The Origins of Ground-edge Axes: New Findings from Nawarla Gabarnmang, Arnhem Land (Australia) and Global Implications for the Evolution of Fully Modern Humans

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The grinding of stone to make sharp cutting edges did not evolve with the emergence of biologically modern humans in Africa, but late in the Pleistocene at the completion or near-completion of the Out-of-Africa 2 migration. Here we discuss the earliest securely-dated fragment of ground-edge axe from Australia, dated at 35,500 cal. BP, an age slightly older or comparable to the earliest ages for edge-grinding from the Pacific Ocean’s western seaboard. In this region ground-edge axes did not evolve with the emergence of agriculture, nor for the clearance of forests, but, rather, as socially mediated technology, part of the development of symbolic storage that is the hallmark of the evolution of cognitively modern humans at the geographical end, during, or following, Out-of-Africa 2.

The world’s earliest stone tools date to 2.52–2.60 million years ago and predate the earliest known Homo species along the Gona River of the Afar region of Ethiopia, eastern Africa (Semaw et al. 1997). Even older knapped stone tools are posited to exist, with the recent discovery of cut marks on 3.4 million-year-old bones from Dikika attributed to Australopithecus afarensis, also in Ethiopia (McPherron et al. 2010). Such early core and flake tools were all manufactured by freehand percussion, although bipolar debitage is also found in Oldowan times (Braun et al. 2009; Clark & Kleindienst 2001; de la Torre et al. 2003; de la Torre & Mora 2009).

With the evolution of Homo sapiens between 200,000 and 100,000 years ago emerged a broad range of technological and cognitive innovations (e.g. Deacon & Deacon 1999) that over time came to incorporate new forms of symbolic behaviour including rock art (Henshilwood et al. 2002; Conard & Bolus 2003; 2008; Conard et al. 2003; d’Errico et al. 2010; Parkington et al. 2005), complex multi-component tools (Mellars et al. 2007; Zilhão & d’Errico 2003), environmental manipulations (de Beaune 2000; 2003), long-distance trade (Bon 2009, 241–63; Hovers & Braun 2009) and fully linguistically mediated group behaviour (Bickerton 2003; d’Errico et al. 2003; Gamble & Coward 2009; Vanhaeren & d’Errico 2006). Each of these components of social life, from complex multi-component tools to environmental manipulations, is permeated with symbolic storage because it incorporates very particular ways of doing things subject to human cognisance. These ‘ways of doing’ result in particular material signatures to all kinds of products, from objects to lived landscapes. While such products may be seen as ‘economic production’, they also involve a socio-economy of symbolic meaning and reproduction. However, such technological and cognitive innovations did not suddenly come in a single package with the evolution of biologically fully modern humans (for a review of the evidence, see Habgood & Franklin 2008). Rather, over the tens of thousands of years following the first emergence of biologically modern humans during the Middle Stone Age by 100,000 years ago in Africa (Anton & Swisher 2004; Field et
al. 2007), new technologies and symbolic behaviours were gradually and cumulatively added out of Africa. Sahul, that region on the extreme eastern edge of the Out-of-Africa 2 migration route, has a crucial part to play in understanding those behavioural traits that emerged following, versus prior to, the out of Africa migration, for innovations identified in Sahul will indicate post-migration inventions that emerged subsequent to Homo sapiens’ early behavioural developments. Identifying such post-migration developments enables a better understanding of the extent to which biologically modern humans became behaviourally modern in a process of ongoing developments.

One of these traits of modernity concerns ‘symbolic storage’, which many authors have identified as originating in Africa but continuing to unfold during and subsequent to the Out-of-Africa 2 migration (e.g. Habgood & Franklin 2008; Wadley 2001). Symbolic storage cannot in itself be reduced to short-term ergonomic efficiency, although this does not mean that it works counter to adaptive principles. Rather, symbolic storage in material culture concerns the way in which objects store information about meaning, meanings that relate to one’s physical and socio-cultural location. Symbolic storage imbues things, physical and non-physical, with a presence enhanced by social value. By adding social meaning, symbolic storage also socially structures use-value, for meaning comes into being in social and cultural codes, in culturally engaged social interaction.

Here we report on the discovery of the oldest fragment of ground-edge axe in the world, and the origins of ground-edge axes, as one such innovation indicative of symbolic storage that took place following Out-of-Africa 2 along the Southern Arc dispersal route as humans crossed from Africa to southern Asia into northeast Asia and Australia between 70,000 and 50,000 years ago (cf. Balme et al. 2009). We argue that this innovation cannot be understood simply in abstract technological terms, but must also consider the evolution of symbolic behaviour as socially mediated technology.

The origins of grinding

Despite the manufacture and use of flaked stone tools by hominins in Ethiopia more than two million years ago (McPherron et al. 2010; Semaw et al. 1997), the shaping of stone tools by grinding does not appear in human evolution until about 35,500 years ago anywhere in the world, coincident in time with the emergence of naturalistic rock imagery (Clottes 2007; Parkington et al. 2005; Valladas et al. 2001). Here we distinguish between tools intentionally shaped by grinding with an abrading tool, such as ground-edge axes and ground flakes, from the abrading tools used to manufacture various materials such as objects of adornment, plant produce, stone tools, and minerals for the production of pigments, such as files and grinding stones. Globally, and concerning raw materials other than stone, the oldest-known cases of grinding are found on bone tools from Swartkrans and Drimolen (Backwell & d’Errico in press; d’Errico & Backwell 2009).

In Europe, fine, intentionally abraded shallow bowls in sedimentary rocks and calcite have been found in residential sites attributed to the Mousterian. The discovery of stone receptacles for the preparation of ochre at Cioarei Cave is testimony to the intentional transformation of blocks of stone by pounding and abrasion (Carciumaru et al. 2010).

