Geoarchaeological Dating of Petroglyphs at Lake Onega, Russia

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This article introduces a new quantitative method of dating petroglyphs and describes its initial application. First, the major recent developments in the field of rock art dating are briefly reviewed, and the continuing difficulties in the dating of petroglyphs are elucidated. The archaeological background of the Lake Onega art, its geological setting and archaeogeophysical dating are explained. The theory of microerosion dating is described, together with its first practical application at the site Besov Nos on the shore of Lake Onega. The article concludes with a brief discussion of the new method's advantages and disadvantages.

INTRODUCTION

Without some form of absolute dating, the scientific study of rock art is not possible. Despite early attempts to date petroglyphs, which began with Belzoni's (1820) speculation about the possibility of establishing a chronological sequence from varying degrees of patination at a Nile cataract, not a single motif of rock art in the world has been dated "directly" i.e. without the use of inference or asserted subsidiary propositions, until about 12 years ago. Rock art dating by archaeological association of one form or another has been attempted in all continents, and a variety of other approaches (e.g., lichenometry) has been proposed (for a recent review, Bednarik, 1992a), but the first tentative attempts at "direct" dating are comparatively recent (Combier, 1984; Denninger, 1971; Grant, 1965). Claims for correlative relationships between rock art and archaeological finds or strata depend on such unfalsifiable assumptions as stratigraphical integrity, and, like those based on various stylistic propositions, are not scientific. Many of the archaeological dating claims for rock art or portable art have had to be questioned upon close examination; in North America (Loendorf, 1986, refuted in Bednarik, 1987), South America (Guidon and Delibrias, 1986, questioned in Bednarik, 1989), Asia (Kumar et al., 1988 in India; Okladnikov, 1977 in Siberia, both refuted in Bednarik, 1992b), Europe (Drouot, 1976; Bednarik, 1986a), and Australia (Morwood, 1981; Bednarik, 1986b, 1992a; Wright, 1971).

Many of the proposed regional rock art sequences of the world are largely based on iconographic and stylistic inferences, such as those for Saharan and Levantine rock art which have recently been refuted (Muzzolini, 1990; Hernández Perez et al., 1988). In both these cases the art had been largely categorized

Geoarchaeology: An International Journal, Vol. 8, No. 6, 443–463 (1993)
 CCC 0883-6353/93/060443-21

and dated on the basis of what was thought to be an art of hunters, yet in both cases it has been shown to be Neolithic. It must be considered that style, like ethnicity, is not necessarily detectable by archaeological means. Archaeology is a subjective pursuit which creates its own styles of artifacts, its taxonomies, and then assumes that they correspond to social or cultural entities of the past (Conkey and Hastorf, 1990). Style, therefore, is not a scientific means of "taxonomizing" art, or any archaeological information (Hodder, 1990). Similarly, iconographic identification of art is not possible in the context of materialist science, in the sense of being scientifically relevant (Tangri, 1989). It is precisely in this area that the anthropocentricity of human endeavors to perceive reality becomes most apparent (Bednarik, 1985a, 1992c).

During the 1970s the writer developed the concept of "direct dating of rock art," contrasting it with the traditional "archaeological dating methods" (Bednarik, 1979, 1981a, 1984), and defining it thus:

> . . . the most reliable means for determining the antiquity of rock art remains the investigation of features related to the art itself, which either date it (e.g. pigment), predate it (e.g. the rock art's medium, or the particular surface it was executed on), or postdate it (e.g. later cracks dissecting a motif, or precipitates deposited over the art) (Bednarik, 1981a).

After first examining the potential of various patinae, rock varnish, and weathering wanes ("wane" refers to the phenomenon of progressive rounding of a rock edge through weathering processes; macro-wanes are a well-known, age-related feature on clastic detritus, micro-wanes occur on a microscopic scale) to provide "direct dating" information relating to the age of petroglyphs the writer focused on the rock art stratigraphies in several newly discovered caves near Mount Gambier, South Australia, from 1979 onwards. Not only was the "stratigraphical relationship" of the art phases (in the sense of Anati, 1961) here a physical, indisputable stratigraphy of rock art and laminar layers of reprecipitated calcite, the latter are datable by various quantitative methods: through the biological origin of one half of the carbon content which renders the deposit susceptible to radiocarbon dating; by the uranium–thorium method for radioactive isotopes present in the speleothems; by radiocarbon dating of organic matter contained in some laminar calcite deposits; and by the determination of its oxygen isotope ratio, which can provide palaeoclimatic information (Bednarik, 1981a, 1981b, 1984, 1985b).

At about the same time, Dorn began developing his cation-ratio dating method in southwestern U.S.A. (Dorn, 1983, 1986). It utilizes the phenomenon of selective leaching of cations from rock varnish, a ferromanganese accretion deposit of biological origin. The readily soluble cations K and Ca are compared with the relatively stable Ti. Following spectacular results in Australia (Nobbs and Dorn, 1988), the cation-ratio method was subjected to stringent review (Bednarik, 1992a for summary), and Dorn (1990) conceded that it remains an experimental method, that he has to revise calibration curves, and that the method "will always be a weaker sister" of other approaches.

Watchman, who identified oxalates at a series of rock art sites in Kakadu National Park, northern Australia, recognized their potential to provide minimum or maximum dating where they are in physical contact with rock art. Whewellite and weddellite are salts of oxalic acid and thus contain organic carbon, which renders them susceptible to radiocarbon dating (Watchman, 1990). The oxalate dating method is therefore similar to the carbonate dating method, in that it can only provide approximate dates for deposits that occur either under or over rock art.

