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The interplay of millets and rice in Neolithic central China: Integrating phytoliths into the archaeobotany of Baligang

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ABSTRACT

Baligang is a Neolithic site with a long occupation, from before 6300 BC up to the first millennium BC, although the bulk of excavated finds and archaeobotanical evidence from the site comes from the Yangshao, Qujialing, Shijiahe and Longshan (4300–1800 BC). The cultural group affiliation of the site varies between northern (Yangshao and Longshan) and southern (Qujialing and Shijiahe) cultural connections. The earliest occupation of the site represents a pre-Yangshao society with early cultivation of rice (*Oryza*). In later periods Baligang has evidence for mixed farming of both rice and millets (*Setaria italica* and *Panicum miliaceum*), although rice is the most prominent crop in the phytolith record throughout the occupation. Wetland rice cultivation is indicated throughout the Yangshao, Qujialing, Shijiahe and Late Longshan periods. However, there is a shift towards better watered rice in the Qujialing and Shijiahe phytolith assemblages, indicated by a decline in sedges (Cyperaceae) alongside occurrence of sponge spicules and diatoms. These data suggest deeper flooding of rice fields in order to suppress weeds and increase productivity, indicating that the ecology of rice cultivation changed over time. In the Late Longshan period, when millet became more prominent and the cultural influence shifted northwards, it appears that more sedge-infested and weedy rice fields became the norm, suggesting a decline in rice cultivation intensity, perhaps connected to influences of cultivation practices from the north. In addition, we can infer aspects of the organisation of crop-processing from the phytolith evidence. In the Yangshao period the remains consist of mostly dehusking waste from the final processing, suggesting storage of a more processed crop and therefore larger scale, more communal post-harvest processing. By contrast this declined in the subsequent period with more evidence for primary winnowing waste indicating a shift towards smaller social scales of harvesting and processing, such as smaller household groups replacing a more communal approach. The household-level of processing is most evident in the Late Longshan period.

1. Introduction

China has long been known as a centre of origin for both rice (*Oryza* L.) and millets. Foxtail millet (*Setaria italica* (L.) P. Beauv.) and common millet (*Panicum miliaceum* L.) were domesticated in the north and rice in the south. Plant remains collected from archaeological sites reveal that rice had been cultivated in the middle and Lower Yangtze River basin from at least 9000 years ago (Crawford, 2006; Lu, 2006). According to archaeobotanical analysis of spikelet bases, rice domestication was a protracted process which took place over a few thousand years. In the Lower Yangtze this had finished by 4000 BC (Fuller et al., 2009), whereas an earlier domestication in the Middle Yangtze is probable (Fuller, 2011; Nasu et al., 2012), including evidence from the dominance of domesticated spikelet bases in the lower (pre-Yangshao) occupation at Baligang before 6300 BC (Zhang and Hung, 2013; Deng et al., 2015). On the other hand, millets appear to have been widely cultivated across several northern Chinese cultures by 6000 BC (Liu et al., 2009; Bettinger et al., 2010; Zhao, 2011; Qin, 2012), while phytolith evidence from the Cishan site, Hebei province indicates possible earlier millet cultivation back to the start of the Holocene (Lu et al., 2009; Yang et al., 2012). Starting from different distribution patterns for rice and millet farming, in south and north China respectively, both kinds of agriculture spread into each other's zone leading to mixed systems, certainly by the Early Yangshao period (4500–3800 BC) (Qin, 2012; Zhao, 2011; Fuller, 2011; Nasu et al., 2012). As a result, a broad band of mixed rice and millet farming stretched between the Yellow River and the Middle Yangtze by around 4000 BC. This raises questions about the relative importance of hardy rainfed millet versus more labour intensive rice cultivation, and the relationships of these agricultural preferences with different cultural traditions and periods. The middle Han Jiang valley in central China, a northerly tributary of the Yangtze located in southern Henan, lies along a key frontier between the Yellow River and Yangtze cultural zones,

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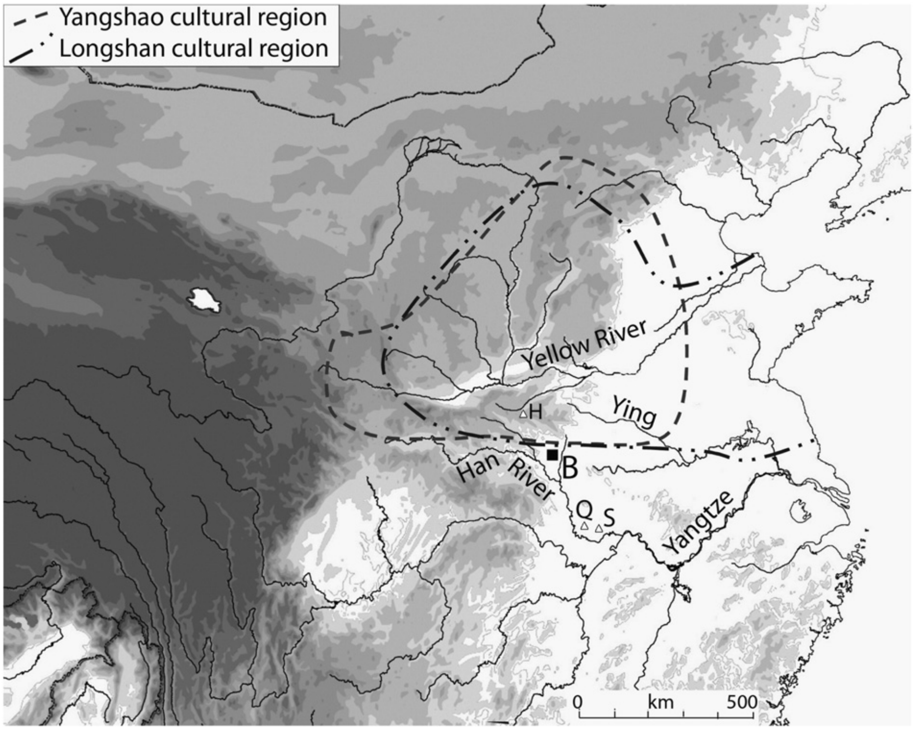


Fig. 1. Map showing the location of Baligang and other sites mentioned in the text. B = Baligang, Q = Qujialing, S = Shijiahe and H = Huizui.

enabling us to better understand the relative contribution of northern and southern agricultural traditions over time.

