

and atmosphere, although it is possible that in some cases there may be a structurally given predisposition. However, these markings never extend beneath the surface layer, so one might define them as 'two-dimensional' rather than the 'three-dimensional' class GP markings. Also, weathering markings are largely restricted to the types of rock that are not usually susceptible to the GP markings, especially sedimentary rocks. I distinguish again two types in this class: the marks caused by solution, which are particularly common on carbonate rocks, and the marks predominantly caused by granular exfoliation, which is typically active on sandstone facies. The secure identification of both types is contingent upon good field experience in observing geomorphological phenomena, particularly karst features and sandstone weathering patterns. It is certainly inappropriate that the discrimination of such markings (and subsequent heritage management decisions) be left to archaeologists.

GW1. Solution marks

Solution is a basic form of chemical weathering, in which solids are dissolved in water or aqueous solution. Susceptibility to solution of any mineral can vary significantly, being a function of such factors as temperature, pressure, pH, turbulence and the presence of catalysts. Solution contributes to many weathering processes, for instance to granular exfoliation or biologically caused weathering, but for some types of rocks, notably carbonates, it is the principal weathering agent.

The limestones or dolomites of karsts are susceptible to solution processes which result in rock markings that may resemble petroglyphs, and have in a number of instances been misinterpreted as such. Essentially, these rocks are readily soluble in aqueous carbon dioxide, which is formed by atmospheric water and respiratory carbon dioxide. The latter is usually derived from the mycorrhizal micro-organisms that live on the roots of vegetation, and that maintain the very high relative concentration of carbon dioxide in the soil atmosphere (which exceeds atmospheric levels about 300 times, see below). Consequently solution of limestone is active primarily at or near the surface, and not subterraneously as is often thought. Solution within caves is mostly phreatic, because vadose water (which has percolated through the closed system of the rock strata above) is generally bicarbonate enriched (or super-saturated due to

the higher pressure in the rock's closed system) and therefore has no solvent potential upon entering a cave (in fact it often has to precipitate surplus solute then, which leads to the formation of speleothems). This means that solution markings inside limestone caves are exceedingly rare, and to the best of my knowledge occur only in two forms: where atmospheric run-off has access, usually near the entrance, or in the form of root channels (see below, under plant marks).

Outside caves, solution markings can be common, especially where water runs over a rock slope after draining from a higher-lying soil deposit. This may result in *Rillenkarren*: sets of linear, subparallel grooves of surprisingly regular spacing, always orientated in the direction of natural water flow (Figure 8). Their regular arrangements may be most suggestive of artificial rock markings, particularly in such countries where similar arrangements are known to occur in rock art (e.g. in Australia). *Karren* tend to deepen with age, and eventually can be as deep as one metre. As mentioned above, turbulence in a flowing solute increases its solvent potential, which probably plays a role in the formation of *Karren*, as it would increase the solvent's potential.

Karren are not as common in Australian karsts as they are in those of other regions (central Europe, Brazil, Caribbean), although they do occur in some Australian areas, such as near Fitzroy Crossing, Kimberley. I have observed only one site where they co-occur with similar-looking rock art, Orchestra Shell Cave near Perth (Bednarik 1989). Although closely resembling the finger flutings in the same cave, their identification presents no difficulty for the experienced observer. Another karst weathering phenomenon, *kamenitsa*, occurs on the Nullarbor plain. In some parts of the world, these depressions have been mistaken by archaeologists for grinding grooves, mortars or petroglyphs, notably at some sites in western U.S.A. I attribute these features to the natural propensity of the slightest depression to retain moisture and acidic matter (e.g. decomposing leaf litter) longer than the adjacent areas, which leads to accelerated solution, and the deepening in turn accelerates the process. It is obvious that limestone is not suitable for grinding other materials, and geomorphological examination of such phenomena should clarify the nature of these phenomena.



Figure 8.
Typical Rillenkarren on a
Tertiary limestone
escarpment. West of
Piccaninnie Cave, Mt
Gambier, South
Australia.



Figure 9. Groove markings on a cliff at Tullaroop Creek, Castlemaine, central Victoria. Almost certainly solution marks, although their precise origins remain unknown.

