

DISCRIMINATING BETWEEN CUPULES AND OTHER ROCK MARKINGS

Robert G. Bednarik

Abstract. A number of natural processes are discussed that may result in phenomena archaeologists have found difficult to distinguish from cupules. In particular, erosion phenomena of several types are presented and their distinguishing characteristics are discussed in adequate detail to facilitate their identification in the field. Similarly, cupules on horizontal surfaces may resemble grinding hollows (mortars, querns, metates) and their discrimination is also discussed. The use of field microscopy is emphasised in discriminating cupules from natural or other artificial rock markings.

Keywords: Cupule, Pothole, Solution pan, Tafone, Solution scallop, Mortar, Metate

Numerous commentators have found it difficult to discriminate between natural rock markings resembling cupules, humanly created features that look somewhat like cupules (or large versions of them), and those features the word 'cupule' is intended to describe. Unless we can be certain that we include in our studies of cupules only those instances or phenomenon populations that we intend to deal with, any further elaboration, interpretation or discussion seems pointless. For instance, there would seem to be no value in considering the orientation of natural rock hollows to determine their astronomical function. Before we can hope to explore our subject productively we will have to master the distinction between natural and 'cultural' rock markings, and determine that what we are considering are indeed non-utilitarian features of quite specific and distinctive morphological characteristics.

Natural rock markings resembling cupules

Potholes

These are fluvial abrasion hollows caused by the grinding action of clasts caught in rock depressions, scouring the bedrock in eddying or swirling water (Figure 1). They range in shape from cylindrical to hemispherical and sub-conical or test-tube shaped, and they can vary considerably in size (Gilbert

2000), but are most commonly in the order of 5 cm to 20 cm in diameter. Except for the smallest specimens, their depth usually exceeds their diameter. The largest reported pothole in the world, Archbald Pothole in Pennsylvania, is 18 m deep, larger examples reported are the result of other processes. These phenomena occur especially along turbulent rivers of high kinetic energy, but they can also be found along marine and lacustrine shorelines. Kayser (1912) distinguishes between *Flusstöpfen* (fluvial potholes), *Gletschertöpfen* (glacial potholes)



Figure 1. Potholes



Figure 2. Convex-floor pothole at Rocas Rio Milloma, near Tarata, central Bolivia.



Figure 3. Small initial potholes in river bed, Punku Cocha, near Tarata, Bolivia.

and *Meermühlen* (marine potholes). Morphologically, he divided these phenomena into three types: shallow with a *Weinflaschenboden* (convex floor), deeper with a flat floor, and very deep with a bowl-shaped floor and spiral-shaped furrows in the wall. Fluvial potholes develop preferentially in rock channels, at waterfalls and at rapids, and they can only begin to form where an initial hollow exists that retains swirling sand or clasts (Elston 1917–1918). Rehbock (1917, 1925) initiated the complex study of hydraulic energy in potholes. Richardson and Carling (2005) limit the term explicitly to round depressions eroded by approximately vertical vortices and through mechanisms other than plucking, thereby excluding one of the two types Rehbock had established experimentally. The convex floor pothole (Figure 2) is thought to result from the centrifugal force of the abrasive material (*Schleifmaterial*) (Ljungner 1927–1930).

Springer et al. (2005, 2006) have examined the potholes on streambeds using empirical analyses of field data and geometric constraints. They report that radius and depth of such features are strongly correlated, using a simple



Figure 4. Cylindrical pothole, Rocas Rio Milloma, Bolivia.

power law, which they explain. Erosion efficiencies within small, hemispherical potholes (Figure 3) must be high if the potholes are to survive in the face of streambed fluvial incision. As potholes deepen, the necessary efficiencies decline and increasing concavity through growth imposes stricter constraints. Thus hemispherical potholes are gradually converted to cylindrical potholes, the geometries of which favour enlargement while they are small. More substrate is eroded by volume from cylindrical pothole walls during growth than from cylindrical pothole floors (Figure 4). Clasts acting as grinders (called ‘tools’ by pothole researchers) play a secondary role to suspended sediment entrained within the vortices that occur in potholes.

Marine potholes (Swinerton 1927: Note 5) are found in places where the bedrock is exposed in the zone of wave action, chiefly due to the breakers’ action. The favoured locations in the formation of fluvial potholes are the upper levels of waterfalls, but the perhaps most important prerequisite is the presence of relatively soft bedrock (particularly sedimentary rocks, even those lightly metamorphosed) and the involvement of very hard abrasive clasts, sand and silt (e.g. quartz). The identification of these rock markings is particularly difficult when they are found high above a present river course, and heavily weathered corresponding to their great antiquity. For instance at Hoover Dam in the United States, ‘fossil’ potholes occur in a palaeochannel 275 m above the present Colorado River bed (Howard 2004). However, even relatively recent and unweathered examples have been misidentified as anthropic markings by archaeologists on many occasions.

