PALAEOART AND MATERIALITY

THE SCIENTIFIC STUDY OF ROCK ART

edited by

Robert G. Bednarik, Danae Fiore, Mara Basile, Giriraj Kumar and Tang Huisheng

ARCHAEOPRESS ARCHAEOLOGY
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Forensic Replication Work with Australian Cave Art

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In an effort to promote the merits of forensic work in rock art science, this paper reports such work conducted in one of the cave art sites of Australia, Ngrang Cave in western Victoria. This relatively small cave contains hundreds of petroglyphs, including sub-parallel sets of grooves and finger flutings. Its entrance chamber contains a large collection of cupules, which are the deepest so far reported anywhere. The cave wall is soft limestone, and many of the holes in it, although weathered, still bear distinct tool traces dating from the time they were made. In order to establish how these deep cupules were made, and with what kinds of tools, detailed forensic and replication studies were conducted. The results are illustrated and reported.

Introduction

The relevance of forensic science to the effective study of rock art and portable palaeoart is a relatively recent development. Intuitively the potential of this approach has long been evident, and has been developed by such scholars as Semenov (1957), Marshack (1985) and, more recently, d’Errico (1991). However, such work focused on portable materials, such as stone tools, engraved plaques and other mobiliary palaeoart. The deliberate application of forensic principles to immovable palaeoart involves the need for intensive field work, as in most circumstances the research cannot be limited to laboratory analyses. Montelle’s (2009) dictum that ‘Rock art [research] is forensics, or it is nothing’ is so obviously valid that it should not need to be rationalised. Non-forensic studies of rock art have resulted in a cacophony of untestable pronouncements about meaning, antiquity, stylistic status and so forth, but very little that could be considered to be of scientific standard or relevance.

Forensics, in the narrow sense, defines the science of determining what happened at a crime scene, although its original Latin meaning refers to the forum of presenting evidence at a public hearing. In the application to rock art research, the site is approached as a crime scene, and the central question remains “What happened here?” Methods of assessing evidence resemble those commonly employed in forensic science: the striations found on a fired bullet that identify the barrel it was fired from become those of engraved grooves preserving properties of the uneven point of the engraving tool; the detection of minute traces, such as blood (and its molecular characteristics) has its parallels in the analysis of rock art paint residues; and the determination of physical aspects of the perpetrator (such as physical size or handedness) also apply to the rock art producer. As predicted by Locard’s Exchange Principle, the universal theory underlying much forensic work, whenever two objects come into contact with one another, a transfer of material will occur. Most of the ensuing reactions occur on a very small scale. Therefore from a forensic perspective, a rock art site must be treated precisely like a crime scene: every modern modification must be avoided, or limited to that occasioned by the forensic scientist. Another aspect shared by forensics and rock art science is the profound importance of the effects of taphonomy (Efremov 1940), just as it is impossible to understand archaeology without the application of taphonomic logic (Bednarik 1994a).

The testability of forensic propositions is generally accomplished by replicative experimentation. Preliminary efforts to use this valuable research tool have been documented for several decades with rock art (McCarthy 1962, 1967; Crawford 1964; Wright 1968; Sierts 1968; Pilles 1976; Savvatyeyev 1977; Loendorf 1984; Lorblanchet et al. 1990), but to formalise them as...
a forensic approach has been a more recent development (Bednarik 1998a, 2001, 2006; Weeks 2001). The present paper offers an example of this approach.

