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Mid-Holocene coastal hydrology and salinity changes in the east Taihu area of the lower Yangtze wetlands, China

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ABSTRACT

During the mid-Holocene the eastern Taihu area, on China's Yangtze delta plain, was populated by advanced late Neolithic cultures supported by intensive domesticated rice cultivation. This agricultural system collapsed around 4200 cal yr BP, with severe population decline, the end of the Liangzhu culture, and about half a millennium of very low-scale human activity in the area before the re-establishment of agricultural production. Microfossil analyses from six sedimentary sequences, supported by AMS ^{14}C dating, has allowed reconstruction of mid-Holocene hydrological conditions and salinity changes which would have had a major influence on agricultural viability and cultural history in the coastal wetlands. These data, allied to existing stratigraphic and sea-level records, show that chenier ridges that developed after ca. 7000 cal yr BP in the east of the area sheltered it from marine inundation and, although still connected to the sea through tidal creeks, low-salinity conditions persisted throughout the Neolithic period. There is no evidence that marine flooding caused the collapse of Liangzhu culture. Marine influence was stable and evolved slowly. Social and cultural causes may also have been important, but if environmental change triggered the collapse of Neolithic agricultural society here, other natural forces must be sought to explain this event.

Introduction

A marked increase in the strength of the East Asian monsoon at the start of the Holocene (Morrill et al., 2003) led to shifts in climate and vegetation patterns throughout eastern China, with a major rise in temperature and rainfall that caused the northerly expansion of woodland and wetland habitats. These changes were very favourable for human communities, encouraging people to move into most areas of the landscape in central and southern China (Jiang and Liu, 2006), and exploit the improved natural resources there. Soon after 8000 cal yr BP people who had settled in the major river valleys of eastern China started a process of increasingly intensive food collection and cultivation that would lead to plant and animal domestication and the adoption of agriculture (Lu et al., 2002; An et al., 2004; Jing et al., 2008; Fuller et al., 2009). This economic adaptation, accompanied by major social and material culture changes, marks the transition to the Neolithic period and occurred at similar times in both the Yellow River and Yangtze basins. Archaeological records from the Yellow River valley indicate that Neolithic communities flourished from ca. 7500 cal yr BP or even earlier (Lee et al., 2007), with dry farming of millet on hill slopes as the dominant activity (Lu, 2007; Liu et al., 2009) conditioned by the drier climate of northern China, toward the northern limit of the influence of the summer monsoon. In southern China, where monsoonal influence was much stronger, the same period saw the development of wet rice farming on the low-lying wetlands of the Yangtze valley (Crawford and Shen, 1998; Liu et al., 2007; Lu, 2007; Zong et al., 2007), with the marshlands of the Yangtze coastal plain a focus of intensive farming and high populations. By the later mid-Holocene these developed Neolithic cultures established sophisticated and structured societies that relied upon the extensive cultivation of high-yielding cereal crops, a productive but vulnerable economic system that required consistently favourable environmental conditions.

After ca. 4200 cal yr BP culturally impoverished or even sterile layers within archaeological sequences suggest that a collapse or outward migration of Neolithic cultures occurred in both the Yellow River and the Yangtze lowlands (Yu et al., 2000; Song, 2002; Wu and Liu, 2004; Shanghai Museum, 2008). While it must be remembered that social and other human factors can also cause culture change (Zhang et al., 2004a,b; Lu, 2007), such is the apparent scale of this cultural disruption that

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researchers have attributed this event to environmental factors, since it coincides with a period of pronounced climatic cooling and instability that lasted about five centuries, may have been the coldest interlude in the whole Holocene, and had major consequences for human societies (Perry and Hsu, 2000). This cold event had global impacts and can be considered to mark the end of the mid-Holocene climatic optimum. Across East Asia this climatic deterioration was associated with a weakened monsoon (Wang et al., 2005) and its timing and consequences varied regionally (An et al., 2000; He et al., 2004; Jiao, 2006), particularly regarding precipitation. Northern and central regions became much drier, but with increased rainfall intensity in the east and south of China. These changes affected vegetation patterns (Shi et al., 1993; Xu et al., 1996; Yi et al., 2006; Ren, 2007; Shu et al., 2007; Zhao et al., 2009), altering forest composition or even causing a switch from forest to steppe, but with increased flood intensity and frequency on the floodplains (Wu and Liu, 2004; Yasuda et al., 2004; Huang et al., 2010). Similar environmental and cultural deterioration at this time has been recorded elsewhere in East Asia (An et al., 2005; Lutaenko et al., 2007). Climate change plays a major role in altering environmental conditions and so can have a significant influence in cultural change (Peiser, 1998), despite the fact that human societies are resilient and had ways of responding to environmental changes and mitigating their effects (Anderson A. et al., 2007). Ironically, the more specialized and intensive is an agrarian society's economic system, as in the example of late Neolithic China, the more vulnerable it is to changes in environmental conditions.

Environmental factors other than climate may also be important, however, and in coastal regions such as the lowlands of the Yangtze Delta sea-level change has been an additional source of significant variation in environmental conditions. After rapid rise in the early Holocene (Zhu et al., 2003; Zong, 2004; Yim et al., 2006; Bird et al., 2007), mid-Holocene sea-level stabilization and the formation of the Yangtze delta (Stanley and Warne, 1994; Hori et al., 2002; Wang et al., 2010, 2011) made the resources of coastal areas predictable and plentiful, making that landscape zone very attractive to human communities (Anderson D.G. et al., 2007). Although by this time major postglacial eustatic readjustment of sea level was virtually completed, coastal zone ecosystems would have remained sensitive to low-amplitude sea-level movements as they changed marine flooding frequency, the salinity of estuarine and perimarine coastal waters and the elevation of water tables in coastal areas beyond the direct influence of marine inundation. Neolithic communities exploiting coastal lowland resources were vulnerable to the effects of such fluctuations (Zong et al., 2007; Chen et al., 2008; Innes et al., 2009; Shu et al., 2010). Indeed, it is possible that distribution patterns of Neolithic settlements in the low-lying Yangtze coastal plain between ca. 7000 and ca. 4000 cal yr BP were closely associated with fluctuations in mid-Holocene sea level (Stanley and Chen, 1996; Chen et al., 2008). Although greatly reduced in rate compared with the early post-glacial, any continuing slow sea-level rise during the mid-Holocene on China's east coast (Chen and Stanley, 1998; Zong, 2004) may have culminated around 4000 cal yr BP in a period of coastal transgression, increased incidence of marine flooding and salinization of groundwater at higher elevations throughout the Yangtze coastal lowland (Stanley et al., 1999; Jiang and Liu, 2001). Adverse hydrological changes in this heavily settled area dedicated to wet rice farming (Huang and Zhang, 2000; Zheng et al., 2003; Qin et al., 2010) could certainly have contributed to, or been primarily responsible for, the fall of the Neolithic culture that had flourished there (Stanley and Chen, 1996; Zhang et al., 2004a,b; Zhang, 2007; Chen et al., 2008), particularly if added to any social or cultural problems that might have existed.

This marine influence hypothesis is, however, controversial. Logically, Neolithic people in the Yangtze delta coastal plain would have adapted to increased marine flooding and saline conditions by simply moving upslope to the many small areas of higher ground that occur in these coastal lowlands, or even to the mountain foothills to the west, out of reach of marine influence, and perhaps did so (Wu and Liu, 2004; Zhang et al., 2004a,b). Presently, however, there is no evidence for such a major population shift although before the cultural collapse the Neolithic community may have migrated coastward to where the ground was slightly higher (Stanley and Chen, 1996). It is difficult to assess the contribution of coastal factors to landscape evolution and the history of the late Neolithic occupation of the lower Yangtze coastal plain, as the actual extent and severity of marine influence in the area at this time is still poorly known. New, high-quality, well-dated palaeoenvironmental records are required that provide detailed data on hydrological conditions in this wetland-dominated coastal region during the development of the final and most advanced late Neolithic culture, the Liangzhu, and especially during the period of its rapid decline and collapse around 4200 cal yr BP. In this paper, therefore, we concentrate upon elucidating the mid-Holocene palaeohydrology of the Yangtze coastal lowlands, presenting data from six sites in the heartland of the Liangzhu culture east of Lake Taihu (Fig. 1), where there are major late Neolithic site concentrations as well as extensive mid-Holocene wetland sediment sequences. Based on our new microfossil data, and supported by previously published borehole records, we reconstruct the detailed hydrological context of the late Neolithic occupation and evaluate the role of marine influence in the mid- to late Holocene in this area, not only to clarify the likely scale of its effects on Late Neolithic cultures, but as a contribution to understanding the palaeoenvironmental evolution of the coastal landscape of central eastern China.