Of particular relevance is that potholes sometimes co-occur with cupules, and in such cases it is reasonably assumed that it was the very presence of the potholes that prompted the production of the more recent anthropic markings (Figure 5). This raises interesting issues concerning the functional context of the latter, but it also demonstrates that the discrimination between the two forms of rock markings is well outside the domain of archaeologists who have

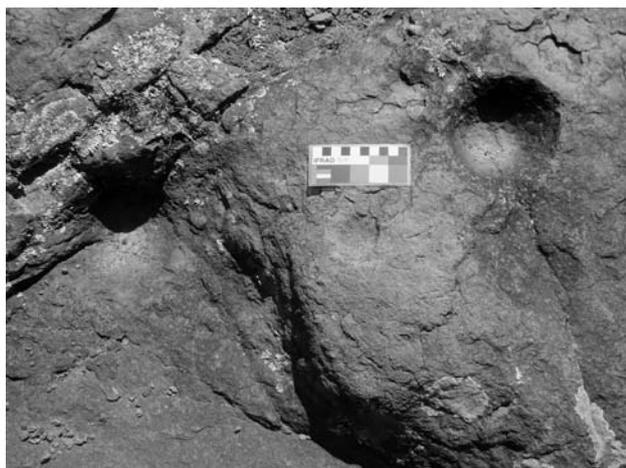


Figure 5. Potholes co-occurring with cupules, near Karakara, Bolivia.



Figure 6. Tessellation on sandstone pavement at Elvina Track site, Ku-ring-gai Chase National Park, near Sydney, Australia.

misidentified the potholes as mortars, *tacitas* or cupules in many cases. Examples are the extensive concentrations featuring cupules, other petroglyphs and potholes at El Valle de El Encanto and El Valle del Sol (Iribarren 1949, 1954; Klein 1972; Ampuero and Rivera 1964, 1971; Ampuero 1993; Van Hoek 2003), or the potholes in the Coquimbo Region (Gallardo Ibáñez 1999), all in Chile (see also Gajardo-Tovar 1958–59). The issue, as far as I have been able to ascertain, seems to have its origins in Menghin's (1957) pronouncements. Similar cases of misidentification can be cited, however, from many other countries, e.g. Azerbaijan (Anati 2001: Fig. 10) or Greece (Papanikolaou 2005).

On the other hand, an illiterate Quechua man of Karakara, Bolivia, has insisted that these phenomena were not created by human hand. He has explained that they are perhaps the result of lightning strikes, presumably because the specific examples he referred to were located on exposed rock outcrops so high above the current riverbed that he could not conceptually relate them to the river. While his explanation is not correct, it does demonstrate, as I have observed on numerous occasions, that the explanations of 'ethnoscience' (sensu Mark P. Leone) are sometimes closer to those of science itself than to those of archaeologists. Non-archaeologists frequently outperform archaeologists in the identification of supposedly archaeological phenomena (Bednarik 1994), and this also applies to potholes.

Lithological cupmarks

Only two types are briefly mentioned here. In the first, thousands of pit markings on tessellated sandstone pavements in the Sydney region, Australia, are the subject of an ongoing controversy (Cairns and Branagan 1992; Branagan and Cairns 1993a). Extensive lattices of deeply eroded natural grooves divide some twenty-five known pavements into mosaics of geometric shapes, most often hexagons.

The tessellation has not been explained satisfactorily by geologists (Branagan and Cairns 1993b), but it is evident that the vertical disconformities causing it extend well into the substrate (at least 20 cm, but probably much deeper). In my view, the tessellation (Figure 6) has been caused by cumulative stresses of a susceptible facies, and the reason for the geometric shapes is much the same as the laws causing the way a drying mud cover in a floodplain breaks up into hexagonal or other geometric features: in both cases the layer consists of a sediment of randomly oriented grains. In both cases the shapes of the tessellation polygons represent Voronoi cells, and their sizes are determined by the spacing of Voronoi sites (Voronoi 1907). These inherent tessellation characteristics of Sydney sandstones have given rise to selective weathering which formed the grooves separating the polygons, whose natural character is generally accepted. The largest of these pavements, the Elvina Track site, measures about 6500 square metres. Many of its thousands of polygonal panels bear a number of pits of 20–50 mm diameter. These pits closely resemble