The first radiocarbon date obtained directly from a rock painting was offered by Van der Merwe et al. (1987), who dated comparatively recent charcoal pigment. A subsequent flurry of activity resulted in several absolute radiocarbon dates from rock paint at sites in France, Australia and U.S.A. (Lorblanchet et al., 1990; Loy et al., 1990; McDonald et al., 1990; Russ et al., 1990). It is now being recognized that organic pigments, or paints containing organic binders, fibers, proteins, and plant dyes may be far more common than had been assumed previously (Cole and Watchman, 1992). For instance, animal proteins have been observed in red rock paint from southern China (Li Fushun, 1991), and presumed manganese pigments are sometimes found to be charcoal. The author has identified at least three organic pigments in India, three in Australia, two in South America, and more in other continents (Bednarik, 1992a).

During 1991 and 1992, rock art pigment has been dated at further sites in France, Spain, Australia, and Brazil. It can only be a matter of time before experimental work in the absolute dating of rock paints gives way to a reasonably comprehensive methodology. Petroglyph dating, however, remains a pursuit demanding considerable methodological creativity. While there are likely to be improvements in the methods of dating surface encrustations, accretions, or patinae that cover and postdate petroglyphs, these can only provide minimum ages for the art. In comparison to this severe limitation, the inherent risk in paint dating (that the substance being dated is actually older than the paint) is minute. The problem is very simply that petroglyphs, in contrast to paintings, are the result of a reductive process; therefore, we have no recoverable material which actually dates from the time of manufacture. All "direct" dating methods so far applied to petroglyphs therefore relate to features concealing or supporting them, such as carbonate precipitates, rock varnish, and oxalate skins. This preoccupation also illustrates another problem in rock art dating: a preference for techniques that can be developed or neatly packaged into standard procedures, or that in some form lend themselves to standardization. Such procedures are seen as maintaining a semblance of the replicability science demands. Complex and perhaps oversophisticated methods involving "high technology" are favored, which contributes further to diminishing scientific participation of developing countries in these endeavours. It also contributes to enhancing the scientific dependence of the poorer countries, and thus to scientific neo-colonialism (Bednarik, 1992d).

Most petroglyph panels present a complex record of many time-related processes and events, and the relative position of rock art phases within these chronological sequences is often readily apparent. For instance, many petroglyphs are dissected by cracks, and each successive crack produces four features that must all be of the same age: two edges and two new surfaces. Edges become progressively blunt and rounded, surfaces become patinated, or they are subjected to granular or laminar exfoliation, the deposition of accretions, scratching by animals (in caves), and other processes. Many phenomena could be utilized in dating, depending on circumstances: the wanes on rock edges; multifacetted boulders that are the result of progressive insolation or brush fire spalling, and bear a patination of different age on every facet (Bednarik, 1979: Figure 1); differential patination, fracture sequences, carved dates, inscriptions, or historically datable symbols; the spatial relationship of the art to specific topographic aspects of the site, such as subsided floors, roof falls (in caves and shelters), changes in sediment levels or in accessibility, and many more.

The actual manufacture of a petroglyph can be dated by only one phenomenon, however: the surface exposed by the impact, abrasion, or etching process that produced the mark forming the petroglyph. That process exposed a new lithospheric surface to the effects of atmosphere, hydrosphere, and biosphere, an event which indisputably dates to the time of execution. If it could be dated, the result would be irrefutable, any deficiencies could be attributable only to shortcomings inherent to the method itself, as no other sources of error or inaccuracy are possible.

THE PETROGLYPHS AT LAKE ONEGA

There are two clusters of petroglyph sites in Karelia, the region of Russia that adjoins Finland: a group on the River Vyg, a few kilometers from where it reaches the White Sea (the Zalavruga group; Savvateyev, 1970), and a series of 22 sites on the east shore of Lake Onega (Figure 1), from just north of the mouth of the River Vodla (Poikalainen, 1990:14), to the two tiny Guri islands some 20 km to the south, and centering on Besov Nos (Figure 2).

The Lake Onega sites occur all within an altitudinal zone of about 2.5 m above the water level, where the shore consists of gentle slopes or undulated pavements of gneissic granite, and in a few cases on islands. This zone is frequently characterized by a distinctive brown accretionary deposit, principally of iron oxides, whose occurrence is clearly related to the environmental pH: the lake water is pH 5.8, while at the Kladovez site small pools among the petroglyphs are in the vicinity of pH 5.1. The zone is free of macro-flora, and at 2.5 m above the water it yields to the lower pH of the lichen zone (under pH 5). The petroglyphs are almost entirely restricted to the lichen-free varnish zone, clearly postdating the varnish in all cases. A few extend marginally into

Figure 1. Location map.

the lichen zone, and ten motifs have been found below the water; but they are on detached clasts which have slid into the water. It can be regarded as certain that the lichen flora has never colonized the varnish zone since the varnish was formed, which suggests that there could not have been a regression in the water level: the varnish would not have survived the corresponding lowering of the vegetation limit.

Although the granite contains some biotite (ca. 5%), the varnish is not a surface alteration or secretionary phenomenon, because it covers all component minerals evenly. Whether it is biogenic (i.e., a true rock varnish; Engel and Sharp, 1958) or a purely chemical precipitate remains to be established. The writer favors the latter possibility, because typical primary characteristics of rock varnish (manganese prominence, laminate morphology, etc.) are lacking.