Some rock markings in this category are far less readily explainable, and again I cite an example from Victoria. It is from near a major Aboriginal stone arrangement site near Carisbrook, west of Castlemaine. At only one point of a long basaltic escarpment along the Tullaroop Creek occur petroglyph-like grooves (Figure 9). They are 15-40 mm wide, of rounded section, and usually peter out without distinct ends. No recognisable arrangements are formed, but neither is there a natural solution process that seems to account for the markings. The rock is dissected by some layers of vesicle-rich material, which is somewhat more resistant to weathering, and where these are crossed by the grooves, the veins project distinctly into the grooves. This discounts the possibility that the grooves were made by people, because impact would have worn the veins as much as the adjacent matrix (Figure 10). However, it does not explain the markings themselves. It is most probable that they are either the result of root action, or of the presence of unusual local chemical conditions. I regard it as likely that a solution process is responsible for the grooves.

Other types of solution marks have led to spectacular misidentifications by archaeologists and epigraphers, notably in North America. One of the best-known controversies concerns the purported Phoenician messages on the 'written stones' of Quebec, which are among the literally hundreds 'deciphered' by epigraphers. Dubois (1985) reports that the markings occur in strata with numerous



Figure 10. Close-up view of one of the Tullaroop Creek grooves that is crossed by vesicle-rich veins in the rock. The veins project out because they have been more resistant to the solution process.

solution grooves that are narrow and distinctively V-shaped in section. Many of the lines contain constrictions that render a production with metal tools entirely impossible. These markings were found in granite and gneiss as well as in a schistose sandstone. In the former rock, they were attributable to selective weathering of aligned plagioclases, in the latter to the corrosive spray of sea water. It is interesting that natural processes that result in such 'inscriptions' occur of course in all continents, but the phenomenon of their identification as writing seems endemic to North America.

GW2. Exfoliation marks

Exfoliation of rock occurs through several processes, which vary according to rock type and environmental conditions. Their scale of magnitude varies from microscopic flaking of particles due to salt formation, to the large-scale mass-exfoliation of, say, unloading of granite masses. In contrast to solution, a continuous or periodic process, exfoliation of each particle is an instantaneous event, even though many such events may be required to cumulatively result in the production of a rock marking. The processes responsible are always physical, even though chemical processes or changes may have precipitated the stresses leading to exfoliation. In other forms, the exfoliation is caused by physical factors alone, among them insolation, *Kernsprung*, lightning strike, *Salzspre-*

gung (wedging by salt crystallisation), stress fracture attributable to ancient material stresses or recent thermal stresses, hydration, and simple gravitational force. When a rock mass is detached, the fracture surface may bear stress marks of various types, including concentric arcs or sub-parallel furrows. Incredibly, such markings have been considered, on occasion, by rock art scholars to be humanly made, which confirms how powerful is the human propensity for seeking order in chaos, and how it affects those who search for rock art.

Exfoliation scars can also resemble non-art anthropic markings, such as grinding grooves. Dickson (1980: 160) determined experimentally that granite is one of the worst media in which to grind stone axes/hatchets, and considered it likely that the few instances of apparent grinding grooves on granite are attributable to alternative agencies. Wade (1941), who described such granite grooves, expressed similar reservations. This needs to be pointed out here because if these granite markings are not anthropic, then they need to be accounted for as natural markings. Granite is much less susceptible than sandstone to weathering phenomena that resemble anthropic marks, but several processes do result in markings likely to be misinterpreted. *Tafoni* and scalloping occur usually just above ground level (Ollier 1965), and they are related to the breaching of case hardening. The exfoliation process operates inwards and upwards on a boulder, eventually forming alcoves and scallops, but it never extends below ground level. The sculptures resulting from this have sometimes been considered to be artificial, though, to my knowledge, not by archaeologists. *Tafoni* are shallow, rounded weathering hollows in granite-like rocks and sandstones. They are rarely, if indeed at all, associated with evidence of sand blasting, and are attributable principally to chemical decay resulting from prolonged moisture presence and the effects of cyclical wetting and drying.