The site of Baligang, Henan Province (N32°41′30″, E112°8′5″E) is situated on the second level terrace on the south bank of the Tuanhe River, which is one of the tributaries of Han Jiang (Fig. 1). Archaeological excavations at this site were conducted from 1991 to 2010, and a large quantity of remains has been unearthed extending from the pre-Yangshao period to post-Han dynasty. A large part of this site consists of a Neolithic settlement, first occupied in the pre-Yangshao period (ca. 6500 BC), and then, after a 2000 year hiatus, used continuously from the Yangshao to the Longshan periods (ca. 4300 BC–1800 BC), with more limited evidence from the Bronze Age (Eastern Zhou, 770–256 BC) (Zhang and Hung, 2013; Weisskopf, 2014; Deng et al., 2015). (Fig. 2). The most common features on the site are bell-shaped pits, inferred to have been primarily storage pits, but their fills represent secondary waste disposal. Although house foundations were excavated from part of the Yangshao site in earlier seasons, these features were not excavated during the seasons when archaeobotanical sampling was carried out. Thus all archaeobotanical sampling comes from contexts that relate to waste disposal from the occupation activities rather than from primary activity areas.

Jiang and Zhang (1998) analysed 15 phytolith samples from Baligang previous to this study, chiefly to identify and reconstruct rice cultivation patterns and investigate the spread of rice agriculture. Here we analyse a larger phytolith dataset (29 samples), from a wider a range of periods (also described in Weisskopf, 2014), and consider this alongside archaeobotanical evidence from macro-remains. Full details of the macro-botanical analysis are published elsewhere (Deng et al., 2015), but are summarized and compared with the phytoliths in the present article. Many of the phytolith samples come from sediments that do not produce charred macro-remains, so they can provide information that complements the macrobotanical record, both by representing additional contexts and identifying species that are not well-represented in the charred macro-remains. The phytoliths from the ash samples supply evidence of plant material that was used or discarded in fires but did not survive burning in recognisable charred forms.

In this study, most samples represent mixed deposits formed from different dumping episodes and charring events over indeterminate periods. The varying contexts should supply information on general trends and routine daily life. These represent Class C samples in the terms of Hubbard and Clapham (1992) or the background noise of daily life routines (Fuller et al., 2014). One strength of phytolith analysis is the ability to see plant parts, including crop-processing waste which is poorly represented in macro-remains (Harvey and Fuller, 2005), thus broadening the scope of issues that it is possible to address. However, it should not be forgotten that the sample types available limit the questions that can be answered. It may not always be possible to distinguish between alternative interpretations. For example, the presence of husk and absence of straw of a species (e.g. *Oryza*) could be due to input of spikelets, which indicates the presence of a consumer site (Thompson, 1996), or because threshing was carried out seasonally off- site (Fuller and Stevens, 2009). The proportions of identifiable phytoliths from crops per sample are low, usually less than 5%.

2. Sampling

Samples for analysis were collected from refuse remains at Baligang in 2004 and 2007. Twenty nine samples were processed and analysed for phytoliths, of which 1 is from the pre-Yangshao period, 13 from the Yangshao period, 6 from the Qujialing period, 3 from the Shijiahe period, 4 from the Longshan period and 2 from the Bronze Age Eastern Zhou Dynasty (Table 1). The samples were collected from either homogenous layers within excavation units, taken to represent midden build-up on the site, or thin laminated layers in pits, which represent secondary infilling of former storage pits with midden material. Both types of units represent secondary refuse from on-site activities, and while these are, broadly speaking, domestic activities, these are not from primary activity areas and as such would have been prone to mixing of various events (Hubbard and Clapham, 1992; Harvey and Fuller, 2005; Fuller and Zhang, 2007; Fuller et al., 2014). The pit fill layers are likely to represent shorter periods of deposition, while the other layers may be more time-averaged, but both can be expected to represent signatures of routine activities of plant use such as day to

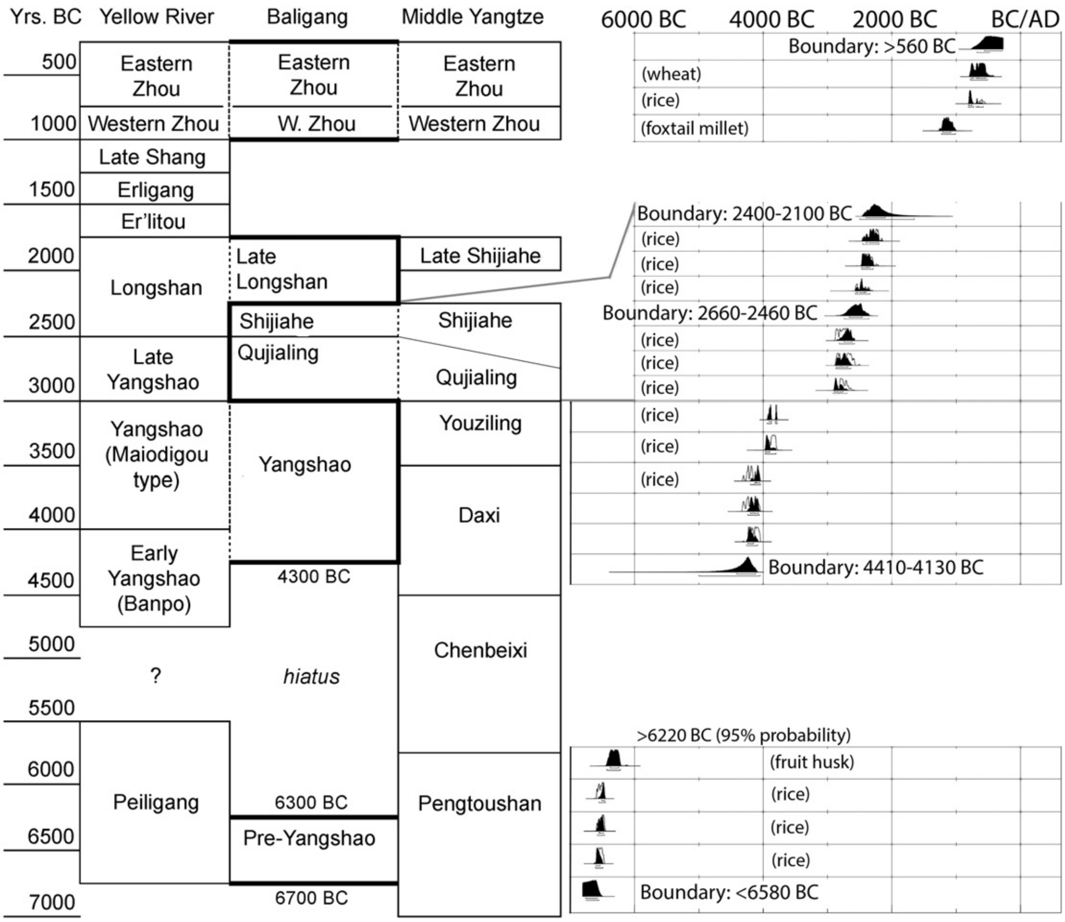


Fig. 2. Chronological phases of Baligang related to those of the Yellow River and the Middle Yangtze (after Deng et al., 2015), correlated with calibrated radiocarbon dates and modelled boundary phases based on a Bayesian sequence model of AMS dates from Baligang (produced with OxCal 3.10 and IntCal13 calibration curve).
Raw radiocarbon data from Deng et al., 2015.

day crop-processing. In terms of macro-remains, 117 sediment samples from different contexts, mainly of Neolithic periods, were floated, using either a floatation tank or the bucket wash-over method and collected in sieves with 0.3 mm as the smallest mesh size (Table 2). Heavy fractions sieved on 2 mm screens, were allowed to air dry and then sorted in the dig house by students, mainly for recovery of small bones and artefacts. Rare charcoal or seed fragments were added to the flots. Most seeds and fruits are charred and well preserved, while a few types were also preserved in silicified (ashed) form.

