KEYWORDS: ***Petroglyph - Stone tool - Ethnography - Replicative experiment - Dating***

THE TECHNOLOGY OF PETROGLYPHS

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Abstract. Methods of making petroglyphs are examined, both through characteristic traces in the rock art and the implements used in creating this rock art. Rock carving tools are discussed from ethnographic and archaeological perspectives, and the scope of their detailed study is considered. Particular attention is given to the use of replication experiments and the newly introduced use of petroglyph-making implements as a means of estimating the age of rock art. The paper concludes with a call for the establishment of a project systematically both to study petroglyphs, and to monitor their taphonomy under controlled conditions over a very long period.

Introduction

Globally, rock art motifs can be divided into two principal classes on the basis of their method of manufacture: those made by a reductive process (petroglyphs), and those made by an additive process (paintings, wax figures etc.). This distinction is not only practical and sensible, but widespread in the art; it affects site preservation and management practices; and, perhaps most importantly, it is reflected in the way we conduct *rock art science*. For instance, the methods used in determining the possible ages of rock art differ greatly according to whether the art was made by an additive or a reductive process. This paper addresses petroglyph manufacturing methods and, particularly, the reductive processes they involve.

The lack of fundamental studies of many aspects of rock art is a fair indication of the recent development of rock art science. For instance, the first scientific publication on how to discriminate rock art from natural rock markings — an issue that is very fundamental to the discipline — appeared only in 1994. Until then it was common for researchers to mis-identify both anthropic and natural rock markings. 'Direct' methods of age estimation of rock art (often called 'rock art dating') have only been developed over the last couple of decades, and especially since about 1990. Similarly, the question of the technology of rock art production has not attracted a great deal of interest, and there is no publication systematically addressing this topic. Because of this lack of basic research, students of rock art have often commented on the technology of rock markings in a cursory and more-or-less subjective fashion. Methods of making rock art were in most cases considered without recourse to ethnographic observation, replication experiments or detailed examination (particularly microscopic analysis).

As in the case of systematically discriminating between anthropic and non-anthropic rock markings (Bednarik 1994a), it is necessary to examine the present topic by considering very basic issues. There is a close nexus between the technology of petroglyphs and the terminology used to describe them. Indeed, terminological ambiguity and confusion have significantly contributed to past misunderstandings.

Terminological issues

In our discipline, there might be seen to be an inverse proportion of the number of hypotheses produced to the quantity of scientific information actually available. It has also spawned the greatest diversity of idiosyncratic terminologies relative to the number of practitioners. In Australia, the two major attempts to create rock art terminologies are those of McCarthy (1967, 1969) and Maynard (1977). Globally, some degree of standardisation has been introduced since the advent of *Rock Art Research* (in 1984) and the International Federation of Rock Art Organisations (IFRAO - in 1988), but agreement on terms remains elusive. This is confusing to the newcomer, it continues to fuel systematic disagreements between researchers, and it is often directly related to issues concerning technology. To see this it is useful to examine the debate between McCarthy and Maynard (cf. McCarthy 1989 and debate).

Maynard, whose proposed system is more consistent and analytically relevant than McCarthy's (essentially for the reasons she states), considers the need for a typology paramount: without it, quantitative analysis is impossible. She compares this need to the prerequisite typology for stone tool studies, apparently considering that the lithic taxonomies created by archaeologists are valid outside of archaeological constructs. Recognising how typologies are not usually designed by sound principles, but 'grow, like mushrooms, in the dark' (Maynard 1977: 388), she offers a comprehensive classification system

based on her own understanding of Australian rock art. In analysing inconsistencies in McCarthy's nomenclature, Maynard observes for instance the ambiguity in using the term 'engraving' both as a major term (in the sense of 'petroglyph') and for a specific technique (incising, scratching or cutting action). In her own system, based on the variables of technique, form, motif, size and character, she lists three headings for reductive-technique rock art forms (petroglyphs) according to whether the figures were made by friction, percussion or rotation. Under 'percussion' she offers the sub-headings 'direct percussion' (pounding) and 'indirect percussion' (pecking). In other words: percussion petroglyphs were made either by using a hammer in one hand ('pounded'), or a hammer in one hand and a chisel (or bit, punch or gad) in the other ('pecked'). The term pecking (or peck marks, pecked designs etc.) has been widely adopted and is one of the most frequently used technological terms one now reads in rock art descriptions.

I have made an effort to follow this terminology (cf. Bednarik 1984), but have found that most Australian writers avoid the word 'pounding', using 'pecking' for practically all percussion petroglyphs. This can either mean that they reject Maynard's nomenclature, or that they believe that most Australian petroglyphs were made by indirect percussion. My own research has produced no evidence that the indirect percussion method was ever used, in Australia or in any other continent, in any significant frequency — if indeed at all. If indirect percussion was used, with a stone 'chisel' and a stone hammer, this should have resulted in vast numbers of discarded stone implements with distinctive bipolar damage (similar to the 'fabricator' or *outil écaillé*). No such tools have been reported from petroglyph sites. The idea of indirect percussion is an unsupported, academic pronouncement ('academic' in the sense of 'impractical') and its advocates have not demonstrated the technique by replication (Bednarik 1991a: 117). It would require between 25 000 and 100 000 impact nicks per square metre of pecked petroglyph area (many figures are larger than that), and on completion the artist's fingers would probably require amputation. I have seen sites with over 1000 m^2 of 'pecked' area, and if we assume that each chisel can make 100 nicks before it is too worn and that each such slug weighs just 25 g, we should have at least 25 tons of such slugs at these sites.

Preoccupation with the question of direct *versus* indirect percussion seems to result from an over-emphasis of difference between motifs with precisely directed, deep percussion marks, and those with more diffuse, shallow and apparently less well directed marks, and the conclusion that the two must be attributable to two different production methods. In reality, other variables are more likely to account for technological differences. These variations might include the type of rock, depth of weathering zone, presence of case hardening, direction of impact, presence of moisture, and various attributes of the percussion tool used. The tendency of explaining different impact marks as the result of different techniques is consistent with other archaeological interpretations: that the specialist is capable of distinguishing taxonomic entities among the physical evidence considered to be of archaeological relevance (Bednarik 1994a).

