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What did grinding stones grind? New light on early Neolithic subsistence economy in the Middle Yellow River Valley, China

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What did grinding stones grind? New light on early Neolithic subsistence economy in the Middle Yellow River Valley, China

Abstract

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Keywords

grinding, did, china, grind, light, early, subsistence, neolithic, stones, economy, middle, yellow, river, valley, CAS

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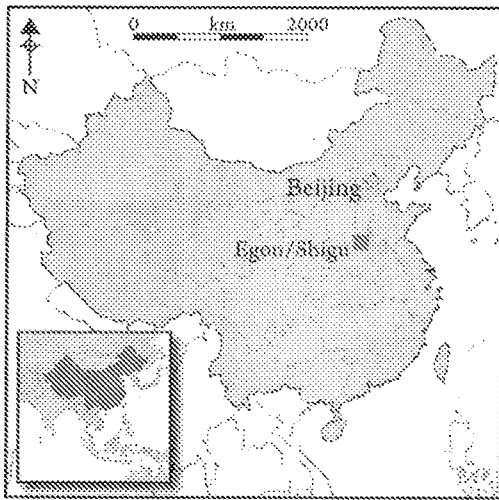
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What did grinding stones grind? New light on Early Neolithic subsistence economy in the Middle Yellow River Valley, China

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Grinding stones have provided a convenient proxy for the arrival of agriculture in Neolithic China. Not any more. Thanks to high-precision analyses of use-wear and starch residue, the authors show that early Neolithic people were mainly using these stones to process acorns. This defines a new stage in the long transition of food production from hunter-gatherer to farmer.

Keywords: China, Neolithic, grinding stones, querns, millet, acorns, agriculture

Introduction

The Peiligang culture (c. 7000–5000 BC) represents the earliest Neolithic settlement in the Middle Yellow River Valley and signals the emergence of food production and ritual

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complexity in the region. These developments indicate a transformation from mobile hunter-gatherer society, characterised by microlithic technology, to an agricultural-based Neolithic economy (Lu 1999), which eventually led to the formation of Chinese dynastic states several thousand years later (Chang 1986; Liu, L. 2004). Archaeological research in China has for decades focused on the Peiligang culture for insight into the origins of plant and animal domestication (Shi 1992; Henan Institute 1999; Lee *et al.* 2007; Luo 2007), sedentary settlement and the full development of cereal (mainly millet) farming (e.g. Bellwood 2005: 120–22; Smith, B. 1995: 134–9; Underhill 1997). However, the argument for the development of a cereal-based agricultural society needs to be further evaluated by scientific methods.

One approach to investigating ancient subsistence is to study the function of grinding stones, which are frequently found at Early Neolithic sites in north China, and constitute a high proportion of Peiligang stone tool assemblages (Liu, L. 2008). The interpretations of their function are based mainly on ethnographic analogy and range from hide-working (Zhao, S. 2005) and wild plant processing (Wu 1986; Liu, L. 2008), to dehussing domesticated cereals (Song 1997; Chen 2002). The last view has been widely accepted and thus grinding stones are claimed to provide key evidence for early agriculture in China (Chang 1986: 91; An 1989; Yan 1992: 114; Smith, B. 1995: 134; Bellwood 2005: 121; Higham 2005: 240). In this paper we present the results of functional analyses on six grinding stones from two Peiligang culture sites, Shigu and Egou, which challenge this view.

The sites and their assemblages

The Shigu site in Changge county is situated at the confluence of the Shiliang and Xiaohong rivers. To the west of the site are the Funiu Mountains, and to the east is the Central Henan floodplain (Figure 1). A total of 214m² was excavated, revealing three subterranean house foundations, 189 ash pits, 69 burials and 440 artefacts. Carbonised plant remains were identified as hazelnuts, walnuts, elm fruit and jujube. Eleven grinding stones, mostly unearthed from burials, account for 14 per cent of the lithic assemblage (Henan Institute 1987). The Egou site in Mixian is situated on a tableland at the confluence of the Wei and Sui rivers and surrounded by low hills. The site is 8000m² in extent and an area of 2781m² was excavated in the 1970s. The cultural deposits are thin at 0.3–0.5m in depth. Six subterranean house foundations, 44 ash pits and around 370 artefacts were uncovered. Among 133 stone tools, 20 are grinding stones, mostly from burials (18), accounting for 15 per cent of the total lithic assemblage (Henan Provincial Museum 1981).

Six stones, three from each site, were examined in this study (Figure 2; Table 1). Grinding stones of the Peiligang culture have distinctive stylistic characteristics. *Mopan* slabs are the lower stones and are normally made of coarse to medium-grained sandstone, elongated in plan with a flat upper surface and four short legs; they weigh around 10–20kg (Figure 2, nos. 1–3). Many *mopan* show striations and pitting on the used surface (Figure 2, no. 7), suggesting an abrading motion and frequent pecking to maintain an effective working surface. *Mobang* (literally grinding roller) are elongated upper stones (Figure 2, no. 4). They are mostly made of medium-grained sandstone, but occasionally other raw materials such as limestone were used. *Mobang* show a range of shapes in cross-section: round, oval,

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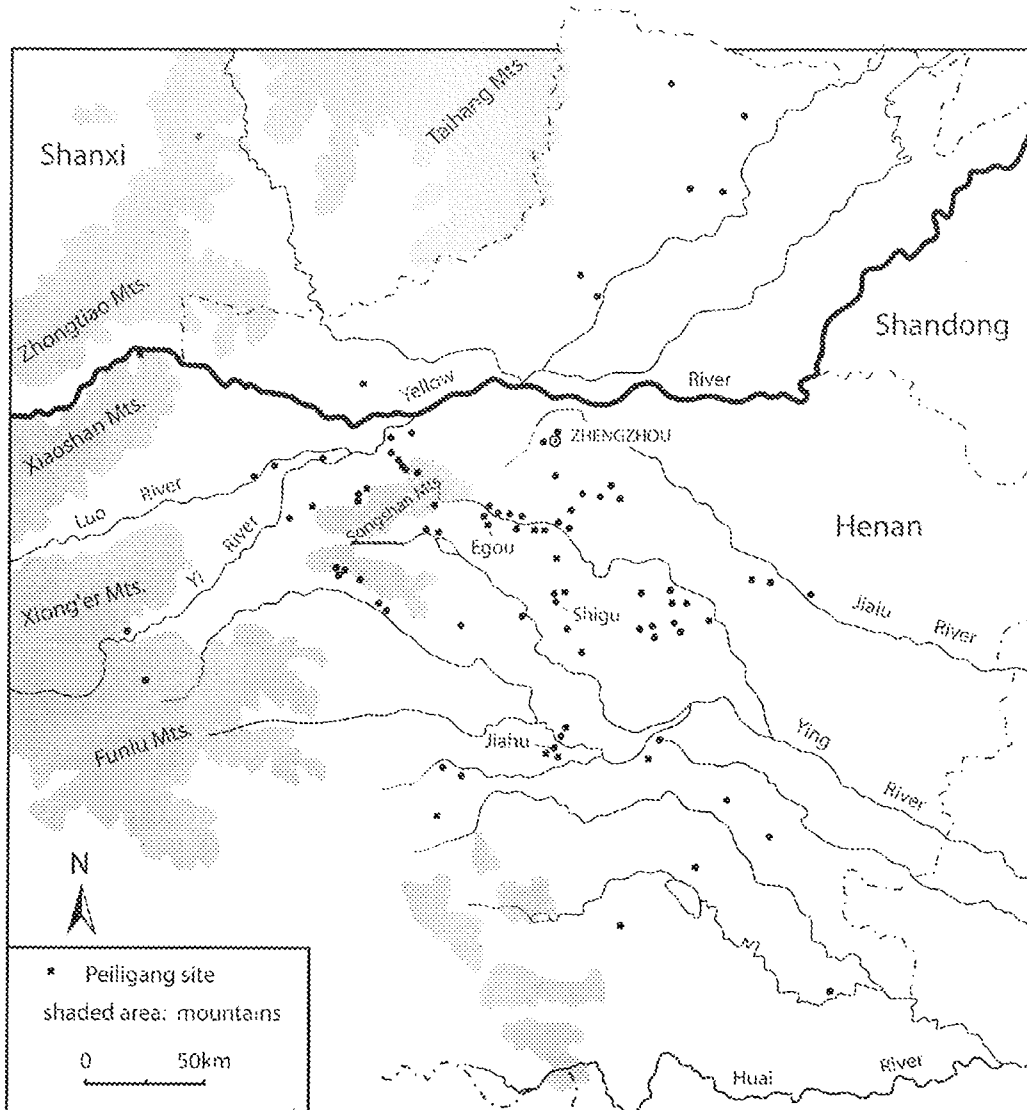


