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RELEVANCE OF SITE LITHOLOGY AND TAPHONOMIC LOGIC TO CUPULES

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Abstract. Most reports of cupules, and for that matter other petroglyphs, fail to provide adequate information on the lithology on which the rock art occurs. The relevance of such data is explained in terms of the taphonomy and technology of the cupules, of their dating and, ultimately, their interpretation. Similarly, the principles of taphonomic logic and their application to cupule research are briefly explained. It is shown that the patterns of cupule occurrence, in any period, environment or lithology, are largely determined by their taphonomy. This renders it impossible to determine the significance of variables relating to cupules, e.g. their apparent distribution or statistics, without first consulting their taphonomy. The principles of applying taphonomic logic to cupules are briefly presented.

Keywords: Lithosphere, Rock hardness, Cupule, Taphonomy, Taphonomic logic

Hardness of the rock

Here we will review the considerations concerning the influence the lithology has on cupules, on their dimensions, their morphology, on distribution and taphonomy. To create a scientific base from which to validly speculate about the cultural roles of cupules, it is essential that these topics be explored first and the relevant variables are understood. Moreover, the lithology of cupules is certainly crucial to such subjects as their scientific dating, or age estimation, also to issues concerning their preservation and site management, as well as a host of other issues. It needs to be remembered that the perspective of, for instance, the archaeologist of cupules is only one of many. It differs significantly from that of the rock art scientist, which is perhaps midway between that of the geomorphologist and the archaeologist. Geologically, cupules and other petroglyphs are a form of biological weathering: anthropically induced weathering. And then, of course, there are the perspectives of the traditional owner or custodian of rock art, the anthropologist, the ethnographer, the semiotician, the art historian and many others who claim a stake in rock art. Thus the scientific study of rock art is a multidisciplinary task, and has relatively weak links with archaeology, a non-scientific pursuit.

I begin the task of reviewing the roles of lithology and taphonomy by considering a cupule site I named after the late Howard McNickle, who drew my attention to it in the 1980s. McNickle's Shelter is located near Wittenoom, a 'ghost town' in the Pilbara of Western Australia. This very large shelter, formed along horizontally bedded rock strata of various types, contains one of the very few painting panels of the entire Pilbara, on the underside of one of the eroding laminae. Between 0.5 m and 1 m above the floor runs a layer of mudstone for the full 50 m length of the shelter's wall. It is significantly softer than the many facies above and below it, and it was apparently this quality that attracted the production of hundreds of pit-shaped markings (Figure 1). Many of these bear distinctive tool marks, which are perfectly preserved, suggesting that these cupules may be of relatively recent ages. The tool marks, both within the cupules and in their vicinity, are readily visible at the macroscopic level, but their microscopic study reveals even more detail about the production of these features. The site is superbly suited for forensic reconstruction of the gestures involved, and if there is a scientific way to

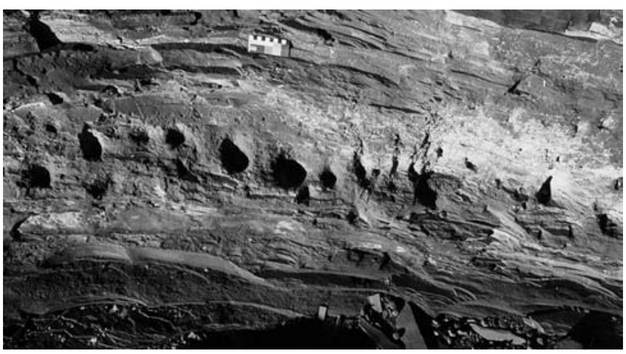

Figure 1. *Vertical cupules on mudstone seam in McNickle's Shelter, Pilbara, Western Australia.*