3. Methods

3.1. Macro-remains

Floated seeds and fruits were separated from charcoal fragments under a binocular stereomicroscope in the archaeobotany laboratory of Institute of Archaeology UCL and School of Archaeology and Museology PKU respectively. In total 123 flotation samples were processed totalling ca. 2400 l of sediment bulk before flotation. Before sorting, all samples were sifted in sample sieves. In most samples charcoals and fragments smaller than 0.3 mm were not sorted, as a sorting test showed no seeds and fruits are to be found in these tiny remains. Excluding this >0.3 mm fraction, all samples were completely sorted and identified referring to modern comparative references. In total 10,082 macro-remains of seeds/fruits were counted. Full detail of this dataset is published (Deng et al., 2015).

3.2. Phytoliths

The standard protocol in the phytolith laboratory at the Institute of Archaeology UCL (Rosen, 1999) was used to process the sediment samples. Samples were dried at <50° in a drying oven for a minimum of 24 h. Around 800 mg of dried sediment from each sample was weighed using an analytical balance. If that amount was not present all the entire sample was processed. The sediment was sieved through a 0.25 mm mesh, and placed in clean PVA 30 ml centrifuge tubes. Next, the samples were treated with 15 ml 10% HCL to remove any pedogenic carbonates and washed in distilled water before centrifuging for 5 min at 2000 rpm and the suspense was poured off. This was repeated twice more to remove all the acid. Clays were removed by adding a 15–20 ml dispersant (5% sodium hexametaphosphate), pouring the sample into a tall beaker and mixing with distilled water. The silt and fine sand fractions were settled through an 8 cm column of water, according to the Stokes law. The samples sat for an hour and the suspension containing the clays was poured off. This process was repeated until the suspension was clear. Then the samples were pipetted into ceramic crucibles and left to dry overnight in a drying oven at <50 °C. Once completely dry the samples were ashed for 2½ hours at 500 °C to remove any organic matter. The cooled samples were placed in 15 ml PVA centrifuge tubes containing 3 ml sodium polytungstate solution (SPT), calibrated to 2.3 sp. gravity for heavy liquid separation, and centrifuged at 800 rpm for 10 min. Opal phytolith specific gravity ranges from 1.4 to 2.3 (Jones and Beavers, 1963; Prychid et al., 2004) while quartz is 2.7 so the phytoliths float. The suspension, containing the phytoliths was removed

Table 1
List of phytolith samples indicating period and context type.

Lab no	Sample	Period	Homogenous (ash layer/midden)	Laminate pit fill
B16	H1985	Pre-Yangshao (~6000 BC)		X
B17	H1977	Early Yangshao (4500–4000 BC)		X
B18	H1959	Yangshao (4000–3000 BC)		X
B19	H1959-2	Yangshao		X
B20	CT601 ZS:1	Yangshao	X	
B21	CT601 ZS:2	Yangshao	X	
B22	CT601 ZS:3	Yangshao	X	
B23	CT701 ZS:1	Yangshao	X	
B24	H1906-4-A	Yangshao		X
B25	H1906-4-B	Yangshao		X
B26	DT 506-5	Yangshao	X	
B27	DT 506-3	Yangshao	X	
B28	DT 506-4	Yangshao	X	
B29	DT 506-4-C	Yangshao	X	
B8	CT1307 10(b) S2	Qujialing (3000–2600 BC)	X	
B9	CT1307 11:S1	Qujialing	X	
B10	CT1307 12:S1	Qujialing	X	
B11	H1634 3:S1	Qujialing		X
B12	H1632 3:S3	Qujialing		X
B13	H1656 2:S3	Qujialing		X
B5	CT1307 7:S1	Shijiahe (2600–2400 BC)	X	
B6	CT1307 8:S1	Shijiahe	X	
B7	CT1307 9:S1	Shijiahe	X	
B3	CT1307 5:S1	Longshan	X	
B4	CT1307 6:S1	Longshan (2400–1800 BC)	X	
B14	H1608 2: S2	Longshan		X
B15	H1646 1:S2	Longshan		X
B1	CT1307 3:S1	Eastern Zhou (770–256 BC)	X	
B2	CT1307 4:S1	Eastern Zhou	X	

and washed twice with distilled water at 2000 rpm for 5 min. The phytoliths were removed from the tubes by pipette and dried and weighed. Up to 2.5 mg from each sample was mounted on slides in Entellan and dried.

The samples were analysed using a Leica microscope fitted with a polarising filter at 400× magnification. Identification of archaeological phytoliths was made using modern comparative reference collections, including the one made specifically for this project (Weisskopf, 2014). In order to better identify the phytoliths from archaeological contexts a modern reference collection of 291 samples was processed, mounted on slides and photographed. A list of grasses and economic plants that are known to produce phytoliths was prepared using the *Flora plantarum herbaceaum Chinae Boreali-Orientalis* (Liou, 1981), the *Flora of Henan*, (Zhang and Wang, 1981; 1998; Zhang et al., 1988; Zhang, 1997a, 1997b), *The grass genera of the world* (Watson and Dallowitz, 1992) and information from Chinese macro-remains (Institute of Archaeology CASS and Banpo Museum, 1963; Underhill, 1997; Liu et al., 2005; Crawford, 2006; Lee et al., 2007; Fuller and Zhang, 2007). We also referred to published photographs and drawings of silica skeletons (Greiss, 1957; Miller Rosen, 1992; Lu et al., 2009) on identification of *P. miliaceum* and *S. italica* (Lu et al., 2009; Weisskopf and Lee, 2014), dicotyledons (Bozarth et al., 1992), grass silica bodies (Mullholland and Rapp, 1992; Lu and Liu, 2000), Cyperaceae (Ollendorf, 1992), and food plants (Scott Cummings, 1992), as well as Kealhofer and Piperno (1996) and Wang and Lu's (1992) general photographic references). In addition, we used Dorian Fuller's and Dominique de Moulin's unpublished SEM photographs of *Panicum* and *Setaria*. We also referred to the descriptions and drawings in Metcalfe (1960).