There are various other problems with Maynard's classification system which need not concern us here. Its best features, however, have tended to be ignored. Her endeavour to establish a technology-based terminology led her to point out that very few Australian petroglyphs are 'engravings' (i.e. have been produced by a method similar to that of traditional metal engraving), and yet the term 'engraving' continues to be used by some Australian and British archaeologists in describing all rock art made by the removal of mineral mass. Again, this misuse of technology-derived terminology is attributable to a misunderstanding of technology: an 'engraving', as Maynard points out, is a marking made with a burin or graver. In palaeoart studies it typically refers to a subtractive process producing markings on portable objects (stone, bone, ivory, ostrich eggshell, amber etc.) and to similar markings on rock. These were, as Maynard argues, made by friction (or, to be more specific, by incision, scratching or abrasion), and certainly not by percussion of any type (unless a combination of techniques was used). In short, the use of 'engraving' to describe a percussion petroglyph seems to indicate lack of technological understanding.

Insistence upon the use of rigorous terminology is not mere pedantry; terminological confusion reflecting poor understanding of technology is likely to result in unrigorous, poorly founded models and, more serious still, in neglect of crucial archaeological evidence.

Archaeological views and their effects

In a recent major review of Australian rock art, Flood (1997) includes a chapter on petroglyph techniques. She begins by repeating the separation of petroglyphs into those made by direct and those by indirect percussion and then states that (Flood 1997: 103)

> It used to be thought that the hammer and chisel method gave clean edges, precise lines and some depth to an engraving, whereas pounded examples were shallower and more diffused, but when John Clegg read this statement in my first draft of this chapter he decided to check it by experimental archaeology. So, at Easter 1996 [i.e. before Flood's book appeared], he drove out to western New South Wales, collected some sandstone slabs from the Mootwingee region (*not* from the site itself) and contacted archaeologist Dan Witter and Badger Bates, an Aboriginal site officer of the New South Wales National Parks & Wildlife Service. In Dan's garden in Broken Hill they proceeded to make engravings by both the indirect and direct methods. Contrary to conventional view, they found direct percussion with a fist-sized quartz hammerstone far more effective than the indirect method.

The question to ask here is not what Clegg's results were, but why there should have been a 'conventional view' among Australian archaeologists that was contrary to the findings of rock art scientists and ethnographic observers of rock art practice (see below). This is a question of heuristic dynamics in archaeology, a subject that I find immensely interesting. Rock art scientists

have conducted such replication work for decades, have learnt to recognise petroglyph-producing implements from their findings and have collected large numbers of such tools, in every continent. Ethnographers have recorded the making of petroglyphs for many more decades (see below). Archaeologists commenting on this subject seem unaware of both the ethnographic and scientific evidence available on this topic, and have created a purely theoretical system of taxonomy which is essentially impractical and derived from confirmation (science is falsification based).

Flood also refers to implements used in the production of petroglyphs elsewhere in her book, in relation to motifs made on the walls and ceilings of Australian limestone caves. She recounts some of my results concerning the tool materials used in making cave petroglyphs, and dedicates several pages to the question of how the anthropic ceiling markings in Orchestra Shell Cave (OSC), north of Perth, were made (Flood 1997: 59-66). Hallam (1971) suggested that the markings were produced with an animal claw fastened to the end of a stick, apparently without previous experience in the study of either animal scratches or finger flutings. As I was conducting a global review of both types of markings, I found her explanation not convincing, and expected to find animal scratches (which I have studied in about 1000 caves and shelters, examining samples in all continents, in dozens of countries) in the cave. Upon examining those in OSC I found that they were clearly finger markings, although heavily affected by travertine growth and erosion. Flood has found that Hallam continues to disagree with my interpretation and to hold fast to her hand-held claw hypothesis.

Flood actually offers a third explanation: that the subject markings in OSC are identical to certain markings in my photograph from Karake Cave which the researchers of the Parietal Markings Project unanimously define as standard animal scratches (Bednarik 1991b: Fig. 16). She concludes from this that both Hallam and I are right. But this is entirely wrong because Hallam and I agree fundamentally that the ceiling markings in OSC are humanly made. We only differ on the tool involved. In OSC, as in any other cave of the world (except on certain islands), there are animal scratches, but they are not the issue; the ceiling markings in one part of the cave are the issue.

This example illustrates the kind of trivialisation of aspects of the technology of rock art: opinions are formed almost without justification, on the basis of pictures in publications or similar spurious factors. In a scientific sense, rock art is not an archaeological phenomenon, but a geomorphological one: it is a form of biological weathering, a subject of human ethology. Most archaeological commentators on rock art ignore the geomorphological processes that have affected the art (e.g. the behaviour of carbonate speleothems or patterns of weathering in a cave environment), and yet rock art science has shown that it is primarily through these processes and their results that rock art can be studied scientifically.

One could argue that it does not matter if archaeologists invent a mythology about rock art; it does no harm. But this is not strictly true. Archaeologists are often placed in positions of executive control over rock art sites; they often excavate at rock art sites. If archaeologists are unable to recognise the tools used in the production of petroglyphs then they will not find or recognise the petroglyph tools in sediments below or near petroglyphs. Such finds will go unreported even though they are of profound importance to the archaeology of the site in question. For example, petroglyph tools in stratified sediments might be able to be dated, and since they were associated directly with some of the petroglyphs present they may provide reliable age estimations for the rock art.

Numerous archaeological excavations have been conducted at petroglyph sites, but there are no reports of stratified petroglyph-producing tools from nearly all of them. Since such tools have often been observed as surface finds by a few specialists (see below) it is to be expected that they should also occur below ground, especially at early sites. The explanation is probably to be found in the inability of most archaeologists to recognise such tools. Any such tools from stratified contexts would provide crucial archaeological evidence at a petroglyph site.

A recent illustration of this limitation is found in the reports of the numerous excavations conducted by several archaeologists in the Côa valley of northern Portugal, in most cases at the foot of petroglyph panels. As Swartz has already observed in relation to these excavations, 'important associated materials may be lost or destroyed, e.g. possible abandoned engraving tools used to make the markings' (Swartz 1997a: 73). Having conducted systematic removal of mineral and lichen covers at these sites (which have eliminated practically all possibilities of 'direct' dating; Jaffe 1996; Zilhão 1996; Bednarik 1996a; Swartz 1997a, 1997b), state-funded researchers have also eliminated the possibility of dating petroglyphs via stratified petroglyph-making implements because they lacked the competence to recognise them.

