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## **A Critical Assessment of Early Agriculture in East Asia, with emphasis on Lower Yangzte Rice Domestication**

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### **Introduction**

As a centre of early Urban civilization, China has long attracted attention as a centre of agricultural origins. A wide range of crops are attributed to origins in China, including cereals, pulses, fibre crops and a range of vegetables (Table 1). In terms of staple cereals, rice origins are attributed to Southern China, in particular the Yangzte valley region, while the 'Chinese' millets, *Setaria italica* and *Panicum miliaceum* are attributed to the northern region of the Yellow River, or further north. All three of these species are major world cereals, with modern and ancient distributions across wide areas of Eurasia, although they are likely to have additional domestication events outside China. Despite wide acceptance of the antiquity of a Chinese centre of origin, problem-oriented archaeological work on agricultural origins has been little. Systematic archaeobotany in China has only recently begun and evidence for the beginnings of agriculture is still limited. Practicing archaeobotanists are few and systematic collection of archaeobotanical remains has been irregular but is on the rise (Zhao 2001; 2004). Big questions remain unanswered, such as where, when and how many times plants were domesticated in China. In recent years, some Western authors have argued for a single process of origins, in which northern Chinese millet agriculture developed secondarily based on early southern rice-farming traditions (e.g. Cohen 1998; 2002; Bellwood 2005: 119). By contrast Chinese archaeological scholarship tends to emphasize the distinctiveness of regional cultural traditions and their own historical trajectories.

In the present paper, we provide both a broad assessment of the evidence for origins in East Asia and a focused consideration of the Lower Yangzte river region. In considering the evidence, particular emphasis is placed on the hard archaeobotanical evidence for the presence of crops, and the extent to which morphological or quantitative data is available to support a case for cultivation or domestication. Of particular interest is trying to identifying use by hunter-gatherers of the wild progenitors of crops, the beginnings of cultivation prior to domestication, and the presence morphologically domesticated plants. A regional chronological framework, in which the presence of key species is indicated, is provided in Figure 1. Our hypotheses for the horizons of pre-domestication cultivation and domestication is also indicated. For the Yangzte region and rice these hypotheses differ from those current in many textbooks but are consistent with the currently available hard evidence, especially from plant macro-remains. The remainder of this paper will attempt to unpack this diagram, with particular emphasis on the Lower Yangzte region. The emphasis on the latter region is due in part to current field and laboratory research with which we are involved but also because this region has a larger body of published quantified data relating to early Neolithic plant remains than other parts of China. We begin with a summary of the biogeography of rice origins as it is now understood through recent advances in genetics. Before turning to the Lower Yangzte, we assess the currently popular accounts of agricultural origins in the Middle Yangzte region, which leave much to be clarified. After our discussion of the Lower Yangzte data, we consider northern China (and the evidence for early millets), and Korea where agriculture dispersed secondarily from China.

## Geography and genetics of rice origins

It is now well-established that *Oryza sativa* was domesticated more than once, with distinct origins of tropical monsoonal *indica* and marshland, sub-tropical *japonica*. Genetic studies are now numerous in support of these separate origins (e.g. Chen et al. 1993; Cheng et al. 2003; Londo et al. 2006). Archaeological evidence also favours distinct centres of early rice cultivation in the Middle Ganges valley India (Fuller 2002; 2006) and the Middle or Lower Yangtze China (Lu 1999). These genetic findings therefore have overturned the widely held presumption of a single Chinese origin for rice, which is widely assumed in archaeological syntheses (e.g. Glover and Higham 1996; Bellwood 2005; Higham 1995; 2005), which were in turn based on an older botanical hypothesis for a single origin of rice (e.g. Oka 1988; T. Chang 1995). Although there is substantial evidence for genetic distinctions between *indica* and *japonica* from a range of data (Sato et al. 1990; Sano and Morishima 1992; Chen et al. 1994; Sato 2002; Cheng et al. 2003; Vaughan et al. 2003; Li et al. 2004; Zhu and Ge 2005; Londo et al. 2006), important recent studies come from nuclear DNA variants called SINEs (Cheng et al. 2003), and a recent study of haplotypes from two parts of the nuclear genome and one from the chloroplast (Londo et al. 2006). These differences exist in wild populations from periods well before agriculture, and have been transmitted to distinct domesticated lineages, indicating separate domestications of *Oryza sativa indica* and *Oryza sativa japonica*. Based on genetic evidence therefore we would not expect there to have been an ancient 'intermediate' form of rice, but rather *at least two* separate trajectories towards domesticated rices in Asia, each with distinct ecological settings. Ecologically the fundamental contrast is between the perennial *O. rufipogon* in marshy environments, and the annual *O. nivara* in seasonal puddles of the monsoon (Vaughan 1994; Sato 2002).

The genetic data also make it plausible that within each lineage, *indica* and *japonica*, there might have been more than one domestication. The recent study by Londo et al. (2006) seems to confirm this, with at least two ancestral, quite divergent haplotypes of the "SAM" gene present in modern *japonica* rices, and two haplotypes of the "p-VATpase" gene, although the latter are so close that one could have evolved from the other under domestication (Figure 2). Similarly for *indica* rice two distinct haplotypes of each dominate. As mapped by Londo et al., the two *indica* haplotypes occur amongst wild rices in north/east India and northwestern Southeast Asia, while *japonica* haplotypes are found in South Chinese rices. This suggests their different geographical origins. Of particular interest is the CC-haplotype of many *japonica* rices, as this is not represented amongst modern wild samples, although closely related forms exist. This seems to be strong evidence that this haplotype has gone extinct, but must have existed in wild rice populations in the earlier Holocene. In other words, the actual wild progenitor population of one of the *japonica* lines was an extinct radiation of wild rice in East Asia, which persists only in the domesticated form. We expect such lines to have gone extinct in parts of the Yangtze region in China, or the submerged eastern coastal plain (which ran between Taiwan and Korea in the late Pleistocene to early Holocene), since wild rice died out at these latitudes due to climate change during the Mid to Late Holocene. The problem of extinct progenitor populations is important to keep in mind in the case of traits like husk phytolith morphology, which are not demonstrably connected to the domestication syndrome. For such traits, differences found between modern cultivars and wild populations may represent the historical contingencies of phylogenetics rather than being markers of domestication.

The genetic evidence therefore falsifies older suggestions about Chinese Neolithic rice as predominantly *indica*, or an ancient 'intermediate type' that evolved into both *indica* and *japonica* (as already noted by Crawford and Shen 1998). Previous studies essentially began with the assumption that archaeological rice was a crop, and only asked instead whether it was *indica*, *japonica* or something 'intermediate' (e.g. You 1976; Zhou 1981; Li 1985; Oka 1988; Zhang 2002). In fact the morphometric data of early rice often fits well

within the range of wild species, including *Oryza rufipogon* but also sometimes *O. officinalis*—a prolific grain producer and therefore an attractive hunter-gather resource

Morphometric data from modern rice populations suggest distinct tendencies in morphological evolution in *indica* and *japonica*. Grain measurements indicate substantial overlap within the *Oryza sativa* 'complex,' including *O. rufipogon*, *O. nivara*, cultivars, and *O. spontanea* that results from hybridizations between cultivated and wild rices (Figure 3). *Oryza sativa* is a spectrum, from short plump *japonica* to long thin *indica*. The domestication process for rice in China should therefore lead evolutionarily from thin *O. rufipogon* towards the short-grained and plump *japonica*, with a possible early offshoot of long-grained *javanica* development. Tropical *indica* rices represent a completely separate evolutionary sequence from shorter, relatively plumper grained *O. nivara* towards the long and thin-grained *Oryza sativa indica*, although many *indica* populations fall within the range of variation found amongst wild populations. Thus in general there has been a greater degree of grain morphological evolution in *japonica*.

### **Evolutionary expectations: the making of domestic rice**

An important distinction needs to be drawn between cultivation and domestication. While cultivation is something people do, domestication refers to the biological status of a plant (genetic and morphological). Domestication traits are morphological features of a plant that evolve under cultivation, which make domesticated plants different from their wild relatives. These features can be explained by unconscious selection on the part of humans, in other words they are the unintentional results of cultivation practices. (see, Harlan et al. 1973; Harris 1989; Hillman and Davies 1990a; 1990b; Zohary and Hopf 2000; Gepts 2004). An archaeological challenge is to identify the beginnings of cultivation amongst morphologically wild rice, and track the gradual biological changes this incurred.

The 'domestication syndrome' is a number of traits that tend to be found in domesticated plants, but that differ from their wild relatives (Hawkes 1983; Gepts 2004). These are traits which evolve under the conditions of cultivation selected by cycles of harvesting and sowing from harvested stores, and may also be influenced by the new soil conditions of tilled fields (Harlan and et al. 1973). As was first realized by Helbaek (1960) and has become increasingly discussed amongst those who study plant domestication this means there is an essential distinction between cultivation (human activity) and domestication (change in the plant), and that we should expect there to be a phase of pre-domestication cultivation (Wilke et al 1972; Hillman and Davies 1990a; 1990b; Harris 1989; 1996; Gepts 2004). Pre-domestication is now identifiable in the Near East (see Fuller and Colledge, this volume). Four components of the rice domestication syndrome might be considered, of which three should be recoverable through archaeology:

1. Relaxation of selection for natural dispersal aids, i.e. the reduction in awns and hairs which help the shed spikelet grip the soil. As humans start to plant seeds this should relax natural selection in favour of maintaining these characters. As others have remarked, many domesticated rices are awnless, and those with awns have many fewer awn hairs (Sato 2002). But there are also awnless wild rices, such as *Oryza meyeriana* or *O. granulata*. (Vaughan 1994).
2. Increase in grain size, or grain weight. This character in cultivated cereals is related to increased efficiency and competitiveness in germination and early growth in open, heavily disturbed soils, with deeper burial of seeds, which is expected under tillage (see, e.g. Harlan et al. 1973).
3. Related to the above is also a relaxation of germination inhibition. In rice, for example, domestic grains are ready to germinate within 2 months of ripening and harvesting, whereas wild rice requires some 6-8 months after maturation before they will germinate (Veasy et al 2004). This is important from the point of view of the farmer as seeds should readily germinate when planted to contribute to an even-

aged stand of crop. This trait, however, is unlikely to be recognizable in archaeological material for cereals. In certain other species, notable early domesticated chenopods of the North America, this trait can be detected in the reduction of seed coat thickness (Smith 1995).

4. Finally, and perhaps most important, is selection against wild-type dispersal, i.e. the development of a non-shattering spikelet base, allowing plants to retain all their grains at maturity and to be efficiently harvested, as by uprooting or by sickle. It is this change which is most often taken as the key trait of domesticated cereals (see, e.g. Hillman and Davies 1990a; 1990b; Zohary and Hopf 2000). This trait however, evolves in response to human harvesting practices and may evolve later than some of the other traits.

