

Forthcoming In: A. Sanchez-Mazas, R. Blench, M. Ross, M. Lin & I. Pejros (ed.) *Human migrations in continental East Asia and Taiwan: genetic, linguistic and archaeological evidence*. London: Taylor & Francis Likely publication date 2007.

Evidence for a late onset of agriculture in the Lower Yangtze region and challenges for an archaeobotany of rice

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Introduction

The origins of agriculture represents a particularly important transition in human prehistory. By producing food through cultivating plants, and to a lesser degree by herding animals, it became possible to store surpluses which could support larger settled populations (sedentism and increased population density), and specialist occupations (non-food producers). With agriculture was created the potential for much greater rates of population increase. The demographic differentiation between the idealized early farmer and hunter-gatherer has been a fundamental assumption for many powerful models of prehistoric population change, genetic change, and language spread (e.g. Bellwood 2005). Within this context, rice agriculture is usually assumed to be an essential factor underlying the Holocene migrations that are supposed to have created cultural geography of much of China as well as Southeast Asia (e.g. Bellwood 2005; Higham 2003). The hard evidence for the timing, geography, and evolutionary processes involved in the establishment of rice agriculture is, however, rather limited and ambiguous. Such evidence will be crucial to any story of agricultural origins and dispersal in East Asia. This paper considers an alternative hypothesis, the late domestication of rice, which sees much of the evidence for early rice as reflecting foraging and a long period of incipient cultivation of still wild plants.

Below we summarize and critically assess the evidence from plant remains, storage features, and tools relating to the plant economy at Hemudu and Kuahuqiao based on the final monographs published in Chinese in 2003 and 2004 (Zhejiang Provincial Institute 2003; 2004), with comments on available comparative data from other sites in China. The hard evidence indicates an economy based heavily on the seasonal collection and storage of nuts, especially acorns, and calls into question textbook descriptions of well-developed rice agriculture. We will focus on the evidence relating to rice at these sites and consider how an understanding of rice evolution under cultivation towards non-shattering, larger-grained and more even-ripening morphotypes requires new analytical approaches to archaeological rice remains. The evidence suggests morphologically wild rice under incipient cultivation through the Hemudu/Majiabang period (5000-4000 BC). This is then situated within a longer-term regional sequence from the Kuahuqiao through the Liangzhu period (6000-2200 BC), where the evolution of clearly domesticated rice forms and the development of field systems and tillage indicates a rapid but late development of intensive rice agriculture,

alongside animal husbandry, craft production and fiber crop cultivation. It remains possible that some parts of the Middle Yangtze valley had earlier, but separate, trajectories leading to domesticated rice, although our review also argues for reassessing claims in this region. This case study raises questions that remain to be addressed through new research, including systematic archaeobotany and quantitative morphometrics.

<<Figure 1 about here>>

Recent discussions on rice domestication

Increasing interest in the origins of agriculture in East Asia has drawn particular attention to the Yangtze basin region as one area of probable rice domestication (Figure 1). In particular, the site of Bashidang (of Pengtoushan culture) on the Lishui river (Hunan Province) and Chengbeixi on the middle Yangtze river (Hubei Province) provide some of the earliest dated rice grain assemblages from the sites of settled village communities by 6500-6000 BC (Pei 1998; Crawford and Shen 1998; Lu 1999; Crawford 2005; Higham 2005; Bellwood 2005). While an important later assemblage comes from Chengtoushan, of Daxi culture, from ca. 4500 BC (Pei 1998; Zhang and Wang 1998; Nasu et al. 2006) An earlier process of rice domestication is attributed to presumably seasonal cave sites south of the Yangtze, although the evidence consists of a few finds of rice grains, and a statistical change in phytoliths through time at the Poyang Lake area cave sites, Diaotonghuan and Xianrendong (Zhao 1998; see reviews by Lu 1999: 93-97; 2006; Yan 2002; Yasuda 2002; Higham 2005; Crawford 2005). These limited data have been assembled in theoretical models that compare the process of agricultural origins in South China to that in the better documented Near East, including timing and causation related to the Younger Dryas and terminal Pleistocene climate change (Cohen 1998; Harris 2005; Yasuda 2002; Yasuda and Negendank 2003; Higham 2005: 235). The implicit assumption is that plant cultivation must precede animal domestication. No attempt has been made to identify a series of progressive subsistence system changes equivalent to that in the Near East in which pre-domestication cultivation has been identified (Hillman 2000; Hillman et al. 2001; Colledge 2001; 2002; Willcox 1999; 2002). Such an evolutionary sequence can be hypothesized for the Lower Yangtze, and probably elsewhere.

Unfortunately, the hard evidence for a transition from wild plant gathering to cultivation remains exiguous. The contrast with the large bodies of data in regions like Southwest Asia (e.g. Colledge 2001; Willcox 2002; 2004; 2005; Bar-Yosef 2003) or North America (e.g. Smith 1992; Browman et al 2005) is stark. As the review by Crawford (2005) emphasises, systematic, problem-oriented archaeobotanical research into agricultural origins is relatively new in Chinese archaeology. Indeed, the first clear exposition of archaeobotanical field sampling methodology (flotation) in Chinese is quite recent (Zhao, Z. 2004). Other recent articles have addressed identification criteria (Liu, C. et al. 2004; Crawford and Lee 2003; Nasu et al. 2006), and the potential contributions of archaeobotany to cultural history (Zhao, Z. 2001; Crawford et al. 2005).

In the present contribution, we will draw attention to the need for greater sophistication in producing detailed models for pathways towards plant domestication and for the systematic collection and study of archaeobotanical data. We will do this through a reassessment of the evidence for early rice exploitation and supposed agriculture in the Lower Yangtze region with some comments on adjacent regions. Evidence from

the final report on the well-known site of Hemudu (Zhejiang Provincial Institute of Archaeology 2003) is reconsidered together with Kua-hu-qiao site (Zhejiang Provincial Institute of Archaeology 2004), both in northern Zhejiang province near the Southern margin of Yangtze river delta. The first occupation at the site of Hemudu (Layer 4) dates from ca. 5000-4900 BC, with the main village occupation ceasing by ca. 4600 BC. Subsequent use is indicated by a few storage pits for nuts from 4400-4000 BC (Layer 3B). These earlier layers define Hemudu culture, which is roughly contemporary with the Majiabang culture north of Hangzhou Bay. After 4000 BC, the site has yielded Songze period burials and a well (Layer 2). Meanwhile Kuahuaqiao has dates that fall between 6000 BC and 5400 BC (based on the authors' calibration of the radiocarbon data in the final reports). While the time span of these two sites is considerably later than the dates for the beginnings of agriculture now widely accepted for the Middle Yangtze region, these sites illustrate some of the challenges in studying early rice cultivation and the pitfalls in the assumption that rice grain finds imply rice agriculture, and dependence on rice.

<<Figure 2 about here>>

Situating Chinese rice: evolutionary biology and geography

Chinese botanical scholarship has a long history of studying rice, although new insights into its origins have come from genetic studies in the last decade. Variation between cultivated forms and within wild populations has been important, both for modern rice improvement programs and for providing insights into the origins of rice (Wang et al. 1999; Vaughan et al. 2003). Genetic findings in recent years have overturned the widely held presumption of a single Chinese origin for rice. There now 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. 1993; Sato 2002; Cheng et al. 2003; Vaughan et al. 2003; Li et al. 2004; Londo et al. 2006). Most significant is genetic evidence from the chloroplast and nuclear DNA variants called SINEs. A sequence deletion in the chloroplast DNA of *indica* cultivars links them with wild annual "*O. rufipogon*" (i.e. *O. nivara* in modern taxonomy) (Chen et al. 1993; Cheng et al. 2003; for current rice taxonomy see Vaughan 1989; 1994). Meanwhile, there are some seven SINEs that separate the *nivara-indica* group from the *rufipogon-japonica* (see Figure 2; based on Cheng et al. 2003). These genetic data, together with biogeography, argue that rice in China was domesticated from perennial wild plants that grew in wetland environments, in contrast to the annual monsoonal rainwater wild rice domesticated in India (Figure 3). The phylogeny of Cheng et al. (2003) also put tropical *japonica* cultivars (including long-grained *javanica*) towards the base of the *japonica* phylogeny. We would not expect there to have been an ancient 'intermediate' form of rice, but rather two separate trajectories towards domestic rices in Asia, each with distinct morphological tendencies in grain shape and with differing ecological settings. Ecologically, the fundamental contrast is between the perennial *O. rufipogon* in marshy environments, and the annual *O. nivara* in seasonal monsoon puddles (Sato 2002).

<<Figure 3 about here>>

Morphometric data from modern rice populations suggest distinct tendencies in morphological

evolution in these two groups. Grain measurements indicate substantial overlap within the *Oryza sativa* 'complex,' including *O. rufipogon*, *O. nivara*, cultivars, and *O. spontanea* that results from hybridization between cultivated and wild rices (Figure 4). *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 of wild populations. Thus in general there has been more grain morphological evolution in *japonica*, which may be explained in part by the absence of the wild progenitor from most of the core *japonica* range, at least for the past few thousand years, as well as adaptation to more temperate environments.

<<Figure 4 about here>>

Another important biogeographic observation is that the actual wild progenitor populations of Yangtze rice domestication(s) are today extinct. This statement is a logical corollary of basic observations in historical biogeography and evolutionary biology. Species vary, genetically and morphologically, across their geographic distribution and this variation is likely to be greater in widespread species or in species that are divided into smaller 'islands' of distribution, and thus are more prone to genetic drift effects. Therefore we would expect there to have been some genetic and morphological variation in ancient Yangtze wild rice. Wild rice must have extended northwards to this region under warmer climatic conditions, first during the terminal Pleistocene and then once again after the Younger Dryas, during the early and middle Holocene (on climatic change in the region, e.g. Yu et al. 2000; Yi et al. 2003; Tao et al. 2006). Thus we would expect wild rice to have been present in the Lower Yangtze when Kuahuaqiao and Hemudu were occupied. Persistence of wild rice, however, is likely to have ended during later Holocene climatic cooling, although there are apparent textual references from the first millennium BC (Chang, T. 1983). This implies that some of the variation of between Yangtze wild rice populations has been lost, and may not be represented in modern populations that are restricted to southernmost China, Southeast Asia, and South Asia. Indeed, one of the genetic lineages of *japonica* rice identified by Londo et al. (2006) is not represented by any modern wild populations. The rice of Kuhuaqiao might represent some of this lost genetic diversity, but what is needed is much larger sampling of ancient rice that has been recorded through morphometric data.

This perspective also raises the possibility that some populations of wild ancestors had unique traits that they transmitted to their cultivated descendants but that differ from existing wild specimens in modern collections. Actual wild progenitor populations were part of now extinct radiations of wild rice that persist only in their domesticated form. This 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.

Hemudu: Claims and underlying assumptions

Hemudu occupies a central position in the archaeological syntheses of early Chinese agriculture and accounts of the dispersal of agriculture in world prehistory. Whatever concerns and debates persist around earlier Chinese Neolithic sites, all authors assume that Hemudu represents a village based on established rice agriculture, “the earliest group reliant on domesticated rice is represented by the Hemudu site” (Crawford 2005: 84; see also, Chang 1986: 210; Barnes 1993: 94; Higham 1995; 2005: 247; Bellwood 2005: 125). We will, however, raise some questions about the status of rice at Hemudu, both in terms of its domestication status and in terms of its importance in diet. Attention is also normally drawn to the pig and water buffalo remains from Hemudu as implying animal herding (Chang 1986: 211; Bellwood 1997: 208), although archaeozoological criteria in support of herding and morphological domestication of these animals is not discussed in any detail and also deserved careful re-assessment.