Ethnographic observations

The most extensive ethnographic information we possess about rock art is that of Australia, where painting on rock continues to the present day. Aboriginal painting traditions have not only survived, they thrive today on media such as bark and canvas. Knowledge about the cultural context and the techniques used in rock painting continues to be collected (e.g. Mulvaney 1996), and numerous Aboriginal communities across the country perceive recent rock art traditions as ongoing — as externalisations of living culture (Ward 1992).

Petroglyphs, on the other hand, are usually ascribed to 'the ancients' (as are some paintings), or are considered to be of non-human origins. They may have been made by ancestral heroes, or they are attributed to the time 'when the rocks were still soft' (Flood 1995; Mow-

aljarlai and Vinnicombe 1995). Although there is certainly a distinct paucity of ethnographic data concerning the production of petroglyphs, detailed accounts nevertheless do exist in Australia. For instance, Mountford has witnessed and photographed the making of petroglyphs on several occasions (1955, 1976). In 1937 he observed the production of sgraffito petroglyphs (figures produced by the removal of a layer of material of colour different to that of the material exposed) at The Granites, and reported that the artist used a 'small rounded pebble held in the hand' (Mountford 1976: 76). His photographs (Pls. 19, 20) show the left-handed use at a pavement site of a fist-sized, flattish cobble of about ten centimetres. A further illustration (Pl. 21) shows a man using a thin cobble of probably much less than 200 grams mass to produce a petroglyph by striking a vertical wall at eye level.

Mountford subsequently observed many recent petroglyphs along the Mann and Musgrave Ranges, and photographed Tjanjundina creating a narrative scene commemorating an emu hunt that had just taken place (Mountford 1976: Pl. 22). Here, the stone hammer held by Tjanjundina is so small it is concealed by his hand.

Much earlier reports are available from the Pilbara, Western Australia. Stokes (1846: 169), in describing the Depuch Island petroglyphs, recognised that images were made by pounding away the dark-brown rock varnish (sgraffito technique), but appears not to have witnessed the making of any petroglyphs. Withnell (1901: 29), also writing about the coastal Pilbara, mentions how the outline of a motif was first sketched with chalk or ochre, and then a 'sharp hard stone' was used to create impact grooves of about four millimetres depth. His description was confirmed by Clement (1903: 9), reporting from the same region. Clement also thought that chalk or charcoal was used to outline the figures, but that they were then hammered with 'a stone axe'. The latter practice seems very unlikely, for two reasons: stone axes are absent or very rare in the Pilbara (cf. Bednarik 1973, 1977: 68), and their sharp edges would not be used for such damaging tasks. So perhaps McCarthy (1961: 143) is right in assuming that Clement and Withnell merely surmised, but never actually saw petroglyphs made. Clement's illustration of a petroglyph-making implement (1903: Pl. 3) is not of an axe, but of a thin cobble, similar to that which Mountford (1976: 81, footnote 9) described from The Granites. On the other hand, Bates (n.d.) reported that petroglyphs were still made at Port Hedland when she was there, and Tindale has mentioned that a petroglyph was made there during his visit (Wright 1968: 71). Moreover, further evidence (Crawford 1964: 44) implies that outlines on Depuch Island were at least sometimes drawn with a sharp object before the petroglyphs were hammered in, which would tend to support Withnell's and Clement's accounts.

Evidence of the use of a pointed tool to initially outline the form of petroglyphs subsequently made by percussion is not limited to Australia. There are many examples among the Côa valley petroglyphs which were first outlined with a stone point, then struck with a stone hammer (Bednarik 1995a). I have observed similar treatment elsewhere, including in Asia (e.g. Siberia) and South America (e.g Peru).

There are further factors suggesting that petroglyph production in the Pilbara continued into this century. When I visited a petroglyph and occupation site near Tom Price (Site 2: Bednarik 1977) in the company of four Indjibandi men in early 1968, one of the men, who was in his seventies then, spontaneously produced a new petroglyph. He made a complex linear, to me non-iconic, motif within ten or twelve minutes. I was curious about several aspects of this event, including whether he had seen this done before. He stated, through a translator, that he had seen the old people do it when he was very young, and that he had done it himself as a child. On the occasion I observed then he used only a single tool, an untrimmed quartz cobble with a pointed end, about seven centimetres long, to strike the rock panel directly.

Implements for the production of petroglyphs

Up to this experience, I had made several false assumptions about the manufacture of petroglyphs, based essentially on the literature I was familiar with at the time: that Australian rock art was sacred and the preserve of initiated men; that one was only allowed to create rock art in one's own tribal territory (the site was not in traditional Indjibandi territory); and that the tools used in making percussion petroglyphs must have been quite large stones. I had not attempted any replication work prior to 1968, and I had simply assumed that to create the impact necessary to achieve the indentations on hard rock (such as diorite, as in the Tom Price example), a tool mass well in excess of a kilogram would be required. I was surprised to see such a small tool (of about 150 to 200 g) used so effectively, and subsequently began to look for suitable tools at petroglyph sites, in Australia as well as in the other continents.

Others have done much the same. In Anati's work, for instance, there are various references to the tools he observed at petroglyph sites (Anati 1976), which he sometimes even found on the carved surfaces themselves (e.g. Anati 1981: 14-5, showing examples from Negev Desert). This prodigious author's principal work is in the Valcamonica of northern Italy, where he has collected many petroglyph-making stone implements (Anati 1994: Fig. 40). At his Centro in Capo di Ponte, in 1981, I examined a series of such tools; they showed me that those found in Europe were practically identical to those I had observed elsewhere since 1968. At nearby Valtellina, similar tools were found in crevices of the large monolith of Rupe Magna, near Grosio (Arcà 1995: Fig. 112; Bednarik in press).