Figure 1. Distribution of major Peiligang culture sites and location of sites discussed in the text.

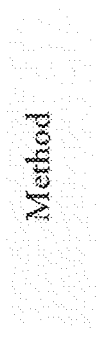
hemispherical and faceted. Different degrees of wear and various grinding motions, such as abrading, rocking and rolling have determined the shape at discard. Most *mobang* have one or more flat surfaces or facets, suggesting that abrading was the dominant action. Use-wear on the end of some *mobang* indicates they have also been used as pestles (Figure 2, no. 6).

Methods of analyses

Two methods were used: use-wear analysis and residue analysis based on the starches surviving on the stone. In each case the identifications were achieved by comparison with a reference collection.

Table 1. Descriptions of grinding stones that were examined in this study from the sites of Egou and Shigu.

Artefact/ sample no.	Starch sample no.	PVS sample no.	Tool type	Stone raw material	Wt (kg)	Use surface observation with naked eye	No. used surfaces & shape
EGT4M26/ GS31	GS31A	GS31-1	slab	medium-coarse grained brown sandstone	10.13	pitting and striations	1, flat-concave
	GS31B	GS31-2					
EGT18M40/ GS36	GS36A (top)	-	foot from a slab	medium-coarse grained grey sandstone	-	-	1, flat
	GS36b (side)						
	GS36c (foot)						
EGM55:6/ R25	R25	R25	handstone	medium-grained grey sandstone	-	polishing and striations	multiple, flat-sphere
SG215/ GS28	GS28A	GS28-1	slab	medium-coarse grey sandstone	10.18	pitting and striations	1, flat-concave
	GS28B	GS28-2					
SGAT62M86:2/ GS29	GS29A	GS29-1	slab	medium-coarse grey sandstone	10.09	rough surface, little pitting	1, flat-concave
	GS29B	GS29-2					
SGT46:1/ R32	R32	R32A R32B	handstone	medium-grained grey sandstone	-	polishing and light striations	multiple, round in cross-section



Method

What did grinding stones grind?

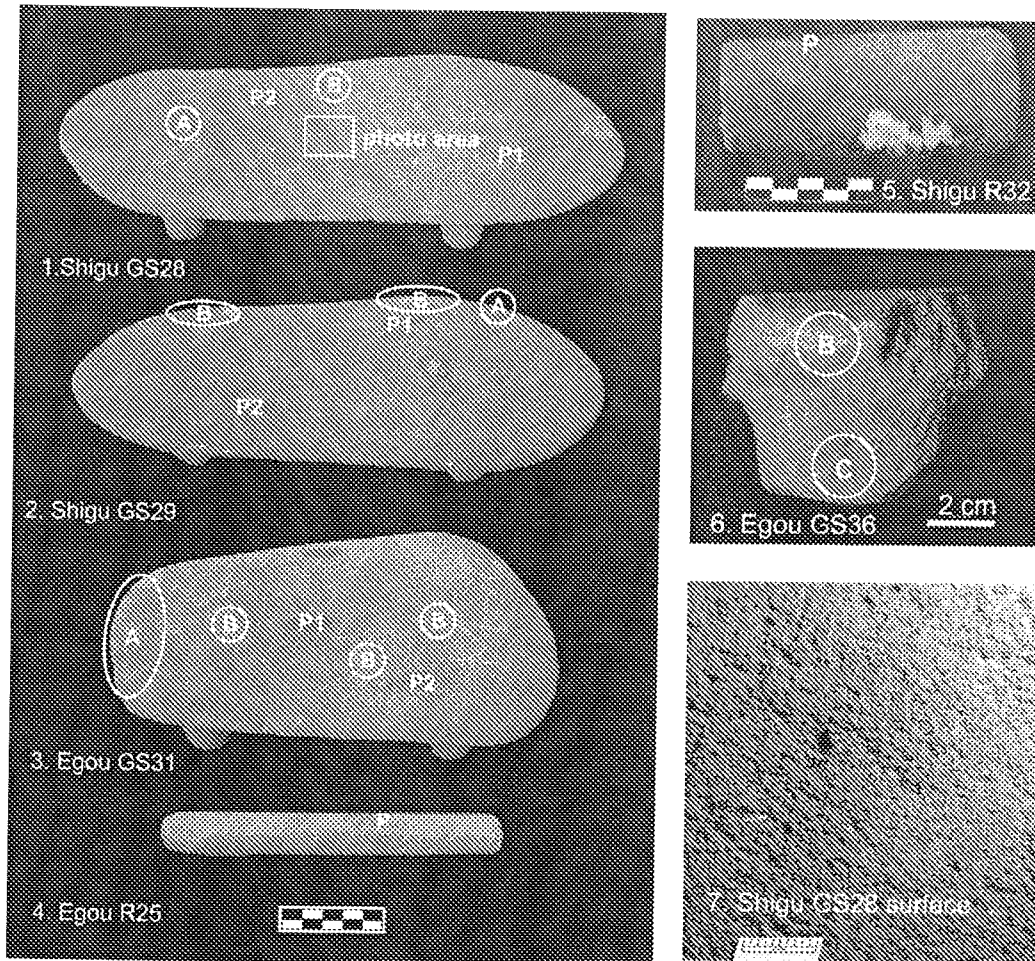


Figure 2. Grinding stones examined in this study, showing the location of samples: 1–3) mopan slabs; 4) complete mobang handstone; 5) fragment of mobang; 6) foot of mopan; 7) striations and pitting on the surface of mopan GS28 under low magnification. P = PVS sampling location; A, B = residue sampling location.