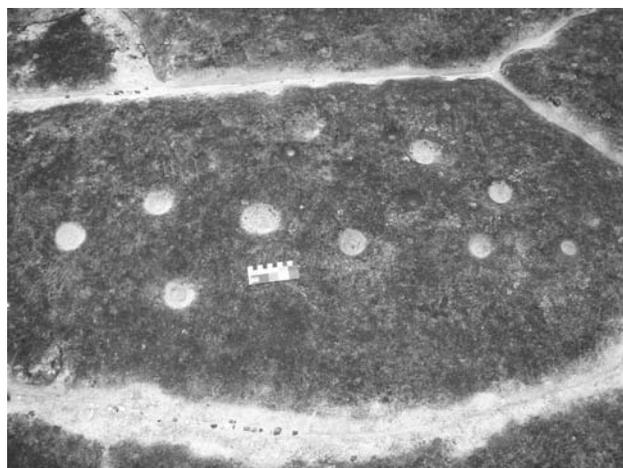


Figure 7. Cup-marks that have formed naturally on a tessellation polygon at Elvina Track site.

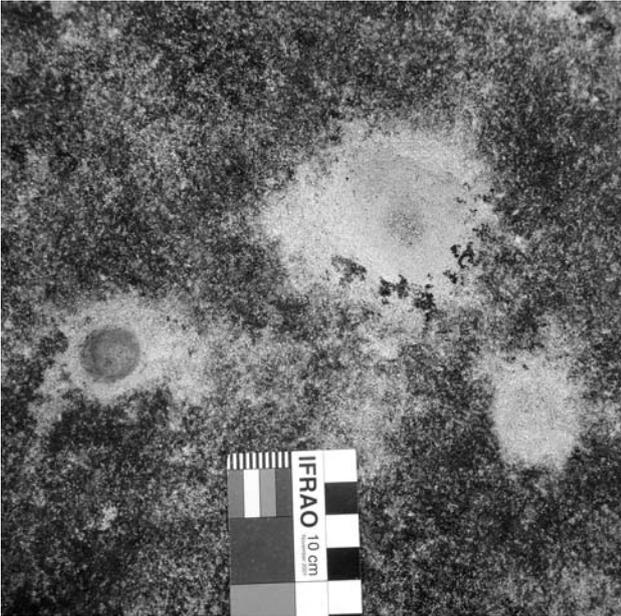


Figure 8. Natural cup-shaped pits, close to 20 mm deep. Elvina Track site, near Sydney, Australia.

small cupules, and it is possible that humans have modified some, because a number of genuine petroglyphs occur also at the site, located in a region rich in rock art. However, the pits are essentially natural phenomena (Bednarik 1990). Each polygon has similar run-off characteristics: near the borders, the profile curves gently towards the surrounding groove, into which rainwater drains readily (Figure 7). Drainage is slower in the more central parts of the polygon, and water will remain in even the slightest depressions there. Differential granular exfoliation is the result, leading to drainage towards the gradually deepening depression. This process favours regular spacings as watersheds are established in the micro-topography of each polygon. Once under way, it leads inevitably to foci of erosional activity, and ever-accelerating rates of erosion in just one



Figure 10. Remains of ferruginous conglomerate in some of the natural pits near Horsham, indicating their geological antiquity.



Figure 9. Natural erosion pits south of Horsham, Victoria, Australia.

location — the pit forming in the middle of each ‘local drainage zone’ (Figure 8). The result is a natural pattern of regularity, which the uncritical observer is likely to interpret as intentional.

While the process responsible for this example can be observed frequently in nature, my second example, also from Australia, refers to circumstances that are more unusual. Several vertical panels of hard but very weathered siliceous sandstone south of Horsham, Victoria, are densely covered by cup-shaped marks of typical cupule appearance. There are several hundred such marks at the site, all measuring between 5 and 10 cm in diameter, and a few centimetres deep (Figure 9). Superficially the exposures seem indistinguishable from anthropic cupule panels, and yet they are entirely natural products of geological antiquity. I consider them to be the result of a complex lithological process at the time the rock formed, in which a layer of highly water-sorted, evenly sized, near-spherical cobbles was deposited on quartz sand. The sand bed was metamorphosed to a slightly quartzitic sandstone. Erosive processes then removed the pebble conglomerate completely, presumably because it was less weathering resistant than the silica cement of the sandstone. This facies was replaced by a highly ferruginous conglomerate of maximal very-coarse-sand/small-pebble-fraction fluvial detritus, filling in the hollows left by the cobbles. Most of this second conglomerate eroded subsequently, and the remaining negative impressions of the cobbles were exposed to weathering action. Once weathered, the dense groups of hemispherical depressions became almost indistinguishable from cupules. However, significant remains of the ferruginous facies still adhere to many areas of the panels (Figure 10).