The topography of the region is largely the product of glacial processes, which have smoothed and rounded all rock profiles and produced pavements bearing

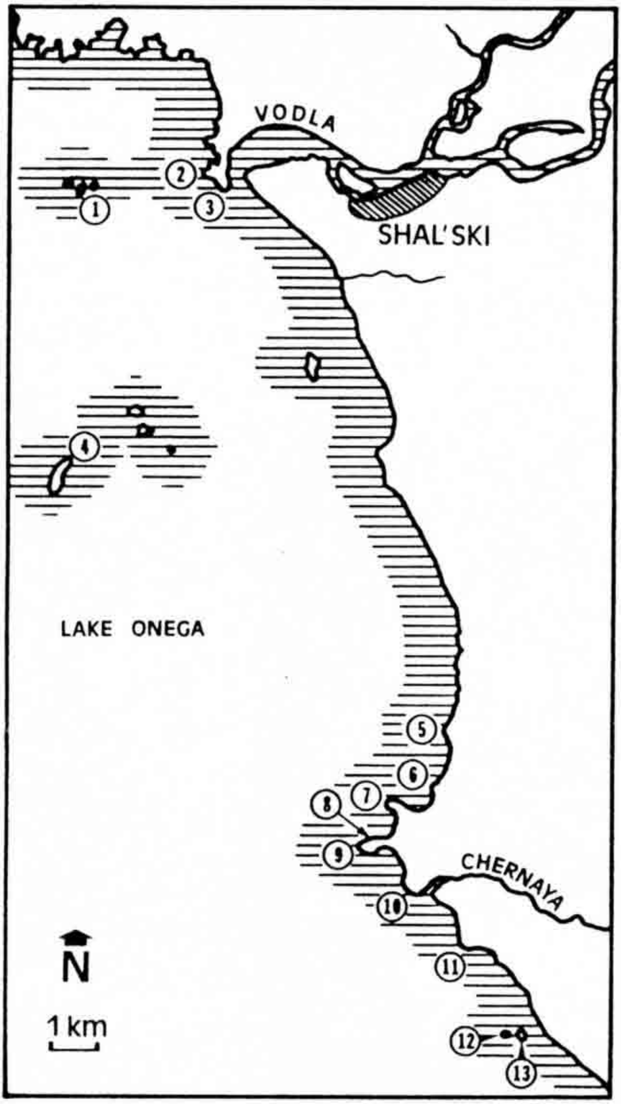

Figure 2. Petroglyph sites on the east shore of Lake Onega, Karelia: (1) Berezo; (2) Joutsenniemi; (3) Ludy Nos; (4) Shag'ski; (5) Karetski Nos; (6) Moduzh; (7) Peri Nos sites 1–7; (8) Besov Nos North sites 1 and 2; (9) Besov Nos, (10) Kladovez; (11) Gazhi Nos; (12) Maly Guri; (13) Bolshoi Guri.

vast numbers of striae. The marks vary considerably in size, with specimens of up to 1 m width being quite common, and the direction of movement can be easily determined from the typical transverse "tear marks" (a phenomenon that is morphologically identical to the microscopic "tear marks" in anthropic engravings (d'Errico, 1988). Petroglyphs are frequently superimposed over glacial striae, but in no case has the writer observed a striation over a petroglyph, having examined nearly all Karelian rock art sites. Since the final glaciers withdrew about 9000 years ago, the petroglyphs can be placed squarely in the Holocene. The varnish covers all glacial phenomena, while itself predating the art. Thus the most probable explanation is to attribute it to the early Holocene, perhaps to the Atlantic transgression (at least 4 m according to Devyatova (1986), 7700–5000 years B.P.; Savvateyev, 1984:120). The deposit is likely to contain organic matter, and it would be worthwhile to subject it to AMS radiocarbon dating (Dorn et al. 1992).

Of the various attempts to date the petroglyphs, that of Savvateyev is by far the most carefully argued. It is based on the hypothesis of Pankrušev (1978:26–53), which attributes Holocene water level changes of the lake to buckling of the continental plate. According to this model, the rock surfaces now bearing the presumed oldest glyphs (such as the "demon" at Besov Nos) emerged slowly from the water during a period commencing about 6000 years ago. The sub-Boreal transgression of about 3.5 m began to inundate all of the rock art 3800 years ago. Later the lake receded, gradually approaching the present level around 2000 years ago (Savvateyev, 1982:43; 1984:117–121; 1988:67). Because it is generally assumed that the petroglyphs predate 2000 years B.P., Savvateyev deduces that they were produced during the period of lower water level that separates the two main transgressions of the Holocene. Since the figures he considers to be oldest, notably the Besov Nos "demon" and the two large animal images on either side of it, begin at 1 m above the present water level, he proposes that they were executed towards the end of that period. According to this model, the water level was lowest between the early 3rd millennium B.C. and the first quarter of the 2nd millennium (Final Neolithic, or Eneolithic), and the rock art dates from that period.

In support of the hypothesis, Savvateyev cites the proximity of some of the numerous excavated occupation sites in the area (in all, there are over 550 archaeological sites on the shores of Lake Onega). Some 31 prehistoric settlements occur in the immediate vicinity of Lake Onega petroglyph sites (Savvateyev, 1988:57), and those at Kladovez and Besov Nos include occupation evidence matching the proposed age of the petroglyphs.

Devyatova (1986) disagrees with Pankrušev's model of water level fluctuations, perceiving a greater number of such oscillations. For instance, she reports a lowering of water level between 4800 and 4700 years B.P., and a rise at 4500–4400 years B.P., resulting in a water level of 2–2.5 m above the present level. According to her model (Savvateyev, 1984:120), it then fell 4300–4000 years ago, rose to the previous level 3900–3700 years B.P., and fell 3400–3300 years B.P. Savvateyev argues that the petroglyphs must date from one of the two regressions postulated between 4800 and 4000 years ago (Savvateyev, 1984:121; 1988:67–68). However, this is not logically consistent, because the Devyatova model does not exclude a post-Neolithic age for the petroglyphs, whereas the Pankrušev model does; so to place the art firmly into the Neolithic he must follow the latter, which means that he cannot resort to the former for fine-tuning of the proposed dating.

