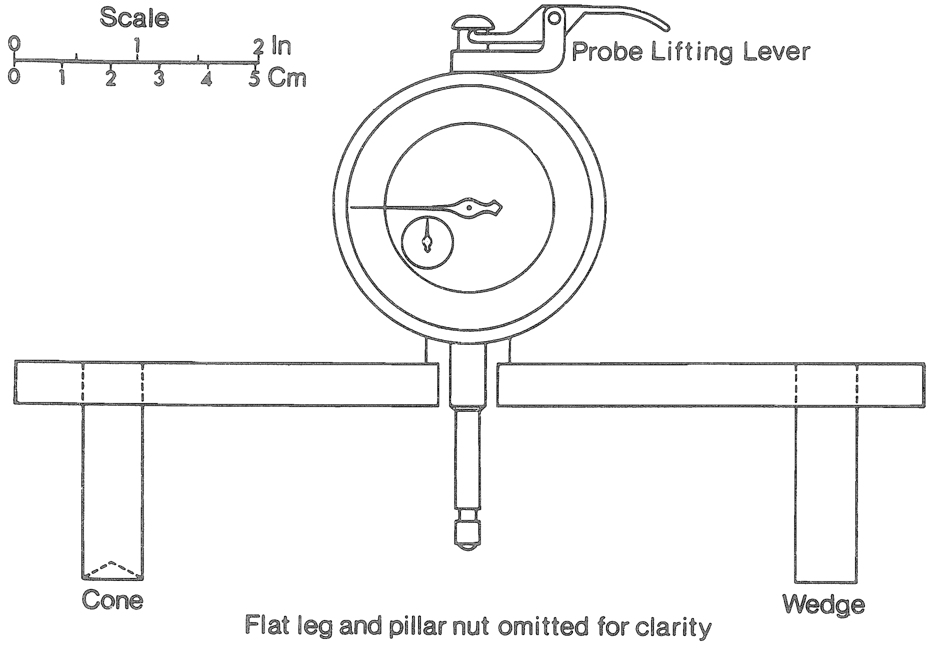
Methods described in the literature that involve direct measurements include those of Hodgkin[2], Dahl[3] and Aub[4]. Hodgkin compared plaster casts of rock surfaces in relation to steel reference pegs over a period of about nine years, the technique was only applied to limestone bedrock in the inter-tidal zone. Dahl used instrumental measurements to assess the differences in height of individual mineral grains weathering on a glacially striated rock surface. Aub employed a spherometer to measure the lowering of chalk surfaces in relation to a reference stud. However, all these methods have distinct limitations if the aim is to measure very small erosional effects on an individual rock surface over a period of a few years. The method described by Hodgkin is only suitable for sites with rapid erosion, Dahl's technique is essentially limited to glacially striated rock pavements and Aub's spherometer measurements are probably only reproducible for erosion differences of a millimetre or so.

The Micro Erosion Meter (MEM)

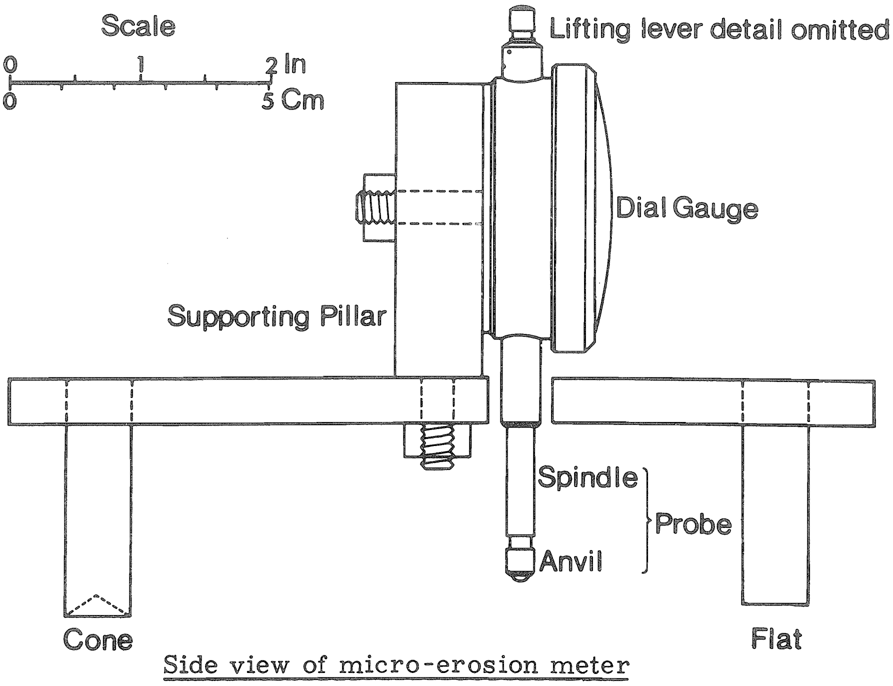
This instrument was developed in the Department of Geography at the University of Bristol in order to obtain direct measurements on the rate of lowering of limestone rock surfaces. It was first described in detail by High and Hanna[5]. This reference describes the basic MEM in the form of a technical report and details its construction and use. Subsequent refinements have occurred and these have not been published in any detailed form. I am indebted to Drs. High and Trudgill for permission to make use of previously unpublished material describing these later modifications[6]. Although the instrument was developed for use on limestone bedrock there is no question that it can be satisfactorily applied to a much wider range of lithologies.