<<Figure 5 about here>>

When first discovered, Hemudu had the earliest rice remains in the world (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 stratigraphy of the site. The material is clearly dominated by chaff, judging by available excavation photographs (e.g. Figure 5), and similar material has been seen by the authors from current excavations at nearby Tianluoshan. This was taken to represent a large quantity of rice, and was interpreted as the remains of a threshing floor (Bellwood 1997: 208). It was estimated that the rice would be equivalent to 120 tonnes (e.g. Yan 1982: 22), although this assumes a continuous deposit of rice. Published photographs (Zhejiang Provincial Institute of Archaeology 2003) and equivalent finds from recent excavations at nearby Tianluoshan, indicate that the rice husk has 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.

Studies of the Hemudu rice have invariably assumed that it represents domesticated rice. Previous studies have focused largely on determining the varietal category of this rice based on ratios of grain measurements (e.g. You 1976; 2003; Zhou 1981; 2003; Li 1985; Oka 1988), husk (lemma/palea) tubercles (Zhang et al. 1996; Zhang and Wang 1998; Zhang 2000; 2002; Tang et al. 2003), and bulliform phytoliths (Zheng et al. 2004a). 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), or the definition of an unique 'ancient' rice that preceded the differentiation of these two types (Zhang et al. 1996; Zhang and Wang 1998; Zhang 2000; 2002; Higham 2005: 244). Similarly, rice assemblages from other Neolithic sites in China have also been suggested to indicate the existence of distinctive, extinct 'ancient' cultivars that do not fit into modern categories (e.g., Zhang 2000; 2002; Pei 1998). At Kuahuqiao it is reported that grain measurements suggest *indica* rice, while bulliform phytoliths indicate *japonica*, a contradiction which is not explained (Zheng et al. 2004b; Zhejiang Provincial Institute of Archaeology 2004). These conclusions raise the question as to whether the assumptions on which comparative studies have been based are valid. The lack of agreement

suggests that prior assumptions have been flawed. This seems to be based largely on the large quantities of rice, and the presence of bone 'spades', but not on careful consideration of what might be expected to be different about rice gathered by foragers as opposed to that cultivated, or genetically transformed by cultivation.

Working from recent advances in genetic research, including that which indicates that Indian and Chinese rice domestications were separate, Sato (2002) argued that all the rice must be of *japonica* type, since a number later ancient DNA samples from the region were entirely of the *rufipogon-japonica* lineage, and *indica* was expected to have come from India (see also Crawford and Shen 1998: 864; Fuller 2002: 297-300).

The published descriptions of the rice from Hemudu contain indications that the rice may not have been fully domesticated. Much of the rice was found in the form of spikelets, and many spikelets lack grains or have incipient unformed grains. This implies that the spikelets were harvested before maturity, which implies a rice population that is not fully domesticated. While some of the spikelets are reported as awnless some have awns, a trait of the wild rice. SEM examination by Sato (2002) suggests that many awns have reduced hairs by comparison with modern wild materials. Sato also considered spikelet bases, although the criteria were not reported in detail (on a sample by sample basis), nor was the sampling procedure from which 81 spikelets were obtained clear. Sato (2002) reports 5 of wild type and 76 of "domestic" type, the latter including some that were "intermediate between wild and cultivated strains".

Herders or hunters?

The situation with animals also is rather more ambiguous than often assumed. Hemudu has also figured prominently in discussions of East Asian animal domestication, with both water buffalo and pig herding assumed by several textbooks (e.g. Chang 1986: 211; Smith 1995; Bellwood 1997: 208; 2005). Following some earlier exaggerated reports, Bellwood (1997: 208) was misled into believing that pigs represented 90% of the animal assemblage, which was taken to indicate major reliance on pig-keeping. In fact this misrepresents the data. Of identified specimens in the final report, 75% are from birds, fish and reptiles (e.g. turtles). Of the quarter that are mammals (NISP=1135), water buffalo account for only 8% and pigs 26% (Zhejiang Provincial Institute of Archaeology 2003:156-216). This is hardly comparable to the 60-90% of domestic/ pro-domestic fauna (sheep/goat/cattle) at early pastoral sites Southwest Asia or Pakistan (cf. Meadow 1993; Bar-Yosef 2000). At Kuahuqiao, mammals are more prominent, representing 62.5% of the reported bones (Zhejiang Provincial Institute of Cultural Relics and Archaeology 2004:260-263). Of these pigs account for only 10.1%, while water buffalo are an impressive 32%. The age profiles for water buffalo are consistent with hunting (Liu et al. 2004). Amongst the pigs it has been suggested that some of the third molars are small enough to be domesticated and a few mandibles are deformed, another feature of domestication. These domesticated morphotypes, however, are represented by just a few specimens, suggesting little reliance of pig-keeping. This could therefore be indicative of a special role for kept pigs, such as for periodic feasts, rather than a crucial subsistence role. The subsequent increase in pigs at Hemudu could indicate greater reliance, and indeed the proportion here is comparable to later sites in the region, from the Majiabang to the Liangzhu period, where pigs range between 21% and 34% of mammalian fauna (Huang

2001; Zhang, M. 1999; Longqiuzhuang Site Archaeology Team 1999: 465 - 492; Administration of Cultural Heritage of Shanghai 1987:111-113; 2002:347-366). At all sites, even into the third millennium BC (Liangzhu period), mammal bone assemblages are dominated by deer (41-72%). The Kuahuqiao and Hemudu periods thus show a reliance on hunting and fishing with some supplemental pig-keeping, established as the Lower Yangtze Neolithic pattern.

One of the surprising things about the Neolithic of the Lower Yangtze is how insignificant water buffalo appear to be. Amongst post-Hemudu sites, water buffalo make up only 4% of the bone assemblage from Majiabang period Longqiuzhuang (Longqiuzhuang Archaeology Team 1999), whereas at other, later sites (Weidun, Longqiuzhuang, Songze, Maqiao) their bones appear to be completely absent (Huang 2001; Zhang, M. 1999; Administration of Cultural Heritage of Shanghai 1987:111-113; 2002:347-366). This is particularly surprising as we expect water buffalo to have been used for ploughing in the Lower Yangtze, and evidence in the form of stone plough tips occurs from the Mid-Late Songze, with the earliest from a burial at Tangmiaosun (Administration of Cultural Heritage of Shanghai 1985). This might suggest that water buffalo were brought under domestication, or adopted, specifically for ploughing rather than initially as a food source. If so, this represents a significant difference from the process inferred from Southwest Asia and Europe for a transition from cattle as meat animals to a wider utility for secondary products including traction (see Sherratt 1981).

Current evidence argues for a predominance of deer-hunting and fishing throughout the Lower Yangtze Neolithic. While some pigs were apparently reared, these are a consistent minority of bones suggesting a special status for these animals, such as for feasting foods. Elsewhere in China, early domestic pigs have been inferred from the same general time horizon as Kuahuqiao, as at Cishan in the Yellow river valley (Yuan and Flad 2002; Yuan 2004) and at Xinglonggou in Northeast China (Yuan, personal communication). These other sites come from a very different environmental and cultural context, from amongst early millet cultivators, and it is not yet possible to determine whether pigs had multiple origins within China (but several domestications across Eurasia are clear, Larson et al. 2005). The lack of material cultural evidence for diffusion prior to the Songze-Middle Dawenkou time horizon might favour separate regional processes

Evolutionary expectations: the making of domestic rice

The basis of food production is a direct involvement of humans in the management of the lives and life cycles of certain plant and animal species, termed 'domesticated'. It is the management of these species, over hundreds of years, that led to the evolutionary changes of domestication. Thus a very real archaeological challenge is to identify the beginnings of cultivation amongst morphologically wild rice, and track the gradual biological changes this incurred. Theoretically this could be a much longer stage than that for wheat and barley due to the cross-pollination common amongst wild rices. In Southwest Asian archaeology, this challenge is now being met in the past 10 years as evidence for pre-domestication cultivation has been recognized through the statistical composition of wild seed assemblages, which document the inferred emergence of weed ecologies (Harris 1998; Colledge 1998; Hillman 2000; Hillman et al. 2001; Willcox

1999, 2002, 2003). Also important is a growing morphometric database from the Near East (Willcox 2004; Colledge 2001, 2004) which indicates that wheat and barley grains increased in size starting in the Pre-Pottery Neolithic A and earliest Pre-Pottery Neolithic B, prior to evidence for the emergence of domestic type seed dispersal (tough rachis dominance of archaeological chaff assemblages). This implies that grain size increased under the selection of early cultivation, prior to the evolution of the full domestication syndrome in Near Eastern cereals (cf. Willcox 2004). In summary, Near Eastern archaeobotany now allows the outline of a phased evolutionary process through which changes in human practices (cultivation) and changes in plant morphology (seed size increase and domestic-type seed dispersal) evolved over an extended period of perhaps 1000-2000 millennia (Figure 6; also, Tanno and Willcox 2006; Weiss et al. 2006). Future research in China needs to pursue similar evidence if we are to understand the processes of agricultural emergence in this region. More flotation, more seeds, and more quantification of their composition is needed, alongside increased attention to quantitative patterns of morphology and size in the crops themselves.

While much data has been published on early Chinese rice, most of it has been seen through the lens of modern variation amongst domesticated rice. In short, authors have assumed that finds of rice are cultivated and domesticated and that research needs only decide whether the rice is *indica* or *japonica*. As already noted, there is no consistency or consensus, which has led some scholars to reject the utility of measuring grains at all, preferring phytoliths (Zheng et al. 2004a) or ancient DNA (e.g. Sato 2002), although the latter is yet to be shown to survive in the most ancient samples. But ancient rice remains, whether of grains, spikelets, or phytoliths, should be studied and characterized in their own right. Then morphometric traits of ancient populations, often represented by a few simple measurements, can be used to look at variations between sites, or between periods. This variation can then be interpreted through evolutionary models and morphometric expectations based on modern comparative materials and principles of the 'domestication syndrome.'

<<Figure 6 about here>>

The 'domestication syndrome' is a number of traits that tend to be found in domesticated plants, but that differ from their wild relatives (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). This implies that the human behavioral change, cultivation, necessarily precedes the morphogenetic change in plants (Figure 6). As was first realized by Helbaek (1960) and has become increasingly discussed amongst those who study plant domestication these 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, however brief, of pre-domestication cultivation (Harlan 1975; Wilke et al 1972; Hillman and Davies 1990a; 1990b; Harris 1989; 1996; Gepts 2004). One quintessential characteristic of domesticated grain crops is the loss of natural seed dispersal (Zohary and Hopf 1973; 2000; Hillman and Davies 1990a; 1990b). This is achieved in rice by a toughening of the attachment of the spikelet base to the rachilla, and as shown by Thompson (1996), this is accompanied by a subtle change in the cross-section of the rachilla attachment scar (also Sato 2002). 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). However, this implies that tough rachis mutants already exist in very small frequencies in wild populations and thus change must be documented at a populational level (Kislev 1997: 226-228). What is more, 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.

Of importance is modeling the rate of change and the time that would be expected to fix the domestic type mutants in a population, and this depends on the strength of the selective force as well as the extent of continued gene flow from wild types into the seed of subsequent generations (Hillman and Davies 1990a; 1990b). Unlike wheat and barley, which are almost exclusively self-pollinating, wild rice has been shown to have significant out-breeding on the order 40-60% of fertilized florets (Oka and Morishima 1967). Thus by contrast with self-pollinating species in which, under strong selection from harvesting and sowing, 'domestication', the populational process of fixing the tough-rachis mutants, could happen in 20-30 years, strong selection in cross-pollinating rice should double this to ca. 50 years. But crucial to this model is the selection pressure favouring the domestic type mutant, if this is greatly reduced to 10% or 5% then domestication slows greatly, even in self-pollinating species, taking on the order 200-400 years. But with reduced selection pressure in a cross-pollinating species this slows to more than 1000 years. Thus it is crucial to consider how human activities set up this selection pressure: this includes harvesting by methods that favour tough mutants, saving a large proportion of the harvest for sowing the following year and sowing in areas without natural wild seeds of the species. If the same wild stand areas are resown, and the quantity of resown grain is equal to or less than the natural seed dispersal by the wild population there will be essentially no selection for domestication. Other factors that might greatly reduce any selection for domesticated morphotypes are methods of harvesting, such as paddle and basket harvesting, widely used ethnographically for gathering wild grass seeds (Harris 1984; Harlan 1989). In addition, and probably quite significant, is that if wild cereals are harvested somewhat green, i.e. before most of the grains are mature, or if individual wild plants have a long period during which grains gradually come into maturity (which is the case with wild rice), grain loss to the harvester may be lessened, but selection for the domesticated type will also be reduced.