Use-wear analysis (Table 1; Figures 3 & 4)

Reference: the reference collection for use-wear analysis was compiled from two sources: (1) sandstones obtained from China (Henan) were used in an experimental study for processing cereals and acorns at La Trobe University, and the use-wear patterns were documented; and (2) a set of modern millstones (sandstone) at Xiazhuang village in Songxian, Henan, China, was examined for use-wear. These tools had been used extensively by the local people to process many different plants, including cereals and acorns (Figure 3).

The character of wear was determined using Polyvinyl siloxane (PVS) impressions or peels, of a type commonly used by archaeologists and other scientists to document surface details of various materials at high resolution (e.g. Mandikos 1998; Fullagar 2006a; cf. the use of acetate peels by Young & Syms 1980). The peels provide negative impressions so that pits and striations appear as raised features. Grinding, pounding and abrasion

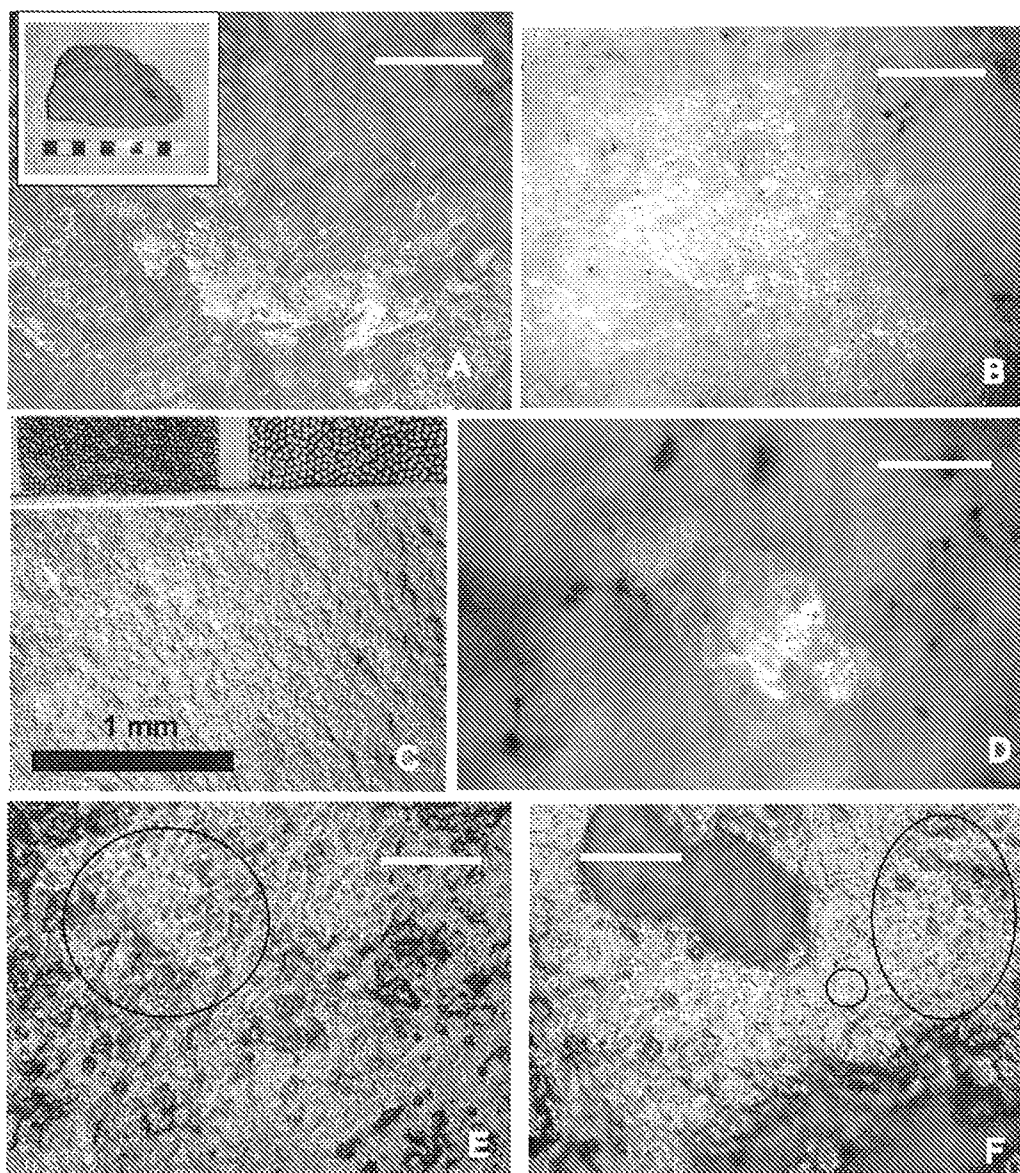


Figure 3. Reference collection of use-wear associated with siliceous plant processing (A), seed grinding (B-D), grinding/pounding acorns (E) and processing both seeds and acorns (F); scale bar: $200\mu\text{m}$ for all images except for C. A: Quartzite grinding stone no. 5473-0006-01 (see inset), from the Kakadu wetlands in northern Australia, $\times 200$. The polish is very similar to that found on sickle blades. B: PVS peel of an Aboriginal seed grinding implement made of sandstone (Australian Museum specimen E45912, western New South Wales), $\times 200$. C: Sandstone slab used for experimental grinding of brown millet (cf. *Setaria* sp.) and barley grains (cf. *Hordeum* sp.). Note the alignment of striations from top left to lower right. The scale indicates quartz grain size of 150–200 microns. D: PVS peel of experimental grinding slab shown in Figure 4C, showing a polished quartz (grain diameter 150 microns) with striations, $\times 200$. E: PVS peel of experimental sandstone mobang used for pounding acorns with shells (2 hours) and grinding acorn kernels (0.5 hour), $\times 200$. F: PVS peel of an ethnographic sandstone mopan from Xiazhuang, Henan, used for grinding both cereals and acorns, $\times 200$. Use-wear associated with grinding and pounding acorns includes relatively few striations and an uneven (irregular) polish texture, with shallow polished pits (circled).