The problem Australian archaeologists have experienced in speculating about the manufacture of petroglyphs (of which their frequent use of the term 'engraving' in the place of 'petroglyph' is symptomatic) has its several parallels in other parts of the world. The

perhaps best example is provided by their Russian colleagues, in relation to the heavily researched Karelian petroglyph sites. Ravdonikas (1936a, 1936b, 1937, 1938) favoured the indirect percussion hypothesis, as did other Russian archaeologists. However, Savvateyev's (1970, 1973, 1976, 1977) detailed research failed to produce such percussion tools from the region's numerous excavations. He mentions dozens of excavations close to petroglyph sites, which have produced not a single tool used for indirect percussion. He did, however, find many 'impact stones', as he calls them: fist-sized quartz cobbles that fit well into the hand, with the working point distinguished by impact-scarring. He reports finding dozens near the mouth of the River Vyg, where Karelia's largest petroglyph site complex is located. Of particular relevance are the petroglyph-making implements he excavated immediately below the Besovy Sledky rock ledge, which bears a very dense concentration of 470 figures covering just a few square metres (Bahn et al. 1995).

At this point I would like to express my exasperation with the term '*petroglyph-making implement*'. Since there is no satisfactory shorter word to define this phenomenon (the word 'pecker' I have seen used is not a good candidate), but one is clearly needed, I shall use the name *mur-e* henceforth. This word is from the Booandik language of the Mt Gambier - Portland region in Australia (Smith 1880: 129). Just to clarify: in its scientific usage, mur-e (singular and plural) refers generically to a tool that has been used in fashioning a petroglyph, and as an adopted word it is not italicised henceforth. Such a tool may be of any material, but in most cases stone was used. Mur-e include percussion tools, abrasion tools, human fingers, and — if we chose to believe Hallam — even animal claws fastened to a stick.

Percussion mur-e

Since becoming aware in 1968 of what to look for, I have observed mur-e, especially those used in percussion, at many sites, and used facsimiles of them in replicative experiments well away from the art. In the Pilbara region of north-western Australia, where I recorded hundreds of petroglyph sites during the 1960s, I had ample opportunity to search the usually barren rock pavements and rock piles with their often large numbers of motifs, frequently being the first non-indigenous person to examine these sites. Mur-e were easy to find in such conditions of very minimal sediment formation and vegetation cover (Figure 1). In the early 1970s I extended my search to various other regions of Australia, increasingly using scientific methods to study mur-e. For instance, in 1971 I examined several at Sturts Meadows, and removed the specimen shown in Figure 2 for detailed analysis. The dark discolouration clearly visible on its impact-fractured point is dark-brown mineral matter. It consisted mainly (in descending order) of SiO_2, Al_2O_3, Fe_2O_3, MnO and TiO_2, and the trace elements Ba, Sr, Cu, Ni, Pb, V, Co and Cr. The composition of the pavement varnish nearby, sampled at the same time, provided a result so similar that there should be no doubt that this white quartz cobble was used to make petroglyphs at the site. In the same year I also observed mur-e at the Mootwingee site mentioned by Flood (1997: 103), but without keeping notes of them.

During the subsequent 27 years I have examined percussion mur-e in all continents except Africa (where I have studied so far only rock paintings and ground rock hollows). While there are no strict consistencies among them (see Figures 3 and 4 for examples) in material type or preparation, several striking characteristics should be noted:

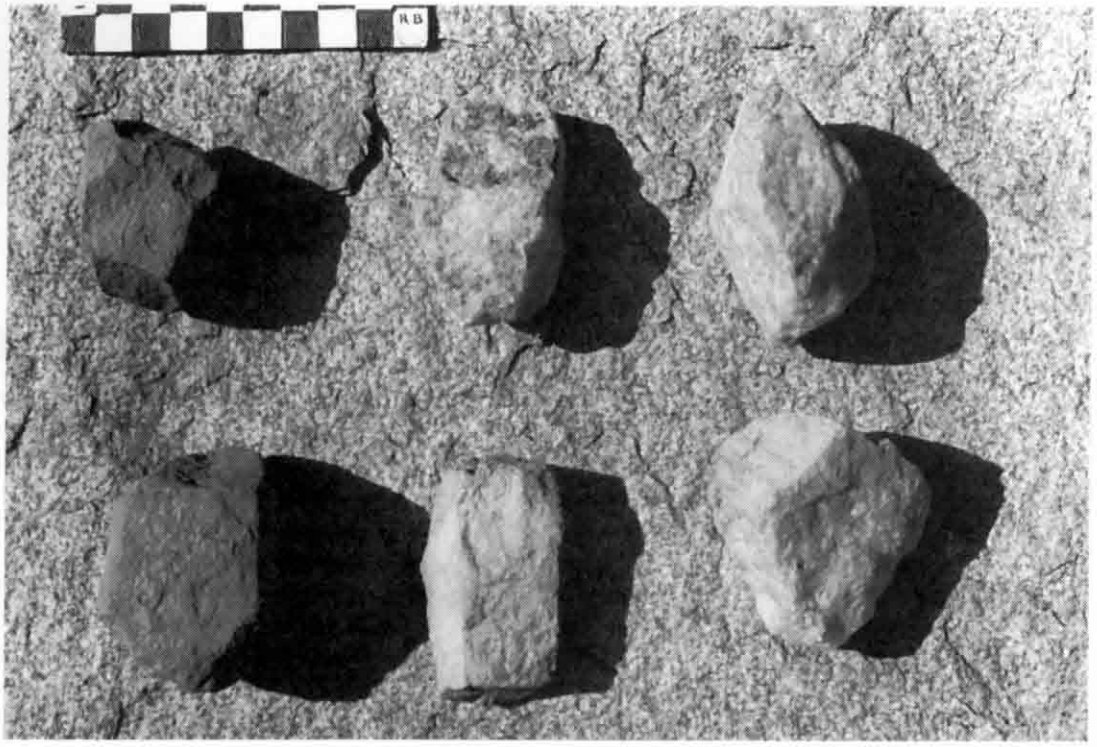

Figure 1. *Mur-e from dense petroglyph concentration on Burrup Peninsula, north-western Australia, photographed in 1968 but left at site.*