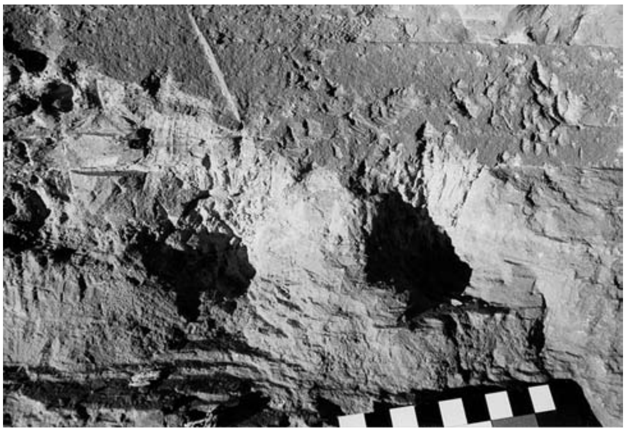

Figure 2. *Impact and scraping activity marks with cupules in McNickle's Shelter.*

Figure 3. *Deep and large cupules on exceedingly soft limestone wall of Ngrang Cave, South Australia.*

determine the physical circumstances of cupule creation, such work has to be at its core.

The most obvious characteristics are the following two. In addition to the randomly arranged cupules along the narrow horizontal band of soft rock, there are also thousands of impact marks, scrape marks, incisions, and some broad abrasion marks, apparently of ages similar to those of the cupules (Figure 2). This suggests that the making of the cupules was perhaps only one aspect of behaviour manifested at the site, and that those traces would not have survived on much harder rock, or at sites that suffered extensive subsequent weathering. Secondly, the cupules are on average deeper relative to their rim diameter than they are on harder rock. There is a distinctive endeavour evident of keeping the diameter small, because on such a relatively soft medium, it would be easy to gouge deeper by allowing the hole to be larger. Therefore one of the most distinctive characteristics of these cupules is that the makers deliberately kept the diameters small, but tried to dig as deeply as possible into the rock.

Much the same has been observed also on very hard rock types, and when we test the underlying proposition by turning to examples on even softer rock, we find the same principle manifested. In the entrance part of Ngrang Cave, a limestone site in Victoria (Bednarik 1990), there are forty-five 'extraction pits' on a single wall, many of them bearing corroded but still recognisable tool marks. This rock is so workable that the holes have been gouged up to 17.5 cm deep, and they are mostly deeper than wide (Figure 3). Naturally this was not possible to achieve by direct percussion, but Yann-Pierre Montelle and I have by replication established the types of tools most likely used. What I wish to emphasise here is that these pits certainly do not look like typical sandstone or granite cupules, and some observers would probably reject their inclusion under the rubric of cupules. In my view, they were created by the very same behaviour patterns as the more 'conventional' cupules, and our definition merely refers to *our convention* of taxonomy, and not necessarily to objective classes. It is easy to become trapped in our own nomenclatures, and in this case, the CCD (crucial common denominator) of the phenomenon category (Bednarik 1994a) may well not be apparent from our preconceived idea of the concept 'cupule' (e.g. a specific diameter/depth ratio or shape or size). Instead of focusing on what we are inclined to formulate as 'the type' — which we can only base on a taphonomically distorted sample under the best possible circumstances — we need to ask: which forms of the phenomenon would be expected to be under-represented in the total available sample? We also need to ask: if we had the 'total living sample' (i.e. all cupules ever made), how would it affect our conjectures about the CCD?

Since it had become apparent to me that there might be a causal relationship between cupule depth and lithology, and since the ratio of cupule depth to rim diameter seemed to matter greatly to most cupule makers, I decided to test that relationship. Cupules are found on rocks of up to hardness 7, so I secured random samples of cupule depths from rocks ranging in hardness from very soft limestone through to massive crystalline quartz and fully metamorphosed quartzite. The result (Figure 4) seems to indicate a strong correlation: the softer the rock, the deeper the cupule, on average. While my samples may be judged too small to offer conclusiveness, and greater refinement of the method is certainly desirable, the trend is far too distinctive to ignore. Nevertheless, I believe that future work of this type should employ different criteria. In particular, we might use the ratio of diameter to depth against hardness of rock, instead of simply plotting cupule depth against hardness. With that method, we are likely to find the trend even more pronounced.