The plate tilt hypothesis is by no means proven, and a different version is espoused by Zemlyakov (1936) and D. D. Kvasov, who suggest that while the northern part of the lake was lifted and the southern part lowered, the central part (which is where the art is located) was the zone of equilibrium in this see-saw, experiencing no significant water level changes (Savvateyev, 1984:118). Indeed, at the northwestern shore, occupation sites at former water lines are up to 41 m above the present water level, and their chronological sequence is reflected in their altitudes. At the southeastern shore, prehistoric sites have been either partly or wholly destroyed by water action.

Various aspects of the proposed models remain obscure. For instance, why should the level of an inland lake be expected to reflect the eustatic fluctuations of the sea? Some petroglyph motifs at Onega are difficult to reconcile with a Neolithic antiquity, but would be considered as belonging to the Bronze Age in Scandinavia. On the other hand, it is true that the Karelian petroglyphs do differ from those of Scandinavia, but, then, so do those at Onega from those at Zalavruga. Most researchers commenting on the possible age of the Onega petroglyphs have placed them into the metal periods, especially the Bronze Age, but some, such as Spitsyn (1929) and Gorodtsov (1926), favor the Iron Age.

Obviously, spatial proximity of rock art to an occupation site provides no relevant dating evidence in a region that has apparently been occupied fairly continuously from the mid-Mesolithic period to the present. Settlements of the Mesolithic, Neolithic, Bronze, and Iron Ages, and of Historic periods all occur within easy walking distance of all the coastal petroglyph sites of Lake Onega. Moreover, if the art sites are regarded as having been of some ritualistic function, as they are by most commentators (which is noted without supporting that connotation), proximity to settlements is no significant criterion.

The writer has not observed any ancient shore lines in the vicinity of the art sites which would indicate major transgressions in the late Holocene. On the tiny island Maly Guri, which rises 2.5 m above the water, a small patch of soil measuring a few meters across contains flints and reticulate pottery. This soil would not survive a rise in the lake level of 1 m, because of the severe pounding by wave action and ice floes. The slightly larger, neighboring island Bolshoi Guri contains rich Neolithic occupation deposits. These could not have survived the 3.5-m post-Neolithic transgression Pankrušev postulates, which Savvateyev relies on to underpin his dating of the petroglyphs. Coastal erosion remains very active in the region, and we have no reason to assume that it would have been significantly less severe in past millennia. Savvateyev himself reports that some occupation sites, as low as 1–1.5 m above the present water level, include post-Neolithic remains: "Kladovez IIa could have only existed at the modern (or lower) level of Lake Onega," he writes (Savvateyev, 1988:63), and yet the site contains Neolithic, Bronze Age, and Iron Age pottery. How should we reconcile this with the model according to which the transgression lasted through the Bronze and Iron Ages? Similarly, the dozen sites at the lower reaches of the River Chernaya are below the level of the postulated transgression. They are of the early Iron Age, so if an inundation did occur, it must have been of significantly lesser duration than suggested. It is also relevant to note that, despite considerable efforts by divers to locate petroglyphs below water level, none have ever been found besides the ten motifs on detached blocks that have slid into the water. Finally, direct evidence (see below) is available from some of the petroglyphs themselves that they could not have been submerged for any great length of time.

Having to refute Pankrušev's sequence of water level oscillations unfortunately means that we have to forfeit the ante quem date it provided for the petroglyphs, and we are back almost at the starting line: Our solid dating evidence is limited to the observation that the petroglyphs are younger than the varnish, which excludes an early Holocene age. But this is of no real help, because occupation evidence from that time is lacking anyway. The art can once again be attributed to any period, or periods, from the Mesolithic onwards.

MICROEROSION DATING ATTEMPT AT LAKE ONEGA

In assessing the age of the Onega petroglyphs the writer concentrated on the central site Besov Nos. Its name means "Demon's Nose," which is the name of both the cape, and of the only nearby contemporary settlement, the now abandoned village Besov Nos, on a hill top about 1 km from the coast. Savvateyev argues that the cape's three main figures, among the largest in the area (it is exceeded in size by only one motif at Lake Onega), are the oldest, and at least for Besov Nos itself this is most plausible. Especially the principal figure, the "demon," is highly unlikely to postdate the smaller figures nearby: It not only occupies the central position of the panel, it is related to a prominent crack that predates the figure, and which was modified and incorporated in the figure. The "demon" is one of only two petroglyphs in the region over which a second, much younger motif has been intentionally superimposed (Figure 3). In both cases, the younger motif is a Russian Orthodox cross, perhaps intended to "exorcise" the earlier "heathen" symbol. This practice occurs elsewhere in the world (Bednarik, 1988). The cross partly covering the Besov Nos anthropomorph, together with a "halo" and four written characters, is attributed to 15th or early 16th century monks from Murom monastery, about 25 km away. They may have sought to "neutralize" the "demon" (and a nearby swan motif), or perhaps even "convert" him.

There are also a few recent, inscribed dates in the vicinity of the "demon," two of which were analyzed: "1933" and "1937." Finally, throughout the Onega rock art sites occur great numbers of glacial striae. They are of the most recent glaciation and thus probably marginally older than 9000 years. My attempts to locate the youngest striae led to the observation that the relative degree of microerosion among superimposed marks corresponds to their relative ages.