Generally, scraped and abraded pigments are most notably found at habitation sites dating from the end of the Middle Palaeolithic. In the southwest of France, more than 500 fragments of red (iron oxides, haematite, goethite) and black (manganese dioxide) pigments were ground for decoration and thus symbolic expression by Homo neanderthalensis during the Mousterian. There are now more than 70 sites that have yielded such pigments; at Pech de l’Azé rockshelter these go as far back as 50–60,000 yr (Sorressi & d’Errico 2007; d’Errico et al. 2009). In the cave of Blombos in South Africa, red-ochre crayons were striated by abrasion during use in the Middle Stone Age, 70,000 years ago and presumably by Homo sapiens (Henshilwood et al. 2002; Henshilwood & d’Errico 2005; d’Errico et al. 2010). Grinding tools and abraded objects appear sporadically during the European Upper Palaeolithic after 30,000 yr and include pestles, handstones, cupules and shallow stone bowls (de Beaune 2000; 2004). The earliest grinding tools used for plant-food processing in Europe come from Bilancino II in Italy (dated to 28,298±301 cal. bc), Kostenki 16 in Russia (31,904±698 cal. bc) and Pavlov VI in the Czech Republic (29,482±288 cal. bc) (Revedin et al. 2010). At the Upper Palaeolithic occupation site of Kostenki IV (Aleksandrovskaya) on the Russian plains, mortars and pestles have also been reported from levels dated to 23,000–21,000 yr (Semenov 1964 [1957], 137, fig. 67).

In Europe there is also firm evidence for the grinding of stone in the manufacture of portable and fixed rock art during the Upper Palaeolithic. In France shallow bowls ground in stone used for mixing pigments and lamps for the burning of animal fat are symmetrically shaped and decorated, such as those of Lascaux and of Solvieux (Sackett 1999, figs. 4.7, 4.8; de Beaune 2000; 2004). Further to the east at Denisova Cave in Siberia a finely polished bracelet dated to
30,000 BP is made of semi-precious ground chloritolite (Derevianko et al. 2008), although the indirect dating, in a complex stratigraphy with superior Bronze age levels, is questionable. From France to Siberia, female (‘Venus’) figurines from the early and middle phases of the Upper Palaeolithic evidence the use of grinding and polishing stone technology to produce figurative objects with presumably high social value. Examples dating to the Aurignacian and Gravettian between 30,000 and 25,000 BP include the famous stone and ivory figurines from Galgenberg, Willendorf, Grimaldi, Sireuil, Tursac and Kostenki for example (Conard 2009; Leroi-Gourhan 1995; Neugebauer-Maresch 1989; Svoboda 2008).

In the Near East, tools to grind grain and vegetable fibre are well known from Natufian levels dated to 15,000 BP (Bar-Yosef 1998, fig. 11; 2002). In southern Africa, grinding stones and the abrasion of stone dates to the Late Stone Age from 8500 BP onwards (Ambrose 1998). Ground shell artefacts are found in the Moluccas 12,000 BP (Bellwood 1997, 187, cited in Anderson & Summerhayes 2008, 51).

In Australia, stones used for grinding have been discovered at Malakunanja II bracketed by 61,000±13,000 and 45,000±9000 year-old TL dates (Roberts et al. 1990, 153), although little has been published about these stones. Pieces of use-stratified haematite occur in the same date-context at Malakunanja II (Roberts et al. 1990, 153), and also at Nauwalabila 1 in close association with a 53,400±5400 year-old TL date (Jones & Johnson 1985; Roberts et al. 1993). Use-stratified ochre is also found at Sandy Creek 1 on Cape York Peninsula dated at 31,900±700–600 BP (Cole et al. 1995, 154). While there are claims for grinding stones dating back to 33,300±530 BP from Cuddie Springs (Fullagar & Field 1997), the chronostratigraphic integrity of this site has been seriously questioned by a number of authors (e.g. Brook et al. 2007; David 2002, 169–76; Gillespie & David 2001; Gillespie & Brook 2006), and cannot at this stage be taken as reliable evidence (see also Habgood & Franklin 2008 for an excellent review of the antiquity of grinding stones and ochre use in Australia).

These findings indicate that the appearance of grinding tools for the production of objects of art, with implications for the production of visual symbolism, have a long antiquity around the world, with most examples coming from late Pleistocene levels onwards in direct association with modern Homo sapiens.

**The earliest ground-stone axes**

Grinding as a technology to create functional stone tools has a similar antiquity in some parts of the world but not in others. In Western Europe, ground axes first appear during the Mesolithic in the United Kingdom, Ireland, Scandinavia and Russia and increase significantly in frequency during the Neolithic (Hernek 2005; Pailler & Sheridan 2009).

The first ground-edge axes are found at the beginning of the Mesolithic in Ireland, such as at Lough Boora (Co. Offaly), in habitation levels dated to 7160–6260 BC. In Wales, Scotland and Ireland, the numerous ground-edge axes reliably dated to the Mesolithic indicate that edge-grinding had appeared by the eighth millennium BC, well before the commencement of Neolithic lifeways (Pailler & Sheridan 2009, 31–2).