Solution phenomena

A variety of rock types, most especially sedimentary facies, can be susceptible to pitting by localised granular or mass erosion. This can take many forms (Bednarik 2007: 20–3), but one distinctive example is found on carbonate rocks, especially limestone, the *Kamenitza*. Numerous examples, often occurring together with cupules, are illustrated by Papanikolaou from Greece (2005: 87, 91–94, 98, 105, 109, 110, 120–125, 134–46). Less pronounced forms of smaller sizes occur, and where such phenomena are well developed they can resemble cupules. A specific weathering phenomenon, the tafone, is defined as a ‘roughly hemispherical hollow weathered in rock at the surface’ (Jennings 1985). It has been documented in sandstone, dolerite, limestone, rhyolite tuff, metamorphosed conglomerate, and particularly in granitic rocks (Dragovich 1969; Martini 1978; Smith 1978). Tafoni can occur in many climates, from the Antarctic to hot arid regions, and are also found on Mars (Cooke et al. 1993). Their development tends to commence from zones of differential weathering on a rock surface, attributable to variations in lithology, structure, composition, texture or biota (Dragovich 1969). Once a tafone has begun to form, the interior of its concavity tends to erode faster than the visor. There are two schools of thought on the formation process: one holds that there are inherent differences in the rock hardness and moisture content between the interior and exterior parts (the ‘core softening’ theory, e.g. Conca and Rossman 1985; cf. Matsukura and Tanaka 2000), while the other attributes the process to microclimatic differences between the interior and the exterior, specifically of humidity and salinity (e.g. Dragovich 1969).

Both are perhaps partially right: the core softening (particularly pronounced on some sandstones) is probably the result of how rock surface geometry affects moisture retention, especially in arid regions (Bednarik 2001 [2007]: 22). More prominent rock aspects dry faster than those sheltered from wind and insolation, and they weather slower (through case hardening). The process leads logically to cavernous, deeply alveolar features that could not be mistaken for anthropic phenomena. However, in the early stages, small tafoni may well resemble eroded cupules or similar anthropic features. Although large specimens measure several metres, the smallest tafoni do fall within the size range of cupules.

Another solution phenomenon found particularly on granite is the gnamma, a rock-hole on a horizontal rock exposure that is of particular importance in Australia, where it commonly served as a water source (Bayly 1999: 18–20, Fig. 2). Forming from initially cup-sized depressions, gnammas can measure several metres across, after gradual enlargement by chemical weathering. Found especially on



Figure 11. *Solution scalloping on the walls and ceiling of Mawanga Cave, Kenya (photograph courtesy of Jean Clottes).*

the top of domed inselbergs (Twidale and Corbin 1963), the name of this geomorphological feature derives from Western Desert Aboriginal languages and means ‘rock-hole’ (Bayly 1999: 20). Gnammas were of great importance to the Aborigines (and European explorers; Giles 1889: Vol. I: 211, 217; Lindsay 1893; Calvert 1897; Carnegie 1898), who protected them against evaporation and fouling by animals (Helms 1896), and who sometimes diverted water into them from nearby rock surfaces by pounding channelling grooves (Tindale and Lindsay 1963: 65; such hydraulic grooves have also been reported from axe grinding panels, see Bednarik 1990). In practice, most gnammas are too large to be mistaken for cupules or other anthropic markings, but it is thought that, in Australia at least, humans contributed to the enlargement of some specimens by removing loose and weakened rock (Jutson 1934). Gnammas are closely related to *Kamenitza*, the main difference being in the role of the rock’s impermeability in the case of the former. Both of these phenomena are *Verwitterungswannen* (solution basins)

Another solution phenomenon resembling cupules has been reported by Campbell et al. (2007), who illustrate dense concentrations of natural ‘cupules’ from the ceiling, walls and to some extent even the floor of a limestone cave (J. Clottes, pers. comm. Dec. 2007) on Mfangano Island in Lake Victoria (Kenya). The phenomenon illustrated is solution scalloping, commonly observed in limestone caves that have been subjected to vadose water flow (Figure 11). Solution scallops are concavities formed through erosion by eddies in flowing water (De Serres 1835: 24; Monroe 1970; Lowe and Waltham 1995; Mihevc et al. 2004: 522). They are separated by sharp ridges, they can range from 1 cm to 1 m in size, and they are asymmetrical in horizontal section. The latter characteristic allows flow direction to be established, because the upstream slope is always steeper (Figure 12). Their size indicates flow velocity, smaller scallops being formed by faster flowing water. The French names of solution scallops are *cannelure* and *vague d’érosion*, while