Between 300 and 400 single cell phytoliths were counted at 400× magnification for each slide. Multi-cell phytoliths were counted separately over the same fields of view to reach a count of 100–200. In total 15,953 phytoliths were counted, including 14,110 identified to morphotype, as well as 129 diatoms and sponge spicules. Phytolith patterns were explored through relative frequencies and ratios in each sample. Although data from these samples have also been included in multi-variate comparisons with samples from other regions and modern data through canonical correspondence analysis (Weisskopf et al., 2014), those results are not presented here, where our focus is on changing crop husbandry at Baligang and the integration of phytolith and macro-remain data from the same site and sequence.

Possible crop processing patterns were examined using the tri-plot template generated by Graham and Midgley (2000). These diagrams 'represent tri-variate data in which the three variables represent proportions of the whole' (Graham and Midgley, 2000). In order to achieve this, the three data groups in each chart are represented as percentages of their total (of only those three categories considered). We used phytolith morphotypes from rice and rice weeds (Table 3), including millet 1 and 2 husks. These husk morphotypes occur in weedy millet grasses such as *Paspalum scrobiculatum* L., *Panicum cambogiense* Balansa, and *Brachiaria reptans* L., all of which have been recorded as *Oryza* weeds in both deep water and upland rice. Weed leaves include all grass leaf/culm morphotypes, except for those recognisably from rice (such as bulliforms and scooped bilobes). Studies in the Lower Yangtze Neolithic where both the palaeosols of fields and occupation fills/middens were studied indicate that the same trends in assemblage composition are present, and thus indicate that the component of agricultural ecology represented in phytolith assemblages swamps most other signals in typical habitation refuse deposits (Weisskopf et al., 2015). Sedges are

Table 2
Summary of distribution of flotation samples by period and context type, with total counts of the main crops and categories represented by macro-remains.

Period	Pre-Yangshao	Yangshao	Qujialing	Shijiahe	Late Longshan	East. Zhou	Total
Volume floated (litres)	691	294	415.5	320	602.5	106	2429
No. of samples	11	14	27	19	46	7	124
Context of samples							
Cultural layer			1		2	2	5
"Ash pit" (secondary fill of storage pit)	11	14	26	19	44	5	119
No. of identified species	13	25	25	33	46	13	53
Crops							
Oryza sativa	545	301	666	356	1369	24	3261
Setaria italica		192	85	44	269	136	726
Panicum miliaceum	1?	227	9	7	36	17	296
Triticum cf. aestivum					9	25	34
Glycine max/soja	2			2	6		10
Fruits	125	8	4	19	9		165
Grasses	17	495	163	120	247	49	1091
Sedges		11	1157	26	1874	1	3069
Other weeds	42	128	216	193	431	27	1037
Total macro-remains	732	1362	2300	767	4250	279	9690

Table 3
Morphotypes included as *Oryza* and *Oryza* weeds.

Rice	Rice weeds
Double peaked glume	Wild Poaceae: long cells, bulliform short cells, grass leaf and husk silica skeletons
Oryza fan-shaped bulliform	Cyperaceae: rods, cones, Cyperaceae leaf and husk silica skeletons
Oryza type scooped bilobate	Dicotyledons: smooth spheroid, platey, polyhedron, scalloped, jigsaw puzzle
Oryza leaf/culm	Commelinaceae (two tiered)
Oryza husk	

also counted as rice weeds, as the cone phytolith morphotypes come from Cyperaceae nutlets. While sedges may have cultural uses (e.g. culms and leaves used as matting), the phytolith record primarily indicates inclusion of sedge fruiting bodies. Cyperaceae are a very common weed category in rice (Kittipong, 1983; Moody, 1989; 1992; Thompson, 1996; Table 32, Bhagat et al., 1996; Galinato et al., 1999; Weisskopf et al., 2014).

4. Results and discussion: seeds and fruits

More than 9500 seeds and fruits of 53 different species have been found in the floated samples, nearly half of which are crops, comprising of rice (*Oryza sativa*), foxtail millet (*S. italica*), common millet (*P. miliaceum*) and wheat (*Triticum cf. aestivum*) (see Table 2 and Fig. 3; Deng et al., 2015). It would seem rice was the only crop cultivated during the earliest period represented by context H2000. Besides this, numerous acorns were also collected from samples from H2000, mostly as carbonized fragments of nutmeat (cotyledons) suggesting loss and carbonization after de-shelling. These data indicate that gathering wild foods was also a significant part of the subsistence strategy, similar to what has been identified alongside early rice cultivation elsewhere in the Yangtze basin (e.g. Fuller et al., 2008, 2009). The pre-Yangshao rice remains include grains that are small and thin, closer to wild rice reference material or early (pre-domestication) populations in the Lower Yangtze, such as Kuahuqiao (see Fuller et al., 2010), but spikelet bases that are predominantly non-shattering, and thus, far more domesticated than later Lower Yangtze sites, such as Tianluoshan (Fuller et al., 2009). This indicates that the domestication trajectory of morphological change, of which Baligang's earliest occupation is representative, differed from that in the Lower Yangtze in the order of selected features, and may have had an earlier beginning. This is congruent with (at least) two distinct domestication trajectories for early *Japonica* rice in the Yangtze basin of China (Silva et al., 2015). A single wild-type *Panicum* seed occurred in this early phase, which is unlikely to have any connection to early millet cultivation.

Between 6300 and 4300 BC Baligang experienced an apparent hiatus in occupation, after which, a mixed Yangshao agricultural system was established. Foxtail millet and common millet both appear in abundance at Baligang. A mixed agricultural pattern was established during the Yangshao. However, this changes significantly with the sharp increase in rice in the Qujialing phase. Even in the following Shijiahe and Late Longshan periods, rice was still predominately used by people living on the site. In contrast, foxtail millet and common millet seem to be used as secondary crops. As well as rice and millets, wheat is also found in samples from Late Longshan and Zhou periods. The only directly radiocarbon dated wheat grain produced an age in the First millennium BC, consistent with the Eastern Zhou period (Deng et al., 2015, Table 2), and therefore presence in the Longshan period could be due to intrusiveness. Nevertheless, ubiquity shows that wheat had a minor role in the crop composition even in the later Bronze Age (Fig. 3).