In Siberia the oldest ground axes date to 20,000 BP in the valley of Yenisei (Oda & Keally 1973, 19, cited by Anderson & Summerhayes 2008, 49). On the Russian plain and in northern Russia ground axes make their appearance around 8500 BP during the Mesolithic; at Zamostje the surfaces of about 50 per cent of axes are entirely ground, and at Nijnee Veretje 1 they are nearly completely ground (Lozovski 1996). In the Near East, ground-stone objects make their appearance at the end of the Natufian as containers and tools for the processing of plant foods rather than as axe-heads. In Sultanian tool kits, between 10,300 BP and 9300 BP, limestone celts are present (Bar-Yosef 1998, fig. 11). In northwestern and Saharan Africa, ground-edge axes begin to appear after the Capsian which developed between 8500 and 6500 BP (Philponson 2005; Smith 2005). Elsewhere in Africa it is in the Late Stone Age and with agro-pastoralists that ground-edge axes become common, often in association with other ground objects. At Border Cave in southern Africa, as early as 38,000 BP the transition from the Middle Stone Age to the Late Stone Age saw the development of a microlithic industry associated with more ‘modern’ assemblages such as bone points and bored stones shaped and perforated by abrasion (Beaumont et al. 1978; Sadr et al. 2006, 405).

Unlike the contiguous region of Europe–Africa–west Asia–north Asia, eastern Asia and the New Guinea–Australian region of Sahul present a different scenario.

In southern China a ground-edge stone axe from layer 4 at Bailiandong Cave in Guangxi Province is dated by two radiocarbon determinations of 19,350±180 BP and 20,960±150 BP (Zhao et al. 2004, 132). At the site of Liyuzui also in Guangxi Province a ground-edge axe is bracketed by radiocarbon dates of 21,025±450 BP and 11,450±150 BP. Terminal Pleistocene ages have also been assigned to ground-edge tools from Dushizai Cave and Huangyandong Cave (both of Guangdong Province). There are also less certain
terminal Pleistocene ‘polished’ stones from Xianrendong Cave and Diatonghua Cave (Zhao et al. 2004).

In Japan the oldest ground-edge axes date to c. 30,000–23,000 BP, the earliest from Stratum Xb of the Musashidai site in Tokyo (Oda & Keally 1992, 25). Approximately 60 per cent of the more than 200 ground-edge or waisted axe-like implements that have been found below the AT marker tephra on Honshu and Kyushu are ground. While poorly dated, these tools are older than the AT marker tephra dated to sometime between 21,000 and 22,000 BP (Machida & Arai 1983, cited in Oda & Keally 1992, 25). Until recently these artefacts represented the oldest evidence of edge grinding in the world, with Australia’s Pleistocene axes dating to a broadly similar age.

Pleistocene ground-edge axes have been excavated from northern Australian sites since the 1960s (White 1967). Most of these tools come from Arnhem Land in the centre-north of the country: examples made on porphyritic dolerite, quartz dolerite and hornfels are known from the lowermost Levels IIIa and IIIb at Malangangerr, dated from 18,000±400 BP to 22,900±1000 BP respectively (Schrire 1982, 84, 107). At Nawamoyin, porphyritic dolerite and hornfels ground-edge axes have also been found in Levels IIIa and IIIb, the latter dated to 21,450±380 BP (Schrire 1982, 118, 143). At Nauwalabil 1, fragments of ground-edge axes were recovered as far down as Unit 45 (149 cm below ground), originally estimated from the extrapolated depth-age curve to date to 15,000–16,000 BP (Jones & Johnson 1985, 216) and subsequently shown to date to sometime between 12,330±120 and 18,330±280 BP by an extensive AMS radiocarbon dating programme using ABOX pretreatment (Bird et al. 2002, 1065) and 13,500±900 and 30,000±2400 years old by OSL dating (Roberts et al. 1993, 58). Chemically-weathered imported porphyritic dolerite flakes likely to have come from ground-edge axes were also found as far down as Unit 70 at depths of 2.13–2.43 cm below ground and thereby dating to sometime between 30,000±2400 and 53,400±5400 years ago by OSL (Roberts et al. 1993, 58), but these artefacts are too weathered and decomposed for surface features including traces of grinding to have preserved (Jones & Johnson 1985, 196–7, 216–18, 297).

To the west at Widgingarri Shelter 1 in the Kimberley, fragments of ground-edge axes have been reported from spit 17 dated to 27,610±600 BP (O’Connor 1990, 194, 246–51). To the east of Arnhem Land, a local amateur dug a hole at the site of Sandy Creek 1 in Cape York Peninsula in the 1960s, retrieving an edge-ground axe supposedly from 3 m (9’ 10”) below ground (Morwood & Trezise 1989). In 1989 archaeologist Mike Morwood excavated a trench parallel and adjacent to Trezise’s original pit and obtained charcoal from the nearby stratigraphy to reveal an age of 31,900±700/–600 BP for the basal rubble that is said to have contained the axe. As the axe was supposedly found at the base of the rubble, Morwood and Trezise (1989, 81) argued that the radiocarbon determination ‘provides a minimum age for the edge-ground axe’. However, the original axe had long been lost and its supposed basal chronostratigraphic positioning was compromised by the amateur enterprise and lack of rigorous scientific procedures, prompting serious doubts about the reliability of the Sandy Creek 1 claims.

Nawarla Gabarnmang

Nawarla Gabarnmang is a newly-rediscovered site in Jawoyn Aboriginal country in southwestern Arnhem Land (Fig. 1). Located on top of the escarpment in the Kombolgie Formation, it is a highly unusual horizontally-bedded but intercalated stable hard orthoquartzite and softer and less stable quartz sandstone formation which has over a geologically-long period been subjected to in situ weathering of the bedrock through hydration and solution processes along bedding planes and fissure lines. The end-product is a double-ended cave with sub-horizontal ceiling ranging from 1.75 m to 2.45 m above the floor level. Across the more open and thus easily accessed part of the site is a natural grid-shaped alignment of 36 stone pillars (Fig. 2) each separated by fissure lines along which the bedrock has weathered away from ground to ceiling, leaving behind the pillars as relicts of weathering processes. The archaeological implication of these geomorphological features is highly significant: a spacious cave, 19 m long by 19 m wide shelters expansive culturally-bearing sediments entirely protected from rainfall. Despite the low pH (3.71–5.93) and thus high acidity values of its sediments (as is the case across all of Arnhem Land generally), the implication is that ancient cultural remains have a better chance of being preserved in this site than in any other known archaeological site in Arnhem Land.