### **The Origins of Rice: Recent Stories from the Middle Yangtze**

The Yangtze river basin is an important early centre of rice agriculture (Figure 4), and the domestication of Asian rice is often attributed to this region. A complete understanding of these processes, however, is still elusive. In recent years, the orthodoxy has been the rice agriculture began early, perhaps at the start of the Holocene or late Pleistocene, in the Middle Yangtze, perhaps amongst seasonally inhabited cave-sites (e.g. Pei 1998; Zhao 1998; Lu 1999; 2006; Bellwood 2005; Higham 1995; 2005; Crawford 2006). The evidential basis of these syntheses is, however, very slim. Systematic studies aimed at establishing the domestication process and large assemblages of systematically collected plant remains have been few. Underlying the textbook syntheses the limited hard evidence is often poorly presented and interpreted in ways that are in contradiction to the evidence of rice origins provided by modern genetics and comparative studies of crop domestication.

Attention has been focused on early Holocene village sites of the Middle Yangtze region. Of particular interest are the sites of Bashidang and Pengtoushan, of which the latter gives its name to the cultural phase (from 6500 BC to ca. 5500 BC). Large quantities of rice were found only at Bashidang (Pei 1998), although in the secondary literature this has sometimes been taken as Pengtoushan. While these have been presumed to be domesticated, a comparative re-assessment suggests that they are more likely to be morphologically wild (see below; cf. Ahn 1993; Crawford and Shen 1998). Other archaeobotanical remains include water chestnuts (*Trapa bispinosa*) and lotus (*Nelumbo nucifera*), and suggest gathering of wild wetland resources. It is unfortunate that larger assemblages through systematic flotation are not yet available. A later Neolithic site, Chengtoushan has recently provided archaeobotanical data from the Daxi cultural period (4400-3300 BC) when it was a moated settlement (Nasu et al. 2006). At this site rice, together with suggested paddyfield weeds has been recovered, together with seeds of the beefsteak plant (*Perilla frutescens*), a domesticated mint in East Asia used both for its leaves and as an oilseed (Chinese *zisu*). Details are not yet available on the domestication status of the rice. Also of interest is recovery of foxtail millet (*Setaria italica*), on which careful comparative work has been carried out on identification (Nasu et al 2006). This is of interest as it represents the spread of domesticated foxtail millets from the North to South where it was incorporated into rice-based subsistence.

Even earlier origins of rice have been suggested sometimes, although the evidence is not convincing. In recent years particular attention has focused on some South Chinese caves, especially some near Poyang Hu Lake (Jiangxi Province), Xianrendong and Diaotonghuan (or Wang Dong), and Yuchanyan cave in southern Hunan. What these sites have in common is very early pottery. As has been long known in the case of the Jomon culture of Japan, ceramics were produced in parts of East Asia since the Late Pleistocene. In Japan ceramics were being made perhaps by 13,000-12,000 BC (13,500 bp) and the technology must be connected with material of similar date in the Russian Far east

(Yasuda 2002; Kuzmin 2006). Similarly, the earliest ceramics in South China are of similar date. However, it is a mistake to presume that ceramics equate with sedentism and agriculture as some authors seem prone to (e.g. Yasuda 2002). A cautionary tale comes from the Zengpiyan cave in Southwest China (Gunagxi Province). Here earlier finds of early Holocene ceramics has been suggested to be connected to early agriculturalists. However, reexcavations of the site which included systematic floatation and sieved animal bone assemblages clearly disproved this. Despite a range of plant seeds (and phytoliths) no crops, nor rice, were recovered (Zhao 2002).

The most suggestive data is that from the Poyang Hu area sites. Research here was carried out as part of the Sino-American expedition of the late 1980s to early 1990s. (MacNeish et al. 1995), although full details await publication. Dating of these sites has been problematic due to old carbonates from the limestone environment affecting some samples. It is generally thought that early ceramic layers began at the end of the Pleistocene, perhaps as early as 13500 cal. BC (13500 bp) and certainly before the start of the Holocene (cf. Zhao 1998; Zhang 1999; Kuzmin 2006). Recent TL-dating puts the pottery of Xianrendong back to 10,000bp (Wu Rui et al. 2005). Animals from these sites were hunted, predominantly deer but also wild pig (Redding 1995). Plant macro-remains were not preserved so systematic sampling for phytolith remains was carried out, and comparative study on rice phytoliths, specifically the double-peaked form of the husks (lemma and paleas) was carried out in an attempt to track the origins of agriculture (Pearsall et al 1995; Zhao et al. 1998; Zhao 1998). These data have been used to suggest a transition from wild rice gathering in the earliest levels at Diaotonghuan Cave to domesticated rice from later levels, inferred from artefactual dating to be 8000-6000 BC (Zhao 1998). This evidence, however, is not convincing. First it is unclear how changes in the shape of husk cells might relate to domestication: this supposed feature is not yet linked to the evolutionary processes of the domestication syndrome. In addition, recent efforts to replicate this approach on modern reference populations have failed to support this method (Harvey 2006). Xianrendong is reported to have similar phytolith evidence, although details have not been reported in detail (cf Zhao et al. 1995; Zhang 2002). While it is not implausible that rice cultivation had begun in this region by 6000 BC, current macro-remains data do not demonstrate domesticated rice by this date, for reasons to be laid out below. And clear domesticated rice macro-remains are yet to be found before the Daxi Phase represented by Chengtoushan.

Reports of rice, uncarbonized, from Late Pleistocene layers at Yuchanyan cave, remain to be confirmed through systematic sampling and AMS-dating (cf. Yuan 2002). If the antiquity of this rice is confirmed it is likely to represent morphologically wild, gathered rice, like that from the Poyang Hu caves. A joint project of the Hunan Province Institute, Peking University and Harvard University is now working on this cave, which promises to improve our understanding of the late Pleistocene through early Holocene occupations in this region.

Critical re-assessment therefore does not indicate that rice domestication has been demonstrated for the Middle Yangtze, although it is likely that cultivation had begun by or during the Pengtoushan period (i.e. cultivation by 5500 BC). When morphological domestication evolved remains unclear, but by the Daxi period (from 4500 BC) seems clear. We would suggest, based on the evidence to be discussed, that this was a separate domestication of rice than in the lower Yangtze river areas.

### **Reconsidering the Lower Yangtze: questioning assumptions about Hemudu**

Hemudu occupies a central position in the archaeological syntheses of early Chinese agriculture and accounts of the dispersal of agriculture in world prehistory. But what does the evidence consist of, and what assumptions have been made? We would like to reconsider Hemudu and the more recently excavated and earlier Kuahuqiao, both which have been published recently in Chinese monographs (Zhejiang Provincial Institute 2003; 2004). This reconsideration forms parts of the background the new, ongoing

archaeobotanical at site of Tian Luo, a site of the Hemudu culture just a few kilometers from the original Hemudu site.

At Hemudu the presence of rice has been emphasized whereas the quantities of nuts, especially acorns, has been mainly ignored. Both Hemudu and Kuahuqiao produced substantial quantities of waterlogged plant remains. While preliminary reports and secondary literature has tended to focus exclusively on the rice remains, in fact this can be seen as a small component of a broader subsistence base with a focus on nuts (Zhejiang Province Institute 2003; 2004): acorns (*Quercus*, *Lithocarpus* and *Cyclobalanopsis*), foxnuts (*Euryale ferox*), waterchestnut (*Trapa bispinosa*), mountain peaches (*Amygdalus davidiana*), apricots (*Armeniaca vulgaris* and *A. mume*), and the fruit *Choerospondias axillaris*, in addition to bottlegourd (*Lagenaria siceraria*), *Sophora*, job's tears (*Coix lachrymal-jobi*) and Polygonaceae nutlets. The authors' current archaeobotanical research at Tian Luo Shan has added horsechestnuts to this list (*Aesculus* sp.) In particular, acorns and waterchestnuts (both high in carbohydrates) were found in large quantities in six of the 15 excavated storage pits at Hemudu (others contained secondary rubbish such as fishbones). The authors' current research indicates this emphasis on stored evergreen oaks (*Cyclobalanopsis*, *Lithocarpus*) and *Trapa* at Tian Luo Shan (Figure 5). All of these taxa are known from archaeological or ethnographic sources as storable food sources that are potential staples or second-tier resources used by hunter-gatherers. The presence of large quantities of stored nuts suggests that Hemudu might be fruitfully compared with archaeological cultures like the Jomon (Takahashi and Hosoya 2002; Kobayashi et al 2004) and ethnographic contexts like native California, all instances where acorns were a staple of primarily hunter-gatherer economies (Heizer and Elsasser 1980: 82-114; Fagan 1995: 231-256).

When it was first discovered, Hemudu had the earliest rice remains in the world, and the largest quantities of remains (Yan 1982; Liu 1985; Zhao and Wu 1987). Attention was drawn to large quantities of rice remains, including culms (straw), panicles and chaff together with some grains, which formed in a distinct layer in part of the waterlogged site's stratigraphy. The material is clearly dominated by chaff, judging by available excavation photographs (e.g. Figure 6). Rice husk was deposited in discontinuous lenses, as if dehusking (not threshing) waste had been periodically dumped from elsewhere. The distinction between *dehusking* and *threshing* is potentially significant as dehusking is a necessary processing activity for wild or domesticated rice, as opposed to threshing which is only necessary for non-shattering domesticated plants. Elsewhere on the site, however, concentrations of nuts and fruits stones were found.

Studies of the Hemudu rice, and other early rice finds, have generally asked whether it represents *indica* or *japonica*, and taken as an unstated assumption that it is domesticated. This has often been based on ratios of grain measurements (e.g. You 1976; Zhou 1981; 2003; Liu 1985; Oka 1988), with L/W greater than 2.5 normally being taken to indicate *indica*, and *japonica* should be less than 2.3. In other cases bulliform phytoliths have been used (Zheng et al. 2004a), or tubercles on the surface of rice husks (Zhang and Wang 1998; Zhang 2000; 2002). Different workers and different techniques have produced apparently contradictory results, with claims for differentiated *indica* and *japonica* at Hemudu (Zhou 1981; Liu 1985; Bellwood 1997: 206), or inferences of just *indica* types (You 1976; Oka 1988). The contradiction between different scholars or techniques has never been explained, and must be seen to raise questions. At Kuahuqiao it is reported that grain measurements indicate *indica* rice, while bulliform phytoliths indicate *japonica* (Zheng et al. 2004b; Zhejiang Provincial Institute of Archaeology 2004). Some have evaded making this distinction by defining an unique 'ancient' rice that preceded the differentiation of these two types (Zhang 1996; Zhang and Wang 1998; Pei 1998; Zhang 2000; 2002; Higham 2005: 244). The latter approach assumes, rather than demonstrates, domestication. In addition, it presumes a single unitary origin for rice, which has been disproven by the genetic data (reviewed above).

