Early Agriculture and Holocene Environments in the Yangtze River Delta, China

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This thesis does not contain work that I have published, nor work under consideration for publication. The thesis is completely the result of my own work, and was substantially conducted during the period of candidature, unless otherwise stated in the thesis.

Pia Atahan
Abstract

Environmental changes have had major impacts on past human societies across the globe, and a better understanding of this human-environment interaction is necessary for building societies with resilience towards future environmental change, and to effectively conserve areas of natural environments into the future. Regions such as the Yangtze delta, that have a long history of rice cultivation (dating to at least ca. 7000 BP) and a high density of prehistoric sites, provide an ideal backdrop to study both long-term human-environment interactions, and the environmental impacts of agricultural societies.

This study aims to provide Holocene palaeoenvironmental reconstructions for three study sites in the Yangtze delta region, with the principle objectives of detecting human activity – particularly that associated with the development of rice agriculture – and identifying environmental changes within the palaeoenvironmental records. A parallel aim is to develop the use of quantitative biomarker and compound specific isotope analyses in Holocene palaeoenvironmental investigations, including in the detection of early agricultural environments, through analysis of sedimentary deposits.

Palaeoenvironmental records for the three study sites, Qingpu, Guangfulin and Liangzhu, cover the time period from ca. 12,000 to ca. 400 BP. Methods of sedimentary analysis used in this research are: estimation of pollen and charcoal (microscopic and macroscopic) abundance, TOC%, magnetic susceptibility, particle size distribution, biomarker quantification, bulk $\delta^{13}$C and compound-specific $\delta^{13}$C analyses. A total of 20 AMS $^{14}$C dates establish chronology for the sedimentary sections.

Based on these analyses, it appears that prior to ca. 7000 BP the climate and relative sea level were the main factors affecting the composition of vegetation in the Yangtze delta region. The landscape was composed of a mosaic of evergreen and deciduous forests, wetlands and open herbaceous areas. Greater proportions of coniferous and deciduous taxa early in the records (prior to ca. 7000 BP) indicate comparatively cooler conditions, while the increased abundance of Chenopodiaceae during that time suggests both cooler conditions and a greater marine influence in the region.
Palaeoenvironmental data obtained during this study suggest agriculture in the delta region to have gradually increased in importance from ca. 7000 – 2400 BP. The Guangfulin study site yielded the earliest evidence of agricultural activity, dating to ca. 7000 BP, principally in the form of a corresponding increase in Poaceae (*Oryza* comp.) abundance and decline of arboreal forest taxa. Subsequent periods of agricultural intensification are noted at ca. 5360 BP at Liangzhu and ca. 4700 BP at Guangfulin. Following the final period of intensification at Qingpu and Guangfulin (ca. 2400 BP), the extent of cultivated land in the delta region may have been comparable to modern times. Technological development during the early dynasties, particularly the greater availability of iron tools, is likely to have been a major factor driving the agricultural intensification detected ca. 2400 BP.

The large tracts of natural vegetation detected by this research prior to ca. 2400 BP, would have afforded a degree of resilience to the human inhabitants of the delta region. Following the contraction of natural vegetation in the delta region, societies would have gained some resilience through access to the extensive trade network of the Chinese state. Resilience acquired through these means may, in part, account for the longevity of agricultural societies in the Yangtze delta region of China.
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<td>BP</td>
<td>Radiocarbon years before present</td>
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<tr>
<td>cal. yr BP</td>
<td>Calendar years before present</td>
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<tr>
<td>μm</td>
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<td>&gt;</td>
<td>Greater than</td>
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<td>&lt;</td>
<td>Less than</td>
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<tr>
<td>m.s.l.</td>
<td>Mean sea level</td>
</tr>
<tr>
<td>a.m.s.l.</td>
<td>Above mean sea level</td>
</tr>
<tr>
<td>GC-MS</td>
<td>Gas chromatograph-mass spectrometer</td>
</tr>
<tr>
<td>CSIA</td>
<td>Compound specific isotope analysis</td>
</tr>
<tr>
<td>k</td>
<td>Volume susceptibility (dimensionless)</td>
</tr>
<tr>
<td>δ</td>
<td>Delta – used to describe isotope ratios (e.g. $^{13}$C/$^{12}$C)</td>
</tr>
<tr>
<td>micro-</td>
<td>microscopic</td>
</tr>
<tr>
<td>macro-</td>
<td>macroscopic</td>
</tr>
</tbody>
</table>
Notes on the Text

The word ‘pollen’ is used in a very general sense in this thesis, as on occasion it refers to pollen in addition to pteridophyte spores. Specifically, this is the case when ‘pollen processing’, ‘pollen diagram’ and ‘total pollen sum’ are stated.

All dates and ages presented in this thesis are uncalibrated radiocarbon dates, unless presented with the ‘cal. yr BP’ postfix or the BC/AD notation is used. When previous texts are discussed, dates will be presented here in their published form. It is acknowledged that the use of several types of date notation will reduce the ‘readability’ of the text slightly, however this has been done to maximise accuracy and avoid excessive confusion.

A weakness of this thesis relates to the author’s inability to read texts in the Chinese language. As a result, a wealth of Chinese literature has regretfully not been read by the author. The present author has drawn on English-language reviews of Chinese literature, and in those cases the Chinese work is cited as being ‘cited in’ the English language reference. As a result there are a number of citations where the author is acknowledged as being ‘cited in’ another reference.
1 Introduction

Understanding relationships and interactions between human activities and environmental change is of fundamental importance to modern societies. Convincing reasons to better understand this human-environment relationship are to both build resilience in societies and assess their vulnerability towards future environmental change (Oldfield and Dearing, 2003); and also preserve areas of natural environments into the future. The need for research in this area has never been greater, given modern society’s unprecedented awareness of, and concern for, trends in future climate change. Regions such as the Yangtze delta – with large human populations, high agricultural productivity and a long history of agricultural societies – are ideal for work exploring long-term human-environment interactions.

The Yangtze delta region is renowned for its high density of prehistoric sites. Hundreds of Neolithic settlement sites have been discovered there (Stanley and Chen, 1996) and new sites are continuously being discovered. This rich archaeological record provides an ideal backdrop to study the long-term dynamics of prehistoric agricultural societies and human-environment interactions. Agriculture in the Yangtze delta region is centred on rice (*Oryza* sp.) and the area accounts for some 70% of China’s rice production (Chapman and Wang, 2002). Rice cultivation appears to have commenced in the delta region ca. 7000 BP, following its development in the middle reaches of the Yangtze River ca. 11,000 BP (Crawford and Shen, 1998; Liu, *et al.*, 2000; Yan, 2005). Until recently, archaeological sites have been the principle source of information about early rice agriculture in the delta region and to date, the use of continuous sediment records, independent of archaeological sites, has been an under-used method in this field of research.

Agricultural societies have altered environments and landscapes on a massive scale. However, despite their major influence, the antiquity of agriculture is only beginning to be understood. Following the discovery of fire, the emergence of settled agricultural society is considered to have been the next major transforming event in human cultural development (Xu, 2005). Since its emergence, the expansion and spread of agricultural societies to previously unfarmed areas has typically been accompanied by the progressive depletion of ecological buffers, as natural environments are replaced with
fields and deserts. Nowhere is the human transformation of environments more advanced than on the low-lying plains of the Yangtze delta. There, innumerable agricultural fields are densely dissected by roads and canals, villages and cities dot the landscape and pollution colours the horizon and accumulates in waterways.

Since its emergence, agriculture has spread to almost every geographical region. Presumably a main incentive for hunter-gatherer societies to adopt agriculture was the ability to gain higher food yields per area of land and as a result, have greater population densities and food surpluses. In addition, the greater efficiency of gaining food by agriculture would have enabled parts of society to pursue non-farming activities, and this is thought to have been a key factor causing increased social complexity and stratification (You, 1999; Lu and Yan, 2005; Shao, 2005). Ultimately agriculture has enabled global human populations to expand and far exceed the numbers that can be sustained by wild plant and animal resources alone.

1.1 A global perspective on the emergence of agriculture and post-glacial climate amelioration

Research shows agriculture emerging independently in several locations on the globe at the Pleistocene/Holocene boundary (Denham, et al., 2003; Bellwood, 2005). Global climates in the Holocene are generally distinguished from those in the Pleistocene by their greater degree of stability, and this increased stability and reliability of Holocene climates is considered to have been a pivotal factor driving agricultural development in several independent centres (Bellwood, 2005).

Ice-core records, which can provide global palaeoclimatic records of unparalleled quality (Alley and Agustsdottir, 2005), are an important source of information about global climates at the Pleistocene/Holocene boundary. Ice core records from eastern Antarctica and Greenland display relative climatic stability during the Holocene compared with the variability of the Pleistocene (Figures 1.1 and 1.2). Some authors however, express reservation about the extent to which polar ice records reflect climate changes at lower latitudes, and it should be noted that work on sedimentary records from the lower latitudes tends to report a lesser degree of Holocene climatic stability (Arz, et al., 2001; Oldfield, 2004). While significant regional differences in climatic variability exist, the overall pattern appears to be one in which climates became warmer, wetter and more reliable at the commencement of the Holocene (Bellwood, 2005).
Figure 1.1: Temperature reconstructions for the Vostok ice core, eastern Antarctica, for the past 100,000 years (modified from Petit, et al., 1999). The area shaded grey represents the Holocene.

Figure 1.2: A ca. 123,000 year record of $\delta^{18}$O values as 50 year means for the GRIP Greenland ice-core (modified from Andersen, et al., 2004). The area shaded grey represents the Holocene.
While climate amelioration at the Pleistocene/Holocene boundary may have produced conditions suitable for agriculture, the specific mechanism, or mechanisms, prompting hunter-gatherers to begin to farm is as yet poorly understood. It is not known why societies in a few regions began to practice an annual cycle of cultivation, while others didn’t. It is apparent that climate change played a role, but clearly other factors were at work also. Some insight into mechanisms behind the development of rice agriculture is gained by comparing societies in the middle Yangtze with those in south China. In the middle Yangtze, rice cultivation appears to have commenced ca. 11,000 BP, when the climate was emerging from a cold/dry period and the northern boundary of wild rice’s range was located there (Yasuda, 2002). Conversely in south China, climates at this time were favourably warmer and moister, and wild rice was abundant, but despite the apparently favourable conditions, rice agriculture did not develop there (Yasuda, 2002). Comparison of these regions leads to two hypotheses for the development of rice agriculture in east China: firstly, more seasonal climates – and even episodes of climatic deterioration – may encourage people to begin to cultivate, perhaps as a means to gain more storable food for winter months (Yasuda, 2002), and secondly, while the presence of a protodomesticate plant (i.e. wild rice) is required, incipient agriculture may not occur where it is abundant (i.e. in south China), as in those areas, foraging may be a more efficient means of gaining food (Lu, 2003 cited in Lu, 2006). The domestication process would also be expected to proceed more rapidly where the protodomesticate plant is scarce, particularly if the plant is cross-fertilised rather than self-fertilised (Bellwood, 2005).

Non-climatic factors are also likely to have affected agricultural development. These factors include sedentism, population pressure, resource abundance, geographic and/or social constraints, technological innovation, storage and wealth accumulation (see Price and Gebauer, 1995; Kinzig, 2002 for more detail). In the middle Yangtze sedentism may pre-date the earliest signs of agriculture, as pottery discovered there – which is interpreted to reflect a degree of sedentism – has been found to date to the Last Glacial Maximum (ca. 18,000 BP) (Yasuda, 2002). Population pressure, however, may not have been a driving factor for the emergence of rice cultivation in the middle Yangtze, as prior to ca. 9000 BP, settlements are thought to have been predominantly cave sites, consisting of only 20-30 people, which were sparsely distributed in the region (Lu, 2006).
1.1.1 Impacts of climate change on human societies

Testing the impact of climate change on prehistoric human societies is notoriously difficult. This is largely due to the inability of such tests to exclude the effects of non-environmental factors, such as warfare, governmental or technological change, on cultural changes. Despite these limitations, inferences about climatic influences on human societies are made, and are commonly based on temporal correlations of climatic and cultural changes. Arguments derived from this method are strengthened as improvements are made to dating precision. However, the difficulty in proving causation is an often acknowledged limitation in this topic of research (deMenocal, 2001; Coombes and Barber, 2005).

When considering the immediate effects of climatic change on human societies, it should be kept in mind both that the direct effect of a single climatic shift on a prehistoric society is largely unpredictable, and that a prehistoric society’s ability to adapt or cope with changed conditions is difficult to estimate. Evidence indicates that the relationship between climate change and cultural development is commonly non-linear (Coombes and Barber, 2005), i.e. a climatic shift may not produce a cultural change of corresponding magnitude. Also, the effect on a society may not necessarily be negative; some authors have linked episodes of climatic deterioration with positive cultural developments, for example technological innovation (including agricultural development) (Yasuda, 2002; Bellwood, 2005) and increased social complexity (Brooks, 2006). A society’s response to a climatic shift is also affected by the rapidity, amplitude and duration of the shift.

The theory of resilience in natural systems stems from the work of ecologist C.S. Holling (1973), and is relevant to the relationship between climate change and past societies. Resilience is defined as ‘the amount of disturbance that an ecosystem can withstand without changing self-organised processes and structures’ (Gunderson, 2000). In theory, during early exploitative successional phases, the resilience of a natural system is high and, as a result, the system can withstand a wide range of disturbances. This phase could be likened to early agriculturalists inhabiting an area, where populations are well below capacity and areas of persistent natural vegetation provide fallback food options if crops should fail. During subsequent phases, although the system gains stability, the stability is local and narrow and a small disturbance is able to push the system out of the stable domain and lead to its collapse (Gunderson, 2000).
small change in this later, brittle, state can rapidly cascade through the system, and lead to a sudden transformation, which in the case of an established civilisation, could mean its sudden collapse.

Climatic shifts often appear in palaeoclimatic records covering the Holocene, and periods of drought in particular appear to have disrupted agricultural societies. Typical responses of societies faced with an unprecedented stress are to reduce social complexity, abandon urban centres and reorganise systems of supply and production (deMenocal, 2001). Well known examples of climatically driven cultural decline include the Lake Uruk culture of southern Mesopotamia ca. 3200 – 3000 BC (Weiss and Bradley, 2001), the Mayan civilisation ca. AD 750 – 950 (Hodell, et al., 1995; Leydon, et al., 1998; Haug, et al., 2003), and the Norse Greenland civilisation ca. AD 1350 – 1400 (McGovern, 1994; Barlow, et al., 1997). Reviews of climatically driven cultural collapses have been provided by several authors, including Diamond (2005), deMenocal (2001) and Weiss and Bradley (2001).

1.1.2 Global centres of agricultural development

Agriculture has emerged independently in several centres, and each of these centres is associated with differing suites of domesticated plants and agricultural technologies. Current evidence indicates that agriculture developed independently in the following regions: east Asia (spanning the Yangtze and Yellow River basins), south-west Asia (spanning the Jordan Valley, Syria, Turkey, northern Iraq and western Iran), highland New Guinea, three centres in the Americas, and sub-Saharan Africa (see Figure 1.3) (Denham, et al., 2003; Diamond and Bellwood, 2003; Bellwood, 2005). A brief overview of the main characteristics of early agriculture in each of these regions is provided in the following paragraphs.
1.1.2.1 East Asia

Agriculture is thought to have emerged independently in two regions in east Asia, and multi-hectare agricultural villages were present there by at least ca. 9000 BP (Bellwood, 2005; Yan, 2005). Early agriculture in the northern region, located on the fertile alluvial terraces and wind-blown loess of the Yellow River valley, was centred on millet (both foxtail (Setaria italica) and broomcorn (Panicum miliaceum)). Subsequent crops were: soybeans (Glycine max), sorghum (Sorghum sp.), wheat (Triticum sp.), barley (Hordeum vulgare), hemp (Cannabis sp.), melons (Cucurbitaceae), vegetables and fruit. To the south, on the floodplains and lake margins of the Yangtze River valley, agriculture centred on rice (Oryza sativa), and later additions were: yams (Dioscorea), beans (Leguminosae), melons, mulberry (Morus sp.), fruit and vegetables (Bellwood, 2005; Crawford, et al., 2005; Yan, 2005).

1.1.2.2 Southwest Asia

Early agriculture in southwest Asia was centred on emmer wheat (Triticum dicoccon), einkorn wheat (T. monococcum), and barley, which were present by ca. 10,000 BP (Nesbitt and Samuel, 1998), and also rye (Secale cereale), which may have been cultivated as early as ca. 13,000 BP (Pringle, 1998). Legumes and flax (Linum usitatissimum) were also important early crops (Bellwood, 2005).
1.1.2.3 New Guinea

In highland New Guinea, early agriculture was centred on taro \((Colocasia esculenta)\), banana \((Musa spp.)\) and yam \((D. alata)\) and appears to have been independently developed there by ca. 7000 BP (Lebot, 1999; Denham, \textit{et al.}, 2003).

1.1.2.4 The Americas

Numerous crops originate in the Americas, and evidence indicates early agriculture to have been present in at least three independent centres: the

Ecuadorian/Peruvian/Argentinean Andes, Mesoamerica/northern South America and eastern North America. While agriculture is believed to have emerged independently in these centres, recent work by Dillehay \textit{et al.} (2007) highlights the early spread of cultivars in the Andes where several cultivars in multiple locations were detected as early as ca. 12,000 – 9000 BP. In the Andes area, early crops include: potato \((Solanum tuberosum)\) (dating to ca. 7000 BP), quinoa \((Chenopodium quinoa)\) (ca. 7500 BP), manioc \((Manihot esculenta)\) (ca. 8000 BP), chili peppers \((Capsicum annum)\) (ca. 6000 BP) and peanut \((Arachis sp.)\) (ca. 8000 BP) (Hawkes, 1991; Smith, 1995; Dillehay, \textit{et al.}, 2007). In the tropical forests of Mesoamerica and northern South America: arrowroot \((Maranta arundinaceae)\) (ca. 8000 BP), yam \((D. trifida)\) (ca. 6000 BP), cotton \((Gossypium sp.)\) (ca. 5000 BP), sweet potato \((Ipomoea batatas)\) (ca. 4500 BP), squash \((Cucurbita sp.)\) (ca. 10,000 BP), maize \((Zea mays)\) (ca. 6000 BP) and beans are important early crops (Smith, 1997; Piperno, \textit{et al.}, 2000; Piperno and Flannery, 2001; Bellwood, 2005). In eastern North America, on the river flood plains separating the Appalachian and the Prairie areas, early crops are: sunflower \((Helianthus annuus)\) (ca. 4800 BP), chenopod \((Chenopodium berlandieri)\) (ca. 4000 BP) and marshelder \((Iva annua)\) (ca. 4400 BP) (Smith, 1989; Crites, 1993).

1.1.2.5 Africa

Knowledge of early agriculture in Africa is hampered by a lack of archaeological sites and uncertainty about the extent of influence from southwest Asia (Bellwood, 2005). However, crops likely to have originated in northern sub-Saharan Africa (from ca. 5° - 15° N) are: African rice \((O. glaberrima)\) (dating to ca. 2000 BP), pearl millet.
(Pennisetum glaucum) (ca. 3000 BP) and sorghum (Sorghum sp.) (ca. 2000 BP)
(D’Andrea, et al., 2001; Marshall and Hildebrand, 2002).

1.2 Research aims

The parallel aims of this study are to test the hypothesis that the development of
agricultural societies in the Yangtze delta region has been influenced by environmental
changes, and assess the timing and nature of human-driven environmental alterations in
this region. In order to do this, the following objectives have been addressed:

- Reconstruct Holocene palaeoenvironments from trench or core records at three
  study sites in the Yangtze delta region;
- Establish chronology using AMS $^{14}$C dating of selected remains;
- Develop the use of quantitative biomarker and compound specific isotope
  analyses in Holocene palaeoenvironmental investigations, particularly in the
detection of early agricultural environments;
- Link the found palaeoenvironmental reconstructions to existing data and
evaluate evidence for early agriculture and human cultural developments in the
Yangtze delta region.

1.3 Thesis outline

This thesis is divided into 9 chapters. Following this introductory chapter (Chapter 1),
Chapter 2 discusses literature on past cultures in the lower Yangtze River valley, and
specifically, the Yangtze delta region. Chapter 3 discusses the nature of the delta
environment and provides a geological, botanical and climatic context to the study.
Chapter 4 discusses issues relating to study site selection and interpretation of
palaeoenvironmental data. Chapters 5-8 present the palaeoenvironmental investigations
for the three study sites: 5 and 6 deal with the Qingpu study site; 7 deals with both the
pilot trench and main trench at the Guangfulin study site; and 9 deals with the Liangzhu
study site. Chapter 9 reviews the main findings, places them within the context of
existing literature and provides conclusions on the research topic. The appendices
contain photomicrographs of selected pollen types, GC-MS traces and raw data for the
pollen, charcoal, magnetic susceptibility and TOC% analyses. The bulk of material in
Chapters 5-8 has been included in papers published or submitted for publication in peer-
reviewed international journals. Where work of a co-author is discussed in this thesis, the relevant paper is cited. Some text repetition between the papers and the chapters of this thesis has been unavoidable; the author has attempted to keep this repetition minimal.

Papers arising from the present research are:


2 The emergence and development of rice agriculture in the middle and lower Yangtze River valley: A literature review

Theory on the origin of rice agriculture in Asia has changed in recent decades. In the 1940’s, India was considered to be the likely origin of domesticated rice, as a large number of wild and domesticated rice varieties are present there (Ho, 1975). Later however, attention turned towards the Yangtze River valley, when considerably older rice remains were discovered there.

The earliest archaeological evidence of rice cultivation comes from the middle reaches of the Yangtze River and dates to ca. 11,000 BP. Archaeological evidence shows rice agriculture to have spread to several sites in eastern China by ca. 9000 BP (Crawford and Shen, 1998; Bellwood, 2005; Yan, 2005). Investigation of the emergence and intensification of agriculture in China is somewhat hampered by a paucity of studies relating to climate and faunal and floral resources between the crucial period of 13,000 – 9000 BP (Lu, et al., 2006). As a result, little is known about the spread of rice agriculture from the middle reaches of the Yangtze River to other parts of China and Asia. Current evidence indicates rice agriculture to have spread to the Yangtze delta region by at least ca. 7000 BP (Stanley and Chen, 1996). By ca. 4000 BP rice agriculture was present in South China (Mingram, et al., 2004), and in Vietnam it was present by ca. 3340 BP (Li, et al., 2006b).

Past change in the geographic range of domesticated rice and its progenitors is relevant to investigations on the emergence and spread of rice agriculture in east China. The closest wild relatives of domesticated rice (Oryza sativa) are O. rufipogon and O. nivara. These wild species are closely related but ecologically distinct: O. rufipogon is a perennial, cross-fertilised plant which inhabits deep-water swamp environments, while O. nivara is an annual, self-fertilised plant which inhabits seasonally dry habitats (Li, et al., 2006a). O. rufipogon is the more common form of wild rice in east China, and its distribution ranges from between 100°47’E and 121°15’E and between 18°9’N and 28°14’N, which includes northern Jiangxi and Hunan provinces (Cooperative Team, 1984 cited in Crawford and Shen, 1998). There are reports of small stands of O. rufipogon being currently present in the Yangtze valley (National Survey Team of Wild
Rice, 1984 cited in Higham and Lu, 1998). During the warmer and wetter period of the mid-Holocene, the range of *O. rufipogon* extended northwards to include areas north of the Yangtze River (Tang et al., 1993 cited in Crawford and Shen, 1998). This northwards expansion of the range of rice is supported by evidence from archaeological sites which indicate that during the Longshan culture (ca. 5000 – 4000 BP) rice agriculture was relied upon further north than currently, and was an important crop in at least one site in Shandong province (Crawford, et al., 2005).

The relationship between the *O. sativa*, *O. rufipogon* and *O. nivara* has not yet been reliably resolved (see Park, et al., 2003; Zhu and Ge, 2005; Li, et al., 2006a), and genetic evidence indicates that the two Asian domesticated varieties (spp. *japonica* and spp. *indica*) derive from separate domestication events (Zhu and Ge, 2005). Current evidence favours an *O. nivara* origin for spp. *indica* and an *O. rufipogon* origin for spp. *japonica* (Li, et al., 2006a; Fuller, et al., in press-a). Based on the early appearance of spp. *japonica* rice in the middle Yangtze, researchers have suggested that it originates there (Yan, 2005), while spp. *indica* rice is suggested to have been domesticated in southern Asia (Second, 1984). Historical documents in China do not refer to the *indica* race until around AD 1000 (Ho, 1977).

### 2.1 Early rice agriculture in the middle reaches of the Yangtze River

### 2.1.1 Yuchanyan, Xianrendong and Diaotonghuan sites

Currently the earliest evidence of rice exploitation comes from three cave sites: Xianrendong and Diaotonghuan in Jiangxi Province, and Yuchanyan in Hunan Province (Figure 2.1). Phytolith evidence from Xianrendong and Diaotonghuan sites indicate inhabitants were collecting wild rice ca. 12,000 – 11,000 yr BP (Higham and Lu, 1998; Zhao, 1998; Yasuda and Negendank, 2003; Bellwood, 2005; Yan, 2005). Following this, rice phytoliths are absent in the record, and this disappearance corresponds with a colder phase (possibly associated with the Younger Dryas) (Zhao, 1998; Bellwood, 2005). Rice phytoliths reappear in the Xianrendong and Diaotonghuan records ca. 10,000 BP, and include a possible domesticated variety. This appearance of both wild and possibly domesticated phytoliths has been interpreted to reflect the collection of wild rice alongside cultivation of a domesticated variety (Zhao, 1998; Bellwood, 2005; Lu, 2006).
Chapter 2: The emergence of rice agriculture in the middle and lower Yangtze River valley: a literature review

Figure 2.1: Locations where early evidence of rice exploitation has been discovered. Archaeological sites in the Yangtze and Huai River valleys: (1) Yuchanyan site; (2) Bashidang and Pentoushan sites; (3) Jiahu site; (4) Xianrendong and Diatonghuan sites; (5) Liangzhu site; (6) Hemudu and Shangshan sites; and (7) the marine core DG9603.

Yuchanyan is a cave site in Dao County, Hunan Province (Figure 2.1). Rice phytoliths and husks, dating to ca. 15,000 – 12,000 BP, have been unearthed at Yuchanyan, and these phytoliths have been suggested to represent a species in an early stage of domestication (Yuan, 2002). However, the identification of these rice remains as an early domesticated strain has been questioned recently (Fuller, et al., in press-b), and caution has also been expressed concerning the age of the rice remains, as age estimates are based on the archaeological context, not the remains themselves (Lu, 2006). In addition to rice, a large quantity of plant and animal remains have been unearthed at this site, suggesting that the inhabitants were subsisting on a range of wild foods (Yuan, 2002). Overall however, remains from Yuchanyan site, in addition to those from Xianrendong and Diatonghuan sites, suggest rice is likely to have been exploited in the middle Yangtze by ca. 12,000 – 11,000 BP (Zhao, 1998).

Evidence from a marine core provided by Lu et al. (2002) supports the findings from Xianrendong, Diatonghuan and Yuchanyan sites of early rice exploitation. The marine core (core DG9603) is located in the palaeo-estuary of the Yangtze River (Figure 2.1) and predominantly records vegetation changes in the middle and lower Yangtze valley.
The earliest appearance of rice phytoliths in the core dates to ca. 13,900 cal. yr BP, after which, from ca. 13,000 to 10,000 cal. yr BP, they are absent from the record. The authors conclude these rice phytoliths to be a strain in an early stage of domestication, and suggest that they reflect rice cultivation occurring in the middle and/or lower Yangtze valley. The authors suggest that their subsequent disappearance results from a climatic shift to cooler and dryer conditions, which caused the range of rice to shift southwards away from the Yangtze valley. Others have suggested that this colder period may have been a crucial factor driving the domestication of rice, as it would have encouraged humans to intensify rice cultivation to meet food shortages (Yasuda, 2002; Bellwood, 2005). Rice phytoliths reappear in the marine record ca. 9000 BP (Lu, et al., 2002).