However, sandstone is much more likely than granite to bear surface markings which are prone to be interpreted as petroglyphs. For instance, Sims (1977), who examined the authenticity of the twenty petroglyph sites reported in Tasmania, and who rejected seven out of the nineteen he could locate, reported most of the misidentifications from sandstone sites. Patterns of sandstone weathering remain most inadequately understood, and some phenomena, such as the Sydney tessellations, remain unexplained. Sandstone is obviously most susceptible to granular mass-exfoliation — the shedding of mass grain by grain — and where such processes are influenced by even minor diagenetic characteristics, such as stratigraphic laminations, they are bound to result in various types of surface grooves and pits, which may resemble artificial marks closely. There is a clear overlap between them and the type GP2 marks. The tendency of true petroglyphs on sandstone to weather comparatively rapidly only facilitates misidentification, because weathered petroglyphs may resemble exfoliation scars. Moreover, sandstone is perhaps the rock type that is most susceptible to case hardening, and this leads to many forms of erosion products which resemble artificial marks. Case hardening may be visually obvious, through the deposition of a surface lamina of distinctive colour or consistency. Other forms of it are not readily visible, but are a form of induration of the surface-near layer, usually up to several centimetres deep. In both instances, the case hardening protects the much more erosion-prone inner material, until weathering or other causes puncture the

cutaneous zone locally and lead to the breakdown of the core. This then results in *tafoni* and similar alveolar formations. I have consistently observed — and not only on sandstone — that moisture retention is the crucial factor in all of these processes: the surface areas most susceptible to them are those most likely to retain atmospheric or capillary moisture longer. This is why the upper part of a sandstone formation, which dries most quickly after rain because of its greater exposure to sun and wind, is the most indurated, and thus the most exfoliation resistant. Once again, an erosion process is accelerated by the geometry of its own products: depressions become progressively more cavernous, and as they do they retain moisture longer again, so the formation process is self-accelerating.

Although not well understood, granular exfoliation is probably a combination of several factors. The cement of all sandstones is more soluble and less resistant than the sand grains. A complex regime of salt removal, temperature change of salt solution, chemical conversion of mineral components and subsequent change in bulk (including subflorescence) and other factors weaken coherence. Hydration of clay components, kaolin or gypsum is often a major influence. Small flakes or individual grains are detached, and no doubt aeolian action or surface wash can contribute to their removal. Interestingly, sandstone that is subjected to fairly continuous high moisture levels is just as erosion resistant as sandstone which remains dry, and there seems to be very little, if any, exfoliation below ground level. Sandstone exfoliation, irrespective of whether it occurs at the granular level or as spalls of up to a few centimetres in thickness, seems to operate primarily in conditions where salts are neither being flushed nor stable, which are those areas where moisture remains longest but still evaporates regularly. This is perhaps the simplest general rule, even if it may in fact be an oversimplification.

The thousands of pit markings on tessellated sandstone pavements in the Sydney region are the subject of an ongoing controversy. The tessellation itself does not concern us here, because it is generally agreed that it is a natural phenomenon (Branagan and Cairns 1993), even though it remains unexplained. This often extensive lattice of deeply eroded grooves divides some twenty-five known pavements into mosaics of sometimes geometric accuracy. The inherent tessellation characteristics extend perhaps 20 cm below the surface, and they have given rise to selective weathering which formed the grooves. The largest of these pavements, the Elvina Track site, measures about 6500 square metres. Many of its thousands of polygonous panels bear a number of pits of 20-50 mm diameter (Figure 11). There are also a number of undisputed petroglyphs at the site, including figurative motifs and regularly spaced grooves. The pits, however, are the dominant feature, occurring in vast numbers. Many specialists, including eminent geologists and rock art scholars of extensive field experience (Cairns and Branagan 1992: 29), accept them as humanly-made cupules, which are a common feature of hundreds of rock art traditions the world over (Bednarik 1993b). However, most Australian rock art specialists believe that they are natural markings. In 1989 an attempt was made to resolve the controversy during an AURA fieldtrip to the site, attended by about forty rock art specialists. The inspection resulted in the acceptance of certain, formerly disputed groove markings as being petroglyphic, but the overwhelming majority of the party rejected the