The Basic Micro Erosion Meter

The general principle of the technique is that the instrument is used in the field on successive occasions to obtain data on the rock lowering (or accretion) between observations. In order to obtain meaningful information it is essential that the



Face view of micro-erosion meter



Side view of micro-erosion meter

Figure 1: Side and face view of basic micro-erosion meter[5].

instrument is located at precisely the same location for each set of measurements.

The MEM consists of an engineering dial gauge mounted on a metal stand with three legs (Fig. 1). Each of the legs fits precisely onto a reference stud which is permanently emplaced in the rock surface; thus for a simple site there are three studs. The major feature of the design is the technique used to obtain exact relocation on the studs. This is achieved by use of a principle known as the Kelvin Clamp. In the early model each stud consisted of a stainless steel bolt to which was affixed a stainless steel ball bearing. The legs of the MEM each have a differently machined base; these are referred to as a wedge, a cone, and a flat. The details are shown in Fig. 2, the angle of the cone and the wedge are 120°. Thus when the MEM rests upon the three ball bearings associated with the studs it has six kinematic restraints; three with respect to translational movement and three with respect to rotational movement. This design permits very precise relocation and within reasonable limits is not dependent upon the precision of the individual parts.

The constructional details of the basic MEM are given in High and Hanna[5] and the summary that follows is based almost entirely on that account.

Dial Gauge

A wide range of engineering dial gauges are commercially available at relatively low prices. Experience has shown that for the construction of the MEM such gauges should:

(i) be calibrated to 0.002 mm;
(ii) have probe tip (or anvil) of stainless steel or for use on rocks dominantly composed of particularly hard minerals, a synthetic jewel could be used;
(iii) have a probe travel length of 12-24 mm, preferably the latter;
(iv) be fitted with a probe lifting lever;
(v) as the instrument will be used under field conditions, models that are shockproof and waterproof have obvious advantages.

The Legs

The legs of the instrument represent the most difficult aspect of the construction. They consist of rods of either high grade, corrosion-resistant, stainless steel or sintered alumina (aluminium oxide). All the models used in Bristol were constructed from sintered alumina but this can be difficult to obtain in the dimensions required. Whichever material is used for the legs, it is necessary that the machining of the cone, flat and wedge, on the bottom of the legs is of the highest workshop standards. It is usual for this to be undertaken commercially.

Construction of the MEM

The legs and dial gauge are combined to form the completed instrument by means of a base plate constructed from a steel plate with a thickness of 6-9 mm and a supporting pillar formed from a single block of steel.