2.1.2 Pentoushan, Bashidang and Shangshan sites

Rice remains have been discovered at the archaeological sites of Pentoushan, Bashidang and Shangshan (Figure 2.1), where cultural remains are not older than ca. 10,000 years. Abundant *Oryza* husks and grains, in sediments and incorporated in pottery, have been unearthed at Pentoushan and Bashidang sites, where they respectively date to ca. 10,000 BP and ca. 9000 BP (Pei, 2002; Yasuda, 2002). Evidence indicates that in addition to exploiting rice, the sites’ inhabitants were also cultivating other aquatic plants, namely: water caltrop (*Trapa natans*), lotus root (*Nelumbo nucifera*) and gorgon fruit (*Euryale ferox*) (Pei, 2002).

With the recent discovery of Shangshan site in Pujiang County, Zhejiang province, the range of early rice sites was extended further eastwards, to the lower reaches of the Yangtze River valley (Jiang and Liu, 2006). Rice remains unearthed at the site date to ca. 10,000 BP, and have been suggested to represent a strain in an early stage of domestication (Jiang and Liu, 2006). However, as with the identification of rice remains at Yuchanyan site, the accuracy of this identification has been questioned by subsequent authors (Fuller, et al., in press-a). Shangshan site consists of a village settlement and includes pile-dwellings which resemble those excavated at Hemudu site ca. 150 km to the northeast of Shangshan (Jiang and Liu, 2006).
2.2 Evidence of early rice agriculture in the Huai River valley

The Huai River valley, located midway between the Yangtze and Yellow Rivers, contains important archaeological sites with evidence of early rice agriculture. Sites in the Huai valley are also important for providing information about the geographic range of early rice agriculture, as the area is located on the current boundary between the southern rice-dominated agricultural systems and the northern millet-dominated agricultural systems (Hu, et al., 2006). The earliest evidence of rice agriculture in the Huai River valley is from Jiahu site and dates to ca. 9000 BP (Figure 2.1) (Chen, et al., 1995). Analysis of stable isotopes in human bones from that site suggest the dominant cereal consumed by the inhabitants changed with climatic fluctuations, with rice dominating during periods of warmer and moister climatic conditions, and millet dominating during dryer periods (Hu, et al., 2006).

2.3 Agriculture and cultural change in the Yangtze delta region

The Yangtze delta region has one of the highest concentrations of prehistoric sites by world standards, with around 340 Neolithic cultural sites known to exist there (Stanley and Chen, 1996; Yu, et al., 2000). Permanent Neolithic settlements were established on the delta plain shortly after the delta began prograding, ca. 8000 – 7500 BP (Stanley and Chen, 1996). Since that time, three distinct Neolithic cultures have occurred in the delta region: the Majiabang culture (ca. 7500 – 5900 BP), the Songze culture (ca. 5900 – 5200 BP), and the Liangzhu culture (ca. 5200 – 4200 BP) (Chen, et al., 2005).

Flooding of the low-lying delta plain has been one of the main environmental constraints affecting prehistoric inhabitants in the region. The flood-prone nature of the delta region accounts for the typical Neolithic building style there (pile-dwelling), with living areas raised several metres above ground level. The distribution of Neolithic settlement sites also appear to have responded to changing levels of surface water on the delta plain. Prehistoric settlements are shown to have moved progressively eastwards, probably as a result of increasingly extensive water inundation in the low-lying central Taihu basin (Stanley and Chen, 1996; Stanley, et al., 1999).
2.3.1 Hemudu Archaeological Site

The discovery of the Hemudu archaeological site in 1973 dramatically changed opinion about the origin of rice agriculture, as at the time of discovery Hemudu held the earliest evidence of rice cultivation in China (Bellwood, 2005; Lapteff, 2006). Hemudu site is located near the Hangzhou estuary, on the banks of the Yao River (Figure 2.1). The site contains four cultural layers which date from ca. 5000 - 7000 cal. yr BP. The remains are particularly well preserved, and provide detailed information on numerous aspects of the inhabitants’ activities. Among the thousands of artefacts unearthed at Hemudu are agricultural tools, pottery, art works and pile-dwellings (Zhao and Wu, 1987). Wooden paddles have been discovered at Hemudu site, and the sea-faring ability of its inhabitants is highlighted by the presence of Hemudu-type archaeological sites on offshore islands in northern Zhejiang Province (Bellwood, 2005). A summary of main findings within the cultural layers is presented in Table 2.1.

<table>
<thead>
<tr>
<th>Strata and age</th>
<th>Stratigraphical description</th>
<th>Archaeological finds unearthed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural strata 1 5100 – 5600 BP</td>
<td>Sticky cinnamon-yellowish silt, 70 – 105 cm thick</td>
<td>Greyish pottery, numerous stone utensils</td>
</tr>
<tr>
<td>Cultural strata 2 5600 – 5900 BP</td>
<td>Sticky green-yellowish silt, 20 – 35 cm thick</td>
<td>Pile dwellings, well, stone utensils and reddish pottery. No elephant or rhinoceros remains</td>
</tr>
<tr>
<td>Cultural strata 3 5900 – 6600 BP</td>
<td>Loose greyish sandy soil, 60 – 110 cm thick</td>
<td>Pile dwellings. Large quantities of bone spades, wood spades, domesticated rice, domesticated animals (dog, pig, buffalo), wild animals (elephant, rhinoceros, David’s deer), greyish pottery, ivory, lacquer works.</td>
</tr>
<tr>
<td>Cultural strata 4 6600 – 7000 BP</td>
<td>Soft darkish silt, 100 – 165 cm thick</td>
<td>Large quantities of domesticated rice, bone spades, pile dwellings, black pottery, wood paddles, wild animals (Asian elephant, Java and Sumatra rhinoceros, David’s deer, Chinese alligator, sea turtle, land turtle), domesticated animals (pig, dog, buffalo).</td>
</tr>
</tbody>
</table>

The early inhabitants of Hemudu were living in an area of numerous lagoons, marshes and dense forests (Zhao and Wu, 1987). Palaeobotanical evidence from the oldest Hemudu deposits indicate that the inhabitants utilised a number of domesticated plants and animals, including rice, water caltrop (Trapa natans), lotus root (Nelumbo nucifera), gourd (Cucurbitaceae), pig, dog and buffalo (Zhao and Wu, 1987; Underhill,
1997). However, they were also utilising a wide range of wild foods including acorn (Fagaceae) and gorgon fruit (Euryale ferox) and also many types of wild animals, particularly aquatic animals (Zhao and Wu, 1987; Underhill, 1997). The inhabitants’ reliance on wild food appears to have slowly diminished with time (You, 1999).

2.3.2 Majiabang Culture (ca. 5500 – 3900 BC)

The Majiabang culture, occurring from ca. 5500 – 3900 BC, is regarded as a variation of the contemporaneous Hemudu culture (Stanley and Chen, 1996; Lapteff, 2006). Majiabang cultural sites are the least numerous of the Neolithic sites in the delta and are widely distributed across the delta plain (see Figure 2.2) (Stanley and Chen, 1996). Majiabang sites included domestic pile-dwellings, storage pits and cemeteries and are typically situated in alluvial or lake edge locations, which are suitable for rice cultivation (Higham, 1995; Stanley and Chen, 1996; Bellwood, 2005). Majiabang sites have yielded abundant remains of rice, as well as stone and bone spades, hoes, stone knives, wooden digging sticks and relic rice fields, indicating that their inhabitants were advanced rice farmers (Higham, 1995; Cao, et al., 2006). The presence of separate rice paddy fields at Majiabang sites was an important development in rice farming, as it would have reduced cross-pollination with free-growing populations and sped up selection for domesticated types in the cultivated population (Fuller, et al., in press-b). Also, separate rice fields may have encouraged experimentation with harvesting techniques; evidence indicates that during the Majiabang, larger quantities of mature grains began to be harvested (Fuller, et al., in press-b). Other common components of the Majiabang diet were fish, shellfish, water birds and wetland plants (Higham, 1995).
The archaeological site Chuo-dun-shan (Figure 2.2) has yielded a large body of information about Majiabang rice farmers. The site, first excavated in 1992-1995 then re-excavated in 2003, includes 46 rice fields ranging in size from 1.4 to 16 m². Cao et al. (2006) have studied these fields, and found them to be surrounded by ridges with outlets connected to ditches or small ponds, which are thought to have enabled control of water level for irrigation. Phytolith analysis revealed a variety of weed plant taxa to have existed within the rice fields; the authors suggest that the Majiabang farmers may have flooded the fields to restrict the spread of invading plants. The authors also found evidence of post-harvest stubble burning in these Majiabang rice fields. Burning of rice fields after harvest has the effect of fertilising the soil and allows for planting without soil turning (You, 1999). This practice, however, quickly exhausts the soil and forces farmers to leave fields fallow, resulting in farmers needing comparatively large areas of land at their disposal (You, 1999).

2.3.3 Songze Culture (ca. 3900 – 3200 BC)

The Songze culture persisted in the Yangtze delta region from ca. 3900 - 3200 yr BC (Figure 2.3) (Stanley and Chen, 1996). The Songze culture is a direct continuation of
the Majiabang culture, and the stone inventory is very similar to that of the Majiabang although Songze pottery has greater variety (Lapteff, 2006). The appearance of stone plough tips in Songze remains indicates a move towards more intensive cultivation methods (Fuller, et al., in press-b). Much evidence of the Songze culture has been gained from a Songze burial site in Qingpu district, where a large variety of pottery, tools and adornments made of stone and bone, as well as an ancient dwelling, have been unearthed (Lapteff, 2006). It is believed that occupation of this site commenced directly after permanent water bodies receded from the area.

Figure 2.3: Map showing geographic distribution of main Songze sites (triangles). Darker grey section represents area of higher elevation (modified from Chen, et al., 2005).

2.3.4 Liangzhu Culture (ca. 3200 – 2200 BC)

The Liangzhu culture is believed to be a direct continuation of the Songze culture (Stanley, et al., 1999). Liangzhu settlement sites are the most numerous of the Neolithic cultures and stretch furthest to the east on the delta plain (see Figure 2.4). The initial expansion of the Liangzhu culture coincides with lowered lake levels and retreating wetland areas in the region (Yu, et al., 2000). Liangzhu settlement sites are commonly located on elevated sandy coastal barriers (chenier ridges), suggesting that water
incursions persistently influenced Liangzhu Neolithics (Stanley and Chen, 1996). The decline of the Liangzhu culture, ca. 4200 BP, is hypothesised to be due to expanding water bodies and wetland areas (Yu, et al., 2000).

Substantial technological and social advancements occurred during the Liangzhu culture. These include improvements in farming tools, pottery and cooking utensils, the development of an early writing system, jade ritual objects, silk textiles, and also a stratified society and political structure (Stanley, et al., 1999; You, 1999; Shao, 2005). Liangzhu pottery is of two main types; black pottery made of fine black paste with a high surface lustre, and red sandy ceramics that incorporate rice husks and hand-stamped decoration (Stanley, et al., 1999). The development of the tripod cooking pot (ding) in the Liangzhu is a significant advancement. Silk ribbon and silk fabric discovered at the Liangzhu Qianshanyang site, in Jiangsu Province, is the earliest undisputed evidence of sericulture (Kuhn, 1988; Yan, 1992).

It is possible that increased efficiency in rice production allowed for this specialisation and advancement in non food-producing areas (You, 1999; Lu and Yan, 2005; Shao, 2005). With the improved hoe (sì) and spade (chu) of the Liangzhu culture, farmers were no longer dependant on ‘slash and burn’ techniques. As a result, improvements to soil structure and fertility would have occurred, and fields would have needed less lengthy fallow periods (You, 1999). Ultimately, the improved farm technologies would have increased farm efficiency, and allowed rice farms to expand in size and output.

The pottery record of Guangfulin site includes evidence of human migration into the delta region, ca. 4300 BP (Cheng, et al., 2006). A new type of pottery appears around the termination of the Liangzhu culture, and may be associated with cultures from northern China (i.e. Shandong and Henan Provinces) (Cheng, et al., 2006).
2.3.5 Maqiao culture (ca. 3900 – 3200 BP)

The Maqiao culture is not considered to be a direct continuation of the Liangzhu culture (Figure 2.5). Differences exist in the style of the dwellings, pits and pottery, indicating that the two cultures are separated by a ‘cultural interruption’ or ‘cultural discontinuity’ (CPAM, 1997; Stanley, et al., 1999). The Maqiao pottery shows some technical improvements compared with Liangzhu pottery. Overall, however, it is considered to be less complicated and have fewer refinements (CPAM, 1997; Stanley, et al., 1999). Elements of Maqiao rice agriculture have also been described as being more primitive than the preceding Liangzhu culture (CPAM, 1997).
Figure 2.5: Map showing geographic distribution of main Maqiao sites (triangles). Darker grey section represents area of higher elevation (adapted from Chen, et al., 2005).

2.3.5.1 The ca. 4200 BP cultural discontinuity

A suggested cause for the cultural discontinuity separating the Liangzhu and Maqiao cultures, ca. 4200 BP, is a period of expanded water bodies in the delta region, causing reductions in land available for habitation and cultivation (Stanley, et al., 1999; Yu, et al., 2000; Zhang, et al., 2005b). Expanded water bodies may also have influenced cultures in the Yangtze delta region at other times during the Holocene (see Figure 2.6). However another suggested cause for this cultural change is a large wave of population migration into the delta region (Song, 1988, 1990, Li, 1989 cited in Stanley, et al., 1999).
Climate changes in the Yangtze delta ca. 4200 BP appear to correspond with climate changes occurring in other parts of the northern hemisphere. Climatically-driven cultural declines have been suggested to have occurred at that time in other regions of China, as well as in Japan, Egypt, Indus and Mesopotamia (Wu and Liu, 2004; Yasuda, 1997 cited in Yasuda, et al., 2004; Liu, 2000 cited in Li, et al., 2006b; Madella and Fuller, 2006; Staubwasser and Weiss, 2006). Compelling evidence for colder conditions in China ca. 4200 BP has been gained from oxygen isotope data from the Dunde ice core, Mt Qilian (Shi et al., 1993 cited in Wu and Liu, 2004), glacier advances in Heyuan, Xinjiang Autonomous Region (Chen, 1987 cited in Wu and Liu, 2004) and the Western Kunlun mountains (Zheng, 1990 cited in Wu and Liu, 2004), and variations of
a warm-water foraminifer species in ocean drill cores from the Okinawa Trough and South China Sea (Wu and Liu, 2004).

2.3.6 Agriculture and farm economy during Dynastic times

The Xia, Shang and Zhou Dynasties, collectively termed the Three Dynasties, were three distinct cultural groups that existed prior to the unification movement of the Qin Dynasty in 221 BC. The Xia, Shang and Zhou were centred in different areas of the middle and lower reaches of the Yellow River. Their method of gaining power by forming relatively strong alliances with groups in other areas facilitated interaction, diffusion and fusion of culture over a wide territory (Lu and Yan, 2005).

Few remains have been unearthed that date to the Xia (which commenced ca. 2100 BC), and the lack of written remains in particular has resulted in speculation regarding the nature of the state, people and rulers. This contrasts markedly with Shang society, about which intricate detail has been gained from the thousands of inscriptions unearthed at Shang sites (Lu and Yan, 2005). These remains show Shang society to have been distinctly stratified, with elites retaining power principally by controlling technologies, including networks of walled settlements, sophisticated armies and copper mines (Thorp, 2006).

The Yangtze River region was outside stronghold areas of the Three Dynasties. The region did, however, play an important role as a source of copper. High concentrations of copper are present in the middle reaches of the Yangtze River (Thor p, 2006). Although great advancements in Bronze metallurgy were made during the Three Dynasties, bronze had little impact on farm economies of the time. Records show farm tools continuing to be predominantly composed of stone, wood and bone, and bronze being primarily reserved for symbols of status and rank (e.g. ritual vessels, musical instruments and battle axes) (Lu, 2005).

The Qin Dynasty contrasts with the Three Dynasties period by having a unifying influence across Eastern China (Thor p, 2006; Lu and Yan, 2005). It was during the Qin that standardised systems were introduced across the state, for example systems of weights, measurements, road widths and writing (Chang, 2003).
The eighth to thirteenth centuries marked a period of cultural transformation in the Yangtze delta region, characterised by the southward migration of people from north China who were hoping to profit from expanding, and highly profitable, rice cultivation and salt production there (Yoshinobu, 1998). Massive land reclamation works in the Yangtze delta region were carried out, particularly in areas surrounding Taihu lake, principally by constructing canals which had the multiple purposes of water drainage, irrigation and transport (Yoshinobu, 1998). By the eleventh century, stone walls lined much of the southern and western banks of Taihu lake, and 36 floodgates were present there (Yoshinobu, 1998).

During the Ming Dynasty, the lower Yangtze valley became a central hub of the empire-wide economy (Yoshinobu, 1998). Labour was markedly divided between rural and urban areas, and new agricultural crops were increasing in importance. Cotton was one such crop, arriving in the area in the late thirteenth century (Huang, 1990). Initially, cotton was grown in elevated areas in the east of the delta plain where rice cultivation was difficult, but later spread westwards to the Taihu basin (Huang, 1990). Increasing cotton production spurred a boom in spinning and weaving industries, and by the seventeenth century large quantities of cloth were being exported to north China and inland to towns along the Yangtze River (Huang, 1990). Large expansions in silk production occurred during the Ming and Qing Dynasties. This industry was markedly divided between rural areas, where mulberry cultivation, silkworm raising and silk reeling occurred, and urban areas where specialists wove the silk (Huang, 1990). As a consequence of the rise of cotton and mulberry cultivation, production and export of rice fell (Huang, 1990).

Imperial China is set apart from other early civilizations by having a high degree of connectivity between its regions, enabled by the extensive canal and river system centred around the Yangtze and Yellow rivers, and the Grand Canal (McNeill, 1998). Prior to the overseas European empires, the geographical reach of the Chinese state, during the Qing Dynasty at least, was probably surpassed only by the Mongol Empire. This reach provided the Chinese state with both access to, and control of, a wide diversity of ecological zones and natural resources, and also a degree of resilience and insurance against hard times, which perhaps in part accounts for the longevity of the Chinese state (McNeill, 1998).
By late imperial times the Yangtze delta was densely populated, even by Chinese standards. On the eve of the Revolution (AD 1911) densities are estimated to have been 2.1 mu (0.35 acres) per farm person, compared with 4.21 mu (0.69 acres) in Hebei Province and 3.7 mu (0.61 acres) in Shandong Province in the 1930s (Huang, 1990).
3 The Geographical setting of the Yangtze delta region

3.1 Introduction

The fertile alluvial soils and reliable water supply that characterise delta environments result in many of the world’s deltas being intensively farmed and densely populated. The Yangtze delta is no exception; the region has a favourable climate, fertile alluvial soils and a water supply brought by precipitation associated with the East Asian Monsoon and the Yangtze River, with sources as distant as the northeast Tibetan plateau. Flooding is a major hazard to humans inhabiting the Yangtze delta region and floods frequently cause substantial damage and loss of life. Flooding can result from typhoon driven storm surges, which commonly reach 2-3 m, however severe flooding occurs when typhoons coincide with astronomical high tides, when sea level set-up can exceed 8 m (Chen, 1999).

3.1.1 Modern topography of the delta region

The Yangtze delta plain is flat and low-lying – its elevation is mostly between 3 and 5 metres a.m.s.l. (Figure 3.1) – and includes a network of canals, ditches and lakes of both natural and man-made origin (Grigg, 1974; Chen, 1999; Li, et al., 2000; Saito, et al., 2001). The delta is classified as being tide-dominated, with a funnel-shaped morphology (Chen, 1999). Average tidal range is more than 2 m, and the tidal limit is about 200 m from the river mouth (Saito, et al., 2001). A series of elongated islands and sandy shoals occur in the river mouth area (Figure 3.2) (Chen, 1999). The sub-aerially exposed delta plain covers around 30,000 km², extends inland about 250 km to its apex at Zhenjiang (see Figure 3.2) and spans about 300 km of coastline (Chen and Stanley, 1995). The delta region is bounded to the south by Hangzhou Bay. Higher ground bounds the western edge of the delta plain, and the Huang and Tianmu mountain ranges lie to the south-west of the delta region. The modern delta is actively prograding, currently at a rate around 50 m/yr (Hori, et al., 2001). The delta’s Holocene strata varies in thickness from around 5 m to 30 m and is composed predominantly of clay and silt sized particles (Chen and Stanley, 1995).
Figure 3.1: Topographic map of Yangtze delta region showing Chenier ridges and central area of low elevation (modified from Chen and Stanley, 1998).
3.1.2 Modern climate of the delta region

The modern climate of the Yangtze delta region is characterised by warm, wet summers and cool, dry winters. Modern mean monthly temperatures for Shanghai range from 4 °C in winter to 28 °C in summer (Domros and Gongbing, 1988). Annual precipitation is about 1100 mm, most of which falls in the summer months (Domros and Gongbing, 1988).

The East Asian Monsoon is the principle influence on the climate of central and eastern China (An, 2000). The East Asian Monsoon system is a product of thermal difference between the Asian landmass and the Pacific Ocean. The summer monsoon acts to transport water vapour and heat from the equatorial ocean to the middle and high latitudes (up to 54°N), while the winter monsoon acts in association with the Siberian high pressure system, and brings cold, dry continental air-masses to east China (to around 22°N) (see Figure 3.3) (An, 2000; Xiao, et al., 2006). The monsoon is further enhanced by the west-east stepwise altitudinal gradient of the Chinese landmass: the Qinghai-Tibetan Plateau in the west is around 4000 m high, the Loess Plateau is around 2000 m high, and the eastern fluvial plains are around 200 – 500 m high (An, 2000;
Winkler and Pao, 1993 cited in Wu and Liu, 2004). Alterations in land-cover caused by human activities may have changed surface fluxes of energy, water and greenhouse gases, and this has been suggested to have had the effect of weakening the summer monsoon and enhancing the winter monsoon over east Asia (Fu, 2003). Any anthropogenic effect would be superimposed on the natural variability of the monsoon system.

Figure 3.3: Winter and summer monsoon regimes affecting China: A, January surface pressure (mbar), dominant wind vectors (arrows) and average summer limit of polar front (bold line); B, July surface pressure, dominant wind vectors and average landward limit of monsoon front (modified from Porter and An, 1995).

3.1.3 Modern vegetation of the delta region

The Yangtze delta lies between two major vegetation regions: the temperate deciduous forest region of north China, which is known for its high species diversity (Wu, 1980; Liu, 1988; Winkler and Wang, 1993; Harrison, et al., 2001), and the tropical evergreen forest regions of south China (see Figure 3.4). The potential natural vegetation of the delta is of a transitional type, and as a result is sensitive to small changes in climatic conditions (Okuda, et al., 2003). Characteristic tree taxa in the area include: deciduous broadleaved trees such as *Quercus acutissima*, *Q. variabilis*, *Q. fabri*, *Q. aliena*, and species of *Castanea*, *Liquidambar*, *Platycarya*, *Dalbergia*, *Tilia* and *Rhus*; broadleaved evergreen trees such as species of *Cyclobalanopsis*, *Castanopsis*, *Elaeagnus*, *Ligustrum*, and *Ilex*; and the conifer *Pinus massoniana* (Wu, 1980; Borrell, 1996).

Intense and persistent human usage of the land has resulted in very little natural vegetation remaining in the Yangtze delta region. Currently agricultural, urban and industrial uses account for most of the land in the delta. Small areas of forest vegetation
occur along main roads, on isolated hills within the delta plain and on the mountains that flank the delta region on the south and west. These forested areas are characteristically either planted or secondary in nature (Okuda, et al., 2003; Yi, et al., 2003).

A vegetation survey of plant taxa occurring in semi-natural forest on the Sheshan hills to the southwest of Shanghai, recorded 655 plant species (Shaobo, 1989) (Figure 3.5). Common trees in the Sheshan hills are *Cinamomum camphora*, *Aphananthe aspera*, *Quercus acutissima*, *Q. Fabri*, *Castanopsis sclerophylla*, *Celtis sinensis* and *Pinus massoniana* (Shaobo, 1989). Plants in urban areas of the Yangtze delta include many exotic species. Common urban trees are: *Ginkgo biloba*, *Cinamomum camphora*, *Plantanus acerifolia*, *Metasequoia glyptostroboides* and *Pterocarya stenoptera*.

Figure 3.4: Natural vegetation map of China, digitised from 113 vegetation type units identified in Hou et al.’s (1982) “Vegetation map of the Peoples Republic of China” (taken from Ni, et al., 2000).
A wide variety of crops are cultivated in the Yangtze delta and important crops include rice (*Oryza sativa*), cotton (*Gossypium hirsutum*), tea (*Camellia sinensis*), mulberry (*Morus* sp.), barley (*Hordeum vulgare*), soybeans (*Glycine max*), wheat (*Triticum* spp.), rapeseed (*Brassica napus*) and a large variety of vegetables and fruit (Ellis and Wang, 1997) (Figure 3.6).

![Photograph of forest vegetation on Sheshan hill, this particular area was dominated by bamboo (Bambusoideae).](image)

**Figure 3.5**: Photograph of forest vegetation on Sheshan hill, this particular area was dominated by bamboo (Bambusoideae).
3.2 Geology and delta formation

The base-rock forming the underlying geology of the Yangtze delta region is composed of two types: in the northern region of the delta, base-rock is primarily made up of terrigenous sedimentary rocks of Paleogene age, while base-rock in the south is primarily volcanic, formed during the Yenshanian Orogeny of the Early Jurassic to the Cretaceous period (see Figure 3.7) (Shaobo, 1989; Shanghai Seismological Bureau, 1984 cited in Chen and Stanley, 1995). Volcanic rock forms the hills which are scattered on the southern delta plain. Numerous fault lines underlie the delta region.
Figure 3.7: Map showing underlying geology in the Yangtze delta region (modified from Chen and Stanley, 1995).

Semi-consolidated to unconsolidated terrigenous deposits of Neogene and Quaternary age overlie the base-rock (Shanghai Seismological Bureau, 1984 cited in Chen and Stanley, 1995). Overlying this, and forming the flat plain that characterises the modern topography of the Yangtze delta, are Holocene deposits, varying in thickness from around 5 m in the west to more than 30 m at the coastline in the east of the delta (Chen and Stanley, 1995).

During the last glacial maximum a deeply incised valley occurred in the location of the modern delta, through which the Yangtze River flowed (Liu, et al., 1992; Li, et al., 2000; Hori, et al., 2001). This valley was formed by down-cutting of the river due to falling sea-levels leading up to the last glacial maximum (Li, et al., 2000). During the last glacial maximum sea-level was around 155 m below present a.m.s.l., and much of the continental shelf east of the current coastline was sub-aerially exposed (Wang and Wang, 1980 cited in Liu, et al., 1992). Rising sea-levels following the last glacial maximum led to infilling of the incised valley (Li, et al., 2000).
Following the valley infilling, a post-glacial marine transgression resulted in a wide estuary forming in the modern delta location (Yan and Hong, 1988 cited in Liu, et al., 1992; Li, et al., 2000). The estuary was large, and at the height of the transgression it extended inland to Zhenjiang (Figure 3.1) (Wang, et al., 1981; Li, 1984 cited in Li, et al., 2000). Foraminifera deposited in the palaeo-estuary during that time consist of both benthic species in situ, and others that were tidally transported to the area (Li, et al., 2000).