The implications of these observations are of considerable consequences to the interpretation of cupules, even to their identification. If I had had no data on cupules of the softest rock type, of hardness 1, I could have predicted their mean dimensions and ratio on the basis of the quantified trend. As the sample from Ngrang and other caves in the

Mt Gambier region shows, I would have been correct had I extrapolated the curve in Figure 4. Therefore the inclusion of these particularly large pits in the category 'cupules' is fully justified, and one can begin to formulate what appears to be a more 'objective' definition of 'cupule'. We are also beginning to realise that what we describe as cupules is essentially the result of specific behaviour patterns, and that these can, in fact, be examined scientifically. That does not mean that all things we currently call cupules were made for the same reasons, or by the same cultural behaviour or motivation, but when it comes to biokinetic behaviour, the empirical evidence narrows the possible range down quite considerably.

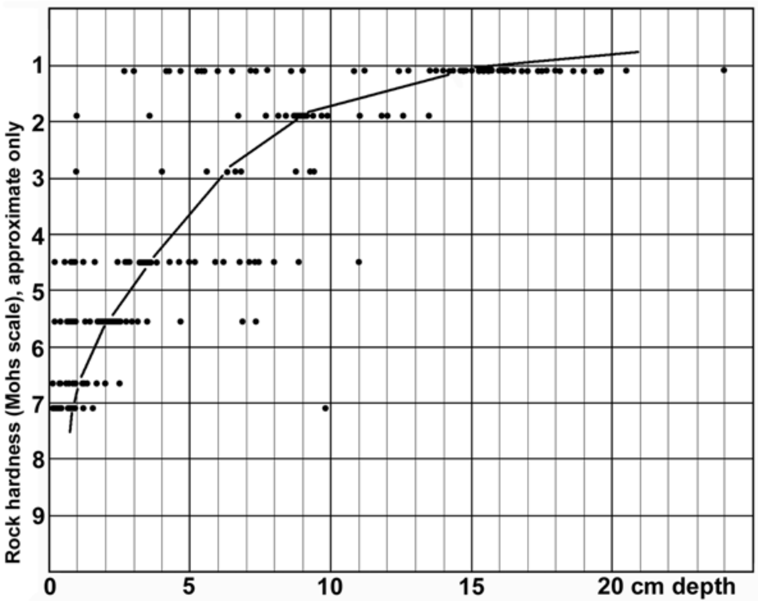

Figure 4. *The depths of 221 cupules on rocks ranging in hardness from 1 to 7. The graph illustrates a distinctive trend.*

Specific issues of cupule lithology

A phenomenon sometimes observed in cupules requires special attention under the heading of 'lithology'. It was first commented upon in relation to a small cupule site located on the plateau above Daraki-Chattan Cave in central India, a few hundred metres north of the cave (Bednarik et al. 2005: 186). A geometric arrangement of cupules, thought to be of the Holocene, bears a remarkable laminar surface feature within each cupule. This resembles an accretionary deposit of some kind (Figure 5), yet microscopic examination excludes that possibility. The cutaneous lamina consists of the original floor of the cupule, rather than a deposited mineral crust, and is exfoliating. The rock surface surrounding the cupules has been subjected to granular exfoliation, whereas in the cupules much of the original surface at the time of their execution has been preserved through this feature. It appears as if the sustained application of kinetic energy during cupule production has somehow created a cutaneous zone that was more resistant to weathering than the unmodified surface. In a nearby palaeo-riverbed, boulders that were heavily polished by fluvial action show precisely the same phenomenon: a surface lamina that is slightly more resistant to erosion than the very dense quartzite.