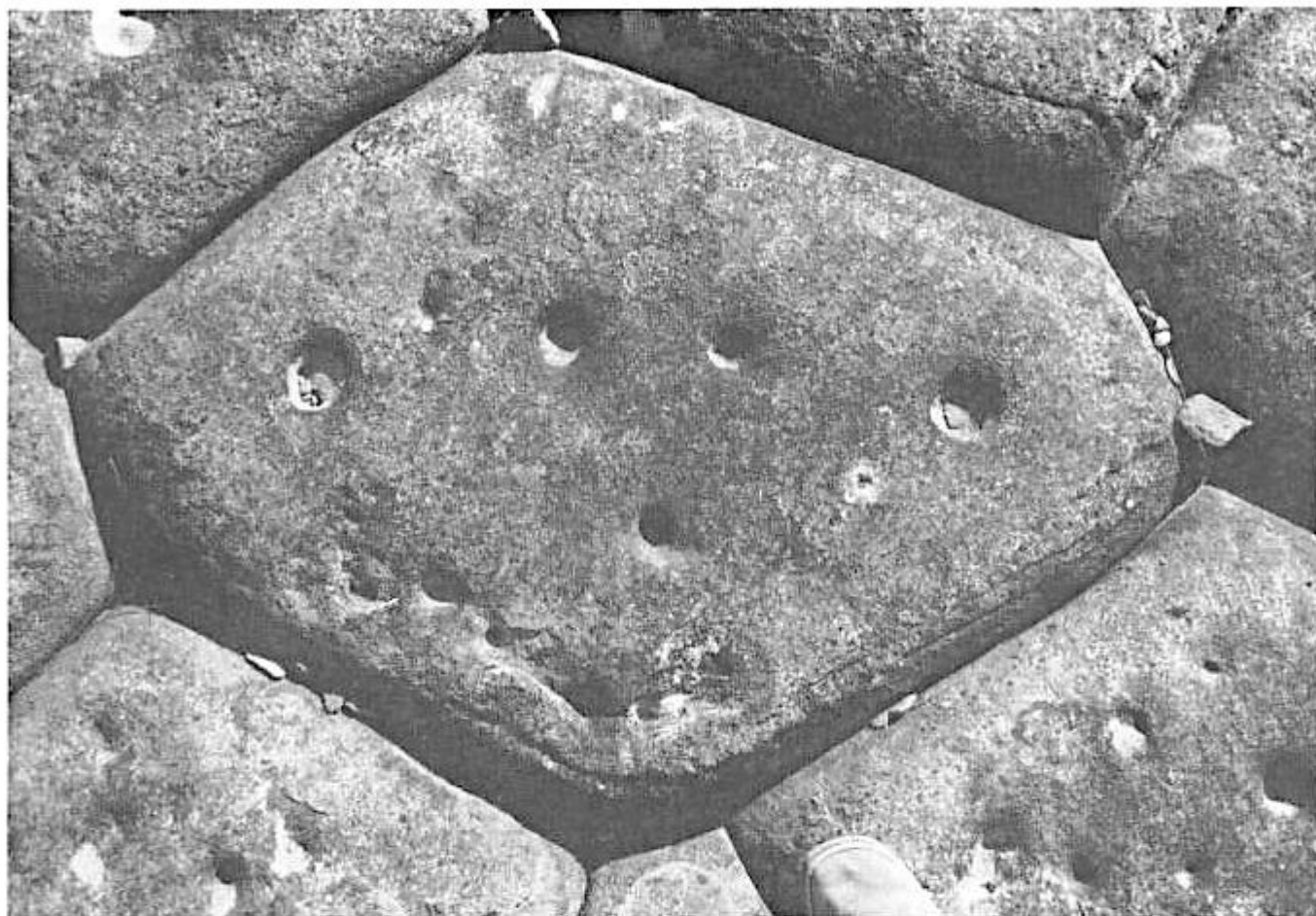


Figure 11. Typical polygonous tessellation at Elvina Track site, near Sydney. The natural origin of the tessellation is generally accepted, but the status of the pits, as either cupules or natural weathering marks, remains disputed. (Photograph by Hugh Cairns.)

idea that the cup marks were also artificial (Bednarik 1990). It is plausible that some may well have been artificially deepened; the site was clearly used by Aboriginal people and the markings are certainly most conspicuous and would have attracted attention (as well as interpretation efforts by pre-Historic 'ethno-scientists'; Kottak 1991: 374).