Grass and weed seeds also appear widely in these Baligang samples. *Setaria* sp. is the most common wild grass, making up nearly 80% of all grasses, but its proportion in the majority of these samples is lower than 10% of all seed remains (including crops). Another group of abundant wild seeds at the Baligang site is the sedges (Cyperaceae), more than 3000 of which have been collected. Over 95.5% are from just four samples, including samples from H1620① and H1949 in the Qujialing period and two samples from H1601① in the Late Longshan period. These are dominated by flatsedges, *Fimbristylis miliacea* (L.) Vahl and *Fimbristylis dichotoma* (L.) Vahl., often preserved silicified (or ashed). Other weeds constitute a very small part of the plant remains. Chronologically, a slight increase of sedges was observed after the Yangshao period with these outliers excluded. Correspondingly, the proportion of dry-land grasses and other dry-land weeds decreases during the same period. This can be seen in a comparison of density of sedge versus wild grass seeds throughout the sequence (Fig. 4).

5. Results: phytoliths

Articulated husk phytoliths provide a means for identifying both millet and rice crops (Weisskopf and Lee, 2014; Lu et al., 2009; Piperno, 1988). While the crop husk percentages per sample increase in the Qujialing and then fall in the Shijiahe phase, phytolith evidence confirms *Oryza* was present at Baligang throughout its occupation, from the 7th millennium BC pre-Yangshao to the 1st millennium BC Bronze Age as also indicated in macro-remains. Low percentages of *P. miliaceum* appear in one sample from the Yangshao and another from the Longshan. *S. italica* only appears in two samples from the Longshan period (Fig. 5). However, millet crops are better represented in the macro-remains record. These could be due to poor silicification of husks, leaving behind more unidentifiable single cells. It is also likely that rice husk phytoliths are generally more robust. This raises questions about the relative preservation potential and biases that differently affect phytoliths and grains of rice versus millets. Another example of how millet crops can sometimes be better represented in the macro-remains record is from a pit in the northern site of Huizui dating to the Longshan that produced a 5 cm layer of charred millet grains but no husk phytoliths from the same level (Weisskopf, 2014; Weisskopf and Lee, 2014), highlighting how these datasets complement one another, and also the need for more taphonomic studies.

A mixed agricultural system had been established by the Yangshao period, comprising rice, foxtail millet and common millet. While the phytolith data suggest rice is by far the most common cereal crop, in contrast, in the macro-remains, foxtail millet and common millet are found in equivalent proportions to rice in this phase. Except for one common millet from the same context as phytolith sample B19, no crop remains were found in three floated samples from the same contexts as phytolith samples B18, B19 and B25. One possible reason for the low densities and proportions of phytoliths from all crops in this phase is that the dehusking stage of crop processing, especially millets, may have been conducted elsewhere. However, ethnographically dehusking often takes place close to where the grain is consumed and the bran is then fed to domestic animals (Nakai, 2008; personal observations of A. Weisskopf in Thailand) so a more likely explanation is

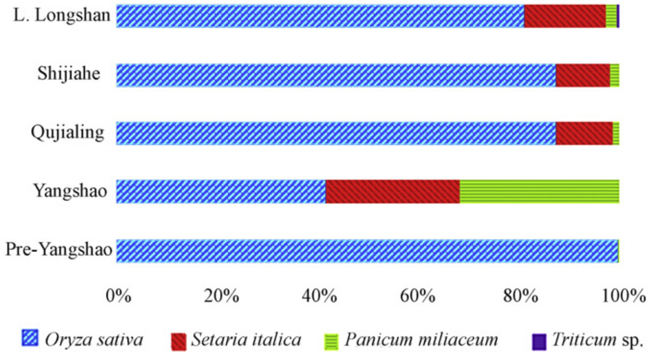


Fig. 3. Proportion of crops from macro-remains in different periods of Baligang site.

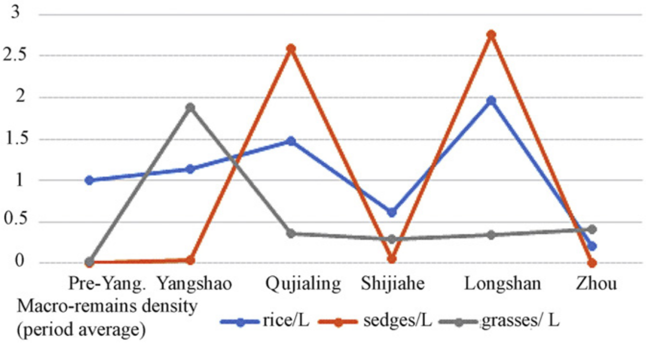


Fig. 4. Density of rice compared to sedges and wild grasses.

the husks, and the phytoliths in them, did not survive into the archaeobotanical record. This shows a systematic bias in favour of identifiable rice phytoliths as opposed to millets. Increased proportions over time of distinctive phytoliths from *Oryza*, for example the husks (represented only as multi-cells rather than single double-peak cells) and leaves (scoop edged *Oryza* fan shaped bulliforms), indicate that rice was widely included in onsite activities.

The agricultural economy in the Qujialing and Shijiahe periods remained mixed, although rice was the predominant crop. A general increase in proportions of phytoliths from crop husks can be observed, and a corresponding increase in rice leaves is particularly noticeable, which points to a possible change in rice harvesting methods as well as continued local cultivation and processing. Macro-remains show that the proportions of millets in relation to the total crop remains decline significantly in these two phases and phytoliths from millets are still infrequent, indicating millet dry-land farming declined in a period of Yangtze cultural influence. It has been argued that rice cultivation practices in this period were more intensive, probably involving irrigation and better control of some weeds such as sedges, and therefore producing higher yields (Weisskopf, 2014; Deng et al., 2015).

We suggest that the Longshan period shows a different, probably less intensive, husbandry regime for rice with changes in harvesting and processing practices. During the Longshan period the proportion of phytoliths from rice leaves remains almost equivalent to the previous phase, while phytoliths from rice husks decrease both in proportion and density. This might indicate a slight change in the rice processing activities, with more straw from lower harvest height perhaps together with more dispersed dehusking activities in time and space. Phytoliths from millet husks are still rare in this period, in contrast to a slight increase in the proportions of millets in macro-remains. We might regard this shift in rice husbandry as connected to the cultural change, representing weedier and less intensive rice practices of the Longshan culture. Given suggestions that the Shijiahe tradition suffered a collapse, perhaps around the 2200 BC climate event (Innes et al., 2014), it could be related to a change in population, or at least a new focus of cultural influence and dominance, from the Longshan tradition of the north, where rice production was less important and less well-developed.