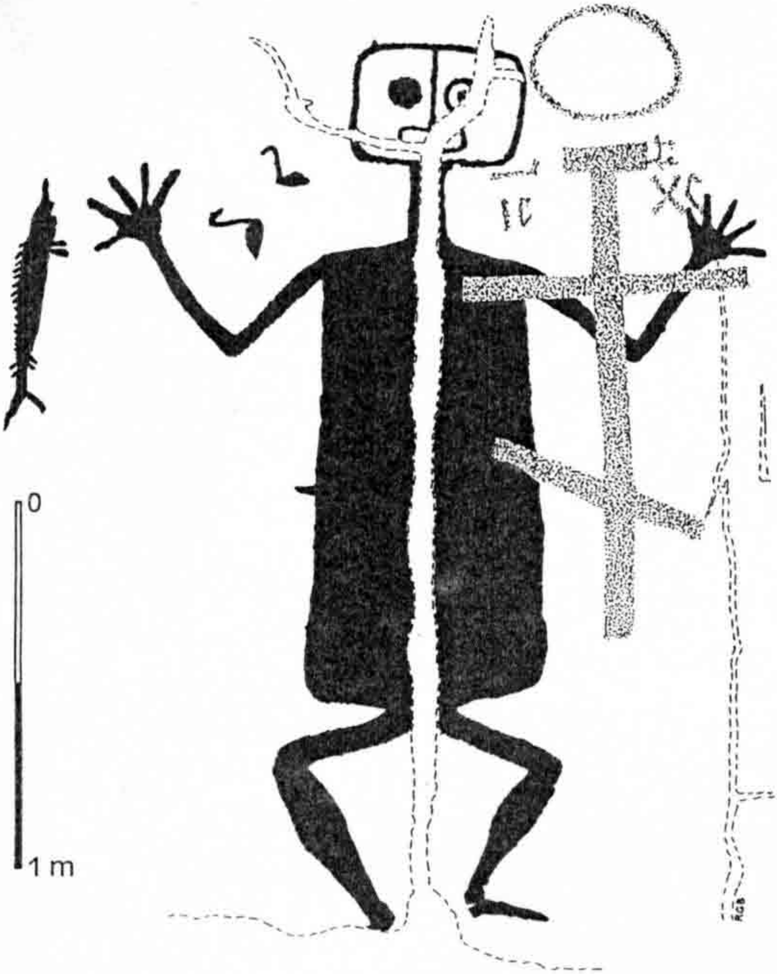

Figure 3. Anthropomorphous petroglyph at Besov Nos, Lake Onega, called the "demon." A Russian Orthodox cross, inscription, and "halo" have been superimposed over the motif, which itself post-dates the central, longitudinal crack.

Detailed scanning of the marks of known, or approximately known, ages was correlated with microscopic surveys of several areas of the Besov Nos "demon," particularly of areas of his head and legs. The observations are summarized here:

(a) *Freshly fractured rock surface:* no weathering of any morphological characteristics. The rock is composed of 60–70% feldspar (plagioclase), 25–30% quartz, and about 5% biotite, as determined from thin sections.

The plagioglase is replaced by small muscovite particles, the biotite by chlorite.

(b) *Two inscribed dates, ca. 50 years old:* the cleavage faces of the feldspar component appear entirely fresh under low magnification (10–20 ×), edges are sharp, and flat crystal faces are highly reflective. Erosion becomes apparent only around 100 ×.

(c) *Orthodox cross, ca. 500 years old:* feldspar edges are blunt even at 10× magnification, wane widths of right angle edges are about 0.1 mm, crystal facets are barely discernible, and "scalloping" is not preserved; reflection is diffuse and surfaces are "frosted." The erosion becomes very apparent at higher magnification, micro-wanes are narrow and well defined, the dimensions of wane widths are clearly a function of edge angles. Micro-wanes of quartz become discernible at 100 × ($A < 10\ \mu m$, see below for details of quantification).

(d) *The "demon" petroglyph, age to be determined:* the feldspar micro-wanes suggest a retreat ranging from 6 to 10 times as much as (c); flat surfaces have retreated so much that they present a "sculptured" appearance. Quartz appears "frosted" even to the unaided eye, and its micro-wanes are quite clear at 20 × ($A \approx 60\ \mu m$ at $\alpha = 90°$).

(e) *The most recent glacial striae, ca.* 10,000 years old: the feldspar has become quite unsuitable for analysis, while the quartz micro-wanes range from 0.1 to 0.2 mm at median angles.

In addition to Besov Nos main site, petroglyphs were also analyzed at Besov Nos North 2, and at Peri Nos 4, 6, and 7 (Figure 2). It became evident that the petroglyphs at elevations of less than 30–50 cm above the water, which are regularly awash, had experienced significant removal of feldspar. While the quartz component is clearly less worn than that of the Besov Nos "demon" (and the petroglyphs are thus younger than that motif), the feldspar is deeply pitted and alveolate, and has eroded in a pattern totally different from the Besov Nos figure. The "demon" extends from 1.05 to 1.46 m above the present lake level, and shows no differential preservation between these elevations. It is concluded that no part of that figure has been submerged under water for any great length of time, and this may well apply to all other Lake Onega rock art above the elevation of 1 m. It is possible that a brief transgression (of perhaps a century or two) could have occurred without leaving any discernible erosion traces, but the absence of any alveolation evidence on the feldspar of the "demon" prompts skepticism. Be that as it may, according to Pankrušev's model that figure should have been inundated for over a millennium, for which there is no evidence. This finding only suggests that the present rock surfaces were above the water level during, at the very least, parts of the Bronze and Iron Ages, and that lake level fluctuations therefore provide no clues to the age of the petroglyphs.