In part, the consensus finding was based on the very steep, sometimes vertical walls of many of the deepest pits (Cairns and Branagan 1992: Figs 1, 2), which obviously cannot be produced by impact, and which look almost as if they had been drilled. However, this is not necessarily a valid objection: an initial cupule is likely to weather because of moisture retention, and this is likely to lead to deepening. The aspect that most prompts observers to favour an anthropogenic origin is the pattern of distribution of the pits within the polygon panels: none of them occurs near the grooves bordering each polygon, and they seem often evenly, 'intentionally' spaced. I regard this as a classic example of selective natural processes resulting in physical aspects of a regularity that lead to the idea that intentionality must be involved: the human propensity, even scientific predisposition, of perceiving patterns imposes order and then interprets it as being intentional, because natural processes are perceived as random. But natural processes are never random; the existence of our entire world is attributable only to their non-randomness. Natural processes can thus mimic intentionality.

This is indeed the case of the Sydney tessellated pavements. Each polygon has similar run-off characteristics:

near the borders, the profile curves gently towards the surrounding groove, into which rain water drains readily. Drainage is slower in the more central parts of the polygon, and if there are even the slightest depressions there, water will remain in them. Uneven exfoliation is the result, leading to drainage towards the 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 location, the pit forming in the middle of each local drainage zone. The logical result is a natural pattern of regularity, which the uncritical observer is likely to interpret as intentional.

GK. Kinetic markings

These may not be as easily identifiable as one might be tempted to think; they have presented great difficulties for archaeologists as well as rock art scholars. In the majority of cases, their attribution tends to be easy, once they have been carefully considered in their environmental context. But there have also been cases where an unusual context responsible for them no longer exists, and if such markings are sufficiently complex they can be most baffling even for the specialist. Kinetic markings are always attributable to the movement of an active component (the marking element) relative to the passive component (the rock being marked). The former is often harder than the latter, but not necessarily so, especially where a great deal of kinetic force is involved. Kinetic rock markings could be sub-divided according to various definitions, but most of the possi-

ble taxonomic criteria are difficult to establish, so I have divided them fairly arbitrarily into 'general taphonomic marks' on portable clasts, and 'clastic movement marks' which are usually found on stationary rock surfaces that have been affected by clasts moving over or past them.

GK1. *Taphonomic marks*

The term taphonomy, derived from palaeontology, is a fairly recent introduction to archaeology. In its primary sense, it refers to the modifications experienced by materials since the time they became part of what is considered to form the 'archaeological record' (Bednarik 1994a). The term has a secondary epistemic sense which does not concern us here. In the present context, taphonomic markings are those that are not attributable to intentional human agency, but were acquired through movement of rock clasts within or relative to a sediment matrix, by such processes as cryoturbation, solifluction, trampling, or even by human agency. For instance, if a human stepped or sat on a rock slab, its underside might be marked by harder sand grains caught between it and the bedrock. Such markings would then not be intentional, and even though they would be anthropic, for the present purpose they would be biospheric taphonomic marks. Even if a rock slab had been used as support in some manufacturing process, such as the cutting of leather or meat, thereby sustaining cut marks, this would still apply from a geologist's point of view, but in the present context it would be more appropriate to consider such marks under BH1 below.

An Australian example of archaeological misidentification of taphonomic markings are the 'engraved plaques' from Trench 9 of Devil's Lair Cave, in the south-western corner of the continent (Dortch 1976). They consist of 'extremely friable' aeolian calcarenite and bear a network of random striations on one of the flat faces of each plaque. The rock is so soft that many striations were added when a specimen was cleaned with a fine nylon brush. Dortch discounts natural causes of the numerous incised markings without discussion, and does not seem to be aware that similar markings can be found on clastic material at many sites the world over. For instance, I examined dozens of specimens from just one site in Brazil (Toca do Sítio do Meio, southern Piauí) which archaeologists had thought to bear tens of thousands of anthropic markings. In this sandstone shelter, a layer of very fine-grained sedimentary rock exfoliates from the roof as angular blocks of 25-40 cm length. Microscopic examination showed that the marks are of greatly varying ages, widths and depths, ranging from barely perceptible examples to 4 mm wide cuts. There are clear sets of two or more subparallel marks, some of which may be interrupted only to continue as different arrangements, perhaps by changing direction. Another hallmark of these typical taphonomic marks is the point of commencement, with a distinct, impact-like impression. The angular edges are also very worn and rounded. There are essentially three potential explanations to account for such marks: they could be attributable either to trampling by humans or other animals; to movement of the slab relative to a rock surface, with loose quartz grains caught between the two surfaces; or to general detrital movement. Quite probably, a combination of these factors applies to densely marked material. In periglacial regions, detrital movement is often attributable to cryoturbation, the movement of sediments by freezing and thawing cycles, or to solifluction, the collapse of sloping sediments when

saturated by moisture upon thawing. Cryoturbation can be most effective in producing markings on rock, which have been reported even on obsidian tools (in Hungary). Clearly these marks are very common at archaeological sites, but they have hardly any archaeological significance.