Assigning rice grains and spikelets, to subspecies *indica* or *japonica* based on

length-to-width ratios, is only plausible if all wild rice species (*Oryza* spp.) can be ruled out by other means. Thus available archaeological measurements might be *Oryza rufipogon*, *Oryza nivara* or even *Oryza granulata*. There is also another possibility, which is that grains are immature, since during rice grain development the grain first reaches full length and then gradually thickens and widens (Figure 7). This means that ratios of immature rice overlap with those of wild rices or *indica*. We believe that the most likely interpretation of the rice from early Lower Yangzite sites, including the Kuahuqiao, Hemudu and Majiabang phase, is immature. This is significant as it relates back to how we expect plants to be utilized by hunter-gatherers and initial cultivators.

### **Morphometric evidence: Domestication as maturity shift**

The non-shedding trait occurs in rice by a toughening of the attachment of the spikelet base to the rachilla, and as shown by Thompson (1996; 1997), this is accompanied by a subtle change in the cross section of the rachilla attachment scar (also Sato 2002). In wild rices, mature spikelets should naturally separate and leave a clean scar on the spikelet base. In domesticated rices this attachment is broken by human threshing and thus the scar should be roughened and uneven. The evolution of this toughened attachment is readily explained by natural selection and population genetics under circumstances of cultivation and harvesting, as has been demonstrated in wild wheats (Hillman and Davies 1990a; 1990b; Willcox 1999). Cereals that are harvested green, i.e. immature, may also mimic this domestic trait as the natural grain shedding mechanism will not yet have set in. In other words, tough rachis characters may be present in green harvested plants as well as coming to dominate mature plants of the domesticated morphotype. Under the circumstances of cultivation and harvesting in which human harvesting is through cutting or uprooting, there is a bias towards collection of toughened mutants, which therefore enter subsequent generations in larger numbers through sowing. When seed dispersal is still by the natural shattering means, we might expect people to target more immature plants to decrease seed loss by shattering during the harvest process. The argument that harvesting was carried out wild plant were just coming into maturity, and has many immature grains, is strengthened by recent experiments in Hong Kong in which it was demonstrated that sickle harvesting wild rice (that had matured) producing very poor yields (see Lu 2006). Therefore we must take seriously the presence, perhaps even predominance, of the immature grain in early assemblages. This means large proportions, or at least half or more, of grains harvested will be immature (Figure 8). Archaeologically we might expect these substandard grains to be more readily lost through processing and thus to be over-represented archaeologically.

Immature grains will differ in the size and shape from their mature counterparts, and will complicate attempts to identify wild or domestic status from grain size and shape. The way the grain matures is that first they lengthen and then gradually thicken in the final days of maturing. This means that immature grains will have exaggerated length-to-width ratios. As conventional studies of modern material always focus on fully mature grains, the simple extension of these ancient materials is flawed. The contradictions in existing interpretations of archaeological rice measurements become comprehensible if we consider these grains to be immature, i.e. harvested green.

The published descriptions of the rice from Hemudu contains indications that the rice may not have been fully domesticated. Much of the rice was found in the form of spikelets, and as described many spikelets lack grains or have incipient unformed grains (Zhou 2003: 430). This is also evident from photographs showing unbroken husks of flattened spikelets (e.g. Figure 6). These included not just de-husking waste but some with immature or indeed unformed grains. At Kuahuqiao similar material was found and quantified, indicating a predominance of immature spikelets including many in which the grain had not yet formed (Zheng et al. 2004b; Zhejiang Provincial Institute of Archaeology 2004). This implies that these spikelets were harvested before maturity, which implies a

rice population that is not fully domesticated as we will argue below.

One implication of this is that if rice plants were harvested immature, then spikelet bases may appear tough if threshed, as they were harvested before the abscission layers had matured. This means that spikelet base data on its own is necessary but not sufficient to infer domestication status, unless more refined identification criteria are developed to distinguish immature wild types from domestic types. What is needed is evidence for mature spikelets/grains, which can be inferred from grain measurements, together with tough domestic type abscission scars. Current research by the first author suggests that spikelet bases can be separated into brittle (wild) mature, tough (domestic) mature, and immature types.

While data published as raw measurements are still relatively scarce, the available patterns appear significant (Figure 9). The morphometric data available from Kuahuqiao and Longquizhuang (mainly of the earlier Majiabang period which equates roughly to Hemudu) suggest that grain assemblages are dominated by immature grains. It must be noted that this assumes the mature grains would have been in the range of modern domesticates. This in fact is plausible if we consider the likelihood that early pre-domestication cultivation had already begun to select for larger grains, as was the case in the Near East with wheat and barley (cf. Willcox 2004). In addition, the reduction in hairs on the awns of rice recovered from Hemudu (Sato 2002) implies relaxation of natural selection for seed dispersal aids, which we would expect under cultivation. Thus the evidence from Kuahuqiao (6000-5400 BC) and from the earlier Majiabang period (from early to mid Fifth Millennium BC) both suggest pre-domestication cultivation. The rice at this stage can be regarded as a 'pro-domesticate' as some aspects of the domestication syndrome had begun to evolve but the key change, in terms of seed dispersal, had not.

A clear contrast is seen with the latest assemblage from Longquizhuang (late Majiabang period, ca. 4000 BC), in which grains are longer, plumper (2.5-3mm) and most likely fully mature. Also significantly plumper grains have been recovered from Chuodun (also late Majiabang), which has evidence for a possible paddy field (Tang 2003; Gu 2003). This suggests an important morphological shift in archaeological rice occurred in the Lower Yangtze region during the later Fourth Millennium BC. This shift seems most likely to be due to a shift towards harvesting of mature panicles as opposed to immature panicles, rather than an evolutionary development in grain shape. Such a shift would imply that it became feasible to allow grains to mature on the plant without loss of the grains, or in other words that tough, domesticated type rachises had evolved to dominate the rice populations being harvested.

Some rice samples from elsewhere, such as the Middle Yangtze region, can also be considered. Rice measurements from Bashidang, 6400-6000 BC (Pei 1998) fall in the midst of the wild/immature 'pro-domesticate' range of Kuahuqiao. Reported measurements from Jiahu (Henan Province Institute 1999), are remarkably small, by comparison to either modern cultivars or to Lower Yangtze Neolithic immature grains. This suggests that they come closest to a wild rice, such as *Oryza rufipogon* (taking into account ca. 20% shrinkage due to charring, and possible immaturity), or other species like *O. officinalis*. Intriguingly, measurements from Chengtoushan, which were only reported as averages of three modal types (Zhang and Wang 1998), include some which suggest immature pro-domesticates, and others which suggest fully mature domesticated types comparable to both the Choudun and later Longquizhuang types. This suggest that in the middle Yangtze region domesticated rice had come to dominance by the Daxi phase, from ca. 4500 BC. When considered in comparison to contemporary and later sites elsewhere in the Yangtze this would seem to raise the possibility that fully domesticated rice may have evolved more than once at different Yangtze localities, and at different periods. It must be concluded that while all of these sites have been assumed in most literature to be agricultural, they are more likely to represent different degrees of cultivation of morphologically wild rice (Bashidang) as well as some pure gathering of wild rice (probable *Oryza officinalis* at Jiahu). Jiahu also has acorns and water chestnuts, and soybean (still wild in terms of size

criteria), and plausible sickles, but also quantities of acorns. The northern position of this site suggest cultural links to northern millet cultivators. Thus the dynamics of agricultural origins would appear to be complex with various subsistence strategies involving various wild and pro-domesticates playing a role. This highlights a need for more systematic archaeobotanical sampling and quantitative analysis, to improve upon earlier unquestioned assumptions that rice (or millet) present on a site equates with full-blown agriculture.

An examination of some Hemudu spikelets by Sato (2002), also indicated intermediate characters which are consistent with the rice being in the process of domestication. While some spikelets appear to be awnless, others with awns showed hair densities that were less than wild types but more than modern domesticated types. This suggests relaxation of natural selection for wild-type seed dispersal, as we would expect under early cultivation. In addition some wild type spikelet bases are reported as well as a domestic type spikelet bases. What is not clear is whether these criteria are sufficient to distinguish immature wild type from domesticated types. What is needed in future work is refined criteria and larger statistical studies of spikelet bases so that the transition can be tracked as an evolutionary process.

There is an additional source of evidence that can be used to assess rice plant maturity. A recent study of morphometric variation in rice bulliform phytoliths (produced in the leaves of rice) has suggested that aspects of this form are under genetic control, in particular the proportions of the 'stalk' which has been used to differentiate *japonica* from *indica* varieties (Zheng et al 2003; 2004a; 2004b). This study also examined other proportions, but found that the size of bulliforms, especially horizontal (HL) and vertical length (VL) show a strong correlation with plant maturity (Zheng et al 2003: 1217, fig. 3). In other words more mature plants produce larger bulliforms. Recent metrical data on bulliforms from sites in the Lower Yangtze indicates a significant shift towards larger bulliforms through time (Figure 10). These data therefore agree with the evidence of grain morphometrics that earlier rice, e.g. of the Majiabang period, was being harvested substantially less mature than later, presumably domesticated rice of the Songze and Liangzhu phases. More research is needed on the comparative morphometrics of rice phytoliths comparing species, and within species, and plants in different ecological traditions and states of maturity.

### **Fieldsystems, tools and social change**

The development of cultivation techniques that we have inferred from the grain and phytolith evidence is also indicated by artifacts and excavated features. Hemudu yielded a great many hafted or haftable bone scapula artefacts, which are regarded as spades or hoes, as well as some wooden spade blades (Liu 1985; Chang 1986: 212; Zhejiang Province Institute 2003). This strongly suggests manipulation of the soil through tillage. Coupled with the evidence that rice grains were largely immature we regard this as a strong case for wild plant food production (sensu Harris 1989; 1996). This hypothesis may be testable through future systematic sampling of seeds and phytoliths for evidence of an emergent weed flora. In addition we should expect a protracted period during which the proportions of domesticated type rice spikelet bases increased in proportion to wild or immature type.