Sea-level rose rapidly during the early Holocene and by 7500 - 7000 BP sea-level was about 7 m below present (Yan and Hong, 1988 cited in Chen, 1999). At this time the coastline was about 150 – 200 km inland of its present position, and much of the modern delta plain area was inundated (Chen, 1999). The central Taihu basin region was an area of higher ground at this time and was a favoured area for human settlement (Chen, 1999). Decelerating sea-level rise from ca. 7000 BP led to the gradual infilling of the palaeo-estuary with fluvial sediments, which eventually formed the modern delta plain (Wang, et al., 1981; Liu, et al., 1992; Chen, 1999; Hori, et al., 2001).

Visible on the surface in the east of the delta are a series of northwest-southeast trending chenier ridges (Figure 3.1), which were formed by the combined effects of coastal currents, high tides and storm processes (Zhang et al., 1987 cited in Stanley and Chen, 1996). The chenier ridges mark positions of the coastline between ca. 7000 and 4000 BP (Zhang et al., 1982 cited in Chen, 1999). A topographic reversal of the delta plain was caused by sediment aggrading at the chenier ridges and also at the northern Hangzhou bay coastline in the south of the delta region (Stanley and Chen, 1996; Stanley, et al., 1999). The reversal resulted in the formerly elevated Taihu basin area becoming low-lying in relation to coastal areas, and led to a large saucer-like depression developing in the central delta plain (Chen and Wang, 1999; Stanley, et al., 1999). Rising groundwater, driven by sea level rise and precipitation, eventually filled the lakes that are currently present in the Taihu basin (Chen and Wang, 1999). This Taihu reservoir now accommodates drainage water from the delta plain and the western highlands (Chen and Wang, 1999).

About 2000 BP the progradation rate of the delta plain increased abruptly from 38 km/kyear to 80 km/kyear (Hori, et al., 2001). Two causes for this increased sediment...
production have been suggested: i) increased sediment production in the catchment due to human activity; and ii) a relative decrease in sediment accumulation in the middle reaches due to increased channel stability, possibly as a result of climatic cooling and/or construction of dykes and levees (Hori, et al., 2001; Saito, et al., 2001; Hori, et al., 2002). Currently the sediment load of the Yangtze River is high, averaging $4.8 \times 10^8$ tons/yr, and progradation rates at the Yangtze coastline are estimated to be between 40 and 100 m/yr (Chen, et al., 2000; Hori, et al., 2001). Flood-waters are a major source of sediment delivered to the delta region (Hori, et al., 2002), and irrigation water probably delivers substantial amounts of sediment to agricultural areas.

### 3.2.1 Holocene sea level change in the delta region

Sea-level change has been the principle factor driving the formation of the Yangtze delta plain and shaping its topography, and through this has influenced the extent of surface water and the distribution of human settlements in the delta region (Stanley and Chen, 1996; Zhang, et al., 2005b). Around 10,000 BP, sea-level was about 20 metres below present a.m.s.l. in the East China Sea at the mouth of the Yangtze River (Zong, 2004). Over the following 2000 years, sea-level rose rapidly and by ca. 8000 BP sea-level was ca. 5 metres below present a.m.s.l. (Zong, 2004). The rate of sea level rise declined markedly soon after ca. 8000 BP, probably as a result of reduced melt-water discharge from northern and southern hemisphere ice-sheets (Stanley and Warne, 1994). This slowing of sea-level rise initiated progradation of alluvium at the mouth of the Yangtze, which eventually formed the delta plain (Stanley and Chen, 1996). Over the past ca. 3000 years a.m.s.l. has been near to its current position (Zong, 2004). Figure 3.8 shows a recently published Holocene sea level curve based on published sea level index points (Zong, 2004).
Some uncertainty surrounds the nature of sea level change in the East China Sea between ca. 7000 and 4000 BP, and this uncertainty mostly stems from differences in opinion about the cause of past sea-water incursions onto the current sub-aerial delta plain (Yan, 1987 cited in Shi, et al., 1994). While some authors suggest marine incursions between ca. 7000 and 4000 BP were due to a higher sea-level than present (some 3-5 metres) (see Chen and Stanley, 1998; Hori, et al., 2001), others argue that the effects of land subsidence, hydro-isostasy, or topographic reversal played a large role (see Stanley and Chen, 1996; Chen and Stanley, 1998; Stanley, et al., 1999; Hori, et al., 2001; Zong, 2004). Reconstructing sea-levels in the delta is complicated by the region’s history of storm surges, flood events and fluctuating lake levels, as the effects of these processes could lend themselves to being misinterpreted as evidence for higher sea-levels (Itzstein-Davey, et al., in press-b).

### 3.3 Climate and vegetation in the delta region since the last glacial maximum

Post-glacial trends in climate and vegetation changes in China have been popular research topics (e.g. Sun and Chen, 1991; Winkler and Wang, 1993; Ren and Beug, 2002) and much of this research consistently finds changes in the East Asian Monsoon to have been a key driver of climate change in east China since the last glacial
maximum. The East Asian Monsoon is itself predominantly affected by changes to solar irradiance and global ice volumes (Xiao, et al., 2006). In addition to monsoon-driven change, hemisphere-wide climatic events, such as the Younger Dryas, may also have affected the delta region (Porter and An, 1995; Kim and Kucera, 2000).

Good quality palaeoenvironmental records are considered to be relatively rare in China, particularly for work conducted in the decades prior to AD 2000 (Ren, 2007). However, comparatively more is known about palaeoenvironmental changes in east China than other parts of the Asian continent. Overall, existing east Asian palaeoclimatic data show clear Holocene climatic shifts to have occurred, although, shifts in the Yangtze delta region appear to have been somewhat smaller in magnitude than those occurring over the same time period in more northerly regions (Yan, 2005). Palaeoenvironmental information provided by seven well-dated sediment sections from the Yangtze delta region (Figure 3.9) is discussed below in addition to data from other sites in east Asia. Comparing palaeoenvironmental records for the Yangtze delta region is somewhat complicated by the tendency of authors to publish findings in both uncalibrated radiocarbon years BP (e.g. Okuda, et al., 2003; Chen, et al., 2005; Tao, et al., 2006), and calibrated years BP (e.g. Yi, et al., 2003; Yi, et al., 2006). In order to avoid confusion, dates presented here are in their published form and indication is made for calibrated ages.
### Chapter 3: Geographical setting of the Yangtze River delta

#### 3.3.1 The last glacial maximum (ca. 18,000 BP)

3.3.1.1 Climate and vegetation patterns in east Asia

During the last glacial maximum (ca. 18,000 BP) conditions in China were colder and dryer than the present; mountain glaciers in western and northwestern China were more extensive, frozen steppe covered larger areas of northern and northeastern China, tropical forests disappeared, and in the east, permafrost extended about 11° further south than present (Winkler and Wang, 1993; Members of China Quaternary Pollen Data Base, 2000). During this glacial maximum, cold continental air from the central east Asian, Arctic and Korean airstreams reached further south, systematically forcing boundaries of vegetation zones southward (Winkler and Wang, 1993; Members of China Quaternary Pollen Data Base, 2000). The cold-water foraminifera, *Buccella frigida*, was displaced at least 5° southward in the East China Sea at this time (Wang, 1984).
3.3.1.2 Evidence from the Yangtze Delta region

The few palaeoenvironmental records in the Yangtze delta region covering the period ca. 18,000 BP indicate that vegetation was dominated by cold-climate coniferous forests, with high proportions of Abies and Picea (Xu et al. 1980 cited in Winkler and Wang, 1993).

3.3.2 11,000 BP: cooler and drier

3.3.2.1 Climate and vegetation patterns in east Asia

Conditions in Asia during the Pleistocene/Holocene boundary, ca. 11,000 BP, although colder and dryer than present, were generally wetter than during the glacial maximum (Winkler and Wang, 1993). Permafrost was more extensive in northeast China than present (Winkler and Wang, 1993) and pollen data indicate temperatures there were around 6-8°C colder than present (Sun and Chen, 1991). Benthic foraminifera evidence shows temperatures in the Yellow Sea to have been colder than present (Kim and Kucera, 2000).

A well documented cold interval, termed the Younger Dryas, appears in numerous records from the north Atlantic and north Pacific regions ca. 12,000 BP (Rind, et al., 1986; Alley, et al., 1993; Severinghaus, et al., 1998). While the cause of the Younger Dryas is still uncertain, a prominent theory suggests that the event was caused by the freshwater forcing of melting ice-sheets which disrupted North Atlantic Ocean circulation (e.g. Broecker, et al., 1989; Bjorck, et al., 1996; Jennings, et al., 2006). Colder conditions in east Asia, associated with a strengthened winter monsoon, coincide with the Younger Dryas, and this has led authors to suggest that Chinese palaeoclimates may be linked to conditions in the North Atlantic Ocean (Porter and An, 1995; Kim and Kucera, 2000). Overall however, the ecological shifts in China during that time are not considered to be as great as those occurring in Europe and west Asia (Yasuda, 2002).

3.3.2.2 Evidence from the Yangtze Delta region

Pollen records from the delta region ca. 11,000 BP include relatively high proportions of cool-tolerant conifers and herbs, and are dominated by Pinus, Artemisia, Poaceae, Cyperaceae and Polypodiaceae (Liu, et al., 1992; Yi, et al., 2003). Broadleaved evergreen and deciduous trees are reported to decline over the same period (Yi, et al.,
2003). While the markedly changed physical landscape of the delta region, with corresponding hydrologic and edaphic changes, is likely to account for some of the differences in vegetation composition at that time (Liu, et al., 1992), vegetation reconstructions predominantly reflect conditions that were cooler and dryer than present (Liu and Chang, 1996; Yasuda, 2002; Yi, et al., 2003).

3.3.3 Early Holocene: ca. 9000 – 8000 BP

3.3.3.1 Climate and vegetation patterns in east Asia

During the early Holocene climates in China were generally warmer and wetter than present, and this was likely to be due to a strengthened summer monsoon (Winkler and Wang, 1993). Around that time Chinese glaciers were retreating, lake levels were high, peatlands were developing in the Qinghai-Tibetan Plateau (probably due to increased melt water, or increased moisture) and forested belts were expanding northwards (see Figure 3.10) (Winkler and Wang, 1993; Ren, 2007).

![Figure 3.10: Arboreal pollen isochrone map for China at 2000 year intervals for the Holocene (modified from Ren, 2007).](image)

An abrupt hemisphere-wide reversal of climatic conditions occurred ca. 8200 cal. yr BP and is termed the ‘8k event’ (also referred to as the ‘8.2 ka event’) (Alley and Agustsdottir, 2005; Kobashi et al., 2007). This event was short lived, lasting around 150
years, and as with the Younger Dryas event the severity of cold/dry conditions appears to have been greatest around the North Atlantic Ocean (Alley and Agustsdottir, 2005; Kobashi et al., 2007). Evidence of the effects of this event in China include: drying at Sumxi-Longmu Co basin in western Tibet (Van Campo and Gasse, 1993), eolian silt deposits in Xinjiang, northwest China (Liu et al., 2003 cited in Alley and Agustsdottir, 2005), cold conditions at Qinghai Lake (Liu, 2002 cited in Alley and Agustsdottir, 2005), drying in the Ning-Zhen Mountains, lower Yangtze River area (Yu, et al., 2003), and cooling in the Dunde ice core record (Jung, et al., 2004). It is considered that additional palaeoclimate records are needed to better understand climatic shifts associated with the event in east Asia (Morrill, et al., 2003).

3.3.3.2 Evidence from the Yangtze delta region

No clear trend is displayed in palaeoenvironmental records dating between ca. 9000 and 8000 BP in the Yangtze delta region. Records indicate a degree of climatic variability occurred over that time period, whereby generally warmer and wetter conditions were punctuated by short episodes of cooler and dryer conditions (Qu, et al., 2000; Zhang, et al., 2005a; Qin, 2006). One record detected markedly cooler and dryer conditions ca. 8200 BP (Zhang, et al., 2005a). However, conflicting evidence from cores HQ98 and CM 97 (Figure 3.9) indicates cool and dry conditions to have prevailed from ca. 9000 – 7600 cal. yr BP, based on increased conifers (Pinus and Tsuga) and xerophytic herbs, and decreased broadleaved evergreens (Quercus (Cyclobalanopsis) and Castanopsis/Lithocarpus) (Yi, et al., 2003; Yi, et al., 2006). In a recent review of existing palaeoenvironmental data, arboreal pollen percentages in the Yangtze and Huai River catchment areas from ca. 10,000 to 6000 BP were found to have been relatively stable (Ren, 2007). An analysis of flood deposits in the lower Yangtze valley by Yu et al. (2003) found extreme flood events to be more common between ca. 9200 – 8200 cal. yr BP, which they interpret to be associated with warmer climates at the time. After ca. 8200 cal. yr BP they found significantly fewer flood events and suggested this to be due to significantly reduced regional precipitation (Yu, et al., 2003).
3.3.4 Mid-Holocene thermal optimum: ca. 8000 – 5000 BP

3.3.4.1 Climate and vegetation patterns in east Asia

Warmer and wetter conditions between ca. 8000 and 5000 BP are reported in all regions of China (Winkler and Wang, 1993), as well as in other regions of the globe (Street-Perrott and Perrott, 1993; Gasse and Van Campo, 1994). The thermal optimum in Asia has been linked with a weakened winter monsoon and a strengthened summer monsoon (Shi, et al., 1994; Liu and Chang, 1996), which caused a northward displacement of eastern vegetation zones (Winkler and Wang, 1993; Shi, et al., 1994; Yu, et al., 1998) (see Figure 3.11). By ca. 6000 BP forest cover in China was more extensive than at any other time during the Holocene (see Figure 3.10) (Ren, 2007).

The evidence for Mid-Holocene warming in China includes: rapidly retreating Chinese glaciers (Winkler and Wang, 1993), $\delta^{18}$O values indicating higher temperatures in the Dunde ice cap record, located on the Qinghai-Tibetan Plateau (Thompson, et al., 1989), expanded forest vegetation (Sun and Chen, 1991; Ren, 2007), and a 4° northwards displacement of the warm water foraminifera, Asterorotalia subtrispinosa, in the East China Sea (Wang, 1984).

![Figure 3.11: Reconstructed vegetation types for part of China at 6000 BP and present (modified from Ren and Beug, 2002). ctf: cold temperate conifer forest; tmf: temperate mixed conifer and deciduous forest; tdf: temperate deciduous forest; wtf: warm temperate deciduous forest; smf: subtropical mixed evergreen and deciduous forest; of: other forest; TS: temperate steppe.](image-url)
3.3.4.2 Evidence from the Yangtze delta region

A distinct period of warmer and wetter conditions ca. 8000 – 5000 BP is detected in palaeoenvironmental records from the Yangtze delta region (Wang, et al., 1986; Kong, et al., 1991; Liu, et al., 1992; Xu, et al., 1996; Qu, et al., 2000; Yi, et al., 2003; Chen, et al., 2005; Qin, 2006; Tao, et al., 2006; Yi, et al., 2006). Pollen data typically show increases of subtropical components of vegetation during this period and temperature estimates of around 2°C – 4°C warmer than present have been suggested for the mid-Holocene based on vegetation reconstructions (Shi, et al., 1994; Xu, et al., 1996). Other evidence gained from work on flood deposits has found a period of extreme flood events to have occurred from 7600 – 5800 cal. yr BP, suggested to result from warmer climates (Yu, et al., 2003). Evidence from faunal remains shows an abundance of species typical of subtropical and tropical habitats, for example monkeys, rhinoceros and elephants (Chang, 1986; Wei, et al., 1990; Lu, 1999). Geochemical indices (Al2O3/Na2O, K2O/Na2O and CaO/K2O) from core ZX-1 (Figure 3.9) suggests warmer and wetter conditions between ca. 7000 – 6000 BP (Tao, et al., 2006).

3.3.5 ca. 5000 – 3000 BP: cooler?

3.3.5.1 Climate and vegetation pattern in east Asia

Forest cover in China from ca. 5000 – 3000 BP underwent a generally declining trend (Figure 3.10), however in addition to changing climatic conditions, anthropogenic influence is likely to be a cause of this (Ren, 2007). A marked episode of climate deterioration from ca. 4200 – 4000 cal. yr BP is noted in numerous locations in Asia (Yi, et al., 2003; Yasuda, et al., 2004) and evidence for this event includes: marked aridity in Sumxi-Longmu Co basin in western Tibet at ca. 4300 BP (Van Campo and Gasse, 1993), and cooling at Lake Tougou-ike, in Japan (Kato, et al., 2003).

3.3.5.2 Evidence from the Yangtze delta region

Cooler conditions generally prevailed in the Yangtze delta region during this post-mid-Holocene thermal optimum period, as indicated by vegetation reconstructions showing expansions of the cool-tolerant conifer Pinus (Liu and Chang, 1996; Yi, et al., 2003; Chen, et al., 2005; Yi, et al., 2006). Some palaeoenvironmental records include a marked cold event which climaxed ca. 4200 – 3800 BP (see Liu, et al., 1992; Yi, et al., 2003; Chen, et al., 2005; Tao, et al., 2006; Yi, et al., 2006 for more detail).
Superimposed on this period of cooler conditions are distinct episodes of flooding and increased surface water, particularly ca. 4000 BP, which are indicated by evidence of expanded wetland vegetation and flood deposits (Stanley and Chen, 1996; Stanley, et al., 1999; Yu, et al., 2000; Yu, et al., 2003). Yu et al. (2003) have suggested frequent flooding around this time to be due to an intensified East Asian Monsoon driven by warmer conditions, however this theory conflicts with the previously mentioned findings for generally cooler conditions in the Yangtze delta region during that time. Another suggested cause for this increased flooding in the region is the contemporaneous topographic reversal of the delta plain (Stanley, et al., 1999), which led to increased entrapment of water in the formerly elevated central area. The entrapment of water on the delta plain would have been further exacerbated by the gradually rising sea levels at the time (Stanley, et al., 1999). With reduced drainage of water from the delta plain, any flood event in the Yangtze River would have had more severe consequences in the delta region.

3.3.6 Late-Holocene: 3000 BP to present

3.3.6.1 Climate and vegetation pattern in east Asia

Palaeoclimatic records in China show a general cooling trend for the last ca. 3000 years, however the rate of change has been slow compared with periods earlier in the Holocene (Sun and Chen, 1991; Winkler and Wang, 1993). Late-Holocene vegetation change in north China has been characterised by contracting deciduous forests and expanding coniferous forests and grasslands, while in south China evergreen forests have been contracting over the same time period (Sun and Chen, 1991). Evidence from Chinese glaciers indicate a cooling trend to have dominated for the past ca. 3000 years (Winkler and Wang, 1993; Shi et al., 1992 cited in Jiang and Piperno, 1999), while in Japan, lake levels have been falling as a result of reduced glacier melt water (Kato, et al., 2003). Temperature reconstructions for China, based on historical documents, indicate that the presence of a cold event between the 16th and 19th centuries, which is contemporaneous with cooler conditions in other parts of the northern hemisphere (Wang and Wang, 1991).
3.3.6.2 Evidence from the Yangtze delta region

Palaeoenvironmental records in the Yangtze delta region are in general agreement with records from other parts of China, for cooling conditions over the last ca. 3000 years. Pollen records show increasing cool-tolerant conifers, Poaceae and Cyperaceae and declining subtropical taxa (Liu, et al., 1992; Yi, et al., 2003; Yi, et al., 2006). Conflicting pollen evidence from a core at Cauduntou (Figure 3.9) shows warmer and moister conditions prevailed after ca. 2500 BP (Okuda, et al., 2003). Temperatures for the last 2000 years, based on historical documents in the Lower Yangtze, have been reconstructed by Ge et al. (2003). Their results show that from ca. AD 0 – 490 temperatures were ca. 1 °C cooler than present, following this a warming trend occurred, and from AD 570 – 1310 temperatures were as much as 0.9 °C warmer than present. Between AD 1310 and AD 2000 four distinct cold periods were detected, at which time temperatures were up to ca. 1.1 °C colder than present, however overall they found temperatures to have been declining over that time period. Their findings show twentieth century temperatures to have been rising.

3.4 Fire regimes: past and present

Investigation of Holocene fire activity in east China is a topic somewhat overlooked in the literature to date. As a result, relatively little is known of natural fire regimes or the manner in which humans have affected them. Some understanding of fire-use by prehistoric people in the delta region has been provided by work at archaeological sites (e.g. Cao, et al., 2006). It is apparent however, that further archaeological and palaeoenvironmental research is required to better understand temporal and spatial variations in the nature of prehistoric human burning in China. There are numerous known reasons for prehistoric people to burn land, including: encouraging regrowth for grazing animal and human consumption, clearing land for cultivation, aiding hunting, improving visibility, facilitating travel, driving away pests and aiding warfare (Day, 1953; Pyne, 1982; Veblen and Lorenz, 1988; Huber, et al., 2004; Heinl, et al., 2007). In addition, accidental ignitions by humans are bound to have occurred throughout prehistory (Veblen and Lorenz, 1988; Heinl, et al., 2007).

Fire is a major influence in a wide range of geographical locations and vegetation types, for example fire is an important disturbance factor in temperate forests of southern Australia (Bowman, 1998), tropical rainforests of south America and Asia (Goldammer
and Seibert, 1989; Cochrane, 2001), tropical savannas of north Australia (Gill, et al., 1996), and boreal forests of Finland (Pitkänen, et al., 2003) to name a few. Of the many environmental and anthropogenic factors influencing fire activity in a region, the principle ones are outlined in Figure 3.12 and discussed in more detail in the following paragraphs.

![Diagram illustrating the interconnectedness of the main factors influencing the fire regime of an area.](image)

**Figure 3.12:** Diagram illustrating the interconnectedness of the main factors influencing the fire regime of an area.

### 3.4.1 Ignition sources

Lightning, volcanism and human activity are the three main ignition sources of forest fires. The availability of each of these ignition sources varies between regions, contrasting examples are: parts of the USA, where lightning accounts for most fires (72%) (Interagency Grizzly Bear Committee, 2002), and parts of Siberia and Mexico, where human ignition has been estimated to account for respectively 90 and 97% of fires (Zhukov, 1976; Stolzenburg, 2001). A human ignition source has been present in China for a long time and indirect evidence from cave sites suggest *Homo erectus* in China were manipulating fire as early as ca. 300,000 BP (Guo, et al., 1991; Weiner, et al., 1999).
3.4.2 Effects of climate on fire regimes

Climate is a key driver of fire regimes. Climate not only affects the frequency of an ignition source, but also the intensity and extent of a fire by governing the nature of the vegetation in an area and the local weather conditions. However, the climate-fire relationship is not straight foreword, and the effect of a climatic shift on fire activity varies between regions. For example, in a biomass-limited environment increased precipitation may lead to greater fire activity through increasing biomass quantity, while in a biomass-abundant environment, the same climatic shift may suppress fire activity by reducing biomass flammability (Ni, et al., 2006).

A strong link between climate change and fire activity has been found in palaeoenvironmental records from east Borneo, New Guinea, Indonesia and Australia, whereby dryer periods and periods of increased seasonality or variability are associated with altered wildfire occurrence (Goldammer and Seibert, 1989; van der Kaars, et al., 2000; Haberle, et al., 2001; Kershaw, et al., 2003). Palaeoenvironmental records from several locations also show a link between human activity and burning, and these locations include parts of Malesia and Europe (Clark, et al., 1989; Haberle, 1998; Haberle, et al., 2001).

3.4.3 The role of disturbance agents on fire regimes

Forest disturbances involving an opening or fragmentation of the canopy generally have the effect of increasing a forest’s susceptibility to fire. A forest disturbance can vary greatly in scale. A small scale change could involve the mortality of a single plant due to senescence or storm damage for example, while a larger scale change could involve humans clearing vegetation to create road networks or tracts of agricultural land. The increased amount of flammable dead biomass in the disturbed area, and alterations in the forest micro-climate are two consequences of forest disturbance that particularly affect fire activity. Micro-climate changes following a forest disturbance result from increased sunlight and wind penetration of the forest canopy, leading to greater desiccation of the forest biomass (see Mount, 1982; Uhl and Buschbacher, 1985; Saunders, et al., 1991; Cochrane, 2001; Nepstad, et al., 2001 for further detail). This effect is illustrated by observations in Amazonian forests which find logging to precondition the forests to future high intensity fire (Stocks and Kauffman, 1997; Caldararo, 2002). Increased fire susceptibility has also been observe to follow
Amazonian forest fires, and results from the post-fire changes to the forest micro-climate (Cochrane and Schulze, 1999; Cochrane, 2001). Conversely, forest fragmentation can reduce fire susceptibility in some areas. For example in eastern Finland, fragmentation of boreal forests has been shown to reduce fire activity by restricting the spread of fires (Pitkänen, et al., 2003).

### 3.4.4 Evidence of pre-historic fire activity in the Yangtze delta region and east China

Work on prehistoric fire activity in east China is scarce, and as a result a distinct gap exists in knowledge about the regions palaeoenvironments. The following paragraphs review existing east China charcoal records:

Charcoal data covering the last glacial and interglacial cycle have been collected from two marine cores from the South China Sea, core 17940 and ODP Site 1144 (Sun and Li, 1999; Sun, et al., 2000; Luo, et al., 2001). Both records show charcoal concentrations to increase during periods of dryer climate. Interpretation of charcoal records from these offshore sites is complicated by the increased continental land area during dryer periods. The authors overcome this complication by separating charcoal particles into different size categories. They suggest that medium and coarse sized charcoal particles (>50 μm diameter) mainly reflect burning on the exposed shelf, while finer grained charcoal particles mostly reflect burning on the current mainland (Sun and Li, 1999; Sun, et al., 2000; Luo, et al., 2001).

Work by Dodson et al. (2006) on a trench section in an agricultural area, Dingnan in southern Jiangxi Province, found microscopic charcoal concentrations to increase slightly ca. 6000 BP, after which a larger increase occurred ca. 4500 – 4000 BP. The authors suggest the initial charcoal increase reflects burning by humans associated with forest clearance, while the latter increase is suggested to result from the expansion of farming activities, and associated burning, into the study-site area (burning of rice stubble for example). Interestingly, the later charcoal increase (ca. 4500 – 4000 BP) coincided with an increase of *Pinus* in the record, suggested possibly to be due to afforestation on surrounding hills, perhaps to increase wood supply for building and fuel, or to control hillside erosion.
Huang et al. (2006) studied fire history at four sites in the southern Loess Plateau. Their records show wild-fire to have been relatively frequent in the early Holocene. Following this (from ca. 8500 – 3100 BP) fire activity was found to be generally reduced, possibly as a result of wetter climatic conditions associated with the mid-Holocene thermal optimum. At two of their study-sites, fire activity increased markedly ca. 3100 BP and the authors suggest this to reflect humans using fire to clear land for agriculture. A later reduction in fire activity, ca. 1500 BP, is suggested to result from the eradication of natural vegetation surrounding the sites as a result of the widespread presence of agriculture. The authors suggest that the relatively low charcoal concentrations after ca. 1500 BP result from post-harvest stubble burning of wheat and maize stalks near to the study sites.