In May 2010, two 50 cm × 60 cm archaeological excavations (Squares A and B) were undertaken in different parts of the site to test its archaeological potential. Here we report on Square A only (Fig. 3). Excavation was undertaken in mean 1.8 cm-thick arbitrary Excavation Units (SU) following Stratigraphic Units (SU) where visible in situ until bedrock was reached 66.2 cm below surface. Cultural materials ≥2.0 cm observed in situ were plotted in three dimensions (3-D) and bagged separately. Charcoal samples were also plotted in 3-D and individually bagged
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for AMS radiocarbon dating. All other excavated sediments were sieved in 2.1 mm mesh sieves and all retained materials bagged for laboratory sorting at the Monash University archaeology laboratories. Relatively large pieces of wood charcoal were found throughout the excavation, sometimes in extremely large quantities measured by the hundreds of grams per XU, thus offering unprecedented opportunities for radiocarbon dating in Arnhem Land. Here we report the significant finding of a confirmed fragment of ground-edge axe sandwiched midway between four AMS radiocarbon determinations, each on a single fragment of charcoal dated to more than 30,000 yr, and thus representing the oldest securely dated ground-edge implement in the world.

The deepest and oldest layer is SU5 with a thickness ranging from 7 cm to 31 cm, depending on the uneven bedrock configuration and whether a sediment-filled narrow fissure in the bedrock is included. The ground-edge axe fragment comes from XU30 in SU5, at a depth between 47.7 cm and 50.4 cm below ground. The buried stones within these XUs lay horizontally flat, and thus parallel to the configuration of the SU in which they lay, indicating a lack of significant post-depositional turbation. No roots or rootlets were evident at this depth; indeed plants

<table>
<thead>
<tr>
<th>XU</th>
<th>SU</th>
<th>Depth below ground (cm)</th>
<th>$\delta^{13}$C‰ (±0.2)</th>
<th>Conventional radiocarbon age (BP)</th>
<th>Calibrated age</th>
<th>Lab no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.3</td>
<td>24.7</td>
<td>250±30</td>
<td>320–280, 170–150 yr (68%)</td>
<td>Wk-28123</td>
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<td>3</td>
<td>2</td>
<td>6.1</td>
<td>26.0</td>
<td>142±30</td>
<td>260–250, 230–170 yr (68%)</td>
<td>Wk-28614</td>
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<tr>
<td>5</td>
<td>3</td>
<td>8.3</td>
<td>23.0</td>
<td>1560±30</td>
<td>1520–1400 yr (68%)</td>
<td>Wk-28615</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>6.7</td>
<td>24.6</td>
<td>2264±30</td>
<td>2350–2300, 2240–2180 yr (68%)</td>
<td>Wk-28124</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>13.0</td>
<td>26.2</td>
<td>2165±30</td>
<td>2310–2240, 2180–2170 yr (68%)</td>
<td>Wk-28612</td>
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<td>11</td>
<td>3-4 interface</td>
<td>17.4</td>
<td>25.1</td>
<td>8616±34</td>
<td>9600–9530 yr (68%)</td>
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<tr>
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<td>3-4 interface</td>
<td>19.9</td>
<td>26.4</td>
<td>8924±31</td>
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<td>3-4 interface</td>
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<td>na*</td>
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<td>11,190–11,090 yr (68%)</td>
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<td>24.2</td>
<td>30,761±314</td>
<td>36,170–35,960 yr (68%)</td>
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Table 1. Radiocarbon data from Nawarla Gabarnmang, Square A. * = $\delta^{13}$C value measured, but not reported. See text for calibration references.
Figure 1. Location of Nawarla Gabarnmang, northern Australia.

Figure 2. Nawarla Gabarnmang, showing stone pillars, with excavation Square B in the foreground. The site is extensively decorated with rock paintings.

Figure 3. East and south sections of Square A, Nawarla Gabarnmang.
Figure 4. A) Side, dorsal and ventral views of the Pleistocene Nawarla Gabarnmang ground-edge axe fragment from Square A. B) Close-up view of the ground surface of the Pleistocene ground-edge axe fragment. C) Close-up view of the ground surface (away from the cutting edge) of the late Holocene ground-edge axe from Square B. D) Close-up view of the ground surface (at the cutting edge) of the late Holocene ground-edge axe from Square B. E) Late Holocene ground-edge axe from Square B, Nawarla Gabarnmang.
tend not to grow today anywhere within the driplines at the site. Sediments in each of the five Stratigraphic Units consist of compact and well-consolidated loamy sands produced by chemical alteration of the surrounding sandstone bedrock and accumulated aeolian sediments. The terminal Pleistocene–Holocene boundary, consist of a layer of exfoliated sandstone roof-fall rocks infilled with compact loamy sands sealing the underlying SU5 (which contains the fragment of ground-edge axe reported here) from overlying sediments. While a proportion of these sediments arguably originated directly from the bedrock, in particular from minor fallen roof or pillar material, another, more important proportion originated externally, transported a short distance through aeolian processes to be deposited into the site and thus forming significant proportions of the soft deposit. At the very base of Square A and upwards for a few centimetres only above bedrock (but well below the lowermost radiocarbon determinations), a concentration of rounded gravel-sized sediments indicates transport along narrow and shallow channels etched into the bedrock by water action during a period prior to the deposition of the present soft sediments.