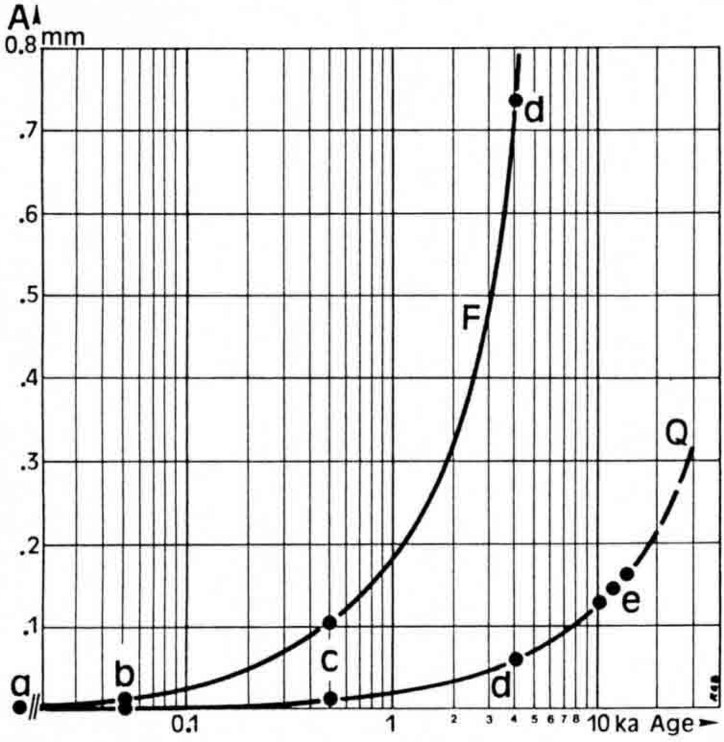

Figure 4. Microerosion calibration curves for the site Besov Nos, Lake Onega. The surface ages (a), (b), (c), and (e) are known, or approximately known. The age of (d) is that of the petroglyph surface of the "demon", and is to be determined from its position on the curves. Curve (F) represents the feldspar component, curve (Q) the quartz component, (A) is the wane width at $\alpha \approx 90°$, the age is shown in ka (thousand years). It is to be noted that the curve shape is a function of the logarithmic depiction, in reality microerosion proceeds in a linear fashion.

Figure 4 provides a tentative model of microerosion calibration curves, exemplified by the Besov Nos data. Rather than stating the proposed age for a sample with a reasonable error margin, it is expressed in the form of a "probability histogram," as shown in Figure 5, based on the observed "spread" of the microerosion data. In this example, the probability that the true age is 4000 years is twice as high as the probability that it is either 3500 or 4500 years, and while an age of below 3000 or above 5000 years remains possible, it is in practical terms outside the range of realistic probability. As more calibrated dates become available and the variables affecting microerosion and wane formation become better understood, such probability histograms would become correspondingly narrower and of higher median peaks, even with quite modest amounts of new data. This is perhaps the clearest indication of the very considerable potential this method offers for improvement.

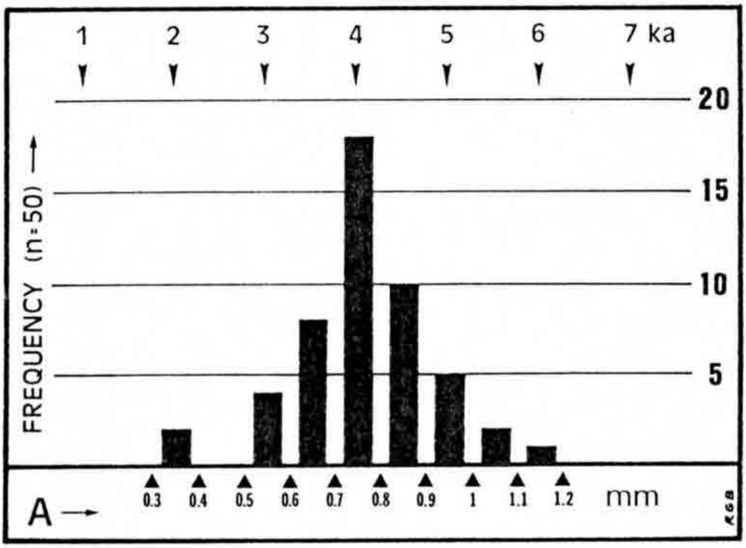

Figure 5. Histogram of fifty values of wane widths (A) at $\alpha \approx 90°$, taken from feldspar on the Besov Nos "demon," providing an indication of the relative probability of the age estimate of E4000 years B.P. being valid.

In order to discuss the relationship between the quantitative data used in microerosion dating and the age of the features being examined, it is helpful to consider the theory of the method.

THE MICROEROSION DATING METHOD

In considering microerosion dating we have to distinguish between two types of rock: those on which the individual grains or crystals that were fractured, exposed, or truncated during the manufacture of a petroglyph are capable of remaining in situ for periods exceeding the age of the petroglyph tradition in question; and those sedimentary rocks that are subjected to relatively swift granular exfoliation or chemical corrosion, such as carbonate-cemented sandstones, calcite, dolomite, etc. (Emery, 1960). Only the former are of interest here, because for microerosion analysis to be possible the presence of crystals or grains truncated (through impact fracture or abrasion) by the rock artist is absolutely essential. Moreover, certain rock types are inherently much better suited than others, and at least initially composite rocks which include quartz (or another comparatively stable component), such as granite, quartz porphyry, gneiss, diorite, granophyre, and the like, are more likely to produce valid results. As reliable quantitative information becomes available, other rock types will become susceptible to the method.

Other preconditions for admissibility are that there must be no mineral

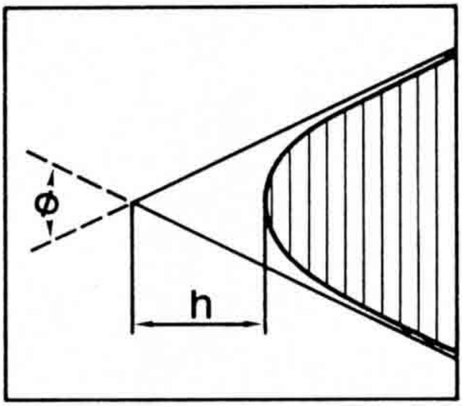

Figure 6. The development of sandstone macro-wanes, after Černohouz and Solč (1966).

deposit covering the petroglyph (which in fact means that the method can only be used where the techniques utilizing accretionary deposits are entirely ineffective), and that the petroglyph has not been emphasized or filled in with paint or other material (a vandalistic practice that remains in use in Scandinavia). It may also be prejudiced by previous application of chemicals (Bednarik, 1990a, 1990b).