An important issue to consider, however, is how these traits relate to the evolution of the domestication syndrome in rice. Both traits relate to the reduction of the wild-type dispersal adaptation, which is reduced or removed through domestication. But they relate to the domestication syndrome in different ways in terms the kind of selection under which they can be expected to evolve. The non-shedding spikelet trait is expected to be strongly selected by harvesting of (mature) panicles with a sickle or knife, followed by subsequent cycles of sowing and harvesting. By contrast, longer, heavily haired awns and hairy husks, are selected for by natural seed dispersal as these appendages, like those in other wild cereals, help to bore into the soil and keep the spikelet there until germination. Thus the reduction in number or size of these appendages is caused by the reduction of natural selection for efficient seed dispersal brought about by

human sowing. The directional reduction in hairs suggests that the removal of selection for hairs is enough. This change may be brought about by a decrease in metabolic developmental costs involved in producing so many hairs.

Another contrast between domesticated and wild cereals that might slow down the domestication process as well as complicate archaeological detection is evenness of ripening. One characteristic of most crops is that their flowering and production of seed is timed almost synchronously across the entire plant (and indeed population). This contrasts with wild relatives which tend to have a much more extended period of seed production, which means that at any particular time a large proportion of the grains are immature or have already been shed. This has been experimentally confirmed in wild rice by Lu (2006), who found extremely low yields to harvesting of wild rice with sickles upon maturation at which time most grain was lost or had already been shed. When seed dispersal is still by the natural shattering, we might expect gatherers to target more immature plants to decrease seed loss by shattering during the harvest process. The implication for archaeobotanists is that ancient wild, and early cultivated, populations would most likely be harvested fairly immature, and would produce a mixture of mature and immature grains. This means we must take seriously the presence, perhaps even predominance, of the immature grain in early assemblages.

This problem is also highlighted by ethnographic parallels. In parts of aboriginal Australia where hunter-gatherers intensively used wild millet grains, grasses might be stripped by hand in a wooden or bark dish, before natural maturation and seed shedding (Allen 1974; Harris 1984: 64). Alternatively they could be uprooted while still green to minimize the loss of seed. These were then stacked, left to dry and then burnt serving to separate the grain and parch the husks. Where the burnt stacks were small, heaps of hulled millet grains were available for dehusking, cooking and consumption. Wild grasses may also be harvested by paddling or with baskets (e.g. Harris 1984; Harlan 1989; Lu 1998), in which case timing must be chosen so as to maximize those grains which are still on the plant and near maturity. This means targeting them early in the cycle of grain maturation when many grains on the plant will still be immature. In modern domesticated rice, individual plants take about 15 days for all grains to mature (Hoshikawa 1993), and we might expect this window to have been even longer in wild or early cultivated populations. In wild-type shattering plants this means that in order to avoid massive loss of grains, especially nearly mature grains, panicles need to be harvested early. This means large proportions, or at least half or more, of grains harvested will be immature (Figure 7). Archaeologically we might expect these substandard grains to be more readily lost through processing and thus to be over-represented archaeologically.

<<Figure 7 about here>>

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 grains mature is that first they lengthen and then gradually thicken in the final days of maturing (Figure 8). This means that immature grains have exaggerated length-to-width ratios (Figure 9). As conventional studies of modern material always focus on fully mature grains, the simple extension to these ancient materials is flawed. The difficulty is highlighted by the fact that measured ancient rices in China match neither modern varieties nor wild forms but fall in an intermediate zone, the basis for proposals of a distinctive 'ancient cultivated rice' varieties (e.g.

Pei 1998; Zhejiang Provincial Institute of Archaeology 2003:439; Zhang 2000; 2002). Ancient rice grains match neither the wild *rufipogon* rices of modern South China/Southeast Asia nor the *japonica* cultivars that were domesticated there, but often come closer, in ratio, to *indica* rices. Actual measurements, however, even allowing for probable size changes due to carbonization, do not match *indica*. This situation is readily explained if we consider these grains to be immature, i.e. harvested green.

As a starting point, we still must consider morphometric variation amongst the mature grains of modern rice varieties. There is great variation in the size and proportions of domesticated rice species today, as well as a broad range of variation encompassed by the several wild species that occur in South and Southeast Asia (Figure. 4). A survey of this variation indicates a great deal of overlap making it difficult to assign one or a few grains to any given population (Harvey 2006; see also Thompson 1996: 176). This problem is made more difficult by the changes, including shrinkage and distortion, during charring, as well as the problem of varying maturity levels. The few studies which have been conducted on the effects of charring on rice grains (Garton 1979; Lone et al. 1993), as well as those studying this effect on other cereals (Nesbitt 2006: 21; Willcox 2004), suggest that reductions in length and breadth are normally 10-20% but can be potentially as much as 30%. Reduction to length is normally greater, making grains tend towards rounder shapes. While further studies are certainly warranted on this issue, we will consider a 20% reduction a useful rule of thumb for the present discussion.

<<Figure 8>>

<<Figure 9 about here>>

Another factor that has particular relevance to the question of rice domestication is the harvesting of wild rice. In regions such as China and India, where populations of wild rice would have been abundant, we can not assume that the rice found on an archaeological site is domestic. Wild rice harvesting is still a fairly common economic strategy for non-agricultural and semi-agriculture groups, for example in parts southern Orissa (India) (Watt 1889-1893) or in North America, where *Zizania aquatica* was seasonally collected by native groups like the Ojibwa (Jenks 1900). The shattering nature of wild rice species means that grains need to be harvested before they are fully mature to avoid grain loss (cf. experimental results of Lu 2006), thus adding immature grains to harvest, which might even be expected to be dominated by immature grains. This will complicate identifications from sites before or during the process of domestication, when accurate identification is most important. Therefore the morphometric identification of archaeological rice assemblages to species or subspecies is far more complicated than is often assumed.

<<Figure 10 about here>>

The rice of Hemudu and beyond: harvesting unripe

The prominent rice deposits at Hemudu are unlikely to represent threshing floors. They consist mainly of husk material, as if they were disposed waste from dehusking episodes (Figure 5), with little evidence of the straw and leaves that would be expected from threshing of domesticated rice or the primary waste from threshing floors. As noted in the Hemudu report most of the remains consisted on empty rice

husks (Zhou 2003: 430), also evident from photographs (Figure 5). These included not just de-husking waste but some with immature or indeed unformed grains. At Kuahuqiao similar material was found and quantified (Figure 10), indicating a predominance of immature spikelets including many in which the grain had not yet formed. One implication of this is that if rice plants were harvested when 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. Rather what is needed is evidence for mature spikelets/grains together with tough domestic type abscission scars. In many reports, rice grains and spikelets have been considered in terms of length-to-width ratios, as a means to assigning them to either the *indica* or *japonica* subspecies, and in some cases to distinct “ancient” varieties of rice. This approach is misleading when a wide range of wild species are taken into account (Figure 11). As implied by the developmental trajectory of rice (Figure 8), these ratios will also differ in immature rice, which is how hunter-gatherers presumably gathered most of their rice. Therefore, rice morphometrics need to be approached through actual scatter-plots of measurements rather than through the use of ratios.

<<Figure 11 about here>>

While data on raw measurements are still relatively scarce, the available patterns appear significant (Figure 12). The morphometric data available from Kuahuqiao and Longqiuzhuang (mainly of the Majiabang period, which succeeds Hemudu chronologically) suggest that grain assemblages are dominated by immature grains. This assumes that the mature grains would have been in the range of modern domesticates. This is plausible if we consider the likelihood that early pre-domestication cultivation has 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 5000-4400 BC) both suggest pre-domestication cultivation. The rice at this stage can be regarded as a ‘pro-domesticated’ as some aspects of the domestication syndrome had begun to evolve but the key change, in terms of seed dispersal, had not.

<<Figure 12 about here>>

A clear contrast is seen with the latest assemblage from Longqiuzhuang (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 Chuoden (also late Majiabang), which has evidence for a possible paddy field (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 taken into account. Rice measurements from Bashidang, 6400-6000 BC (Pei 1998) fall in the midst of the wild/immature 'pro-domesticated' range of Kuahuqiao. Reported measurements from Jiahu (Henan Province Institute 1999), are remarkably small, by comparison with either modern cultivars or Lower Yangtze Neolithic immature grains. This suggests that they come closest to a wild rice, perhaps *Oryza rufipogon* (taking into account ca. 20% shrinkage due to charring, and possible immaturity), or more likely *O. officinalis*, a prolific grain-producer. 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. This suggests domesticated rice was being harvested at this site. 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. While all of these sites have been assumed in most literature to be agricultural, they may represent different degrees of cultivation of morphologically wild rice (Bashidang and the Pengtoushan culture) as well as some pure gathering of wild rice (at Jiahu). Jiahu also has acorns waterchestnuts and soybean (possibly cultivated but still wild in terms of size criteria), and sickles. 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.

<<Figure 13 about here>>

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 12). 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. Phytolith morphometrics might also provide a means for assessing variation between populations of ancient wild rice. As is clear from Figure 12, the Lower Yangtze sequence from Majiabang through Liangzhu shows a clear regression that suggests one morphological population. One complicating factor that requires consideration is the possible presence of other *Oryza* spp. in the region during the earlier Holocene. While we can have little doubt the *Oryza sativa* complex was present. What is needed is more comparative data on the range of morphometrics in bulliforms across Asian *Oryza* spp. as well as untransformed raw archaeological measurements so that the population level metric characters can be compared across time and space rather than being simply pigeonholed as "*indica*" or "*japonica*".

Rice in a nut-based economy

The rice that was used at Hemudu and Kuahuqiao should be considered in the context of a broader plant economy. Despite the lack of flotation or systematic efforts at sieving for plant remains, both Hemudu and Kuahuqiao produced substantial quantities of plant remains, thanks in large part to waterlogged preservation. While preliminary reports and secondary literature has tended to focus exclusively on the rice remains, this can be seen as a small component of a broader subsistence base with a focus on nuts. Table 1 summarizes the species present at these sites based on the final reports (Zhejiang Province Institute 2003; 2004). What is striking about this list of taxa is the wide range of nuts, in particular acorns (Figure 14), but also foxnuts (*Euryale ferox*), peach and apricot stones (which contain almond like seeds that can be made edible by roasting), and water chestnuts. Polygonaceae nutlets (knotgrasses) are also a potential food source. 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. More than their mere presence, acorns were stored in large quantities. At Hemudu, a number of straight-sided to bell-shaped pits were excavated. While these have probably been truncated, their profiles suggest storage pits. In several cases these contained vast stores of acorns, and in one case foxnuts, and peach pits (which have almond-like kernels edible when roasted). From the 2004 excavations of the Zhejiang Provincial Institute of Archaeology at Tianluoshan (directed by Sun Guoping), a contemporaneous site near to Hemudu, vast quantities of nuts, including acorns (probably *Cyclobalanopsis* sp.), water chestnuts (*Trapa bispinosa*) and foxnuts (*Euryale ferox*), have been once again recovered. The authors are currently collaborating in archaeobotanical studies of this material, and it is clear that in addition to storage pits with nuts, nutshell fragments are ubiquitous across samples. Rice spikelet bases and chaff fragments are also widespread.