A marked increase in fire activity in the Manchurian Plain, northeast China, was found to occur ca. AD 900 – 1100, based on evidence from a peat-profile (Makohonienko, et al., 2004). This rise coincided with a period of deforestation and establishment of agriculture in the area, signified by the appearance of Fagopyrum (buckwheat) pollen in the record. The authors suggest that the increased fire activity results from the adoption of post-harvest stubble burning in the area.
4 Site selection and interpretation of palaeoenvironmental data

Environmental reconstructions presented in this thesis are based on analysis of continuous sediment sections collected from three study sites in the Yangtze delta region, referred to as Qingpu, Guangfulin and Liangzhu (Figure 4.1). Several methods of analysis were applied to the sediment samples, namely: analysis of pollen and charcoal abundance, quantitative biomarker, stable carbon isotope, particle size and magnetic susceptibility analyses. Chronology was determined by AMS $^{14}$C dating. Another researcher, Dr Itzstein-Davey, has conducted phytolith analysis on duplicate samples from the Qingpu and Guangfulin trench sections. The purpose of this chapter is to outline the principle reasons for selection of the field site locations and to discuss interpretation of the palaeoenvironmental data.

![Figure 4.1: Location of Qingpu, Guangfulin and Liangzhu study sites. The elevation map of the delta region has been modified from Chen and Stanley (1998).](image)

Ultimately, the suite of methods chosen for the current research is designed to contribute towards improving understanding of early human inhabitants and palaeoenvironments in the delta region. The purpose of using multiple methods of
analysis in this study is two-fold: to increase the type of information gained from the sediment samples; and to increase the certainty of palaeoenvironmental findings (e.g. in detecting the presence of rice agriculture in samples). A sense of scale and spatial characteristics of the palaeoenvironmental changes are provided by the use of multiple study sites on the delta plain.

4.1 Site selection

Site selection is of critical importance in any study reconstructing palaeoenvironments based on sediment sections (Jacobson and Bradshaw, 1981). The current study sites were chosen with the objective of finding locations with a history of continuous sediment deposition which are also located in a relatively stable sedimentary setting. Sites were purposely situated far from roads, buildings, rivers and waterways in order to minimise likelihood of past major sedimentary disturbances. The parallel objective in choosing study sites was to maximise the detection of early human activities, and in order to do this, sites were chosen to be near to studied Neolithic archaeological sites.

The deltaic sediments sampled in this study provide a rich sedimentary archive of past conditions, but their nature also presents some challenges for palaeoenvironmental research. The trench and core sediments of the study sites are predominantly silts and clays, presumably deposited under relatively low-energy conditions. The current nature of the upper deposits at the sampling sites is best described as terrestrial or semi-terrestrial soil, which is not optimal for microfossil analysis. Long-established difficulties in studying microfossils in terrestrial soils are principally associated with: (1) the more rapid deterioration of microfossils (e.g. through corrosion); (2) downwashing of material through the soil profile; and (3) a higher degree of mixing and dispersal of material within the soil matrix (Dimbleby, 1957; Davidson, et al., 1999; Kenyon and Rutherfurd, 1999). Furthermore, storage of material prior to deposition is an acknowledged problem of reconstructing palaeoenvironments from deltaic sediments (e.g. Stanley and Hait, 2000).

The problem of downwashing may not be of great importance at the study sites, as the sediments are made up of very fine particles – predominantly clays and silts – and sedimentation rates are generally very high. Also, downwashing may be further hindered by the poor drainage that characterises much of the delta region, particularly in
the central area. The problem of sediment mixing in terrestrial soils is mainly due to the activity of soil fauna (Davidson, et al., 1999) and because of this, the study sites may not be expected to have as high a degree of temporal resolution as other types of sedimentary deposits (varved lake deposits for example), despite their high sedimentation rate.

In order to maximise the likelihood of capturing human activity in the palaeoenvironmental records, study sites were located near archaeological settlement sites. This ensured a human presence near to the study sites at some point in time, and also maximised the chance of detecting agricultural fields on the boundaries of the settlement sites. The archaeological settlement sites were not directly sampled as it was deemed that this area would be biased towards plants transported there by humans. In addition, the sediments there may not have been continuously exposed to the open air and have probably undergone a high degree of disturbance due to the activities of prehistoric occupants. Previous work has shown that pollen records from settlement sites are not in equilibrium with the pollen rain of the time, and are therefore of minimal use for broader scale ecological interpretation (Dimbleby, 1985).

4.2 Pollen in sedimentary samples

4.2.1 Pollen dispersal and source area

Uncertainty about the source area of pollen in sedimentary deposits is a common limitation in studies using pollen analysis (Birks and Birks, 2000; Seppa and Bennett, 2003). This uncertainty arises from the unknown distance that a pollen grain travels prior to being deposited at a site. Principle factors affecting this are: the morphological traits of the pollen (which are often related to dispersal/pollination mechanisms of the plants), the position of the plant in relation to surrounding landscape and vegetation, and the population density of source plants (Traverse, 1988; Moore, et al., 1991).

Most pollen records include both local and regionally derived pollen; however studies show that the proportion of these can vary dramatically between different geographical locations. At one extreme are treeless alpine steppe areas, where pollen deposits tend to be mainly composed of pollen originating from regional sources, while at the other extreme are closed forests, or woodland areas, where deposits can be composed of
pollen entirely derived from local sources (i.e. within several metres of the sampling site) (Handel, 1976; Traverse, 1988; Birks and Birks, 2000).

In delta or floodplain environments, some fluvial-transported pollen, derived from distant sources in the catchment, would be expected. However, work on modern pollen assemblages in the Yangtze delta region has found the vast majority of pollen recovered there to have a relatively local origin, from vegetation growing on the delta plain or surrounding hills (Wang et al., 1982 cited in Liu, et al., 1992). This finding has been supported by studies of other floodplain sediments, for example in the Barmah Millewa forest of southeast Australia, where pollen was mainly derived from local floodplain vegetation (Kenyon and Rutherfurd, 1999). Also, the terrestrial nature of the sampling sites means that pollen assemblages are likely to be dominated by vegetation growing at or near to the site (Andersen, 1986).

4.2.2 Pollen representation and preservation in sedimentary deposits

The preservation and representation of pollen from any plant taxon in a sedimentary deposit is not only affected by the abundance of the source plant, but also by several other factors, namely: i) the pollen productivity of the source plant; ii) the pollen dispersal mechanism of the plant; and iii) the nature, or strength, of the pollen exine (Traverse, 1988; Fægri and Iversen, 1989). Linking sedimentary pollen assemblages with the composition of source vegetation is a topic of much study, requiring detailed analysis of modern pollen rain and source vegetation communities. General criteria for determining plant abundance based on pollen representation in sediment samples has been suggested by Ren and Beug (2002) and is based on published pollen data from North America, Europe and China (Table 4.1). Their criteria are useful in highlighting differences between the studied taxa, however inferences based on them should be made with caution as they cannot account for the large differences that occur between sites.
Table 4.1: Pollen criteria for presence and abundance of major taxa devised by Ren and Beug (2002).

<table>
<thead>
<tr>
<th>Taxon name</th>
<th>Present (%)</th>
<th>Abundant (%)</th>
<th>Dominant (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinus</td>
<td>&gt;25</td>
<td>&gt;40</td>
<td>&gt;55</td>
</tr>
<tr>
<td>Betula</td>
<td>&gt;10</td>
<td>&gt;20</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Quercus</td>
<td>&gt;3</td>
<td>&gt;15</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Ulmus</td>
<td>&gt;2</td>
<td>&gt;10</td>
<td>&gt;25</td>
</tr>
<tr>
<td>Artemisia</td>
<td>&gt;10</td>
<td>&gt;25</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Chenopodiaceae</td>
<td>&gt;5</td>
<td>&gt;20</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Trees</td>
<td>&gt;40</td>
<td>&gt;60</td>
<td>&gt;80</td>
</tr>
</tbody>
</table>

4.2.3 Pollen identification

Pollen identification in the present study is aided principally by reference to Wang et al.’s (1995) ‘Pollen Flora of China’, and the majority of identified grains are distinguished to family or genus level. Fifty-four percent of the 204 pollen types encountered in the present study were identified. Photomicrographs for a selection of identified pollen grains are presented in Appendix 1. It was not possible to identify some pollen grains due to damage to the exine. Unidentified grains rarely contributed more than 5 % of the samples’ total pollen sum, and are excluded from pollen diagrams.

4.2.3.1 Identification of cereal pollen

Poaceae is a diverse family of more than 655 genera and more than 10,000 species (Wooller and Beuning, 2002). The pollen of Poaceae however, has very few morphological features which enable it to be distinguished at sub-family level. The tendency of cultivated plants to produce larger pollen grains than those of wild varieties (CPAM, 1997; Li, et al., 2006) is useful in separating cereal pollen from that of wild grasses (Dickson, 1988; MacNeish and Libby, 1995). The application of this size classification for distinguishing the pollen of domesticated rice is a topic of debate (see Maloney, 1990; Tweddle, et al., 2005). Substantial variation exists between published dimensions of rice pollen (see Table 4.2).
Table 4.2: Published dimensions of rice pollen.

<table>
<thead>
<tr>
<th>Rice Variety</th>
<th>Pollen dimensions</th>
<th>Literature source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Oryza</em> sp.</td>
<td>43 (36 – 51) x 42 (36 – 45) µm</td>
<td>(Wang, et al., 1995)</td>
</tr>
<tr>
<td><em>O. rufopogon</em></td>
<td>34 – 41 µm (mode value = 37 µm)</td>
<td>(Maloney, 1990)</td>
</tr>
<tr>
<td><em>O. sativa</em></td>
<td>37 µm (mode size)</td>
<td>(Maloney, 1990)</td>
</tr>
<tr>
<td><em>O. sativa indica</em></td>
<td>(29 – 49) x (36 – 52) µm</td>
<td>(Datta and Chaturvedi, 2004)</td>
</tr>
</tbody>
</table>

The present study separates Poaceae pollen into two size categories: those with a longest axis greater than 40 µm (referred to as ‘Poaceae (*Oryza* comp.)’); and those with a longest axis less than 40 µm (referred to as ‘Poaceae’). While this method used alone is a fuzzy method for distinguishing cereal or cultivated rice pollen, when considered alongside other lines of evidence (e.g. phytolith data) the argument for its representation of cultivated rice is strengthened.

4.3 Charcoal analysis

4.3.1 Dispersal: size classification

The tendency of charcoal particles of differing sizes to reflect burning in different geographical areas is the reason for quantifying sedimentary charcoal particles into size categories. The underlying theory is that smaller charcoal particles, having greater capacity for aerial transport, tend to disperse greater distances from a fire and therefore represent burning in a larger geographical area (Clark, 1988; Odgaard, 1992). Conversely, larger sized charcoal particles in sedimentary deposits tend to reflect local fire histories (Carcaillet, et al., 2001). The usefulness of micro-charcoal (present on pollen slides) to reconstruct local fire activity has been questioned by some authors (Clark and Royall, 1995), however other work comparing sedimentary charcoal records with fire-scar data conclude local fires to be recorded in the micro-charcoal record (Pitkänen, et al., 1999; Carcaillet, et al., 2001).

Choosing a suitable particle size to isolate predominantly locally derived charcoal is problematic and the literature is divided on this point; size categories for principally locally derived charcoal range from >80 to >200 µm diameter (Carcaillet, et al., 2001). Previous work has shown that charcoal particles of around 200 µm or larger, tend not to be transported further than ca. 0.5 km from the burnt area under low wind-speed conditions (Wein, et al., 1987) and probably very few particles >500 µm in diameter spread beyond the edge of the burnt area (Ohlson and Tryterud, 2000). This study aims to
capture locally derived charcoal particles by separating particles with longest axes >150 µm. This size distinction has previously been used by Carcaillet et al. (2001).

### 4.3.2 Human versus natural fire in sedimentary charcoal records

Study of sedimentary charcoal alone cannot distinguish burning by humans from burning from natural causes. However, by using sedimentary charcoal in combination with other lines of evidence (e.g. palaeovegetation), some information about human fire-use can be gained. Human-fire has been detected in palaeoenvironmental records from numerous locations. For example in Britain and northern Europe a corresponding decreases in arboreal pollen and increases of micro-charcoal concentrations have been interpreted to reflect humans using fire to clear land (Moore, 2000).

### 4.4 Radiocarbon analysis

Accelerator mass spectrometry (AMS) $^{14}$C dating is a common tool used in studies of Holocene palaeoenvironments. The accuracy of this method, however, is greatly affected by the choice of material dated and the nature of the depositional environment. The dating of deltaic sediments by radiocarbon analysis is problematic. Comparisons of radiocarbon dates for several deltas show dates often to be inverted (i.e. not falling within chronological or stratigraphical order) and occasionally to be considerably older than expected. Stanley and Hait (2000) suggest the main reason for these inaccuracies is due to the temporary storage of material in river channels prior to deposition on the delta plain.

### 4.5 Magnetic susceptibility analysis

Mineral magnetic parameters of sediment archives are commonly used to investigate past environments, particularly erosion activity, soil forming processes and bacterial activity (Thompson & Oldfield, 1986). Magnetic susceptibility measurements, which estimates the ease with which a substance can be magnetised, reflect the concentration of magnetic minerals within a material. Iron is an important constituent of most rocks on the Earths surface, and the magnetic minerals detected in sediment archives are predominantly oxides of iron (Thompson & Oldfield, 1986).
5 Mid- to late-Holocene palaeoenvironments at Qingpu: pollen, charcoal and magnetic susceptibility evidence

5.1 Introduction

This chapter presents a palaeoenvironmental record, based on pollen, charcoal and magnetic susceptibility evidence, for the Qingpu study site. Chronology is provided by eight AMS $^{14}$C dates. In addition, comparisons between the palaeoenvironmental record and archaeological data are made in order both to assess environmental impacts of prehistoric cultures in the area and to identify environmental constraints affecting cultural development.

Land surrounding the Qingpu trench is rich in archaeological sites. Songze is a comparatively well studied archaeological site in the area having been excavated by the Shanghai Municipal Committee of Cultural Relics’ Protection from the 1960s to 1990s. Palynological analysis of four sedimentary layers at Songze site has been undertaken by Wang Kaifa et al. (1986). Their main findings follow. The immature soil bed underlying the cultural deposits contained abundant arboreal taxa, principally Quercus glauca and Castanopsis, while herbs were dominated by Chenopodiaceae, and to a lesser extent, Potamogeton and Poaceae. The deepest cultural layer, dating to ca. 5360 BP, was characterised by a large reduction of arboreal taxa compared with the underlying immature soil bed. Dominant herb taxa were Poaceae, Alismataceae and Potamogeton. The authors describe the middle cultural layer as belonging to the Neolithic Clan Primitive Cultural Period. This layer, like the underlying layer, was found to contain abundant Poaceae pollen. The upper cultural layer belonged to the ‘Spring and Autumn’ Period (722 – 476 BC), and contained increased amounts of arboreal pollen, including Morus, in addition to abundant Poaceae and Ceratopteris.

Other palaeoenvironmental work has also been carried out on a core section in the Qingpu area (core ZX-1), which is located to the east of the current study site (Chen, et al., 2005; Tao, et al., 2006). The palaeoenvironmental findings of that core are discussed in Chapter 3 of this thesis.
Two archaeological sites excavated relatively recently in Qingpu District are Siqian and Tangyu. Siqian site was excavated in 1990 and 1991 and covers an area of about 140 m². Objects unearthed at the site belong to the Songze (ca. 5900-5200 BP) and Liangzhu (ca. 5200-4200 BP) cultural periods (Archaeology Department Shanghai Museum, 2002b). The 200 m² Tangyu site, excavated in 1998, is thought to have been inhabited mainly during the Yuan period (1279 - 1368 AD) before being abandoned during the Ming period (1368 - 1644 AD) (Archaeology Department Shanghai Museum, 2002a).

5.2 Qingpu study site

Qingpu trench site is located southwest of Shanghai (N 31° 07.728’, E 120° 54.656’) in the low-lying central area of the delta plain (ca. 6 m a.m.s.l.) (see Figure 5.1). Land surrounding the study site was being used for both urban and agricultural purposes at the time of the visit (August 2003). Important crops in the area included rice, vegetables and orchards.

![Map showing the location of Qingpu trench site in the Yangtze delta region. The area shaded darker grey represents land of higher elevation.](image-url)

**Figure 5.1:** Map showing the location of Qingpu trench site in the Yangtze delta region. The area shaded darker grey represents land of higher elevation.
5.3 Methods

5.3.1 Sampling

An existing 1.5 m deep pit at the site was further excavated to 2.6 m depth. Following this, one trench wall was scraped clean, a stratigraphic description was made and samples were collected (Figure 5.2). Sampling involved removing contiguous blocks of sediment (10 x 5 x 5 cm) from the trench wall between the depths of 60 and 260 cm. Each section was later divided into five, 2 cm thick sub-samples and sent to The University of Western Australia for storage at 4 °C. A replicate set of samples was stored at Tongji University, Shanghai. The upper 60 cm of trench sediments contained modern components such as plastics, and lacked the structure seen in the underlying clays. It was therefore determined to have been disturbed by recent agricultural activity and was excluded from sampling and further analysis.

5.3.2 AMS $^{14}C$ dating

Eight pollen residue samples were prepared for AMS $^{14}C$ dating as no suitable macrofossils were encountered in the trench section. Preparation of the pollen residues involved: sieving (200 µm and 5 µm meshes) to remove material of a size unlikely to be pollen, 10% NaOH to remove humic acids, 15% HCl to remove carbonates, and 40% HF to remove silicates. Residues were sent to The Institute of Geological and Nuclear
Sciences, New Zealand, for dating. Dates presented here are uncalibrated radiocarbon dates unless otherwise specified.

### 5.3.3 Pollen and charcoal analysis

Pollen and charcoal analysis was conducted on 100 samples. Processing used a combined technique which allowed for the simultaneous preparation of pollen and phytolith residues. Samples of 2 cm$^3$ were treated with: 10% NaOH to remove humic acids, 15% HCl to remove carbonates, acetylisis to remove cellulose, and heavy liquid flotation (ZnBr$_2$ in water to make a solution with specific gravity between 2.3 and 2.4) to separate the pollen/phytolith fraction from the remaining material. The samples were then halved and one half was further prepared for pollen analysis: 40% HF to remove silicates, ethanol and TBA to dehydrate residues, and mounting in silicon oil on glass slides. The remaining half was prepared for phytolith analysis (see Itzstein-Davey, et al., in press-a, for further detail). Samples were spiked with *Lycopodium* spore tablets to enable the quantification of pollen and micro-charcoal concentrations. Macro-charcoal analysis was conducted on additional samples of 1 cm$^3$ and involved deflocculation in 5% Calgon solution and gentle disaggregation with a manual water spray as samples were sieved through a 150 µm mesh.

A preliminary scan of a single pollen slide was conducted in order to determine a representative number of pollen grains to count for each sample. During this scan, a comparison was made between the number of taxa observed and the number of grains counted, until a total of 400 grains were counted. Based on this comparison, it became apparent that a count of 300 grains gave an adequate representation of the taxa on the pollen slide, and was thus deemed to be a suitable ‘total pollen sum’ for the Qingpu samples. The slides were scanned under an Olympus Nikon microscope at 400 x magnification and 300 grains were counted in all samples. Identification was aided by reference to Wang *et al.* (1995) and assistance from Prof. Dodson (Australian Nuclear Science and Technology Organisation, *pers. comm.*) and Prof. Li (Xi’an Institute for Earth Environments, *pers. comm.*). Poaceae pollen was segregated into two size categories: <40 µm and > 40 µm. The larger fraction is referred to as Poaceae (*Oryza* comp.) (see Chapter 4 for more detail). Pollen counts are represented as percentages of the total pollen sum on stratigraphic diagrams. The diagrams include pollen and spore
taxa that exceeded 5% of the total pollen sum at least once, or were deemed to be of particular environmental or anthropogenic interest. Pollen zones were determined with the aid of a dendrogram created using CONISS software (Grimm, 1987, 1992). All stratigraphic diagrams were made using C2 version 1.4.2 software (Juggins, 2003).

Micro-charcoal (longest axis 5 – 150 μm) was quantified using the point-count method (Clark, 1982), and presented as concentration values (cm²/cm³) on stratigraphic diagrams. Macro-charcoal (longest axis ≥150 μm) was counted on a Nikon stereoscopic microscope at 20 x magnification and reported as concentration values (particles/cm³). During counting, macro-charcoal particles were assigned to further size categories based on the length of their longest axis. These size categories commenced at 0.15 – 0.5 mm length, and then increased in size at 0.5 mm increments to 3.0 mm length. Statistical analysis of charcoal concentrations was aided by the software SPSS statistical package version 13.0 for windows (SPSS, 2004).

5.3.4 Magnetic Susceptibility

The magnetic susceptibility of 2.5 cm³ of sediment was measured on all 100 samples. Samples were prepared by drying in an oven at 48 °C, following which the magnetic susceptibility was determined using a Bartington MS2 meter with a sensitivity of 0.1 x 10⁻⁸ SI.

5.4 Results

5.4.1 Stratigraphy and sediment analysis

The Qingpu trench section contains three distinct stratigraphic layers (Figure 5.3). High pollen concentrations are present throughout the section with all samples containing more than 11,000 grains/cm³. The lowest layer, from 196 – 260 cm depth, is composed of pale grey silt/clay and characterised by high magnetic susceptibility values which include an anomalous peak in susceptibility at 206 cm depth (21.8 k). Pollen concentrations show a high degree of variability throughout this layer. A dark grey peaty silt/clay layer occurs between 146 and 196 cm depth and contains high organic carbon content, low magnetic susceptibility and highly variable pollen concentrations. An orange/grey oxidized layer occurs between 60 and 146 cm depth, and is
characterised by relatively low organic carbon content and magnetic susceptibility values. A large peak of pollen concentration occurs at 116 cm depth (1,881,300 grains/cm$^3$); this peak underlies 40 cm of very low and stable pollen concentration values.

Figure 5.3: Stratigraphy, age-depth profile (circles represent radiocarbon dates, solid lines represent regression lines) and magnetic susceptibility ($k$) for Qingpu trench.

5.4.2 AMS $^{14}$C dating

AMS $^{14}$C dating indicates the age of Qingpu trench to range from ca. 1800 to ca. 6000 BP (Table 5.1, Figure 5.3). An age reversal occurs in the lower four dates. Problems of this type have been reported previously in delta sediments, and may result from storage and reworking of carbon prior to deposition (Stanley and Chen, 2000; Stanley and Hait, 2000). All dates have been included in calculation of sediment accumulation rates as no persuasive reason to dismiss any sample in particular as being inaccurate is apparent. It is acknowledged that this method is problematic, and may lead to an overestimation of
sediment age. Inferred ages are based on two fitted least square regression lines calculated from the radiocarbon dates. A change in sediment accumulation rate is suggested to occur where these regression lines intersect, around 202 cm depth, and a change in stratigraphy at 196 cm supports this. Regression lines indicate sediment accumulation rates to be 0.15 mm/yr below 202 cm and 2.1 mm/yr above 202 cm depth.

Table 5.1: AMS $^{14}$C dates for pollen residues from Qingpu trench. Calibrated dates are determined from the calibration curve IntCal04 (Reimer, et al., 2004) using the program OxCal v4.0.1 (Bronk Ramsey, 1995, 2001).

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Laboratory code</th>
<th>Age ($^{14}$C yrs BP)</th>
<th>Calibrated date (95.4% prob.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>62-64</td>
<td>NZA 21231</td>
<td>1827 ± 35</td>
<td>AD 85 – AD 315</td>
</tr>
<tr>
<td>120-122</td>
<td>NZA 21213</td>
<td>2152 ± 35</td>
<td>359 BC – 58 BC</td>
</tr>
<tr>
<td>182-184</td>
<td>NZA 20038</td>
<td>2386 ± 35</td>
<td>732 BC – 392 BC</td>
</tr>
<tr>
<td>210-212</td>
<td>NZA 21230</td>
<td>3853 ± 40</td>
<td>2462 BC – 2205 BC</td>
</tr>
<tr>
<td>238-240</td>
<td>NZA 22222</td>
<td>5780 ± 30</td>
<td>4708 BC – 4549 BC</td>
</tr>
<tr>
<td>242-244</td>
<td>NZA 20037</td>
<td>5600 ± 40</td>
<td>4491 BC – 4359 BC</td>
</tr>
<tr>
<td>250-252</td>
<td>NZA 22221</td>
<td>5114 ± 35</td>
<td>3979 BC – 3800 BC</td>
</tr>
<tr>
<td>258-260</td>
<td>NZA 21212</td>
<td>4920 ± 35</td>
<td>3770 BC – 3645 BC</td>
</tr>
</tbody>
</table>

5.4.3 Pollen and spore analysis

A simplified pollen diagram for the Qingpu trench section is presented in Figure 5.4. Eighty-eight pollen and spore taxa were identified in the Qingpu samples (see Appendix 2 for a full list of taxa encountered). Three distinct pollen zones are present in the Qingpu record and these were identified with the aid of CONISS software (Grimm, 1992). Their characteristics follow:

(1) Pollen Zone QP1 (260-186 cm depth, ca. 6000 – 2400 BP)

The oldest pollen zone is characterised by high proportions of arboreal taxa. Dominant arboreal taxa are Quercus, Castanopsis/Castanea and Pinus. Betula, Juglans, Diospyros and Salix are present to a lesser extent. Non-arboreal pollen is dominated by Poaceae, Artemisia, Chenopodiaceae and Brassicaceae. Poaceae (Oryza comp.) is present in low abundance in the upper 10 cm of this zone. Wetland taxa are dominated by Cyperaceae, Typha, Triglochin-Potamogetin and Pteridophytes.
(2) Pollen Zone QP2 (186-120 cm depth, ca. 2400 – 2100 BP)

The lower boundary of the second zone is marked by a major decline in arboreal pollen and a large increase of Poaceae of both size categories. *Artemisia* occurs in relatively high abundance in this zone. *Quercus* continues to dominate the arboreal taxa, although in reduced amounts. In contrast to other arboreal taxa, Moraceae/Urticaceae and *Osmanthus* pollen occur in increased abundance in this zone compared with the underlying zone. Of the wetland plants, *Cyperaceae* pollen persists, but in reduced amounts, while *Typha* and *Ceratopteris* appear in generally greater percentages than the underlying zone. The abundance of other pteridophyte spores is generally reduced compared with the pollen zone QP1.

(3) Pollen Zone QP3 (120-60 cm depth, ca. 2100 – 1800 BP)

The youngest pollen zone is characterised by abundant *Osmanthus* pollen and Poaceae of both size categories. The wetland taxa, *Cyperaceae*, *Typha* and pteridophytes, persist in values similar to zone QP2, while arboreal taxa continue in relatively low abundances. Other dominant arboreal taxa are *Pinus*, *Quercus* and *Salix*. 
Figure 5.4: Pollen and charcoal diagram for Qingpu trench, including inferred ages and pollen zones.
5.4.4 Charcoal analysis

Down-profile variations in micro-charcoal correspond with the pollen zones (Figure 5.4). Zone QP1 is characterised by large peaks of micro-charcoal, separated by periods of low concentration values. The boundary between zones QP1 and QP2 is marked by a large peak in micro-charcoal concentration (237.8 cm²/cm³). Zone QP2 is characterised by greater and more variable micro-charcoal concentrations than QP1. Micro-charcoal concentrations in the upper-most zone, QP3, are very low and display little variation compared with the lower zones.