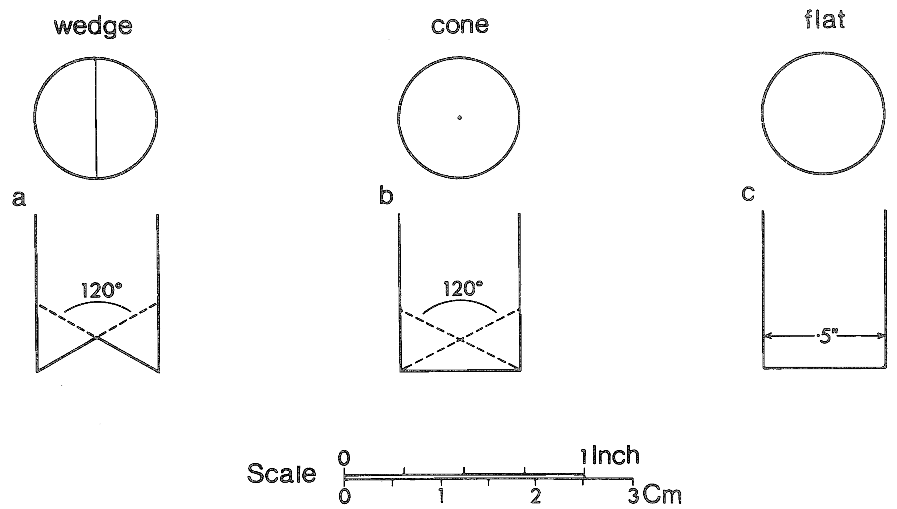


Figure 2: Details of the micro-erosion meter legs[5].

The details and dimensions can be seen from Figs. 1 and 2 which are from High and Hanna[5]. If stainless steel legs are employed these should be threaded into the base plate, but with sintered alumina, an epoxy resin (such as Araldite) is used. It is essential that all joints are cemented with resin before the instrument is used in the field as any subsequent re-tightening will invalidate a run of sample observations. The wedge-shaped leg must be fitted so that the axis of the wedge points towards the cone. The size of the instrument is not critical, the instrument illustrated has the legs positioned so that they form an equilateral triangle with sides of about 15 cm.

Calibration Plate

No calibration in the normal sense is required but a test plate is necessary to ensure that the instrument has not suffered any damage between sample runs. The test plate should be constructed from a sheet of heavy steel which is fitted with reference studs and ideally has at least one measuring point that consists of a stainless steel ball bearing fixed to the plate. The test plate should also be used to check for any possible modification of readings due to temperature expansion effects of the MEM itself or the studs.

Initial tests with the MEM has shown that temperature effects, certainly over the range of 10°C, can be ignored, however, for some sites it would be necessary to use the test plate at temperatures that correspond to those encountered in the field. The effects of probe erosion on most rock surfaces can also be ignored, if there is any doubt a test slab should be set up for detailed testing.

Studs

The most satisfactory method is to use a rock bolt device as illustrated in Fig. 3. A suitable commercial version is marketed (in the U.K.) as a

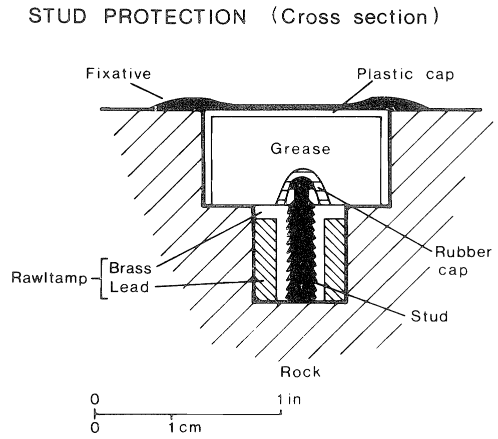


Figure 3: Details of micro-erosion meter studs[6].

Rawltamp. A Rawltamp consists of a threaded brass central section (which will take a standard thread bolt) surrounded by an outer lead cylinder. To install the Rawltamp it is inserted into a pre-drilled hole in the rock surface and struct with a Rawltamp 'tamping' tool so that the outer lead sleeve expands. The Rawltamp is then firmly fixed into the rock surface and the stud is firmly screwed into position.

The holes for the Rawltamp can either be drilled by hand using a star drill and a lump hammer or a power drill with carbide-tipped bits. In either case the holes are initially drilled with a diameter of about 1.5 cm (or a suitable size for the Rawltamps) and a depth of about 3 cm. Then the top 1.2 cm of each hole is re-drilled with a 2 cm bit, this is necessary to allow a spanner to be inserted to tighten the studs in the Rawltamp. It is useful to use a template to mark the position of the centres of the holes before drilling.