Moreover, Francaviglia's (2005) photographs of cupules from Umm Singid and particularly from Jebel as-Suqur (Sudan) seem to illustrate the very same phenomenon (Francaviglia 2005: Figs 2, 7, and especially the close-up in Figure 5). I have observed a similar instance of cutaneous consolidation in cupules in northern Saudi Arabia, at Shuwaymas 1 (Bednarik and Khan 2005), on much less metamorphosed sandstone (Figure 6). Closer examination of these features is warranted and their origins need to be established. They seem to differ from case hardening in that the resistant skin is very thin, and the phenomenon may be relevant to issues of dating. One possible explanation would be that the great kinetic energy brought to bear on a cupule has somehow converted (slightly metamorphosed?) the colloid silica cement. I cannot cite a process by which this could have occurred, but as it seems the most reasonable explanation, I place the possibility before the reader and perhaps someone may care to comment.

Walsh (1994: 35) contends that some Kimberley cupules

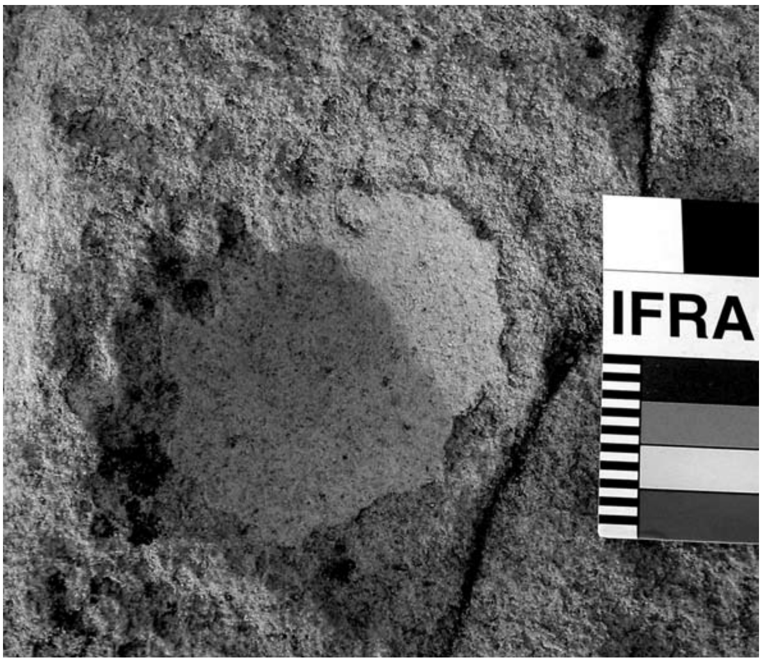

Figure 5. *Cutaneous surface feature in a cupule on eroding quartzite, Indragarh Hill, near Daraki-Chattan, central India.*

are what he terms 'pebraded', i.e. first pecked and then abraded, 'to create a very smooth recess and perimeter'. Although he acknowledges the very great investment of time and energy in making cupules, he goes on to suggest that they were made before the sandstone had fully metamorphosed. This implies that he misunderstood both the technology and the relevant petrography. Taphonomy (see below) ensures the preferential survival of cupules on the hardest rocks, which it would be impossible to abrade in the fashion Walsh imagines. The 'abraded' appearance he observed is the result of the pounding action: as the crystals or grains are literally crushed into fine dust particles, the cupule surface and its rim take on a macroscopically polished appearance. But under the binocular microscope, no evidence of abrasion has so far been observed in any genuine cupule anywhere in the world. Not only is the term 'abraded' clearly inappropriate here, the term 'pecked' (Maynard 1977) in Walsh's portmanteau word is so also. There is no evidence whatsoever that cupules were made by pecking (indirect percussion), except on soft rock types. Moreover, Walsh's assumption that the rock had not been fully metamorphosed at the time of cupule production is geologically naive. The metamorphosis of these rocks to quartzite takes many millions of years, indeed hundreds of millions of years. The earliest cupules of Australia can, according to present knowledge, be no more than a few tens of thousands of years old. In fact Walsh's pronouncement comes close to the view of Aborigines that petroglyphs were made 'when the rocks were soft' (Flood 2006). It is far more likely that his 'pebraded cupules' are relatively unweathered specimens still showing the sheen of the crushing, whereas his 'pecked cupules' are weathered examples that experienced some degree of granular exfoliation.