Total macro-charcoal concentrations show considerable variation through the trench section (Figure 5.4). Total macro-charcoal concentrations are predominantly low and stable in zone QP1, however a very large peak in concentration occurs between 190 and 198 cm depth. Zone QP2 has generally high macro-charcoal concentrations, which gradually decline towards the upper boundary of the zone. As with the micro-charcoal concentrations, total macro-charcoal concentrations are low and stable through pollen zone QP3. When macro-charcoal is separated into six different size categories (Figure 5.5), most particles fall in the 0.15 – 0.5 mm size range (90.5% of total macro-charcoal particles on average) and the maximum number of particles in this size category occurs at 196 cm (3315 particles/cm³). Abundance of macro-charcoal particles declines with increasing size: particles sized 0.5 and 1.0 mm accounted for 9% of the total count on average, while particles sized 1.0 and 1.5 mm accounted for 0.5% on average. Only one particle with a longest axis greater than 2.5 mm was encountered in the trench section (at 194 cm depth).
Figure 5.5: Macro-charcoal concentrations (particles/cm$^3$) for six size categories (particles’ longest axis) and their total sum in the Qingpu trench section. Inferred ages and pollen zones are also shown.

Pearson’s correlation coefficient comparing micro- and total macro-charcoal curves produced an r-value of 0.165, a p-value of 0.1 and an $r^2$-value of 0.027, indicating no significant correlation is present between the two charcoal curves. However, when Pearson’s correlation coefficient was calculated for each pollen zone separately, significant correlations were present in two of the three pollen zones. Significant correlation between macro- and micro-charcoal curves were found in pollen zones QP2, with r, p and $r^2$ values of 0.378, 0.03 and 0.143 respectively and QP3 with r, p and $r^2$ values of 0.455, 0.011 and 0.179 respectively. No significant correlation was present in pollen zone QP1 (r = -0.001, p = 0.997 and $r^2 = 0.0$).

5.5 Discussion

5.5.1 Vegetation reconstruction and the depositional environment at Qingpu

Qingpu trench is composed of fine-grained sediments (predominantly silts and clays), which is consistent with a low-energy depositional environment such as a floodplain or periodically inundated area. Magnetic susceptibility values of the trench samples show
some down-profile variation and may reflect alterations in erosion, weathering and sedimentation in the catchment, which could result from either natural or human cause (Thompson and Oldfield, 1986; Yu, et al., 1990). The pronounced peak of increased susceptibility at 206 cm (ca. 3660 BP) suggests the occurrence of a sedimentary disturbance.

Pollen analysis indicates that between ca. 6000 and 2400 BP a mosaic of forests, wetlands and open herbaceous vegetation was present in the Qingpu area. Forests were composed of deciduous and coniferous elements, and were dominated by *Quercus, Castanopsis/Castanea* and *Pinus*. Open grassy and herbaceous areas, dominated by Poaceae, *Artemisia*, Brassicaceae and Chenopodiaceae, were present in the area prior to ca. 2400 BP, along with wetlands, which were dominated by Cyperaceae, *Typha*, *Triglochin/Potamogetin*-type, *Myriophyllum* and pteridophytes.

A widespread decline of forest vegetation occurred ca. 2400 BP. Following this, open herbaceous areas expanded and Poaceae (including *Oryza* comp.) became a major component of vegetation in the area. Contractions of forest vegetation in the late Holocene are detected in other east China pollen records, and have been interpreted to reflect climate change towards cooler and/or dryer conditions (Sun and Chen, 1991; Ren, 2007). However, human activity is the likely cause of the forest decline at Qingpu, as arboreal taxa with differing ecological tolerances decline synchronously.

### 5.5.2 Evidence of agriculture at Qingpu

Prior to ca. 2400 BP human influence on vegetation in the Qingpu area was minimal and may have been restricted to small-scale cultivation in forest openings. The forest decline ca. 2400 BP corresponds with an increase of Poaceae (including *Oryza* comp.), and is likely to mark the onset of rice agriculture near the trench site. Evidence from phytolith analysis undertaken by Dr Itzstein-Davey (Itzstein-Davey, et al., in press-b; in press-c) provides more certainty to the presence of *Oryza* in the Qingpu record. The results of both single-cell and multi-cell phytolith analyses show *Oryza* to become an important component of the vegetation ca. 2300 BP. Differences in dispersal tendencies of pollen and phytolith microfossils may account for the later appearance of *Oryza* phytoliths, compared with Poaceae (*Oryza* comp.) pollen, in the Qingpu record.
Phytoliths tend to be aerially transported shorter distances than pollen (Zhao and Piperno, 2000), and as a result the earlier appearance of Poaceae (*Oryza* comp.) pollen in the record may be due to rice growing initially in more distant source areas and then after ca. 2300 BP in areas nearer to the trench site.

The increase of *Ceratopteris* in the Qingpu record after ca. 2400 BP is consistent with an expansion of rice cultivation in the area. *Ceratopteris* is a common and widespread weed often associated with rice paddies, and furthermore, one species (*C. thalictroides*) is considered to be dependant on a rice field environment (Mineta, *et al.*, 2005; Naples, 2005). The increase of *Typha* ca. 2400 BP is also consistent with agricultural intensification in the area. *Typha* is favoured by nutrient-enriched environments (Davis, 1994; Čížková-Končalová, *et al.*, 1996) and its increase not only suggests an expansion of wetland areas and surface water, but could also indicate increased nutrient levels in the wetland areas, possibly due to fertiliser-use by farmers.

An expansion of *Osmanthus* after ca. 2100 BP marks a change in cultivation practices at the trench site. *Osmanthus* is a small evergreen tree, cultivated for its aromatic properties (Mabberly, 1987). Evidence of an early human-use of *Osmanthus* in China has been provided by the discovery of remains of *O*. *fragrans* leaves in a vessel at Changzikou Tomb, Henan province. The leaves date to the late-Shang/early-Western Zhou Dynasty (ca. 1250 – 1000 BC) and are suggested to be associated with production of a beverage (McGovern, *et al.*, 2004).

### 5.5.3 Fire activity at Qingpu

Fire regimes have also undergone change at Qingpu. It is clear that human activity has been the principle factor driving much of this change in the Qingpu area, as the slight cooling and drying of the climate since the mid-Holocene thermal optimum did not have the expected effect of increasing fire activity there. The lack of correlation between macro- and micro-charcoal concentration curves in pollen zone QP1 (ca. 6000 to 2400 BP) support generally accepted theory that charcoal particles of different sizes originate from burning in different source areas. Micro-charcoal, being more easily dispersed in the atmosphere, is commonly interpreted to originate from a relatively large regional
area, while macro-charcoal is interpreted to reflect burning relatively near to the site of deposition (Clark, 1988; Tinner, et al., 1998; Ohlson and Tryterud, 2000).

The high peaks and large variability of micro-charcoal concentrations prior to ca. 2400 BP suggest the dominant regional fire regime during this time was probably one of occasional, extensive, high intensity fires separated by periods of little or no fire activity. Much of this fire activity is likely to have occurred some distance from the trench site, as macro-charcoal concentrations are low during the period. Maximum macro-charcoal concentrations occur ca. 2450 BP, and maximum micro-charcoal concentrations occur soon after that (ca. 2426 BP). Human disturbance leading to fragmentation or openings in the forest canopy can increase forest flammability by allowing the desiccating effects of sunlight and wind to penetrate larger areas of forest biomass (see Mount, 1982; Uhl and Buschbacher, 1985; Cochrane, 2001; Nepstad, et al., 2001 for further detail). It is possible that these anomalous peaks of charcoal concentration indicate increased human influence on environments in the area, particularly as they occur alongside a change in sediment accumulation rate and are just prior to human induced vegetation changes detected in the pollen record.

After ca. 2400 BP, reduced forest vegetation and the commencement of intensive agriculture at Qingpu are accompanied by generally high micro- and macro-charcoal concentrations. The increase of macro-charcoal particles in particular, suggests local burning increased after this date. Greater local fire activity is likely to have been associated with elevated disturbance to natural vegetation in the area, particularly while intensive agriculture was being established. Reduced forest biomass, due to the widespread replacement of natural vegetation with agricultural fields in the Qingpu area, may be partly responsible for the low micro- and macro-charcoal concentrations after ca. 2100 BP, in combination with altered agricultural techniques, for example the development of flood weeding rice agriculture and low intensity stubble burning. In the southern Loess Plateau, Huang et al. (2006) similarly found fire activity to decline with the commencement of intensified agriculture ca. 1500 BP, and they attributed this to the widespread presence of agriculture in the area.
5.5.4 Comparisons with local archaeological record

Archaeological evidence indicates that human settlements were present in the Qingpu area at least by ca. 5360 BP (Wang, et al., 1986). It is therefore surprising that humans had minimal influence on environments near Qingpu trench prior to ca. 2400 BP. It is possible that prior to this time, Neolithic people were utilising the natural vegetation in the area for hunting and gathering purposes, and the areas of open, grassy and herbaceous vegetation detected in the Qingpu trench section could have been sites of small-scale cultivation. The Qingpu Neolithic people may have utilised a mixed agriculture hunting and gathering system, similar to that occurring at the Hemudu archaeological site (Zhao and Wu, 1987; Underhill, 1997). An element of resilience against years of poor crop production would have been afforded by the natural vegetation in the area, and this resilience would have been reduced after ca. 2400 BP when forest vegetation declined.

Climate change is considered to have significantly affected human cultures in the Yangtze delta region, particularly during the transition from the Liangzhu to the Maqiao culture, ca. 4000 BP (see Stanley, et al., 1999; Zhang, et al., 2005). The cultural discontinuity and possible cultural collapse at this time, is suggested to have been caused by increased flooding in the delta region (Stanley and Chen, 1996; Chen and Stanley, 1998; Yu, et al., 2000). Social factors have also been suggested as a cause for this discontinuity (Zhou and Zheng, 2000, Ding and He, 1997 cited in Zhang, et al., 2005). The results from Qingpu trench section show wetlands to have been an important component of the Qingpu landscape since the mid-Holocene, however, apart from a pronounced peak in magnetic susceptibility ca. 3660 BP, persuasive evidence for an expansion of wetland or inundated area ca. 4000 BP is not detected in the palaeoenvironmental data.
6 Agriculture and environmental change at Qingpu: a biomarker, compound specific stable isotope and palynological approach

6.1 Introduction

Analysis of molecular biomarkers and compound-specific δ\(^{13}\)C in sedimentary organic matter is useful for investigating Quaternary palaeoenvironments. The technique commonly referred to as compound specific isotope analysis (CSIA), uses isotope ratio monitoring gas chromatography mass spectrometry (irm-GCMS) to measure the δ\(^{13}\)C of individual organic compounds (Matthews and Hayes, 1978; Hayes, et al., 1990). CSIA is capable of providing a considerably wider range of palaeoenvironmental information than the δ\(^{13}\)C data of the bulk organic matter (Freeman, et al., 1990; Schoell, et al., 1994; Grice, et al., 1997; Schouten, et al., 1998; Grice, 2001), which only provides an average δ\(^{13}\)C for all compounds in a sediment sample. This chapter explores the application of biomarker and CSIA methods in investigating environmental changes in the Qingpu trench and particularly in detecting the presence of rice agriculture. In doing so, the clear need for additional techniques to study Holocene environments and agricultural development by sediment analysis, is addressed.

Organic matter in sediment deposits is the residue of past biota (Meyers, 1997). Molecular fossils or biomarkers carry a wealth of information concerning the composition, ecology and diversity of ancient communities. Many biomarkers found in sediments have also been discovered in living organisms (land plants, algae, bacteria and heterotrophs), allowing for the recognition of their precursor lipids and the establishment of a biomarker connection (Peters and Moldowan, 1993; Grice, 2001; Brocks and Summons, 2003). Lipids are the molecular components of cell membranes and include sterols, hopanols, alcohols, phosphor-lipids and ether-lipids (Cranwell, 1978, 1981; Kawamura and Ishiwatari, 1984; Meyers, 1997).

Biomarkers are often unambiguously detected by gas chromatography-mass spectrometry (GCMS) and discrete stable isotopic signatures can be measured with CSIA. In relatively immature sediments, biomarkers and their isotopic signatures may carry essential information about biotic evolution, palaeoenvironmental change and food web relationships. The alteration of indigenous biomarker signatures over...
geological timeframes can also indicate the occurrence of various physico-chemical processes (e.g. thermal maturation, degradation, fractionation and water washing). Since many factors can adversely affect the interpretation of individual biomarker relationships, a suite of biomarkers are typically assessed, along with their complimentary analytical data, to reconstruct the origin and palaeodepositional characteristics of sedimentary organic matter. However, hydrocarbon molecules, which are lacking in active functional groups, are relatively resistant to diagenetic alteration and as a result are particularly useful in the study of palaeoenvironments (Prahl and Carpenter, 1984; Cranwell, et al., 1987).

Carbon has two stable isotopes, $^{12}\text{C}$ and $^{13}\text{C}$. The ratio of these isotopes in living organisms is dependant on several factors, principally (Hayes, 1993): the $\delta^{13}\text{C}$ of the carbon source utilised by the organism, isotope fractionations associated with assimilation of carbon by the organism, and isotope fractionation associated with metabolism and biosynthesis by the organism (e.g. C$_3$, C$_4$ and CAM pathways). Carbon isotope ratios are reported in parts per mil (‰) according to the formula

$$\left(\frac{(^{13}\text{C}/^{12}\text{C})_{\text{sample}}}{(^{13}\text{C}/^{12}\text{C})_{\text{standard}}} - 1\right) \times 1000.$$  

Plants discriminate against $^{13}\text{C}$ to varying degrees during photosynthesis. Plants utilising the C$_3$ photosynthetic pathway typically have bulk $\delta^{13}\text{C}$ values between ca. -22‰ and -30‰ and account for around 76% of gross primary productivity (GPP) by plants, while C$_4$ plants typically have bulk $\delta^{13}\text{C}$ values between -10‰ and -16‰ and account for around 23% of GPP by plants (Bender, 1971; Still, et al., 2003). Plants utilising the CAM photosynthetic pathway typically have bulk $\delta^{13}\text{C}$ values between ca. -11‰ and -28‰ (O'Leary, 1981).

Biomarker and CSIA methods are increasingly being used to study Quaternary environmental change (e.g. Tareq, et al., 2005; Zhou, et al., 2005). Examples of biomarkers which, together with the $\delta^{13}\text{C}$, are useful palaeoenvironmental indicators include: lipids (e.g. n-alkanes) and terpenoids (e.g. oleanane) which can derive from angiosperm plants, selected hopanes which can derive from bacteria and algae, and highly branched isoprenoid (HBI) alkanes which can derive from diatoms (see Grice, 2001; Pancost and Boot, 2004; Peters, et al., 2005; Simoneit, 2005 for more detail). At present biomarker analysis and CSIA are not as diagnostic of higher plants as analysis of other sedimentary remains (e.g. pollen or phytoliths); they are however, promising tools which require further research to expand their use in the area of Quaternary palaeoecology.
6.2 Methods

6.2.1 Sampling, AMS $^{14}$C dating and pollen analysis

The sampling design, AMS $^{14}$C dating and microfossil analysis of Qingpu trench are described in detail in Chapter 5. The results of these analyses, however, are referred to and discussed in the present chapter.

6.2.2 Total organic carbon (TOC%) and bulk $\delta^{13}$C analysis

Total organic carbon and bulk $\delta^{13}$C were analysed simultaneously. Preparation of 33 samples for TOC% and bulk $\delta^{13}$C analysis involved washing in 16% HCl to remove all carbonates, drying in a cool (48 °C) oven and grinding to a fine powder. Sub-samples containing roughly 1000 µg of carbon were analysed. Analysis of TOC% and $\delta^{13}$C were carried out at the West Australian Biogeochemistry Centre, using a Tracermass Ion Ratio Mass Spectrometer and Roboprep preparation system. The method involved combustion at 1000 °C, removal of excess oxygen at 600 °C and separation at 110 °C by gas chromatography. Calibration was performed using known international $^{13}$C reference samples (NBS-19, NBS-18 and NBS-22). Atropine and Acetanilide were used to calibrate the system for TOC%.

6.2.3 Lipid analysis

Twelve samples from Qingpu trench underwent lipid analysis. The chosen samples were those with a relatively high TOC%, and those which gave good depth representation of the trench. The samples were prepared by: drying in a cool oven (48 °C), gentle grinding, and extraction by accelerated solvent extraction using 90% dichloromethane and 10% methanol as solvents. Aliquots of the extracts were fractionated into subsequent fractions by silica gel chromatography (50 mm x 5 mm, 150 °C, overnight) and pre-eluted with n-hexane. Gradient elution was obtained using solvents of increasing polarity with approximately two column volumes of solvent in all cases. Fractionation of the extracts yielded three fractions: a saturated hydrocarbon fraction (hexane), an aromatic hydrocarbon fraction (20% dichloromethane in hexane), and a polar fraction (50% dichloromethane in methanol). The solvent from each fraction was carefully removed on a heated sand bath (80 °C). The saturated and aromatic hydrocarbon fractions were analysed by gas chromatography-mass spectrometry (GC-
MS) and quantified using an internal standard which was added to the samples to allow estimation of relative compound concentrations (in μg/g of TOC).

6.2.4 Gas chromatography-mass spectrometry (GC-MS)

GC-MS analysis was performed at the Stable Isotope and Molecular Biogeochemistry Group, Department of Applied Chemistry at Curtin University of Technology, Australia. GC-MS analysis was conducted on an HP 5973 MSD interfaced to HP 6890 gas chromatograph, which was fitted with a 60 m x 0.25 mm i.d. column containing a DB-1 phase (J and W Scientific, 0.25 μm phase thickness). The GC oven was programmed from 40 °C to 300 °C at 3 °C/min with initial and final hold times of 1 and 30 minutes, respectively. Samples were dissolved in hexane and injected on-column using a HP 6890 auto-sampler. Helium was used as the carrier gas at a linear velocity of 28 cm/sec with the injector operating at constant flow. Typically the MS was operating at ionisation energy of 70 eV, a source temperature of 180 °C, with an electron multiplier voltage of 1800 V and a mass range of 50 to 550 amu.

6.2.5 Metastable reaction monitoring (MRM-GC-MS)

Samples were analysed by MRM-GC-MS at the Stable Isotope and Molecular Biogeochemistry Group, Department of Applied Chemistry at Curtin University of Technology, Australia. Hopanes and methyl-hopanes were analysed on a VG AutospecQ, equipped with an HP5890 Series II gas chromatograph and a DB-5 coated capillary column (60 m × 0.25 mm i.d., 0.25 μm film thickness) using helium as carrier gas. Samples were injected in splitless mode. The GC oven was programmed at 35 °C (1 min), heated to 235 °C at 10 °C/min, and then to 315 °C at 2 °C/min with a final hold time of 30 min. The source was operated in EI-mode at 70 eV ionization energy and 8 kV acceleration voltage. The mass spectrometer was operated in MRM function using 20 selected transition channels with a scan time of 1.4 seconds over a mass range of 50 to 500 Da. Data were acquired and processed using OPUS V3.5.

6.2.6 Isotope ratio monitoring gas chromatography-mass spectrometry (irm-GCMS)

Irms-GCMS analysis was undertaken at the Stable Isotope and Molecular Biogeochemistry Group, Department of Applied Chemistry at Curtin University of
Technology, Australia. The analyses were performed on a Micromass IsoPrime irm-GCMS mass spectrometer. The IsoPrime is an upgraded version of the Isochrome and consists of a gas chromatograph, combustion unit and a dual reference gas injection system, all on line with an isotope ratio mass spectrometer fitted with an electromagnet. For CSIA, the samples were dissolved in hexane and analysed using an HP 6890 gas chromatograph equipped with an autosampler and a split/splitless injector and helium carrier gas. A 60 m x 0.25 mm i.d. column containing a DB-1 phase (0.25 µm phase thickness) was used and the sample was injected using pulsed splitless mode (injection holding for 30 seconds at 15 psi above the head pressure of the column and the purge time of 35 seconds). The flow rate used was kept constant at 1 ml/min. The GC oven was programmed from 40°C (1 min) to 300 °C at 3 °C/min and held isothermally at 300 °C for 30 min. The isotopic compositions were calculated by integration of the masses 44, 45 and 46 ion currents of the peaks produced by combustion (in a CuO quartz packed tube, 850 °C) of the gas chromatographically separated compounds. The compositions are reported relative to those of CO₂ pulses produced by allowing CO₂ of a known ¹³C content into the mass spectrometer. Values reported are averages of at least two runs and standard deviations are ±0.4‰ or less. The stable carbon isotopic compositions are reported in the delta notation relative to the Vienna Pee-Dee Belemnite (VPDB) carbonate standard.

6.3 Results

6.3.1 AMS ¹⁴C dating, TOC% and bulk δ¹³C

The AMS ¹⁴C dates reveal the age of the trench sediment to span from ca. 1800 to ca. 6000 BP (Chapter 5: Table 5.1). Inferred ages are based on two least square regression lines to fit the radiocarbon dates (Figure 6.1). A change in sediment accumulation rate is suggested to occur where these lines intersect, at around 202 cm depth. A change in accumulation rate is further supported by a stratigraphic change which occurs near to this depth; around 196 cm. Regression lines indicate mean sediment accumulation rates to be 0.15 mm/yr below 202 cm and 2.1 mm/yr above 202 cm.

Total organic carbon content for the 12 Qingpu samples ranges between 0.6% and 5.8% and the bulk δ¹³C range between -28‰ and -24.4‰ (Figure 6.1). The bulk δ¹³C indicates that plants and algae utilising the C₃ photosynthetic pathway contribute largely to the organic matter (Deines, 1980).
6.3.2 Pollen and spore content

A full description of the pollen and spore content of Qingpu trench is provided in Chapter 5. In brief, three main types of vegetation were found. From 260 – 186 cm (ca. 6000 – 2400 BP) a mosaic of forest, open herbaceous and wetland vegetation occurred in the area. Dominant taxa were Quercus, Castanopsis/Castanea and Pinus in forested areas, and Artemisia, Chenopodiaceae, Brassicaceae, Cyperaceae and Typha in herbaceous and wetland areas. From 186 – 120 cm (ca. 2400 – 2100 BP) herbaceous vegetation dominates, with principle taxa being Poaceae (including Oryza comp.). The reduced forest vegetation continues to be dominated by Quercus, Castanopsis/Castanea and Pinus. Between 120 – 60 cm (ca. 2100 – 1800 BP) vegetation in the area is distinguished by Osmanthus, open herbaceous areas (dominated by Poaceae (including Oryza comp.)), and wetlands. Forest vegetation persists in reduced amounts.

6.3.3 Biomarkers

Several compounds which are likely to be derived from algal, bacterial and higher plant sources were identified in the trench sediment. An example GC-MS trace for the sample at 172 cm depth is shown in Figure 6.2 (see Appendices 8 and 9 for all GC-MS traces).

Figure 6.1: Qingpu trench inferred age, stratigraphy, AMS 14C dates and best-fit regression lines, magnetic susceptibility (low frequency), TOC% and bulk δ13C values.
3β-methyl-hopanes were identified by MRM-GC-MS. Concentrations of selected specific compounds are shown in Table 6.1 and Figure 6.3 and structures of selected biomarker compounds are shown in Figure 6.4. Stable carbon isotopic compositions of the biomarkers are reported in the delta notation in per mil relative to the VPDB carbonate standard and are listed in Table 6.2.

Figure 6.2: GCMS trace of the saturated hydrocarbon fraction of Qingpu trench at 172 cm depth.
Table 6.1: Concentrations of compounds identified in Qingpu trench (in µg/g TOC).

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>n-C_{27}</th>
<th>n-C_{28}</th>
<th>n-C_{29}</th>
<th>n-C_{30}</th>
<th>n-C_{31}</th>
<th>C_{30} HBI</th>
<th>Diploptene</th>
<th>Perylene</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>5.3</td>
<td>1.5</td>
<td>9.8</td>
<td>1.2</td>
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<td>0.0</td>
<td>0</td>
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<tr>
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<td>3.4</td>
<td>0.2</td>
<td>1.9</td>
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<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>88</td>
<td>3.7</td>
<td>1.1</td>
<td>5.9</td>
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<td>1.0</td>
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<tr>
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<td>1.0</td>
<td>0.2</td>
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<td>0.0</td>
<td>0.1</td>
<td>0</td>
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<td>18.2</td>
<td>5.5</td>
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<td>7.9</td>
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<td>27.8</td>
<td>8.7</td>
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<td>20.4</td>
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</tr>
<tr>
<td>196</td>
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<td>4.2</td>
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<td>4.1</td>
<td>1.5</td>
<td>1.0</td>
<td>5.5</td>
</tr>
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<td>3.3</td>
<td>14.1</td>
<td>1.1</td>
<td>2.6</td>
<td>67.4</td>
</tr>
</tbody>
</table>
Figure 6.3: Perylene, diploptene and C$_{25}$HBI concentrations (µg/g TOC), total odd carbon number $n$-alkane concentration (µg/g TOC, C$_{27}$+C$_{29}$+C$_{31}$+C$_{33}$), mean carbon number (MC#), total Poaceae pollen (both size fraction %) and pollen zones with inferred vegetation for Qingpu trench. MC# = $\Sigma$[C$_i$] x C$_i$/Σ[C$_i$], where [C$_i$] is the concentration of the $n$-alkane with carbon number C$_i$, over the range 27-31 (Pelzer and Gagosian, 1989).
Table 6.2: $\delta^{13}C$ of biomarkers identified in Qingpu trench

<table>
<thead>
<tr>
<th>Compound</th>
<th>$\delta^{13}C$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$-alkanes (C$<em>{27}$-C$</em>{33}$)</td>
<td>-29.8 to -36.0</td>
</tr>
<tr>
<td>Diploptene</td>
<td>-39.6 to -47.4</td>
</tr>
<tr>
<td>C$_{31}$ 3β-methyl-hopane</td>
<td>-38.2 to -46.8*</td>
</tr>
<tr>
<td>C$_{20}$ HBI alkane</td>
<td>-32.3 to -33.9</td>
</tr>
<tr>
<td>Perylene</td>
<td>-26.5 to -27.6</td>
</tr>
</tbody>
</table>

* 3β-methyl-hopane coelutes with a regular hopane, although the 3β-methyl-hopane is a large part of the combined peak.

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6.3.4 Higher plant derived hydrocarbons

The $n$-alkane distributions display an abundance of $n$-alkanes in the C$_{25}$-C$_{33}$ carbon number range with an odd/even preference, which are attributed to higher plant waxes (see Eglinton and Hamilton, 1967). The most abundant components are $n$-C$_{27}$, $n$-C$_{29}$ and $n$-C$_{31}$ and their concentrations vary between 0.5 and 27.5 µg/g TOC (Table 6.1). Stable carbon isotope ratios are between -29.8‰ and -36.3‰ for the C$_{27}$-C$_{33}$ $n$-alkanes (Table 6.2), which are consistent with a predominant C$_3$ plant input (Riely, et al., 1993).

The mean carbon number (MC#) was calculated for $n$-alkanes within the range C$_{27}$-C$_{31}$. MC# may follow changes in the plant contribution to sediments, in particular, changes in the dominance of grasses versus arboreal vegetation (see Fisher, et al., 2003; Tareq, et al., 2005 for more detail). The results support this finding, as MC# values show a similar trend to Poaceae pollen percentages (Figure 6.1). Pearsons correlation coefficient comparing the MC# values with Poaceae percentages of the same samples...
produced an r-value of 0.673, a p-value of 0.016 and an r²-value of 0.453, indicating that a significant correlation is present.

**6.3.5 Biomarkers from organisms associated with an active methane cycle**

A dominant input from a C₃₁ 3β-methyl-hopane identified by MRM was detected in several samples. 3β-methyl-hopanes are diagnostic of some microaerophilic proteobacteria, particularly type 1 methanotrophs (Summons and Jahnke, 1992). Although the C₃₁ 3β-methyl-hopane was coeluting with a regular hopane, the δ¹³C data for these compound peaks range between -38.2‰ to -46.8‰, and support a source from an organism feeding on ¹³C-depleted methane (Zundel and Rohmer, 1985; Summons, et al., 1994; Cvefic, et al., 2000). The biomarker diploptene was also identified in the samples at a maximum concentration of 8.7 μg/g TOC at 172 cm (Table 6.1). δ¹³C of diploptene ranged from -39.6‰ to -47.4‰ (Table 6.2), which is consistent with a dominant methanotrophic bacterial origin (Summons, et al., 1994).