Černohouz and Solč (1966) have described a method for determining the ages of macro-wanes on sandstone by using two constants a and b, the angle of the edge (ϕ), and the distance of retreat at the edge (h), in cm:

$$h = \frac{at\sqrt{(2)}}{1 + b\sqrt{(t)}} \cot\frac{\phi}{2} \tag{1}$$

Time t in millennia can be obtained, reportedly with an accuracy of ±10–20%. However, dimension h is intended to measure the retreat since the sharp edge was originally formed (Figure 6), but the rock surface not only recedes at the edge, it does this also on the two surfaces forming the edge. The reason for the wane formation is that the retreat proceeds markedly faster from the edge than from the flat surfaces: An eroding mass aspires to a shape in which erosion coefficients would affect the surface uniformly, i.e., a spherical form (Bednarik, 1979). Therefore, the original position of the edge, and of the two surfaces at the time it was produced, are unknown, and the retreat cannot be measured. It should also be noted that the retreat at the edge "does not occur as the simple curvature shown by Ollier (1969: Figure 149), it consists of a hyperbola in section" (Bednarik, 1979:28).

The theoretical relationship of the various factors one must consider in

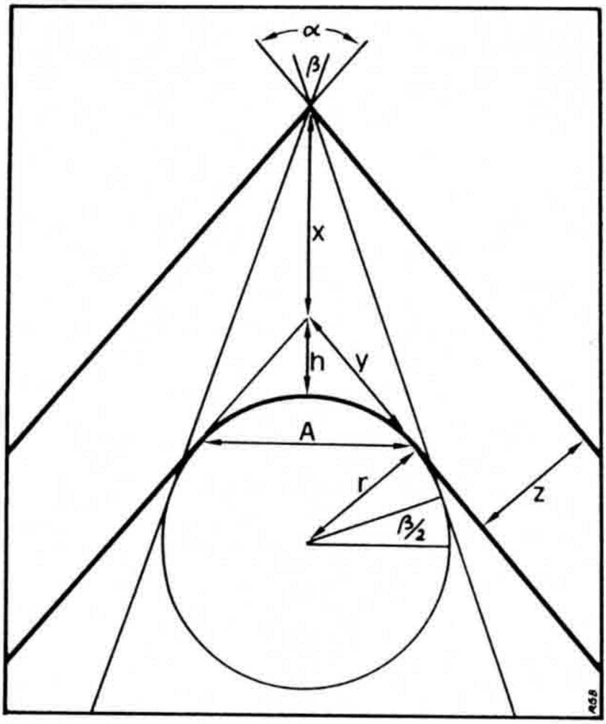

Figure 7. The laws of wane formation, depicted in a simplified diagrammatic fashion. The retreat from the original surface to the present surface is expressed by (z).

analyzing rock wanes are depicted in Figure 7, in which the wane is shown of circular section rather than hyperbolic, in order to simplify the principles of interdependence. It is clear that h, α, y, and A are measurable, and that "radius" r can be either determined physically, or thus:

$$r = y \tan \frac{\alpha}{2} \tag{2}$$

The ratio h : r is constant for any angle α, irrespective of distance of retreat. The ratio x : z is a function of α, and at $\alpha = 60°$, $x = 2z$; x itself is a function of β and r, and can be expressed in algebraic fashion:

$$x = \left[\left(\frac{z}{\tan 0.5\alpha} \right)^2 + z^2 \right]^{1/2} \tag{3}$$

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

$$\beta = 2\sin^{-1}\left(\frac{r}{x + h + r}\right) \quad (4)$$

The only realistic expression of the stage of wane development is therefore the wane width A; its relationship with age, irrespective of actual retreat, is ultimately determined by the ratio $\alpha:\beta$, which must be established empirically: A, r, z, α, and β are all related in a complex fashion which could be expressed in tabular form. For example, at an assumed $\beta = 0.66\alpha$, z will be about 0.79A at $\alpha = 60°$, and r will be 1.16A; for $\alpha = 160°$, z will be 1.9A, and r will be 5.6A. For our present purposes it suffices to know that the incremental increases in time of the variables A, r, x, z, and h are all proportionally equivalent.

DISCUSSION

These laws of wane formation are universal; they apply macroscopically as well as microscopically, and probably also in areas other than those discussed here. For instance, it is to be expected that the fundamental laws that apply to the progressive rounding of dissolving or melting objects are the same as those just expounded. Similar rounding of edges occurs as a result of chemical erosion at the microscopic level. Such micro-wanes are particularly distinct where component minerals are exposed as formed crystals upon fracture of a rock, or provide numerous sharp angles and clear cleavage faces for examination. As such freshly formed surfaces are exposed to erosion processes, weathering attacks component minerals at different rates. For instance, in a porphyry, the orthoclase, plagioclase, and hornblende will all weather faster than the quartz. The rates of micro-wane development may vary somewhat through time; they are likely to be susceptible to environmental factors, but such fluctuations may cancel each other out over long timespans. Obviously there are also variations to be expected according to relative location of an edge (i.e., relative to prevailing climatic factors, exposure to anomalous influences such as abrasive wear, and other factors), but these have no bearing on the regularity of the underlying theoretical principles of the wane-forming processes as described. These factors are the method's only potential major error source, but while they can influence its accuracy they can certainly not affect its intrinsic validity.

In a practical application of dating a geomorphic or petroglyph surface through assessing microerosion phenomena, it is essential to determine the rate of micro-wane development, initially by establishing a calibration curve for adjacent surfaces of known, or approximately known, ages. These rates may vary in different climates, rock types, and even mineral compositions, and since the influence of all such variables is an unknown in the case of a new dating method, one must begin by establishing the necessary knowledge by determining known erosion rates.