The study area

Taihu Lake is one of the largest in China (Chang, 1987; Sun and Huang, 1993). Occupying a shallow depression in the coastal plain between the Yangtze River and Hangzhou Bay (Fig. 1), its history reflects the complex palaeohydrology of the area. Its western part is a separate small basin that has existed as a lake since before the Holocene (Qu et al., 2000; Wang and Liu, 2000; Wang et al., 2001), whereas the rest of Taihu came into existence in the mid-Holocene as a result of elevated regional water-tables driven by high sea level, coupled with fluvial input from the nearby Yangtze valley and the creation of the Yangtze delta and its sedimentary geomorphology (Sun et al., 1987; Yang et al., 1987; Hong, 1991; Wang and Liu, 2000). Always a shallow water body, the lake's extent has fluctuated considerably in the mid- and late Holocene in response to monsoonal phases of high or low rainfall, while penetration of the lake by saline marine water has occurred at intervals. Taihu has therefore functioned alternately as freshwater lake or coastal lagoon, but since the early mid-Holocene the lake has been surrounded by wetlands that expanded or contracted according to changing rainfall and sea level. Although vulnerable to flooding from both river and ocean, these natural wetlands allowed the gradual development in the late Neolithic of intensive wet rice farming (Cao et al., 2006; Atahan et al., 2008; Qin et al., 2010) using sophisticated water management and ploughed, labour-intensive paddy-field systems, sustaining high populations. During the Songze culture from ca. 6000 up to ca. 5200 cal yr BP but particularly in the Liangzhu culture thereafter, this process culminated in a densely occupied coastal plain around Lake Taihu and Hangzhou Bay (Chen et al., 2008; Li et al., 2010a,b) with a rich, socially stratified and technologically advanced society manufacturing luxury products including complex ceramics and high-quality jade work (CPAM of Shanghai, 2000; Liu, 2004; Fuller and Qin, 2009). Only slightly above sea level, these wetlands were protected from direct marine flooding by chenier ridges to the east that were deposited during the development of the Yangtze delta (Chang et al., 1987; Zhao, 1987; Liu and Walker, 1989; Yan et al., 1989; Stanley and Chen, 1996; Chen, 1998), although it is likely that they experienced some seasonal penetration by tidal saline waters (Wang and Murray, 1983) along the many creeks that

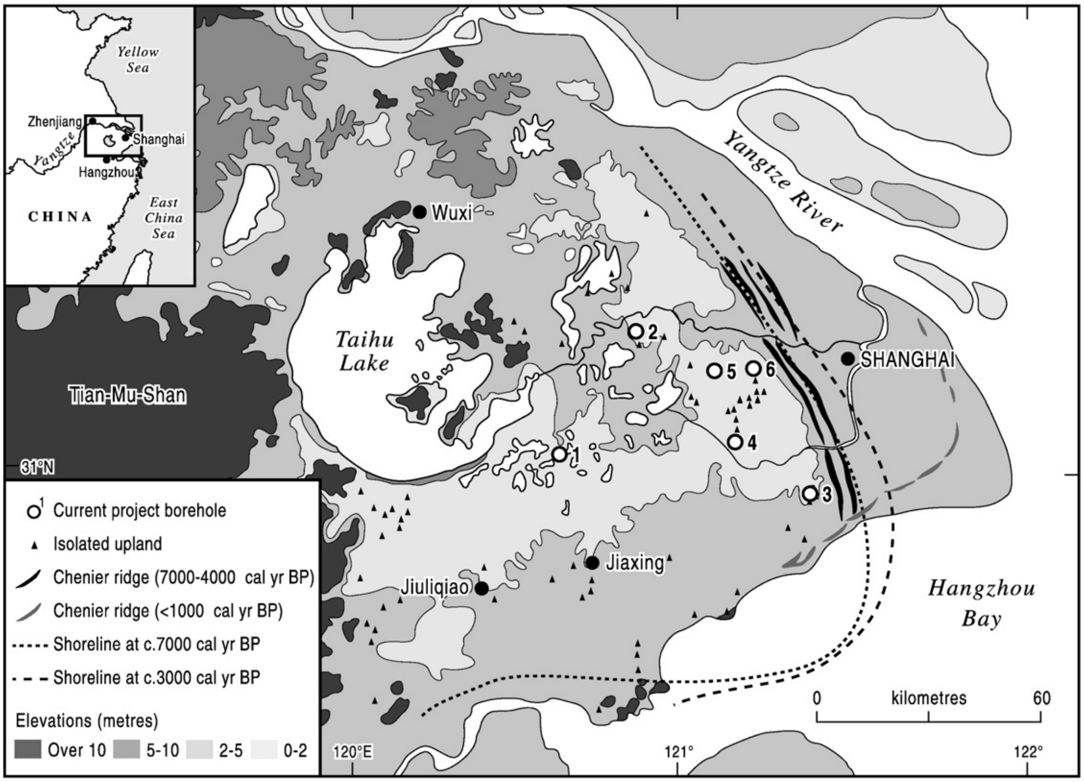

Figure 1. Location of the study area, east of the Taihu Lake in the Yangtze coastal plain, showing the topography, chenier ridges, palaeo-shorelines and the position of several other, smaller, lakes. Isolated uplands within the marshy plain that are over 20 m above local sea level (Yellow Sea Datum: YSD) are shown. The six newly investigated sites are 1: Pingwang, 2: Guoxiangcun, 3: Siqian, 4: Tangcunmiao, 5: Tinglin, 6: Beiganshan, and broadly form a transect across the area from westerly, more inland, locations to the chenier ridges in the east.

connected them to the sea via the Yangtze estuary to the north or Hangzhou Bay to the south (Yan and Huang, 1987).

Methods

Selection of archive sites

To establish the study area's palaeoenvironmental context, borehole records were obtained from as many previous studies and engineering reports as were available, in order to provide an overview of the general post-glacial lithostratigraphy of the whole of the lowland plain, from the present coast in the east to the area beyond Lake Taihu in the west. Inspection of all the borehole logs made it clear that the plain could be subdivided into distinct sub-regions within which environmental and sedimentary history would be closely comparable, but between which there would have been significant differences. These sub-regions include the area to seaward of the chenier barrier ridges, the area in the landward lee of the ridges, the central basin area of the plain and the inland area around Lake Taihu itself. From the many archive records that were obtained from across this wide geographical range, six previously published cores were selected that were individually typical of the evidence from their sub-region, and so were fully representative of it. They also had good dating control to allow correlation with our new data. Presentation and referencing of all the data from the entire lithology archive is impractical, and using such ‘representative’ cores to summarise the evidence makes it unnecessary. The locations of these selected cores form a transect from the low-lying inland area south of Taihu almost to the present coast (Fig. 2A), and their lithologies, their altitudinal and dating information and their references are shown in Figure 2B and the figure caption. Data from the whole of the borehole archive, however, were used to reconstruct the general palaeolandscape of the Taihu area. Land survey data were also used to map the present landscape, including detailed altitudinal characteristics (Fig. 1). These two landscape maps, along with borehole records and published radiocarbon dates, form the basis for the lithostratigraphic conspectus.

Selection of new sites

The following six new sites, shown on Figure 1, were selected for detailed microfossil analyses to assess hydrological characteristics in the various sub-regions across the study area during the mid-Holocene. A new site was not selected to the seaward of the chenier ridges as the land in that area is of late-Holocene creation. Two types of new site were chosen: (a) those close to archaeological sites and which included sedimentary units that incorporated or could be directly correlated with late Neolithic cultural layers, and (b) those not directly associated with cultural material and which would therefore contain only a ‘natural’ environmental signal, although archaeological sites might not be too far away. It is not easy to get far away from Neolithic cultural sites in this region, as there are so many. The first two sites are of the ‘natural’ type. Pingwang (1) is the most westerly, lying about 10 km from late Neolithic settlements, while Guoxiangcun (2) lies midway between Taihu and the chenier ridges, near a small hill in a location rich in Liangzhu sites (Chen et al., 2008), although not adjacent to one. The next three sites include culturally-correlated sediments. Tinglin (3) lies near the southern edge of the chenier ridges adjacent to a late Neolithic settlement. Tangcunmiao (4) lies 20 km inland from the chenier ridges, again beside a Neolithic site. Siqiang (5) is surrounded by many Liangzhu settlements containing abundant quality jade work and is adjacent to one. Beiganshan (6) is a ‘natural’ type site that lies 3 km west of the chenier ridges close to the major tidal inlet to the wetland system. Sediment profiles from the six sites were recovered using a hand-operated corer, and the lithological characteristics recorded in the