**Forensics of rock art**

A prime example of forensic analysis of rock art, the microscopic study of engraving tool traces, has also been developed only recently (Bednarik 1984, 1986a, 1987/88, 1992a, 1997, 1998a; Kitzler 2000; Alvarez 2001), despite the corresponding criminal forensics technique of matching bullet striae having been in use since Alexandre Lacassagne, professor of forensic medicine at the University of Lyons, introduced it in 1889 (improved by Paul Jesrich in 1898 and Victor Balthazard in 1910). Similarly, any other forensic methods were introduced in rock art research much later than elsewhere, if indeed at all. Occasional attempts to establish paint ‘signatures’ (Clottes et al. 1990; Bednarik and Fushun 1991), the identification of microscopic plant fibres in paint residues (Cole and Watchman 1992), and the nano-stratigraphic excavation of accretionary mineral deposits (Bednarik 1979; Watchman 1993, 2000) all qualify as forensic work. However, the most extensive work of this kind has been applied to the determination of paint composition (Koski et al. 1973; Clarke 1976; Ballet et al. 1979; Moffat et al. 1989; Clottes et al. 1990; Peisach et al. 1991; Clarke and North 1991; Pepe et al. 1991; Petit and Valot 1992; Watchman 1993; Scott and Hyder 1993; David et al. 1993; Morwood et al. 1994; Hyman et al. 1996; Mawk et al. 1996; Scott et al. 1996; Meneses L. 1996; Barker et al. 1997; Ward et al. 1999; Rowe 2001; Ward et al. 2001; Edwards 2004; Edwards and Chalmers 2005; Howell 2005; Valdez et al. 2008; Sepúlveda et al. 2012). The only attempt so far to detect blood residues in rock paintings (Loy et al. 1990), however, has been refuted (Nelson 1993; Gillespie 1997; cf. Scott et al. 1996).

A similar forensic approach targeted at the study of petroglyphs has only been attempted rarely. For instance, a hammerstone used in the production of percussion petroglyphs was found to bear traces of ferruginous patination at the impact-flaked point, which yielded the same chemical signature as the patination into which designs had been hammered nearby (Bednarik 2001: 40). In this case the analysis had the specific purpose of testing the proposition that the hammerstone was used to create rock art at the site, which illustrates the important role of forensics in subjecting interpretations of evidence to falsification attempts.

In comparison to principally chemical work, anthropometric studies of rock art have remained relatively neglected. Both handprints and hand stencils (Freers 2001; Gunn 2006, 2007) can provide such data, and in Australia other human body parts have frequently been stencilled. The endeavours to determine the sex of hand stencil producers on the basis of the ratio between the 2nd and 4th digits of the human hand (e.g. Guthrie 2005; Chazine and Noury 2006) illustrate that care needs to be taken not to over-interpretsuch evidence. Finger length ratios can differ considerably among populations (Henneberg and Mathers 1994; Gunn 2006). Hand sizes may offer more robust metrical data through systematic measurement of prints and stencils, and the same applies to finger-stamped patterns on painted plaques (Bednarik 2002) and to finger sizes determined from parietal finger flutings in caves (Bednarik 1986a, 1987/88; 2008a; Sharpe and Van Gelder 2006). Kinetic mechanics in mark production could also be applied in forensic investigation, although the issues involved are too complex for simplistic generalisations or indexation and are in need of much more attention. Both cultural and physiological factors influence kinetic mechanics and they need to be accounted for.

There are numerous further forensic techniques that could be potentially applied to rock art, but this field remains in an embryonic state and has yet to develop a reasonably comprehensive arsenal of methods. For instance it is very likely that specific photographic techniques may profit a forensic investigation of palaeoart; for instance ultraviolet photography can render pigment traces detectable that are not visible to the unaided eye. However, such approaches have only been used rarely so far. Here it is attempted to demonstrate that a comprehensive replication program of forensic method can be profitably employed in testing interpretative propositions in rock art studies.

**Forensics in Australian caves**

Australia has the third-largest concentration of cave art (after south-western Europe and the very recently discovered corpus of northern Papua New Guinea), which has been studied by the Parietal Markings Project (PMP) since 1981 (Bednarik 1982). This project has developed and applied forensic methods for decades. Australian cave art comprises mostly petroglyphs and is exclusively non-figurative. Over the past three decades the PMP has developed forensic methodology of discriminating between natural and anthropic rock markings in caves (Bednarik 1980, 1986b, 1991a), and of the traceological analysis of engraved line markings (Bednarik 1991b, 1992a, 1994b, 1997).

Geological, radiometric and stylistic evidence and contextual relationship (e.g. superimposed megafaunal scratch marks) suggest that most Australian cave art is of the Pleistocene, although a significant Holocene component has also been demonstrated (Bednarik 1998b, 1999). The following basic types are provisionally identified: finger flutings on moomilk deposits, deeply pounded and abraded petroglyphs of the Karake genre, apparently non-utilitarian tool markings, deep pits or
cupules, shallow engravings and recent petroglyphs, and pigment stencils. The relative chronological relationships among these classes have only been resolved partially, and the age of the chert mining evidence frequently co-occurring with Australian cave art has not been conclusively established.