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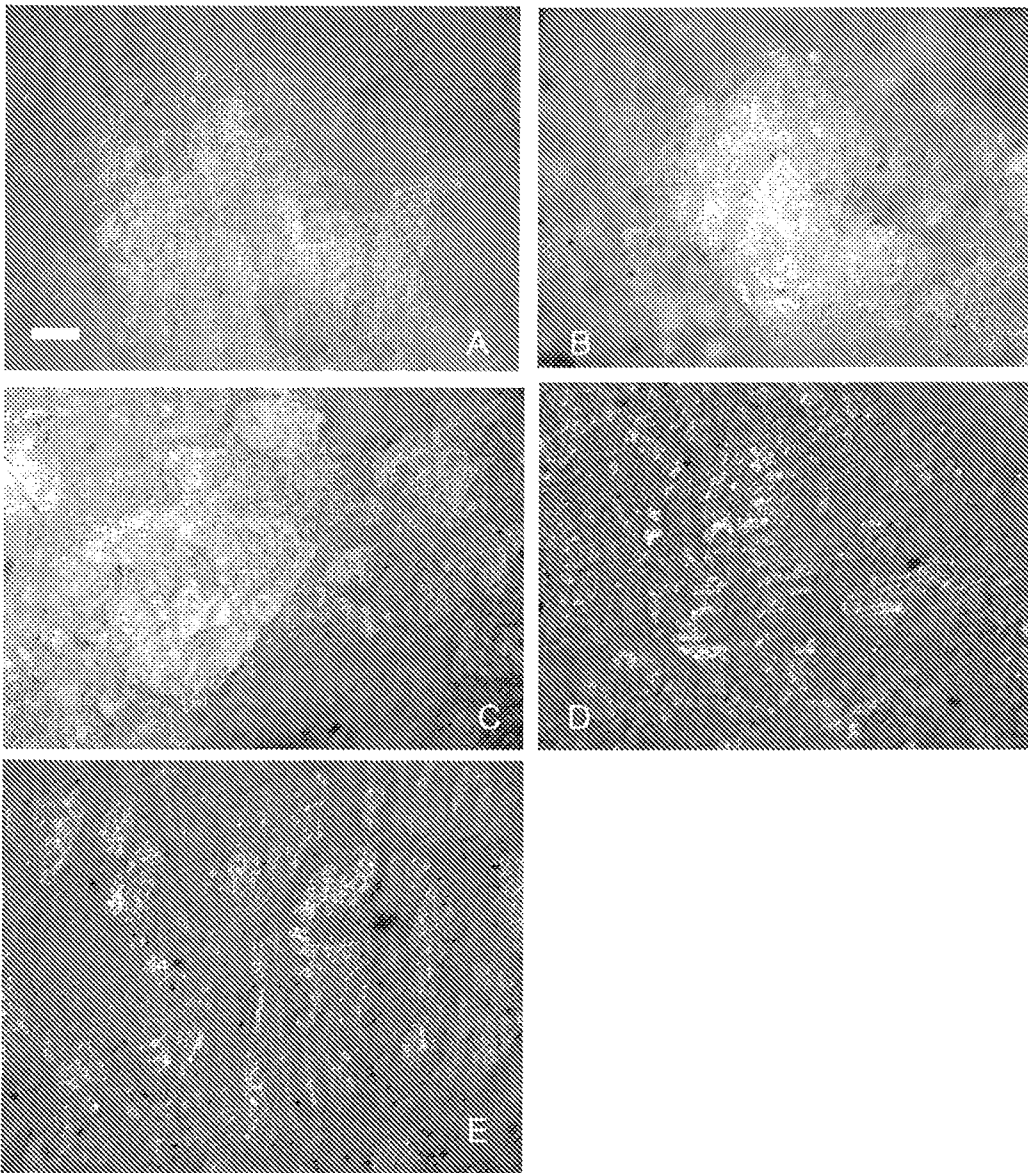


Figure 4. Use-wear patterns from Peiligang grinding stones (scale bar for all images: 0.1 mm; all PVS images). A: Shigu mopan GS28, PVS GS28-1, Slide 30; lighter, white areas are polished with fine striations visible oriented vertically up and down the image. B: Shigu mopan GS29, PVS GS29-1, Slide 32; lighter, white areas are polished with fine striations visible. C: Shigu mobang R32, PVS R32, slide 52; showing lighter areas which superficially look smoothed and polished, but undulating meniscus-like boundaries suggest that moisture has been trapped on the surface under the peel. D: Egou mopan GS31, PVS GS31-1, Slide 37; striations are visible in lighter polished areas that form a slightly reticular pattern. E: Egou mobang R25, PVS R25, Slide 44; broad striations are visible as lighter polished areas that form a slightly reticular pattern and with irregular corrugations, running up and down the image.

experiments undertaken by Fullagar (unpublished data) have utilised sandstone, granite, dolerite, quartzite, flint and basalt stones. Materials worked include seeds (i.e. millet, barley, rice and water lily), tubers, ochre and bone. However, smoothing, polish and other use-wear can, to a certain extent, be extrapolated from experiments on flaked stone (Fullagar 1991, 2006b) and other experimental datasets (e.g. Cunnar 2007; Hamon 2008). The current database of use-wear on ethnographic and archaeological grinding stones, in addition to the aforesaid materials from China, also includes extensive study of granite bedrock grinding patches (for seeds) in north-western Australia (Fullagar & Wallis 2008); numerous seed grinding dishes from arid regions (e.g. Fullagar 1985; Fullagar & Field 1997) including those from museum collections; and archaeological specimens used for processing tubers in more temperate regions of Australia (e.g. Hall *et al.* 1989; Fullagar & Jones 2004).

Based on our reference samples, stones used to process acorns and cereals can be readily distinguished. Use-wear on sandstone grinding stones used exclusively to pound and crush acorns produces far fewer striations than experimental tools used for grinding seeds such as millet and oats. Striations are not completely absent but rare, and compared with grinding seeds, the polish and smoothing from processing acorns is less flat and more uneven at high magnification ($\times 200$). Small depressions in the sandstone surface are polished and give the appearance of a surface that has been pitted and subsequently polished, which is likely to be what has happened.

Analysis and results: nine PVS peels from five grinding stones, three from Shigu and two from Egou, were examined microscopically under a compound (reflected light) microscope at magnifications of $\times 100$ and $\times 200$ (Figure 4). Two PVS samples from Shigu *mopan* (GS28) have no clear striations visible at low magnification, although possible pitting is present (Figure 4A). Striations seem to be present on some macroscopic images. At high magnification striations are present but rare, and polish development is generally low, with rare patches of more developed polish with a reticular pattern. Striations (longitudinal) were rarely visible at low magnification on two PVS peels taken from slab GS29 (Figure 4B). Striations were similarly rare at higher magnifications ($\times 100$ and $\times 200$). Polish development was low with rare reticular polish patterns. A PVS sample from *mobang* R32, which has a convex surface and an oval cross-section, had no striations visible at low magnification (Figure 4C). At high magnification ($\times 100$ and $\times 200$), striations are also rare and polish development is medium with clear reticular patterns and smoothed surfaces. However, the polished surface is uneven with apparently polished pits. The scarcity of striations and a polish pattern with apparent pitting are more typical of pounding and crushing acorns than cereals, although other plants may have been processed on the same stone. The two PVS peels from an Egou *mopan* GS31 show that longitudinal striations (furrows) are visible at low magnification, on flat, smoothed surfaces (Figure 4D). Polish development is low-medium with rare reticular polish visible at magnifications of $\times 100$ and $\times 200$. Furrows are common also at these higher magnifications and *sleeks* (ribbons of polish, see Kamminga 1979: 148) are rare. The polished surface is uneven and patchy at high magnification ($\times 200$) and the furrows may be associated with manufacture or surface rejuvenation, rather than use. The use-wear, particularly polish and striations, indicates the grinding of plant material, although further grinding experiments are required with local plants and other

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Table 2. Measurement data for comparative reference material used in this study.