The recovery of highly ¹³C-depleted biomarkers (3β-methyl-hopanes and diploptene) points strongly to the presence of an active methane cycle in the environment. This finding is consistent with the presence of natural wetlands and rice fields in the area, as those ecosystems are seen as two major sources of global atmospheric methane (Ruddiman and Thomson, 2001).

**6.3.6 The source of the C₂₀ Highly Branched Isoprenoid (HBI) alkane**

The saturated C₂₀ HBI and its monoene have been found in both marine and freshwater sediments (Rowland, et al., 1985). The structural similarity of the C₂₀ HBI to two diatom biomarkers – the C₂₅ and C₃₀ HBIs – led Sinninghe Damste et al. (2005) to suggest a diatom source for the C₂₀ HBI. The C₂₀ HBI however has not been identified in any cultured diatoms (Volkman, et al., 1998; Sinninghe Damste, et al., 2005), although it has been identified in field samples of algal aquatic macrophytes, Chara sp. and Enteromorpha prolifera (Rowland, et al., 1985; Jaffe, et al., 2001) where a suggested biological source for its presence was epiphytic algae (Volkman, et al., 1998). The C₂₀ HBI and its monoene show a maximum concentration (27.8 μg/g TOC) at 172 cm. They also show a similar concentration pattern to diploptene and the higher plant waxes as described above. The δ¹³C of the C₂₀ HBI in five samples ranges between -32.3‰ and
-33.9‰. These values are very similar to the δ¹³C for the C₃₁ n-alkane in the same samples (Figure 6.5). The source of the C₂₀ HBI is presently unknown (Sinninghe Damste, et al., 2005) but the similar δ¹³C of the C₂₀ HBI to that of the C₃₁ n-alkane implies these components originate either from the same source organism, or originate from organisms utilising similar carbon sources. The similar δ¹³C of the HBI to the δ¹³C of the C₃₁ n-alkane might be consistent with an epiphytic algal source. Interestingly the macrophyte Chara sp. has been associated with rice agriculture (e.g. Guha, 1995). An alternative carbon source available to the biological source organisms of the two biomarkers might be CO₂ formed by methane oxidation. A similar in situ recycling of methane has been demonstrated to occur in peat bogs between methanotrophic bacteria and Sphagnum moss (Raghoebarsing, et al., 2005).

Figure 6.5: δ¹³C for C₂₀ HBI and C₃₁ n-alkane for Qingpu samples.

6.3.7 Perylene

The depth distribution of perylene concentrations is markedly different to those of other biomarkers (Figure 6.3). Perylene concentrations increase with depth (maximum value 67.4 µg/g TOC at 256 cm depth); the compound was not detected in samples above 160 cm depth. Previous authors have found perylene concentrations to increase rapidly with depth (e.g. Jiang, et al., 2000), and this has been suggested to be due to the formation of the compound in sediments during early diagenesis after deposition (Hites, et al., 1980; Wakeham, et al., 1980; Jiang, et al., 2000). The δ¹³C of perylene, which range from
-26.5‰ to -27.6‰ (see Table 6.2), suggests the compound derives from a difference source to the n-alkanes of probable plant wax origin. The deuterium content of the same samples has been analysed by Erin James (Curtin University of Technology). The δD of perylene, which was found to range from -206‰ to -292‰, is consistent with a precursor associated with wet environmental conditions and high rainfall (James, 2007).

The biogenic source of the perylene precursors is unclear. Perylene has been found in a variety of depositional environments including marine (Silliman, et al., 2000; Medeiros, et al., 2005), lake (Zarate-del Valle, et al., 2006) and river sediments (Countway, et al., 2003; Boonyatumanond, et al., 2006), as well as peat deposits (Aizenshtat, 1973; Venkatesan, 1988; Jiang, et al., 2000). Terrestrial plants (Aizenshtat, 1973; Jiang, et al., 2000; Countway, et al., 2003; Dahle, et al., 2003), fungi (Jiang, et al., 2000), termite nests (Wilcke, et al., 2003), and diatoms (Wakeham, et al., 1979; Hites, et al., 1980; Venkatesan, 1988) have been suggested as sources of perylene. Also, trace amounts of perylene can be generated through combustion of fossil fuel (Boonyatumanond, et al., 2006).

6.4 Discussion

C₃ plants are a dominant input throughout the Qingpu sedimentary record, as indicated by the bulk organic matter having δ¹³C values in the C₃ plant range (δ¹³C values range from -23.6‰ to -28.0‰) and by the presence long-chain n-alkane waxes (with odd/even preference and isotope values between -29.8‰ and -36.0‰). This is consistent with the findings of pollen analysis which shows forest vegetation to be dominant in the area prior to ca. 2400 BP. Biomarker results showing the presence of ¹³C-depleted diploptene, likely to originate from methanotrophic bacteria (Summons and Jahnke, 1992), in all samples older than ca. 2400 BP, support the findings of the pollen analysis which indicate wetland vegetation to be a major feature of the area prior to ca. 2400 BP.

Rice plants utilise the C₃ photosynthetic pathway (Smith and Brown, 1973), as is common in grasses of temperate climates or high altitudes. Grasses using the C₄ photosynthetic pathway tend to occur in warm, monsoonal and tropical climates (Twiss, 1992; Ehleringer and Monson, 1993). The Yangtze delta region, with a climate including both monsoonal and temperate elements, has both C₃ and C₄ grasses. Vegetation surveys conducted last century have been used to estimate percentages of C₄
photosynthesis in grasses in areas of east China. Estimates for Anhui and south Jiangsu Province are 53% to 48% respectively (Sage, et al., 1999). Given the large areas used for rice cultivation in those provinces (see Xu, et al., 2006), it is likely that estimates excluding cultivated rice would yield much greater percentages of C₄ photosynthesis by grasses. C₃ plants dominate the Qingpu area after ca. 2400 BP, as indicated by the long-chain n-alkane waxes (with odd/even preference and isotope values between -29.8‰ and -36.3‰) and bulk organic matter δ¹³C values in the C₃ plant range. This high C₃ plant input occurs together with high percentages of Poaceae pollen (including Oryza comp.), and Oryza phytoliths (Itzstein-Davey, et al., in press-b; in press-c), and implies that C₃ grasses were a dominant component of the vegetation after ca. 2400 BP. This input is consistent with rice agriculture being present in the area, although it is difficult to determine what proportion of other C₃ grasses were also present at the time.

The C₂₀ HBI has previously been reported in field samples of Chara sp. (Jaffe, et al., 2001), which is a common weed of rice paddies (Guha, 1995; Ariosa, et al., 2004). Its presence there was suggested to be due to a source from epiphytic algae occurring on the Chara sp. (Jaffe, et al., 2001). The C₂₀ HBI and its monoene found in the Qingpu trench sediment may have a similar origin, of either epiphytic algae or Chara sp. Both sources, however, are consistent with a rice paddy ecosystem being present in the area. Methane produced in rice paddies is a major source of global atmospheric methane, and rice farmers may have been causing elevated global atmospheric methane levels from as early as 5000 BP (Ruddiman and Thomson, 2001). Methane oxidation by the methanotrophic bacteria occurring at Qingpu trench site is suggested by the ¹³C-depleted C₃₁ 3ß-methyl-hopane and diploptene. The similar concentration profiles for the C₂₀ HBI and C₃₁ n-alkane (attributed to C₃ plants) with depth, and the similar δ¹³C values of the C₂₀ HBI and C₃₁ n-alkane, indicate the HBI source organism was utilizing a similar carbon source to the C₃ plants. Given that the depositional environment is characterized by an active methane cycle, CO₂ formed by methane oxidation could have provided a carbon source for the plants (i.e. rice) and algae inhabiting the ecosystem (see Raghoebarsing, et al., 2005).

Throughout the study period, ca. 6000 – 1800 BP, wetlands were present in the area, as evidenced by input from a strong methane cycle and wetland plant taxa. This wetland environment would have been attractive to rice farmers, as they would not have required sophisticated irrigation techniques to manage water levels (Smith, 1995). However,
Despite Neolithic cultural sites being located in the Qingpu area (many within 15 km of the trench site) during the early part of the Qingpu record (Stanley and Chen, 1996), human alteration to environments near the Qingpu trench site is minimal prior to ca. 2400 BP. Increased inputs from C\textsubscript{3} grass, methanotrophic bacteria and a C\textsubscript{20} HBI which may originate from epiphytic algae, occur ca. 2400 BP and may indicate the beginnings of rice paddy dominance in environments near Qingpu trench site.

Although this study does not find biomarker evidence capable of being used as a single proxy for detection of rice agriculture, it does provide a suite of interesting biomarkers which, in combination with palynological evidence, provide evidence to support the presence of a rice paddy ecosystem. Coupling palynological analysis with analysis of biomarkers and stable isotopes is a novel approach to detecting early agricultural environments and if used in other areas of Asia has the potential to improve understanding of the spread and development of rice agriculture in the region.
7 A palaeoenvironmental record from Guangfulin

7.1 Introduction

This chapter presents a palaeoenvironmental record for Guangfulin trench site using the sediment proxies: pollen, charcoal, magnetic susceptibility and particle size analysis. Chronology is defined by eight AMS $^{14}$C dates. Numerous archaeological sites exist in the Guangfulin area, including the recently excavated ‘Guangfulin archaeological site’ which has yielded remains spanning a period from the Liangzhu culture (ca. 5200-4200 BP) to the Eastern Zhou dynasty (770 – 221 BC) (Zhang, et al., 2003; Cheng, et al., 2006). The site is well known for its pottery remains, which hold evidence of early cultural connections between the Delta region and more northern regions (Zhang, et al., 2003).

Preliminary pollen and phytolith analyses have been conducted on samples collected from cultural layers of the excavation pits at Guangfulin archaeological site (see Chen, 2002; Zhang, et al., 2002). Phytolith analysis was conducted on 13 samples and the findings indicate rice to have been growing in the area by ca. 5000 BP (Zhang, et al., 2003). Pollen analysis of samples dating to ca. 5300 BP found Poaceae to be dominant in the area since that time. Pollen analysis also found evidence for an intensification of agricultural around the early- to mid-Liangzhu culture (Chen, 2002; Li, et al., 2006a). This chapter builds on these previous investigations by providing a continuous and higher resolution palaeoenvironmental record for the Guangfulin area.

7.2 Guangfulin trench site

Guangfulin trench site (N 31º 3.870”, E 121º 11.500”) is located on flat farming land near to the Sheshan hills, ca. 40 km southwest of Shanghai, (Figures 7.1, 7.2 and 7.3). The trench site is located within an agricultural area where principle crops are rice, vegetables and fruits. Land immediately surrounding the trench site was undergoing a rotation of rice and legumes at the time of the visits. Guangfulin trench site was visited twice for the current research: in 2003 samples were collected from a 2 m deep trench for a pilot investigation (Guangfulin pilot trench), and in 2005 a 1.9 m deep trench was excavated and sampled for the main study (Guangfulin trench). A sediment core was
also collected during the first visit, however, due to poor sediment recovery during coring (approximately 30% of sediment was lost in each core section) the core was deemed unsuitable for further analysis. The two trenches are located several metres apart and are approximately 200 metres south of the excavation pits for the Guangfulin archaeological site.

![Figure 7.1](image_url)

**Figure 7.1:** Location of Guangfulin archaeological site and trench site in the Yangtze delta region. The area shaded darker grey represents land of higher elevation.
Figure 7.2: View of fields at Guangfulin trench site in October 2003. Rice is the principle crop being grown in the area during the initial visit. The Sheshan hills can be seen in the background.

Figure 7.3: View of fields at Guangfulin trench site in April 2005. Legumes were the principle crop at the time of this visit.
7.3 Guangfulin pilot study

7.3.1 Guangfulin pilot study: methods

Guangfulin pilot trench was excavated to a depth of 2 m (Figure 7.4). A total of 24 samples were collected in 2 cm thick slices taken at 4 cm intervals between the depths of 18 and 96 cm (Figure 7.5). Samples were sealed in plastic bags and transported to the laboratories of The University of Western Australia where they underwent analysis. Two duplicate sets of samples were collected, one of which was sent to Trinity College, Dublin, for phytolith analysis, the remaining set was stored in laboratories at Tongji University, Shanghai. The basic trench stratigraphy was described in the field prior to sampling.

Figure 7.4: Digging Guangfulin preliminary trench, October 2003. Note pottery to the digger’s left.
Figure 7.5: Guangfulin preliminary trench wall, after sampling.

AMS $^{14}$C dating was undertaken on pollen residues of two samples. Preparation involved sieving (200 µm and 5 µm meshes) and washing in 10 % NaOH, 15 % HCl, and 40 % HF. Residues were sent to The Institute of Geological and Nuclear Sciences, New Zealand, for dating. All dates presented here are uncalibrated radiocarbon dates unless otherwise specified.

Subsamples of 1 cm$^3$ were prepared for pollen and micro-charcoal analyses. Preparation procedures followed standard techniques outlined in Moore et al. (1991) and involved treatment with 10 % NaOH to remove humic acids, 15 % HCl to remove calcareous minerals, 40 % HF to remove silicates, acetolysis to remove additional unwanted organic material and mounting in silicone oil. All samples were spiked with Lycopodium spore tablets. Pollen identification and counting were carried out using an Olympus Nikon microscope at 400 x magnification. A total of 300 pollen and spore grains were counted for each sample and counts are presented on the pollen diagram as percentages of the total pollen sum. Poaceae grains > 40 µm were counted separately and referred to as Poaceae (Oryza comp.). Micro-charcoal (longest axis 5-150 µm) was quantified using the point-count method (Clark, 1982), and is presented as concentration values (cm$^2$/cm$^3$).

The pollen diagram was created using C2 version 1.4.2 software (Juggins, 2003) and includes taxa best showing main vegetation changes. The raw pollen and micro-charcoal data are presented in Appendix 4 of this thesis. Microfossil zones are based on changes in pollen and charcoal curves and were determined with the aid of CONISS software (Grimm, 1987, 1992).
7.3.2 Guangfulin pilot trench: Results

7.3.2.1 Stratigraphy

The trench section includes four stratigraphic layers (Figure 7.6): a dark grey organic-rich layer from 65-98 cm depth, a gradual boundary from 60-65 cm depth, a light brown dry crumbly layer from 46-60 cm depth, and a dark grey organic-rich clay layer from 18-46 cm depth.

Figure 7.6: Stratigraphy, total pollen concentration, AMS $^{14}$C dates and regression line for Guangfulin pilot trench.
7.3.2.2 AMS $^{14}$C Dating

The results of the AMS $^{14}$C dating indicate that the trench section dates to the mid- to late-Holocene (Table 7.1). Inferred ages are based on a least squares regression line calculated from the radiocarbon dates (Figure 7.6). It is acknowledged that two radiocarbon dates are probably an insufficient number to extrapolate inferred ages and sediment accumulation rates. The inferred ages are therefore treated with caution and considered here only within the context of a pilot investigation.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lab reference</th>
<th>Age ($^{14}$C yrs BP)</th>
<th>Calibrated date (95.4% prob.)</th>
<th>Dated material</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>NZA 21232</td>
<td>3245 ± 40</td>
<td>1614 BC – 1435 BC</td>
<td>pollen residue</td>
</tr>
<tr>
<td>94</td>
<td>NZA 21233</td>
<td>4492 ± 40</td>
<td>3352 BC – 3030 BC</td>
<td>pollen residue</td>
</tr>
</tbody>
</table>

7.3.2.3 Pollen and Charcoal Analysis

Total pollen concentrations were generally high, with values ranging from 15,420 grains/cm$^3$ at 94 cm depth to 221,329 grains/cm$^3$ at 42 cm depth (Figure 7.6). The three zones identified with the aid of CONISS software (Grimm, 1987, 1992) are shown on the pollen diagram (Figure 7.7). The main characteristics of these zones are described in the following paragraphs:

The deepest identified zone, GP 1 (94 - 56 cm, ca. 4500 – 3400 BP), is characterised by high proportions of wetland and dryland herb taxa. Of the wetland herbs, *Typha*, Cyperaceae and *Persicaria* are dominant. The dryland herbs are dominated by Poaceae (both size categories), *Artemisia* and Chenopodiaceae. Arboreal taxa are present, and of these, *Quercus*, *Carpinus*, *Salix* and Moraceae/Urticaceae dominate. Micro-charcoal concentrations are highest in this zone, and a large peak occurs at 88 cm (36.3 cm$^2$/cm$^3$).

Zone GP 2 (56 – 30 cm, ca. 3400 – 2600 BP) differs from the underlying pollen zone (GP 1) by having a slightly greater abundance of Poaceae and *Triglochin/Potamogetin* pollen. Other pollen taxa persist in similar abundances to the underlying zone. Micro-charcoal concentrations are generally reduced and do not display a high degree of variability.
The upper-most zone, GP 3 (30 – 18 cm, ca. 2600 – 2200 BP), is dominated by high proportions of *Osmanthus* pollen. *Pinus* abundance is also increased, while *Quercus*, *Salix*, Moraceae/Urticaceae and *Carpinus* percentages are reduced. *Typha* and Poaceae pollen are reduced in this zone, however, Poaceae (*Oryza* comp.) shows little difference to the underlying zone (GP 2). Micro-charcoal persists in relatively low and stable concentrations.
Figure 7.7: Pollen diagram for Guangfulin pilot trench, including micro-charcoal concentrations and inferred ages.

Chapter 7: A palaeoenvironmental record from Guangfulin
7.3.3 Guangfulin pilot trench: Discussion

Over the study period (ca. 4500 – 2200 BP), vegetation in the Guangfulin area is dominated by open herbaceous and wetland vegetation. Grasses are dominant, and the relatively high percentages of Poaceae (*Oryza* comp.) suggest that rice may have been cultivated throughout the study period. More conclusive evidence for the presence of rice is not available, as phytolith analysis has not been conducted on sediments from this pilot trench. Wetlands in the area are dominated by *Typha* and Cyperaceae. Given the possible presence of rice agriculture, much of the wetland area could be associated with irrigated rice fields, with *Typha* and Cyperaceae inhabiting bordering irrigation canals and water storage ponds.

The dominance of *Osmanthus* pollen in the youngest pollen zone, GP 3, suggests that the plant was being cultivated in the area. However, the upper pollen zone, GP 3, occurring from 18 – 30 cm depth, is very shallow, and could have readily been disturbed by recent farming activities. Also, the lack of radiocarbon dates above 30 cm depth lends a degree of uncertainty to the inferred ages of this upper zone. Disturbance of this upper zone is supported by subsequent analysis of the main Guangfulin trench (described in following paragraphs) which reveals an absence of *Osmanthus* pollen in sediment of supposedly similar age. It is probable that this upper section has been disturbed somewhat, and therefore should not be considered further.

Given the good pollen preservation in this trench and apparent human indicators in the pollen record, the site was decided to warrant further investigation. It was predicted that a second deeper trench, with a larger number of AMS $^{14}$C dates, would prove useful for investigation of palaeoenvironmental change and human-environment interactions in the Guangfulin area.

7.4 Guangfulin main trench: methods

7.4.1 Trench site and sampling design

The main Guangfulin trench was excavated to a depth of 1.9 m (Figure 7.8). A total of 53 samples were collected for analysis, and these consisted of 2 cm thick slices taken at 5 cm intervals between 191 and 144 cm depths, and 2 cm thick slices taken contiguously between 140 and 40 cm depths. The upper 40 cm was excluded from sampling as it lacked the structure of underlying sediments and was therefore likely to
have been disturbed by recent agricultural activities. A fast rate of water seepage into the trench prevented the sampling of deeper sediments. Numerous pottery fragments were recovered from the trench during digging (Figure 7.9).

Figure 7.8: Guangfulin trench prior to sampling. Some stratigraphic change in colour is visible on this exposed trench wall.
7.4.2 AMS $^{14}$C dating

Eight samples from the trench were submitted for AMS $^{14}$C dating. Five of these samples were pollen residues, the preparation of which involved treatment with: 10% NaOH to remove humic colloids, 15% HCl to remove carbonates, 40% HF to remove silicates, and sieving through a 5 µm mesh to remove fine material. The three remaining samples were made up of macrofossils: a wood fragment collected at 62 - 64 cm depth, a large charcoal fragment collected at a depth of 88 cm, and charcoal fragments (>150 µm) hand-picked under a stereomicroscope from a depth of 174 cm. The preparation of macro-fossil samples for dating involved an acid-base-acid pre-treatment using 30% HCl and 10% NaOH. AMS $^{14}$C analysis was conducted at The Institute of Geological and Nuclear Sciences, New Zealand. Dates presented here are uncalibrated radiocarbon dates unless otherwise specified.

7.4.3 Magnetic susceptibility and particle size analysis

The magnetic susceptibility of 10 g of sediment, oven dried at 38ºC, was measured using a Bartington MS2 meter with a sensitivity of 0.1 x 10^-8 SI. Samples for particle size analysis were pre-treated with 15% H$_2$O$_2$, 12% HCl and 5% Calgon solution and measured on a Beckman Coulter LS 230, with a measuring range of 0.04 - 2000 µm.
7.4.4 Pollen and charcoal analysis

Processing for pollen and micro-charcoal analysis followed standard pollen techniques outlined in Moore et al. (1991): 1 cm$^3$ samples were treated with 10% NaOH to remove humic acids, 15% HCl to remove calcareous minerals, 40% HF to remove silicates and acetolysis to remove unwanted organic matter. Due to low pollen concentrations towards the base of the trench, an additional 2 cm$^3$ was processed for samples at 149, 154 and 184 cm depths, and 3 cm$^3$ for samples at 159, 169, 179 and 189 cm depths. Lycopodium spores were added prior to processing to allow for estimation of pollen and micro-charcoal concentrations. Pollen residues were mounted in silicon oil and scanned under an Olympus Nikon microscope at 400 x magnification. Pollen counts are expressed as percentages of the total pollen sum, which was 300 in all samples except two: samples at 164 and 174 cm depth had pollen sums of 241 and 236 grains respectively. Micro-charcoal (5-150 µm) was quantified using the point-count method (Clark, 1982) and presented as concentration values (cm$^2$/cm$^3$).

Fifty-three samples of 1 cm$^3$ were prepared for macro-charcoal (>150 µm) analysis, which involved gentle disaggregation in 5% Calgon solution and sieving through a 150 µm mesh. All charcoal particles larger than 150 µm were counted under a stereomicroscope at 20 x magnification and reported as concentrations (particles/cm$^2$) on stratigraphic diagrams. During counting, macro-charcoal particles were assigned to six further size categories, which were based on the length of their longest axis. These length categories began with a longest axis size of 0.15 – 0.5 mm, then increased at 0.5 mm increments from 0.5 mm to 3.0 mm. Statistical analysis of charcoal concentrations was performed with the SPSS statistical package version 13.0 for windows (SPSS, 2004).

Pollen identification was made with reference to Wang et al. (1995) and the assistance of Prof. Dodson (Australian Nuclear Science Technology Organisation, pers. comm.) and Prof. Li (Xi’an Institute for Earth Environments, pers. comm.). Poaceae pollen was divided into two size categories: grain diameter ≤ 40 µm and > 40 µm. Pollen grains larger than 40 µm have previously been classified Cereal-type pollen (Dickson, 1988) and are likely to include pollen of Oryza (see Wang, et al., 1995; Chatuvedi, et al., 1998). This size category is referred to here-on as Poaceae (Oryza comp.). It is however acknowledged that this larger Poaceae size fraction cannot conclusively identify cereal-type or Oryza (see Maloney, 1990; Tweddel, et al., 2005). Quercus pollen was also
separated into two size categories: grains with the longest axis greater than 30 µm were classified as ‘Quercus (deciduous comp.)’, and grains with a longest axis ≤ 30 µm as ‘Quercus (evergreen comp.)’ (following Chang and Wang, 1986). Difficulty was encountered in distinguishing Moraceae and Urticaceae pollen, and as a result, pollen grains belonging to these families are referred to as Moraceae/Urticaceae. The morphology of Moraceae/Urticaceae in the Guangfulin samples closely resembles published information on Morus pollen morphology (e.g. Punt and Malotaux 1984). Given the large presence of Morus, associated with sericulture, currently in the delta region, many of the Moraceae/Urticaceae grains observed in the Guangfulin sediments may be Morus.

Pollen counts are represented as percentages of the total pollen sum on the pollen diagram, which includes pollen and spore taxa with values exceeding 5% at least once, or thought to be of particular environmental or anthropogenic interest. Raw pollen data for the Guangfulin trench are presented in Appendix 5. Pollen zones were determined with the aid of a dendrogram created using CONISS software (Grimm, 1992). All stratigraphic diagrams were made using C2 version 1.4.2 software (Juggins, 2003).

7.5 Guangfulin main trench: results

7.5.1 Stratigraphy and sediment analysis

The trench section includes five sedimentary layers (Figure 7.10). The deepest layer, 190 – 130 cm depth, is composed of homogenous light grey clay and includes numerous plant fragments which appear to be mostly plant root remains. Mean particle size and magnetic susceptibility values are generally high in this layer compared with overlying sediment, pollen concentrations are mostly low (<10,000 grains/cm³) but increase above 140 cm. From 130 – 105 cm depth, a darker grey silty clay horizon occurs, which is characterised by green mottling and some plant fragments. Pollen concentrations are greater in this layer.

A layer of rounded stones, with fine gravel fragments, occurs at 105 cm depth and a diffuse boundary is present from 105 – 103 cm depths. Sediments from 103 – 88 cm depths are composed of dark grey silty clay, rich in pottery and containing plant and charcoal fragments. A peak of magnetic susceptibility (31.8 k) occurs at 96 cm depth,
and this coincides with greater mean particle size values (Figure 7.10). A sharp stratigraphic boundary is present at 88 cm depth and from 88 – 44 cm dark grey silty clay – which includes plant fragments, occasional pottery fragments and large stones – is present. Pollen concentrations are high in this layer, values exceeding 600,000 grains/cm\(^3\), while mean particle size and magnetic susceptibility values are low. A diffuse boundary is present around 44 cm depth, above which a disturbed agricultural layer occurs.

![Stratigraphy, AMS \(^{14}\)C dates (BP) and regression lines, mean particle size (\(\mu m\)), magnetic susceptibility (\(k\)) and total pollen concentration (grains/cm\(^3\)) for Guangfulin trench.](image)

**Figure 7.10:** Stratigraphy, AMS \(^{14}\)C dates (BP) and regression lines, mean particle size (\(\mu m\)), magnetic susceptibility (\(k\)) and total pollen concentration (grains/cm\(^3\)) for Guangfulin trench.
7.5.2 AMS \(^{14}\text{C}\) dating

AMS \(^{14}\text{C}\) dating indicates the age of sediment samples from Guangfulin trench to range from ca. 1000 to ca. 12,400 BP (Table 7.2 and Figure 7.10). An age reversal occurs in the lower sediments: the sample at 174 cm depth is younger than three overlying dates. As the date at 174 cm depth is a stratigraphic outlier compared with all other dates, it is excluded from estimations of inferred ages. Deltaic settings are considered to be difficult to date by AMS \(^{14}\text{C}\) methods, due to carbon being stored or reworked prior to deposition (Stanley and Chen, 2000; Stanley and Hait, 2000). An anomalously young date, however, would not result from this process; it would more likely result from contamination due to downward percolation of more recent carbon.