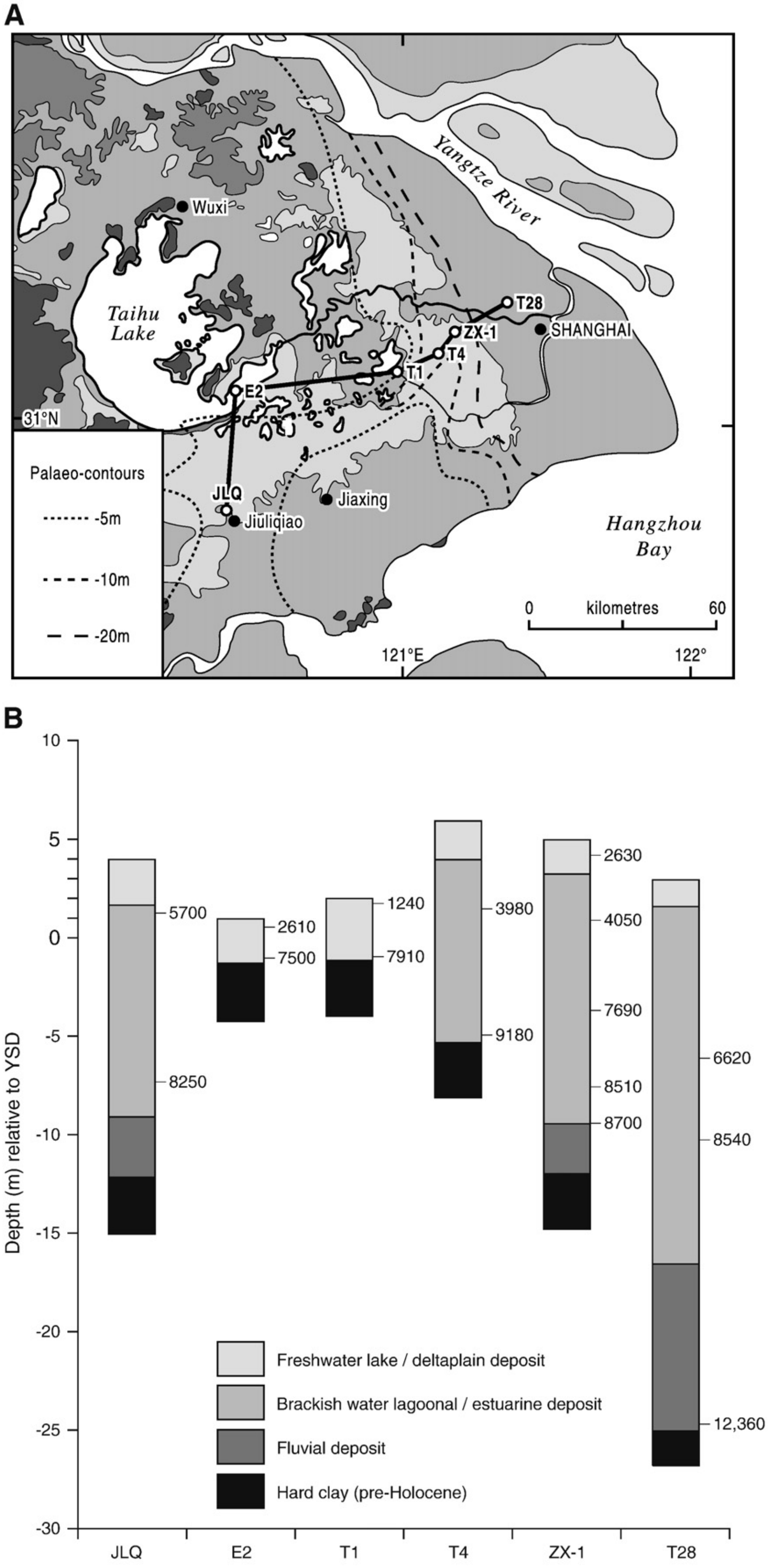

Figure 2. Fig. 2A shows palaeo-contour lines at −5, −10 and −20 m intervals, superimposed upon current surface topography, and a transect line of boreholes derived from previous literature and used to reconstruct the area's postglacial lithological history in Fig. 2B. These are: JLQ from Hong (1991); E2 from Wang et al. (2001); T1, T4 and T28 from Li et al. (2000); ZX-1 from Chen et al. (2005). Fig. 2B shows the stratigraphies from these sites with their published calibrated mean radiocarbon ages (Table 2), illustrating the altitude, timing and spatial variability of the various main litho-stratigraphic units.

field. Cores were sub-sampled at 2.5 cm or 5.0 cm intervals, sealed in polythene and stored at 4°C.

Microfossil and radiocarbon analyses

Samples were prepared for palynological analysis using standard laboratory techniques, including alkali digestion, sieving at 180 μm, hydrofluoric acid digestion and acetolysis (Moore et al., 1991). Microfossils (all palynomorphs <180 μm in size) were identified using reference keys and type slides and counted using a stereomicroscope at magnification of ×400, using ×600 oil immersion lenses for critical features. Identification of pollen grains followed Wang et al. (1995) and pteridophyte spores Zhang et al. (1990). A minimum of 200 land pollen grains was counted at each sampled level, plus all aquatic pollen and pteridophyte and bryophyte spores observed while attaining that sum. Non-pollen palynomorphs (NPPs), mainly comprising fungal spores and algae, were also recorded with at least 200 identified on the pollen slides at each level. Taxonomic identification of NPPs was achieved where possible, otherwise they were identified using the catalogue of Type numbers at the Hugo de Vries laboratory, Amsterdam, using illustrations and descriptions published in several papers (e.g. van Geel, 1986, 2001; van Geel and Aptroot, 2006). NPP frequencies are shown as percentages of the total land pollen sum.

Diatom counts were made from the sedimentary sequences. The technical procedures for diatom analysis follow Palmer and Abbott (1986). A minimum count of 300 diatoms was reached for most samples, and all diatoms were identified to species level using reference keys (van der Werff and Huls, 1958–66; Jin et al., 1982). Taxa were classified according to a halobian system of salinity tolerances (Vos and de Wolf, 1993). During diatom counting, rice phytolith numbers were also recorded. Foraminifera were counted from one sediment core in which diatoms and pollen were poorly preserved.

To concentrate on local environmental conditions, the focus of this paper, only taxa that contribute to an understanding of hydrological history are shown on the diagrams, often as summary curves, and terrestrial plants with a more regional pollen signal (e.g. trees) are not included. All radiocarbon dates are AMS determinations on peat, plant macrofossils or pollen residues, avoiding the problems associated with bulk alluvial sediment, as discussed further below. Dates were calibrated according to Calib5.1 (Stuiver et al., 1998) using the IntCal04 programme. Microfossil diagrams were constructed using TILIA (Grimm, 1993).

Results and interpretation

AMS ^{14}C dating

Reliable site chronologies are required for the reconstruction of mid-Holocene hydrological history across the Taihu area, but the primary objective of this study is simply to search there for any evidence of direct marine impacts in the late Neolithic. Our research strategy therefore does not require high resolution dating at each site, merely the secure identification of the late Neolithic levels in general. A few rangefinder dates are therefore sufficient to establish which parts of the profiles are of overall late Neolithic age, supported where possible by relative dating using correlation with cultural horizons. Any marine episodes identified would have been specifically dated, but in the event none were and so this was not required.

Our rangefinder dates comprise AMS radiocarbon results and in this study, as in most other recent research in this area, only fragile

Table 1
Details of the stratigraphic sequences recorded from the six study sites.

Depth (m)	Descriptions
Pingwang, E120′38′25′, N30′57′30′, Alt: 1.6 m YSD	
0.00–0.45	Paddy field soils
0.45–1.10	Brown to yellowish grey, hard to firm, clay
1.10–1.25	Blackish grey, soft, clay
1.25–1.80	Greenish grey, soft, clay
1.80–2.10	Brownish grey, soft, organic rich clay
2.10–3.10	Dark grey, soft, organic rich clay with small shells found in upper part
3.10–3.70	Greenish grey, soft, silt and clay
3.70–3.80	Blackish brown peat
3.80–4.00	Sticky hard clay (pre-Holocene)
Guoxiangcun, E120′49′20′, N31′15′36′, Alt: 1.6 m YSD	
0.00–0.40	Paddy soils
0.40–2.20	Brownish grey, firm, clay with large amount of herbaceous roots, becoming yellowish grey, soft and fewer roots from 1.50 m downwards
2.20–5.10	Greenish grey, soft, organic rich clay
Siqian Village, E121′06′25′, N31′11′50′, Alt: 2.1 m YSD	
0.00–0.35	Vegetable bed soils
0.35–1.40	Brownish grey, firm but moist, silt and clay with herbaceous roots, related to the Liangzhu-Songze cultural layer (Shanghai Museum, 2002a)
1.40–2.20	Grey to dark grey, soft, silt and clay
2.10–2.40	Sticky hard clay (pre-Holocene)
Tangcunmiao, E121′05′30′, N31′01′48′, Alt: 1.8 m YSD	
0.00–0.65	Vegetable bed soils
0.65–1.00	Blackish grey, hard but moist, clay
1.00–1.70	Grey to brownish grey, soft, organic rich clay with herbaceous roots
1.70–2.10	Dark grey, soft, clay with herbaceous roots, related to the Liangzhu-Songze cultural layer (Shanghai Museum, 1985)
2.10–2.30	Dark grey, silt, sand and gravel (possibly early Holocene)
Tinglin, E121′18′42′, N30′53′12′, Alt: 1.8 m YSD	
0.00–1.20	Filled building materials
1.20–1.55	Grey to dark grey, soft, sandy silt and clay
1.55–1.70	Grey to dark grey, firm, gravel with silt and clay
1.70–2.00	Yellowish grey, firm, silt and clay with herbaceous roots, related to the Liangzhu cultural layer (Shanghai Museum, 2002b)
2.00–3.00	Dark grey, soft, silt and clay with herbaceous roots
Beiganshan, E121′11′32′, N31′08′56′, Alt: 1.6 m YSD	
0.00–0.55	Vegetable bed soils
0.55–0.75	Dark grey, soft, organic rich clay
0.75–1.10	Greenish grey, soft, clay with yellowish spots
1.10–1.15	Brownish grey, soft, clay with rich organic matters
1.15–5.05	Light grey, soft, clay