All cupules on hard rock (hardness 4 to 7 on Mohs scale) can safely be assumed to have been created by direct percussion, i.e. pounding with a hand-held hammerstone. We may reasonably assume that the type of tools used in their production were similar to those observed not only ethnographically, but were also used in all recorded replication work (see article by G. Kumar, in this volume). Moreover, they are identical to the tools recovered in excavations at petroglyph sites, as well as from the surface at or near major concentrations of petroglyphs. Of greater technological interest are cupules on very soft rock, because in favourable circumstances, good traces of their production have remained intact. The chance of detecting such traces is best on softest rock types, offering the potential of securing valuable technological data. The softest rock on which I have recorded cupules is moisture-containing Miocene limestone in caves, which is soft enough to be easily marked by a fingernail (hardness 1 or 1½). Such instances show that indirect percussion has often been used on soft types of rock, but with non-lithic tools. Cupule-like pits in cave walls in the Mt Gambier region of southern Australia are the subject of detailed forensic studies, examining not only tool traces on limestone, but also the gestures involved in the making of these features.

Figure 6. *Eroding cutaneous feature in a cupule on sandstone, Shuwaymas Site 1, Near Ha'il, northern Saudi Arabia.*

The taphonomy of cupules

Reference has already been made to the importance of taphonomic considerations. The first demand in any pursuit that professes to be a scientific study of palaeoart is always the *coherent identification of that part of the extant characteristics of the evidence that is not the result of taphonomic processes* (Bednarik 1993). Taphonomic logic (Bednarik 1994b) requires that we expect a significant part of the empirical evidence about cupules to be greatly distorted, most especially variables related to degradation. In much the same way that it takes perhaps a thousand times longer to create a cupule on quartzite than to make an identical one on chemically very similar siliceous sandstone (several days vs two minutes, in fact; see my chapter on technology, this volume), it may take a thousand times longer to wear away the quartzite cupule by natural processes of erosion. To understand the scale of the effects of taphonomy, the great magnitude of these ratios must be fully appreciated. The probability that a cupule of a specific depth would survive for a given period of time might be a thousand times greater if it occurred on a very hard rock rather than a much softer rock. But rock hardness is certainly not the only variable determining longevity;

others are location, climate (e.g. precipitation pH, which is variable through time), rock chemistry, site morphology or hydrology, biological factors and so forth.

It is certainly no coincidence that the oldest cupules so far discovered occur on extremely weathering-resistant rock and are located in caves, safe from atmospheric water. At Daraki-Chattan (Bednarik et al. 2005), very faint traces of probable cupules occur on one boulder outside the cave, but they were only found in the course of careful examination of the site and would not be noticed *or* accepted elsewhere. They suggest that the site's cupules only survived in good condition because they were not exposed to rain. Similarly, cupules in a sandstone shelter should not be expected to have survived for such a great time span (i.e. since the Lower Palaeolithic), even though they were not exposed to rain. At the other end of the scale it would be absurd to expect cupules on, say, schist exposed to rainfall to survive for more than a few millennia — notwithstanding the belief of many European archaeologists that even very shallow, perfectly preserved rock engravings in the Côa valley of Portugal survived practically unweathered on schist for more than twenty millennia. And it would probably be futile to expect finding cupules of much more than 2000 years age on exposed limestone (Mandl 1995; Bednarik 2007: 164), unless it was metamorphosed (to marble). It is thus very apparent that the interdependence of lithology and taphonomy is a great deal more important to the scientific study of cupules than anything archaeology can provide, and that the potential effects of these variables tend to be significantly greater than their cursory consideration might imply. Another important taphonomic conclusion is that cupules, despite being the oldest rock art found, cannot be the earliest rock art made (Bednarik 1997). If the earliest examples of a phenomenon category in archaeology are the most deterioration resistant possible, it is illogical to assume that they are the earliest produced.