<<Figure 14 about here>>

<<Table 1 about here>>

Nuts potentially provide an important staple resource for hunter-gatherer groups, which may be intensifiable through storage, but is unlikely to lead to cultivation (Harris 1977). Nuts have played the role of subsistence staples across a wide range of hunter-gatherer societies, from the mongongo nuts of !Kung bushmen of southern Africa, which contributed about one-third of traditional diet (Lee 1968), to the acorn starch staples of aboriginal Californian tribes (Heizer and Elsasser 1980: 82-114). In the case of California, above ground granaries were constructed to store large autumn harvests for use through the winter and early spring. Together with substantial fishing and hunting, California hunter-gatherers reached substantial population densities in late prehistory, including some village settlements (Fagan 1995: 231-256). Archaeologically, the advent of Californian nut-use is associated with quantities of milling stones, more substantial and long-term occupations with substantial middens and burial grounds that become widespread between 6000 and 3000 BC (Wallace 1978; Fagan 1995: 219-230). In Eastern North America nuts were the staple food of Holocene hunter-gatherers, and even once cultivation and domestication of local seed crops had occurred (ca. 2500 BC), nuts continued to predominate in archaeobotanical assemblages for the next 2500 years (Johanssen 1988; Milner 2004: 86-87). It has been suggested that the cultivation of small-seeded

crops in Eastern North America may have played a role of risk-buffering and providing dietary breadth to nut-focused subsistence, and thus food production remained small-scale (Winterhalder and Goland 1997; Gardner 1997; Smith 2001). Acorns were also important alongside wild cereals and grasses in the Late Pleistocene, pre-agricultural Near East, as evident at Ohalo II (Kislev et al 1992; Weiss et al. 2004). For this region, estimates of foraging and processing efficiency suggest that acorns ought to have been preferred resources, even by comparison to wild wheat and barley if they are available in sufficient quantity within a 25km radius of sites (Barlow and Heck 2002). Elsewhere in East Asia, amongst the Jomon tradition of the Japanese archipelago, nuts, including acorns and toxic horse chestnuts, were staple resources stored, and in part detoxified, in subterranean pits dug into wetlands (Imamura 1996; Takahashi and Hosoya 2002; Kobayashi et al 2004). In some parts of Jomon Japan, such as southern Hokkaido, some groups began to cultivate local plants, such as barnyard millet, which served as a supplement to, but did not replace, wild nuts in the diet (Crawford 1983).

We believe that the substantial evidence for stored acorns and other nuts at Kuahuqiao and Hemudu argues for including the early to middle Neolithic of the Lower Yangtze amongst these comparisons. Elsewhere, sites such as Jiahu have produced quantities of acorns and water chestnuts as well (Henan Provincial Institute of Archaeology 1999; Zhao, Z., personal communication), suggesting this pattern might be more widespread in southern China than previously recognized. As demonstrated by the Jomon and in parts of prehistoric North America, substantial social complexity and artistic traditions can be supported on a nut-based foraging economy. It was, nevertheless, within such an economy that some communities, such as Hemudu, began to tend, plant and till wild plants, notably rice. It was these practices that gradually ended in agricultural dependence and morphological domestication.

Economic developments after Hemudu

Other archaeological evidence, both tools and excavated features, suggest that techniques of cultivation underwent development through time during the course of the Hemudu, Majiabang, and Songze cultural phases. As is well-known, 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 (see Figure 6). 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 spades were also found at Kuahuqiao (Zhejiang Provincial Institute 2004). However, these were not necessarily used for cultivation, as the excavators noted that the spades from Kuahuqiao were very poorly hafted by comparison to the later Hemudu material and may not have been very practical for tilling mud (Zhejiang Provincial Institute 2004: 176-177). 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, 2.4-2.8 cm diameters. This would have made for very weak hafting inadequate for working heavy muds. By contrast, Hemudu's bone spades have elaborate 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 (exapted) to managing soils in rice marshes, which would have necessitated refinements in hafting. Tillage, perhaps with replanting, probably began in the sixth millennium BC, and had perhaps begun on a small scale by Kuahuqiao. Certainly by the time of Hemudu and/or Majiabang 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 somewhat thicker grains from lower Longqiuzhuang, compared to Kuahuqiao, 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 Majiabang period, however, when the first documented evidence for field systems occurs. 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), with intensive cultivation of small plots (Figure 15). This development would prevent the cultivated wild rice from cross-pollination with free-growing populations. The creation of separate rice paddy fields could have sped up the selection for domesticated types in the cultivated populations.

<<Figure 15 about here>>

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 Longqiuzhuang 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.

In the later Songze period and Liangzhu phase, the first stone plough tips occur, indicating more intensive cultivation methods. The earliest plough tip is from a mid to late Songze period cemetery (see Administration of Cultural Heritage of Shanghai 1985), which suggests a minimum age for water buffalo domestication, as these are the only plausible energy source for pulling these early ploughs. Archaeozoological analyses at Kuahuqiao are consistent with hunting of wild buffalo (Liu et al. 2004), and 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 *Bubalus* 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 1995: 100). Such tools are, however, unknown from Kuahuqiao, Hemudu and Majiabang periods in the Lower Yangtze, suggesting that harvesting during those periods did not involve sickling. Uprooting, or 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, or harvest knives in the Lower Yangtze date from the Liangzhu period (Chang 1986: 256-2; Barnes 1995: 100). Thus an intensification of wild plant food production (pre-domestication cultivation) focused on rice can be inferred for the Kuahuqiao-Hemudu-Majiabang sequence, for a period of at least one millennium (if beginning from Hemudu) or two millennia (if, 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; Fuller 2005). 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.

Cultural and social developments

The sequence of agricultural evolution in the Lower Yangtze makes sense in terms of cultural and social developments in the region during the course of the Neolithic. While earlier sites comparable to Kuahuqiao and Hemudu, are still few and far between, from the Majiabang, Songze and Liangzhu phase considerable numbers are known. This includes not only settlement sites but numerous cemeteries, which provide a useful window into aspects of social organization and complexity (Qin 2000; 2003). From the Majiabang period through the earlier Songze, large cemeteries are known, with the largest known cemeteries having hundreds to more than 1000 burials, as at Weidun (e.g. Changzhou Museum 1974; 1984; 2001) and Sanxingcun (Sanxingcun Archaeology Team 2004). While finds in these graves include some of the earliest objects of craft production, including jade *Jue* and *Huang*, there is little evidence for major stratification within cemeteries in terms of access to wealth nor differences between cemeteries. One exception is the site of Lingjiatan, early Songze period (Anhui Provincial Institute of Archaeology 2000), which is markedly richer than any other site, and included the distinctive object types known as jade figurines, tortoise-with-plaque, dragon, eagle-bear-shaped-ornaments, and so on. While this may have been a significant centre of craft production and wealth accumulation, it did not continue in this way into subsequent periods.

By the later Songze period (ca. 3500-3300 BC), important social changes suggest developing social stratification. Cemeteries are smaller than the previous period, with grave counts numbering around 100 graves per cemetery, such as Songze (Administration of Cultural Heritage of Shanghai 1987) and Nanhebang (Zhejiang Provincial Institute of Cultural Relics and Archaeology 2005a). Within these cemeteries there is recurring evidence for internal social differentiation suggested by access to prestige objects such as jade ornaments and stone axes, and the total number of ceramic vessels deposited in graves (Qin 2003). The emergence of small paddy fields during the late Majiabang period would have provided a new means of producing a controllable form of wealth in terms of grain surpluses, and would have necessitated increased territoriality and a system of land ownership. It was the more productive and intensive agriculture made possible by full morphological domestication that would have provided for increased production of wealth

objects. Agricultural intensification, in terms of increased labour input and increased productivity per unit of land (cf. Boserup 1965; Morrison 1994), occurred during the Songze period as indicated by the first appearance of stone plough tips (Administration of Cultural Heritage of Shanghai 1985), implying the emergence of animal (buffalo) traction. As argued in the context of the Near East and Europe (Sherratt 1981; 1999) this 'secondary product revolution' would have enhanced the production of wealth differentials and changes in social organization relating to status difference between families and probably between genders. The increasing size of plough heads through the course of the subsequent Liangzhu period suggests a further trend towards more intensive and probably more productive rice agriculture.

Social differentiation became increasingly marked during the course of the Liangzhu period (from 3300 BC), with increasing regional population density and craft specialization, especially evident in the production of prestige jade objects (Qin 2003). Cemeteries in this period became significantly smaller and more exclusive. Groups of graves generally number between 20 and 40. The cemeteries occur in two types, those dug into specially prepared clay platforms (e.g. Luodun site, see Suzhou Museum 1999) and those dug adjacent to houses (e.g. Puanqiao site, see Archaeology Department of Peking University et al. 1998). By the mid Liangzhu period (3000 BC) it is clear from burial objects that the platform cemeteries have particular access to wealth, including large numbers of jade objects produced by a very limited number of specialized production centers that were probably linked to distinct, and controlled, geological jade sources (e.g. Fanshan Site, see Zhejiang Province Institute of Archaeology 2005b; Qin 2003). The richest platform cemeteries are clearly located at the key regional centers, such as Liangzhu itself (Zhejiang Province Institute of Archaeology 2005c). By this period sites were widely distributed across the landscape, and with quite small habitation structures located on low anthropogenic mounds. This pattern suggests a high density of farmers practising rice plough agriculture.

A wider context of rice production and domestication in Neolithic China

The revised model for the development of agriculture in Lower Yangtze needs to be understood in a wider comparative context of Neolithic economies in China. Figure 16 provides a synthetic chronological framework for various regional Neolithic traditions in China on which we have charted our revised model for the evolution of plant cultivation and domestication in the Lower Yangtze and suggested equivalent hypotheses for other regions. For virtually all of these regions, published archaeobotanical data is not yet adequate to unambiguously chart these developments. Nevertheless a coherent framework emerges, in which agriculture based on domesticated rice is much later than generally assumed. This succeeds long-lasting traditions of wild plant food production (of 1-2,000 years) and presumably an even longer period of wild rice collecting by early Holocene (and late Pleistocene) hunter-gatherers. Sites with wild plant food production tend to have abundant evidence for gathered plant foods, most notably nuts and acorns. Elsewhere in China, in the Yellow River basin and further north, millet cultivation, and harvesting with sickles, was already well established.

<<Figure 16 about here>>

These broad chronological patterns may correlate with important aspects of environmental change. A

number of recent palaeoenvironmental studies from Lower Yangtze region provide well-dated information 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, suggesting that these indeed reflect primarily regional climate change. After 15,000 BP, East Asia warmed, reflected in chemical analyses of South China sea sediments (Wang et al. 1999) and in pollen diagrams from the broader region, such as Japan (Yasuda 2002; Yasuda and Negendank 2003), which indicate the decline (or northward retreat) of coniferous taxa and the increase of broad-leaved taxa, including oaks (*Quercus/ Cyclobalanopsis /Lithocarpus*) and chestnuts (*Castanopsis/ Castanea*). Under such circumstance we would expect wild rice species to have migrated into the Yangtze basin for the first time (and perhaps further north). This is probably reflected in the first occurrence of rice bulliforms at 14,000-13,000 BP in a core in the palaeo-estuary of the Yangtze (Lu et al 2003), although identification of these phytoliths with domesticated rice is doubtful. After this period, the earliest reports of archaeological rice grains and phytoliths occur in cave sites south of the middle Yangtze region, e.g. Yuchanyan, Xianrendong, Diaotunghuan (Zhao 1998; Zhang 2002; Yuan 2002; Yasuda 2002), which we would interpret as hunter-gatherers beginning to add this newly available species-group to their foraging strategy. This favourable climate was interrupted by the Younger Dryas which is clear in most palaeoenvironmental datasets.