plant macrofossils, pollen residues or peat that has accumulated in situ have been dated. Dating of bulk sediment samples has been avoided as deltaic and alluvial sediments can easily incorporate reworked carbon of any age and so produce anomalous results for individual dates (Stanley and Chen, 2000). Pollen residues, however, have been shown in several published studies (Itzstein-Davey et al., 2007; Atahan et al., 2008; Qin et al., 2010) to provide internally consistent and therefore reliable age curves, despite the occasional age inversion, and upon this basis we can be confident that the new dates listed in Table 1, although one mild inversion does occur, can be accepted as accurate. This is confirmed at Siqian, Tangcunmiao and Tinglin by the good correlation of the dates with sediments directly linked with late Neolithic cultural material, mainly Liangzhu (Tables 1 and 2). At the 'natural' sites, a good series of dates occurs at Pingwang, supporting their reliability, while the date at Guoxiangcun, although rather older than expected, is indirectly supported as early Holocene by the presence of marine influence, a consistent feature of other early Holocene profiles in the area (Zhu et al., 2003; Li et al., 2010a,b), including Pingwang. Dating was not possible at Beiganshan where suitable material could not be found. The reliability of the dates for the six previous study sites on Table 2 is less certain, some being on bulk sediment, but critical inspection of all the available radiocarbon dates in the required areas suggests that they are as likely to be accurate as those from any other cores. They do form good age series and seem reasonable for their depths, altitudes and associated biostratigraphy, and so are accepted as valid rangefinder dates for the time periods of interest to us.

The pre-Holocene landscape and the Holocene lithostratigraphy

Interpreted from over 100 borehole records, during the early Holocene the land to the east of Taihu Lake (Fig. 1) comprised the pre-Holocene land surface, stiff clay which is probably the weathered crust of an old marine sequence formed during the previous interglacial sea-level highstand (Qin et al., 2008), capped by compacted Late Pleistocene fluvial or aeolian material in places (Wang et al., 2001, 2006). The early Holocene study area was a flat, marine terrace on the southern side of the deeply-incised palaeovalley of the Yangtze. As shown in Figure 2A, the three contours of −20 m, −10 m and −5 m mark the sloping edge of the terrace, running in a NW and SE direction. Towards the palaeovalley, ground altitude reduces from ca. −5 m at location T1 to ca. −30 m at location T28, beyond which the valley incised to about −80 m during the last glacial period (Li et al., 2000).

Resting upon this palaeosurface is the sedimentary sequence deposited during the Holocene. Selected borehole records (Fig. 2B) show that its thickness decreases from over 20 m at location T28 to about 5 m at location T1, but from location E2 to location JLQ its thickness increases from less than 4 m to about 15 m. The early and mid-Holocene sediments in boreholes JLQ, T4 and T28 are dominantly soft estuarine or lagoonal mud (Li et al., 2000) deposited as sea level rose to its postglacial highstand. Foraminiferal assemblages are well preserved in this unit (Chen et al., 2005), which had a rapid vertical sedimentation rate (Stanley and Chen, 2000). The top few metres of the sediment sequence across the area appear to be freshwater lake or marsh deposits, except in location T28 where deltaic plain or tidal flat sedimentation was recorded. Geomorphological surveys (Chang et al., 1987; Zhao, 1987; Stanley and Chen, 1996) show that it was along the seaward rim of this palaeovalley terrace between location ZX-1 and T28 (Fig. 2A) that the emplacement of chenier ridges created a stable shoreline from about 7000 cal yr BP (Fig. 1) that ran continuously south into Hangzhou Bay then turned west (Chen et al., 1990). The southern section of the ridges remained in place until ca. 2000 cal yr BP. Since the 4th century AD the ridges have been pushed north, forming the current northern shoreline of Hangzhou Bay (Chen et al.,

Table 2
Radiocarbon dates obtained from the Taihu area.

Location	Depth (m)	Dated material	^{14}C age (^{14}C yr BP)	Calibrated date range (cal yr BP) (1σ)	Central cal. age (cal yr BP)	Laboratory code[*]
From this study						
Pingwang	1.85–1.87	Pollen residue	4430 ± 40	4960–5210	5090	Beta-266433
	2.25–2.27	Plant macros	4720 ± 40	5330–5580	5460	Beta-243208
	3.20–3.22	Pollen residue	6800 ± 50	7580–7700	7640	Beta-253340
	3.75–3.77	Peat	6290 ± 50	7160–7310	7240	Beta-228442
Guoxiangcun	2.70–2.72	Pollen residue	9950 ± 50	11,240–11,610	11,420	Beta-266440
Siqian	0.75–0.77	Pollen residue	5410 ± 40	6190–6280	6240	Beta-245331
	1.40–1.42	Pollen residue	7310 ± 50	8010–8200	8110	Beta-253341
Tangcunmiao	1.72–1.74	Pollen residue	4140 ± 40	4530–4830	4680	Beta-253342
	2.12–2.14	Pollen residue	5230 ± 40	5930–6000	5970	Beta-253343
Tinglin	2.10–2.12	Pollen residue	5800 ± 40	6490–6680	6590	Beta-253345
	2.30–2.32	Pollen residue	7390 ± 50	8170–8220	8200	Beta-253346
From previous studies[**]						
JLQ	2.5	Bulk organic	4975 ± 70	5640–5750	5700	?
	11.2	Bulk organic	7400 ± 80	8163–8342	8250	?
E2	0.2	Bulk organic	2575 ± 110	2353–2867	2610	AA9242
	2.26	Bulk organic	6575 ± 75	7411–7585	7500	AA9240
T1	1.9	Bulk organic	1369 ± 180	1065–1417	1240	ANU
	3.2	Bulk organic	7064 ± 300	7650–8172	7910	ANU
T4	4.9	Bulk organic	3650 ± 190	3716–4237	3980	GIGAS
	11.0	Bulk organic	8225 ± 300	8850–9504	9180	GIGAS
ZX-1	1.1	Bulk organic	2580 ± 60	2461–2795	2630	Beta-87397
	4.5	Shell	4160 ± 40	3966–4136	4050	Beta-159203
	8.8	Bulk organic	6850 ± 80	7610–7759	7690	OS-11658
	12.6	Peat	7750 ± 50	8420–8603	8512	Beta-87400
	14.1	Peat	7900 ± 35	8628–8767	8700	OS-11655
T28	9.1	Bulk organic	5830 ± 180	6436–6805	6620	QIMG
	13.1	Bulk organic	7820 ± 270	8065–9006	8540	QIMG
	27.8	Bulk organic	10,410 ± 300	11,951–12,762	12,360	QIMG

[*] Beta: Beta Analytic, USA; AA: University of Arizona, USA; ANU: Australian National University, Australia; GIGAS: Guiyang Institute of Geochemistry, China; OS: National Ocean Science AMS Facility, USA; QIMG: Qingdao Institute of Marine Geology, China.

[**] These dates are from Hong (1989) for JLQ, Wang et al. (2001) for E2, Li et al. (2000) for T1, T4 and T28, and Chen et al. (2005) for ZX-1, and are calibrated by this study.

1990). The area east of the chenier ridges has only emerged during the last 2000 yrs as the southern flank of the Yangtze deltaic plain grew (Chen and Zong, 1998).

The mid-Holocene palaeoenvironment

Landward of the chenier ridges, the Holocene sediment sequences are generally thin, and sedimentation usually started at the end of the early Holocene after 8000 cal yr BP, as suggested by boreholes E2 and T1 (Fig. 2B). The detailed environmental history for this sheltered area is clarified by the analysis of microfossil assemblages from our six new sediment cores. Only taxa most relevant for reconstructing local hydrological conditions are shown on the figures, and procedures for diagram construction are explained in the captions.