Species	N	Mean	SD	Median	Range (μm)
<i>Lithocarpus glaber</i>	189	12.93	3.25	12.36	6.77–24.13
<i>L. fenestratus</i>	135	13.05	5.24	11.54	5.67–38.63
<i>Quercus acutissima</i>	101	10.9	4.74	9.94	3.31–27.53
<i>Q. aliena</i>	123	10.85	4.34	10.27	2.88–22.11
<i>Cyclobalanopsis fleuryi</i>	117	15.57	4.05	15.82	7.90–25.14
<i>C. nubium</i>	130	11.16	3.03	10.52	5.92–19.15
<i>Setaria italica</i>	124	10.58	2.73	10.01	5.83–20.54
<i>Panicum miliaceum</i>	131	7.90	1.76	7.73	3.93–13.07
<i>Trapa</i> sp.	117	25.07	5.11	26.00	11.18–40.66
<i>Fagopyrum</i> sp.	109	7.72	2.47	7.40	2.70–14.48
<i>Vigna</i> sp.	102	20.56	8.85	25.27	5.27–42.85

materials. *Mobang* R25 with a nearly round cross-section showed transverse furrows at low magnification (Figure 4E). At high magnification ($\times 100$ and $\times 200$), the surface is smooth with medium polish development with a reticular pattern, striations, rare sleeks and corrugated alignments. There are similarities with the stones used for grinding seeds, although at high magnification ($\times 200$), the polished *mobang* surface appears slightly more uneven than seed grinding stones. The corrugated alignments are unusual and may relate to grinding and pecking during manufacture.

In general, the use-wear, particularly polish and striations, indicates the processing of plants, although there are differences in the wear on the Egou and Shigu *mobang*. The orientation of striations appear to distinguish *mobang* (with transverse furrows) and *mopan* (with longitudinal furrows and sometimes sleeks). The Egou *mobang* appears to have less extensive polish with larger areas of unpolished depressions. The *mobang* also appear to have a greater degree of polish development than *mopan* from the same site. Compared with those grinding stones used for processing cereals in our reference collection, Shigu and Egou slabs have less polish development and fewer striations, but most have some later stages of polish with a reticular pattern developing, as is the case on Australian sandstone seed grinding stones (Figure 3). However, the polished surfaces on *mobang* and *mopan* are more uneven at high magnification ($\times 200$), and are distinct from the smoothed striated patches typical of experimental stone-on-stone use-wear. It is likely that all artefacts with this pattern have been used for processing plants of some kind.

Starch residue analysis (Tables 2 & 3; Figures 5–8)

Reference: a comparative reference collection has been compiled with which to identify the archaeological residues. It includes acorns, tubers, grasses and legumes (Table 2; Figure 5).

Analysis and results: dry sediment or water-extractions were collected from 12 locations on the use-surfaces of *mopan* and *mobang* from Shigou and Egou (Figure 2). The starch residues were extracted by heavy liquid separation using sodium polytungstate with a specific gravity (SG) of 2.35. Extractions were mounted on glass slides in 50 per cent

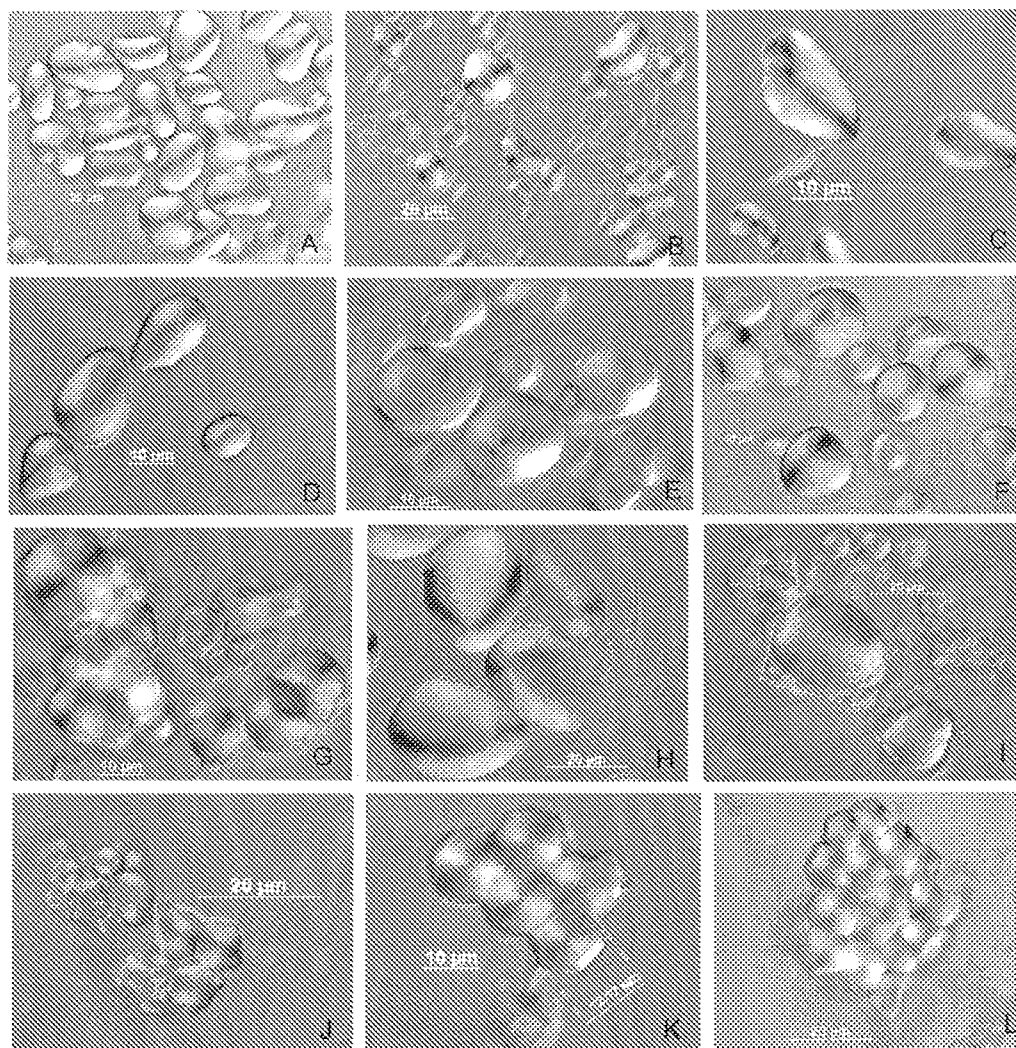


Figure 5. Comparative starch reference material used in this study: **A**) water caltrop (*Trapa* sp.); **B**) acorn (*Quercus aliena*); **C**) acorn (*Q. acutissima*); **D**) acorn (*Cyclobalanopsis fleuryi*); **E**) acorn (*C. nubium*); **F**) acorn (*Lithocarpus glaber*); **G**) acorn (*L. fenestratus*); **H**) Chinese yam (*Dioscorea opposita* Thunb); **I**) mungbean (wild) (*Vigna* sp.); **J**) broomcorn millet (*Panicum miliaceum*); **K**) foxtail millet (*Setaria italica*) (millet starch grains showing polygonal shapes and fissures at the hilum); **L**) buckwheat (*Fagopyrum* sp.) (photographs: J. Field).

glycerol. Complete scans of the slides were undertaken using a Zeiss Axioskop II brightfield microscope fitted with polarizing filters and Nomarski (Differential Interference Contrast) optics. The Nomarski method is specifically designed to enhance the contrast of unstained specimens, thus providing good visualisation of surface features. Images were collected using a Zeiss HRc digital camera and Zeiss Axiovision software.