These practices may have had somewhat earlier origins, as a few spades were also found at Kuahuqiao (Zhejiang Provincial Institute 2004). At Kuahuqiao, only 4 possible bone "spades" were recovered, accounting for just 4.4% among all bone and horn tools. By contrast the later Hemudu Site yielded 192 bone spades, 6.6% among all bone and horn tools. There are also significant differences between Kuahuqiao and Hemudu spades in terms of how they were hafted. At Kuahuqiao, these have small holes drilled near the top of the tool, 9-10 cm in depth, 2.4-2.8cm diameters. This would have made for very weak hafting that may not have been sufficient for working heavy muds. By contrast Hemudu's bone spades have elaborate hafting features, including large holes lower down

the blade within a groove, all of which would have stabilized the hafting making them effective digging tools. This may indicate the bone scapula 'spades' were initially developed for some other function and were subsequently transferred to managing soils in rice marshes, which required refinements in hafting. In any case it seems clear that tillage, perhaps with replanting, began in the sixth millennium BC, and had perhaps begun on a small scale by Kuahuqiao. Certainly by the time of Hemudu replanting and tillage had become the norm, as this would account for the reduction in awn hairs which, as already argued above, implies the relaxation of natural selection for natural seed dispersal aids. This period therefore involved wild plant food production, or pre-domestication cultivation, of rice. The relative role of this cultivation in an economy that involved large scale collection and storage of nuts requires further assessment but tends to suggest that rice was a supplement to the economy, either for adaptive reasons of risk buffering or perhaps reasons of social "food choice" in which rice provided desired, special foods.

In the subsequent Majiabang period, from ca. 4800 BC, wild rice cultivation can be inferred to have continued. The measured grains from Longquizhuang (lower levels) and smaller rice bulliforms suggest harvesting of immature rice (see above), although the somewhat thicker grains compared to the earlier Kuahuqiao assemblage could suggest some selection for more domesticated plants, including more harvestable mature individuals as well as the thicker grains which characterize *japonica* domesticates as opposed to wild *rufipogon*. It is from the late Majiabang period (later Fifth Millennium BC), however, when the first documented evidence for field systems occurs (Figure 10). At the site of Caoxieshan (Jiangsu province), a network of channels and dug-out features suggests small scale wetland farming plots (Zou et al. 2000), indicating intensive cultivation of small plots (similarly at Chuodun, Gu 2003). This development would have an important effect in terms of separating the cultivated wild rice from cross-pollination with free-growing populations. It may also be the case that this development was a response to a decline in wild rice population as a result of climatic changes (see below). Whatever the case, the creation of separate rice paddy fields could have sped up the selection for domesticated types in the wild concentration.

In addition, the small and concentrated populations of rice in these fields might have encouraged experimentation with harvesting and harvesting efficiency. This would have involved both timing, to obtain larger quantities of mature grain, and techniques such as uprooting and cutting, which taken together could have increased selective pressure for non-shattering fully domesticated morphotypes. As evident from the measured grains of the upper level at Longquizhuang and the Songze and Liangzhu bulliforms, there appears to have been a shift towards harvesting more, or largely, mature rice plants during the latest Majiabang phase and the Songze, and certainly by Liangzhu times. This could only be readily achieved if the plants were domesticated.

It is from the later Songze period, and Liangzhu phase, when the first stone plough tips occur indicating more intensive cultivation methods. As already mentioned the earliest plough tip is from a mid to late Songze period cemetery (see Administration of Cultural Heritage of Shanghai 1985), and it is these stone plough tips that suggest a minimal age for water buffalo domestication, as these seem the only plausible energy source for pulling these early ploughs. Recent archaeozoological analyses at Kuahuqiao are consistent with hunting of wild buffalo (Liu et al. 2004), but clear bone evidence for changing patterns of manipulation of this species or morphological change is so far lacking. While the domestication of this animal should be sought through systematic archaeozoology in assemblages dating between Kuahuqiao (5400 BC) to the Songze (3500 BC), the surprising lack of bones of *Bubalis* remains a challenge.

The evidence for harvesting tools also supports the evolutionary scheme hypothesized here. Stone sickles or harvesting knives are well-known from Middle Neolithic sites in northern China in millet-growing traditions, such as the Cishan, Beixin, and Dawenkou cultures (Chang 1986: 93, 160; Barnes 1993: 100). Such tools are, however, unknown from Kuahuqiao, Hemudu and Majiabang periods in the Lower

Yangtze. This suggests that harvesting during those periods did not involve sickling. Uprooting, some other form of cutting or beating while plants were still in their early stages of grain formation must be assumed. The first clear sickles in the Lower Yangtze date from the later Songze and Liangzhu periods (Chang 1986: 256-2; Barnes 1993: 100). Thus the intensification of wild plant food production (pre-domestication cultivation) focused on rice can be inferred for the Kuahuqiao-Hemudu-Majiaibang sequence, for a period of at least one millennium (if started from Hemudu) or two millennia (if started from Kuahuqiao). This phase of pre-domestication cultivation of 1000-2000 years is comparable to that suggested by recent research in the Near East (e.g. Hillman 2000; Willcox 1999; 2002; 2004; 2005; Tanno and Willcox 2006; Weiss et al. 2006). When subsequent domestication occurred (by Late Majiabang/Songze, ca. 4000 BC), it may have been in part based on a newly adopted harvesting technology of sickles, which had been long-established elsewhere in China.

Our revised model of late rice domestication in the Lower Yangtze also makes sense in terms of social inferences from the region's archaeology. If, as some have suggested, rice cultivation (and domestication) were indeed present from the Late Pleistocene, it raises the question as to where the agricultural village sites are between the Pleistocene and mid-Holocene. Rice agriculture is highly productive and would be expected to promote marked population density increases in the region, but large numbers and densities of sites do not occur before the Late Majiabang, Songze and Liangzhu periods, i.e. from the Late Fifth Millennium BC. Our model provides a framework which explains this demographic transition and the lack of substantial numbers of earlier settlement sites.

These broad chronological patterns may correlate with important aspects of environmental change. A number of recent paleoenvironmental studies from Lower Yangtze region provide well-dated data on Holocene climate and vegetation (Yu et al. 2000; Yi et al. 2003; Lu et al. 2003; Tao et al. 2006) and in broad outline these correlate with data from the South China sea (Wang et al. 1999), suggesting that these indeed reflect primarily regional climate change. An important habitat change, reflected in pollen diagrams, is a marked decline in nut-bearing trees shortly before 5000 BC, including *Quercus* (true oaks), *Cyclobalanopsis* (Qinggang oaks) and in some cores *Castanopsis* (Chinquapin chestnuts) (Tao et al. 2006; Yu et al. 2000). This is reflected in a broader pattern of declines in arboreal pollen (Yi et al. 2003). It is striking that this correlates with the period of the emergence of the Hemudu culture. We might hypothesize therefore that nut-using foragers of the region responded by relying increasingly on available wild rice and they began to bolster rice supplies through cultivation. One issue which is still not clear is how these climatic changes of the mid-Holocene would have impacted wild rice stands, which may also have influenced strategies of the Kuahuqiao-Hemudu nut-foragers.

### **North China, millets, and domestic animals**

Cultivation of millets in North China seems to be earlier than rice. In the Yellow River basin and further north, millet cultivation, and harvesting with sickles, was already well established, prior to the appearance of domesticated rice or sickles in the Songze culture of the Lower Yangtze. In Northern China the millets *Setaria italica* and *Panicum miliaceum* were the initial crops. While their origins in China are not in doubt, issues remain as to where within Northern China they were domesticated, how many times, and how many additional domestication events occurred outside of China. The current genetic variation in *Setaria italica* (see Jones 2004; Fukunaga et al 2006), suggests at least three domestications, including one in Central Asia (perhaps Afghanistan or northwestern Pakistan), as well as at least two plausible origins within the Chinese region. Multiple origins are also suggested by the early appearance of *Panicum miliaceum* in Neolithic central Europe, without *Setaria*, as well as in northern China where it seems to always be accompanied by *Setaria*.

The earliest well-documented millets are from ca. 6000 BC at Xinglonggou, in

Eastern Inner Mongolia by which time plump-grained *Setaria* were already established but grains of *P. miliaceum* were near the wild-type in size and shape (Zhao 2005). This evidence may suggest that it is the cultural adaptations to the desert margin and arid steppe environments that must be considered when modeling the domestication of millets. Such environments might be particularly prone to subsistence instability during climatic fluctuations. In this sense the context of millet domestication appears more comparable to the woodland-steppe transitions of the Near East which figure in models of Near Eastern plant domestication (cf. Hillman et al. 2001). Shelach (2000) had already drawn attention to the likelihood that the Neolithic cultures of the Chifeng area of northeast China represent an independent trajectory towards food production and sedentism.

Subsequently millet cultivation was established in much of the Yellow River basin by 5500 BC (the Peiligang, Cishan, Beixin and Dadiwan cultures) (Lu 1998; 1999; 2002; Crawford et al. 2005; Crawford 2006). As, suggested by Shelach (2000) this region could represent an independent development from the Xinglonggou area, as there is little material culture evidence for contact nor indicating spread north to south (or vice versa). In these latter cultures fully domesticated *Setaria* and *Panicum* are reported as are stone harvesting knives, although large scale archaeobotanical sampling and laboratory study are not available. Lu (2002; 2006) maintains that earlier composite sickles in this region may have been involved with millet domestication, although it remains to be established whether such tools indeed correlate with the emergence of domesticated millets. Other models for domestication are conceivable and it may be the case that sickles or harvesting knives represent a good technological adaptation to already domesticated plants rather than a reason for domestication!

Possibly associated with early millet cultivation was the keeping of some pigs, and perhaps chickens. Numerous early reports of Chickens from the Yellow valley date back to perhaps the 5<sup>th</sup> Millennium BC (West and Zhou 1988), although there remains serious concerns over the reliability of identification criteria. Metrical studies of pigs' teeth from Xinglonggou have recently suggested that some domesticated animals may have been present, but if so they were the minority. Similarly pigs have been suggested to have been reared in the Cishan culture and other Yellow river Neolithic sites (Yuan and Flad 2002). Pigs vary as a proportion of the bones, sometimes in the majority and other times not, suggesting that hunting also remained prominent in the economy. In the South, a few reduced size pig remains have also been identified recently from Kuahuqiao in the Lower Yangtze (Zhejiang Provincial Institute 2004: 260-263), which might mean that pig-keeping was also practiced in the Lower Yangtze, prior to cultivation, although pigs account for only about 10% of the faunal assemblage. But in that area too available faunal assemblages suggest an emphasis on hunted deer and fish, with a consistent minority of pigs (in the range of 10-30% of mammal bones) (cf. Huang 2001; Zhang, M. 1999; Longquizhuang Site Archaeology Team 1999: 465-492; Administration of cultural Heritage of Shanghai 1987: 111-113; 2002: 347-366). Thus in Neolithic China, both south and north, pig-keeping was practiced but did not dominate the animal economy initially. This was presumably to change in the Late Neolithic and Bronze Age as pigs became increasingly significant, including for sacrifices in large numbers. By the end of the Third Millennium BC cattle (*Bos taurus*) and sheep (*Ovis aries*) were adopted in Gansu on the western edge of the Central Chinese cultural zone, and were to become important domestic animals by the Shang Dynasty in the later Second Millennium BC (Yuan, J. 2002; Yuan and Flad 2005). The domestication of the water buffalo, which is likely to have origins in South China, independent of those in South Asia (cf. Hoffpauir 2000; Fuller 2007: 395-396), remains mysterious. Evidence for ploughs in Lower Yangtze Songze culture (after 3500 BC) may imply domestication, while textual evidence from the Shang period (after 1500 BC) clearly indicates their importance in the Yellow river by this later period, when bones also occur in large quantities (Chang 1980: 138-142). The early history of Chinese water buffaloes remains to be determined, and methodological problems in distinguishing domesticated from hunted *Bubalus* are yet to be resolved in China.