Reading the MEM

After the installation of the studs the site should be carefully washed using a wash bottle. It is then ready for the first reading. The basic MEM is only capable of readings three points within the triangle formed by the studs. These three points are obtained by using the instrument in its three possible positions, i.e., by turning the instrument through 120° after each individual point has been read.

The reading and booking are relatively straight forward but a number of points need to be stressed. First, the site and studs must be cleared of all loose material but in a manner that does not itself cause measurable erosion. The MEM should be placed very carefully onto the studs commencing with the cone. Once the instrument is firmly in position the probe is gently lowered and the dial read. The probe is then raised and the sequence repeated for the second position and similarly for the third. It is good practice to take more than one reading for each of the three positions on each occasion that the site is measured. This enables a mean value to be obtained; an exception to this procedure would be in those cases where probe erosion presents a problem. The booking itself presents no complications although it is helpful if a reference mark is engraved near to one of the studs.

The frequency of sampling will depend on a variety of factors but for exposed sub-aerial sites of the kind often associated with rock art an interval of six months or longer would be considered suitable. The difference in dial gauge values between readings is the erosional lowering. It is recommended that this is reported in the form of millimetres of lowering per year.

For a sequence of MEM readings at a particular site it is necessary that the same instrument is used. If the instrument is in any way damaged the initial sequence is concluded although clearly the studs can be used for a new run of observations. Between observations it is suggested that the studs, which are countersunk into the rock, are packed with water pump grease and if possible, capped with plastic cover.

Disadvantages of the Basic MEM

The basic MEM has proved to be a very reliable field instrument but it has a major disadvantage in that the number of actual measurement points is restricted to three. This limitation is particularly pertinent where details of the micro-topography of a small area of rock is required. To some extent this problem has been overcome by developing a new model known as the traversing MEM.

The principles are the same as for the basic model but the modifications enable a very much larger number of points to be measured within the triangle formed by the studs. The traversing model illustrated in Figs. 4 and 5 is capable of measuring up to 80 individual points within a 12 cm sided triangle. Traversing MEM's with longer sides can

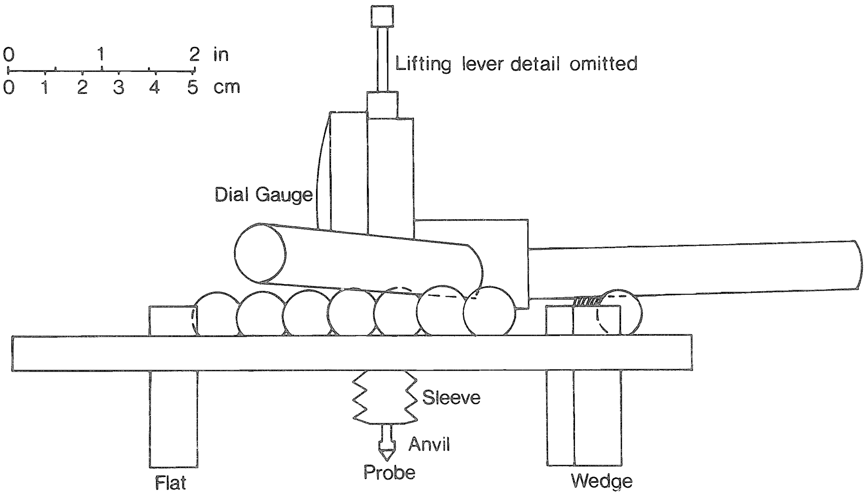


Figure 4: Side view of the traversing micro-erosion meter[6].