6. Changing agricultural strategies: wet or dry rice

The proportions of morphotypes from *Oryza* leaves accompanying the husks at Baligang point to local cultivation and processing (Fig. 6). This is supported by the presence of phytoliths from *Oryza* crop weeds such as Cyperaceae, as well as accompanying diatoms and sponge spicules (Fig. 7). A possible explanation for the far higher proportions of cone shaped phytoliths from sedges during the Yangshao may be related to more threshing onsite. During the Yangshao there are higher levels of sedge nutlets suggesting that these are produced together with rice straw as a threshing by-product because these sedges, such as *Fimbristylis*, are shorter than the rice plants (Galinato et al., 1999). The drop in the number of phytoliths from sedges in the Qujialing and points to a possible change in cultivation practices to combat weeds, which could be achieved through deeper irrigation or transplanting (Smith, 1983; Reissig et al., 1986; Moody, 1989; Bhagat et al., 1996). These subsequently disappear in the Shijiahe period. The better control of water, and probable deeper irrigation early in the growing season that controlled sedges is also congruent with the evidence from seed remains among which wetland weed species are most frequent in the Qujialing and Shijiahe periods, while upland weed taxa are lower than in other phases (Deng et al., 2015). That such intensive rice cultivation practices characterised the Qujialing and Shijiahe periods may also be suggested by the increase in site number and site size in this period (Zhang, 1997a; Zhang and Hung, 2008; Lu et al., 2009; Li et al., 2013). However, sedge cones (from the nutlets) return in the Longshan and the Eastern Zhou periods, indicating a different tradition of cultivation practices. The better control of sedges in the Yangtze traditions represented by Qujialing and Shijiahe is replaced by possibly less intensive rice farming practices associated with the Longshan culture from the Yellow River region. This raises questions about the extent to which husbandry practices and perhaps varieties change with new cultural influence and/or immigrants. The increase in rice leaves in the Longshan period (Fig. 6) might also suggest a shift towards harvest heights lower on the straw. That this might indicate a wider cultural trend is suggested by the increase in sedges with rice during the Longshan at Huizui in northern Henan (Weisskopf, 2014).This might also be shown by the increase in sponge spicules over time (Fig. 7). However, one should also consider the possibility that the diatoms and sponge spicules were brought onto site in water used to mix with clays for construction and are not related to the crop processing.

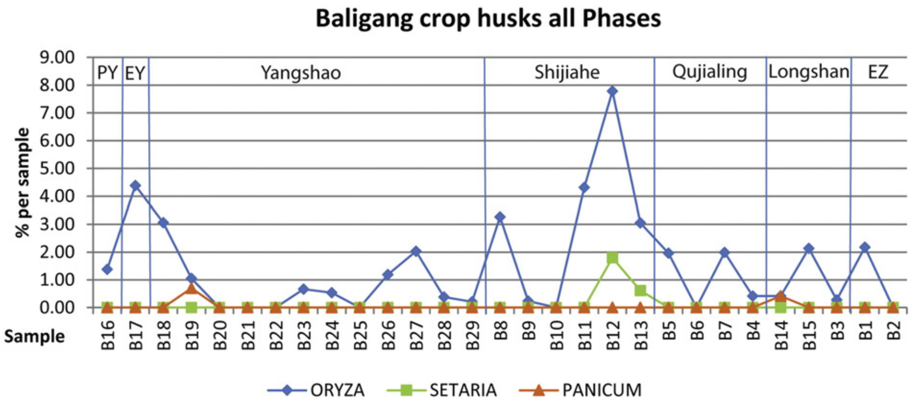


Fig. 5. Crops identified by husk phytoliths from all phases (PY = Pre Yangshao, EY = Early Yangshao, EZ = Eastern Zhou).

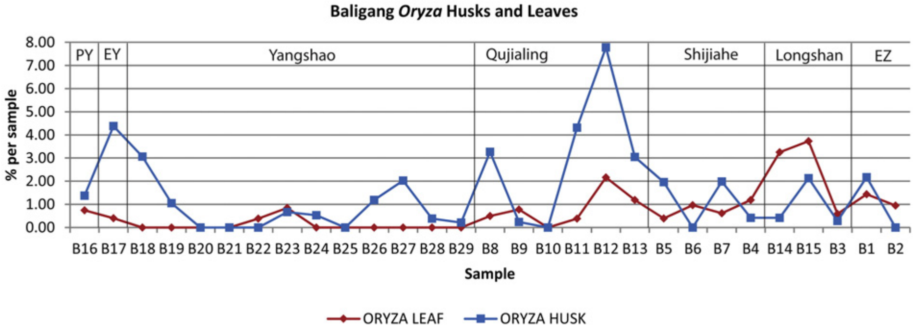


Fig. 6. Baligang Oryza husk and leaves (PY = pre-Yangshao, EY = Early Yangshao, EZ = Eastern Zhou).

Comparative studies on modern rice stands suggest that a ratio of sensitive versus fixed grass phytolith morphotypes can track degrees of wetness in rice fields (Weisskopf et al., 2015). The fixed (dry) morphotypes are those which normally silicify and are considered genetically predisposed to form phytoliths. Sensitive types are from cells that function when not silicified and only silicify under conditions of excess evapotranspiration, i.e. when much more water is available, especially from later in the plant's life cycle (Madella et al., 2009; Jenkins et al., 2010; Weisskopf et al., 2015). In the earliest phases, representing the Yangshao and pre-Yangshao, fixed morphotypes are all lower than 20% while the sensitive (wet) types are all higher than 20% suggesting the rice was farmed in a more continuously wet environment, probably the river's edge (Fig. 8). In the Qujialing period there is a drastic change. The majority of samples have fewer wet or dry morphotypes and wet (sensitive indicators) are generally fewer than dry (fixed) types. This suggests drier fields, which might be consistent with crops that are irrigated early in the growth cycles (e.g. to drown weeds) and then dried out. These practices increase yields for many rice varieties (Bhagat et al., 1996). The Shijiahe period shows a return to generally moister conditions, and could indicate increases in, or prolonged irrigation to later in the growing season. Such practices might have been called for if climatic conditions had worsened and become drier (Hu et al., 2008; Li et al., 2010; Li et al., 2013; Innes et al., 2014). The later northern-related cultural phases (Longshan and Erlitou Bronze Age) show a much more mixed pattern, consistent with a less consistent and less intensive rice regime.