Among the specific forensic preoccupations of the PMP have been the determination of the types of tools used in making wall markings, including the recognition of the ‘signatures’ of specific rock types through traceology (e.g. Bednarik 1987/88, 1992a); the determination of the approximate ages of the producers of finger flutings by metric analysis (e.g. Bednarik 1986a, 2008a); the detection of geomorphological events contextually related to the rock art, such as tectonic adjustments, roof falls, subsidences, inundations, speleo-weathering processes or biospheric weathering (e.g. Bednarik 1989, 1999); the reconstruction of superimposition sequences of finger flutings (e.g. Bednarik 1984, 1985, 1986a); the determination of the order of tool applications and their direction to reconstruct wall marking events (e.g. Bednarik 1987/88, 1992a, 2006); and a variety of replicative experiments to test hypotheses.

Other anthropic activities demonstrated to have occurred in Australian caves containing rock art include the mining of sedimentary silica deposits, their use as habitation sites and living quarters, and the exploration of deep passages, especially by young people. The PMP focused specifically on chert mining evidence in two caves and chalcedony mining in a third (e.g. Bednarik 1986b, 1990, 1992b, 1995), which in some cases involved the application of specialised mining techniques and tools, determined through forensic evidence provided by tool marks and impressions of tool points. Pleistocene silica mining is known from one cave site each in Hungary and France (Bednarik 1986b; 1990), and from two alluvial sites in Egypt (Vermeersch et al. 1986). In Australia, extensive traces of subterranean silica mining have been located in nine caves so far, and in six of them they occur close to petroglyphs. The reconstruction of the activities that led to these traces employing forensic methods has provided a basis of distinguishing five basic mining methods at the Australian pre-Historic silica mines.

The deep cupules of Ngrang Cave

Since 2007, the authors have focused on one of the rock art phenomena of one Australian site, Ngrang Cave, used here to illustrate some generic principles of forensic work with cave art. This work involves various levels of analysis (see Montelle 2009):

1. The macro-level: overall setting of the cave, its speleogenesis and establishing how the present evacuational and convacuational spaces developed through time.

2. The medium level: the site formation processes that contributed to the present state of the immediate environment of the cave art (i.e. within a few metres of it).

3. The micro-level: the precise details of the features which the previous levels of investigation have identified as relevant, such as wall markings, weathering details, speleothems, or any form of tectonic, fluvial, phreatic, vadose or biological traces.

4. The microscopic level: the magnified examination of tools, markings, residues, traces and so forth, details which are not visible to the unaided eye.

5. Replication: this refers to the experimental work of reproducing observed outcomes or traces for the purpose of testing specific hypotheses concerning specific observations.

From a scientific perspective it is important to appreciate that in the absence of knowledgeable ‘owners’ or custodians of the rock art in question, any credible understanding of the circumstances of the production of the rock art can only be derived through this procedure, and in combination with an understanding of taphonomic effects and the relative or absolute chronology of relevant events. Ngrang Cave is a fluvial tunnel cave formed by a Pleistocene subterranean stream that very likely drained into the nearby Glenelg River, in the far south-west of Victoria. After the general lowering of the region’s aquifer levels during glacial periods the horizontal tunnel, just a few metres below the surface plain, began to collapse in some places along its course (Figure 1). A part of this tunnel is now accessible in one place, from where it can be followed for about 30 m. The very low convacuational space contains very numerous anthropic wall markings of various types, but here a specific location is considered, a series of 52 tool-made cavities (‘deep pits’ or ‘alveoli’, considered to be a deep
## Table 1. The primary characteristics of the forty-five deep cupules in Ngrang Cave, south-western Victoria, Australia.