In the Early Holocene a climatic optimum favoured once again the spread of sub-tropical/ warm-temperate broad-leaved trees, including nut-bearing oaks and chestnuts, as well as wild rice. Rice phytoliths reappear in the offshore core from ca. 9000 BP (Lu et al. 2003). In the Lower Yangtze region much of today's low-lying land area had not yet formed, which occurred subsequently due to the combination of alluvial sedimentation and sea-level fall. Kuahuqiao lies in slightly higher topographic position than Hemudu or Majiabang which is likely to reflect colonization in the later periods of emerging low-lying land. These areas are likely to have had many favourable habitats for wild rice. An important habitat change, reflected in pollen diagrams, is a marked decline in nut-bearing trees shortly before 5000 BC, including *Quercus*, *Cyclobalanopsis* and in some cores *Castanonopsis* (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. Nut-using foragers of the region may have responded by relying increasingly on available wild rice and they therefore 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 the strategies of the Kuahuqiao-Hemudu nut-foragers.

Conclusion

The reappraisal of the archaeobotany and archaeology of the Lower Yangtze in this paper should provide a new framework for problem-oriented research. We have proposed some explicit and testable hypotheses about the nature of rice and rice use in the Lower Yangtze from the period of the 6000 to 2500 BC, with implications for earlier periods and other regions of China (such as the middle Yangtze). Our model of rice-use by nut-focused forager-hunter-fishers until the sixth millennium BC, followed by a long period of 1,000-2,000 years of initial pre-domestication cultivation, differs from previous descriptions of the archaeological cultures in this region. Our model fits with available archaeobotanical data and predicts what further systematic sampling should find: grains with morphometrics in the wild/immature range that become

mature and domesticated over the course of the sixth and fifth millennia BC and rice populations that shift statistically from immature and wild type shattering to predominantly mature and non-shattering. This is congruent with causal factors that incorporate regional environmental change. New samples of rice spikelet bases and rice grains provide an opportunity to assess this hypothesis, and indeed recent excavations at Tianluoshan (a Hemudu culture site), provide such an opportunity. The authors' current collaborative research on archaeobotany of Tianluoshan has been designed specifically with these problems in mind and initial results indicate not only great quantities of water-chestnuts and acorns but also rice spikelet bases. Initial results suggest that we can distinguish the presence of mature wild, immature wild and domesticated abscission scar types, and the proportions of these will indicate where along the evolutionary trajectory of domestication this site lies.

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, where are the agricultural village sites between the Pleistocene and mid-Holocene? Rice agriculture is highly productive and would be expected to promote marked population density increase in the region, but large numbers and densities of sites do not occur before the Late Majaibang, 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. One of the contributing factors to previous misconceptions has been an anachronistic emphasis on rice agriculture, with little research effort expended on understanding the role of nuts, fish and other wild resources. A contrast can be drawn with Early Holocene archaeology in Japan, where more emphasis has been laid on nut use, because rice domestication is not an issue. Indeed, as noted by Crawford (2005: 84) early ceramic producing societies are conventionally interpreted in contrasting ways in the archaeological research traditions of China and Japan, with the assumption that they represent agriculturalists in China and hunter-gatherers in Japan. The archaeobotanical evidence from the Lower Yangtze suggests that it is time to take seriously the importance of nuts and hunter-gatherer practices in the formation of early village cultures on Southern China.

Acknowledgements

The authors would like to thank our Zhejiang province colleagues, especially Sun Guoping and Zheng Yunfei, who introduced the first author to the material of the Hemudu museum and other sites under research by the provincial institute. We have also benefited from discussions from Zhao Zhijun. Our current archaeobotanical collaboration at Tianluoshan has been made possible by Sun, Zheng, Zhao and the provincial director, Cao Jin Yan. The authors' involvement in this project is supported by grants from the Sino-British Trust of the British Academy and China National Education Ministry Project Grant for the Center for the Study of Chinese Archaeology at Peking University. Research on the morphometrics of modern rice species was conducted by E. Harvey as a research student supported by an Arts and Humanities Research Board studentship.

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Taxa; Common names (English, Chinese)		Probable use ¹
<i>Lagenaria siceria</i> Eng. Bottle gourd, Ch. 葫芦 <i>Hu lu</i>	H K	Containers, fishing net floats, seeds can be processed for oily kernel
<i>Quercus</i> spp. Eng. Oaks, acorns, Ch. 橡子 <i>Xiang zi</i>	H K	Potential carbohydrate staple (storable)
<i>Choerospondias axillaris</i> Eng. "Southern Sour Jujube", Ch. 南酸枣 <i>Nan suan zao</i>	H K	Edible fruits, rich in vitamin C; also medicinal
<i>Amygdalus davidiana</i> (syn <i>Prunus davidiana</i>) ² Eng. Chinese mountain peach, Ch. 山桃 <i>shan tao</i>	H	Edible seasonal fruits, seeds can be eaten roasted (like almonds), and stored in stone
<i>Amygdalus (Prunus) persica</i> [Rosaceae], Eng. True peach, Ch. 毛桃 <i>Mao tao</i> ; probably <i>A. davidiana</i> ?	K	As above.
<i>Prunus mume</i> Eng. Mume apricot; Ch. 酸梅 <i>Suan mei</i>	K	Edible seasonal fruits, seeds can be eaten roasted (like almonds), and stored in stone
<i>Prunus armeniaca</i> Eng. Apricot, Ch. 杏 <i>Xing</i>	K	Edible seasonal fruits, seeds can be eaten roasted (like almonds), and stored in stone
<i>Euryale forox</i> Eng. Foxnut, "gorgon seeds"; Ch. 芡实 <i>qian shi</i>	H K	Seeds dried to make starchy flour (storable); stems and roots eaten as vegetable
<i>Sophora</i> sp. Eng. Sophora, Ch. 槐 <i>Huai</i>	H :	Leaves or roots used medicinally (<i>Sophora</i> spp.); pods used as a yellow dyestuff (<i>S. japonica</i>)
<i>Coix</i> sp Eng. Job's tears, 薏苡 <i>Yi yi</i>	H :	Grains edible as cereal (storable)
<i>Trapa</i> sp. Eng. Water chestnut, Ch. 菱角 <i>Ling jiao</i>	K	Edible nut
Polygonaceae, Eng. Knotweed (family) , Ch. 蓼科	K	Edible with roasting; speices in this family known to have been used in aboriginal North America and Jomon Japan (Crawford 1983; 1997)
<i>Oryza rufipogon/sativa</i> ³ [Poaceae], Eng. Rice, Ch. 稻 <i>Dao</i>	H H	Potential carbohydrate staple (storable)

Table1. Plant species identified from Hemudu and Kua-Hua-Qiao from fruit remains, and their possible uses, taken from the final reports (Zhejiang Provincial Institute of Archaeology 2003; 2004). Notes: 1. Ethnographically documented uses based on Usher 1974; Menninger 1977; 2. Not recorded in report, but included amongst unidentified fruit seeds, examined by the authors at the Hemudu museum, Nov. 2004. This species was identified in the report of the basis of leaf remains; 3. On the specific identify and domestication status of rice, see discussion in text.

List of Figures

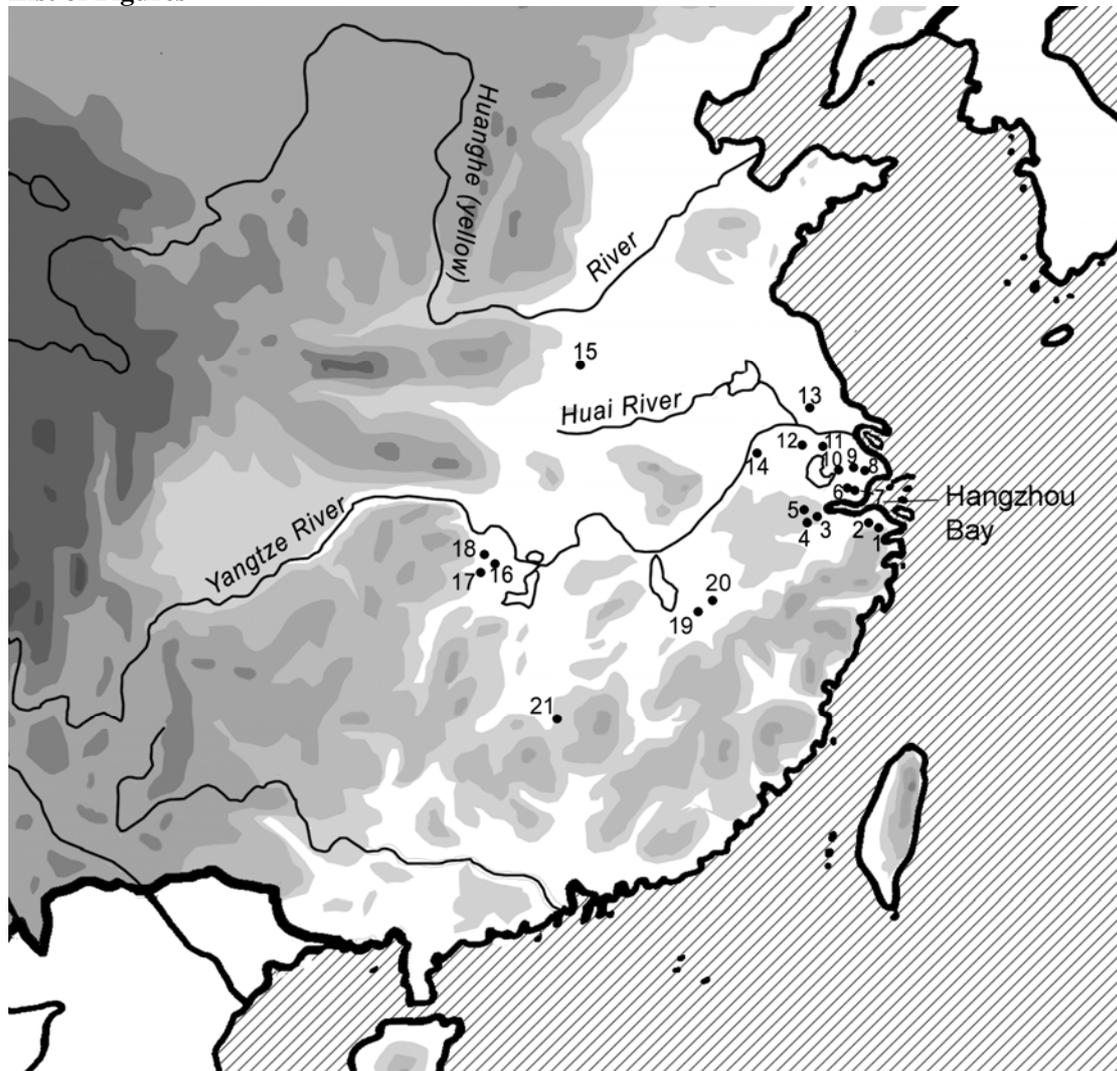


Figure 1. Map of the Middle and Lower Yangtze showing archaeological sites mentioned in text:
1. Hemudu 河姆渡 2. Tianluoshan 田螺山 3. Kuahuqiao 跨湖桥 4. Shangshan 上山
5. Liangzhu 良渚 6. Majiabang 马家浜 7. Nanhebang 南河浜 8. Maqiao 马桥 9. Songze 崧泽
10. Longnan 龙南, Caoxieshan 草鞋山, and Chuodun 绰墩 11. Weidun 圩墩 12. Sanxingcun 三星村
13. Longqiuzhuang 龙虬庄 14. Lingjiatan 凌家滩 15. Jiahu 贾湖 16. Bashidang 八十挡
17. Pengtoushan 彭头山; 18. Chengtoushan 城头山; 19. Diaotonghuan 吊桶环; 20. Xianrendong 仙人洞; 21. Yuchanyan 玉蟾岩