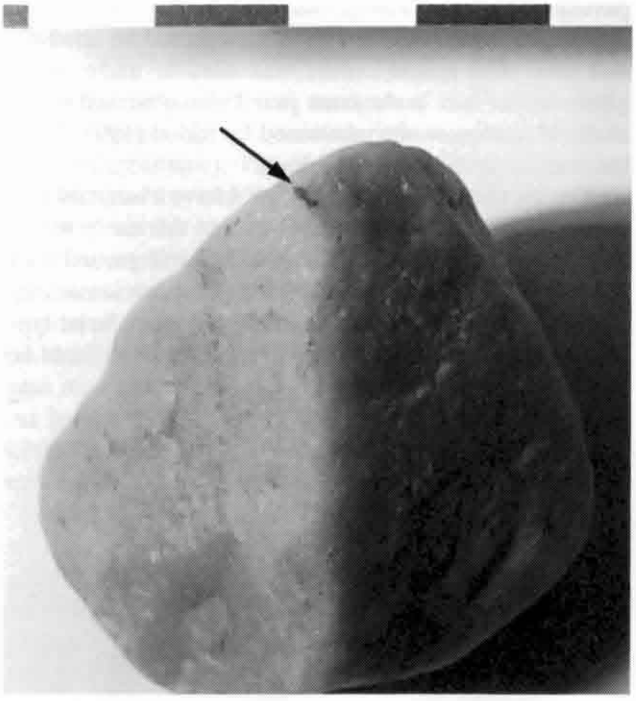

Figure 2. Two views of a quartz mur-e from Stuart's Meadows, western New South Wales. A residue of rock varnish and impact facture are visible on the point (arrow). Collected in 1971, now in AURA Archive.

Size: percussion mur-e are rarely large. As I have not taken scales to the field, and have rarely removed the finds from the sites, I cannot offer detailed statistics. However, percussion mur-e are usually under 150 g, and very rarely over 250 g. Weights of 100 to 130 grams are very common. Depending on the shape and relative density, this would correspond to a maximum dimension of 6 to 8 cm.

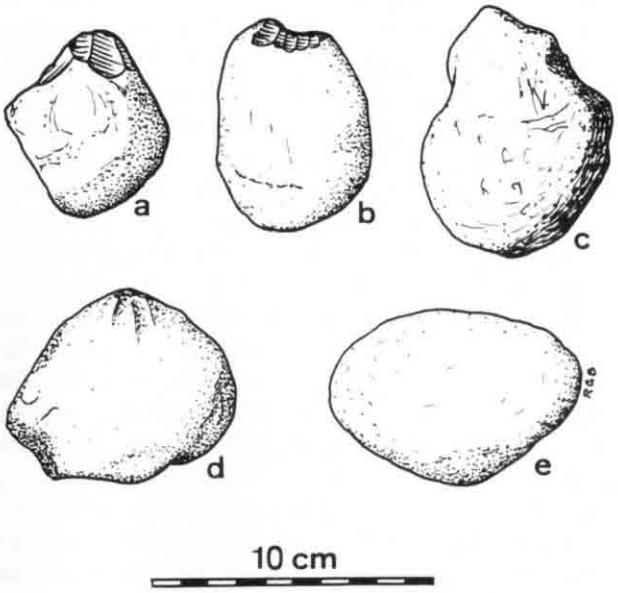

Figure 3. Quartzite mur-e excavated at Luine, a petroglyph site in Valcamonica, northern Italy.

Figure 4. Mur-e of coarse quartzite from the major petroglyph complex of Cerro Blanco, near Caborca, Mexico, collected in 1985 immediately below large decorated panel, now in AURA Archive.

Shape: the axis of maximum dimension usually coincides with the direction of application. There is considerable variation in shape, but overall there is a global preference for pieces with a thick end to be held in the hand, and a pointed end with which to strike the rock surface and which bears the wear marks. There

are, however, also flat and elongate shapes represented, and for patina-bruising even quite round pebbles or cobbles may have been used. Finally, there are also specimens that were used at more than one point (sometimes accounting for more than 25% of the mur-e present at a site).

Materials: in regions with an abundant variety of alluvial cobbles or clastic rocks, there is a distinctive preference for dense quartzites and crystalline quartz of various types. However, in regions of soft rock facies such as schists, carbonates or poorly consolidated sandstones, alternative materials may have been used for mur-e.

Preparation: contrary to a common assumption, few mur-e seem to have been prepared by prior flaking, in Australia and elsewhere. Quite early in my investigations I realised that even where there is some flaking around the working point, this is probably use-wear rather than intentional trimming. If small flakes are removed around the point as a result of impact they actually tend to lead to a more acute point rather than a blunting. However, I estimate that at least 80% of percussion mur-e bear no macroscopic flaking at all, be it use-wear or intentional preparation.

Wear: this is by far the most important and consistent aspect of percussion mur-e. Its characteristics are a direct function of the tool material properties, the rock panel's physical properties, and aspects of application of the tool to the rock panel. If the first two are well understood (see replication work, below), we can reasonably speculate about the third factor. The typical, most common wear-pattern to be observed is that generally acquired by quartzite mur-e when used on sandstone, variations of which are also found when applied to other rock types. There is an elongate, discrete area of bruising, convex (often of 4 to 5 mm latitudinal radius) and of a highly distinctive morphology. The microscopic relief of this facet is greatest at the margins, amounting to just a few microns of depth in the central part. Individual grains are rarely cracked, but their surface has a distinctly 'frosted' appearance when fresh. This wear-pattern cannot be identified with the unaided eye.

Wear-patterns on quartz are quite different. Microscopic conchoidal flake scars are found around minute depressions or faults within the wear facet. They measure usually from 50 to 150 μm. On a highly metamorphosed coarse quartzite, microscopic flaking and deeply developed macroscopic impact fractures can be observed adjacent to the principal impact area. Naturally there are also significant differences according to the type of rock that caused the mur-e wear. Recognition and interpretation of these features is a specialist task. I consider that it would be possible, on the basis of experimentation, to estimate the duration of time a mur-e was used for (i.e. approximately how many nicks it produced, or what length of engraved line).

Other mur-e

Leaving aside stick-mounted animal paws, a great variety of other materials may have been used to produce petroglyphs, especially where the rock is comparatively soft. The softest rock ever used in the making of petroglyphs is a carbonate speleothem called moonmilk (*Mondmilch*, *Montmilch*, *Bergmilch* etc.), a substance of pure calcite that may have the appearance, consistency and crystal structure (in the macroscopic sense) of freshly fallen snow. It can be marked by the slightest finger touch, and it has been marked in this way to produce petroglyphs called finger flutings (digital flutings, *sillons digitaux paralleles* etc.) during the past thirty millennia (Bednarik 1986), in at least France, Spain, Australia and New Guinea. This is one of the most widespread forms of cave art in the world, having survived in at least fifty limestone caves. Details of its very basic 'technology' have been reported in various of my publications, but a new development is the replicative work of Sharpe and Lacombe (1997).