Throughout much of the excavated sequence above the thin concentration of very basal gravels, stone artefacts mainly made of quartzite and chert number in the thousands, but preliminary analysis of the entire excavated deposit indicates that the fragment of ground-edge axe reported here is a rare example of volcanic rock found. We note that high-quality quartzite for the manufacture of long cutting edges is available in large quantities within the site itself, whose ceiling was also a quartzite quarry.

Four charcoal samples were taken for radiocarbon determination from the lower excavation units (XU27 to XU31 in SU5) surrounding the fragment of ground-edge axe. These four near-basal determinations continue a sequence of an additional 14 AMS radiocarbon ages from the surface down, in good chrono-stratigraphic order. These samples were prepared at the Waikato Radiocarbon Dating Laboratory in New Zealand using a standard acid-base treatment (Olsson 1986). Graphite targets were prepared by the reduction of cryogenically-purified CO$_2$ to graphite, using hydrogen over pre-cleaned iron powder at 550°C. The radiocarbon results were calibrated using IntCal09 (Reimer et al. 2009) in OxCal v4.1.7 (Bronk Ramsey 2010) and produced a combined statistically indistinguishable age of 36,230–35,880 and 35,580–34,850 cal. yr BP, equivalent to a mean age of 35,400±410 cal. yr BP for the four SU5 samples (95.4 per cent prob.; $\chi^2_{30.05} = 1.232 < 7.815$).

### Technical description of the fragment of ground-edge axe

The stone raw material is crystalline, of a basaltic type with reasonably fine crystals. The surface is beige in colour and chemically altered. It has been affected by contact with clay deposits, and residual red staining in spaces between grains suggests the presence of iron oxide. Thin-sectioning for petrographic analysis cannot be undertaken because of the high historical and cultural value of the piece.

The object is a thin flake detached by percussion from a straight edge. It measures 2.55 cm x 3.93 cm and 0.61 cm in thickness (Fig. 4). The ventral surface reveals the crystalline structure of the rock. The point of impact from which the flake was detached can be clearly distinguished. The flake exhibits no evidence of further modification following detachment. Its morphology shows that it was removed from the upper surface of the original tool. The percussion angle was close to 90° with the adjacent side, and the precision of the percussion angle and force combined with the thinness of the flake indicates that it was removed intentionally.

The dorsal surface of the flake is smooth, slightly convex in width and slightly less convex in length. Under acute-angled light it exhibits grinding striations along its entire length, created by a material necessarily of greater hardness and abrasiveness than the flake itself. The flake was ground smooth with a relatively fine-grained raw material. Likely candidates are the quartz sandstone or ortho-quartzite bedrock of the Kombolgie Formation, found across much of Arnhem Land and of which Nawarla Gabarrnang is a part.

The distribution and structure of the abraded surface indicates that grinding was intentional. The abraded surface contains a homogeneous central plateau, ground smooth along its upper reaches, below which along its slope the relief becomes coarser with an increasing density of shallow surface depressions, vestiges of prior hammer dressing or of the original surface of the rock.

On this plateau can be distinguished under binocular microscope (10× magnification) sets of superimposed and criss-crossing striations notable for their short length (0.5 cm on average). Some sets are more pronounced, in particular among the longer striations. This suggests either a disparity in the size of the grains on the grinding stone used (if this was the case this disparity should also be seen in their distribution across the flake, which it is not) or, more likely, variations in the down-force employed during grinding, further re-enforcing an intentional cause.
The ends of the abraded striations along the edge of the flake are flush with the detachment edge. There is no evidence of subsequent modification in the form of retouch or subsequent grinding. We are therefore dealing with a fragment of an originally larger ground object that can be further investigated microscopically.

The cutting edge of ground-edge stone axes is generally characterized by their unidirectional final abrasion, either longitudinal or transverse (Fig. 4D). The ground flake from Nawarla Gabarnmang cannot therefore come from the cutting edge itself of the axe, given the positioning of its abrasions and the multidirectional distribution of its striations. Ground-edge stone axes are usually only partially ground, and in Arnhem Land no examples of fully-ground tools are known. The axe is usually manufactured from a large flake or core blank initially shaped by percussion. On some axes only the cutting edge is ground, but grinding can also be found on the adjacent sides. For an axe to work efficiently, the zone of contact with the worked material needs to be smooth. Residual surface protrusions thus need to be flattened and ground smooth to eliminate friction points that would limit the capacity of the cutting edge to penetrate. Any coarseness along the cutting edge would counter the work of the axe as a tool of penetration. Consideration of these functional characteristics can be seen on the known complete ground-edge axes from Arnhem Land, one example of which was also excavated at Nawarla Gabarnmang, in late Holocene levels in XU24 of Square B (Fig. 4E).

This late Holocene axe enables better understanding of the Pleistocene ground flake, as the most salient aspect of the former’s cutting edge is that it has been reduced by grinding against a fine-grained abrasive material, with very short and highly localized criss-crossing movements resulting in sets of intersecting striations (Fig. 4C) reminiscent in structure and distribution of those on the Pleistocene ground flake (Fig. 4B). The left side of the late Holocene axe’s cutting edge has a morphology that is entirely comparable to the detached Pleistocene flake, wider than long, from a removal surface partially ground and detached by percussion from an unground rectilinear edge.

Although the Pleistocene flake does not intersect the cutting chord of the original tool, the sum of its observed technological traits excludes the possibility that we are dealing with an artefact that was ground after the production of the flake, or a portion of grinding stone or percussion tool, and no other similar Aboriginal object is known from ancient or more recent, ethnographic times other than ground-edge axes. Therefore, we can safely conclude that the Pleistocene ground flake from Nawarla Gabarnmang, wider than it is long, with large straight butt and a dorsal surface evenly ground to a slight convexity prior to its detachment, exhibits all the characteristics of a lateral fragment of the cutting surface of a ground-edge axe. The percussion angle is close to 90° with the dorsal surface, and the precision of application of percussion force combined with the thinness of the removal indicates an intentional action. The removal of the flake was aimed at thinning a side of the axe, near its lateral margin and fairly close to the effective cutting edge so as to remove a small protuberance indicated by a concentration of short, multidirectional striations.