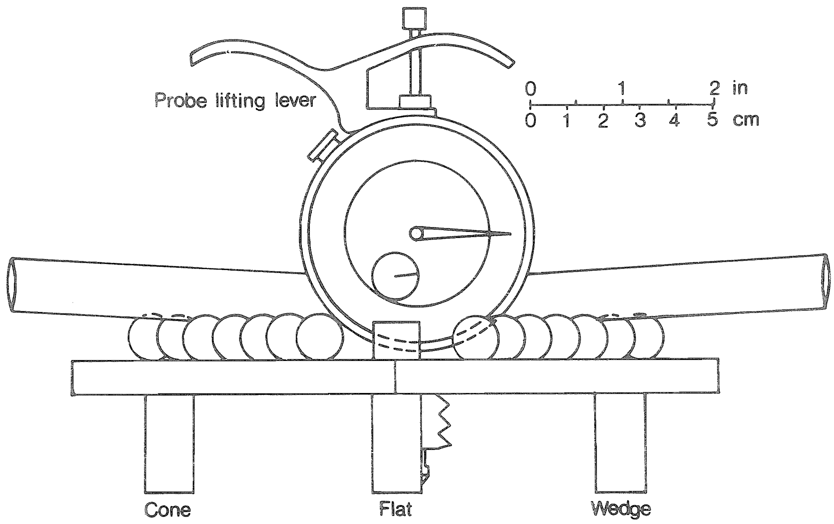


Figure 5: Face view of the traversing micro-erosion meter[6].

increase the number of points still further. For example with a 30 cm sided base plate, some 1000 individual points can be measured within the triangle of the studs.

Traversing MEM

Construction

The construction of the legs for the traversing MEM is the same as for the basic model. The major difference is that the instrument is in two separate parts, the dial gauge, which is fitted with three horizontal arms, and the base plate. The dial gauge and the three horizontal arms, which are constructed from sintered alumina rod, are fitted rigidly into a steel block. The base plate is fitted with three legs of cone, wedge and flat construction as for the basic model. The base plate has the centre removed to leave a frame with a width of 2-3 cm. On each arm of the frame a row of ball bearings are mounted so that they touch each other, see Fig. 6. These are of a diameter that approximates to the diameter of the material forming the horizontal arms of the dial gauge. The ball bearings are placed into small depressions drilled into the arms of the base plate and securely fixed using epoxy resin.

This instrument too, has proved effective but considerable care is needed in its construction and greater attention is required to avoid damage during transit.

The method of reading the instrument is similar to that for the basic model but great care needs to be taken with the booking. The base plate is placed on the studs and the dial gauge section rested in the spaces between the ball bearings. It is necessary to label the instrument and a method is illustrated in Fig. 6. The rows of ball bearings are labelled A, B and C and the spaces 1 to 6. Thus for the position illustrated the booking would be 'dial gauge facing flat' and the specific location A2, B5 and C4. It is worth noting that the sum of the spaces for this instrument must total 11, e.g., 2 + 4 + 5. Having obtained this reading the dial is left facing the 'flat' and a new point measured.

A further set of readings can be obtained by facing the dial gauge to the wedge and a third set by facing the dial to the cone. At that stage the base plate can be rotated through 120° and further sequences measured, a further rotation of the base plate gives a third sequence. The location of the points for plotting purposes is obtained by setting the instrument up in the laboratory and noting the probe positions used in the field.