Other types of cave petroglyphs offer considerably more scope for technological analysis. Engravings made with implements (rather than fingers) occur in numerous limestone caves in south-western Europe and southern Australia. Their detailed study (Bednarik 1986, 1987, 1994b, 1997) uses aspects of the methods pioneered by Marshack (1972, 1975, 1986, 1989), and experimentally developed by d'Errico (1987, 1991, 1992, 1994), for portable art objects of antiquity. Foremost in the application of these methods to cave engravings is the use of field optical microscopy, an approach I have used for decades, for securing technological information, for microerosion analysis, and since the 1970s for nanostratigraphy (Bednarik 1979).

As in the study of portable engravings (i.e. markings made with burins or similar tools), such as those of the Upper Palaeolithic of western Europe, microscope-assisted 'internal analysis' can clarify many aspects of the production of cave engravings. These include the direction of abrasion, the point of commencement, and priority of markings in a superimposition sequence. Markings made with the same instrument can sometimes be identified, although I reject the claims of both Marshack and d'Errico that they can also identify tool changes in what are said to be notational sets (cf. Bednarik 1991c).

Cave engravings have sometimes survived in superb detail, especially where a formerly soft wall deposit hardened soon after it was marked. This can often be observed on cave travertine deposits, especially in Australian sites, and 'internal analyses' of engravings have been conducted in both Europe and Australia (Bednarik 1986, 1992, 1994b). At some of the Australian sites, the types of stone tool material used in abrading mur-e were determined through replication studies from the striation patterns (e.g. Bednarik 1987).

Replicative experiments

The great significance of replicative experimentation in the study of petroglyph technology has been empha-

sised repeatedly in papers on fundamental rock art science (Bednarik 1991d [see chapter 'Replicative experiments'], 1992, 1994b). Replication studies of percussion petroglyphs have been conducted on numerous occasions, both in Australia and abroad. Crawford (1964: 44), in considering the technique used in making the petroglyphs on Depuch Island, Western Australia, remarked on how easy he found it to make petroglyphs 'in a minute or two' with 'a few taps on the stone'. McCarthy has conducted various experiments; for instance, he used 'the sharp corner of a piece of ironstone or ferruginous sandstone' to create direct percussion petroglyphs on Sydney sandstone (McCarthy 1967: 19). McCarthy's (1962: 44) experiments at Port Hedland using whelk shells to bore rather than to pound the oolite pavement led to Maynard's (1977) inclusion of the category 'drilled petroglyphs' in her schema. Wright (1968: 34), conducting his own replication experiments, found that he could produce only very small pits in the limestone by rotating the point of a sharp, hard stick. He suggests that sharp hard rocks were used, which is consistent with my own observations at the Port Hedland sites in 1967, later confirmed by microscopy.

Among the examples of replicative petroglyphs that I have examined with the microscope, I found some Russian examples particularly impressive. Many were made under controlled conditions, some were recorded on film. Savvateyev (1977) used mur-e collected from nearby excavations at Belomorsk, on the White Sea, to produce a filled-in image of a whale, similar to pre-Historic figures, in 30 minutes. The most difficult part, he reports, was to produce a precise edge; he attributes this to his lack of experience. His replication studies, like those of other Russian researchers working in Karelia (such as, more recently, A. Faradjev, pers. comm.), were conducted on massive, frequently un-patinated granite pavements.

In my own replicative experiments, conducted from 1968 to the present on many lithologies, I found that the physical effort involved in producing percussion petroglyphs varied enormously according to the rock type, its weathering state or patination (Bednarik 1979), and to a lesser degree on the type of mur-e and technique employed. It is entirely impossible to generalise from isolated experiences, and all variables need to be fully recorded and quantified in such experimentation. For instance, rock types on which percussion petroglyphs were most frequently made are the facies of sandstones found in the sections of the Gondwana plate. Having conducted experiments on these sandstones in southern Africa, India, Australia and South America, I have asked scholars how long they think it would take to create (a) a hammered and abraded groove of ten cm length and one cm depth, and (b) a cupule of 12 mm depth, on well-weathered sandstone. The true answers are (a) one minute and (b) two minutes respectively, but all estimates I was given were very significantly higher (ranging from 15 minutes to 6 hours). This is a fair indication of the effects of an acute lack of experimental work in petroglyph technology, and of inadequately published results of experiments (Figure 5).

Figure 5. Standard petroglyph replicas, consisting of a 10-cm-long hammered and abraded groove of 10 mm depth, and a cupule of 12 mm depth. The mur-e used for each marking are shown, and were subjected to detailed study of wear traces.

The microscopic examination of abraded petroglyphs (engravings) is similar to the forensic procedures of determining from which firearm a bullet was fired. Indeed, many of the well-established methods of forensic science are of relevance to rock art science, but we appear to be reluctant to avail ourselves of them (Bednarik 1992). For instance, the detection of human blood residues, a standard technique in forensic science, was attempted in rock art only a few years ago (Loy et al. 1990; but cf. Nelson 1993). I have described experiments designed to determine the types of stone tool material used in Australian cave engravings at such sites as Nung-kol Cave in South Australia and Mandurah Cave in Western Australia (Bednarik 1987 — this work was not conducted within the caves, but on substitute materials).

There are good reasons, however, to replicate open site percussion petroglyphs at nearby rock surfaces, and to record all details of their production. I have found such replicas, including those I made decades ago, most useful in studying weathering and patination processes. Such studies, in turn, may be relevant to dating research and conservation work. What is therefore required are not only comprehensive records, but a central repository of these records so that future taphonomic studies of petroglyphs can be based on sound information rather than conjecture. Such records, to be adequate for future reference, perhaps centuries from now, need to include the following minimum details:

a. Precise location, so that the actual marking(s) can be found again. The location must be referenced to permanent features, not vegetation, sediment or unstable rock features.
b. Condition and aspects of the rock surface at the time: depth of weathering rind; details of patination; exposure to rain, insolation and wind. Is the rock dry or wet? Which direction is the replica petroglyph facing?
c. Petrology of support rock substrate; rainwater acidity at the site; annual precipitation details.
d. Type and material of mur-e used; their weight; microscopic description of tool wear.
e. Description of manufacturing technique used; time taken.
f. Recording of true colours by photography with a colour scale calibrated for digitised colour re-constitution (IFRAO Standard Scale — Bednarik and Seshadri 1995).