Pingwang

South-east of Taihu lake (Fig. 1), the Holocene sediment at this site is only 3.80 m thick (Table 1). Pollen and diatom curves are shown although diatoms are well preserved in only eleven samples from the lower part of the core. Four stages of environmental history can be reconstructed

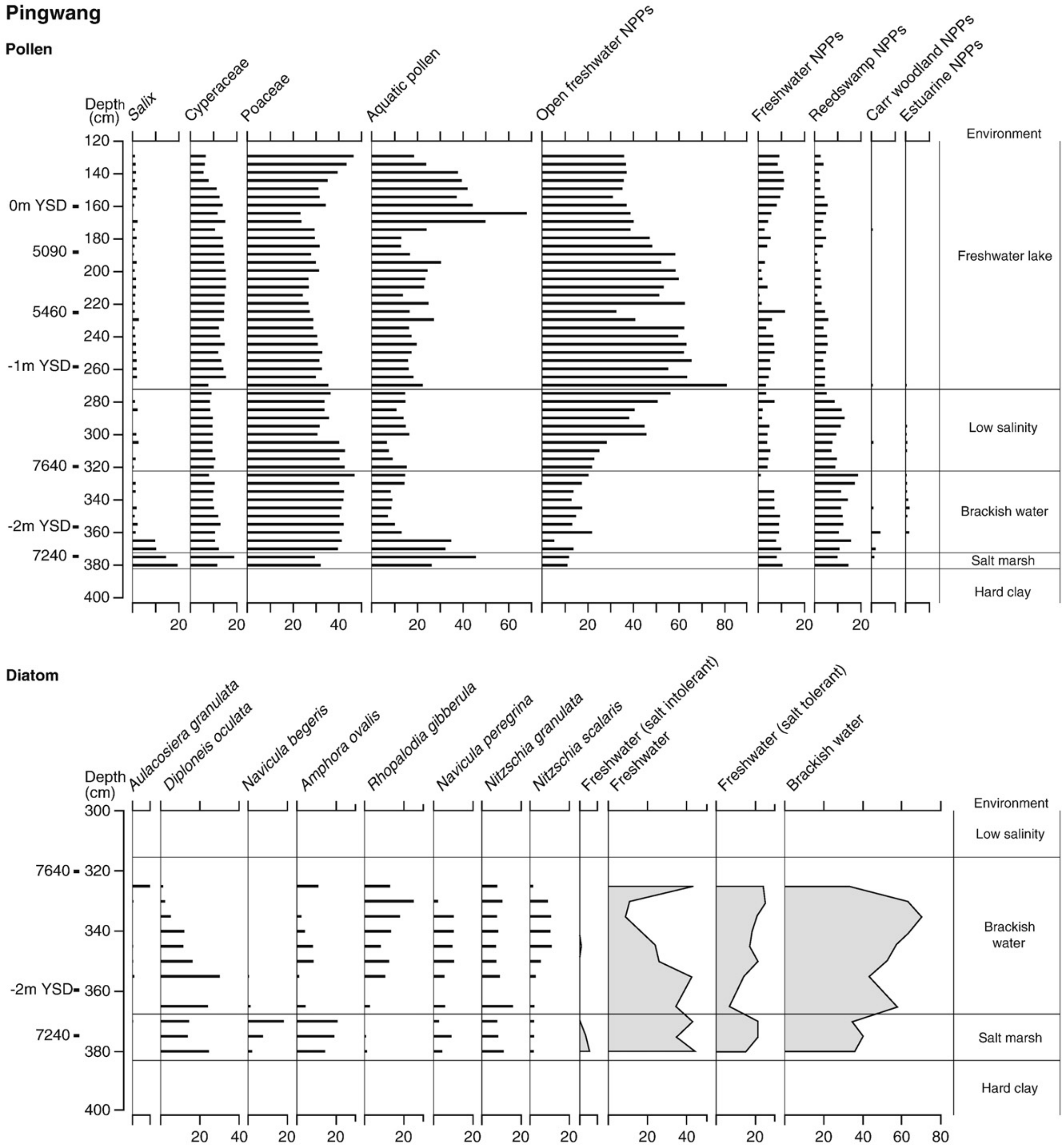

Figure 3. Selected diatom, pollen and non-pollen palynomorph (NPP) frequency curves from Pingwang, with only those taxa shown that are most instructive regarding hydrological history. Diatom frequencies are calculated as percentages of the overall total diatom valve count. Pollen and NPP (which comprises algae and fungal spores) frequencies are calculated as percentages of the overall total land pollen count (spores excluded). Altitudes (relative to local sea level datum, YSD) calibrated radiocarbon dates and ecological interpretations are shown.

(Fig. 3). Above the basal hard clay, a thin layer of black peat contains an assemblage of willow (*Salix*), grasses (Poaceae), sedges (Cyperaceae), various aquatic pollen, and some open freshwater, freshwater marsh and reedswamp NPPs, suggesting a marsh-carr environment dating to the early mid-Holocene. Within this peat layer, diatom assemblages contain high values of the freshwater forms *Diploneis oculata, Navicula begeris* and *Amphora ovalis*, species often appearing within an upper intertidal high marsh assemblage (e.g. Zong and Horton, 1998). Confirming such an environment are equally high values in this layer for brackish water diatoms such as *Navicula peregrina* and *Nitzschia granulata*, indicating significant tidal influence at the site. Above 3.70 m, the marsh changes into a brackish-water, lagoonal environment as indicated by the silt-clay sediment (Table 1) and diatoms which show an increase in the proportion of brackish water taxa, with consistent frequencies of freshwater salt-tolerant species. At 3.25 m, however, a sharp increase in freshwater diatoms is recorded, particularly *A. ovalis* and *Aulacoseira granulata*, the latter a planktonic species flourishing in low-salinity estuarine environments (e.g. Zong et al., 2006, 2010). Between 3.70 m and 3.20 m, the pollen data show a sharp decline in willows and aquatics at 3.60 m, but no significant variation in grasses and sedges. In the same horizons, the open freshwater NPPs increase steadily, and only low numbers of estuarine NPPs are found. From 3.20 m to 2.70 m estuarine NPPs disappear and open freshwater NPPs increase, suggesting the cessation of tidal influence at the site. Above 2.70 m, both the organic-rich clay sediment and the pollen results indicate a freshwater marsh/swamp or lake environment because of the continued high frequencies of aquatic pollen and NPPs. The sedimentary and microfossil evidence from this site well inland of the present coast indicate a change from a high salt marsh to a brackish-water swamp in the early mid-Holocene, and then a gradual change to a low-salinity, then entirely freshwater, marsh/swamp or lacustrine wetland during the rest of the mid-Holocene.

Guoxiangcun

The Holocene sediment is just over 5 m thick, and the organic-rich clay below 2.20 m has been examined (Table 1). The microfossil results reveal subtle alterations in environmental conditions at this site (Fig. 4). Below 2.70 m, the diatom results show a change from a dominantly brackish water assemblage with *Actinoptychus senarius, Coscinodiscus blandus, C. divisus* and *Cyclotella striata*, all planktonic species commonly found in estuarine waters (e.g. Zong et al., 2010), to a mixed assemblage with marked increases in freshwater taxa percentages, suggesting a reduction in tidal influence. Also below 2.70 m, the pollen assemblages are characterised by the dominance of grasses, with a relatively high presence of sedge and aquatic pollen, and also with high frequencies of open freshwater NPPs and some freshwater marsh and reedswamp NPPs (Fig. 4). There are also saltmarsh pollen types (i.e. Chenopodiaceae family and Compositae cf. *Youngia*), confirming tidal influence. Above 2.70 m, the abundance of both aquatic and saltmarsh pollen is reduced, and open freshwater NPPs increase their frequencies, while other types of pollen and NPPs change little. Diatoms at these depths are poorly preserved. However, the fact that the freshwater diatoms increase up-core towards 2.70 m suggests a change from a brackish-water