Ten of the twelve samples examined in this study yielded starch grains. Their measurements (maximum length through the hilum) were plotted against a range of comparative reference material for comparison to eliminate those plants that were unlikely

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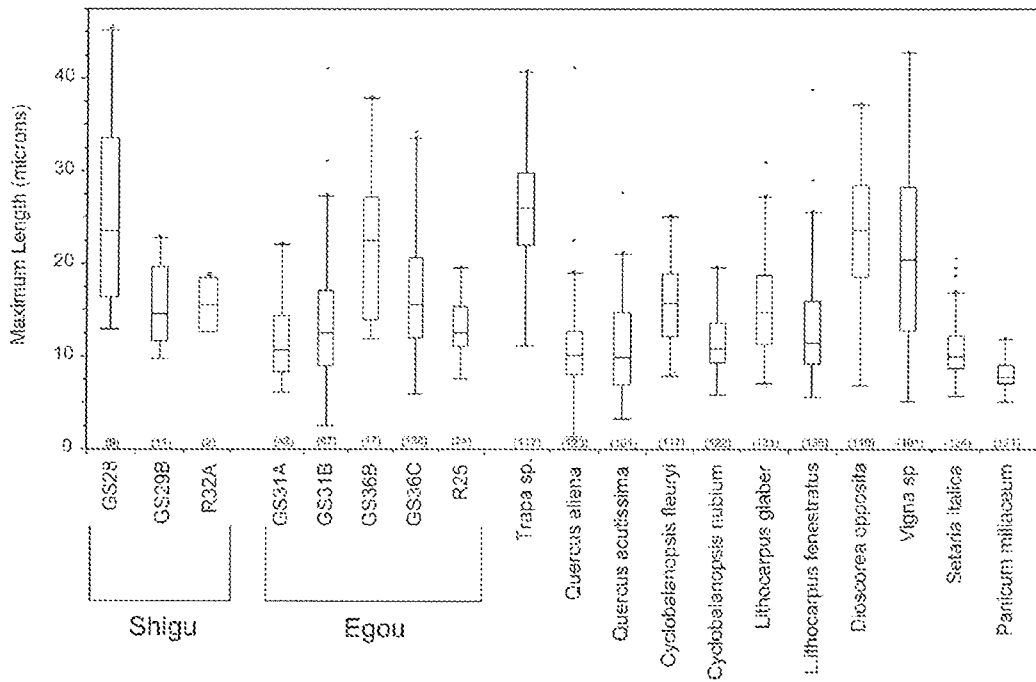


Figure 6. Boxplots of starch grain maximum length of the archaeological samples against a range of comparative reference collection data. Numbers in brackets indicate the number of grains measured.

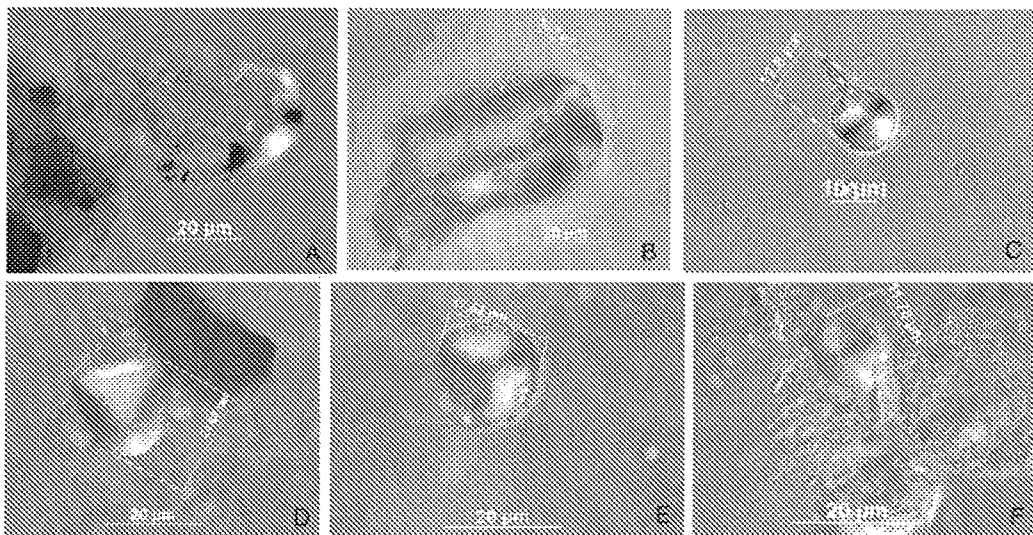


Figure 7. Starch grains from Shigu: **A & B**) damaged grains from sample GS28A; **C**) the single round grain from R32A, a shape and size that is common to many starch producing plant species; **D–F**) some of the starch grains from the sample GS29B assemblage. There are faceted grains (**D & E**) and irregular shaped grains (**F**) with fissures (photographs: J. Field).