This type of work can produce invaluable new information, not just that concerning petroglyph dating and conservation, but also concerning chemical and physical erosion rates, chemical changes in rock subsurfaces, lichenometry, the formation of rock varnish or other accretionary mineral deposits, and so forth, all of which can help other disciplines besides rock art research. The *ad hoc* approach to the need of replicative experimentation that seems evident from the literature needs to be replaced with a systematic program of research. Such a program could be guided or even administered by the International Federation of Rock Art Organisations (IFRAO).

The dating of mur-e

The most recent development in the study of mur-e is their use in the dating of petroglyph-making activity. The practice of dating the mur-e rather than the petroglyphs was first applied in Bolivia in 1997. The difficulties in dating petroglyphs by a 'direct' method (for definition see Bednarik 1981, 1996b) are well appreciated. Essentially, those very few methods that might provide reliable results are notoriously imprecise and their application is limited to specific rock types and site morphologies. Other methods do exist but they are without exception fraught with difficulties (Bednarik 1979, 1996b; Dorn 1996). One possibility that has not been explored so far is to determine when any mur-e found at petroglyph sites were used. It cannot usually be known on which motif they were used, but if the number of motifs present is small and they seem to be of similar ages, this might suffice to arrive at an estimate of the age of those motifs. Where several mur-e are available from a single site they may be used to estimate the times when different marking traditions were in use. This has been successfully done already.

As in the case of petroglyphs there are two fundamentally different ways of estimating mur-e ages. One is by archaeological methods, using deductive reasoning. Generally this would involve indirect dating of some kind, probably radiocarbon determination of charcoal found in apparent association with the mur-e. Results acquired by these means may well be valid, but it must be cautioned that, as in the case of petroglyphs dated by indirect, archaeological means, there is no simple way to refute the proposition: we have to accept inductive pronouncements on trust (e.g. that the validity of the chronological association of charcoal and mur-e has not been negated by taphonomic factors).

The second method of determining the time a mur-e was used (or last used) is to estimate the age of the wear marks on it. The only technique used so far is that of microerosion analysis applied to fracture edges of percussion mur-e (Bednarik in prep. a). This can only be applied to mur-e found on the surface, preferably on an open rock pavement, and with the certainty that they have not been covered by any sediment since their use. Moreover, it is limited to the kind of rocks suitable for microerosion analysis, particularly the quartz or quartzite often used for mur-e. A further limitation, one which affects precision rather than reliability, is the absence of calibration curves (which continues to hamper the application of microerosion dating generally).

During recent fieldwork in Bolivia I examined several petroglyph sites on the foot of Cerro Tunari in the pleasant company of Jack and Sandra Steinbring, André Prous, Roy Querejazu Lewis and Robert Bednarik Jr. This series of sites exists on monolithic outcrops, several

hundred metres apart, that dot the glacial valley floor some distance from where it abuts the mountain's steep slopes. The outcrops measure several metres across and are a few metres high, and are usually steep sided. The petroglyphs have been made on their upper platform surfaces. We found tiny slivers of white quartz in the cracks of the decorated platform at Kalatrancani 3, and, at nearby Kalatrancani 1, a mur-e of white quartz a few metres from the outcrop. Microscopic examination indicated that the mur-e had been used to pound a hard surface, and I collected quartz fragments at site 3 for detailed analysis. Since they were found on top of the steep-sided rock, several metres above the surrounding plain, it seems highly likely that they have remained from the petroglyph-making activity. Microerosion analysis can easily determine whether these quartz chips were made recently or in the distant past.

Preliminary examination of seven quartz chips from Kalatrancani 3, all under 11 mm long, suggests that they derive from a crystalline quartz morphologically similar to the mur-e from Kalatrancani 1. They were detached about 500 to 600 years ago, which suggests that the petroglyphs among which they were recovered — or at least some or one of them — were made shortly before the arrival of the Spanish in South America. The mur-e from the second site was used slightly earlier.

On another field trip in Bolivia I completed an intensive study of a site I had begun in 1987, the small sandstone cave of Toro Muerto, in the Mizque valley, located near Saipina. The barren rock shelf in front of the cave is strewn with hundreds of stone tools, which I surveyed systematically, finding ten mur-e. Among these I selected the five best specimens (Figure 6), based on clarity of bruising marks and their susceptibility to microerosion dating. (These are now in the keeping of the Sociedad de Investigación del Arte Rupestre de Bolivia.) Excellent microerosion data have been secured from them, indicating that the three most recently used date from about the same time, one is almost twice as old, while the fifth has clearly been used on two different occasions, separated by about 3500 years (Bednarik in prep. b). Earlier I had proposed (Bednarik 1988) that there are three or four episodes of use of the cave documented in its petroglyphs; this proposition was based on the evidence of four exfoliation events then discernible, and directly relatable to the rock art (much of this evidence is no longer present, because in the meantime someone has destroyed part of the petroglyph panel with dynamite). This study shows that, under favourable conditions, it is possible to estimate the ages of a series of petroglyphs without excavating any sediments or even examining the motifs.

Summary

This preliminary review of petroglyph technology is not intended to be exhaustive or comprehensive. My purpose is to stimulate a basic appreciation of the potential and general procedures of technological studies in petroglyph manufacture, and to suggest that there are similar prospects for rock paintings. The primary intention is to convey the enormous potential of this neglected aspect of rock art research, and to show its close nexus with terminological constructs in petroglyph studies.

Several fundamental issues emerge from this paper. In the first place, archaeologists who lack the ability to recognise and to study mur-e need to be discouraged from excavating at and near petroglyph sites, unless they can secure the collaboration of a specialist for this purpose. We cannot afford to continue destroying key evidence at petroglyph sites.