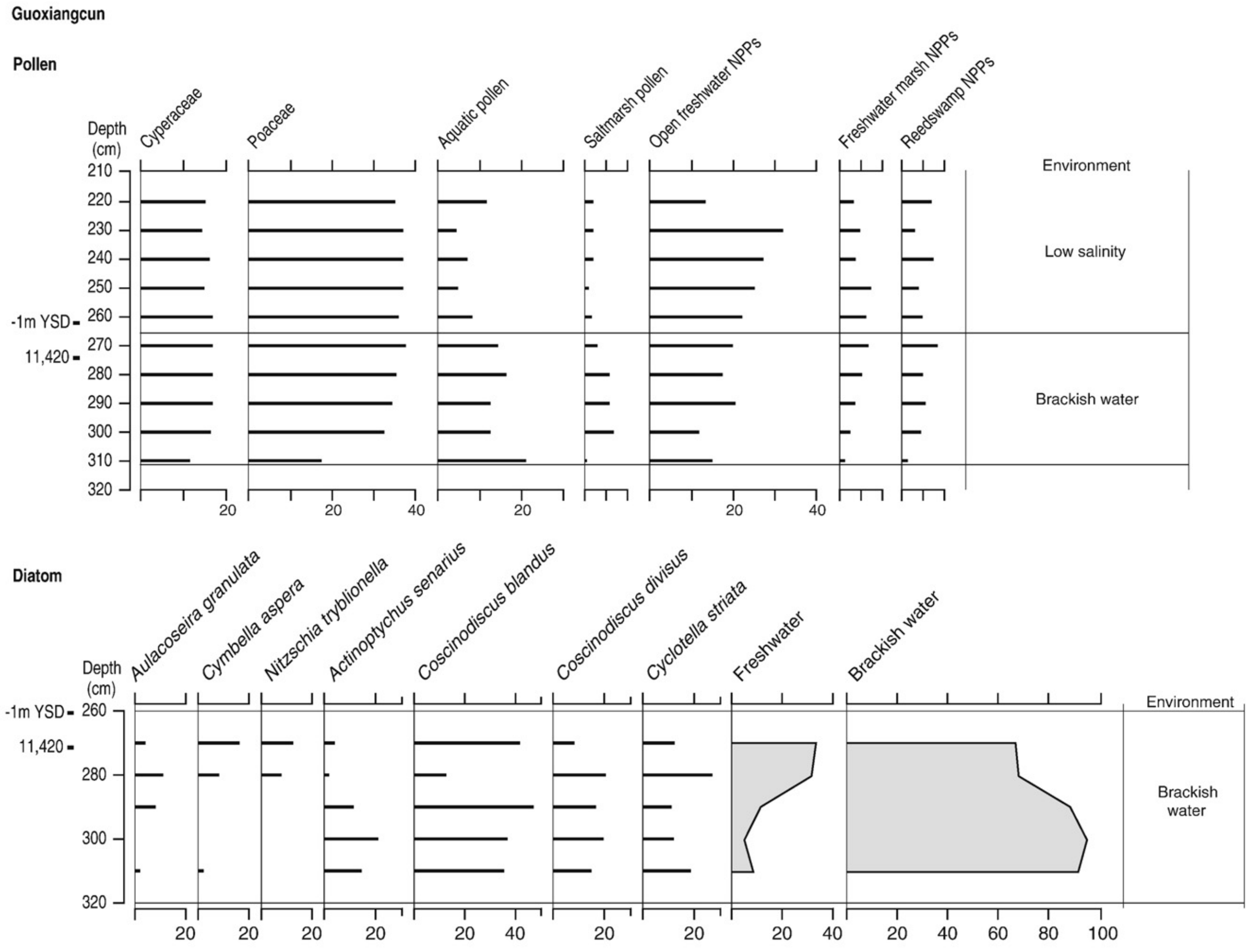

Figure 4. Selected diatom, pollen and NPP results from Guoxiangcun, calculated and presented in the same way as in Fig. 3.

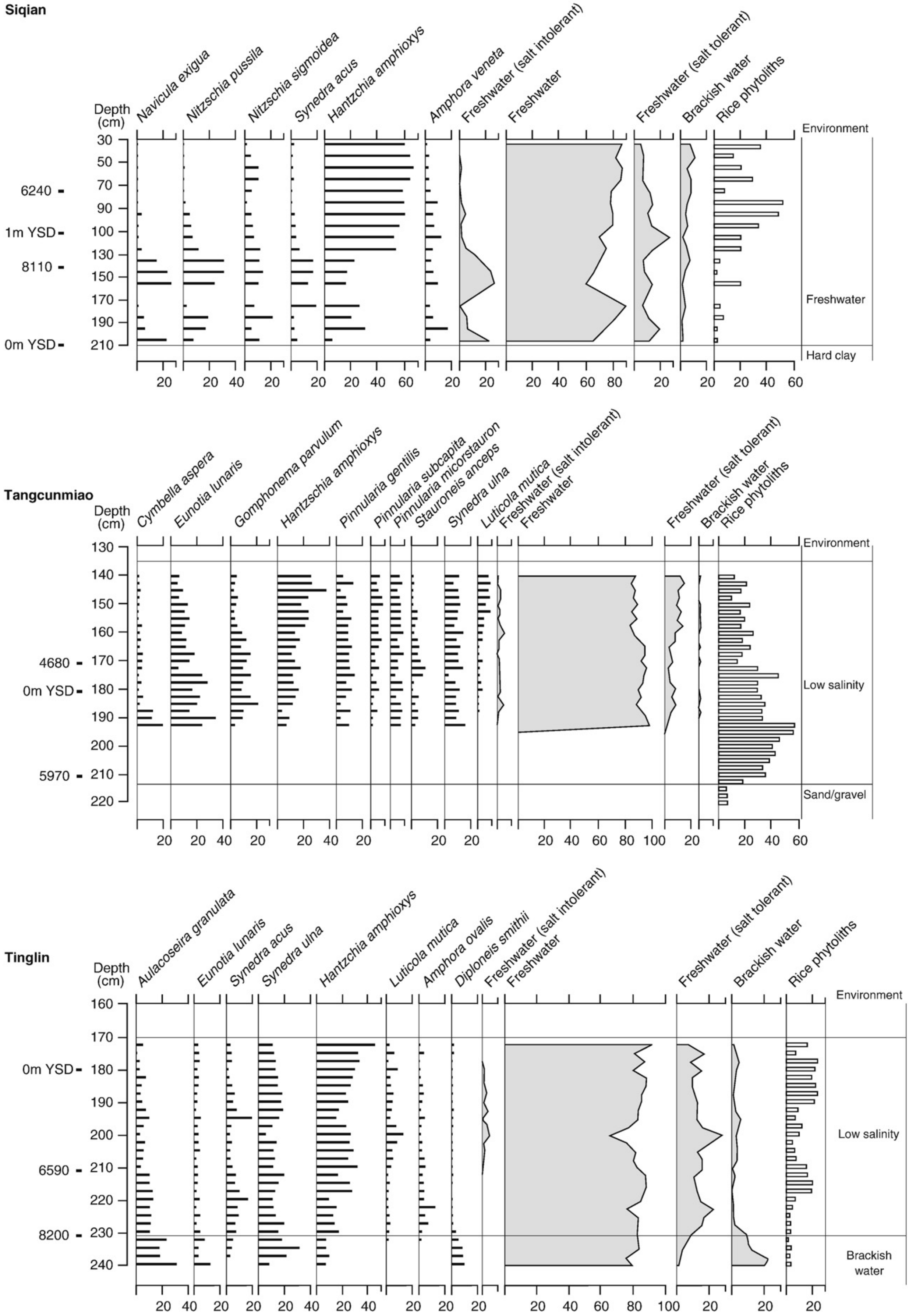

Figure 5. Selected diatom results from Siqian, Tangcunmiao and Tinglin, calculated and presented in the same way as in Fig. 3. Rice phytolith values are presented as an indication of local human activity.

environment to a low-salinity paludal marsh. Such low-salinity conditions may have persisted up to 1.50 m, above which a freshwater marsh was possibly established, as herbaceous roots increase from this horizon up-core (Table 1). A date at 2.70–2.72 m appears much too old (Table 2), and the brackish-water sequence is likely to be of early mid-Holocene age.

Siqian, Tangcunmiao and Tinglin

At these sites the Holocene sediment sequences are all thin (Table 1) and pollen preservation is poor. In each case diatoms are well preserved except for the lower section at Tangcunmiao. At Siqian, the diatoms show a change at 1.30 m from a more diverse assemblage including *Navicula exigua*, a salt-intolerant species, to an assemblage dominated by a single diatom (Fig. 5), *Hantzschia amphioxys*, a benthic species commonly appearing in high intertidal marshes where freshwater supply is abundant (e.g. Zong and Horton, 1998). No single brackish-water taxon exceeds 10% abundance, but their total number increases slightly up-core, in contrast to the decrease in freshwater salt-intolerant species. Thus the microfossil evidence suggests a weak, but persistent, tidal influence at the site, which remained predominantly under freshwater conditions throughout. The two radiocarbon dates suggest that the sequence below 1.30 m belongs to the earlier Holocene, and the one above to the mid-Holocene. The former, between 1.30 m and 2.10 m, appears to have been deposited under almost entirely freshwater conditions, unlike those at Pingwang, Guoxiangcun and Tinglin where the earlier Holocene sequences are dominantly of brackish-water origin. This can be explained because the ground altitude at Siqian is a little higher than at the other sites. Nevertheless, the mid-Holocene low-salinity sequence is clearly associated with local Neolithic human activity as indicated by the high frequency of rice phytoliths in those levels.