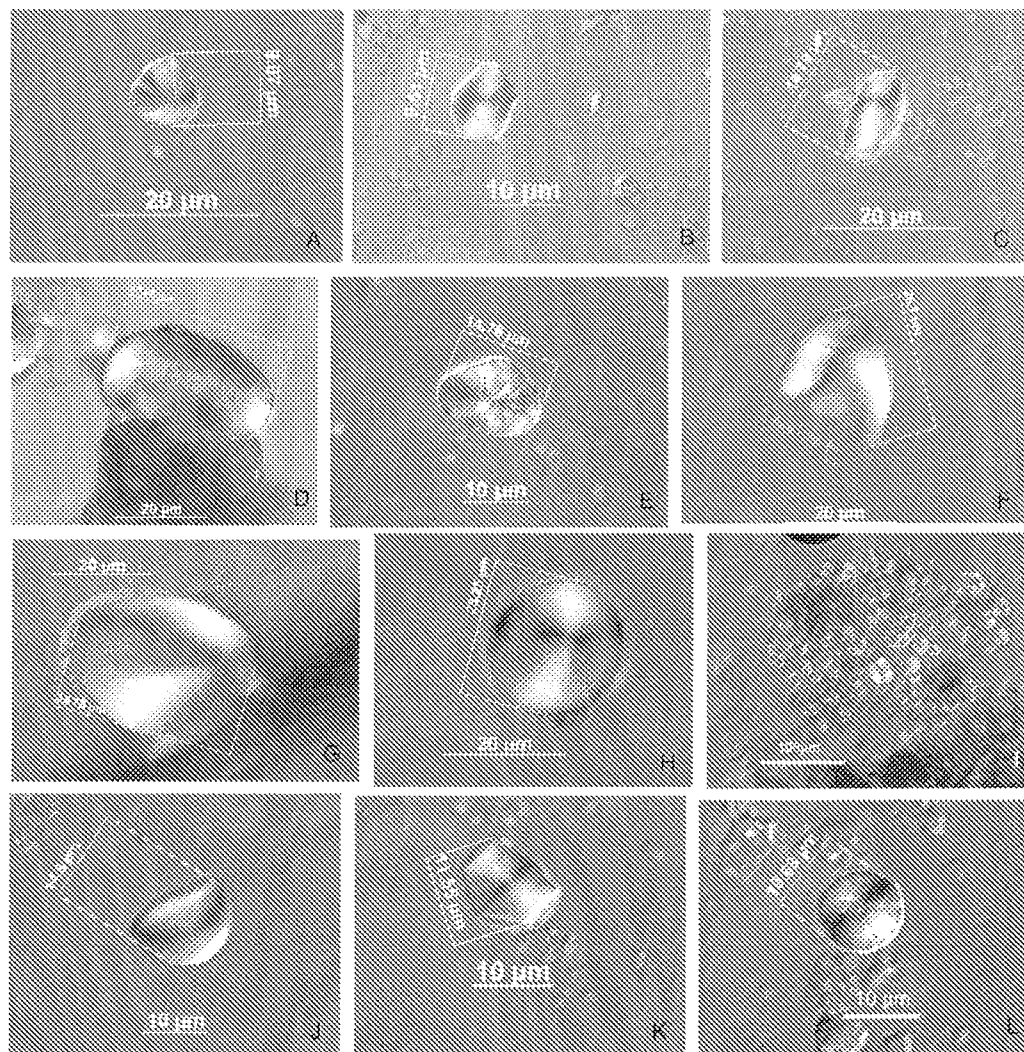


Figure 8. Starch grains identified on samples collected from grinding stones recovered at the Egou site: A–C) GS31A; D–F) GS31B; G–H) GS36B; I) GS26C; J–L) R25 (photographs: J. Field).

to contribute to the assemblage (Figure 6; Tables 2 & 3). Subsequent identifications were undertaken on the basis of morphological features of the starch grains.

Shigu: four of the six Shigu samples yielded starch grains, but of these only two samples yielded >2 grains (Table 3). GS28A and GS28B are from the same tool, and yielded only nine grains so are combined and considered as GS28. On the basis of this preliminary analysis, GS28 starch had dimensions in the *Trapa* sp. (water caltrop) range, though the archaeological samples showed greater size variability. It is unlikely to have been used for cereals as none of the reference material overlapped to any degree with this sample, nor were the morphological features observed consistent with cereals. Furthermore as only a small number of grains were recovered from this artefact, any confident allocation to species would

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Table 3. Results of starch analysis of samples from grinding stones from Shigu and Egou, showing mean and maximum lengths of grain.

Site and sample no.	Tool type	N	Mean	SD	Median	Range (µm)
Shigu						
GS28 (A,B)	slab	9	26.04	10.46	23.7	13.14–45.13
GS29A	slab	0	–	–	–	–
GS29B	slab	11	15.57	4.43	19.66	9.82–22.81
R32A	handstone	2	15.72	–	–	12.8–18.64
R32B	handstone	0	–	–	–	–
Egou						
GS31A	slab	42	10.88	3.89	10.08	5.82–20.94
GS31B	slab	97	13.06	6.29	11.87	2.47–38.68
GS36A	slab	0	0	–	–	–
GS36B	slab	17	21.00	7.75	21.24	11.2–35.78
GS36C	slab	138	16.00	5.59	14.81	5.65–32.30
R25	handstone	24	12.55	2.88	11.86	7.24–18.47

be speculative and require further consolidating studies. GS29B yielded 11 starch grains and produced an assemblage which appears to vary markedly with the starch recovered from GS28. Size range and morphology of this assemblage correlates to the acorns (cf. *Lithocarpus* sp., *Quercus* sp. and *Cyclobalanopsis* sp.). Part of the GS28 assemblage also falls within this size range and some of these species may have contributed to the final starch assemblage. Interestingly, of the small amount of starch that was identified from this sample (GS28) most appeared to be heavily damaged, consistent with the grinding process, making measurements and possible identification problematic (Figure 7A & B). For the Shigu material, it is unlikely that cereals were being processed but attributing any other species or genera identification to the starch is not possible.

Egou: six samples were examined from the Egou site, of which five yielded starch grains (Table 3). As with most analyses, the larger the number of starch grains recovered the greater the possibility of identification to genera or species for the plants being processed. In this case, sample GS36C yielded 138 grains which is a good yield for an archaeological sample. Samples GS31A and B were collected from the surface of a *mopan*. The starch grain dimensions from GS31A fall well within the range of acorns (Figure 6) and the morphology of the individual starch grains are consistent with this broad grouping. Note the grains in Figure 8A, B and C show morphologies also observed for a range of *Lithocarpus*, *Cyclobalanopsis* and *Quercus* species (Figure 5G), namely the faceting of some grains and the fissures at the hilum. Sample GS31B had a higher median value than GS31A and may reflect that the larger sample analysed captured a greater variability in sample sizes. It is also consistent with a range of acorns with the higher median value aligning it more closely to *Lithocarpus*. This *mopan* (GS31) may have been used as a multifunctional tool as evidenced by the presence of kidney shaped starch grains with fissures (Figure 8D), similar to those produced by beans, e.g. *Vigna* sp. (Figure 5I), and unidentified faceted grains (Figure 8F). Two samples, collected from the side (GS36B) and bottom (GS36C) of a broken slab foot, showed great variability in starch yields (Table 3). Sample GS36B yielded a tuber grain (Figure 8G) consistent with

the Chinese Yam (*Dioscorea opposita* Thunb.) (Figure 5H). Sample GS36C produced the highest number of starch grains (Figure 8I). The measurements and features of this starch assemblage is similar to *Cyclobalanopsis*, though some very distinctive grains observed in the reference samples were not observed in the archaeological sample. As the starch was found mostly in clumps on this slide it is likely that the assemblage represents one plant. Sample R25 was collected from the elongated surface of a *mobang*, and yielded 24 starch grains. A range of morphologies presented in this sample including faceted, round and irregular shaped grains (see Figure 8L). Five of the grains are strongly faceted (e.g. Figure 8K) and are consistent with a range of material from the Poaceae (grass) family, in particular foxtail millet (*Setaria italica*). The starch assemblages recovered from the Egou grindstones are consistent with an acorn origin for most of the starch found there. However, the presence of possible beans, yam and millet starch suggest either a multifunctional use for these implements or at least the associated presence of these plants.