Figure 6. Five mur-e from Cueva Toro Muerto, central Bolivia, collected in 1997, now in SIARB collection.

Secondly, a lack of understanding of the technology of petroglyphs leads to a misuse of terminology. The names used for additive rock art forms are more appropriate than those often applied to petroglyphs, precisely because they are technology-derived terms: stencils, paintings (applied wet), drawings (applied dry), beeswax figures etc. Reductive rock art (petroglyphs) is often defined by subjective technological labels: engraving (often misused), carving (inappropriate), pecking (possibly always misused), pounding, etching (a possibly inappropriate description from South America), boring or drilling (doubtful). Petroglyphs come in two basic forms: as sgraffiti (defined by colour contrast) or as relief petroglyphs (defined by relief depth). Both of these types can be made either by percussion or abrasion. The sgraffito method has been widely used on ceramics in the past and is still used with cement render on building facades. The majority of the world's petroglyphs were sgraffiti. Sgraffito petroglyphs have a limited life span (Bednarik 1994c, 1995b); in most cases they remain visible only for as long as it takes the rock surface to repatinate fully. This applies particularly to rock art sgraffiti made by merely bruising a varnish cover. In archaeology, the technological definition of sgraffito has remained almost unknown (Bednarik 1979: Note 1), and false chronologies were based on this taphonomic misapprehension of how technique may determine longevity (Bednarik 1994c: Fig 1). Indeed, inadequate understanding of taphonomy is a major factor in misinterpreting rock art quantitatively as well as qualitatively, and it is closely related to misapprehensions about technology as it relates to petroglyphs.

Finally, I have suggested the need for an international register of petroglyph replication experiments, which would be a multi-purpose project. A similar proposal was made at the First AURA Congress in 1988: it was intended to facilitate a long-term study of the development of rock varnish, a more limited intent. At that time, digitally-supported colour calibration was not available. The project I envisage would consist of two strategies:

(1) Establishing test stations at suitable sites, in a range of climatic, lithological and biological environments, at which petroglyph replicas are made under entirely controlled and fully recorded conditions. These would then provide the basis of a taphonomic study over several centuries, during which weathering, patination, and microerosion are monitored. This, obviously, would result in a massive improvement of our understanding of the processes involved, beginning with petroglyph technology, and ending with solid knowledge about the effects of variables on dating and other analytical prospects as they relate to petroglyphs. Australia, with its great diversity of rock art environments, would be ideally suited, and such a program would produce significantly better data than laboratory-based experiments of accelerated weathering.

(2) The creation of a global archive of all past and future petroglyph replication work conducted. Establishment and management of such an archive needs to be done by an international organisation; IFRAO could undertake to collate information, and to disseminate the data and results freely to all researchers.

This strategy would not only lead to a significant increase of our basic knowledge of all variables that relate to the preservation/deterioration of petroglyphs, their dating and analytical study, but also would lead to an unprecedented broadening of the scientific basis of our discipline, one that is not realistically achievable by other means. No simplistic approach can improve rock art science; this is a field that needs to take into account many variables. We have experienced significant improvements over the last couple of decades, but we have also learnt that our embryonic science has serious limitations (Bednarik 1996b). What our experiences over the last three or four years (during which we recovered from an initial euphoria) should have shown us is that there are no shortcuts in this discipline. Spectacular discoveries, claims or results have been useful in focusing public attention upon our work. Sometimes they even withstood critical assessment. But bold and adventurous forays into uncharted territory are essentially opportunistic; they need to be augmented, if not replaced, by a systematic approach. Our scientific base in rock art research remains diminutive; it needs to be increased many times if our discipline is to operate in the orderly way of scientific pursuit. A determined collective effort of the type envisaged here is necessary for this development.

I end this paper with a cordial appeal to all colleagues: if you are aware of a petroglyph replication experiment that has been conducted in your country or research region, would you please record the details available to you and send them to the IFRAO Archive at the address below. The very minimum necessary is precise location of the replica (as defined above), and the year the motif was created; details of the tool used would help greatly. All contributions will be acknowledged in future publications, but if you prefer to remain anonymous your information is still welcome.

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Résumé. *On examine des méthodes de production des gravures sur roche, à l'aide des traits caractéristiques dans l'art rupestre et des instruments utilisés pour créer cet art pariétal. On discute ces outils des perspectives ethnographiques et archéologiques, et on considère les limites de leur étude détaillée. Nous prêtons particulièrement attention à l'usage.*

d'expériences reproductrices et à l'utilisation d'outils à graver sur roche récemment introduite en vue d'estimer l'âge de l'art rupestre. L'article conclut en demandant la création d'un projet non seulement pour étudier la production de gravures systématiquement, mais aussi pour maîtriser leur taphonomie sous des conditions contrôlées au cours d'une période très longue.

Zusammenfassung. *Petroglyphen-Herstellungsmethoden werden untersucht, durch charakteristische Spuren in der Felskunst ebenso wie die in der Schaffung dieser Felskunst verwendeten Geräte. Solche Werkzeuge werden von ethnographischen und archäologischen Gesichtspunkten erörtert, und der Bereich ihres detaillierten Studiums wird in Betracht gezogen. Besondere Beachtung erhält die Anwendung von Replikationsexperimenten, und die neu-eingeführte Verwendung von Petroglyphen-Herstellungswerkzeugen als ein Mittel, das Alter der Felskunst zu schätzen. Der Artikel schließt mit dem Vorschlag der Einführung eines Projektes, das nicht nur die Herstellung von Petroglyphen systematisch untersucht, sondern auch ihre Taphonomie, unter Beaufsichtigung über einen sehr langen Zeitraum.*

Resumen. *Se examinan métodos para hacer petroglifos, tanto a través de vestigios característicos en el arte rupestre como en los instrumentos usados en crear dicho arte rupestre. Herramientas para grabar las rocas son discutidas desde perspectivas etnográficas y arqueológicas, y el alcance de su detallado estudio es considerado. Se presta atención especial al uso de experimentos con réplicas y el recientemente adoptado uso de instrumentos para hacer petroglifos como un medio para calcular la edad del arte rupestre. El artículo concluye con un llamado para establecimiento de un proyecto, tanto para estudiar sistemáticamente petroglifos, y para monitorear su tafonomía bajo condiciones controladas sobre un período muy largo.*

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