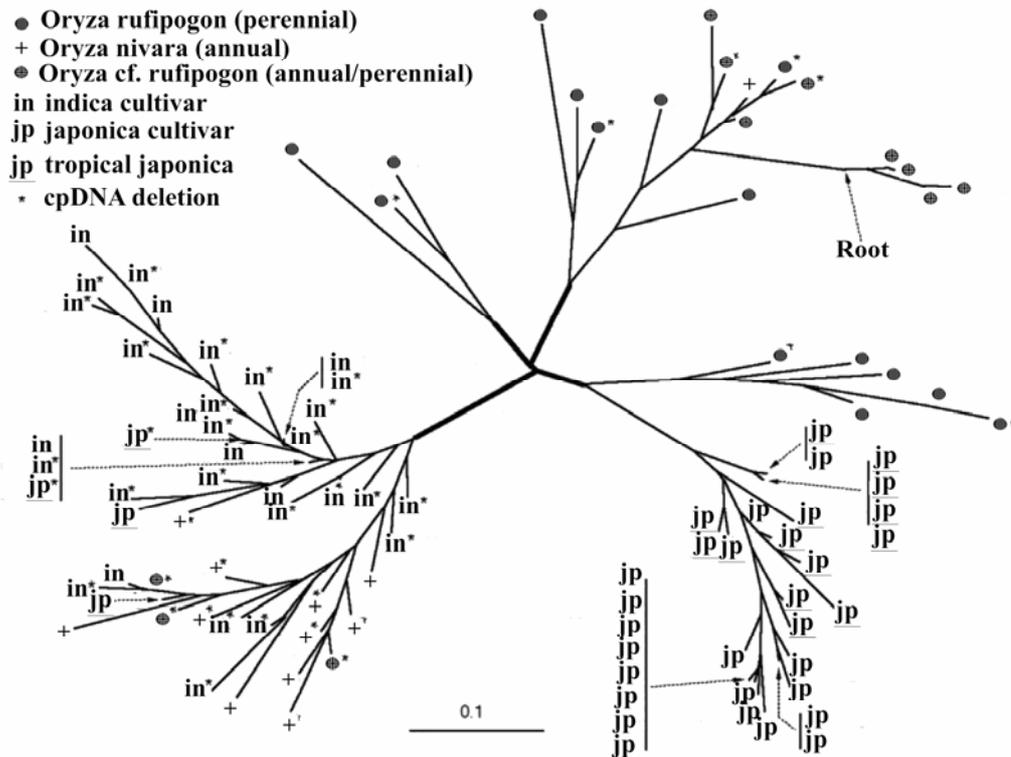


Figure 2. A phylogenetic representation of modern rice cultivars and wild populations based on SINE genetics (after Cheng et al. 2003; taxonomy revised to follow Vaughan 1994). This shows the clearly distinct lineages of *japonica* (including tropical forms, sometimes called *javanica*) and *indica* cultivars, which are interspersed with the annual wild populations (*Oryza nivara*)

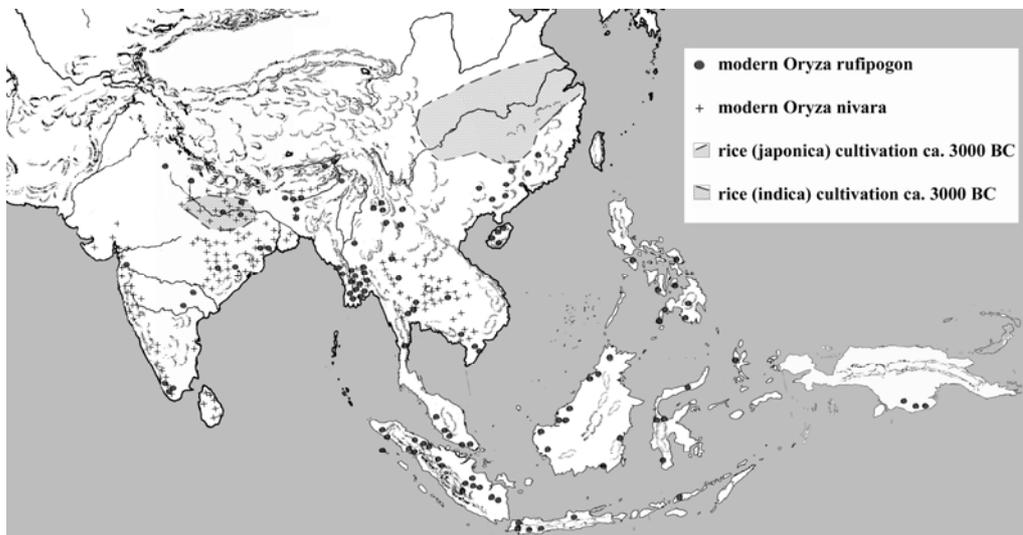


Figure 3. A map of wild rice distribution and likely zones of domestication. The distribution of the two wild progenitors of rice is plotted after Vaughan (1994). The extent of rice cultivation ca. 3000 BC is indicated based on archaeological evidence (for China, after Yan 2002; for India, based on Fuller 2002 but updated).

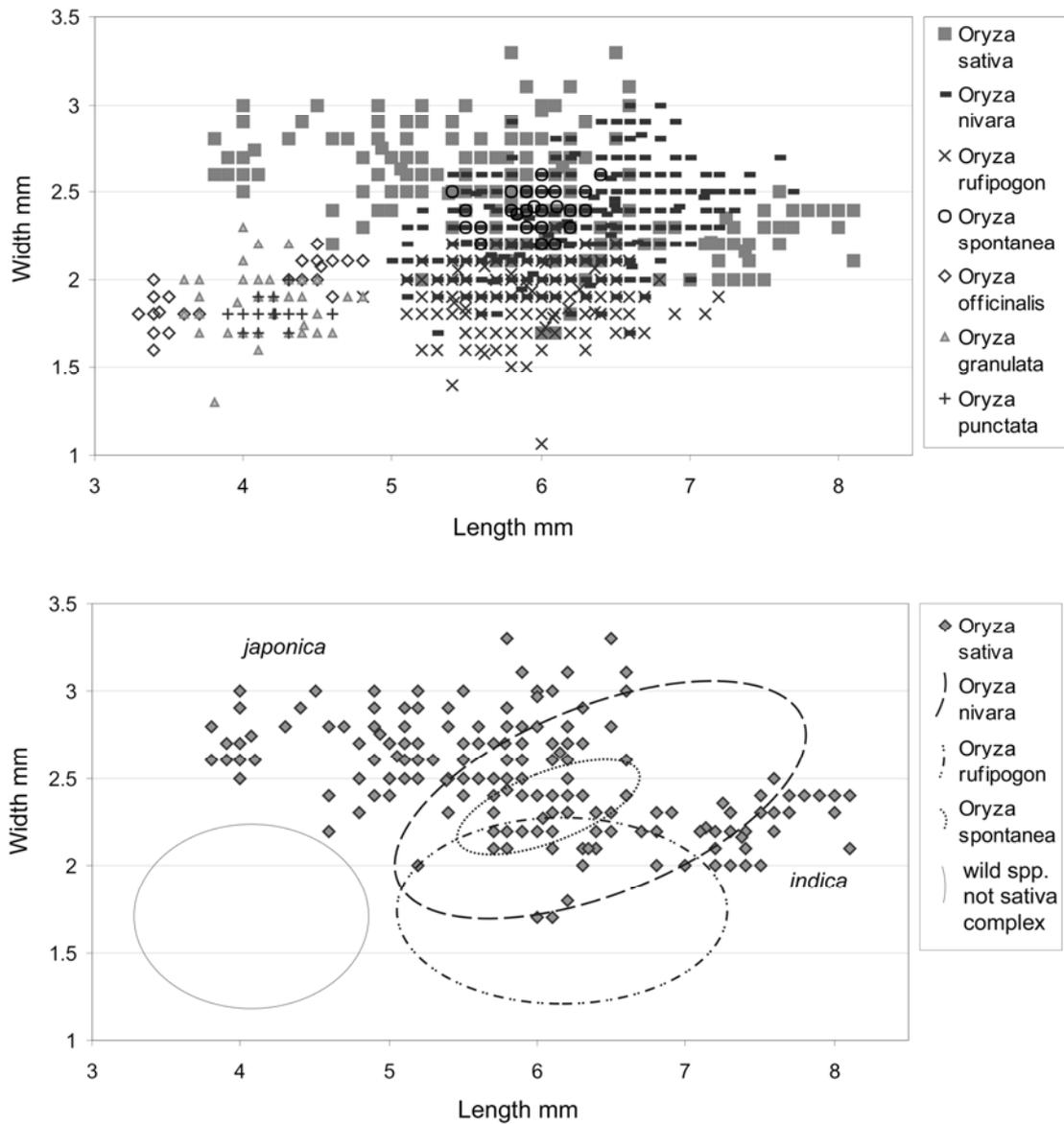
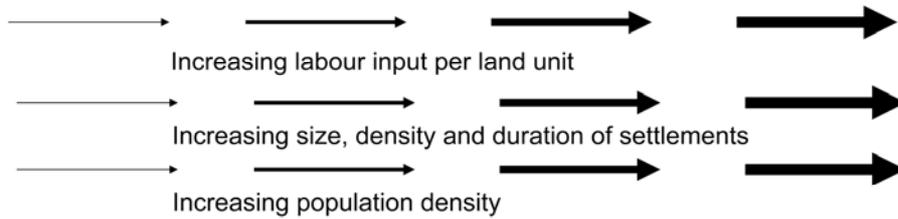


Figure 4. A scatter plot of length and width of grains measured in modern populations (measured by E. Harvey on 72 populations). The top graph shows individual grain measurements for a range of species, whereas these are replaced by ovoid distributions for wild species in the lower graph.



Figure 5. Rice husk lens *in situ* during Hemudu excavations (reproduction from Zhejiang Province Institute 2003, pl. XLI.2)



	Wild plant food procurement	Wild plant food production	Cultivation with systematic tillage	Agriculture: cultivation of domestic crops
	Gathering burning tending	Replacement planting, harvesting, storage	Land clearance, tillage	D
South-west Asia	Foragers using wheat/barley (e.g. Ohalo, Natufian)	management of dwindling Wild cereals (inferred) (Abu Hureyra)	Emergence of arable weed flora (assemblage change); evolution of larger grains (PPNA)	Occurrence of domestic type rachis (PPNB)
Lower Yangzi, China	Foragers using wild rice (and nuts) (Early Neolithic with ceramics: Shangshan, Kuahuqiao?)	Kuahuqiao(?), by Hemudu. Reduction of awn hairs implies sowing. Some tillage suggested by spades.	First small paddy fields separation of cultivars from wild rice fields (Majiabang period)	Domestication with intensification and new harvest methods Tillage with ploughs (Songze period)

Figure 6. The idealized evolutionary spectrum from pure foraging to agriculture based on domesticated crops, indicating the significant stages of wild plant food production and pre-domestication cultivation (after Harris 1996). On the rows at the base of the chart the inferred presence of these stages in the Near East is indicated and our suggested identification of these stages in the Lower Yangtze river area.

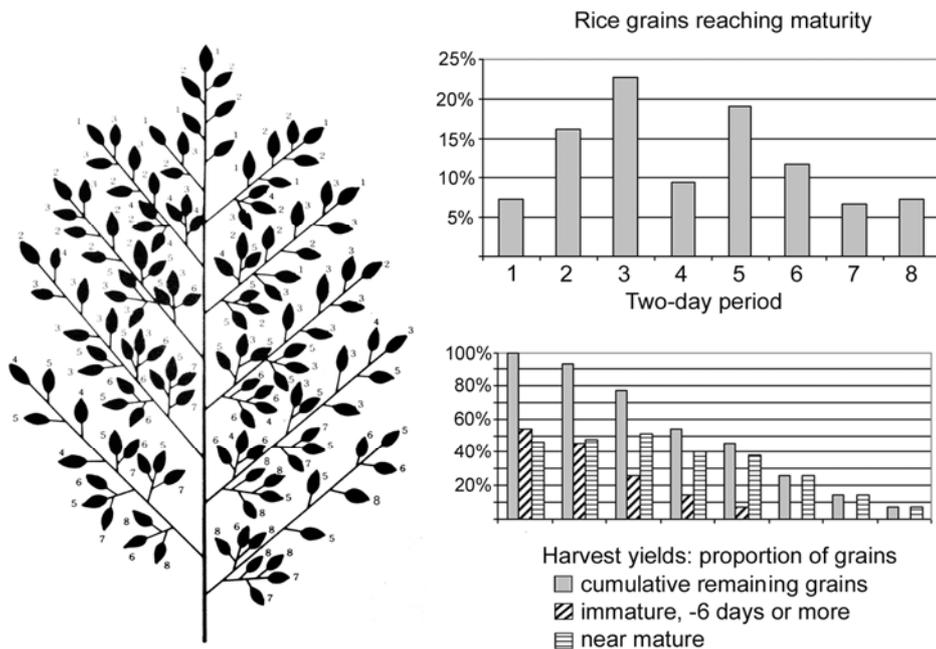


Figure 7. Rice panicle maturation and harvest yields assuming wild type grain shedding. The diagram on the right indicates the stage of pollen shed, and by extension grain initiation on an individual rice plant (after Hoshikawa 1993) The graph at the top right converts this into the percentage of grains 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).