<table>
<thead>
<tr>
<th>Extr. pit No.</th>
<th>Max. dia.</th>
<th>Min. dia.</th>
<th>Depth, mm</th>
<th>Orientation</th>
<th>Inclination</th>
<th>1 cm from deepest point</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP1</td>
<td>105</td>
<td>69</td>
<td>124</td>
<td>10°L</td>
<td>20°D</td>
<td>35</td>
<td>Extensive groove marks on upper half.</td>
</tr>
<tr>
<td>EP2</td>
<td>60</td>
<td>45</td>
<td>42</td>
<td>10°L</td>
<td>0°</td>
<td>31</td>
<td>Groove markings on top and left; very faint.</td>
</tr>
<tr>
<td>EP3</td>
<td>102</td>
<td>88</td>
<td>196</td>
<td>30°L</td>
<td>5°D</td>
<td>40</td>
<td>Grooves all around except on floor.</td>
</tr>
<tr>
<td>EP4</td>
<td>56</td>
<td>46</td>
<td>65</td>
<td>20°L</td>
<td>5°D</td>
<td>20</td>
<td>Fairly cylindrical shape. Faint broad grooves across most surfaces.</td>
</tr>
<tr>
<td>EP5</td>
<td>95</td>
<td>70</td>
<td>72</td>
<td>10°L</td>
<td>10°U</td>
<td>30</td>
<td>Faint and primarily on top rim. Potential scars of tool tips.</td>
</tr>
<tr>
<td>EP6</td>
<td>73</td>
<td>60</td>
<td>72</td>
<td>35°L</td>
<td>0°</td>
<td>20</td>
<td>Very pointed section with very faint grooving on top.</td>
</tr>
<tr>
<td>EP7</td>
<td>112</td>
<td>85</td>
<td>175</td>
<td>20°L</td>
<td>20°D</td>
<td>25</td>
<td>Deeply grooved on most surface, including floor.</td>
</tr>
<tr>
<td>EP8</td>
<td>60</td>
<td>52</td>
<td>67</td>
<td>30°L</td>
<td>0°</td>
<td>30</td>
<td>No markings visible.</td>
</tr>
<tr>
<td>EP9</td>
<td>70</td>
<td>64</td>
<td>53</td>
<td>30°L</td>
<td>0°</td>
<td>25</td>
<td>Faint.</td>
</tr>
<tr>
<td>EP10</td>
<td>140</td>
<td>90</td>
<td>110</td>
<td>10°L</td>
<td>0°</td>
<td>10</td>
<td>Amorphic/atypical with very deep grooves. Tool tips in floor.</td>
</tr>
<tr>
<td>EP11</td>
<td>120</td>
<td>70</td>
<td>55</td>
<td>10°L</td>
<td>10°D</td>
<td>40</td>
<td>One groove on top tunnels along the surface.</td>
</tr>
<tr>
<td>EP12</td>
<td>65</td>
<td>42</td>
<td>42</td>
<td>10°L</td>
<td>5°U</td>
<td>20</td>
<td>No visible markings.</td>
</tr>
<tr>
<td>EP15</td>
<td>95</td>
<td>80</td>
<td>65</td>
<td>30°L</td>
<td>5°D</td>
<td>15</td>
<td>Some groove marks around the top.</td>
</tr>
<tr>
<td>EP16</td>
<td>Amorphic</td>
<td>28</td>
<td>0°</td>
<td>20°U</td>
<td>Amorphic</td>
<td></td>
<td>Atypical shape with several tool tip impressions but no grooves.</td>
</tr>
<tr>
<td>EP17</td>
<td>Amorphic</td>
<td>28</td>
<td>0°</td>
<td>20°U</td>
<td>Amorphic</td>
<td></td>
<td>Several tip marks but no grooves (too shallow).</td>
</tr>
<tr>
<td>EP18</td>
<td>90</td>
<td>65</td>
<td>87</td>
<td>20°L</td>
<td>0°</td>
<td>40</td>
<td>Faint grooving all around + tool tips on floor.</td>
</tr>
<tr>
<td>EP19</td>
<td>110</td>
<td>90</td>
<td>165</td>
<td>10°L</td>
<td>10°U</td>
<td>40</td>
<td>Groove marks on all surfaces.</td>
</tr>
<tr>
<td>EP20</td>
<td>85</td>
<td>75</td>
<td>76</td>
<td>5°L</td>
<td>0°</td>
<td>35</td>
<td>Faint tool marks on right, fairly corroded.</td>
</tr>
<tr>
<td>EP21</td>
<td>95</td>
<td>70</td>
<td>47</td>
<td>0°</td>
<td>5°U</td>
<td>20</td>
<td>Angular appearance. 'comet'-like morph.</td>
</tr>
<tr>
<td>EP22</td>
<td>88</td>
<td>50</td>
<td>54</td>
<td>0°</td>
<td>5°U</td>
<td>40</td>
<td>Shows evidence of indirect impact - good grooves around top; flat floor.</td>
</tr>
<tr>
<td>EP23</td>
<td>90</td>
<td>68</td>
<td>60</td>
<td>45°L</td>
<td>5°U</td>
<td>25</td>
<td>Five parallel grooves on top, faint groovings on bottom. Rounded floor.</td>
</tr>
<tr>
<td>EP24</td>
<td>75</td>
<td>75</td>
<td>72</td>
<td>25°L</td>
<td>0°</td>
<td>15</td>
<td>Floor very pointy with irregular grooves on roof and left.</td>
</tr>
<tr>
<td>EP25</td>
<td>80</td>
<td>50</td>
<td>55</td>
<td>5°L</td>
<td>5°D</td>
<td>20</td>
<td>Very large groove on top associated with grooves on left. Impact marks.</td>
</tr>
<tr>
<td>EP26</td>
<td>70</td>
<td>45</td>
<td>34</td>
<td>10°L</td>
<td>0°</td>
<td>20</td>
<td>Grooves around the rim.</td>
</tr>
<tr>
<td>EP27</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>10°L</td>
<td>5°U</td>
<td>25</td>
<td>Well rounded floor with low grooves.</td>
</tr>
<tr>
<td>EP28</td>
<td>90</td>
<td>65</td>
<td>92</td>
<td>15°L</td>
<td>10°D</td>
<td>25</td>
<td>Very deep grooves over entire lower half and singular groove on upper rim.</td>
</tr>
</tbody>
</table>
version of cupules), up to 20 cm deep and forming a single panel. The research target is to formulate testable propositions, based on the forensics of the site, of how these deep cupules were made.