In all periods there is evidence for both dehusking waste (rice husk and some weed husk) and threshing waste (weed leaf and some weed husk). While this suggests all stages of rice crop processing were always practiced at the site, the phases are distinct, pointing to other changes in crop husbandry. The Longshan has generally higher proportions of rice and rice weed straw suggesting possible changes in harvesting practices during the Longshan. In particular, there is more winnowing waste (straw) on site during this phase. As noted above, this correlates with higher levels of sponge spicules. The higher proportions of weed and crop husk in the Yangshao could be related to weedier crops, with the reduction in some weed types in the Qujialing and Shijiahe due to improved husbandry practices, as already inferred from evidence of better control of sedge weeds. However, the higher levels of cultivated millet grains (*S. italica* and *P. miliaceum*) in the Yangshao period (Table 2) may mean that it was the higher inclusion of waste from millet processing (including millet weeds) that accounts for the distinctiveness of the Yangshao. Overall, there is less differentiation between the Yangshao and the Qujialing, although there are lower proportions of *Oryza* husk in contrast to the higher relative levels of the Shijiahe samples and little evidence of winnowing waste. In broad terms, samples from the Yangshao period at Baligang show a mixed economy, while those from later phases tend to demonstrate rice-focused crop choice, with foxtail millet and common millet as secondary crops with an increase in the importance of millets in the Late Longshan (Table 2, Deng, 2009; Deng and Gao, 2012; Deng et al., 2015). Higher proportions and densities of phytoliths from *Oryza* leaves compared to those from foxtail millet and common millet can be seen in all samples. The results correspond with what might be expected from Baligang's geographical position in southern Henan within the Yangtze catchment. According to Quaternary climate change research the Qujialing and Shijiahe periods are comparatively colder and drier than the Yangshao period (Hu et al., 2008; Li et al., 2010; Li et al., 2013). In this case a focus on crops that require less water, such as millets, might be expected, but the results show the opposite so the changes that happened in this period are less likely a response to climate change than a change driven by cultural factors, especially dietary habit and perhaps agricultural

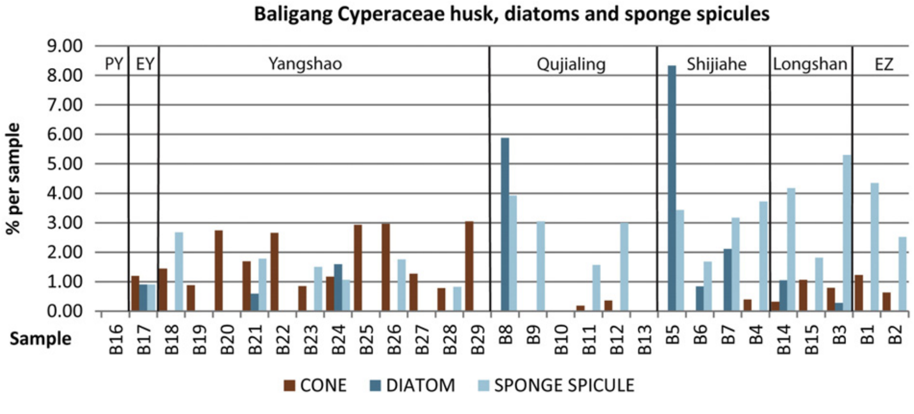
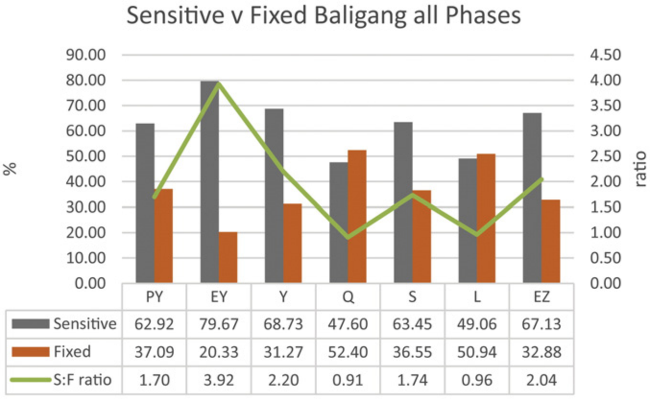


Fig. 7. Baligang Yangshao and Longshan Cyperaceae husks (cones), diatoms and sponge spicules (PY = pre-Yangshao, EY = Early Yangshao, EZ = Eastern Zhou).



	PY	EY	Y	Q	S	L	EZ
Sensitive	62.92	79.67	68.73	47.60	63.45	49.06	67.13
Fixed	37.09	20.33	31.27	52.40	36.55	50.94	32.88
S:F ratio	1.70	3.92	2.20	0.91	1.74	0.96	2.04

Fig. 8. The Phytolith Wet:Dry index based on the proportion of fixed and sensitive grass phytolith morphotypes (as defined by Weisskopf et al., 2015).

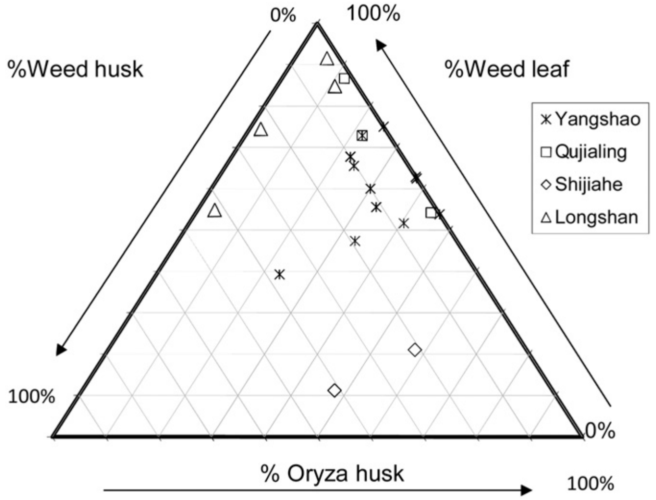


Fig. 9. A three axis scatter plot of individual samples in terms of the relative proportions of morphotypes relating to crop-processing. These represent the proportions of three categories (others excluded), including rice husk phytoliths, other grass husks and Cyperaceae cone (taken to represent weeds), and grass/sedge leaf/culm phytoliths, plus dicot weeds and Commelianaceae (taken to represent straw/leaves from weeds). Morphotype categories are indicated in Table 3.

techniques that facilitated rice cultivation through control of water. During the Yangshao and Late Longshan periods, this area was situated within the distribution range of the Yangshao Culture and the Late Longshan Culture, the core area of which is in the middle Yellow River Basin. However, between the Yangshao and Late Longshan periods, the southern part of Henan Province was greatly influenced by the Qujialing–Shijiahe Culture from the Middle Yangtze Region. The spread of the Qujialing–Shijiahe Culture into this area would have impacted greatly on local dietary habit, rice farming and processing skills, changing the agricultural pattern to a more rice-focused Yangtze pattern.