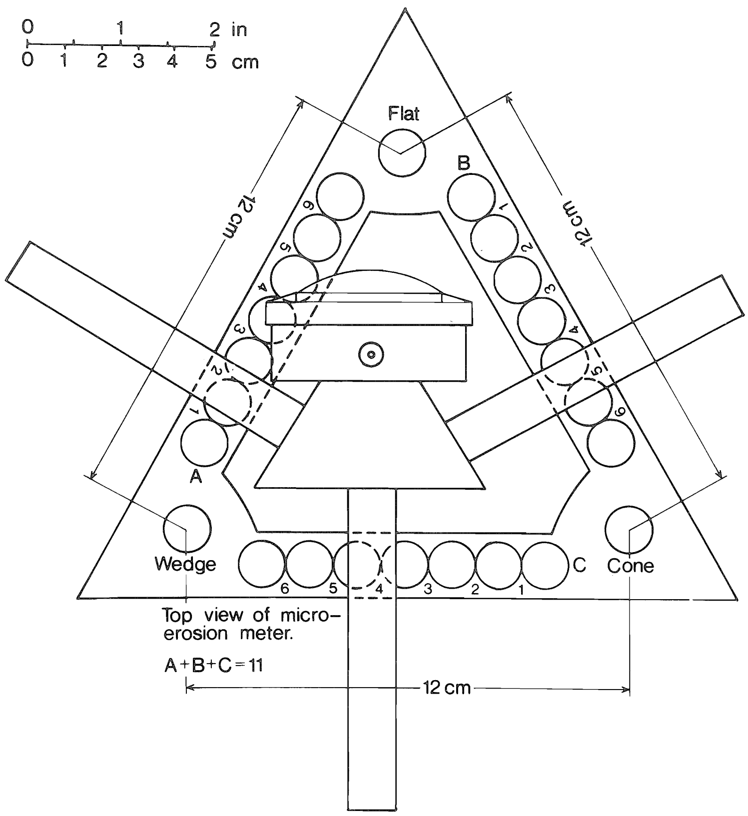


Figure 6: Plan view of the traversing micro-erosion meter illustrating the procedure for reading[6].

Modified Studs

The form of stud originally described by High and Hanna[5] which consisted of a stainless steel ball bearing fixed with epoxy resin to the top of stainless steel bolt has not proved fully satisfactory. A new form of stud has been used which is more satisfactory. This is machined from a stainless steel bolt so that the bolt head is converted into a hemisphere. Emplacement of the bolts is a little more difficult and 'flats' are left on the bolt head so that a specially constructed spanner can be used to tighten the bolts into the Rawltamps. The details of construction and emplacement are shown in Fig. 7.

Results obtained using the MEM

Most of the published data obtained using the MEM has been from sites located on limestone bedrock surfaces. The basic presentation of the information is in the form of a graph of lowering against time. Fig. 8 shows such a graph for three points measured with a basic MEM over a total period of some 500 days. In this case the lowering of the three observed points were similar. In Fig. 9 the plot is for three points from a neighbouring MEM site, in this case there is clearly a variation of lowering rate for the three observed points.

Trudgill[7-10] has presented a range of observations from his study of the limestones of Aldabra. A large number of MEM sites were installed on a variety of limestone lithologies and with differing geomorphological settings. The results show that for subaerial limestone rock surfaces the mean rate of lowering was 0.26 mm/yr, with a range from the differing sites from 0.09 to 0.86 mm/yr. This information can be further subdivided into erosion rates related to differing limestone lithologies. For inter-tidal sites the range was from 1.25 to 5.00 mm/yr, again depending on details of site location and lithology. For subsoil sites the rates varied from a lowering of 20.5 mm/yr to an accretion of 0.70 mm/yr.

Other aspects of this work considered the rates of lowering at individual traversing MEM sites and it was possible to demonstrate variations in rate for small upstanding limestone masses as opposed to those for minor hollows and depressions. High[11] using a larger model traversing MEM obtained several hundred readings with an area of some 150 sq.cm and was able to comment most satisfactorily on minor erosional differences.

The geomorphological significance of these studies is not of concern in this account but the information gathered for rock surface lowering corresponds to the ranking of erosion that would be expected from less direct estimates of erosion.