It follows also that cupules on soft rock are greatly under-represented on the surviving record, and that their frequent occurrence on basaltic, granitic or harder rocks is a taphonomic phenomenon. The more typical cupules should be those found on, say, limestone or mudstone, and as expected, these tend to be relatively recent, unless occurring in well-sheltered locations. Clearly, then, we need to apply taphonomic logic to the surviving corpus of cupules.

The term *taphonomy* (Efremov 1940; Solomon 1994) is only a recent introduction in archaeology. It cannot even be found in an archaeological dictionary that is more than a few decades old, and yet it is of crucial importance to understanding how the archaeological record relates to what happened in pre-History. In archaeology, taphonomy refers to the study of the processes that have transformed those materials, which archaeologists consider to constitute the archaeological record. Initially, taphonomy defined merely some of these many processes, particularly those affecting skeletal remains: animal scavenging, chemical decay, trampling and other mechanical processes. Today we mean by taphonomy any process that affects any characteristics of those remains deposited in the past that now form what we regard as the surviving record. If a multitude of processes combine to distort the record, one would not initially be capable of isolating the effects of any one of these many processes. Some taphonomic processes are related to preservation, other forms concern selective deposition; others again are attributable to selective recovery, and by extension, some even to selective reporting (cf. metamorphology; Bednarik 1995). It is therefore clearly impossible to separately address the effects of any one of these factors a priori, i.e. before we understand their interplay with all of the others. In short, it would be advisable to address the entire range of taphonomic processes together, at least initially.

It is fairly self-evident that most rock art ever produced has not survived to the present time. What is now found on the rocks is but a minute fraction of what was once produced. The extant record is the result of a highly complex interplay of natural deterioration, cultural factors such as art techniques and site selection, which affect survival chances, and even predispositions of researchers. The extant record must be massively distorted in favour of rock arts of better survival properties and of more advantageous locations, such as deep caves, especially the older an art is. Consequently any statistical characteristics of a corpus of rock art or a rock art tradition are so heavily distorted that they are of no value to interpretation. Such statistical data are purely descriptive of a current state. They must not be used in any form of interpretation without being taken through a 'taphonomic filter' first.

Most interpretative studies of palaeoart have been conducted with an implicit assumption that the surviving remnants are an accurate reflection and a representative sample of the symbolic production of a given culture, tradition or period. In reality, nearly 100% of the symbolic production of all past societies does not survive, and the characteristics of the tiny fraction of a per cent that does survive are almost entirely the result of taphonomic processes. The geographical distribution, the colour, groove depth, motif type, rock type, site type profile — in short, all quantifiable variables of the surviving remnant of rock art — may be and often are the result of selective processes. Ignoring these will almost certainly lead to the invention of non-existent traditions, or whole sequences of traditions. The normative laws determining the effects of taphonomy have been explained and quantified, at least as integral functions (Bednarik 1994b). *Taphonomic logic* thus deals with quantifying the idea that the characteristics of a record of past events or systems are not an accurate reflection of what would have been a record of the live system or observed event.

In rock art science, taphonomy is the study of the processes affecting rock art after it has been executed, determining its present appearance and statistical properties. Taphonomic logic is a form of logic viewing rock art as the surviving remnant of a cumulative population that has been subjected