Archaeological implications

The advent of ground-edge axes around the world has been widely heralded as a technological achievement of ecological, environmental and adaptive innovation and efficiency that enabled the cutting of trees for clearing, the working of timber, branches or bark, extraction of prey from natural hollows, hollowing of dugout canoes, working of wood towards the construction of tools and complex installations and the like. In the Northern Hemisphere, explanations for the onset of edge grinding typically evoke the exploitation of forest landscapes where axes are seen as highly efficient, adaptive tools that emerged as a result of increasing post-glacial demographic pressures necessitating deforestation and the clearing of land in preparation for agriculture and a sedentary lifestyle (Lewin & Foley 2003; Toth & Schick 2009). Other explanations would see ground-edge axes in Neolithic Europe used in wood-working and for cutting thinner items than tree-trunks. There is a very rich organic material culture in northern Europe that used wood for anything from houses to snow-shoes or baskets, and these small but sharp axes would have been useful for those.

In Australia, explanations revolving around the clearing of early Holocene forests for agriculture do not hold, firstly because ground-edge axes precede by many millennia the last glacial maximum, and secondly because they were not typically used for deforestation in a move towards agriculture and sedentism. On the other hand, ground-edge axes were here produced into the late nineteenth century AD, and continue to be made today in the neighbouring island of New Guinea (Pétrequin & Pétrequin 1993).

Ethnographic sources indicate that the exchange of ground-edge axes was integrated with regional circulation networks of prestige goods, kinship relations and ceremonial activities informed by local and regional cosmologies (see Paton 1994; Sharp 1952; Thomson 1949). Ground-edge axes played an
important role in the dissemination of cosmological understandings of the world and their symbolic representations. The universal lesson here is that the construction, use and geographical circulation of objects such as ground-edge axes are mediated by the way that people understand the world to operate cosmologically, and in doing so the object becomes a vehicle of socially-mediated symbolic storage. Understanding the manufacture, trade, function and use of ground-edge axes in Australia, and by implication elsewhere, requires us to go beyond their utilitarian roles as chopping tools to see them as objects of high social repute accessed between groups through the way their raw materials and originary landscapes were imbued with meaning and cosmological powers that connect people to places and to the ancestors (cf. Brumm 2010). Owing to their highly-localized position in the landscape, stone quarries, and in this regard ground-edge axe quarries in particular owing to their intensified and therefore embedded work effort as highly curated quarried objects, also externalize territorial understandings and their culturally-specific cosmological dimensions (Thomson 1949). It is this spatio-temporal landscape inscription of objects that takes place when stone-axe quarries are accessed, axes are manufactured, and exchanged, conferring extended notions of value and utilitarianism onto their handlers that go beyond their immediate economic worth as chopping tools. In those exchanges came the passing of values, meanings and symbolic understandings not only of the objects themselves, but of the lived and meaningful landscapes which connected groups with their resources as cosmological-territorial inscriptions.

In relating the ancient, 35,500-year-old fragment of ground-edge axe from Nawarla Gabarnmang to ethnographic observations of the cosmological significance of axes in Aboriginal Australia, we are not arguing for continuity in meaning across this vast period of time or from Australia to Europe, but for the universal point that objects are always socially meaningful — and thus always have social value and thus social use-value over and above their more conventionally considered ‘economic efficiency’ — through the way that places and things are cosmologically mediated in social interaction. Here we consider this issue through the example of stone axes, as a tool conventionally thought of only for its extractive potential. The above principle of the social value of objects applies just as much to things made and held by peoples of Europe, the Americas or Australia, as it does to cognitively fully-modern peoples of the past and of the now (for greater exposition of this topic, see e.g. Appadurai 1986; Dant 1999).

The question remains as to why, if at all, ground-edge axes deserve special consideration greater than that applied to flaked artefacts as objects of symbolic storage. We suggest that in themselves, flaked and ground tools are no different in this sense. What is different in the case of ground-edge axes is two-fold:

1. The social aesthetics of symmetry. Ground-edge axes are produced as symmetrical or near-symmetrical objects, and this aesthetic dimension gives them added symbolic weight (we would extend this same argument to other symmetrical objects including Acheulian ‘hand-axes’, as others have done before us). Grinding is a short-cut to symmetry; here it is not so much grinding itself that is at issue, for symmetry can also be created by flaking, but that grinding facilitates symmetry beyond flaking for most stone workers. Their relatively large size enhances their potential to be seen at a distance, and in this their aesthetic value crosses from the hidden to the public, affording ground-edge axes a heightened sense of social prestige.

2. The symbolism of efficiency. The success of an axe as a cutting or chopping tool resides in the angular smoothness of its cutting edge. Other than melting metal (and prior to the advent of recent synthetic products), stone grinding is the most efficient technological process known for creating a smooth cutting edge on an axe. This edge-efficiency renders ground-edge axes not only the most efficient chopping tools, but also gives them a high symbolic value as ‘state of the art’.