The great variety of forms in which taphonomic marks occur is illustrated by the following example. Cave divers had discovered a panel of incised markings in a limestone cave near Mt Gambier, South Australia, under 7 m of water, in a downward sloping passage. If they were human markings, as the divers thought, they would probably be of Pleistocene age, because the passage would have been flooded during the Holocene. We know from the finger markings recently found below sea water in Cosquer Cave, France, which are of the Pleistocene (Clottes et al. 1992), that such markings can survive below water. However, my detailed examination of the Australian markings revealed no evidence of human involvement; they seemed to be taphonomic marks. Their occurrence on the wall of a recess in the passage seemed puzzling, but I noted that the water-filled caves in the region frequently contain ancient tree trunks with their roots and branches which had fallen into the sinkhole entrances. This prompted me to suggest that perhaps such an ancient log had become lodged in this position and, buffeted by water flow, produced the incisions with its limbs. It is not a proven explanation by any means, but perhaps the most realistic one under the circumstances.

GK2. *Clastic movement marks*

These are perhaps among the most common rock markings in the world: glacial striae alone would probably account for millions of times as many marks as rock art motifs do. The great majority of these marks can be readily identified, if only because of their enormous numbers, but there are still exceptions. Clastic movement is a common phenomenon at many types of archaeological sites, and it can be attributed to a variety of causes. Fluvial sedimentary movement, animal burrowing, and simple gravity are among them, but also tectonic adjustments. This applies especially in limestone caves, where several processes can effect large-scale clastic movement. Many cave systems form above a sub-floor phreatic reservoir, and where the clastic breakdown from roof falls causes the floor to progressively settle, blocks move not only relative to each other, but also down along the walls of the cave. Often this results in deeply incised wall markings (for a photograph of a good example, see Maynard and Edwards 1971: Pl. 32). Similar movement of talus clasts is caused by seismic events, and even by eustatic fluctuations. The aquifer level in coastal regions falls with the sea level, which means that huge masses of boulders that were submerged in water become exposed as the water drains from these systems. The boulder structures may have been tectonically stable as long as they remained submerged, but they are not once they are above water, during stadials. Finally, tectonic subsidence can be caused by certain mining methods (Sefton 1992), and this could conceivably result in similar kinetically caused rock markings.

The deep incisions occasioned by downward movement of clasts or other detrital matter, be it in limestone caves or other types of sites, are fairly easy to identify where they are relatively fresh. However, if they are very corroded, patinated and considered in isolation it is quite possible to mistake them for anthropic marks, especially where several occur together and they seem to form 'arrangements'.

Another type of rock marking occasioned by clastics movement is easy to recognise. Glacial striae were made by rocky detritus dragged or pushed by glaciers over stationary rock surfaces, which had often been planed smooth in the process. Such glacial pavements are most common in the Northern Hemisphere, and they often form the support surfaces of petroglyphs, for instance in Val Camonica (Italy), Britain, Scandinavia, Karelia and Canada. The direction of the striae is generally uniform, they are inevitably aligned with the flow of the former glacier, but their sizes are far from uniform. They range in width from barely perceptible incisions, under a millimetre wide, to massive gouges of about one metre in width and many tens of metres in length. Irrespective of their size, they bear a number of morphological features which are of importance to our present study. These permit the clear determination of the direction in which the marking point was moved over the rock, through transverse tear marks, the serrated patterns at the longitudinal edges of the margins, and the form of the point of commencement, including comet-like marks. Some of these features are similar to those observed in other types of kinetic markings, both natural and anthropic, and even on materials other than rock. The transverse tear marks, for instance, have been observed at the microscopic level, in pre-Historic engravings on portable stone objects (d'Errico 1989), but they have also been reported at the macroscopic level, in the finger flutings found on formerly soft speleothem deposits in caves (Bednarik 1986a, 1992c). These stress marks can be found even in the largest glacial striae; they are arcuate and always curved in the direction the boulder was dragged over the pavement (i.e. the convex side points in the direction of movement). Where a boulder scraped over an elevated aspect of the panel topography, the impact mark is obviously on the oncoming side, and the comet-like arrangements sometimes seen at the point of commencement may indicate where the boulder first struck, and then either bounced or turned slightly, affecting the morphology of the resulting mark.