Rice from the south was added to this agricultural system only in the Third Millennium BC, with a few rice finds from Late Yangshao contexts (3000-2500 BC) and many more from the Longshan period (2500-2000 BC) (Crawford et al. 2005). This means that foxtail millet may have begun to disperse southwards before rice dispersed northwards. Recently, evidence has been reported for foxtail millet in the Daxi cultural phase of the middle Yangtze region (4500-3300 BC) (Nasu et al. 2006). Millet also spread earlier to Korea than rice, but rice and millets appear to the south in Taiwan at the same time (Tsang 2005). The site of Nuanguanli (2700-2400 BC) provided evidence for both *Setaria italica* and *japonica* rice. This evidence from Taiwan might suggest that rice and millets spread from the Shandong peninsula (contra Bellwood 2005), where both sets of crops were cultivated by the early-mid Third Millennium BC, by contrast to the Lower Yangtze region in which millet cultivation is not indicated in the archaeological evidence nor in historical or ethnographic records. These observations are congruent with a hypothesis that the north Chinese millets were domesticated earlier than rice and that millet agriculture began to expand (to the Middle Yangtze and Korea) at an earlier date than agriculture based on domesticated rice.

Wheat may have arrived from the West shortly after rice. Although wheat is a significant crop of the Shang period (1500-800 BC), known from textual evidence (Chang 1980), as well as significant quantities of archaeobotanical finds, such as at Zhouyuan (Zhouyuan Archaeological Team 2004), its introduction in China, perhaps a millennium earlier, is still represented by very few finds. The earliest finds of wheat (*Triticum cf. aestivum*) date from towards the end of the Third Millennium BC, and are attributed to diffusion eastwards along the silk road. Finds include AMS-dated wheat from Donghuishan in western Gansu near Qinghai (Li 2002; 2004),<sup>1</sup> Longshan period finds in Shandong (Crawford et al 2005), and Longshan period finds from Baligang in Southern Henan province (Fuller, unpublished data). Recently the site of Taosi, 2200-1900 BC has produced finds of barley (Zhao 2006), suggesting that this crop may have accompanied wheat. By ca. 2000 BC, wheat is associated with desert 'mummy' burials in the Tarim basin of Western China, and it is presumed that the influx of wheat in Central China is connected to increased trade and interaction with these Central Asian cultures (such as the Qawrighul culture of Lopnur and the mid-Second Millennium BC Yengidala; see Mallory and Mair 2000: 138, 145). These cultures are best known from their burials and systematic archaeobotany is needed from settlement sites of the preceding period. At present finds of wheat are earlier in Central China (and in Korea, see below) than in the far west of China and adjacent Central Asia—this calls for further archaeobotanical research!

As with South China (and Korea and Japan), ceramic production appears to precede food production. Ceramics are not as old in northern China, nor in Korea, as they appear to be in Southern China, Japan and the Russian Far East (Kuzmin 2006). While dates for pottery may go back into the Pleistocene a recent assessment suggests they are not older than 10,000 BC in these areas. Early ceramics are documented from the settlements mounds of Hutouliang and Nanzhungtuo on the North China plains on either side of the Taihang mountains (Guo and Li 2002; Lu 2006). These sites include artefactual evidence for harpoons, bone tools and microliths associated with hunting and fishing as well as small quern fragments and stone pestles suggesting some intensive forms of plant food processing. In the absence of plant remains these tools are just as likely for use with tree nuts and wild tubers as with crops. Faunal remains indicate deer and gazelle hunting, as well as wild pig, wild equids, small game, fish and mollusks. There remain chronological and geographical gaps in our knowledge of the Early Holocene of the northern parts of China. Filling these gaps is crucial to understanding the origins of agriculture in these areas and even beginning to infer whether millets were domesticated once or more than once (with the latter suggested by *Setaria* genetics, cf. Fukunaga et al. 2006).

## The Spread of Agriculture to Korea and Japan

The “Neolithic” in Korea is conventionally defined on the basis of ceramics and microliths, as the Chulmun (or Jeulmun) cultural horizon, and lacks agriculture (Barnes 1993; Nelson 1999; Ahn 2004). Chulmun ceramics begin to be produced before 5000 BC, and most plant remains from these sites consist of nut remains, especially acorns. Millets diffuse from China during the Middle Chulmun, in the Fourth Millennium BC, with secure direct dates of ca. 3400 BC, although they may have arrived a few centuries earlier (Crawford and Lee 2003; Ahn 2004). Millet cultivation then would appear to have been added to a nut-based economy as a supplement. It remains unclear whether domestic fauna, such as the pig, diffused at this time or significantly later.

In the later Chulmun period additional crops are adopted, including rice, and it may be that wheat, barley and *Cannabis* are also present. Unambiguous rice finds date from ca. 2000 BC—based on the earliest direct rice AMS date at Oun 1 (Crawford and Lee 2003; Ahn 2004). However, recent evidence from Daecheon-ri (at Okcheon-gun, South Korea), includes rice, wheat and barley, *Cannabis* and *Setaria italica*. Bulk charcoal dates and ceramics suggest that site dates from 2800-3000 BC and no later than 2500 BC (Central Museum of Hannam University 2003), but there are no direct dates on the seeds and the site is very close to the surface so some intrusion is possible. Nevertheless, published photographs indicate a good morphological basis for identification. Several other sites have reported remains of rice that could be early Third Millennium (Ahn 2004). The Daecheon-ri material thus suggests that the first rice here may be nearly as old as that in northern China. In addition, if accepted these dates for wheat and barley would make them earlier than in the Central Plains of China, raising the possibility of an earlier diffusion of the cereals by a northern Steppe route, whereas the conventional later third millennium BC diffusion of wheat and barley in Central China is probably via the central steppe and the “Silk Road”. Setting aside Daecheon-ri, the next evidence for wheat is ca. 1000 BC in the early Bronze Age, or Mumun period (Crawford and Lee 2003). During the Mumun period, social hierarchy is suggested by megalithic burials, and it has been suggested that rice agriculture supported this development of social complexity (Nelson 1999; Bale and Ko 2006). From this period comes the earliest preserved field system of probably rice paddy land in Korea (Gwangju National Museum 1997).

From Mumun Korea intensive paddy field rice was probably introduced to Southwestern Japan, although food production, including some indigenous domesticates, had already been established in Japan. Intensive rice agriculture, bronze metallurgy and new forms of settlement organization and burial customs began in parts of Japan perhaps as early as 900 BC with the Initial Yayoi period (Imamura 1996; Terasawa 2002; Fujio 2004). Earlier, however, during the Jomon tradition there is evidence for cultivation and the adoption of crops in some parts of Japan by or during the Middle and Late Jomon. This includes one indigenous domestication of barnyard millet (*Echinochloa crus-galli* subsp *utilis*) on the northern island of Hokkaido. This is indicated by grain size increases through time at the sites of Hamanasuno and Usujiri during the late Fourth to Third Millennium BC (Crawford 1983; 1992; 1997), although this crop appears to have been used on a small scale alongside gathered foods. Meanwhile on the northern part of the main island of Honsu (in the district of Aomori), at the site of Kazahari, finds of foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) indicate the adoption of crops of the mainland at least in some areas by the first half of the Third Millennium BC (D’Andrea et al. 1995; Crawford 1992; 1997: 101). Rice cultivation was established by the start of the First Millennium BC, in both southwest Japan and northern Honsu, with a direct AMS date of ca. 900 BC at Kazahari (D’Andrea et al. 1995). Even earlier may have been the adoption of buckwheat (*Fagopyrum esculentum*) in the Fourth Millennium BC on Hokkaido (Crawford 1983), although only a single nutlet has been found, in addition to evidence from pollen of buckwheat from pollen cores (D’Andrea 1999: 170). As pointed out by D’Andrea (1999), these data for early cultivars in parts of Japan indicate that the beginnings of cultivation, and the spread of intensive wet field agriculture, associated with the Yayoi in the First Millennium BC, represent two separate events.

## Conclusions

We have suggested that rice domestication is much later than previously assumed, closer to 4500-4000 BC, with pre-domestication beginning by 5500-5000 BC if not earlier. While it is conceivable that cultivation began earlier in the Middle Yangtze than in the Lower there is no good archaeobotanical evidence for this. There is also no reason to assume that rice was domesticated only once in China as migrationist models (e.g. Bellwood 2005) presume, and the latest genetic data (Londo et al. 2006) would seem to favour two *japonica* domestications, which is congruent with cultural evidence for limited contacts between the different parts of the Yangtze during the earlier (Middle) Neolithic. This reappraisal of the archaeobotany and archaeology of the Yangtze in this paper should provide a new framework for problem-oriented research. New samples of rice spikelet bases and rice grains provide an opportunity to assess this hypothesis, and indeed recent excavations by the Zhejiang Provincial Institute of Archaeology at Tianluoshan (a Hemudu culture site), provide such an opportunity. The authors' current collaborative research on archaeobotany of this site has been designed specifically with these problems in mind and initial results indicate not only vast quantities of water-chestnuts and acorns but also rice spikelet bases. Initial results suggest that we can distinguish the presence of mature wild, mature domesticated and immature abscission scar types, and the proportions of these will indicate where along the evolutionary trajectory of domestication this site lies.

It is therefore necessary to consider many early rice finds in East Asia as morphologically wild. These therefore represent evidence from the now extinct wild progenitor populations, which are likely to have provided important hunter-gatherer foodstuffs alongside nuts such as acorns. The presence of extinct wild rice populations in coastal zones during the final Pleistocene is implied by the finds of *Oryza* phytoliths. The presence of extinct wild rice populations in low (sub-tropical) coastal zones during the final Pleistocene when sea levels were still significantly lower is to be expected. It just such populations that are implied by the finds of *Oryza* phytoliths (not demonstrably domesticated) from the off-coast core near Shanghai at 13,000 bp (Lu et al. 2003). Morphological diversity was found suggesting that more than one wild rice species was present, such as *O. rufipogon* and *O. officinalis*. Similarly, the divergent bulliform morphotypes illustrated by Jiang and Liu (2006) from Shangshan (ca. 8000-7000 BC) in Zhejiang province imply phylogenetic diversity. Morphological diversity in the past, and inferred phylogenetic diversity, needs to become a focus of quantitative and morphometric research. It is uninformative to assume that all ancient rice can be forced into a few modern categories (Ahn 1993), rather we need to grapple with morphometric evolution as well as maturity issues.