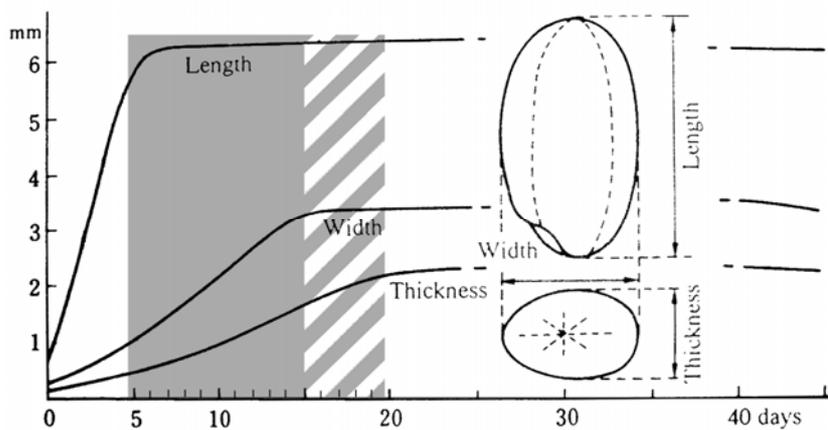


Figure 8. Chart of *japonica* rice grain metrical development in terms of length, width and thickness measures (after Hoshikawa 1993), on which is shaded the period of grain immaturity in which grain proportions differ from those of standards based on the mature grain. Shown in solid grey is an approximate 10-day window during which immature grain proportions will be biased towards length, and thus closer to *indica* or *rufipogon*, rather than *japonica*.

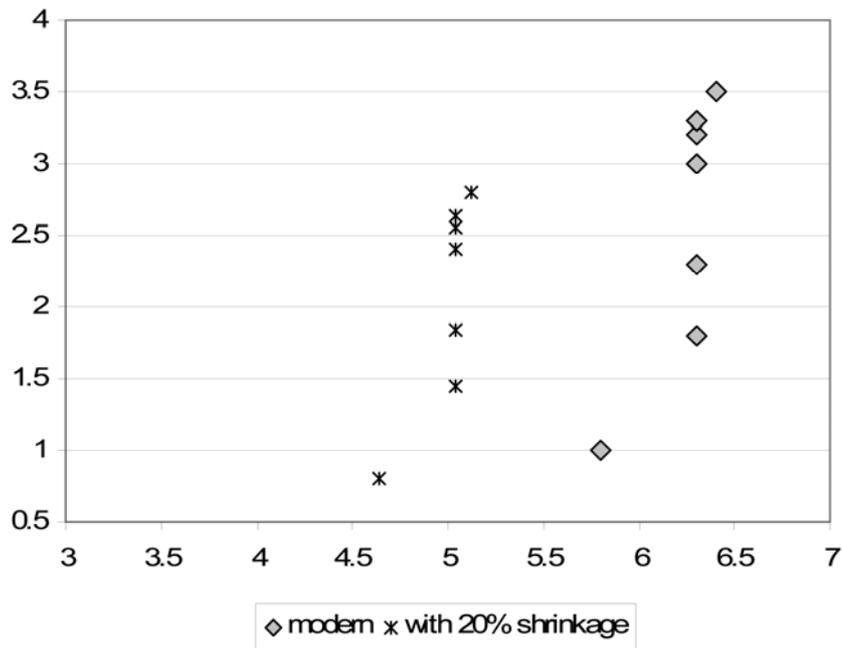


Figure 9. Graph of grain length and width over the course of development, based on Figure 7. This trajectory is also adjusted for 20% reduction to account for the likely affects of charring.

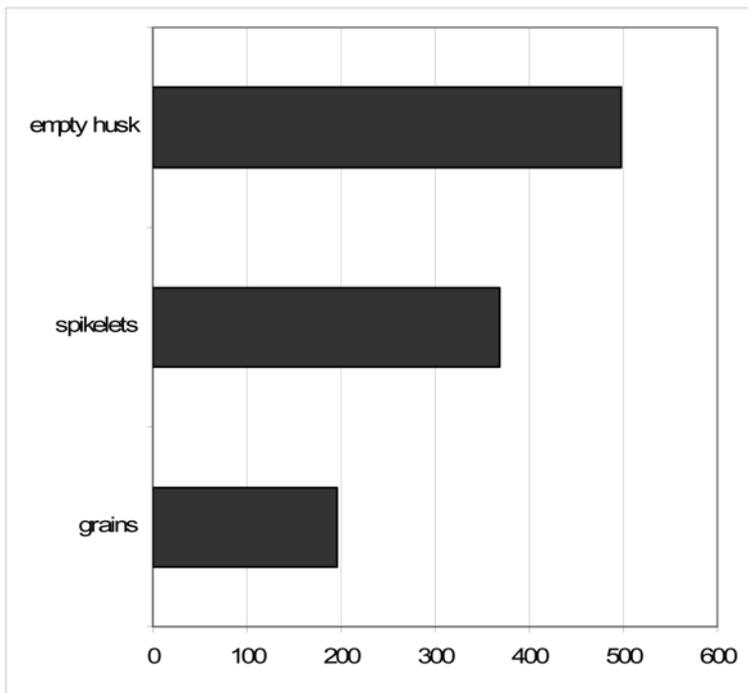


Figure 10. Counts of rice find types from Kuahuqiao (after Zheng 2004).

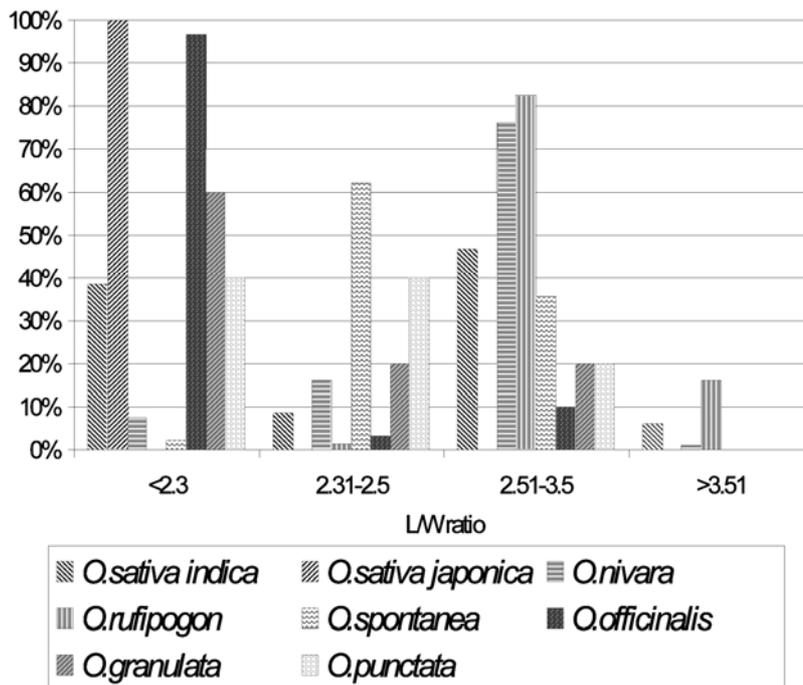
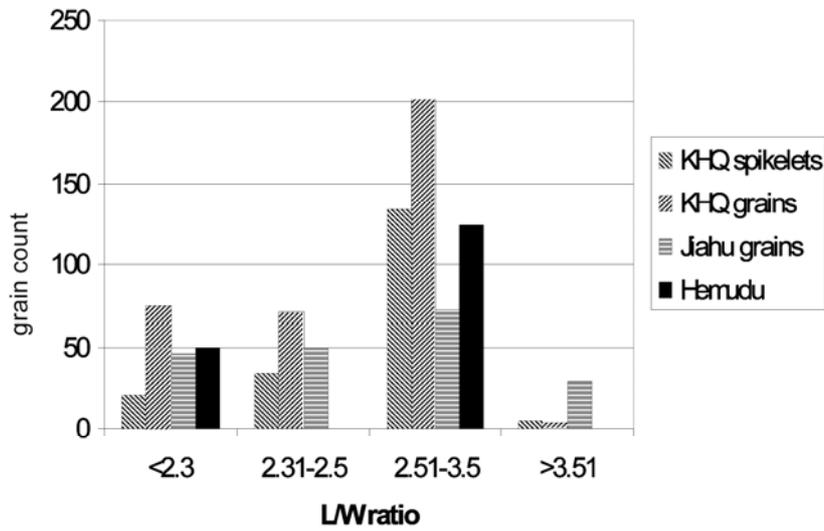


Figure 11. The proportions of rice grains and spikelets within given shape ranges based on length-to-width ratios, from selected Chinese Neolithic sites (top), and from modern measured rice populations (dataset the same of Figure 4). While such data have traditionally been used to arrive at the mix of *indica* and *japonica* grains on Neolithic sites, this clearly only have validity if the presence of any wild rice species can be ruled out, and ancient grains are assumed to be fully mature.

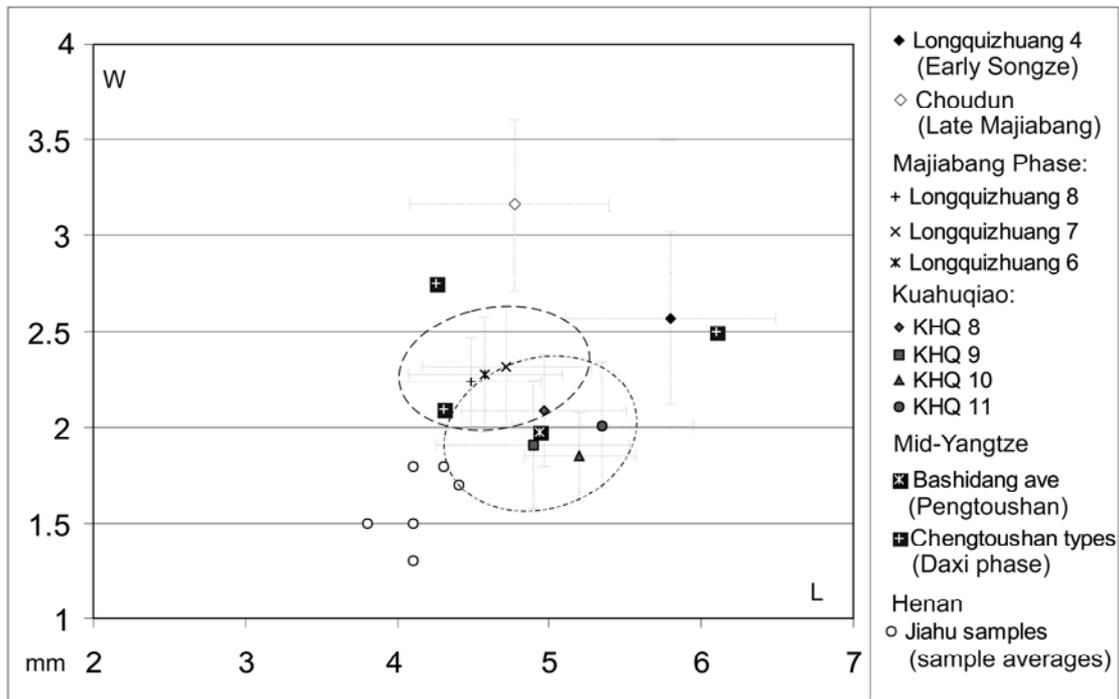


Figure 12. A scatter plot of grain measurements from selected Neolithic sites, including Kuahuqiao (after Zheng et al. 2004b), Longquizhuang (after Huang and Zhang 2000) and Choudun (Tang 2003). Cases where only spikelets (with husk) appear to have been measured, as at Hemudu, have been excluded. Notice 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 and Wang 1998). Middle Yangtze sites Bashidang also suggests wild and/or immature grains, while the later Chengtoushan suggests domestication. Jiahu measurements may be more comparable to a different wild species, such as *O. officinalis*.