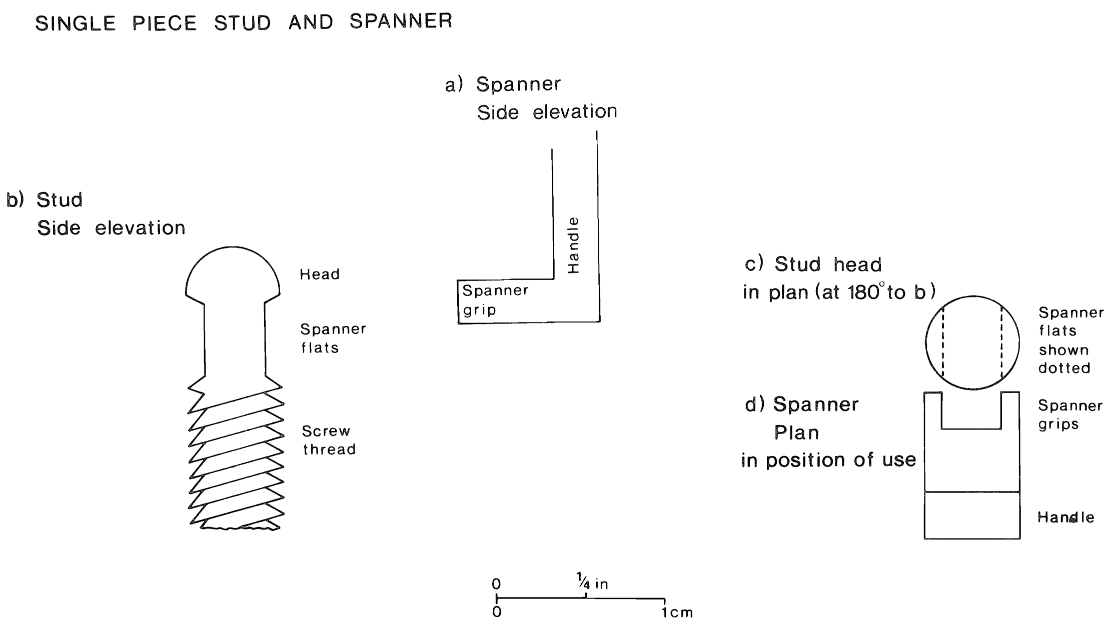


Figure 7: Single piece stud and spanner[6].

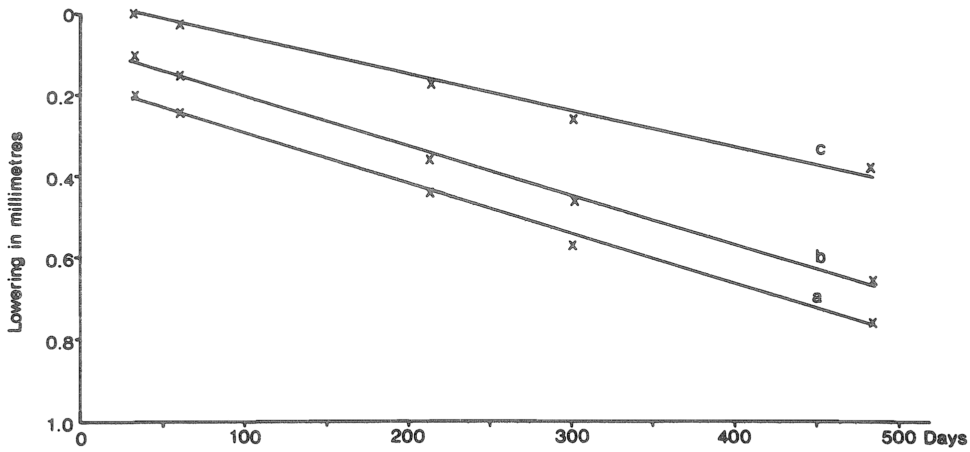


Figure 8: Graph of lowering of a stream bed at three adjacent points[5].

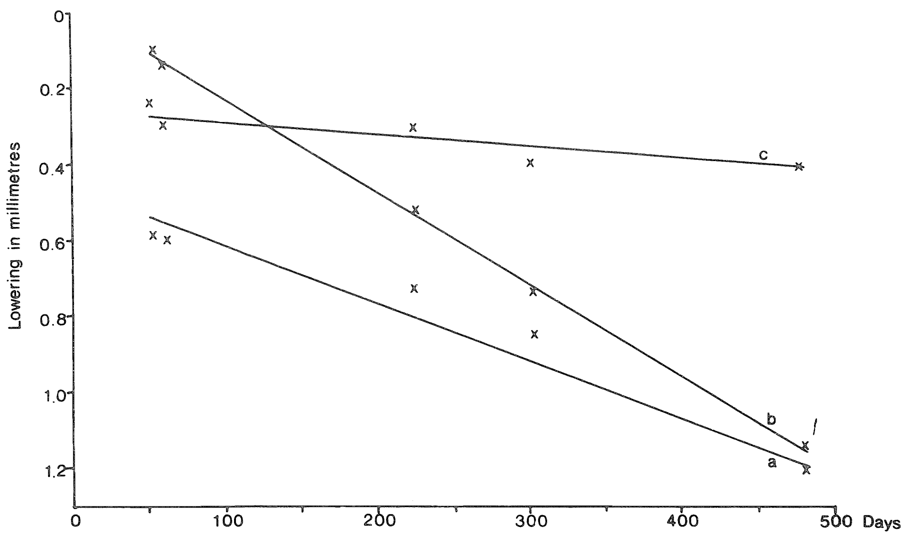


Figure 9: Graph of lowering of a stream bed at three adjacent points, showing marked variation in erosion rates[5].