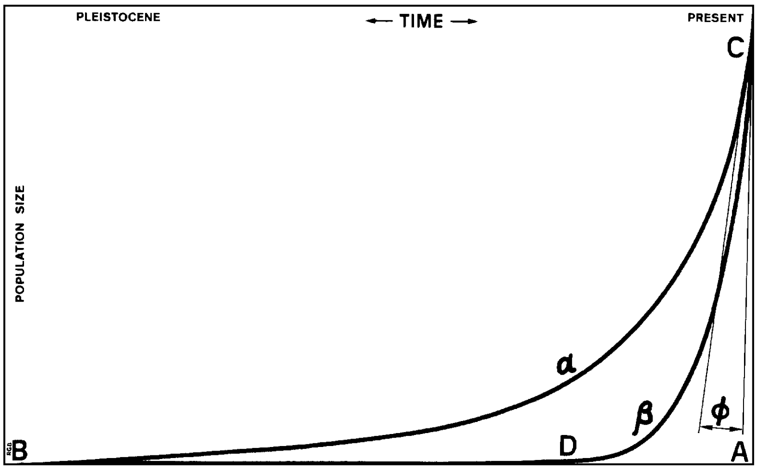

Figure 7. *Principles of the relationship of total cumulative production of phenomenon category s_α to its surviving instances s_β as a function of angle φ, depicting the basis of taphonomic logic.*

to continuous degradation that selects in favour of specific properties facilitating longevity (Figure 7). It inevitably leads to the concept of the *taphonomic threshold*, which is the point in time at which instances of a specific class of material remains ('phenomenon category') either begin to appear, or begin to appear in significant numbers. Before their respective taphonomic thresholds, all classes of material remains experienced a *taphonomic lag time*. This is the period during which the phenomena resulting in the material remains in question did exist, but from which we have found no such evidence — or so little that it is usually explained away as a 'running ahead of time' (Vishnyatsky 1994), or as incorrectly dated or identified. Until examined closely this may seem a minor issue, but for most classes of material remains, the taphonomic lag times are well in excess of 90% of the phenomenon's historical duration. Indeed, taphonomic lags in excess of 98% and 99% are quite common in archaeology.

In rock art, taphonomic lag times remain largely undetermined, but they would certainly differ greatly according to the climate, type of rock art and type of support rock. The taphonomic threshold of beeswax rock art in the Northern Territory of Australia (Nelson et al. 2000) has been estimated to be about 800 years BP (Bednarik 2001). One of the most common forms of surviving rock art consists of red paintings in sandstone shelters, and their threshold is believed to be in the order of 8000 years. For most other rock paintings the taphonomic threshold is lower. However, there are notable exceptions, especially rock art sites located in deep limestone caves offering extraordinary preservation conditions. In other words, the Palaeolithic 'cave art' traditions of Europe are known to us *only* because some of the art of the societies concerned was placed in 'fluke preservation conditions'. That evidence would probably not have survived elsewhere.

The ability of petroglyphs to survive in the open, i.e. exposed to precipitation, is governed largely by the rock they were made on, besides the ambient environment. Those on limestone have a taphonomic threshold of well under 2000 years (Mandl 1995), while those on granite can easily survive from the Pleistocene, and recent dating evidence suggests that their threshold might be in the order of 30,000 or 50,000 years under arid conditions (Bednarik 2002). Other relevant variables are climate and geochemistry. Taphonomic logic demands that rock art of the respective types was produced before all of these thresholds, but evidence of it should be either unavailable or extremely rare. Since occurrence, distribution and other characteristics of surviving corpora are all determined by taphonomic factors, it would be meaningless to state that a particular tradition produced only deep line petroglyphs, or painted only in caves, or left no open-air engravings. All characteristics of rock art that might contribute to their longevity (e.g. groove depth, location, type of rock support, morphology of site, composition of paint) are of no relevance to defining a tradition, because taphonomy skews their statistics systematically. For instance, the probably most common technological form of petroglyph is the sgraffito, made by the removal of a patina or weathering zone to reveal a differently coloured surface beneath. Sgraffiti tend to be obliterated by repatination processes within three or four millennia; therefore it is pointless to observe that the earliest petroglyphs of a region are consistently those that are deeply engraved. This observation, while valid, leads to misinterpretation of the sequence, unless moderated by taphonomic logic.