To limit the possible effects of past climatic fluctuations on the results of microerosion analysis, it is useful to compare the microerosion coefficients of two or more component minerals of composite rocks. In the example from Lake Onega, those of quartz and feldspar were compared. It is reasoned that, whatever the past climatic fluctuations were, and however they affected the minerals, it is likely that two different minerals would have been differently affected, and this would be reflected in differences in the two calibration curves. If the related values on the two calibration curves correspond, it suggests that erosion rates have not been sufficiently affected to distort age estimates significantly, and the reliability of the result is considerably enhanced.

While this method was conceived initially for estimating the age of petroglyphs, it is of course valid for any geomorphic surface. It can be applied to any rock surface where edges of crystals were freshly exposed to weathering, provided that there are at least remnants of the crystals still present for examination. However, on present indications it would appear that the susceptibility of quartz to the method would be limited to a maximum of a few tens of thousands of years, because beyond that age microerosion intensity would not permit reliable measurement. However, it seems unlikely that rock types suitable for analysis would need to be dated to greater antiquities—at least not in archaeology.

CONCLUSIONS

The microerosion dating attempt at Besov Nos seems to confirm Savvateyev's dating of the petroglyphs to between 4800 and 4000 years B.P., or the Eneolithic period—at least broadly speaking. But the described first result of this new method should not be regarded as a valid confirmation of Savvateyev's dating attempt, even though the microerosion date of E4000 years B.P. (the E is to indicate that it is erosion-derived) does appear to confirm it. It is merely an encouraging result of a new, experimental method to date petroglyphs directly and reliably. It does demonstrate the viability of microerosion dating as a research tool in rock art studies. At the very least, the pre-Historic age of the Onega petroglyphs has been established beyond reasonable doubt. The notion that the art was submerged for any great length of time can be regarded as refuted, a finding which is confirmed by some of the archaeological data. Thus the possibility that a number of consecutive traditions were involved in creating this Karelian corpus of art is reinstated—a possibility not only supported by what have been perceived as Bronze Age motifs and by apparent stylistic diversity, but also by the often seen practice of depicting similar motifs by different graphic conventions. It is true that such variations could alternatively be attributed to idiosyncratic factors, but in the case of the Lake Onega petroglyphs the multitradition model of explanation is preferred. Certainly, the microerosion dating method would be capable of clarifying this matter, which is but one way in which it can revitalize regional research.

Equipment and methods used in this pilot project were comparatively crude, as the purpose of the work was not to produce actual results, but to test the viability of the method as such. Major improvements of the method are therefore easily possible. Several simple refinements will have significant effects. For instance, if—as seems to be the case—some of the sites were used during different periods, this should certainly be detectable by microerosion analysis. For such relative dating, it is only necessary to select a representative sample of the motifs in question and conduct comparative analyses at a single locality.

The disadvantages of microerosion dating will gradually disappear as an increasing number of sites are compared. Its initial dependence on calibration dates will obviously diminish with time, as microerosion rates in different climates and lithologies become better understood. One will need initially to focus on rock art regions where suitable rock types coincide with rich concentrations of historically datable rock surfaces (monuments, structures, quarries, lava flows, inscriptions, etc.), such as the granite zones of India and on the Nile. As reliable calibration becomes available for the three main variables (climate, rock type, and age), many regions throughout the world will become eligible for routine application of this method.

The immediate, tangible advantages of the microerosion dating method are its most impressive aspects: It is cheap and reliable, and requires little training; it offers very considerable scope for development; it is the only petroglyph dating method that seeks to date the event of petroglyph manufacture itself; it is the only viable rock art dating technique currently available that involves no sample removal; it involves no possibility of sample contamination and offers a mechanism of internal cross-checking when two or more component minerals are considered; it is the only currently available rock art dating method that has the capacity of satisfying statistical sampling requirements, because it can furnish vast numbers of age-related values from a single motif. Finally, and perhaps most importantly, microerosion dating will induce researchers to scan petroglyphs very carefully in the field, prompting the finding of much evidence concerning the history of the motif and its support surface that would otherwise be overlooked: later modifications to the motif, use traces, traces of aeolian wear, fire damage, glacial or sediment scouring, frost or regelation damage, precipitate deposits and their alterations through time, patination and weathering, effects of vandalistic recording practices. Indeed, where microerosion dating differs most from previous methods is that the latter are rather like hunting expeditions, from which researchers bring their samples to the safety of the laboratory. Microerosion analysis involves very lengthy field studies, and no laboratory work at all. Finally, it reverses the underlying strategy of previous attempts to date petroglyphs directly: instead of using nonarchaeological data to produce minimum dates of the art, it utilizes surfaces of known ages to calibrate a nonarchaeological process (erosion), which is then used to provide a time frame in which to place a petroglyph.

I express my gratitude to Dr. Yuri Savvateyev, who went to such extraordinary lengths to acquaint me with Karelian rock art, accompanying me to all sites of the region, and never tiring of explaining all aspects of the exploration and archaeological background of this magnificent corpus of rock art. I also thank Academician Valery P. Alexeev and the Academy of Sciences, under whose auspices this work was conducted, for making my study possible, for masterminding the logistics and for providing the expedition ship *Neptun*. Without this generous support and guidance, none of my work in Karelia, and elsewhere in the former U.S.S.R., would have been possible. Nor would it have been as successful without the dedication of Katja Devlet, who accompanied me throughout the country, from its border with Finland to that with Mongolia. I also thank all the researchers and the support team at the Besov Nos camp, particularly the team from Estonia, and the crew of the *Neptun*, for their friendship, concern, and support.

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Received January 5, 1993
Accepted for publication August 4, 1993