At Tangcunmiao, both the age and origin of the basal sandy gravel (Table 1) are unclear. The clay sequence between 2.10 m and 1.40 m contains well preserved microfossils. The diatom assemblages are diverse and mainly freshwater forms (Fig. 5), although salt-tolerant taxa, including *Luticola mutica*, a benthic species commonly found in the high saltmarsh (e.g. Zong and Horton, 1998), are consistently present, together with low numbers of brackish-water diatoms. The results suggest a stable, low-salinity environment throughout the mid-Holocene at the site. The representation of rice phytoliths also remains broadly consistent throughout the period, although declining above 1.70 m. At Tinglin, both freshwater (*Aulacoseira granulata* and *Synedra ulna*) and brackish-water (*Diploneis smithii*) diatoms are important at the base of the sediment sequence, indicating a low-salinity environment (Fig. 5), but between 2.30 and 1.70 m the diatom assemblages are dominated by freshwater forms. However, species that are commonly found in the high saltmarsh, such as *Hantzschia amphioxys* and *Luticola mutica*, occur persistently throughout the sequence, suggesting a stable, low-salinity environment similar to the one at Tangcunmiao.

Beiganshan

Here reasonably well preserved foraminiferal assemblages are recorded from the soft clay below 1 m depth. About 1 km north, the Holocene sediments are up to 15 m thick, as revealed by core ZX-1 (Fig. 2B), the upper part of which also contains foraminifera (Chen et al., 2005). The assemblages from these two cores (Fig. 6) suggest a brackish-water environment that was possibly well connected to the sea, judging from their substantial number of marine taxa. It is notable that the abundance of foraminifera decreases sharply from 2.60 m to 2.40 m at Beiganshan. Above 2.40 m, the sediment characteristics do not change up to 1.15 m, but no foraminifera were recorded, suggesting a decrease in water salinity from 2.40 m up-core. According to the radiocarbon dates from the ZX-1 core, the brackish-water conditions in this area (immediately behind the chenier ridges) ended about 3000 cal yr BP.

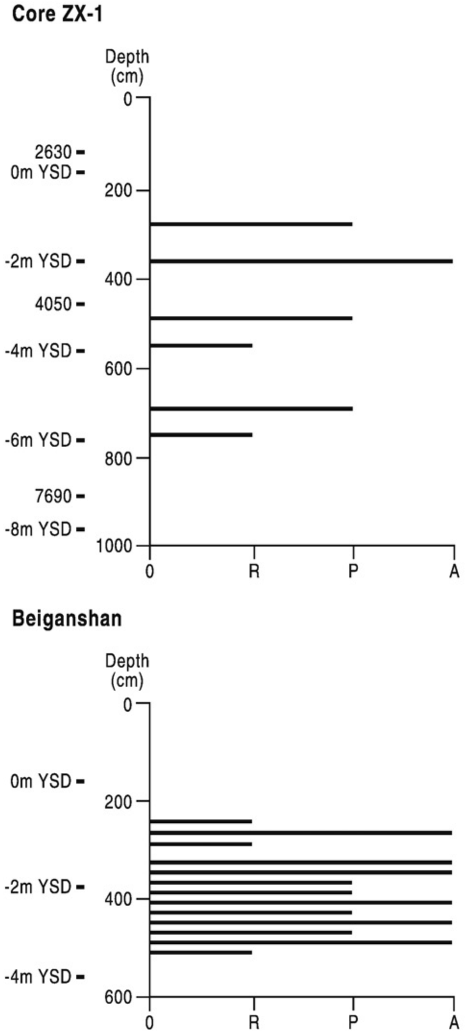

Figure 6. Foraminiferal assemblages from Beiganshan and core ZX-1 (after Chen et al., 2005) are shown as numbers of tests counted per 0.5 cc., providing a measure of relative abundance (R = 50–100, P = 100–200, A = over 200) through the lithologies.

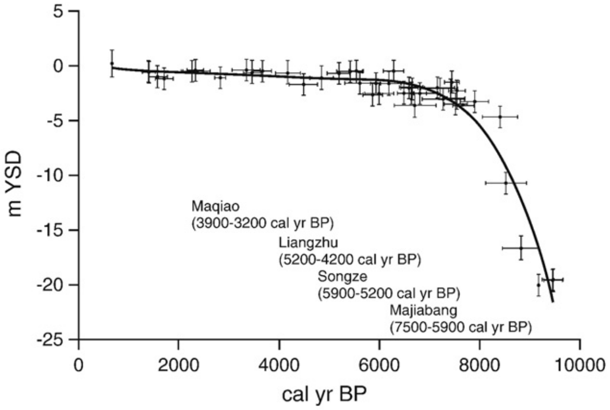

Figure 7. An age/altitude curve that summarises the sea-level history of the Yangtze delta area, derived from data index points, with error bands, that are shown by the crosses (after Zong, 2004). Approximate cultural stages in the lower Yangtze Neolithic are also shown to enable linkage with local human historical development. Note the inflexion point in the curve at ca. 7000 cal BP when rapid postglacial rise terminated at near modern altitudes, followed by a gradual, consistent slight rise thereafter. YSD: Yellow Sea datum.

Discussion

Hydrological history

The sedimentary and microfossil records presented above reflect three periods of hydrological history. The first is characterized by estuarine sedimentation and widespread marine incursion, corresponds to the early to mid-Neolithic, and is represented at most of our sites from Pingwang in the west to Beiganshan near the chenier ridges with a spread of dates through the early to mid-Holocene. The minor date reversal at Pingwang is an anomaly that commonly occurs at other published sites (Itzstein-Davey et al., 2007) without compromising dating integrity, and our dating conforms well with the consensus of previous work that direct marine influence and its associated environmental conditions persisted until ca. 7000 cal BP or soon after (Stanley and Warne, 1994; Stanley and Chen, 2000; Zhu et al., 2003; Zong, 2004).

Relative sea level on this coast (Zong, 2004) rose rapidly to −5 m by ca. 8000 cal yr BP, after which it continued to rise more slowly, reaching −2.5 m by ca. 7000 cal yr BP (Fig. 7). This resulted in marked changes in the sedimentary regime and hydrological conditions in the study area. Rapid sedimentary infilling of the Yangtze palaeovalley, which was instigated by the post-glacial rising sea level, elevated ground surface altitudes from below −20 m to −10 m along the southern bank of the Yangtze valley during the early Holocene (Fig. 2B), providing the opportunity for the development of the chenier ridges and a stable shoreline around 7000 cal yr BP (Fig. 1). As the pre-Holocene ground level of the study area was generally at −5 m at this time (Fig. 2A), a brief period of marine inundation around 7000 cal yr BP should have occurred in the Taihu area and is recorded at Pingwang (Fig. 3), Guoxiangcun (Fig. 4) and Tinglin (Fig. 5) by the introduction of brackish-water diatoms and other diagnostic intertidal microfossils, as well as at other nearby sites (e.g. Jiang and Liu, 2001; Wang et al., 2001; Li et al., 2009, 2010a,b). There is little evidence for human occupation of the Taihu lowland during this phase (Zhang et al., 2005), although settlement sites could be concealed beneath later sediments.

The second period equates to the time of Neolithic occupation of the area after ca. 7000 cal yr BP (Zhu et al., 2003) during which relative sea level rose very slowly (Fig. 7). Our data (Figs. 3–6) indicate that low-salinity depositional environments persisted during this mid-Holocene period, indicating that the east Taihu area was protected by the chenier ridge barrier from direct major marine inundation. However, there are significant variations in hydrological successions across the area both spatially and temporally (Table 3). Well inland at Pingwang, the environment changed gradually from brackish-water conditions to low-salinity high saltmarsh and then to freshwater marsh/swamp and lake habitats. Gradually, water depths seem to have slightly increased at Pingwang as indicated by the behaviour of the curves for aquatic pollen and open freshwater NPPs. To the east, in the central part of the study area (Fig. 1), low-salinity high saltmarsh conditions persisted as suggested by the low frequency of brackish-water and freshwater salt-tolerant diatoms at Siqian, Tangcunmiao and Tinglin. Further east, immediately behind the chenier ridges, a brackish lagoon environment lasted until 3000 cal yr BP as supported by the persistent occurrence of estuarine foraminifera at Beiganshan and ZX-1 (Chen et al., 2005). Freshwater marsh/swamp, lacustrine, low-salinity high saltmarsh and lagoon sedimentation across the east Taihu area kept pace with the slowly rising sea level during the Neolithic period, expanding freshwater habitats and restricting significant marine influence, although thin estuarine clays within the archaeological succession at some Neolithic sites indicate occasional local penetration by marine water (Zhu et al., 2003). Such slight water salinity may have constrained mid-Holocene agriculture to some extent (Zeng and Shannon, 2000), and there are areas where palynological evidence suggests only low-scale rice production (Atahan et al., 2008), but Neolithic people clearly found enough places where farming, allied to other food resources, could support considerable populations.