The present entrance of Ngrang Cave is at a roof collapse proceeding E to W, whose rim retreat rate exceeds the build-up of the cone deposit inside it, facilitating continued access to the tunnel. The cave remains accessible only because the rate of rim retreat exceeds the rate of sediment deposition below the rim. Because the quantity of the collapsed rock is known from the tunnel’s morphology and size, the contents of the cone slope can be estimated: 32 m³ limestone (c. 78 t) and 14 m³ sediment (c. 25 t), assuming airspaces of about 2 m³. Pleistocene sediment from the exterior descends down...
the slope and contributes to creating the cone deposit’s stratigraphy. Within it occur dense lenses of evidence of occupation, comprising charcoal, bone fragments, emu eggshell fragments and chert tools. As the rim of the collapse retreats with every new rock fall, the lower limestone strata (the tunnel roof) become similarly unstable and are claimed by gravity. One such event has claimed the northern end of the panel of deep cupules, when a projecting wall portion bearing seven of the deep pits broke off and fell to the ground relatively recently. This study is only concerned with the 45 cupules that have remained in situ (Figure 2, Table 1).

This reconstruction through its geomorphology and tectonic adjustments over time provides a relative timeframe within which the production of the extraction pits on the wall ledge must be situated. A test pit has provided dense evidence of human occupation next to the rock art, embedded in colluvial sediments. Its contemporaneity with any of the rock art activity cannot be demonstrated; in fact the cupules cannot even be related with any of the numerous other tool and finger marks deeper in the cave. They are not related to any speleothem, and only one of them has been truncated by a subsequent mass-exfoliation event. This leaves only one index of relative age, surface retreat by speleothem-weathering, but it can be applied in three different ways.

First, the Miocene limestone contains tiny marine fossil casts that tend to weather significantly less than the matrix, and at the opening of one of the cupules, one such cast extends 9 mm above the present surface. This would suggest a considerable surface retreat since the cupule was made, but it needs to be assumed that the cast was not protruding some of the distance at that time. Secondly, the cupules contain numerous tool marks, the relative degree of weathering of which is a measure of antiquity (Figure 3). However, several factors complicate the utility of this index: weathering rates differ depending on the depth within the cupule; the detailed morphology of the tool gouges at the time they were made is unknown and must be assumed (Figure 4); and the type of tool used is not known. These considerations render it desirable to conduct replicative experiments to better deal with these issues.

The third indicator of the age of the cupules is perhaps the most reliable, and the easiest variable to quantify effectively. The rims of the cupules are considerably more rounded today than they can be assumed to have been at the time of manufacture. There can be no doubt that the more acute rims become progressively rounded with time. However, to determine their initial morphology, replication is again required.