Ground-edge axes are thus social investments in aesthetism and symbols of efficacy; what is at stake here is not only the productive efficiency of the tool, but its socially-reproductive value (symbolic value enhances the maintenance of knowledge). Symbolic storage operates in all objects, not only ground-edge axes, but the latters’ social symbolism is enhanced by the foregoing qualities. Because the extraction of stone from localized quarries and the prolonged working of the stone into ground edges is geared to the manufacture of a non-expedient tool that can be used anytime in the near or distant future, a ground-edge axe’s immediate work value transforms the tool’s delayed-use value through its prolonged social value. The temporal space in this delay of value from the immediate work of manufacture to a potential future use allows for its social exchange, and in doing so for its radical re-orientation from a functional tool to a symbol of prestige where the material attracts and embodies social meaning replete with flexible, re-definable use-values. Simply put, a ground-edge axe’s functional value remains dormant until the axe is put into use, its on-going (i.e. non-dormant) mate-
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material existence as possession not only allowing but also requiring, by virtue of its retention, the object to accrue meaning in its social embeddedness. This social retention of the object, used or unused, directs its social value; and the knowledge of its social presence and material possibility from then-on causes a sociality of its material presence even in the event of its particular absence (i.e. through memory + meaningfulness, the damage, destruction or disappearance of individual axes attain social meaning as a momentum towards curation, renewal and access of ground-edge axes into the future). In these senses a ground-edge axe is an example of heightened 'symbolic storage'.

Edge-grinding enhanced symbolic storage in stone in a new way evident only after the arrival of Homo sapiens along the western rim of the Pacific, indicative of the continued cognitive evolution of, or at least the application of symbolic cognitive abilities to a new material realm by modern humans following the Out-of-Africa 2 migration.

Conclusion

Because of the high investment in effort and time required for their manufacture as an efficient, large, socially-visible, portable symmetrical tool, as well as the limited distribution of raw material sources, ground-edge axes attain high regional symbolic value steeped in the cosmologies of their makers and receivers, rendering them worthy of exchange as socially-valued objects, often over very long distances (e.g. Brumm 2010). This social layer of heightened non-utilitarian value, we argue, represents a level of human cognition and symbolism that grew from the Out-of-Africa 2 migration as early biologically fully-modern Homo sapiens populations adapted to new landscapes and their social configurations.

The discovery of the Nawarla Gabarnmang ground-edge axe fragment confirms that the oldest ground-edge axes appeared in northern Australia around 35,500 years ago, many millennia before their independent invention in the contiguous region of Africa, Europe and western Asia. The implication of its timing and of the geographical distribution of the world's oldest known ground-edge axes suggests a continued process of symbolic evolution subsequent to the Out-of-Africa 2 migration and associated with the development of behavioural modernity. That the earliest, Pleistocene ground-edge axes emerged in a utilitarian context untethered to post-glacial reforestation, population packing, anthropogenic deforestation, the advent of agriculture or sedentism indicates that other kinds of explanations are required. The Australian ethnographic evidence is salutary in this regard.

With the Nawarla Gabarnmang fragment of ground-edge axe, now the oldest in the world, the excavated sites of Arnhem Land have arguably produced one of the most significant set of ground-edge axes of the Pleistocene. This poses questions as to how and why it is here along the western Pacific rim that stone edge-grinding appears to have first evolved, without denying the possibility of subsequent independent inventions elsewhere. We conclude with three observations that enable a better appraisal of this question.

1. Hunter-gatherer populations of the Southern Hemisphere adopted the grinding of rock for the manufacture of ground-edge axes well before their counterparts in Mesolithic and Neolithic Europe. This discovery has archaeological implications very different from those that have prevailed in the standard explanations of the Northern Hemisphere.

   In the Northern Hemisphere excluding east Asia, and in Europe in particular, the grinding of stone occurs only during the Upper Palaeolithic after 30,000 yr, as evidenced by examples of mobiliary and fixed (rock) art. Yet the application of grinding on the edges of axes appears much later, between 8500 and 5000 yr and in association with changing environmental, ecological and economic conditions. Thus late Mesolithic–Neolithic technological innovations such as the onset of edge-grinding have been directly attributed to the functional practicalities of intensified food production, sedentism, and restructured subsistence imperatives (Lewin & Foley 2003; Toth & Schick 2009). These are economic and adaptive approaches to technological innovation that, while themselves relevant components of change, have usually (but not always) come as exclusive explanations at the cost of symbolic interpretations of a kind seen to operate ethnographically in other parts of the globe. The problem with such explanations is that, by themselves, they silence meaning outside of economic rationalism. At Nawarla Gabarnmang, and Arnhem Land generally, we argue that the onset of the world’s earliest ground-edge axe technology some 35,500 years ago was at its core embedded in symbolic dimensions that allowed people to interact meaningfully with each other and with their landscapes and their products, in the process enhancing the socially-structured and value-laden movement of goods and the construction of socially meaningful territory, stone sources included. We argue that here ground-edge axes were adopted because they aided subsistence and made certain tasks more efficient, but in doing so
they took on important new social and symbolic roles that served to cement social and environmental (territorial) relations.

2. Irrespective of their spatial and temporal distributions and of our explanatory frameworks, the grinding of stone in the production of ground-edge axes is embedded in the gambit of social realities. In this sense ground-edge axes remain inseparable from the lithic raw material sources from which they came: their lives endure as ancestry, or historical artefacts. This is because a ground-edge axe’s originary landscape is symbolically transported across the landscape as the tool is moved around by people (whether carried by an individual or traded between individuals and groups), spatially expanding its meaningfulness (and modifying its specific meanings) along the way. Such objects live only in the eyes of their owners, onlookers and the communities in which they make their mark.

The onset of ground-edge technology some 35,500 years ago in northern Australia, following the Southern Arc dispersal out of Africa, and the subsequent emergence of similar technologies in other parts of the world, indicate a common cognitive and symbolic process of spatial expansion and transference of meaning through and into the material, a process significantly enhanced among fully modern *Homo sapiens*.