An Example of the Applications of the MEM Technique to Rock Art

There are no published results on the application of the MEM to problems of the erosion of rock art sites. However, T.C. Atkinson and the author installed a number of sites in the Hornos de la Pena Cave in northern Spain as a part of an extensive study of rock art in the area undertaken by Dr. P.J. Ucko. There are no results currently available from this study although it is hoped that repeated readings may be made on the sites in years to come. However, it may be of interest to sketch the nature of the problem in order to see the possible application of the method. The cave contains numerous examples of sculpted rock art and there are two major problems.

(i) To obtain estimates of the rate of rock lowering for various sites under contemporary conditions.

(ii) Parts of the cave have considerable groupings of sculpted rock art which are frequently superimposed while other sections of the cave, which are physically similar, have no art. The problem was to ascertain whether the art was originally more widespread in the cave and was removed by variations in the rate of erosion or whether the art was originally restricted to specific locations.

Sites were therefore installed at various localities within the cave. There was a problem in that the studs could not be installed on actual examples of the art, thus homologous sites were selected. A further problem was that there is a limitation with the MEM models described in that they are not fully satisfactory on steeply sloping sides such as cave walls. The traversing model can only be used on sites with a slope of up to about 10°. The basic MEM can be employed on slightly steeper slopes but an angle is soon reached where any reading of the instrument necessitates it being held onto the studs which is not fully satisfactory.

A further restriction with the method is that the climate of the area in which the cave was located was probably more humid in the period since the art was engraved. Thus any rates obtained under contemporary conditions should not be extrapolated back into time without a full account of the limitations.

There was a bonus for this investigation in that the MEM will measure deposition, in this case of stalagmatic material, at a site as well as its potential for the assessment for rock lowering.

Suggested General Applications of the Technique of Rock Art

There is little doubt that the technique is capable of producing good quality measurements on rock lowering (or deposition) over small areas of rock surface for relatively short periods of time. The instrument is not expensive to build and its operation is relatively straightforward. However, it must be stressed that at every stage of its operation considerable care is needed and the instrument and the sites must be handled in the most delicate fashion.

There are a number of observations that can be made concerning the application of the MEM to problems of rock art erosion.

(i) The method of installation of the studs is such that it is unlikely that they could be emplaced directly on the rock art surface.

(ii) In some cases the lithology may be too friable to allow the studs to be easily installed. In these cases modifications of the methods of installation described in this paper may overcome the problem.

(iii) If the erosion of the site is dominantly by granular disintegration, and if the grain size is smaller than the probe tip, detailed measurements may not be possible.

(iv) The problems of the diameter of the probe tip may also apply to attempts to measure the actual lowering of the engraved lines that delineate the art form.

The obvious application of the MEM is to measure the erosion of the rock art and rock surface at, or near to, the field example. However, it may well be that an equally useful application of the technique is to study the erosion of experimentally engraved lines. Studies of this kind need not necessarily be made in the field but could be undertaken on rock slabs under laboratory conditions. The methods used for engraving could employ tools similar to those available to the original artist and could be made on a variety of lithologies.

This account, which is in large part a review of established techniques, is presented in the hope that the methods of one field discipline, in this case geomorphology, can find a useful application in another, namely prehistory. The methods as described have undoubtedly been of value to the study of rock lowering in geomorphology but it should be stressed that the technique is capable of further modification to more closely meet the needs of other disciplines.

Acknowledgements

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Editor's Note:

At the Workshop Dr. J.M. Taylor drew the author's attention to a recent paper also concerned with the direct measurement of erosion on engraved rock art sites. The reference is Adams, W.P., Crozier, M.J. and Glew, J.R. (1975) Report on Techniques and Equipment Design for Measuring Surface Lowering on the Crystalline Limestone of the Peterborough Petroglyph Site. *Canadian Rock Art Research Associates Newsletter*, 7, 19-34. This was reprinted from *Measurements in Physical Geography*, Occasional Paper No. 3, Trent University 1974.