Age-depth comparisons of AMS \(^{14}\text{C}\) dates suggest two main accumulation phases to have occurred (Figure 7.10). These were separated by either a period of slow sediment accumulation, or a hiatus covering the period from the terminal Pleistocene to the early Holocene (154 – 138 cm depths). No corresponding stratigraphic change is apparent, although marked changes in pollen concentration and abundances of certain plant taxa occur around 140 cm depth. Due to this possible hiatus, inferred ages are not calculated for samples at 144 and 149 cm depths. Inferred ages are calculated from two least square regression lines, and the regression lines indicate the rate of sedimentation to be 1.7 mm/yr below 154 cm depth and 0.13 mm/yr above 138 cm depth.

Table 7.2: AMS \(^{14}\text{C}\) dates for from Guangfulin trench. Calibrated dates are determined from the calibration curve IntCal04 (Reimer, et al., 2004) using the program OxCal v4.0.1 (Bronk Ramsey, 2001).

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Laboratory code</th>
<th>Age ((^{14}\text{C}\text{ yrs BP}))</th>
<th>Calibrated date ((95.4%\text{ prob.}))</th>
<th>Dated Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>62-64</td>
<td>NZA 26016</td>
<td>945 ± 30</td>
<td>910 - 735</td>
<td>wood fragment</td>
</tr>
<tr>
<td>70-72</td>
<td>NZA 26011</td>
<td>2057 ± 30</td>
<td>2038 - 1875</td>
<td>pollen residue</td>
</tr>
<tr>
<td>88-90</td>
<td>NZA 26017</td>
<td>2453 ± 30</td>
<td>2684 - 2342</td>
<td>charcoal fragment</td>
</tr>
<tr>
<td>124-126</td>
<td>NZA 26012</td>
<td>6209 ± 30</td>
<td>7165 - 6938</td>
<td>pollen residue</td>
</tr>
<tr>
<td>138-140</td>
<td>NZA 26013</td>
<td>6375 ± 30</td>
<td>7317 - 7164</td>
<td>pollen residue</td>
</tr>
<tr>
<td>154-156</td>
<td>NZA 26014</td>
<td>12218 ± 45</td>
<td>14195 - 13957</td>
<td>pollen residue</td>
</tr>
<tr>
<td>174-176</td>
<td>NZA 26264</td>
<td>5517 ± 55</td>
<td>6406 - 6210</td>
<td>macroscopic charcoal fragments</td>
</tr>
<tr>
<td>179-181</td>
<td>NZA 26015</td>
<td>12366 ± 55</td>
<td>14762 - 14085</td>
<td>pollen residue</td>
</tr>
</tbody>
</table>
7.5.3 Pollen and charcoal analysis

Four microfossil zones have been identified in the Guangfulin record, based on changes in pollen, charcoal and phytolith contents (phytolith analysis was conducted by Dr Itzstein-Davey (see Itzstein-Davey, et al., in press-a for more detail)) and aided by statistical analysis (CONISS) (Grimm, 1987, 1992). The pollen and charcoal records are presented in Figure 7.11, and a description of them follows:

The oldest zone, GFL 1 (191 – 140 cm, ca. 12,400 – 7000 BP), is characterized by high amounts of pollen from arboreal taxa, of which *Pinus* and *Quercus* (evergreen comp.) dominate. *Quercus* (deciduous comp.), *Tsuga, Betula, Castanopsis/Castanea, Juglans* and *Salix* are present to a lesser extent. The abundance of herb pollen and pteridophyte spores is also high, and herbs are dominated by Poaceae, Chenopodiaceae, Cyperaceae and *Typha*. The upper boundary of this zone is marked by a rapid reduction in *Pinus* pollen, and to a lesser extent *Quercus* (evergreen comp.) and Chenopodiaceae. Coinciding with this is a steady increase of Poaceae and *Typha* pollen. Micro- and macro-charcoal concentrations are very low in this zone, averaging respectively 0.8 cm²/m³ and 8.5 grains/cm³.

Zone GFL 2 (140 - 110 cm, ca. 7000 – 4700 BP) is characterised by high percentages of herbs, principally Poaceae, *Typha*, Cyperaceae and *Artemisia*. *Pinus* percentages are greatly reduced compared with Zone GFL 1. Reduced percentages of *Tsuga, Quercus* (deciduous) and *Juglans* pollen also occur. Dominant arboreal taxa in this zone are Moraceae/Urticaceae, *Quercus* (evergreen comp.), *Carpinus, Castanopsis/Castanea* and *Salix*. Most pteridophyte spores are reduced, however, *Ceratopteris* is slightly increased compared with GFL 1. Concentrations of micro- and macro-charcoal are greater, averaging 2.7 cm²/cm³ and 134.1 grains/cm³ respectively.

Zone GFL 3 (110 - 80 cm, ca. 4700 – 2400 BP) is distinguished primarily by having very high macro- and micro-charcoal concentrations. The charcoal curves are characterised by four peaks, the greatest micro-charcoal peak (25.8 cm²/cm³) occurs at 100 cm depth while macro-charcoal concentration peaks at 102 cm depth (9692 grains/cm³). Most macro-charcoal particles larger than 1.5 mm occur in this zone (Figure 7.12). Herbs occur in high abundance, Poaceae, *Typha*, and *Artemisia* being the
main taxa. *Persicaria* occurs in greater abundance and two peaks of *Persicaria* coincide with two large peaks of Moraceae/Urticaceae at 82 cm and 86 cm depths. Slight decreases of *Quercus* (evergreen comp.) and *Salix* are noted.

The upper zone, GFL 4 (80 – 54 cm, ca. 2400 – 400 BP), contains the highest percentages of Poaceae pollen in the trench section (average 46.8%). *Typha* also occurs in high abundance, while Cyperaceae and *Artemisia* are present to a lesser degree. The aquatic herb *Myriophyllum* has increased abundance compared with zone GFL 3. Arboreal pollen is dominated by Moraceae/Urticaceae, *Quercus* (evergreen comp.) and *Carpinus*. Moraceae/Urticaceae percentages are less than in GFL 2 and GFL 3, while percentages of *Carpinus* are greater. Micro- and macro-charcoal concentrations decline gradually towards the upper boundary of the zone and are substantially lower than the underlying zone (GFL 3).

Statistical analysis indicates that a significant correlation exists between the macro- and micro-charcoal curves for the trench section. Analysis using Pearson’s correlation coefficient produced an $r$-value of 0.857, a $p$-value of 0.0 and an $r^2$-value of 0.734. However, when Pearson’s correlation coefficients were calculated for the macro- and micro-charcoal curves for each zone separately, only one of the four zones produced a significant correlation: a significant correlation was present in zone GFL 3, with $r$-, $p$- and $r^2$ values of, respectively, 0.791, 0.0 and 0.626. No significant correlations were found in zone GFL 1 ($r = 0.346$, $p = 0.327$, $r^2 = 0.12$), GFL 2 ($r = 0.446$, $p = 0.095$, $r^2 = 0.199$) or GFL 4 ($r = 0.370$, $p = 0.109$, $r^2 = 0.137$).
Figure 7.11: Pollen and charcoal record for Guangfulin trench.
Figure 7.12: Macro-charcoal results for Guangfulin trench, including different size fractions of the macro-charcoal component.

### 7.6 Discussion

#### 7.6.1 Environmental interpretation

The generally fine-grained deposits composing the Guangfulin trench section highlight the relatively low-energy conditions under which the sediments were deposited. A slowing of sediment accumulation occurred ca. 7000 BP and is likely to be associated with the contemporaneous geomorphological change (from estuarine to deltaic conditions) discussed by previous authors (e.g. Wang, et al., 1981; Liu, et al., 1992; Chen, 1999; Hori, et al., 2001). The high variability of particle size, magnetic susceptibility and total pollen concentration values throughout the trench section probably reflects a relatively high variability in erosion, weathering and sedimentation in the catchment and delta region over the study’s time period (Thompson and Oldfield, 1986). A large disturbance in the catchment (flooding or human clearing for example) may have caused the anomalous peaks in magnetic susceptibility and particle size values ca. 3587 BP.
The deepest section of the Guangfulin trench was deposited around the Pleistocene/Holocene boundary (ca. 12,000 BP) when conditions in the delta region were markedly different. Sea-level was around 60 m below the modern level and the coastline was located more than 100 km east of its current location (Saito, et al., 1998; Chen, et al., 2000). The current delta region was part of a wide coastal plain, covered by a network of incised, frequently flooding, river channels (Stanley and Chen, 1996), and hydrological factors are likely to have been a major influence on vegetation in the delta region, probably limiting the extent of forest development in the area (Liu, et al., 1992).

The Guangfulin trench pollen data indicate that landscapes at Guangfulin around the Pleistocene/Holocene boundary (ca. 12,000 BP) were composed of a mosaic of forests, open herbaceous vegetation and wetland areas. Principle arboreal components were Pinus, Tsuga, Quercus (both deciduous and evergreen), Castanopsis/Castanea, Juglans, Salix and Betula. Poaceae and Chenopodiaceae were dominant herbs, while Cyperaceae, Typha and pteridophytes were abundant in wetlands areas. The Guangfulin trench results support previous pollen data covering this time period, which include increased proportions of conifers (mainly Pinus and Tsuga), deciduous trees (Quercus and Juglans) and Chenopodiaceae (Liu, et al., 1992; Yi, et al., 2003). Previous authors have interpreted this vegetation composition to reflect cooler conditions at the time, in both the Yangtze delta and the broader region of eastern China (Winkler and Wang, 1993; Jiang and Piperno, 1999).

Part of the Guangfulin palaeoenvironmental record is obscured either by very slow sediment accumulation rates or a hiatus from ca. 11,000 BP to ca. 7000 BP. Following this, greater pollen concentrations and sediment accumulation rates are accompanied by a marked increase of open herbaceous vegetation and a decline of forested areas. The timing of this change roughly coincides with the regional change from an estuarine to deltaic setting (see Wang, et al., 1981; Liu, et al., 1992; Chen, 1999; Hori, et al., 2001). Of the arboreal taxa, the decrease of Pinus is proportionately greater than that of the other tree taxa and this differential decline may be due to differing tolerances to changed environmental conditions between the arboreal taxa.

A wetland expansion ca. 7000 BP is suggested by an increase of Typha in the Guangfulin area. Typha species are considered to be moderately salt tolerant, although
salinity levels of only 3-5‰ can significantly affect growth of the plant (Glenn, et al., 1995). The seeds and seedlings of Typha are particularly sensitive to salt, and this restricts spread of the plant during periods of higher salinity (Beare and Zedler, 1987). The success of Typha in brackish areas is attributed to its ability to grow rapidly when freshwater is available and then persist in a dormant state during periods of elevated salinity (Beare and Zedler, 1987; Glenn, et al., 1995). The increase of Typha after ca. 7000 BP coincides with a reduction of Cyperaceae and the halophytic Chenopodiaceae, and probably reflects reduced salinity in wetland areas.

After ca. 7000 BP Poaceae and Artemisia increase markedly, and Poaceae (Oryza comp.) becomes a consistent component of the non-arboreal taxa. Minor amounts of Oryza phytoliths appear ca. 7000 BP (Itzstein-Davey, et al., in press-a), and their presence in the record supports an Oryza origin for the large-grained Poaceae pollen. The high percentages of Moraceae/Urticaceae type pollen in the record after ca. 7000 BP may reflect the presence of Morus and sericulture in the area.

Poaceae continues to dominate the Guangfulin area after ca. 4700 BP and the increased presence of Poaceae (Oryza comp.) pollen and Oryza phytoliths (Itzstein-Davey, et al., in press-a) suggests an intensification of rice agriculture in the area. Forest vegetation persist after ca. 4700 BP, but in reduced amounts, and is dominated by Quercus (evergreen), Carpinus and Betula. Pinus is unlikely to be growing near to the trench site, as only small percentages of pollen (less than 1%) are recorded in the sediments. Possibly by this time forest vegetation is principally restricted to upland areas on the delta plain (e.g. Sheshan hills) and bordering hills to the south and south-west. Moraceae/Urticaceae persists in high abundance after ca. 4700 BP and may reflect an increased importance of sericulture in the area.

7.6.2 Fire activity

Prior to ca. 7000 BP, both regional and local fire activity at Guangfulin is low. An increased human presence in the delta region ca. 7000 BP, and the possible commencement of permanent settlement, could explain the moderate increase in local and regional burning at that time. The possible presence of rice farmers near the trench site, as suggested by the presence of Poaceae (Oryza comp.) pollen and Oryza
phytoliths, could be a source of burning in the area, particularly as burning is associated with Majiabang rice farming practice (see Cao, et al., 2006). Another cause for the increased fire activity after ca. 7000 BP could be forest disturbance associated with the establishment of human settlements in the delta region.

Around ca. 4400 BP a large increase in fire activity occurs, both near the trench site and in generally the delta region. The rapid increase in local burning may mark the onset of human settlement near the trench site, and could include burning by inhabitants of the Guangfulin archaeological site. Although fire activity declines after ca. 2400 BP, the level of burning remains relatively high to the upper boundary of the trench section. This decline in fire activity ca. 2400 BP is not contemporaneous with alterations to forest taxa, as forested areas underwent large contractions prior to that date. The decline in fire activity may reflect a change in fire-use by farmers in the area and is possibly associated with a reduction in the practice of burning fields due to the greater availability of iron tools around this time (Cao, et al., 2006).

7.6.3 Human influence on environmental change at Guangfulin

Prior to ca. 7000 BP no clear indication of human activity is apparent in the Guangfulin record. Regional burning is occurring over this time period, but burning from natural causes cannot be discounted for this fire activity. Evidence from the Guangfulin palaeoenvironmental record indicates that vegetation in the delta region during the Pleistocene/Holocene boundary (ca. 12,000 BP) consisted of a mosaic of forest, wetland and open herbaceous areas. The archaeological record provides little information on human activity in the delta region in this pre-deltaic period. Stanley and Chen (1996) have suggested that humans based in the western highlands may have seasonally visited the coastal plain area for hunting and gathering purposes.

The findings for the Guangfulin trench section suggest rice cultivation to have been occurring in the area from ca. 7000 BP, this is based on the coincident gradual decline in Quercus and gradual increase of Poaceae (including Oryza comp.) and Oryza phytoliths (Itzstein-Davey, et al., in press-a), and an increase in local and regional fire activity. Also, Moraceae/Urticaceae pollen is abundant after ca. 7000 BP, and this allows for speculation that Morus exploitation has been occurring in the area since this date. This, however, would predate the earliest evidence of sericulture from
archaeological sites in the lower Yangtze, which dates ca. 4850 – 4650 BP (Kuhn, 1988; Yan, 1992). Further study on this Moraceae/Urticaceae pollen, as well as better archaeological or macrofossil evidence for sericulture during the Neolithic cultures, is needed before firmer conclusions can be drawn about an early emergence of sericulture in the area.

The impact of the so called “cultural interruption”, which occurred at ca. 4000 BP, is difficult to discern in the Guangfulin record. From ca 4700 BP to ca. 2400 BP (zone GFL 3) a high degree of environmental variability is present in the record. Increased Poaceae pollen (including Oryza comp.), Oryza phytoliths (Itzstein-Davey, et al., in press-a) and high fire activity reflected in both the micro- and macro-charcoal records suggest that agriculture is likely to have been established in the Guangfulin area by this time. The peak in magnetic susceptibility and particle size ca. 3587 BP (96 cm depth) suggests the occurrence of an anomalous hydrological event in the catchment area.

The Eastern Zhou dynasty (770-221 BC) was a period of heightened war and conflict, but also of great economic and technological progress. Improvements in metallurgy around the time led to the widespread use of iron tools and increased use of oxen to till land (Rostoker, et al., 1983; Lu, 2005). Iron tools and oxen would not only have allowed farmers in the Yangtze delta region to increase the area of tillage, but iron tools would also have aided in the construction of canals for irrigation and transport purposes (Rostoker, et al., 1983; Lu, 2005). Further technological advances in the Han Dynasty include the development of rice seedling transplantation (de Crespigny, 1990). The palaeoenvironmental record presented here indicates that after ca. 2400 BP human activities dominate the Guangfulin area and rice fields are probably a major feature in the landscape.
8 A palaeoenvironmental record from Liangzhu

8.1 Introduction

The Liangzhu culture existed from ca. 3200 – 2200 BC and was widespread throughout the lower reaches of the Yangtze River, including the delta region. The Liangzhu culture was initially discovered in 1936 at a site near Liangzhu town. Since then, a cluster of over 50 “Liangzhu culture sites” have been unearthed within a 33.8 km² area encompassing the towns of Liangzhu, Anxi and Pingyao (Dredge, 2004). The cluster includes settlement sites, cemeteries and ritual mounds. The area is currently densely populated, and largely because of this the Liangzhu sites have been included on the List of Cultural World Heritage in Danger (Dredge, 2004).

Although the Liangzhu culture is best known for the high quality jade artefacts unearthed at the sites, it also represents an important new phase in human cultural development in the Yangtze delta. Important changes in agricultural practices are associated with the Liangzhu culture, in addition to major developments in construction projects and social organisation (Dredge, 2004). Agricultural advances include the development of triangular stone ploughs and sericulture. Advances leading to increased farming efficiency would have enabled sections of society to specialise in activities unrelated to food production, and this liberation of parts of society from agricultural activity is thought to have been a key factor leading to increased cultural complexity (Stanley, et al., 1999; You, 1999; Shao, 2005).

The purpose of this chapter is to investigate environmental and human dynamics during the mid-Holocene in the Liangzhu area of the Yangtze delta region. The investigation is based on pollen and charcoal analysis of a core section and chronology is provided by two AMS $^{14}$C dates.

8.2 The study site

The present study is based on a 25 m deep sediment core, collected from Dawang Village (30° 22.669’ N, 120° 3.301’ E, ca. 20 metres a.m.s.l., Figure 8.1). The core site is located directly to the east of the Liangzhu archaeological site cluster, approximately
16 km northwest of Hangzhou city in Zhejiang Province. The core site is situated on flat land to the east of the Tianmu Mountains. Agricultural, urban and industrial land uses dominated the area surrounding the coring site at the time of the visits (see Figures 8.1, 8.2 and 8.3).

Vegetation at the site has been greatly modified by human activities. Grasses and herbaceous vegetation dominate the area, while trees are scattered, primarily alongside roads and canals. Agricultural land use includes fields of cereals, mixed vegetable patches and orchards. The area is also a major producer of silk (Barfield, 1979). The lower slopes of the Tianmu mountain range occur within 7 km of the Liangzhu core site. Currently the highland area is forested and protected as a nature reserve, which is famed for its relic stands of Ginkgo biloba trees.

Figure 8.1: Location of the Liangzhu core site. The area coloured darker grey represents land of higher elevation which is the lower slopes of the Tianmu Mountain range.
Figure 8.2: Photograph of Liangzhu core site, with urban land in the background and left section of the photograph.
8.3 Methods

8.3.1 Sampling

The 25 m deep sediment core with a diameter of 10.5 cm was recovered from the Liangzhu site in approximately 1 m sections, using a truck-mounted drilling rig. The core was described and sampled in May 2005 in the laboratories of Tongji University, Shanghai. This study investigates a section of the core covering the depths of 4.9 to 1.35 m. The upper 1.35 m of the core was not sampled in this study, as it appeared to have been disturbed; it had signs of mixing, and lacked the structure of lower core sections. Sixteen samples were selected for pollen and charcoal analysis. The samples were removed from the core section in 1 cm thick slices taken at intervals ranging from 15 - 40 cm.

8.3.2 AMS $^{14}$C dating

Two samples from Liangzhu core were prepared for radiocarbon dating. The samples were composed of large fragments of charcoal, extracted from the core at depths of 2.05 m and 3.05 m. The samples were sent to Beta Analytic Inc., USA, for dating.
8.3.3 Pollen and charcoal analysis

Pollen residues were prepared following standard procedures outlined in Moore et al. (1991). One cubic centimetre samples were sieved through 150 μm and 5 μm meshes to remove material unlikely to be pollen, and treated with 10% NaOH to remove humic acids, 15% HCl to remove calcareous minerals, 40% HF to remove silicates, and acetolysis to remove unwanted organic matter. Residues were mounted in silicon oil. Lycopodium spores were added prior to processing to allow for estimation of pollen and micro-charcoal concentration. Slides were scanned under an Olympus Nikon microscope at 400 x magnification. Pollen counts are expressed as percentages of the total pollen sum, which was 200 in all samples except three: samples at 2.86, 3.06 and 3.25 m depths had pollen sums of 79, 124 and 188 grains respectively.

Pollen and charcoal identification and quantification followed procedures undertaken on the Guangfulin trench (Chapter 7). C2 version 1.4.2 software (Juggins, 2003) was used to create all stratigraphic diagrams, pollen zones were determined with the aid of CONISS software (Grimm, 1987, 1992).

8.4 Results

8.4.1 Stratigraphy and bulk sediment properties

The stratigraphy of the core section included three sedimentary layers: sediment from 1.35 – 2.3 m depth was composed of light brown clay which included orange mottles, sediment from 2.3 – 2.67 m depth was composed of dark grey clay, and sediment from 2.67 – 4.9 m depth was composed of light grey clay (Figure 8.4). A 5 cm thick orange/brown mottled layer occurred from 2.52 – 2.57 m depth, and this directly overlay a 1 cm thick band of clay which included very fine sand-sized particles. Pollen concentrations in the Liangzhu core section were mostly low, with all but two samples containing less than 20,000 grains/cm³ (Figure 8.4). The lowest concentration value was 2715 grains/cm³ and this occurred at 2.86 m depth. An anomalous peak in pollen concentration (228,036 grains/cm³) occurred at 2.41 m depth.
Stratigraphy, $^{14}$C age (BP) and total pollen concentration (grains/cm$^3$) for the Liangzhu core section.

**8.4.2 Radiocarbon dating**

Radiocarbon dating of two samples indicates the core section derives from the mid-Holocene period (Table 8.1). Inferred ages are based on a single regression line calculated from the two dates, and consequently the accuracy of these inferred ages is likely to be low. Inferred ages are therefore presented here only as very rough estimates.

**Table 8.1:** AMS $^{14}$C dates from Liangzhu trench. Calibrated dates are determined from the calibration curve IntCal04 (Reimer, et al., 2004) using the program OxCal v4.0.1 (Bronk Ramsey, 2001).

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Laboratory code</th>
<th>Age ($^{14}$C yrs BP)</th>
<th>Calibrated date (95.4% prob.)</th>
<th>$\delta^{13}$C (%)</th>
<th>Dated Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.26</td>
<td>Beta 222951</td>
<td>4350 ± 40</td>
<td>3090 BC – 2894 BC</td>
<td>-29.3</td>
<td>Charcoal fragment</td>
</tr>
<tr>
<td>3.05</td>
<td>NZA 23034</td>
<td>5969 ± 35</td>
<td>4948 BC – 4730 BC</td>
<td>-12.7</td>
<td>Charcoal fragment</td>
</tr>
</tbody>
</table>
8.4.3 Pollen analysis

The summary pollen diagram for the Liangzhu core section is presented in Figure 8.5. The raw pollen data, including the full list of taxa encountered, is presented in Appendix 7. Two zones, based on the pollen and charcoal curves, were identified using CONISS software (Grimm, 1987, 1992).

The oldest zone, LZ1 (4.9 – 2.75 m depth, ca. 9710 – 5360 BP), includes high proportions of arboreal, non-arboreal and wetland taxa. Of the arboreal taxa, Pinus and Quercus (evergreen comp.) are dominant while Castanopsis/Castanea, Juglans, Salix, Betula and Ulmus/Zelkova occur to a lesser degree. Non-arboreal pollen is dominated by Poaceae and Chenopodiaceae, Artemisia is also present. Cyperaceae dominates the wetland taxa, with Typha and Pteridophytes also occurring in relatively high proportions.

In zone LZ2 (2.75 – 1.35 m depth, ca. 5360 – 2530 BP) Quercus (evergreen comp.) continues to be a principle component of the arboreal taxa, and Pinus is greatly reduced. Of the non-arboreal pollen, Poaceae continues to dominate and occurs in greater proportions than in the underlying zone (LZ1). Poaceae (Oryza comp.) and Persicaria are also present. Typha dominates the wetland taxa. Ceratopteris increases in abundance, while Cyperaceae and other pteridophytes persist in reduced abundances compared with zone LZ1.
Figure 8.5: Pollen, spore and charcoal diagram for the Liangzhu core section.
8.4.4 Charcoal analysis

Micro- and macro-charcoal concentrations are plotted in Figure 8.5. Zone LZ1 has slightly higher concentrations of both micro- and macro-charcoal than the overlying zone, with concentration values averaging 0.82 cm\(^2\)/cm\(^3\) and 62 grains/cm\(^3\) for micro- and macro-charcoal respectively. A relatively high degree of variability characterises macro-charcoal concentrations in this zone (LZ1). Charcoal concentrations in LZ2 are generally lower, however a large peak in charcoal concentration occurs at 2.26 m depth (ca. 4370 BP) where micro- and macro-charcoal values are respectively, 3.04 cm\(^2\)/cm\(^3\) and 180 grains/cm\(^3\). Excluding this large peak, micro-charcoal concentrations do not exceed 0.45 cm\(^2\)/cm\(^3\) and macro-charcoal concentrations do not exceed 36 grains/cm\(^3\) in zone LZ2.

8.5 Discussion

Prior to ca. 5360 BP the vegetation at Liangzhu is composed of a mosaic of forest, open grassland and wetland areas. *Pinus*, Cyperaceae and Pteridophytes occur in relatively high abundances. Grasses are prevalent at the core site, however the absence of any Poaceae (*Oryza* comp.) in the record suggests that rice agriculture is not occurring in the area. The very low δ\(^{13}\)C (-12.7 ‰) value for the AMS \(^{14}\)C-dated sample (ca. 5969 BP) suggests marine influence in the area.

Around 5360 BP a marked alteration in vegetation occurs at the site. A freshening of water bodies and wetlands in the area is suggested by the synchronous decline of Chenopodiaceae and Cyperaceae and increase of *Typha*. Poaceae also increases after ca. 5360 BP, and the appearance of Poaceae (*Oryza* comp.) in the record possibly results from an intensification of rice agriculture at the site. Rice cultivation in the Liangzhu area was possibly hindered by elevated salinity levels prior to ca. 5360 BP.

Forests persist in the area after ca. 5360 BP, with some alterations in composition. Around 5360 BP, *Pinus* and Castanopsis/Castanea decline markedly, while other forest taxa remain essentially unchanged. The lower slopes of the Tianmu mountain range, which lie to the west of the trench site, are a possible large source area for arboreal pollen in the Liangzhu record. Hillsides, being less suited for agriculture and more susceptible to erosion than the flat land on the delta plain, may not have been utilised by early agriculturalists in the area. Although it is impossible to identify the exact source
area for pollen in a sedimentary record, the Tianmu mountain range is a possible origin for a substantial portion of the arboreal pollen in the Liangzhu record.

The Liangzhu culture existed in the Yangtze delta region from ca. 5200 – 4200 BP (ca. 3200 – 2200 BC). The proposed date for an initial episode of agricultural intensification at the Liangzhu core site, inferred from two AMS $^{14}$C dates, is ca. 5360 BP. This roughly coincides with the beginning of the Liangzhu culture.