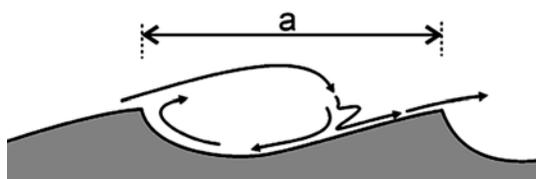


Figure 12. Section through solution scallop in the direction of water flow, showing flow and eddy current.

in German the phenomenon is known as *Fließfacette*, and in Spanish as *huella de corriente*.

Clegg's 'snames'

Clegg (2007) has recently described a phenomenon he calls 'snames'. He defines these as 'shallow, approximately circular, flat-bottomed depressions, a metre or so in diameter', which he has found on Sydney sandstone. His illustrations depict them as being several centimetres to perhaps 10 cm deep, and clearly unrelated to the site's tessellation. He is baffled by them and reports that several geologists could not explain them and had never encountered such features before. But the phenomena he describes are well known (e.g. Cremeens et al. 2005), including in Australia (Figure 13). They have been described as '*Opferkessel*' (another severely misleading archaeologist's term) and their correct geomorphological name is *Verwitterungswanne* or solution pan (cf. pan hole, *tinajita*, *Kamenitza*, *kamenica*, *kamenitsa*, *lakouva*, *ythrolakkos*, *bljudce*, *cuenco*, *tinajita*, *erime tavasi*, *skalne kotlice*, *scalba*, *skalnica*; see Bednarik 2001 [2007]: 21). This biochemical phenomenon occurs on flatish horizontal rock surfaces lacking drainage and it can be found on many lithologies. It occurs most commonly on sedimentary rocks, but similar forms occur also on granitic facies (see gnamma) and other rock types. After the nature of his 'snames' was explained to Clegg he continued to insist that they are a new phenomenon, because if they were solution basins they would have to be horizontal, whereas those he checked had slopes ranging from 0 to 0.2%, i.e. they were not precisely horizontal (Clegg 2008: Fig. 5). That is indeed the case, but again Clegg is mistaken: the sandstone slab on which his 'snames' are located is unstable and has changed its inclination since the time these *Verwitterungswannen* formed, long before the arrival of humans. Recently, Rowe and Chance (this volume) have described a few similar examples on limestone in Qatar, which are best defined as *Kamenitza*. *Verwitterungswannen*, the generic phenomena defining Clegg's 'snames', have distinctive features by which they can be identified, and their formation processes are understood. It is not appropriate to invent a new name for them, there already are far too many names because other commentators have done so without realising that the phenomenon has a name and has been defined and explained scientifically.

I have examined many of Clegg's 'snames' at the Elvina



Figure 13. *Verwitterungswannen* (solution pans) on Uluru (formerly Ayers Rock), central Australia.

Track site and other, nearby locations in Ku-ring-gai Chase National Park, Sydney (Figs 14 to 16). Some of



Figures 14 and 15. Solution pans, Elvina Track site, near Sydney.