It now appears that millet domestication occurred far to the north/northeastern parts of China in the desert margin or steppic contexts. The ecological and cultural contexts of millet domestications must have been very different from those of rice in the Yangtze. It now appears that millets were probably domesticated earlier and in the context of domesticated millets the East Asian stone harvest knives evolved. This technology then diffused from the millet zone to the rice zone by the Fourth Millennium BC. Millets also spread northwards and eastwards towards Chulmun Korea and Jomon Japan. In the Third Millennium BC, probably towards the middle part of that Millennium rice agriculture spread expansively, into Late Yangshao and Longshan Central/North China and southwards to Taiwan and towards Southeast Asia. It may be at this time that the earliest rice went to Korea and Japan, although this early spread of northern rices may not have involved the highly productive and labour intensive forms of cultivation known from later periods (the Bronze Age Mumun and Yayoi). Pigs may have been domesticated separately in both the northeastern millet and the Lower Yangtze rice zones, but even the pigs were not immediately the most important meat sources, as hunted deer remained dominant, and fish were widely important.

China was an important region for Neolithic transformations. As more data becomes available, however, it is clear that we need to break down a single Chinese “centre” into a number of distinct centres and processes where the transitions to agriculture took place over an extended period of time from the early to mid Holocene. East Asia suggests important lessons about the potential distinctions between cultivation, morphological domestication and dependence on intensive agriculture. The earliest rice cultivation may have supplemented and eventually supplanted nut-based foraging in Southern China, while the spread of domesticated rice and millets into Korea and Japan may have initially also been relatively small scale. The intensification of production based on domesticated rice had important social consequences, witnessed by increasing craft specialization and social production in the Late Neolithic of the Lower Yangtze (Liangzhu culture), and similarly by the spread of intensive paddy agriculture through Korea and Japan in the First Millennium BC. Further systematic archaeobotany has much to offer about elucidating these economic systems and processes of change.

### Notes

1. The wheat from Donghuishan raised unresolved questions. A 1998 AMS date on a grain from the Peking University radiocarbon lab gave 4230±250 bp (2500-3000 cal.BC), although the material culture from the site is the Early Bronze Age Shibo culture, conventionally taken to start around ca. 2000 BC. This may indicate that some of the crop remains represent older material than the bulk of the known archaeology on the site (Li 2004). Recently reinvestigation, including flotation, has been carried out.

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Table 1. Selected seed crops domesticated in China, with comments on region and earliest

Tables and Figures: Fuller/Qin/Harvey

Table 1. Selected seed crops domesticated in China, with comments on region and earliest archaeological evidence (based on Li 1969; Simoons 1991; Crawford 1992; updated by Fuller). Fruit trees, vegetable and tuber crops not included. Staple tubers may have been important in Southern (tropical) China, including taro (*Colocasia esculenta*, a triploid variety), Chinese Yam (*Dioscorea opposita* Thunb., syn. *D. batatas* Decne.) and several southeast Asia *Dioscorea* spp., and had independent domestications there (see Simoons 1991; Hotta 2002; Yoshino 2002).

Crop	Common names	Region(s) of origin	Archaeobotanical evidence
<b>Cereals</b>			
<i>Oryza sativa</i> L. subsp. <i>Japonica</i>	Asian rice (short-grained, japonica type) Ch. <i>Dao</i> 稻, <i>da mi</i> 大米	Yangtze Basin: possibly two domestications (in addition to 2 or 3 <i>indica</i> domestications in South/Southeast Asia) (Londo et al. 2006)	See discussion in text
<i>Coix lachrymal-jobi</i> L. var. <i>ma-yuen</i> Bor	Jobs tears Ch. <i>Yi mi</i> 薏米	Southern China/ Southeast Asia/ Assam, amongst tuber cultivators(?) (Arora 1977; Yukino 2002)	Reported from Hemudu-wild gathered (?) (Yu and Xu 2000; Zhejiang Provincial Institute 2003)
<i>Panicum miliaceum</i> L. subsp. <i>miliaceum</i>	Common millet, broomcorn millet; Ch. <i>Huang mi</i> 黄米, <i>shu</i> 黍	Northern China, Inner Mongolia; also towards Western Central Asia/ Eastern Europe(?)	Neolithic sites from Northern China an Yellow River Basin (6500-5000 BC); LBK Neolithic sites in Central Europe (5500-5000 BC); Arukhlo in Caucasus (?6000-5000 BC)
<i>Setaria italica</i> (L.) P. Beauv. subsp. <i>italica</i>	Foxtail millet, Ch. <i>Xiao mi</i> 小米, <i>Su</i> 粟, <i>ji</i> 稷, <i>liang</i> 粱	Northern China, Inner Mongolia; also Central Asia (Afghanistan) (Fukunaga et al. 2006)	Neolithic sites from Northern China an Yellow River Basin (6500-5000 BC); Arukhlo in Caucasus (?6000-5000 BC); Bronze Age Europe (2500-1000 BC)
<b>Pulses</b>			
<i>Glycine soja</i> (L.) Merr.	Soybean, Ch. <i>Da dou</i> 大豆	Central/Northern China, and Japan(?)	Jiahu (6500-5500 BC), wild(?); several Late Yangshao and Longshan sites in Yellow river basin; Late Bronze Age Korea (Crawford and Lee 2003)
<i>Vigna angularis</i> (Willd.) Ohwi & Ohashi	Adzuki bean, Red bean, Ch. <i>Hong dou</i> 紅豆	Sub-tropical South China and/or Korea and/or Japan (Tomooka et al. 2003)	Longshan period Liangchenzhen, Shandong, wild(?) (Crawford et al. 2005); Late Bronze Age Korea

			(Crawford and Lee 2003)
<u>Oilseeds and Fibres</u>			
<i>Cannabis sativa</i> L. (subsp. <i>Sativa</i> )	Hemp, especially for fibre and oilseed Ch. <i>Da ma</i> 大麻	Northern, northwestern China, and/or Central Asia	Linxia site (Majiyao/Late Yangshao), 3500-2500 BC; Known from early inscriptions (Shang period, ca. 1500-1000 BC)
<i>Boehmeria nivea</i> (L.) Gaud.	Ramie Ch. <i>Zhu ma</i> 苧麻	Southern China	Fibre/textile remains from Liangzhu, Lower Yangzte (3300-2200 BC).
<i>Abutilon theophrasti</i> Medik. (Syn. <i>A. avicinnae</i> Gaertn.)	Chinese jute, Indian mallow Ch. <i>Qing ma</i> 苘麻 <i>Bai ma</i> 白麻 <i>Tang ma</i> 塘麻	Southern China	?
<i>Perilla frutescens</i> (L.) Britt. (Syn. <i>P. ocymoides</i> L.)	Beefsteak plant, perilla, Ch. <i>Zisū</i> 紫苏, Jap. <i>egoma</i> (oil seed, vegetable, herb)	Southern China and Japan: two origins(?)	Single seed from Tian Luo Shan (ca. 4600 BC), Lower Yangtze (authors' data); Chengtoushan (4400-3300 BC) (Nasu et al. 2006); Middle Jomon Japan (4000-2000 BC) (Crawford 1992; Fujio 2004); Early/Mid Mumun Korea (1300-700 BC): Oun, Nam Riv. (Crawford and Lee 2003)
<i>Broussonetia papyrifera</i> (L.) Vent.	Paper mulberry (fibre; also food source for silkworms). Ch. <i>gou shu</i> 构树		Torihama shell midden, Japan, by 3500 BC (Crawford 1992: 18). No direct evidence in China. Earliest preserved silk fibres: Liangzhu, Lower Yangzte (3300-2200 BC).
<i>Morus alba</i> L.	White mulberry (food source for silk worms, edible fruits), Ch. <i>Sang</i> 桑	Northern China	?; historical evidence from Shang period oracle bone inscriptions for silk, silkworm and mulberry (Chang 1980: 149)
<i>Brassica juncea</i> (L.) Czern. <i>sensu lato</i>	Brown mustard; Ch. <i>Jie cai</i> 芥菜 includes cabbage forms such as leaf mustard ( <i>B. juncea</i> ssp. <i>integrifolia</i> )	Central Asia, northwest South Asia, East Asia(?): likely multiple origins	Yangshao seeds from Banpo, China (4000 BC); Torihama shell midden Japan (by ca. 3500 BC)

Ch. *da wang jie* 大王芥  
& heading leaf mustard  
or Swatow mustard (*B.*  
*juncea* ssp. *Integrifolia*  
var. *rugosa*)  
Ch. *Bao xin jie cai*  
包心芥菜

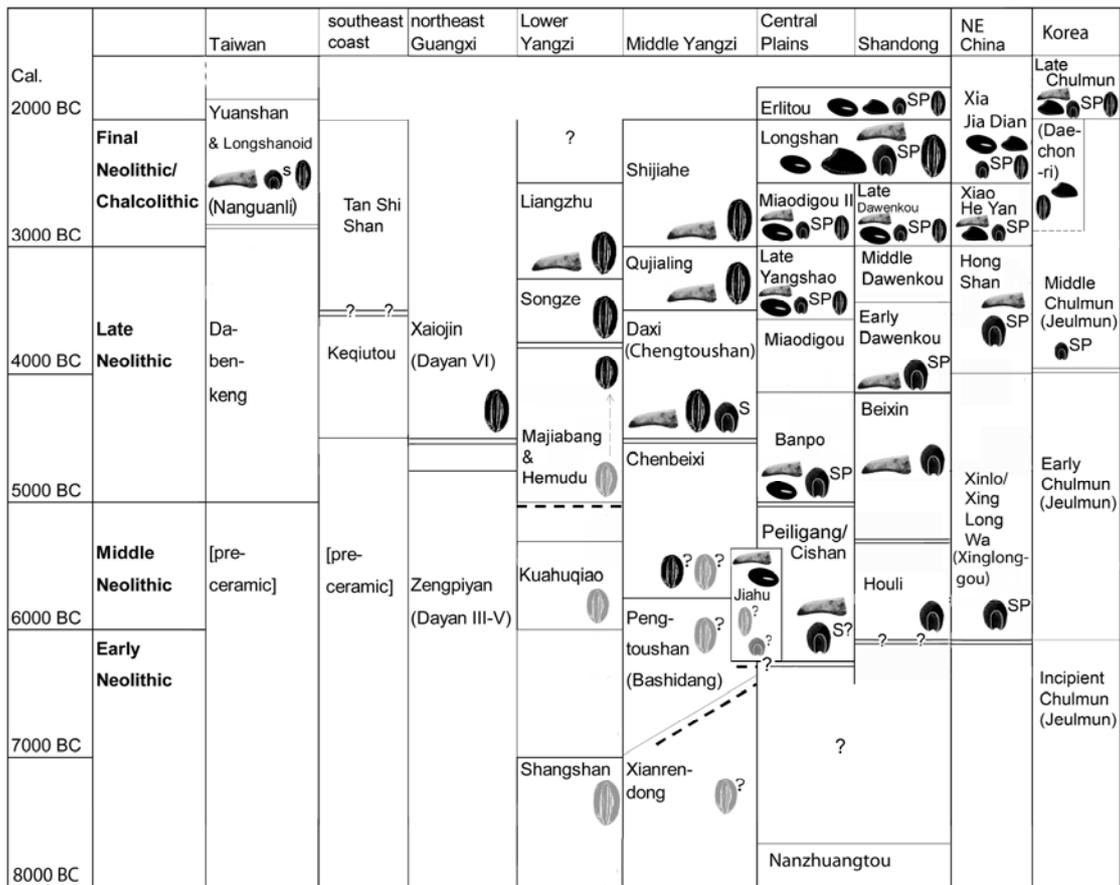


Figure 1. A synthetic chronology of Neolithic China based on evidence for major crops and the transitions to cultivation and domestication.