Three field campaigns of one week each have provided a series of experiments to establish (a) what tools and what extraction method(s) were most likely to have been used in making the cupules; and (b) what would the rims of the fresh cupules have looked like. For this purpose flat surfaces on blocks of the same limestone forming the cave walls were selected and a dozen holes were created under controlled conditions, using three types of tools: the broken leg bones of kangaroos; pointed chisels of hardwood; and large stone picks freshly knapped from local chert. Each of these artefact types was applied by both direct and indirect percussion, using suitable hammerstones in the latter cases. The stone tools were also experimentally used by direct rotational action. Details of all experiments were recorded by film, photography, measurements and notes. The experimental pits were generally modelled after cupule EP23 (approximate depth 6.5 cm; approximate diameter at rim 7.5 cm).

Results of the Ngrang Cave experiments

The following lithic, bone and wooden tools were created for the experiments (Figure 5):
L1: (manufactured by YPM) of brownish chert, distal tip shaped as a point, proximal end fully rounded, length 18.7 cm, width 8.5 cm at centre, weight 609.2 g, bifacial (Figure 6).

L2: (manufactured by RB; retouched by YPM) bicolour greyish chert, distal tip shaped as a chisel, proximal end only partially worked, length 21.3 cm, width 10.5 cm at centre, weight 795 g.

B1: (manufactured by YPM) aged macropod tibia, distal tip fractured and shaped as a tube, proximal end unmodified, length 18.9 cm, width 2 cm at centre, weight 84.3 g.

B2: (manufactured by YPM) aged macropod tibia, distal tip shaped like a flat chisel, proximal end unmodified, length 21.0 cm, width 3 cm at centre, weight 100.3 g.

W1: (manufactured and retouched by YPM) Eucalyptus sp., distal tip shaped as a point, proximal end left unmodified, length 18.9 cm, width 2 cm at centre, weight 84.3 g.
with bark, length 46.5 cm, width 3 cm at centre, weight 135 g.

**W2:** (manufactured YPM; retouched YPM and RB)

'Eucalyptus' sp., distal tip shaped as a chisel, proximal end left with bark, length 44.9 cm, width 4 cm, weight 160 g.

The following experimental cupules were created, and the details of each experiment were recorded as follows (Figure 7):

**PMP2 - 23.1**
Rotational movement using lithic implement L1, manufactured in the shape of a pic.
Manufacturing time 2:30 mins.
Horizontal surface, rim and shape are too perfect relative to deep cupules.
Parsimonious diameter.
The floor is systematically conical.
The tool marks are characteristically circular (by-products of rotation).

**PMP2 - 23.2**
Gouging movement using L1.
Manufacturing time 4 mins.
Horizontal surface, rim shows minimal and faint tool marks.
Characteristic breakages on the rim due primarily to a kinetic pattern analogous to leverage and could potentially be used as signatures.
The overall diameter was easily controlled during manufacture.
Of the three pits 23.1, 23.2 and 23.3, 23.2 was the easiest to control in terms of overall layout (shape, diameter, angulation).
The floor shows characteristic erratic features which are similar to some of the deep cupules.

The floor shape can be easily controlled in terms of shape (conical or flat).
Tool marks clearly defined on the rim as leverage tool marks.
Beyond the rim, erratic tool marks are visible but faint.

**PMP2 - 23.3**
Indirect percussion using L1 and a hammerstone (chert).
Manufacturing time 3:30 to 4 mins.
Horizontal surface.
As a general note, this particular mode of manufacture did not allow the operator to control the outcome.
Rim shows characteristic irregularities which cannot be found in the deep cupules.
Tendency for convexity to appear on the floor (extraction forms distinctive patterns on the floor).
Tool marks best defined on rim but becoming almost completely absent past mid-point.

**PMP2 - 23.4**
Indirect percussion using bone implement B1 with a tip in the shape of a smooth circular breakage and a hammerstone (chert).
Manufacturing time 3:30 mins.
Horizontal surface.
Rim shows characteristic irregularities which cannot be found in the deep cupules.
Tendency for convexity to appear on the floor (extraction forms distinctive patterns on the floor).
Tool marks (impressions) clearly visible around the rim, but faint to invisible on the actual wall surfaces.
A very flat and round base.
There seems to have been no difficulty maintaining vertical extraction during manufacture.
Leverage plays a key role in the overall configuration of this pit.