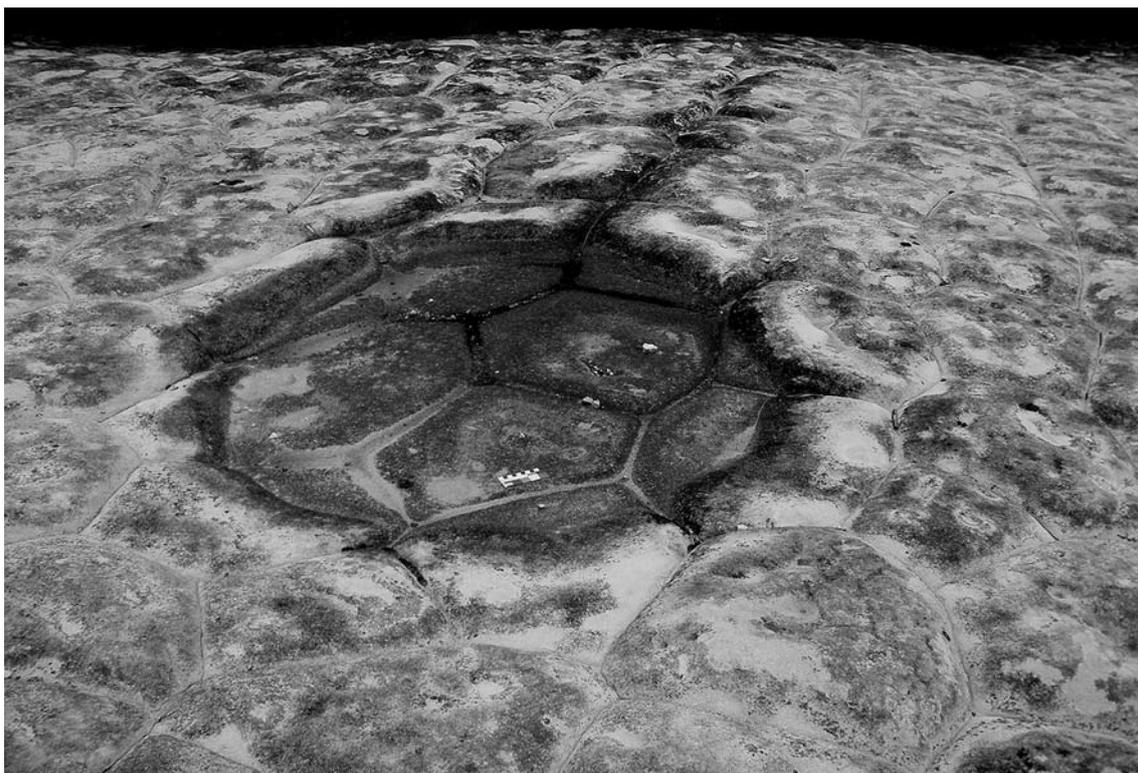


Figure 16. Solution pan, Elvina Track site, near Sydney, truncating several tessellation polygons. Scale in cm.

they are roughly circular, but irregular shapes also occur. They range in size up to 4 m and are without exception horizontal, because it is the retention of rainwater that causes their formation. Any variation from the horizontal position is entirely due to the dip in the sandstone slab, the southern part of which is gradually being lowered as its support facies gives way. It is wrong to separate them taxonomically from other solution phenomena at the site, on the basis of size or shape. In reality, there is a continuum ranging in size from 20 mm to 4 m, and in shape from circular to any random shape, the most common sizes being between 5 cm and 20 cm (Figure 17). While the smaller fraction has been falsely defined as cupules (see above), some of the larger examples, which can extend across several tessellation polygons, constitute Clegg's 'snames'. All of these phenomena are natural features, as shown by field microscopy (Figure 18).

The difficulties in discriminating between natural and artificial features have spawned countless confrontations between archaeologists and other researchers, in many areas of archaeology (beginning, perhaps, with Boucher de Perthes' 'worthless pebbles' of well over a hundred years ago). An early example involving rock depressions featured Leiden professor K. Martin who ridiculed C. A. van Sypesteyn (a later Governor of Suriname) over this issue (Martin 1887; see also Bubberman 1977: 566) — who turned out to be right.



Figure 17. Sandstone pavement with a great diversity of solution phenomena, Elvina Track site.

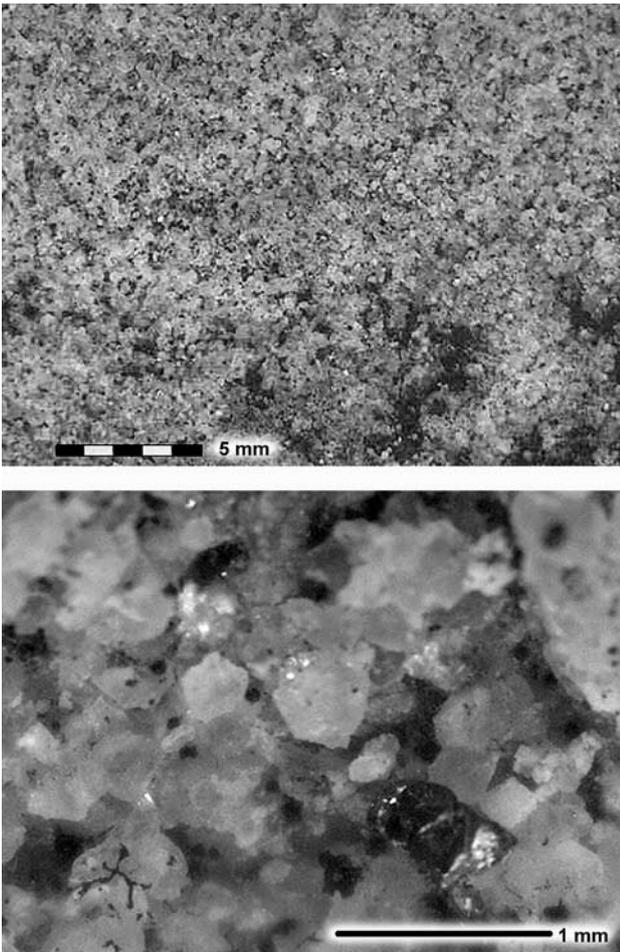


Figure 18. *Microphotographs of the heavily weathered surface of one of Clegg's 'snames'.*