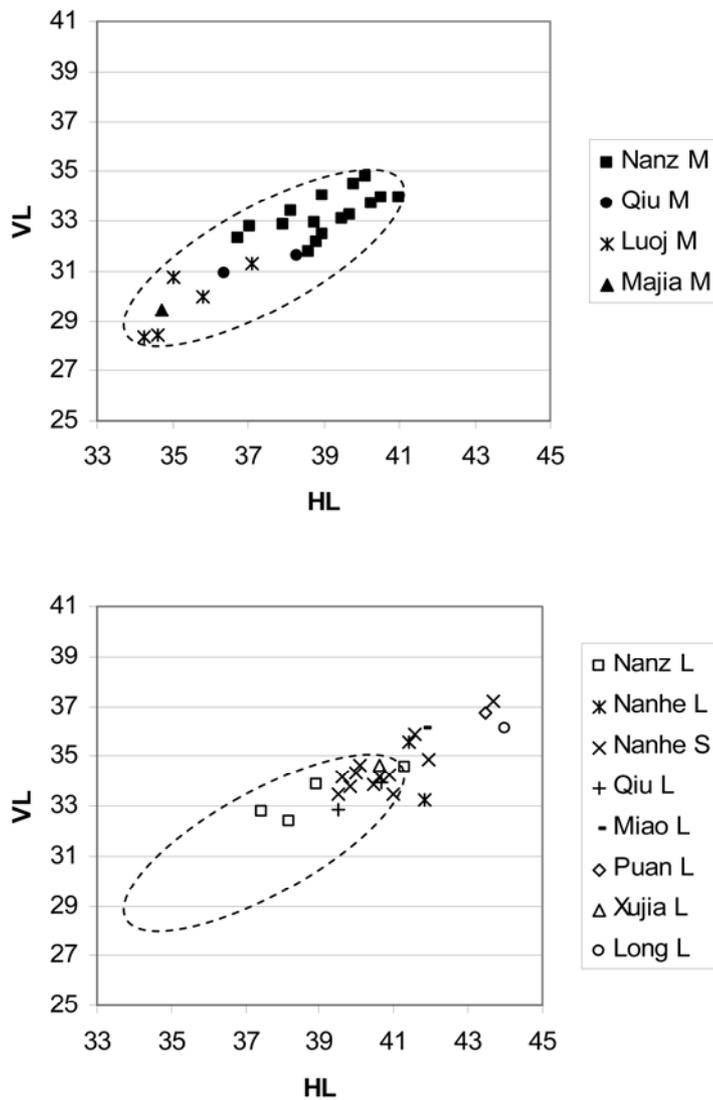


Figure 13. Size increase in Lower Yangtze rice phytoliths. The upper graph shows measured horizontal length (HL) and vertical length (VL) of rice bulliform phytoliths from Majiabang period samples (M), while the lower graph shows measurements from samples of the subsequent Songze (S) and Liangzhu (L) phases. The dashed oval represents the distribution of the Majiabang measurements. Data re-plotted, from Zheng et al. 2004a. Site names abbreviated: Nanzhuangqiao, Nanhebang, Qiucheng, Luojiyajiao, Miaoqian, Puanqiao, Xujiawan, Longnan, Majiabang.



Figure 14. A concentration of acorns at the base of pit H27 at Hemudu (from Zhejiang Provincial Institute of Archaeology 2003)

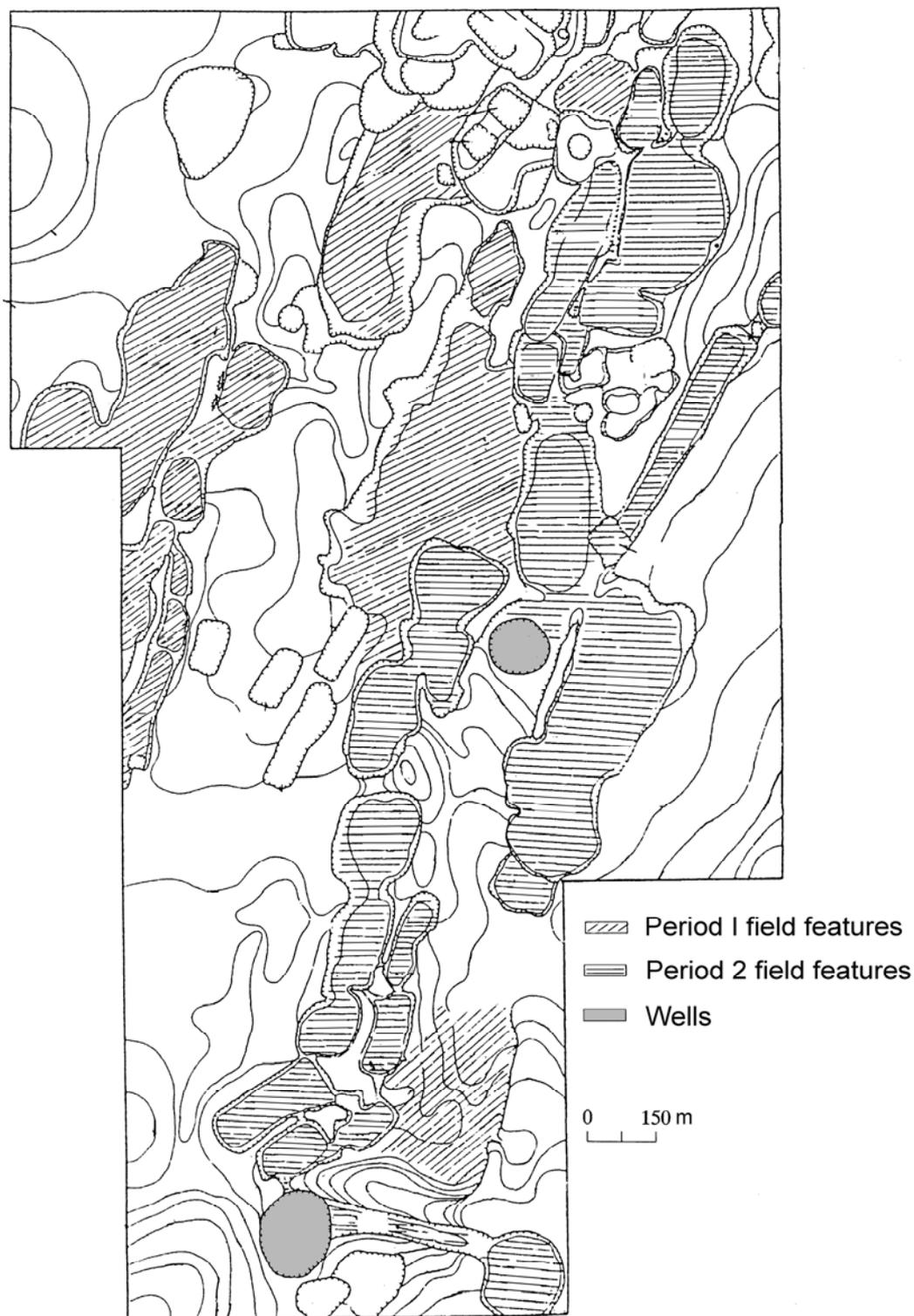


Figure 15. Plan of dug features of early paddy fields from Caioxieshan, late Majiabang period (4500-4000 BC), Jiangsu Province, China (after Zou et al. 2000).

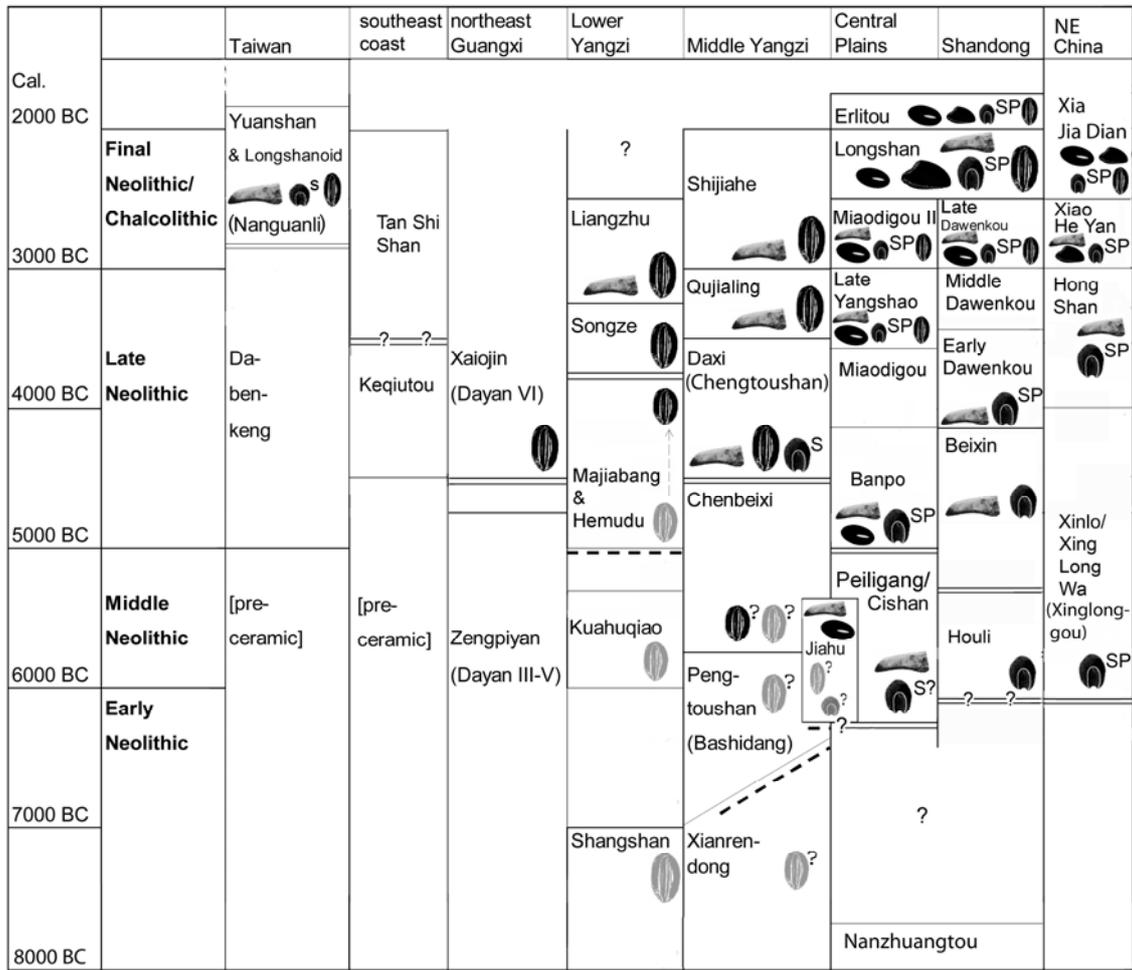


Figure 16. A synthetic chronology of Neolithic China based on evidence for major crops and the transitions to cultivation and domestication.