**PMP2 - 23.5**
Indirect percussion using bone implement B2 with a tip shaped with a broken and bruised pointy edge (chisel) and a hammerstone (chert).
Manufacturing time 2 mins.
Horizontal surface.
Manufacturing was easier than 23.4 due primarily to the nature of the distal point.
Rim not as regular as other experimental pits, showing more distinctive features (breakages and grooves).
Base is flat.
Note: grooves might be the best forensic evidence when comparing the experimental pits with the archaeo-cupules.

**PMP2 - 23.6**
Gouging movement using bone implement B2.
Manufacturing time over 5:30 mins.
Horizontal surface.
Occasionally some very deep tool marks (levering impressions) on the rim.
Considerable energy expenditure.
Verticality of walls not maintained and base characteristically rounded.
Note: the time factor and the exhaustive biomechanical requirements make this manufacturing process unlikely.

**PMP2 - 23.7**
Direct percussion using a lithic tool with a tip manufactured in the shape of a chisel (L2).
Manufacturing time 1 to 1:30 min.
Pit was made by horizontal strokes on a vertical surface.
The rim shows flaking as a by-product of impact of L2 on rim.
No leverage needed (hence no leverage signature marks on rim).
The floor is noticeably flat and the operator has a great deal of control over the floor’s shape.
Some noticed similarities in terms of kinetic process with pit 23.2.
Tool marks are clearly detectable from rim to floor.
Important note: production of the pits would have been greatly facilitated by using a tool which would bear a distinct curvature in its profile.

**PMP2 - 23.8**
Direct percussion using bone implement B2.
Manufacturing time 6 mins (with only approximately half of the pit manufactured).
Vertical surface.
Characteristically rugged rim.
Complete absence of discernible tool marks.
Flattish floor (would eventually become progressively more conical).
Note: the manufacture of this pit would have become increasingly harder as pit becomes deeper.

**PMP2 - 23.9**
Indirect percussion using a wood implement with a tip shaped as a point (W1) and a hammerstone (chert).
Manufacturing time 2 mins approx.
Horizontal surface.
Erratic rim with an absence of leverage marks.
Tool marks distinctively noticeable on rim but quickly becoming faint at mid-section.
The walls are non-parallel.
Floor has a typical pointed shape (between a V shape and a U shape).

**PMP2 - 23.10**
Indirect percussion using a wood implement with a tip shaped like a chisel (W2) and a hammerstone (chert).
Manufacturing time 3 mins approx.
Horizontal surface.
Variable definition of the rim (noticeably well-defined in some places).
Limited amount of discernible tool marks running from rim to floor and characteristically flattish.
Some control over the layout of the pit due primarily to a certain control of the directional impact of the tool.
Flattish but somewhat erratic (undulating and uneven) floor.

**PMP2 - 23.11**
Gouging movement using W2.
Manufacturing time over 2:30 mins.
Horizontal surface.
Rim shows distinctive leverage marks; tool marks are well defined.
Walls are sloping and asymmetrical.
No noticeable characteristic tool marks; some potential faint traces would be quickly weathered.
Floor is sub-conical.

**PMP2 - 23.12**
Direct percussion using W2.
Manufacturing time 2:30 mins.
Vertical surface.
Sharp rim with isolated impact marks.
Walls are almost parallel due to the fact that tool point is asymmetrical and rotating the tool creates parallelism in the overall layout.
Steepness can be easily maintained.
Tool marks extend from rim to floor and are very distinctive.
Floor has noticeable uneven shape with prominent uneven ridges.

Therefore the following techniques were applied:

Rotation: 23.1
Gouging: 23.2, 23.6, 23.11
Indirect percussion: 23.3, 23.4, 23.5, 23.9, 23.10
Direct percussion: 23.7, 23.8, 23.12

**Preliminary analysis of the results**

Preliminary discussion of the results of these experiments led to the designation of seven defining categories:

1. Steepness of wall of experimental cupule
2. Overall configuration of walls
3. Tool marks
4. Floor topography
5. Operator control in implement application
6. Manufacturing time
7. Relative energy expenditure

After further discussion it became clear that of these categories, 5, 6 and 7 — while genuinely important — were significantly affected by context, operator skill and manufacturing choices that might or might not have been under consideration for the deep cupules. Therefore the following five attributes were selected as the most suitable for empirical assessment unbiased by possibly subjective choices:

1. WC: wall configuration, defined on a scale from 1 to 10 as parallel (1) to conical (10).
2. CR: configuration of rim, from fully circular (1) to irregular (10).
3. *TM*: tool marks, from highly visible (1) to virtually invisible (10).
4. *FL*: floor morphology, from flat (1) to conical (10).
5. *CSO*: cross section opening, from parallel (1) to divergent (10).