Anomalous peaks of total pollen and charcoal concentrations occur ca. 4370 BP in the Liangzhu section and correspond with a band of fine sand inclusion in the core stratigraphy. These anomalies suggest the occurrence of a change in sediment deposition at the site, and this could have been produced by an alteration to the hydrological regime in the catchment area. The temporal similarity between this date and the termination of the Liangzhu culture (ca. 4200 BP), gives some support to previous authors’ suggestions that the demise of the Liangzhu culture was driven by increased water inundation in the delta region.
9 Discussion on Environmental Change and Agriculture in the Yangtze delta region

9.1 Introduction

This chapter aims to contribute to discussion on the spread and development of agricultural societies in the lower Yangtze, and also discuss the wider cultural and environmental contexts within which this occurred. Specifically, this chapter reviews palaeoenvironmental reconstructions for the three study sites presented in chapters 5-8: Qingpu, Guangfulin and Liangzhu, and compares them with existing archaeological and palaeoenvironmental records for the Yangtze delta region. Finally, the long-term sustainability of agriculture in the Yangtze delta region is discussed.

The low-lying topographically saucer shaped delta plain is highly prone to flooding, and existing archaeological and palaeoenvironmental data shows flooding to have been a major influence on prehistoric humans inhabiting the Yangtze delta region (Stanley and Chen, 1996; Stanley, et al., 1999; Zhang, et al., 2005b). Evidence of flooding has been found at archaeological settlement sites in the region, mostly in the form of coarse sand or silty layers separating cultural horizons (Yu, et al., 2003; Zhang, et al., 2005b). Other evidence for periods of widespread flooding (e.g. buried trees and peat deposits) in other parts of the delta region have also been found to correspond with periods of cultural decline (Zhang, et al., 2005b). Flooding has continued to be a major hazard for humans living in the delta region; the delta region flooded catastrophically on three occasions last century (Zong and Chen, 2000; Jiang, et al., 2005).

Consistently reported climatic shifts in the Yangtze Delta region are the mid-Holocene climatic optimum, occurring ca. 8000 – 5000 BP, and a cooler period occurring ca. 4200 – 3800 BP (Liu, et al., 1992; Yi, et al., 2003; Chen, et al., 2005; Tao, et al., 2006; Yi, et al., 2006). These shifts are, however, considered to be smaller in magnitude than climatic shifts reported in more northern areas of China (Yan, 2005). A distinct episode of flooding is also suggested to have occurred ca. 4000 BP in the delta region, and this appears to have severely impacted on humans living there (Stanley and Chen, 1996; Stanley, et al., 1999; Yu, et al., 2000; Yu, et al., 2003; Zhang, et al., 2005b).
9.2 Findings from the trench sites

The basal dates for the three study sites, Qingpu, Guangfulin and Liangzhu, are respectively ca. 6000 BP, ca. 12,400 BP and ca. 9700 BP. A possible hiatus in the Guangfulin record has resulted in part of the early-Holocene and terminal-Pleistocene (ca. 11,000 – 7000 BP) being absent from the record. The locations of Qingpu and Guangfulin trench sites are similar in several respects: both are located on low-lying land in the central area of the delta plain, they are less than 30 km apart, and both are located in primarily agricultural areas. Despite these similarities, the palaeoenvironmental records display marked differences. Liangzhu core site is located some distance from Qingpu and Guangfulin sites, in the south of the delta region. The greater proximity of the Liangzhu site to upland areas – which border the southern and south-western margins of the delta plain – is likely to have resulted in greater representation of palynological remains originating from hillside areas in the Liangzhu record. The main findings for the three study sites are summarised in Figure 9.1.
Chapter 9: Discussion

9.1 Vegetation history

Figure 9.1: Comparisons between environmental change at Qingpu, Guangfulin and Liangzhu, cultural periods and important cultural developments in the Yangtze delta region.

<table>
<thead>
<tr>
<th>Years BP</th>
<th>Cultural timeline</th>
<th>Important cultural changes</th>
<th>Qingpu environmental change</th>
<th>Guangfulin environmental change</th>
<th>Liangzhu environmental change</th>
</tr>
</thead>
<tbody>
<tr>
<td>12,000</td>
<td>Qing Dynasty</td>
<td>Iron tools and the use of draft animals become widespread</td>
<td>QP 3: Rice agriculture dominant feature of landscape. Osmanthus cultivation also present. Low fire activity</td>
<td>GFL 4: Rice agriculture dominates the landscape. Wetlands are also present. Forests vegetation is scarce. Moderate fire activity.</td>
<td>LZ 2: Rice agriculture and wetland environments dominate the area. Fire activity is mostly low. Forests are present in the area.</td>
</tr>
<tr>
<td>9,000</td>
<td>Ming Dynasty</td>
<td>Development of iron metallurgy</td>
<td>QP 2: Forest are reduced. Rice agriculture dominates. High, variable fire activity</td>
<td>GFL 3: Rice and possibly mulberry are being cultivated. Wetlands are present. Forests are reduced. Fire activity is high.</td>
<td>LZ 1: Forests, wetlands and open herbaceous vegetation are present. Likely marine influence in the area.</td>
</tr>
<tr>
<td>7,000</td>
<td>Song Dynasty</td>
<td>Cultural discontinuity at many sites</td>
<td>QP 1: Forests dominate. Forest openings and wetlands are reduced. Low fire activity overall, with possibly occasional extensive and/or high intensity fires.</td>
<td>GFL 1: The landscape consists of a mosaic of forest and wetland vegetation. Fire activity is low, particularly near the trench site.</td>
<td></td>
</tr>
<tr>
<td>5,500</td>
<td>Yuan Dynasty</td>
<td>Development of silk production</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5,000</td>
<td>Five Dynasties</td>
<td>Permanent human settlement and agriculture commences in the delta region</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4,500</td>
<td>Tang Dynasty</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4,000</td>
<td>Sui Dynasty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3,500</td>
<td>The Six Dynasties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3,000</td>
<td>Han Dynasty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,500</td>
<td>Eastern Zhou Dynasty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,000</td>
<td>Western Zhou Dynasty</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,500</td>
<td>Shang Dynasty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,000</td>
<td>Xia Dynasty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>Majiabang Culture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Remark: The Pleistocene/Holocene boundary (ca. 12,000 - 9,000 BP) forest cover was at its highest in this area.
maximum extent, and the comparatively high proportions of conifers (*Pinus* and *Tsuga*), deciduous trees (*Quercus* (deciduous comp.)) and herbs (especially Chenopodiaceae) suggest cooler and dryer conditions. This finding is in agreement with previous records in the Yangtze delta region covering that time period (Liu, *et al.*, 1992; Liu and Chang, 1996; Yi, *et al.*, 2003). In addition to this, the high proportions of *Typha*, Cyperaceae and pteridophytes in the Guangfulin and Liangzhu records indicate marsh and wetland environments to have been important features of the landscape around that time.

By the recommencement of continuous sedimentation at Guangfulin, ca. 7000 BP, the vegetation is markedly different; a greater amount of open-herbaceous vegetation is present at the trench site. A decline in marine influence in the area is suggested by the contemporaneous increased of *Typha* and decline of Chenopodiaceae and this may be linked to the retreat of the palaeo-estuary in the delta region previously detected to have occurred around that time (Wang, *et al.*, 1981; Li, *et al.*, 2000). The increased amounts of Poaceae (*Oryza* comp.) and *Ceratopteris* (a common weed of rice paddies (Mineta, *et al.*, 2005; Naples, 2005)) at Guangfulin after ca. 7000 BP, leads to the hypothesis that rice agriculture is present in the area. Additional evidence for the commencement of rice agriculture at the site is the appearance of *Oryza* phytoliths in the record at that time (see Itzstein-Davey, *et al.*, in press-a). Moraceae/Urticaceae is the only possible arboreal taxon to show a large increase in abundance at Guangfulin after ca. 7000 BP.

The earliest indication of rice agriculture at Liangzhu does not occur until ca. 5360 BP and is evidenced by increased abundance of Poaceae (*Oryza* comp.) and *Ceratopteris*. The timing of commencement of initial rice cultivation at Guangfulin, ca. 7000 BP, and Liangzhu, ca. 5360 BP, may have been associated with reductions in salinity levels in the areas due to a retreating marine influence. High salinity levels may have hindered rice farming in these areas prior to these dates, as domesticated rice does not grow well under saline conditions (Zeng and Shannon, 2000; Latha, *et al.*, 2004). At Guangfulin site, a period of intensification of rice agriculture appears to occur ca. 4700 BP, due to a marked increase of *Oryza* phytoliths in the record (Itzstein-Davey, *et al.*, in press-a).

At the commencement of the Qingpu section, ca. 6000 BP, forest vegetation is abundant and C₃ plants dominate the area. High amounts of ¹³C-depleted diploptene – likely to originate from methanotrophic bacteria (Summons and Jahnke, 1992) – and also the presence of wetland taxa in the pollen record, indicate wetland and marsh environments
to be an important component of the landscape. At Qingpu, evidence of agriculture prior to ca. 2400 BP is not clear. However, the open herbaceous areas, detected near the trench site prior to this time, could have been sites of small-scale rice cultivation.

A synchronous intensification of rice agriculture appears to occur at Qingpu and Guangfulin ca. 2400 BP, and this suggests a widespread, perhaps delta-wide, intensification of rice agriculture to have occurred at this time: the Liangzhu section does not cover this time period. This intensification is accompanied by a marked decline in forest vegetation in the Qingpu area, and possibly following this decline, the extent of forest vegetation near Qingpu and Guangfulin approached present day levels. Abundant Poaceae (*Oryza* comp.) pollen and *Oryza* phytoliths (Itzstein-Davey, *et al.*, in press-a; in press-b; in press-c) in the records after ca. 2400 BP indicates rice to have been an important crop at both Qingpu and Guangfulin. Also, the presence of the C$_{20}$ HBI and its monoene in the Qingpu record – with a possible origin of either epiphytic algae or *Chara* sp. (Jaffe, *et al.*, 2001) – is consistent with a rice paddy ecosystem being present in the area. No major vegetation alterations occur after ca. 2400 BP in the Qingpu and Guangfulin records.

### 9.2.2 Fire History

Fire histories at the three study sites are markedly different (see Figure 9.2) and this suggests relatively local fire activities to have dominated the records. Trends and variability in fire activity ca. 12,000 BP, based on the Guangfulin record, are difficult to deduce due to the low number of samples in this early period. However the existing charcoal data suggests that fire activity was relatively low around that time. Declining forest vegetation at Guangfulin, commencing ca. 7000 BP, is accompanied by relatively low levels of burning. This low fire activity is consistent with the warmer and wetter climatic conditions commonly reported to have occurred in east China around that time (the mid-Holocene thermal optimum), as any increase in moisture content in the existing biomass-rich forest vegetation might be expected to have reduced the occurrence of fire in the area. However, this low fire activity also suggests vegetation disturbance by humans in the area to have been low, and it is unlikely that widespread conversion of natural vegetation to agricultural fields was occurring. The detected rice agriculture in the Guangfulin area at that time is therefore likely to have been small-scale, and perhaps entirely restricted to small forest openings. The Qingpu record also
reports low fire activity between ca. 6000 BP, and just prior to 2400 BP, which also suggests a low level of human activity in the area.

![Figure 9.2: Macro-and micro-charcoal records for the three study sites: Qingpu, Guangfulin and Liangzhu.](image)

A large increase in fire activity occurs at Guangfulin ca. 4700 BP; much of which is close to the trench site. Due to the synchronous agricultural intensification at the site at that time, the increased burning probably resulted from increased forest disturbance by humans in the area. Agricultural settlements are likely to have been becoming established and the conversion of natural vegetation to agricultural fields, or felling trees for timber or fuel, would have accompanied this.

The proposed intensification of agriculture ca. 2400 BP is accompanied by two markedly different alterations in the Qingpu and Guangfulin charcoal records. At Guangfulin, marked reductions in macro- and micro-charcoal concentrations coincide with the vegetation change, while declines in charcoal concentrations at Qingpu appear to lag behind Guangfulin. Differences between the sites relating to timing of the commencement of agriculture, and the rate of agricultural intensification, may be responsible for the observed differences in fire activity. At Guangfulin, fire activity
increased with the initial agricultural intensification ca. 4700 BP, and subsequently decreased around the time of the second intensification period ca. 2400 BP. While at Qingpu, a marked increase in local fire activity is accompanied by the initial intensification of agriculture, ca. 2400 BP, however, this high fire activity is short-lived and burning is soon reduced to the low levels that characterise the upper part of the trench section. It appears that the rate of land conversion, from relatively natural vegetation to an intensive agricultural setting, may have been greater at Qingpu than at Guangfulin. This more rapid decline of naturally vegetated areas at Qingpu may explain the relatively short period of high fire activity.

Following the agricultural intensification, ca. 2400 BP, the low fire activity at both Qingpu and Guangfulin sites may be due to multiple reasons, namely: low fuel quantities in the agricultural fields compared with natural vegetation; fuel quantities reduced further by regular low-intensity controlled burning of agricultural fields by farmers; and suppression, by humans, of wild-fires that occur in remnant forest stands. A decline in fire activity has also been noted to follow the establishment of cereal cultivation in parts of the southern Loess Plateau; there, it has been suggested to be due to the widespread establishment of agriculture in the area (Huang, et al., 2006).

In contrast to Qingpu and Guangfulin areas, the probable commencement of rice agriculture at Liangzhu, ca. 5360 BP, does not correspond with a marked change in fire activity. A peak in charcoal concentration occurs after the establishment of agriculture, at ca. 4370 BP, and coincides with a peak in total pollen concentration and a band of fine sand inclusion in the core stratigraphy. This combined evidence suggests that the charcoal peak may be associated with a change in sedimentation at the site, rather than an episode of increased fire activity.
9.3 Comparison with previous records in the Yangtze delta region

The dominance of local, and human induced, environmental changes in the Qingpu, Guangfulin and Liangzhu records may have had the effect of muting signals of climate change or regional environmental change. This may explain why the dominant Holocene climatic shifts detected by previous authors – the mid-Holocene climatic optimum (ca. 7500 – 5000 BP) and the subsequent cooling (ca. 4200 BP) (Liu, et al., 1992; Yi, et al., 2003; Chen, et al., 2005; Tao, et al., 2006) – are not detected in the Qingpu, Guangfulin and Liangzhu records. This dominance of local environmental change in the records is consistent with the terrestrial soil setting of the study sites, and as a result, the records are sensitive to local environmental conditions and local human activity (Andersen, 1986). However, some regional influence is present in the records. Cooler and dryer conditions during the Pleistocene/Holocene boundary (ca. 12,000 BP) are detected in the Guangfulin record: also, varying levels of marine influence are detected in the records, and may be in response to sea-level driven topographic changes of the delta plain described by previous authors (Stanley and Chen, 1996; Chen and Wang, 1999; Stanley, et al., 1999).

Work at archaeological sites show agricultural activity to have commenced in the Yangtze delta region by ca. 7000 BP; however, the earliest evidence of agricultural activity in existing palaeoenvironmental records, located beyond the boundaries of archaeological sites, occurs considerably later. Existing palaeoenvironmental records find the earliest evidence of agriculture to be *Fagopyrum* pollen in a core from Chongming Island, dating to ca. 4500 BP (see Figure 9.3) (Yi, et al., 2003). Somewhat later, Chen et al. (2005) suggest that a marked increase of Poaceae pollen ca. 3000 BP, at site ZX-1, reflects the commencement of rice agriculture in the study area. The later increase of Poaceae and other herbs at sites HQ98 and CM97, ca. 1300 BP, is suggested to reflect intensified rice agriculture in the areas (Yi, et al., 2003). Also, a sudden increase in Yangtze River sediment discharge, suggested to be due to widespread vegetation disturbance in the Yangtze River valley, is detected no earlier than ca. 2000 BP (Hori, et al., 2001). This combined existing palaeoenvironmental evidence suggests that agriculture did not become widespread in the delta region until sometime in the mid- to late-Holocene.
The findings of the present study support this evidence for a slow spread of agriculture in the region. The current study first detects rice agriculture ca. 7000 BP, and this is contemporaneous with the earliest archaeological evidence of rice farming in the delta region, at Hemudu. However, persuasive evidence of rice agriculture is not detected at the other two sites studied here, Liangzhu and Qingpu, until ca. 5360 BP and ca. 2400 BP respectively.

Figure 9.3: Location of selected well-dated Holocene sediment records in the delta region in addition to the trench sites of the present study: (1) Linfengqiao (Yu, et al., 2003; Zhang, et al., 2005a); (2) Cauduntou (Okuda, et al., 2003); (3) HQ98 (Yi, et al., 2003; Yi, et al., 2006); (4) ZX-1 (Chen, et al., 2005; Tao, et al., 2006); (5) CM97 (Yi, et al., 2003; Yi, et al., 2006); (6) Maqiao (Yu, et al., 2000); (7) Qidong (Liu, et al., 1992); (8) Qingpu; and (9) Guangfulin.

9.4 Key human factors affecting landscapes and vegetation in the Yangtze delta region during the Holocene

Both natural change and human activity have affected environments in the Yangtze delta region over the Holocene. Perhaps three principle factors affecting the magnitude of prehistoric human influence on environments can be summarised as: (i) population size; (ii) technological innovation; and (iii) social or governmental change. It is generally the case that prehistoric populations are difficult to quantify by archaeological means (Xue, et al., 2006), and therefore it is mainly the roles of these second and third factors that are discussed below in relation to successive periods in human cultural history in the delta region.
9.4.1 The Majiabang period

The first settlers on the newly formed delta plain were accomplished potters, carpenters, and farmers; Majiabang Neolithics were controlling water to irrigate rice fields and conducting stubble burning to improve soil quality (Cao, et al., 2006). They were also, however, hunter-gatherers, and heavily utilised natural terrestrial and marine resources as a food source (Zhao and Wu, 1987; Underhill, 1997). Agriculture would have offered the Majiabang Neolithics a more efficient method of food production, capable of sustaining larger populations (Olsson and Hibbs, 2005). And as Majiabang farmers intensified their agricultural production, their reliance on wild food sources would have gradually declined (You, 1999). Palaeoenvironmental data presented here, however, suggest that large tracts of natural vegetation persisted in the delta region during the Majiabang and subsequent Neolithic periods, and it wasn’t until ca. 2400 BP – when natural vegetation became limited – that the delta’s human inhabitants would no longer have had the option of supplementing agricultural produce with wild food resources.

9.4.2 4000 BP: a period of transition

Archaeological records show a cultural discontinuity in the Yangtze delta region at ca. 4000 BP. This abrupt cultural change is mirrored in other cultures in the Lower Yangtze River valley, as well as other parts of the world (Egypt, Mesopotamia and Japan for example) (Catto and Catto, 2004; Yasuda and Catto, 2004). A wave of human migration to the delta region followed this cultural decline (Cheng, et al., 2006), however, the effect that this had on the total population size in the delta region is unknown. This human arrival is not contemporaneous with major vegetation alterations at the Qingpu, Guangfulin or Liangzhu study sites. However, anomalous peaks in magnetic susceptibility and particle size dating to ca. 3587 BP at Guangfulin, a peak in magnetic susceptibility dating to ca. 3660 BP at Qingpu, and fine sand inclusions dating to ca. 4370 BP at Liangzhu, lends support to the theory of widespread flooding affecting cultural development in the delta region ca. 4000 BP.

9.4.3 2400 BP: the early dynasties

The early dynasties of China transformed society in terms of technology, social structure, and enhanced trade and communication. This period is marked in the Qingpu
and Guangfulin records by a dramatic intensification of agriculture, ca. 2400 BP, which corresponds roughly to the late-Zhou, Chin and early-Han Dynasties (see Figure 9.1). The development of iron metallurgy in the late-Spring and Autumn Period of the Zhou Dynasty (841 – 476 BC) and its subsequent spread in the Han Dynasty (206 BC – AD 25) may have played a key role in this agricultural intensification in the Yangtze delta. The expansion of iron farm tools in the Han has previously been observed to have produced increased agricultural productivity in China (Wang, 1982).

The Han Dynasty is noted for its technological advancements, including large expansions in canal systems (aided by iron tools), expansions in sericulture, and also increased use of draft animals and the seed-plough (Wang, 1982). Probably as a result of technology-driven improvements in farming efficiency, early dynastic populations rose rapidly. Estimates indicate the population of China increased from ca. 20 million during the Warring States Period (475 – 221 BC) to ca. 60 million by the end of the western Han Dynasty (206 BC – AD 9) (Wang, 1982). Despite the improved farming efficiency of the time, official records show the life of Han farmers to have been harsh. Han farmers had little surplus of yearly harvests, and despite this, were required to pay taxes and participate in corvée labour (Wang, 1982). Increasing populations would not only have necessitated clearing for expanding agricultural land, clearing would also have been necessary to gain fuel for heating, cooking, industry (e.g. for kilns and smelters) and also to gain timber for construction works for the growing population (Fang and Xie, 1994; Elvin, 2004). Ancient texts reveal wood for fuel to have been scarce in central-east China by the eleventh century AD (Elvin, 2004). This period of low farm surplus and reduced natural vegetation suggests the delta inhabitants, and particularly the poor, would have had little ability to tolerate climatic anomalies affecting agricultural production.

The rise of *Osmanthus* cultivation near to Qingpu trench site ca. 2100 BP marks a change in agricultural strategy in the area. Unlike rice, *Osmanthus* cultivation does not produce food; *Osmanthus* is cultivated for its aromatic properties (Mabberly, 1987), and would have principally been traded by the farmers. The enhanced trade during the early dynastic period would have provided a degree of protection for people in the delta region, by enabling the importation of food in years of poor agricultural production. This wide reach of the Chinese state, to vastly different ecological areas, enabled through the extensive river and canal system, would have had the effect of increasing
the resilience of the Chinese state (McNeill, 1998). This resilience, gained through trade, may have become increasingly important as populations increased and natural resources became scarce.

9.5 Implications for the sustainability of agriculture in the Yangtze delta region

The concept of agricultural sustainability is poorly defined, however, it is usually associated with the persistence of agricultural practices over a long temporal scale. Traditional forms of agriculture are therefore sometimes cited as being sustainable, as they have ‘stood the test of time’ (Abbona, et al., 2007). However, other indicators of sustainability are also discussed in the literature and these include: low dependence on external inputs, minimisation of land degradation, preservation of biodiversity, economic viability, and agricultural diversity (Altieri, 1992; Cai and Smit, 1994; Abbona, et al., 2007).

The long history of agriculture in East China is not in itself proof of a high degree of sustainability in agricultural practices there (Dodson, et al., 2006). Environmental alterations by humans in the Yangtze delta region have been immense: the region is almost entirely deforested, human-made canals and waterways densely dissect the delta plain and most of these are heavily polluted with nitrogen and phosphorus (Zhang, et al., 2007), exotic species are widespread, and native species lost. In addition, large-scale human-driven land degradation in the Yangtze River valley ca. 2000 BP, is suggested by a marked increase in the Yangtze River sediment discharge, and increased progradation of the delta plain (Hori, et al., 2001). Despite these impacts, Qingpu and Guangfulin records show intensive agriculture persisting uninterrupted in the area from ca. 2400 BP to ca. 400 BP.

The longevity and high yields of agriculture in East China has been suggested to relate to the nature of traditional agricultural practices there. These traditional practices include ecological principles considered innovative to modern agriculturalists, and relate to making complimentary combinations of crops and livestock to establish coordinated production systems (Guo et al., 1988, Zhang et al., 1996 cited in Ye, et al., 2002). Ancient Chinese agriculturalists appear to have had an advanced understanding about the connectivity of ecological systems; for example, three thousand years ago the classic work Zhou Li (rites of the Zhou Dynasty) presented the concept of the earth.
humans and heaven (which is perhaps partly analogous to climate) being interactive components of a single system (Ye, et al., 2002). The grain-livestock-mulberry-fish integrated system of the Taihu basin has existed for at least 1000 years (Shi et al., 1990 cited in Ye, et al., 2002).

Some explanation for the longevity of Chinese society during dynastic times must be attributed to the extensive trade network of the Chinese state. And while flooding, in particular, has been a major impact on the human occupants of the delta region, the ability to trade would have allowed delta societies to recover more quickly following these major environmental disturbances.

**9.6 Further Research**

Further research is required to develop an integrated understanding about the development and spread of agriculture in east China. In order to do this, particular attention needs to be given to better correlating and comparing palaeoenvironmental and archaeological records in early agricultural regions of east China; particularly in the area encompassing the middle and lower reaches of the Yangtze and Yellow river valleys.

A major finding of the current research is that the expansion and spread of agriculture in the delta region was slow, occurring over thousands of years; and prior to dynastic times, agriculture is likely to have been relatively localised and small-scale. Further testing of this theory is needed at additional sites in the Yangtze delta region, where particular attention is given to detecting human influence within the sedimentary records.

Another major research question that requires investigation relates to the spread of agriculture from centres in the Yangtze and Yellow River valleys to other parts of China, particularly to south China where work on pre-historic agriculture is scarce. Work in this area would contribute to the broader topic of investigation relating to the spread of agriculture from several centres in China to other parts of the Asia-Pacific region.

Developing the use of biomarkers and CSIA in the area of Holocene environmental change and human-environment interactions is another important area for future work. The current research has applied some comparatively well-studied biomarkers to this
topic, but has also detected other potentially useful palaeoecological biomarkers (Perylene and the C$_{20}$ HBI) and further investigation is required to understand their potential. In addition to these compounds, a better understanding about the origins of other biomarker compounds commonly encountered in Holocene sediment deposits is needed. Work in this area could potentially provide tools to explore aspects of past environments currently unknown due to limitations associated with current methods of sedimentary analysis.

9.7 Concluding remarks

Records of palaeoenvironmental change, from three sites in the Yangtze delta region (Qingpu, Guangfulin and Liangzhu), covering the time period from ca. 12,400 to ca. 400 BP, are presented in this thesis. The records indicate environments in the delta region to have been responding to both natural and human influences over that time. The main findings of the current research follow:

- Climate and relative sea level are likely to have been the main factors influencing the Yangtze delta environments during the terminal-Pleistocene to early-Holocene (ca. 12,000 – 7000 BP). Cooler conditions during that time are indicated by higher proportions of coniferous and deciduous elements in forest vegetation. Greater abundance of Chenopodiaceae over that time period also suggests cooler conditions, as well as greater salinity levels in wetland areas.

- The timing and nature of agricultural development varied considerably in the Yangtze delta region, and is likely to have been highly dependant on local environmental factors, particularly levels of water inundation and salinity.

- Results support a slow expansion of agriculture in the delta region, occurring over the period from ca. 7000 BP to ca. 2400 BP. The earliest indication of agriculture occurs at Guangfulin site at ca. 7000 BP, principally in the form of increased abundance of Poaceae (Oryza comp.) pollen and Oryza phytoliths. This is contemporaneous with the earliest evidence of agriculture in the delta region, at the Hemudu archaeological site. Following this, agricultural intensification is noted at ca. 5360 BP at Liangzhu and ca. 4700 BP at Guangfulin. A final period of intensification occurs ca. 2400 BP at Qingpu and Guangfulin. This gradual onset of
intensive agriculture in the area would have allowed for continued utilisation of natural food sources by early agriculturalists; ultimately affording them a degree of resilience against any disruption to agricultural food production caused by environmental disturbances.

- Marked increases in fire activity accompany periods of agricultural intensification at Qingpu and Guangfulin. Following the establishment of intensive agriculture at these sites, fire activity is reduced and this reduction is probably due to an absence of wildfires, associated with a scarcity of forest vegetation in the area, and also the occurrence of regular low intensity burning of rice fields.

- Technological advancements associated with the early Dynastic period are likely to be responsible for the detected widespread intensification of rice agriculture ca. 2400 BP. The greater abundance of iron tools in particular, is likely to have driven this agricultural intensification as it would have enabled greater farming efficiency and larger-scale earthworks.
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