The mechanics of taphonomic logic are rather more complex than indicated in the present brief comments, but it must be emphasised that they are of crucial importance to the interpretation of primary data about rock art. This is the most important methodological tool so far developed in the interpretation of rock art data, and indeed, in archaeological interpretation of data and in hypothesis building. Its importance to the study of cupules cannot be overstated, as the following example illustrates.

If we compare my experimental shape predictions of the β-curve (surviving component of the phenomenon category) for quartzite, basalt and limestone cupules (Figure 8), ignoring here other taphonomic variables, we see that it is difficult to avoid the conclusions that increasing over-representation is a function of (a) the rock's resistance to erosion and (b) antiquity. For the sake of simplicity I assume here that the cumulative population (α-curve) of each of the three groups is identical. That taphonomy selects in favour of any properties facilitating longevity is obvious, but how effective is this selection quantitatively? If we focus mainly on the right part of the graph we see that the logic clearly demands that, for the duration of the time with appreciable numbers of surviving limestone specimens, nearly all quartzite ones and most of the basalt ones would have survived. Naturally we do not know the total population numbers, or how production varied through time, but even this preliminary model implies that we must expect the over-representation factor to be far more effective than a common sense prediction might suggest. Taphonomy eliminates nearly all populations on some rock types during a time period that registers very little impact on certain other types. In fact the difference may be a thousandfold, as we noted above.

This may sound over-theoretical, but it provides a timely warning that, when we consider the world's surviving cupule repertoire, we see a sample that must be assumed to be greatly distorted, and the phenomenon it is intended to represent would need to have appeared very differently if we only had access to the entire population. Therefore, our construct of 'cupule' is not set in stone; it is a tentative working hypothesis that remains very much in need of testing of the type I have implied here. I have teased out a whole list of reasons for this scepticism, which stands in stark contrast to the brash but unfounded interpretation attempts we have seen for much more than a century (addressed in my chapter on interpretation, this volume).

The perhaps most obvious factor preventing a development of such a scientific approach to cupules is the distinctive lack of systematic empirical information about the subject. No standardised forms of comprehensive data are available, which means that we even lack proper description of what has presently survived. In surprisingly many cases, we lack the most basic descriptions of petrography, metrics and statistics, therefore no attempt has been made to even rudimentarily describe the sites, apart from their locations and some possibly inconsequential archaeological pronouncements about them (e.g. presence of other signs of human activity, which may date from a different period). This is not a criticism of those who have collected field data, but of those who created the conditions that determined what data ought to be collected. While the field researcher needs to know what types of data are required, a rudderless discipline, relying on archaeology's bootstrapping epistemology, has not determined this and left the site surveyor to his or her own devices. This has been a monumentally wasteful exercise, in the sense that enormous efforts have been invested in securing data that are not adequate for scientific purposes.

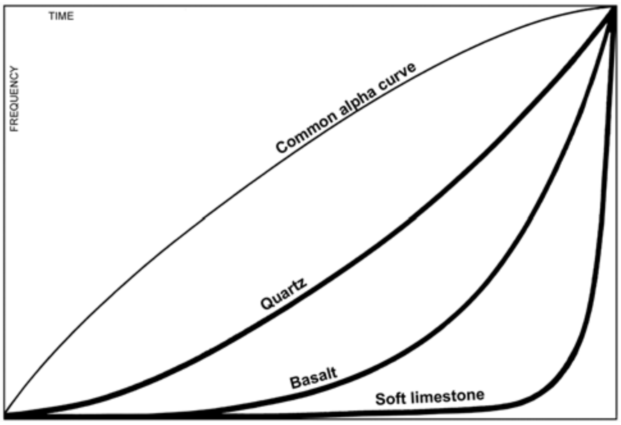

***Figure 8**. Prediction of β-curves for cupules on hard (quartz), intermediate (basalt) and soft rock (limestone) according to taphonomic logic (Bednarik 1994b).*

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