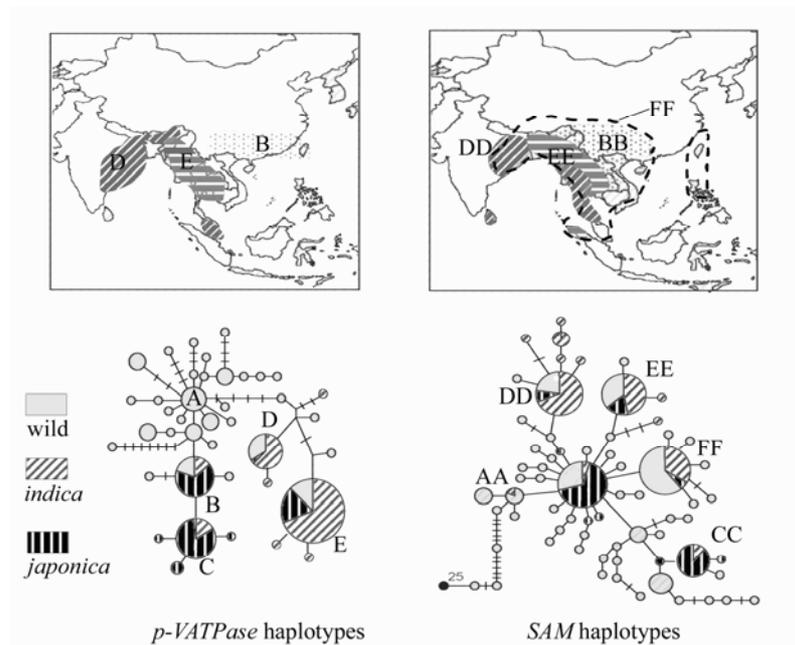


Figure 2. The phylo-geography of haplotypes (variants) of two genes in wild rices (*Oryza rufipogon/nivara*) and domesticated *japonica* and *indica* (after Londo et al. 2006). The maps at the top show the geographic distribution of the main haplotypes in wild rice populations. The network diagrams indicate the presence of these haplotypes in modern rices, including both wild and domesticated types. The circles branches represent mutational differences between haplotypes, while the size of the circles is relative to the quantity of modern samples possessing a haplotype. The pie-charts in the circles indicate the relative frequency of wild, *japonica* and *indica* amongst the samples.

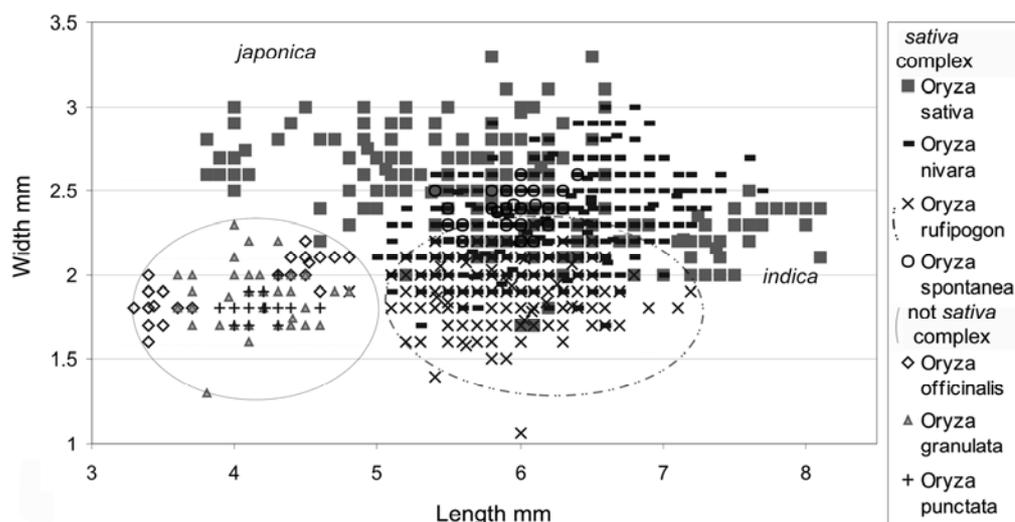


Figure 3. A scatter plot of length and width of grains measured in modern populations (measured by E. Harvey on 72 populations). The top graph shows individual grain measurements for a range of species, whereas these are replaced by ovoid distributions for wild species in the lower graph.

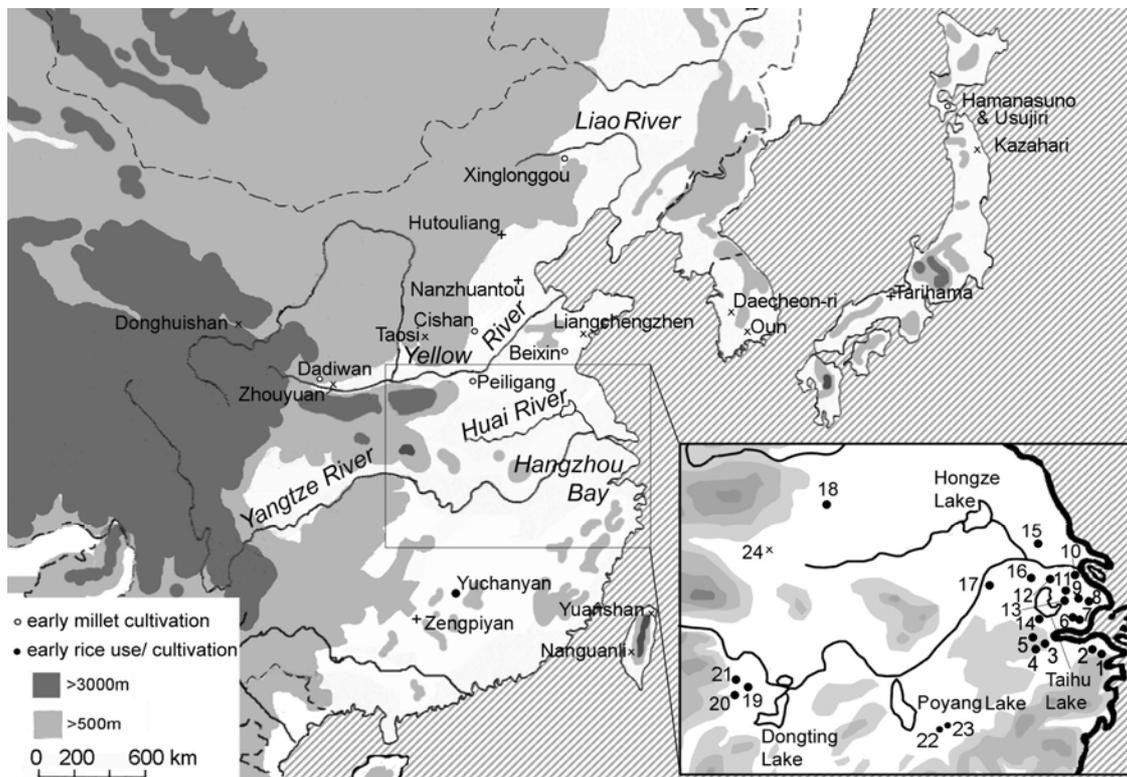


Figure 4. Map of East Asia with inset of Yangtze region, showing archaeological sites mentioned in this article. Early sites with rice (including wild rice) indicated by black circles. Early sites of millet cultivation indicated by hollow circles. Early sites without crop/ wild progenitor evidence indicated by crosses. Later sites discussed in relation to crop diffusion indicated by x. Sites in inset, numbered: 1. Hemudu; 2. Tianluoshan; 3. Kuahuqiao; 4. Shangshan; 5. Liangzhu; 6. Majiabang area, including Nanzhuangqiao, Luojiqiao and Pu'anqiao; 7. Nanhebang; 8. Maqiao; 9. Songze; 10. Xujiawan; 11. Choudun; 12. Weidun; 13. Longnan and Caoxieshan; 14. Qiucheng; 15. Longqiuzhuang; 16. Sanxingcun; 17. Lingjiatan; 18. Jiahu; 19. Bashidang; 20. Pengtoushan, 21. Chengtoushan 22. Diaotonghuan (Wangdong) 23. Xianrendong; 24. Baligang



Figure 5. An excavated storage pit at Tian Luo Shan site, showing the concentration of acorns at its bottom. Photo courtesy of Sun Guo-ping (Zhejiang Provincial Institute of Archaeology).



Figure 6. Rice husk lens *in situ* during Hemudu excavations (reproduction from Zhejiang Province Institute 2003, pl. XLI.2)

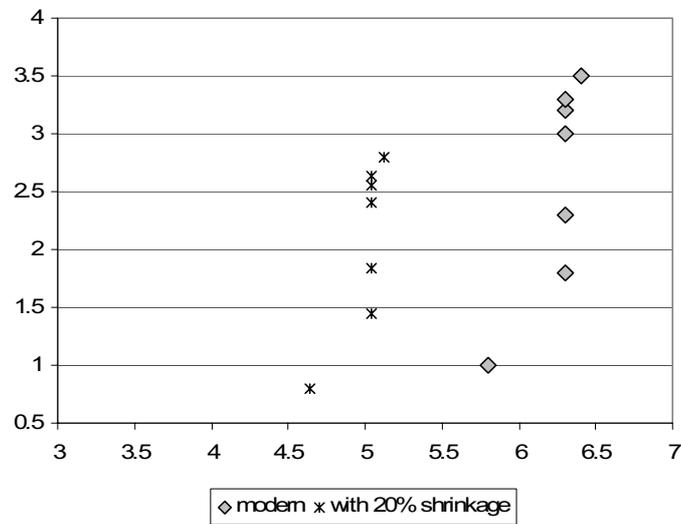


Figure 7. Graph of grain length and width over the course of development, day number indicated along right hand side. Based on metrical data of Hoshikawa (1993). This trajectory is also adjusted for 20% reduction to account for the likely affects of charring, which are expected to reduce the length of rice grains by 10-20%.