3. In light of the above, subsistence-based economic arguments are not, in themselves, sufficient to understand the origins and adoption of ground-edge technology towards the manufacture of stone axes, although questions of tool efficiency are an important component of the issue. While ground-edge axes arguably possess more efficient cutting or chopping edges, their high manufacturing and maintenance costs, coupled with their use as occasional chopping rather than systematic forest-clearance tools in Australian contexts, highlight their importance as items of social value that, while requiring a consideration of their extractive potential, are not reducible to such functional, extractive abilities. Here a ground-edge axe’s symbolic value is other and, in this, more than the sum of its functional values. Ground-edge axes are highly-curated, more-or-less symmetrical and lasting tools usually made of volcanic raw materials found in highly-localized sources subject to territorial circumscription, unlike sandstone or quartzite tools which, in Arnhem Land at least, can be obtained from widespread sources across a vast landscape. The considerable work-time invested in the manufacture of a ground-edge axe extends its value beyond its immediate production and use; such time investment extends the period of manufacture into a future use-time through the tool’s social value expressed as maintenance and care. This social value is itself encoded in the cosmological meanings attached to sources as landscape features that are themselves given meaning through origin stories and the like, while at the same time also encapsulating the tool’s functional utility. Social value thus becomes embedded into an object’s exchange value through its extraction, transformation, use-potential, curation, maintenance and trade in a network of inter-personal relations. In this sense, as highly-curated and shaped objects originating from localized sources subject to territorial circumscription, ground-edge axes gain a level of symbolic value unmatched by more expedient tools typical of most percussion-flaked artefacts. The act of owning and carrying a ground-edge axe thus gives the owner more than an economic advantage by which to cut down trees or work wood, but also social value as the extended work-value of an object originating from a source that itself is already imbued with meaning and prestige through its territorially-mediated cosmological identity.

The implications of these findings are either that:

1. edge-grinding to make cutting or chopping edges first developed in Sahul, past the eastern edge of Wallacea and the Sunda shelf where a sea crossing was required to the east of the Asian continent. Such a scenario would see the earliest invention of edge-grinding taking place geographically past, and therefore after, the terrestrial completion of the Out-of-Africa 2 migration to the eastern Asian seaboard;

2. the global temporal pattern, currently showing that the earliest ground-edge stone tools in northern Australia predate similar tools in eastern Asia by 1000 to 4000 years, does not reflect the true geographical chronology, a problem of sampling limitations at a global scale; in this case yet-unknown east Asian ground-edge tools would predate the earliest Australian evidence; or

3. an as-yet undiscovered common ancestral axe-making tradition exists at the geographic waypoint between colonization of eastern Asia and Sahul.

If the early Australian and east Asian ground-edge technology are historically related (i.e. the two regional cases are homologous and thus are not independent inventions), which is suggested by their spatial proximity and near-contemporaneity, Option 1 would indicate initial invention in Sahul (Australia-New Guinea) with a back-migration subsequently
introducing the technology into eastern Asia via Sunda. Option 2 would see an original invention of edge-grinding technology in eastern Asia soon followed by its dispersal into Australia by incoming populations. This would indicate evidence for the arrival of people bearing ground-edge axes into an already-occupied Australia, presumably from Sunda, shortly before 35,000 years ago, some 15,000 years after the initial colonization of Sahul. Option 3 would see future locations of ground-edge axe manufacture located close to the way-point between a branching of dispersing populations into eastern Asia and Sahul. This would also imply that early axe-making technology will one day be detected in Southeast Asia.

At this stage, which of these three options is correct is difficult to determine with the available evidence. Insufficient archaeological sampling in eastern Asia and northern Australia, and insufficient precise and accurate dating, render also insufficient the resulting spatial history. One hint as to the more likely option comes not from the earliest evidence of edge-grinding itself, but rather of flaked waisted (as evidence of hafting) axe technology, the earliest evidence also coming from Sahul. At Bobongara in the Huon Peninsula (Groube et al. 1986) and at Kosipe (Summerhayes et al. 2010) in the highlands of Papua New Guinea, unground, symmetrical flaked and waisted axes have been recovered from archaeological contexts securely dated to ≥40,000 and 44,000–49,000 years ago respectively. In contrast, the earliest flaked and waisted stone axes in eastern Asia come from Hoabinhian and Middle Jomon sites, and are dated to the early- and mid-Holocene respectively (for reviews, see Anderson & Summerhayes 2008; Golson 2001). On this basis, the current evidence suggests that ground-edge axes emerged in situ in northern Australia from locally invented waisted (hafted) axe technology some 8000 to 15,000 years after the invention of hafted flaked axes in Sahul rather than in eastern Asia. Golson (2001) suggested that the spread of what were then apparently very early waisted and ground-edge axes across northern Australia-Papua New Guinea indicates the presence of an ancient and innovating sphere of cultural interaction in northern Sahul. In any case, there is no indication at this stage that edge-grinding technology arrived in Australia with the first Australians, nor is there indication of its invention in eastern Asia around the time of the colonization of Australia. On this basis, and with an absence of earlier evidence elsewhere in the world, the invention of edge-grinding technology at or subsequent to the completion of the Out-of-Africa 2 migration seems secure, with implications for developing symbolic practices as outlined in this article.

Acknowledgements

We thank the Jawoyn Association Aboriginal Corporation Committee, and Margaret Katherine, Sybil Ranch, Preston Lee, Wes Miller and Ray Whear, for inviting and caring for us during research in their country. Thanks to Ben Gunn and Lance Syme for assistance in the field, Luke Weatherley for sorting, Laure Dubreuil of the Department of Anthropology, Trent University, Canada for advice concerning grinding stones of the Near East, and Chris Clarkson, Francesco d’Errico and two anonymous referees for useful comments on earlier drafts. We thank the Australian Research Council for QEII Fellowship DP0877782 to BD and ARC Linkage Grant LP110200927 to enable this research to take place.

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