Artificial rock markings resembling cupules

In addition to the many *natural* features that have been misunderstood or misidentified as cupules or cupule-like phenomena (the above list is not complete) there are also various anthropic rock markings they have been

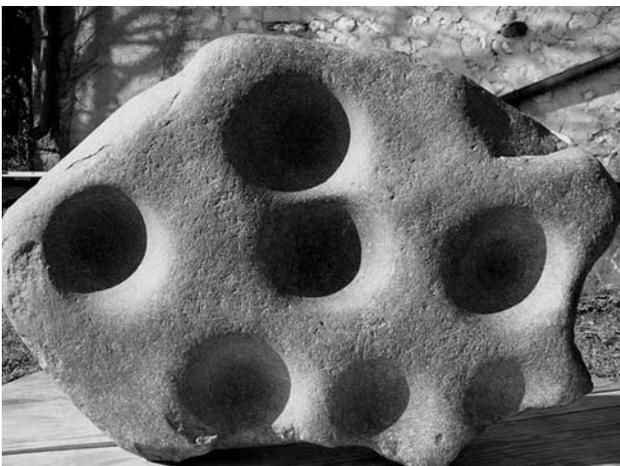


Figure 19. *Stone slab with mortars resembling cupules, central Niger.*

confused with. In particular, rock mortars and metates can resemble large cupules (Figure 19). A metate typically consists of a stone slab with a ground depression, which may be elongate or circular, depending on the direction of movement of the grinding stone (called *mano*), used generally in grinding materials such as foodstuffs (e.g. Lange 1996). In Mesoamerica, especially Costa Rica, decorated ceremonial metates made of volcanic rock have been described. In North America, the term 'grinding slab' has been used to define large rocks bearing a number of anthropic hollows that were used, for instance, to grind acorns, and these features can resemble cupule boulders rather closely (Alvarez and Peri 1987: 12). The term metate is an American variation of the more widely found quern stones, which occur especially among the remains of agricultural societies. The term mortar also is more general, describing essentially a rock hollow, portable or non-portable, that was used in conjunction with a pestle to crush, grind and mix substances (grain, meat, ochre, medicines or numerous others). It is obvious that distinctions between these various terms are fairly arbitrary, depending mostly on assumed economic activities, and that in reality the surviving traces of these features tend to grade into other types. The only major technological distinction might be that metates are most often the result of to-and-fro abrasion, while mortars or querns relate more to rotating or crushing motions.

Similarly, there is no obvious or self-evident separation between some of these economic features and non-utilitarian cupules; rather, the discrimination can only be made after exhaustive study of the features in question, and after detailed consideration of various aspects. This is usually beyond archaeological taxonomisation endeavours and involves a whole host of considerations, concerning lithology, macroscopic and microscopic traces, orientation, inclination, spatial context and so forth. These are discussed in other parts of this volume. Similarly, many cupules occur on lithophones, and it is then questionable whether they could reasonably be described as non-utilitarian, as cupules are generally presumed to be. The proper recognition of lithophone cupules is in itself a complex subject that will need to be considered in any identification of cupules (see chapter on lithophones). Indeed, an absolute separation between utilitarian and non-utilitarian cupule-like features is in the final analysis impossible, even if we had reliable ethnographic information. A cupule could only be entirely non-utilitarian (symbolic) if no practical consideration were involved in its production. We cannot determine this with finite precision in the extremely sparse ethnographic instances of interpretation available to us, so it would be correspondingly much more difficult to make such distinction in the countless cases we have that lack any form of ethnography. Clearly, science cannot involve itself in such issues, on the basis of the sound data currently available to it.

Other types of anthropic and utilitarian rock markings vaguely resembling cupules of various types occur. One



Figure 20. Deep and large utilitarian pits on soft tuffaceous rock, near La Paz, Bolivia.

example are large and deep rock depressions in soft rock that have been suggested to have served as storage pits (Figure 20). Modern tool marks have sometimes been mistaken for petroglyphs by archaeologists (Bednarik 1994), including markings by rock drills, core drills and other modern equipment. Some of these traces can resemble cupules and similar phenomena, especially when they have been subjected to rapid weathering. An example are the several dozen rock holes at Blue Tier in Tasmania, arranged in an alignment that is 19.5 metres long (Sharland 1957; see Bednarik et al. 2007: Fig. 2).