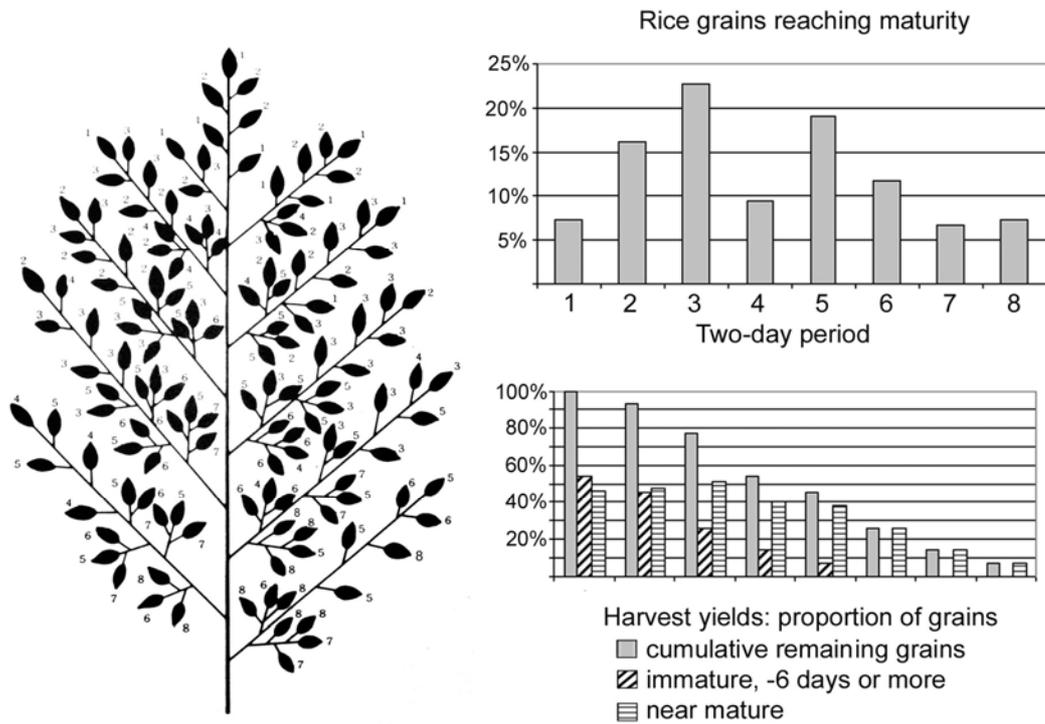


Figure 8. Rice panicle maturation and harvest yields assuming wild type grain shedding. The diagram on the right indicates the stage of pollen shed, and by extension grain initiation on an individual rice plant (after Hoshikawa 1993) The graph at the top right converts this into the percentage of grains that are expected to come into maturity at each of these stages, approximately 2 days each, i.e. a total of 16 days for the grains of an entire plant to mature. The graph at lower right indicates that total number of grains remaining on the plant at each stage and the proportions that are near mature and substantially immature (by 6 days or more).

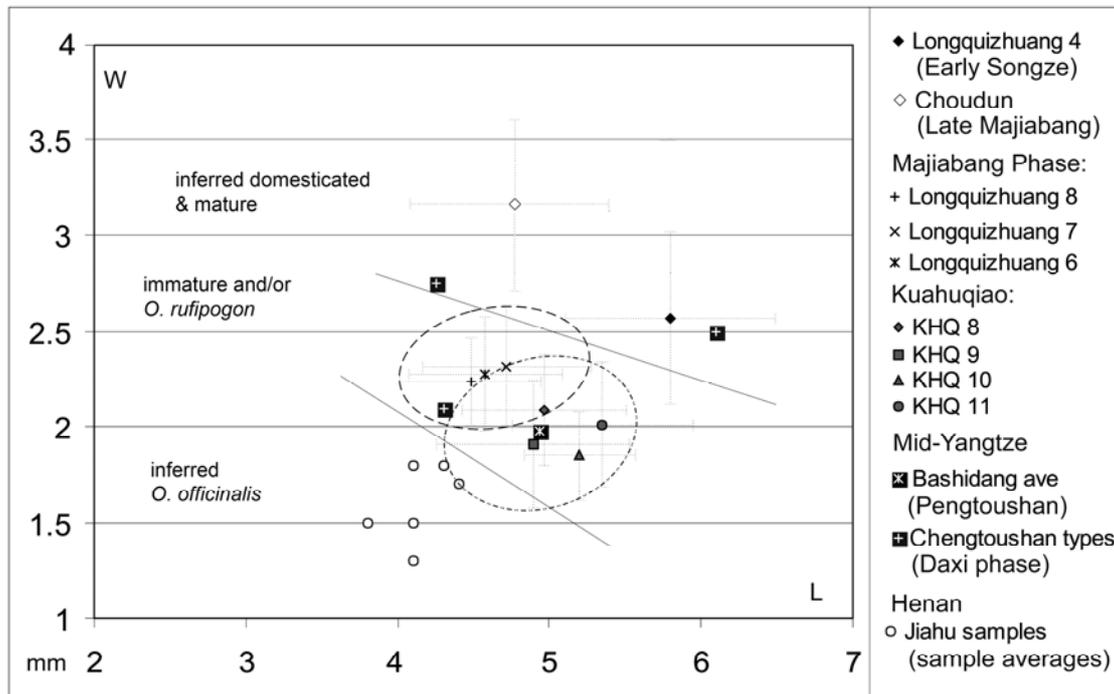


Figure 9. A scatter plot of grain measurements from selected Neolithic sites, including Kuahuqiao (after Zheng et al. 2004b), Longquizhuang (after Huang and Zhang 2000) and Choudun (Tang 2003). Cases where only spikelets (with husk) appear to have been measured, as at Hemudu, have been excluded. Notice that grains from Kuahuqiao and the lower (Majiabang period) levels (8-6) at Longquizhuang fall largely or entirely in the expected immature grain proportions (compare Figure 8), while the latest Majiabang period grains from Longquizhuang (level 4) indicate a clear shift towards longer and fatter grains that can be regarded as fully mature, and thus domesticated. Published averages from selected Middle Yangtze sites are also shown, including individual sample means from Jiahu (Henan Provincial Institute of Archaeology 1999), reported site average from Bashidang (from Pei 1998) and for the three rice types ('*japonica*', '*indica*' and 'ancient rice') from Chengtoushan (from Zhang & Wang 1998).

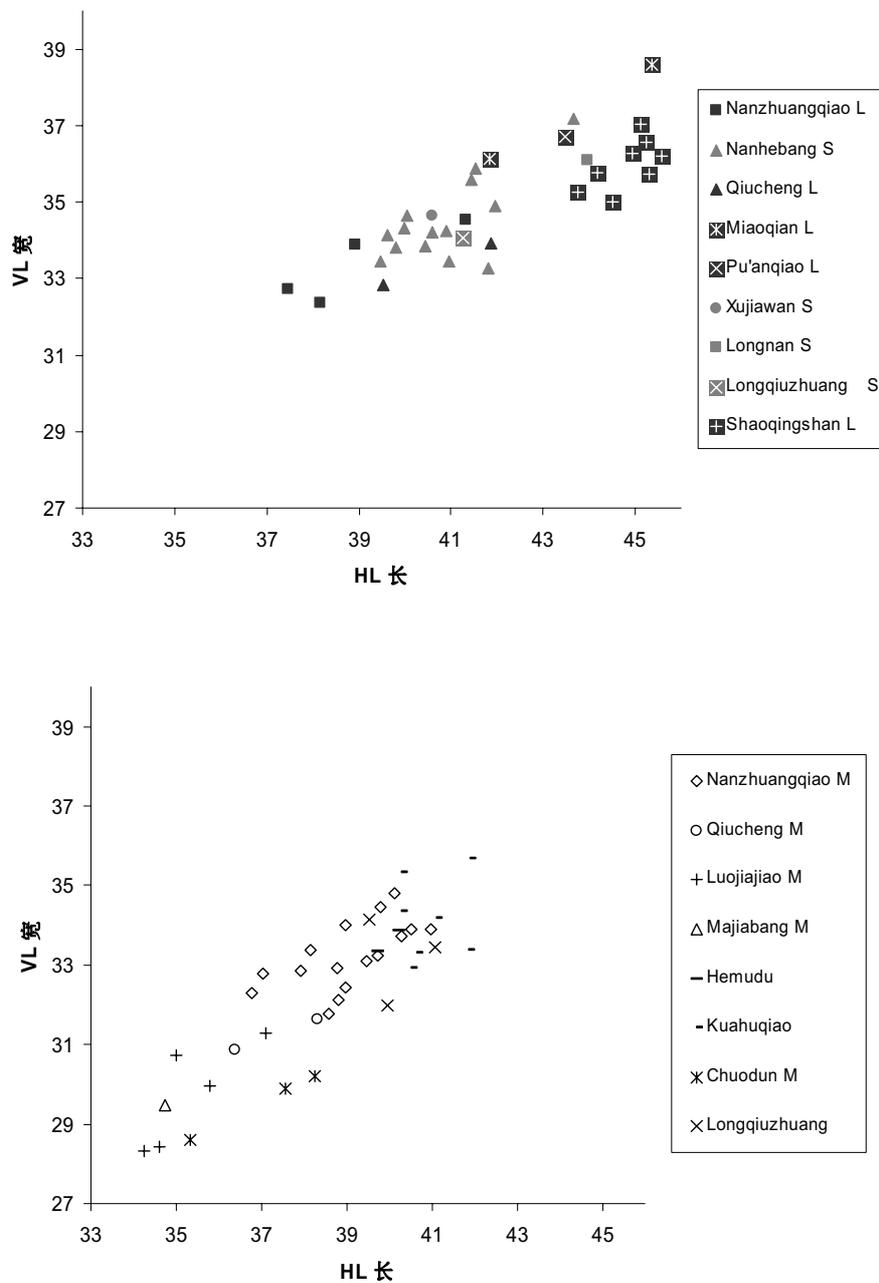


Figure 10. Size increase in Lower Yangzi rice phytoliths. The upper graph shows measured horizontal length (HL) and vertical length (VL) of rice bulliform phytoliths from Majiabang period samples (M), while the lower graph shows measurements from samples of the subsequent Songze (S) and Liangzhu (L) phases. A trend towards size increase can be seen. Majiabang measurements. Data re-plotted, from Zheng et al. 2004a. Site names abbreviated: Nanzhuangqiao, Nanhebang, Qiucheng, Luojiajiao, Miaoqian, Puanqiao, Xujiawan, Longnan, Majiabang.