Usually it is not just the distinctiveness of striae that enable their secure identification, but also their abundance, typical location and direction. Other kinetic movement marks may be extremely rare and thus much harder to identify. While examining the Siberian rock art site Tal'ma II (near the upper Lena river), I noted sets of parallel grooves high up on the vertical cliff face, about 6 m from the ground, on very smooth rock (Figure 12). Unable to reach them, I inspected them through binoculars to determine what caused them. However, I remained unable to form an opinion: intuition told me the marks were natural, but they were clearly attributable to mechanical force or impact, and there seemed no natural agency that could have caused such strange, regular marks. I had studied lightning markings before, and a variety of other unusual natural marks, but had never encountered anything resembling these strange grooves. In the subsequent weeks, I located similar marks at two more Siberian sites, again high on steep cliffs overlooking a river, but in one case I managed to reach and examine them. They certainly looked like man-made impact grooves, but microscopic inspection revealed no evidence of actual impact. Rather, there was dense crushing evidence of grains, as if the marks had been *pressed* into the rock with considerable force. I then hypothesised that perhaps there had been a rock tower leaning against the cliff, and if a hard clast had become lodged between it and the cliff, it might have

slowly wandered downwards with each minute seismic movement, only to be pressed against the cliff by the weight of the tower, in each successive position. It seemed a desperate explanation at the time but it turned out to be valid. Soon afterwards I found a clast which had become stuck in such a position between a sheer cliff and a detached rampart, and had already produced several pressure marks. Each time there was movement in the tower, be it seismic, tectonic, or caused by temperature change, moisture, freezing and thawing, or whatever else, the clast dropped a few centimetres.

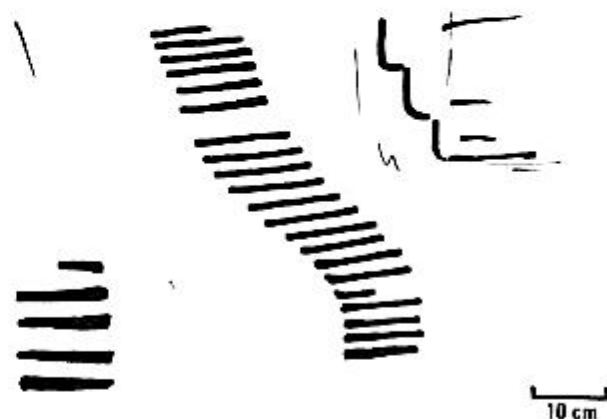


Figure 12. Unusual clastic movement marks at the upper Lena, central Siberia, high on smooth and vertical cliff.

I have explained this phenomenon in some detail for two reasons: firstly, it shows poignantly how even the most unlikely explanation may turn out to be correct, and how judicious and wary the researcher really needs to be in pursuing natural explanations for unusual phenomena. Secondly, the markings appeared comparatively fresh, and yet all traces of the collapsed ramparts had been removed by the river, so these 'natureglyphs' were likely to be many centuries old.

BP. Plant markings

We now proceed to the second major division, *biological rock markings*. Again, I divide them into three classes: those made by plants (BP), non-human animals (BA), and humans (BH). In each class, I distinguish again two types.

The division of plant markings into kinetic and chemical types is as obvious as it is opportune. Such rock marks can be readily identified by the specialist, but they have been a source of difficulty for many writers and commentators, and we have no shortage of misidentifications of both the types listed here.

BP1. Kinetic plant marks

Although it is a distinguishing characteristic of all species of the vegetable kingdom that they lack the power of locomotion, that does not prevent them from producing kinetic rock markings. These are only possible where vegetation occurs immediately adjacent to rock, and the necessary energy is provided mostly by the wind. If a tree, shrub or even a large tuft of grass stands next to a rock surface, it may rub against the rock. A pliable limb, stalk or tuft may perform a semi-circular movement for months and years, and this can result in distinctive arcuate marks even on hard rock, such as granite (Twidale et al. 1983: Fig. 8). Much softer rocks may incur markings of some