Discussion

What emerges from this paper is that archaeologists have often found it difficult to discriminate between cupules and other anthropic rock markings, and especially to recognise natural markings. The latter have not been summarised before, and the above is intended to assist in such discrimination. However, by itself an appreciation of these alternatives may not suffice to generate reliable identifications in the field. The best analytical tool in this quest is field microscopy — the use of specially adapted binocular microscopes or digital microscopes at the sites in question (Figure 21). Unfortunately field microscopy is widely eschewed by both general archaeologists and rock art researchers. This is regrettable because it is a powerful tool in detecting crucial diagnostic details. In the case of cupules, mortars and natural features resembling them, such details demanding the use of field microscopy are especially:

1. *Impact-modified rock crystals or grains*: all cupules were created by percussion, and in the harder rock types this will lead to the frequent occurrence of fractured, crushed or shattered surface grains, and particularly in quartz grains with typical conchoidal fractures. These unmistakable signs of impact are rare or absent in any

such features other than cupules. Where weathering has not obliterated such details, they provide clear diagnostic evidence.

2. *Abrasion-truncated crystals or grains*: the particles of rock that has been abraded, e.g. as a metate or quern stone, are inevitably truncated at the surface. Unless

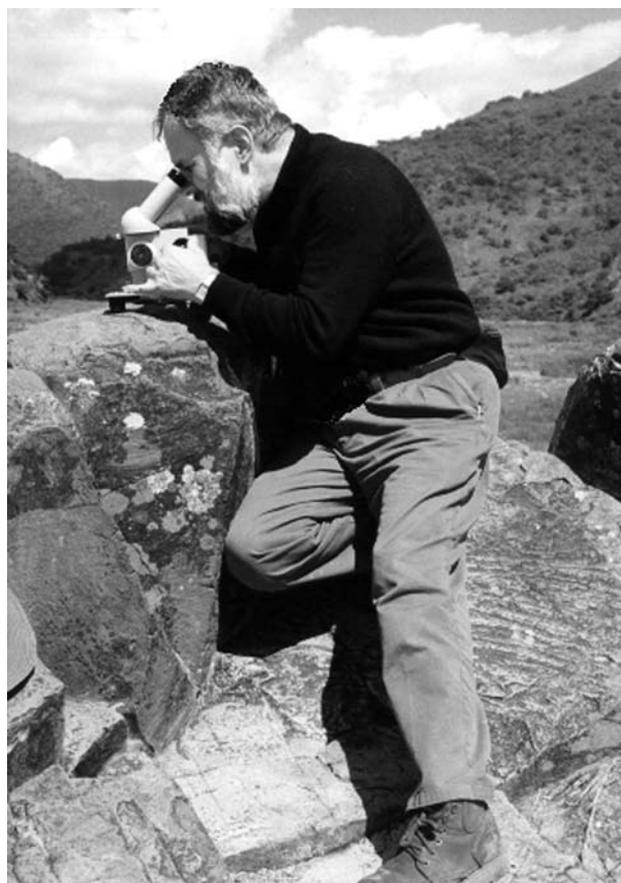


Figure 21. Specially adapted binocular microscope in use to examine cupules on quartzite at Inca Huasi site, Mizque valley, Bolivia.

they have been lost to granular surface exfoliation, these grains or crystals provide solid evidence of grinding or abrasive action (Bednarik 2000).

3. *Striations*: grains or crystals truncated by abrasion may bear microscopic striae dating from the last use of the surface. Where these are orientated in similar directions, the use of the surface as a metate, in a to-and-fro movement, is indicated, whereas random orientation implies use as a quern stone.
4. *Microerosional indices*: Where mineral crystals, such as the quartz grains of sandstones or quartzites, have been either truncated by abrasion or fractured by percussion, the newly formed edges of the new surfaces correspond in age to the last use of the feature. These edges then begin to form micro-wanes, i.e. they become rounded with time. Such rounded edges provide therefore a metrical index of the age of the feature, and where the wane development process can be calibrated against time, they facilitate absolute age estimation of the cupule or mortar. This is the basis of the principal method of microerosion analysis (Bednarik 1992).

The availability of such significant analytical features indicates the importance of microscopic examination of cupules and any other phenomena these have been confused with. It is hoped that this paper can help prompting archaeologists to consult specialists of rock markings (rather than general geologists) when facing such issues, and particularly when needing to discriminate between cupules and other rock markings.

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