The third period saw no direct marine incursions into the study area, although there was some transformation of the landscape caused by human activities in the late Neolithic. During most of the Liangzhu culture between ca. 5200 and 4200 cal yr BP the local and regional environmental and archaeological evidence (Yu et al., 2000; Zhou et al., 2004; Zhang et al., 2005; Huang et al., 2006; Tao et al., 2006; Wu et al., 2010) shows that a drier phase and a lowering of water tables in the Yangtze delta lowlands, including significant contractions in lake areas and depths (Wang et al. 2001; Zhang et al., 2004a,b; Chen et al. 2009) allowed major expansion of Liangzhu settlement and intensive rice farming (Li et al., 2010a,b). Even in the later stages of the Liangzhu, when conditions became much wetter, there is still no evidence of marine transgression. After the cultural break of some centuries after 4200 cal yr BP, the level of human impact again increased markedly by 3500 cal yr BP, as shown at several sites in the area including the type site of the Maqiao culture (Shanghai Museum, 1985, 2002a,b, 2008; Zou et al., 2000; CPAM of Shanghai, 2002; Atahan et al., 2007; Chen et al., 2009), as well as at locations south of Hangzhou Bay (Itzstein-Davey et al., 2007; Li et al., 2010a,b), after which land reclamation and drainage actually pushed the shoreline seawards (Chen and Zong, 1998) reducing the capacity of sea-level fluctuation to affect agriculture in the area.

Upland environments

To understand the late Neolithic wetland landscapes of the Taihu lowlands, they must be considered in the context of the wider landscape, which includes upland areas beyond the reach of groundwater movements, marine fluctuations and fluvial input. Palynology has shown that the isolated hills that were scattered across the plain and the higher uplands to the west and south supported dryland vegetation that was mainly dense sub-tropical mixed forest during the Songze and Liangzhu periods (Liu et al., 1992; Xu et al., 1996; Yi et al., 2003; Chen et al., 2005; Tao et al., 2006; Shu et al., 2007). Itzstein-Davey et al. (2007) found little evidence of significant impacts on this forest during the Liangzhu period around Qingpu in the eastern Taihu plain, but

Table 3

A summary of the environmental history for the eastern Taihu area. Note that the relatively higher ground altitude of the central area Siqian site, not shown on the table, prevented its inundation by the sea during the early Holocene. Only freshwater conditions are recorded there.

Time cal yr BP	Inland sites around Taihu	Sites in the central area	Behind the chenier ridges	Deltaic plain seaward of ridges
	Pingwang, E2, JLQ	Guoxiangcun, Tinglin, T1, Tangcunmiao	Beiganshan, T4, ZX-1	T28
1000			Freshwater marsh	Low-salinity marsh
2000				Saltmarsh
3000		Freshwater marsh/lake	Saltmarsh	
4000				
5000	Freshwater marsh/lake		Brackish water (lagonnal)	
6000	Low-salinity marsh	Low-salinity marsh		
7000	Brackish water	Brackish water	Brackish water	Brackish water (estuarine)

elsewhere there is evidence that the dryland forest, though initially dense, suffered significant clearance at this time, perhaps due to population pressure requiring expansion of agriculture onto the hillslopes above the lowland plain. Li et al. (2010a,b) have recorded pollen evidence of substantial deforestation and expansion of grassland and cultivation in the foothills around a Liangzhu-period site on the southern shore of Hangzhou Bay. Liu et al. (1992) noted that many pollen indicators of land clearance occurred during this period while Yi et al. (2006) also noted some forest clearance on the higher ground during the Liangzhu period, with deforestation for cultivation, including *Fagopyrum* (buckwheat), after about 4500 cal yr BP. Chen et al. (2009) recorded an increase in charcoal frequencies, woodland clearance and the spread of grassland around Lake Chaohu in the north of the study area after ca. 4800 cal yr BP, while Atahan et al. (2008) also recorded increased charcoal values around archaeological sites to the east of lake Taihu, likely to be linked to land clearance for agriculture. That Liangzhu forest clearance may have led to increased soil erosion is suggested by Wang et al. (2010, 2011) who noted the appearance of magnetic mineral grains signifying fluvially transported soil material in subaqueous Yangtze sediments of this age. Analogous examples of deforestation at the time of maximum late Neolithic cultural and agricultural development occur in the middle Yangtze valley (Yasuda et al., 2004), to be followed by settlement abandonment there around 4200 cal yr BP. During the later Liangzhu, any removal of tree cover from the higher ground in the Taihu plain or from the hillslopes that enclose it to the west would have greatly increased drainage water discharge into the Taihu basin, adding significantly to any increased wetness caused by climate change, as well as promoting significant soil erosion.

Hydrology and cultural history

Palaeogeography, particularly the extent and nature of wetland environments, in the low-lying Yangtze delta coastal plain east of Taihu must have had a major influence on the location of mid-Holocene Late Neolithic settlements (Wu, 1983; Stanley and Chen, 1996; Zhang et al., 2005; Wu et al., 2010), primarily because of the vulnerability of wet rice cultivation to changes in water depth and quality. Short-lived episodes of marine flooding, shown by foraminiferal studies and by thin layers of estuarine sediment devoid of cultural material (Wang and Murray, 1983; Zhang et al., 2005; Li et al., 2009, 2010a,b), temporarily affected settlements during the phase of rising sea level. By translocating their fields and settlements within the area farmers could cope with low-amplitude variability in the perimarine hydrological regime in near-estuarine wetlands but a rapid, high amplitude sea-level rise could easily have resulted in an inability of people to adapt, causing abandonment of the area. The major example of such an interlude of greatly reduced cultural and agricultural activity, at the end of the Liangzhu culture in the centuries from 4200 cal yr BP, suggests the virtual collapse of a previously highly successful late Neolithic economic and social system in all areas around Taihu and Hangzhou Bay (Zhang, 2007; Zheng et al., 2009). Although sea level was high on this coast (Stanley et al., 1999; Zong, 2004), our multi-site, microfossil-based high-resolution investigation of sedimentation and hydrology throughout the east Taihu area has found no evidence of any direct marine influence at the time of the Liangzhu's fall. Instead, increased dominance of freshwater systems occurred, even in the lowest-lying central areas of the plain. Because of the chenier ridge barriers and continuing sedimentation, the marshlands were protected from any direct effects of sea-level rise. Very low-salinity or even totally freshwater conditions persisted throughout the later Neolithic period across almost all of the Yangtze delta plain, which was a time of stable, slowly evolving wetland environments. In the absence of any evidence of abrupt marine inundation of any kind, environmental problems caused by sea-level change would have been indirect at most and were almost certainly not responsible for disruption of Neolithic agriculture and society around 4200 cal yr BP. If environmental stress was the major contributor to Liangzhu collapse, added to any social or cultural causes (Lu, 2007), then other environmental factors must be sought (Yu et al., 2000).

Our palaeoenvironmental data from the eastern Taihu plain support much previously published evidence from the wider lower Yangtze area in indicating that if hydrological problems did contribute greatly to the disappearance of the Liangzhu and analogous late Neolithic cultures in river valleys and coastal plains in eastern China, then it was not sea-level rise but freshwater flooding that was responsible (Yu et al., 2000; Zhang et al., 2005, Tan et al., 2008; Huang et al., 2010; Wu et al., 2010). Except beside coastal inlets, our data show transition to freshwater lake and swamp everywhere east of Lake Taihu, and it is likely that throughout lowland eastern China repeated severe freshwater floods could have overwhelmed Neolithic fields and settlements (Wu and Liu, 2004; Yasuda et al., 2004; Huang et al., 2010). Major river floods in the lower Yangtze (Gao et al., 2007), allied to a major increase in the size of the Taihu lake, the many other lakes in the plain and their surrounding peatlands (Chang et al., 1994; Wang et al., 2001; Zhang et al., 2004a,b), could well have made Neolithic occupation of the eastern Taihu area untenable, where stable high sea level would have exacerbated the problem by keeping groundwater tables high and hindering drainage. Deforestation of hillslope areas for intensive agriculture that caused greatly increased overland run off and erosion would have added to the hydrological problems. Regionally, lowland areas well beyond any influence of the sea were equally affected and Neolithic people's apparent abandonment of river bottomland and coastal plains (Gao et al., 2007; Wu et al., 2010) at this time followed greatly increased incidence and intensity of freshwater flooding.

Conclusion

Our investigations have allowed a spatial assessment of the hydrological changes that occurred in the eastern Taihu area, the heartland of late Neolithic cultural development in the lower Yangtze region, particularly in relation to any possible effects of coastal change and marine incursion. There is no evidence of any extreme marine event at the end of the Liangzhu cultural period, or even of heightened marine influence, that could have brought about that culture's failure and archaeological disappearance. The chenier barrier system that protected the coastal marshlands remained in place and as sea level rose only very slowly in the mid- and later Holocene, saline influence via tidal creeks and seepage remained low and did not adversely affect agricultural or settlement viability. Other factors need to be investigated, primarily freshwater flooding and climate change, and the social problems these may cause, to explain the collapse of the Liangzhu culture in the Yangtze Taihu lowlands.

Acknowledgments

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