In order to compare the twelve experimental cupules with an identical number of deep cupules, the twelve most suitable of the latter were selected for analysis. These were selected on the basis of two criteria: apparent degree of completion, and clarity of the variables being considered. This led to the selection of the following twelve deep cupules for detailed in-situ analysis (see Table 2): EP23, EP24, EP19, EP13, EP28, EP33, EP34, EP35, EP37, EP39, EP42, EP36.

As indicated in Table 2, the averages for the experimental cupules were *WC* = 4.75, *RC* = 5.41, *TM* = 5.91, *FL* = 4.83, *CSO* = 1.00. Those for the deep cupules were *WC* = 2.75, *RC* = 6.33, *TM* = 3.91, *FL* = 6.41, *CSO* = 1.25.

The averages of all attributes in Table 2 are 3.8 for the three gouged experimental cupules, 4.6 for the five made with indirect percussion, and 3.86 for the three made with direct percussion. The average of all cupules made with lithic tools were 5.4; of those made with bone tools they were 3.3; and those made with wood tools averaged 4.6. Table 3 shows the average ratings relative to the three tool materials.

**Conclusion**

This study has not yielded conclusive forensic evidence to determine the tool type used in creating the deep cupules in the entrance chamber of Ngrang Cave. However, there are several factors in support of the use of fractured long-bone in conjunction with a stone hammer (Figure 8):

1. Breakage for marrow would result in an appropriate tool point, including chisel shape.
2. Bone elasticity is more efficient than wood for equal diameter.
3. Significantly less effort is required in preparing the tool.
4. During operation the hollow tube of the long-bone acts like a core drill, in that the hollow accommodates limestone particles that can be shaken out periodically.
5. Such bones are likely to occur on site and be readily available for use.
6. In cases where the impression of a tool point has survived in a deep cupule it is distinctly circular (Figure 9).
7. Most importantly, many of the deep cupules bear wall markings that signify the use of a narrow but sturdy, elongate instrument of relatively small diameter. This excludes a lithic tool and renders wood less likely.

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**Table 2. Comparison of five key morphological attributes of twelve experimental cupules (23.1 to 23.12) with a sample of twelve deep cupules (EP), Ngrang Cave.**

**Table 3. Attribute ratings for the three tool materials used in creating the experimental cupules in Ngrang Cave.**
The use of wooden tools emerges as the second-most likely possibility, and the use of stone tools cannot be ruled out conclusively for the more shallow cupules. Therefore the application of different tool materials used in the production of the whole assemblage is not conclusively refuted by this replication project. However, many of the tool markings observed and the occasional occurrence of walls faintly converging towards the opening demand the use of a relatively thin but sturdy, elongated tool, and this applies particularly to the ensemble of deeper pits (≥75 mm, n=16, or 35%). These cases imply a motivation to drive the holes as deeply as possible, yet maintaining the smallest possible opening diameter. This characteristic can be frequently detected in cupules on any lithology (Bednarik 2008b), but it is certainly most succinctly expressed on the softest rock types. The brittle and relatively porous Tertiary limestone of Ngrang Cave, which is of hardness 1 on Moh’s Scale, permits the creation of the deepest cupules recorded so far, up to almost 20 cm depth. The hardness of the rock is a function of its moisture content: it tends to be slightly harder if the rock is dryer. There are no silica nodules in the Miocene rock within the cave.

Due to the erosive nature of the support, the Ngrang Cave deep cupules have failed to provide unequivocal collective evidence for the tools used in their creation. Future research will need to focus on the kinetics involved in pit configuration, rim details and parallelism of walls, to be able to refine the results of this analysis to a point where a higher degree of confidence could be achieved. Another factor being subjected to continuing study are the effects of accelerated weathering on the surface aspects of the experimental cupules and their rims.

References


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