7. Crop-processing and social organisation

The results suggest that the bulk of the phytoliths is from crop processing residues. The majority of non-diagnostic phytoliths are from non-crop plants and represent weed seeds gathered with the harvest or the leaves and stems, the straw, from the crops and weeds that have been harvested with the cereal crop and removed during crop processing. This line of archaeobotanical input is argued to be widespread in flotation samples of macro-remains (e.g. M. Jones, 1985; G. Jones, 1987; Fuller and Stevens, 2009; Fuller et al., 2014). If, as Fuller and Zhang (2007) suggest, the ashy midden deposits contain the residues of routine daily activities, spatial and temporal differences can be identified. Evidence of varying scales of crop processing products and residues can suggest how bulk and daily processing were organised. This may highlight levels of organisation and labour mobilisation during the harvest period during which there is likely to be high demand for labour (Stevens, 2003; Fuller et al., 2014). Understanding whether such organisation is within small scale, kinship-based family units, large scale, or even centrally organised can provide insight into changes in how society was organised.

At Baligang this can be illustrated with a comparison of samples on the basis of co-variation of three variables, the proportion of rice husk, weed husk (other grasses) and weed leaf (grass leaf/culm) (Fig. 9). Overall comparison of leaves/stems, weed husks and crop husks from all phases demonstrates higher levels of the early stages of processing, threshing waste, than any other stage, except for during the Shijiahe period when it would seem that more winnowing was taking place off site. Baligang has comparatively high levels of rice and differentiation between the cultural phases is clear. During the Yangshao the majority of samples contain rice and weed husks but rarely rice leaves, suggesting dehusking was a routine activity and, as the rice was used on a daily basis, probably took place in a domestic context. Crops were threshed and winnowed elsewhere but stored in the husk and processed as needed. This suggests larger scale mobilisation prior to storage, either through communal activities or in extended family groups. In contrast the Qujialing, Shijiahe, Longshan and Eastern Zhou samples are predominantly mixed, leaf and husk. The levels of straw increase over time indicating a change in crop processing practices. The contents of the samples from the Longshan suggest bulk-processing waste from all stages being discarded in the same place. This could imply all processing stages were taking place at the same time, which may point to storage of at least some of the crop in the sheaf. Following the logic outlined in Fuller and Stevens (2009) this would imply that the labour that could be mobilised during the harvest season was insufficient (also Fuller and Zhang, 2007; Fuller et al., 2014), which may suggest more focused, small-scale household production and processing. This pattern would be reinforced if production per household was also increased, for example to support tribute to community elites, as society became more hierarchical. Fuller and Zhang (2007) argue that crop-processing evidence in the Ying Valley of northern Henan was more uniformly semi-communal in the Yangshao period with some sites in the Longshan period shifting to small-scale household labour units. Thus the changes identified at Baligang parallel those identified in parts of northern China (also Song, 2011). Increasing social hierarchy challenged more small-scale household units to cope with higher production without more labourers, which could indicate a form of intensification. It may be that this also reflects the intensification of agricultural production, seen in changing weed flora, and centralised rather than household organisation in the Shijiahe period. Less centralised labour organisation during the Longshan corresponds with de-intensification of rice agriculture. Organised labour would be needed for construction and maintenance of paddies. Greater rice production could require large groups of organised labour for the harvest of increased yields. The evidence from the phytoliths suggests a change from more communal organisation in the Yangshao to more household-based in the Qujialing and later phases. These results are reinforced by the remains of Late Yangshao longhouses at Baligang, which suggest corporate organisation (Underhill, 2002). The changes in how crop processing was organised indicate changes in social organisation.

8. Expansion, intensification and extensification

Increasing demographic pressure on limited resources may have led to innovations, such as the development of paddy farming, technological advances seen by improved water management and a higher labour input to construct and maintain the new field systems, harvest, process, and distribute increased yields. The combined evidence of an increasing ratio of wetland weeds (in the seed record), decreasing input of sedges (in the phytolith record), and a shift towards a drier fixed:sensitive grass morphotype ratio in the shift from Yangshao to Qujialing may at first appear contradictory, but we take this to indicate quite strategic intensification of rice production: sedge weed control through increased watering early in the growing season but drying out later on before a higher proportion of sensitive grass morphotypes silicify. Improved water management suggests higher labour input and presumably higher yields. Nevertheless, a diversified risk-buffering strategy may have been maintained through growing common and foxtail millets, probably on more marginal land. Improved rice agriculture at Baligang after the Yangshao also probably involves the expansion of land used for rice cultivation.

The sharp increase in *Oryza* husk phytoliths in the Qujialing might be related to the demands of an increasing population and developing social competition (Linduff et al., 2004). The advent of chiefdom level polities together with the ability to mobilise labour for large construction projects such as building rammed earth town walls suggests the organisation required to build and maintain paddy fields was in place by this period. The climate fluctuated then dried and cooled throughout the Longshan period (Xiao et al., 2004; Schettler et al., 2006). Along with an increasing population, this may have provided motivation to improve rice farming technology, as evidenced at Baligang by the dramatically falling levels of sedge husk. There is a corresponding increase in phytoliths from rice leaves in the Qujialing, suggesting a change in harvesting practices from taking the top only to harvesting lower down the plant to include the leaves. Crop leaves can be a valuable processing by-product as fodder, although it is not clear how early in the Longshan period sheep and cattle were adopted in China (Flad et al., 2007; Yuan et al., 2008). Further dating evidence is needed to assess whether the increase in rice correlates with the advent of domesticated ruminants in what had previously been a pig-keeping economy. Given that harvesting lower on the rice plant would be expected to increase the incorporation of weed leaves, such as sedges, the fact the sedge morphotypes remained low supports the contention that weeds were being better managed through cultivation practices.

9. Conclusions

We conclude that agriculture was changing in three directions after the end of the Yangshao. First, water control and weed reduction suggest that intensification of rice production was underway, increasing yields from existing fields. This was probably focused on lower lying flatlands. Secondly, expansion onto new lands is likely, to support a growing population. Lastly, the production of millets can be regarded as extensification as a way of using more marginal and drier lands to buffer risk.

The results of this study demonstrate how phytolith data can be used to interpret archaeobotanical questions, including identification of cultivated rice and millets, inferences about cultivation practices of rice including a trend towards intensification, and the likelihood of shifts in the harvesting and crop-processing practices applied to rice. Our identification of changes in the crop repertoire and cropping methods in rice correlate with cultural changes, including differing cultural traditions that had Yangtze or Yellow River foci, but these shifts also reflect the increase of production, including through more intensive field management practices, as well as probable expansion and extensification. The farming community was also reorganised from an extended family/semi-communal scale of labour mobilisation in the Yangshao period, to a more focused, small-scale family organisation in the progressively more hierarchical societies of the Qujialing and Shijiahe periods, when farmers would have found themselves working harder to control water levels and weeds to intensify production.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ara.2015.10.002.

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