Discussion

The use-wear of these grinding tools show some similarity with grinding stones used for processing seeds in Australia (Smith, M.A. 1988; Fullagar & Field 1997). Detected differences include surface unevenness at high magnification and the frequency of striations. For example, compared with the grinding stones used for processing cereals (Figure 3A–D), the Peiligang grinding stones have sustained less surface smoothing, and have polished, pit-like depressions. The role of silica in development of use polish on these grinding stones is unclear, and may be less significant than processes of abrasive smoothing (cf. Fullagar 1991). Unlike many residues from Australian grinding stones (e.g. Fullagar *et al.* 2008), phytoliths have not been recovered from the Peiligang grinding stones. While this may be due to a number of taphonomic factors such as pH of the enclosing sediments, survivability of the phytoliths relative to the starch, the lack of phytoliths from the Peiligang grinding stones may reflect the fact that grass seeds were not the main plant material being processed.

It is not surprising that millet starch was rarely found on grinding stones. Millet needs to be dehusked, but does not have to be ground to flour for human consumption. Experimental studies indicate that mortar and pestle are the most effective tools for dehussing cereals (Meurers-Balke & Lüning 1999), including millet (Wang 2008). On the other hand, acorns have to be ground and leached for human consumption (Mason 1992). Experimental studies indicate that processing dry and fresh acorns produces polish on grinding tools made of basalt and sandstone, probably influenced by oil in this plant (Dubreuil 2004; Wang 2008). The polish appears to be more developed in sandstone than in basalt, according to Wang's study (Wang 2008). Dubreuil (2004), like us, noted an irregular surface and that striations were rare on processing implements used to grind acorns, but suggested that this was a problem with highly reflected surfaces of polished basalt. We think that the absence of striations is real in sandstone grinding stones and that it is probably related to the cushioning effect of large kernels and minimal contact between upper (i.e. handstone) and lower grinding stones. There are various ways of processing acorns in different regions in China. According to our ethnographic observation in Songxian, Henan, the locals soak the acorns overnight and then grind them with shells attached on a machined millstone. The millstone was used

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for grinding acorns and other plants, including dehusking cereals. Its used surfaces had patches of wear very similar to our experimental acorn grinding experiments (Figure 3F), but also had other patches with the relatively flat heavily striated polish observed on seed grinders.

The starch assemblages in this study appear to be predominantly of acorns, while starch grains identifiable to yam, bean and millet occurred much less frequently. This finding is consistent with several functional studies of grinding stones dating to the early and middle Holocene periods in other parts of China (Wang 2008; Yang, X. *et al.* 2009; Liu, L. *et al.* in press). According to our ethnographic study in Zhejiang, China, people still make acorn jelly today. Acorn flour is mixed with starch from other plants, such as sweet potato, in order to improve the flavour and texture of the product. A similar way of making acorn foods by combining various plant flours may have already been practised in prehistory.

The use-wear variability and the recovered residues suggest that the grinding stones from Peiligang sites are likely to have been used as multifunctional tools, and they may not have been limited to processing foodstuffs like seeds and nuts. Other artefact materials that could cause polish on grinding tools include medicines, wood, bone, ochre, shell and skin or hides (Cunnar 2007). Further experimental study on use-wear and residue patterns from more grinding stones is warranted to understand the range of the functions of these tools.

The results from this study shed light on two important problems in prehistory: the function of grinding stones in the Peiligang culture of the Middle Yellow River region and Early Neolithic subsistence strategies. The current study indicates that a wide range of starchy plants was exploited by the Peiligang culture people, including acorns from various species/genera, millet, yam and bean. Chinese yam (*Dioscorea opposita*), *shanyao*, is an indigenous plant, distributed widely in both north and south China today. Wild yam grows on mountain slopes, near forests in river valleys, near streams, and in shrubs and grasses (Flora of China 1985: 103–105). Henan is known to produce high quality yams, a plant which has been used not only as food but also as medicine. Starch analysis has the advantage of identifying tuber remains, which have rarely been found in carbonised forms in archaeological contexts. It is not currently known when yam was first domesticated, though the Peiligang people probably exploited wild yam. In China seeds of beans have been uncovered from many Neolithic sites. Starch identifiable to species belonging to the genus of *Vigna* have been found on grinding stones from the Middle Neolithic site of Shangzhai in Beijing (Yang, X. *et al.* 2009). Starch grains from several species of *Vigna* show similar morphology; and in this study it has not been possible to identify the bean starch to species.

The earliest macrobotanical remains of domesticated millet have been found in the Liao and Yellow rivers in China, including the Henan region, all dating to the late seventh and early sixth millennia BC (Zhao, Z. 2004; Liu, C. 2006; Lee *et al.* 2007). Our starch analysis confirms that millet was indeed a part of the diet of the Peiligang people. It is important to point out that starches present on grinding stones examined here do not represent the whole range of plants used by the Peiligang people. Soybean, for example, which have been found as seeds in flotation samples from many Early Neolithic sites, is absent in our starch assemblages. This is because soybean contains a low proportion of starch, and its starch grains are very small in size and lack diagnostic characteristics. Also, the composition of plants shown in the recovered starch assemblages does not necessarily reflect the relative

proportions of different plants exploited by the Peiligang people. Except for acorns, almost all plants identified, including millet, beans and tubers, can be consumed after being boiled in pottery, without being processed into flours with grinding stones. Nevertheless, given that grinding stones account for significant proportions in tool assemblages of the Peiligang culture, it is reasonable to argue that acorn was an important staple food used by the Peiligang people.

Conclusion

This pilot study of Peiligang culture grinding stone tools greatly improves our understanding of the Early Neolithic subsistence economy in the Yellow River region by providing direct evidence of economically important plant foods. Peiligang grinding stones were used for (but not limited to) processing a variety of plant foods, predominantly acorns, followed by millet and beans, among others. Several studies have previously pointed out that the Early Neolithic Peiligang culture was characterised by wide-spectrum subsistence economy (Henan Institute 1999: 898; Lee *et al.* 2007), and our findings certainly support this proposition. The presence of grinding stones in the Early Neolithic sites should no longer be used as an indicator of intensive agriculture based on cereals; but, instead, it is more likely to suggest a wide-spectrum subsistence economy, with a particular focus on acorn exploitation.

Acorns are known to have been used as a staple by many hunting-gathering peoples throughout history in many parts of the world, such as North America, Japan and Europe (Mason 1992, 1996; Bettinger *et al.* 1997; Crawford 1998; Anderson 2005; Matsui & Kanehara 2006). However, it is a new concept in Chinese archaeology that the Early Neolithic Peiligang people, who were previously thought to have been farmers, also relied on acorns as a staple food. This finding challenges the traditional concept of the Neolithic Revolution in China, which has often been viewed as a package of inter-related developments, including cereal farming (millet and rice), animal domestication (pig and dog) and sedentary settlement. On the contrary, cereal farming, although practised, did not play a significant role in the subsistence economy until all the other components of Neolithic culture were already in place.

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