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Holocene vegetation history with implications of human impact in the Lake Chaohu area, Anhui Province, East China

Wei Chen · Wei-Ming Wang · Xue-Rong Dai

Abstract Palynological analyses of Holocene deposits located about 2 km to the southwest of the Lake Chaohu, Anhui Province, documented well the local vegetation history, its inferred environment and human impacts for the first time. An evergreen and deciduous mixed broad-leaved forest dominated by *Cyclobalanopsis* and *Quercus* existed from ca. 10,500 cal B.P. and became fully developed between ca. 8,250 and 7,550 cal B.P. Notable fluctuations occurred in the main components of the flora indicated by the decline in *Cyclobalanopsis* and other arboreal plants (AP), and an increase in terrestrial herbs between ca. 7,550 and 3,750 cal B.P., inferring the progressive opening of the forest under considerable human interference, which largely agrees with the archaeological evidence. After ca. 3,750 cal B.P., the broad-leaved forest largely gave way to terrestrial herbs, and never again recovered. *Pinus* continued to rise alongside the majority of herbs between ca. 3,750 and 2,000 cal B.P., then also declined after ca. 2,000 cal B.P. Human influence on the natural vegetation displayed in the pollen diagram seems to increase greatly up the core. The disappearance of broad-leaved forest indicates significant human impact after ca. 3,750 cal B.P., which is consistent with both the archaeological evidence and historical records. From that time the natural environment in the study area was subjected to long-standing pressure from increasing farming and population.

Keywords Palynology · Holocene · Palaeovegetation · Human impact · Lake Chaohu · East China

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Introduction

Lake Chaohu, one of the five biggest freshwater lakes in China, is located in the lower reaches of the Yangtze River. Within this area, lakes and other water systems are densely developed. As this is one of the most important areas for the origination of the earliest civilizations, and is also known as a major culture and economic center in China, many papers have focused on Holocene environment studies in the past decades and large amounts of pollen data have also been acquired (Li 1962; Liu 1993; Wang 1974; Wang et al. 1984, 1993, 1996; Xu and Zhu 1984; Xu et al. 1996; Yi et al. 2003b; Zhen 1988; Shu et al. 2007). Previous studies are mostly concerned with Holocene climatic changes, with one of the most frequently discussed topics being the holocene climatic optimum (HCO). Scientists using different approaches have contributed various viewpoints on its duration (e.g. Liu et al. 1992; Tang 1992; Tang et al. 1996; Liu 1993; Zhao et al. 1994; Xu et al. 1996). Through synthesis of comprehensive Holocene data, such as palynology, palaeobotany, palaeozoology, palaeosol, palaeolimnology, ice core, archaeology etc., Shi et al. (1992) deduced that the HCO in China might have begun around 8,500 B.P. (ca. 9,510 cal B.P. as calibrated by the authors) and ended around 3,000 B.P. (ca. 3,170 cal B.P.), accompanied by some

marked climate fluctuations and cooling events. This is more or less an overall deduction. There is still disagreement on the duration of the HCO among data from different areas of China generated by various approaches. The real situation might also have varied from place to place. Additionally, so far we have no standard Holocene climatic profile for China. It has also been deduced that the annual mean temperature was 2°C higher than today during the period between 7,200 and 6,000 B.P. (ca. 8,000–6,840 cal B.P.) (Wang and Gong 2000).

Since a large number of Neolithic culture sites have been excavated in the lower reaches of the Yangtze River (e.g. Wu 1988; Wu and Cao 2000), many archaeologists have suggested that this area is one of the most important places for the origination of paddy rice in East Asia (e.g. Wu 1983). Gao (2004) synthesized the data from 757 Neolithic culture sites in the lower reaches of the Yangtze River, and summarized them into three prehistorical culture periods, the Majiabang (ca. 7,000–5,800 cal B.P.), Songze (ca. 5,800–5,200 cal B.P.) and Liangzhu (ca. 5,200–4,000 cal B.P.) cultures. Furthermore paddyfield relics were recovered at some Neolithic culture sites.

However, the data referred to above are mostly from the Yangtze River delta area, and mainly concern the past environment. Detailed study of the interface between the natural environment and human activities is generally lacking. To date there has been no published pollen study from the lake Chaohu area, although over 30 Neolithic sites have been excavated in the study region so far. These show extensive human activities including rice agriculture and house construction dated to some 7,000 years ago (Yang 2002; Ren and Zhang 2005; Shou et al. 2006). The early rice agriculture has been recently confirmed by phytolith evidence from the same core (Fan et al. 2006).

Biogeographically, the lower reaches of the Yangtze River lie between temperate and subtropical zones. The vegetation shows a transition between temperate deciduous forest and subtropical evergreen forest (Li et al. 1995). This means that the vegetation in the area is somewhat sensitive to a few degrees of temperature variation. Consequently, reconstructing the past vegetation and climate of the area is considered as a significant analogue of natural response to the coming global warming. This paper concerns the Holocene vegetation history in the study area. An effort was also made to explore the possible relationship between vegetation changes and human activities.

Study area

Location

Our study site ACN (31°31′47.1″N, 117°22′29.8″E) is located in Nanling Village, Anhui Province. It is about

2 km to the southwest of lake Chaohu and less than 50 km to the south-southeast of Hefei, the capital city of the province (Fig. 1). The lake covers a geographic range between 31°25′28″–31°43′28″N and 117°16′54″–117°51′46″E. It was formed on the river valley plain and developed in the Late Pleistocene as a shallow water lake (Du et al. 2004). The drainage area of the lake lies in foothills between the Yangtze River and the Huai River, and is surrounded by mountains including Mts. Yinpingshan, Fenghuangshan, Yefushan, Dabieshan and Fanghushan. Because of its topographic features, the water system around the lake is evenly distributed and unconstrained, and converges radially on the lake. There are around the lake the Hangbu, Fengle, Pai, Nanfei, Dianbu, Zhegao, Niutun, Yuxi, Xi and Zhao rivers. Of these, only the Yuxi River connects the lake to the Yangtze River. The Borehole ACN is located on the deltaic plain of the Hangbu River, the biggest inflow river of the lake. This area is currently divided into farming land. The Hangbu River originates from Mt. Dabieshan, and supplies the lake with most of its deposits. The drilling area was once a large bay and sedimentary records from it could record the detailed development history in this drainage area.

Climate and vegetation

At present the climate of the lake area is controlled by the north subtropical monsoon, characterized by a hot summer and cold winter with four distinct seasons. Annual mean temperature ranges from 14.5 to 16.1°C, January mean temperature from 1 to 2.6°C and July mean temperature
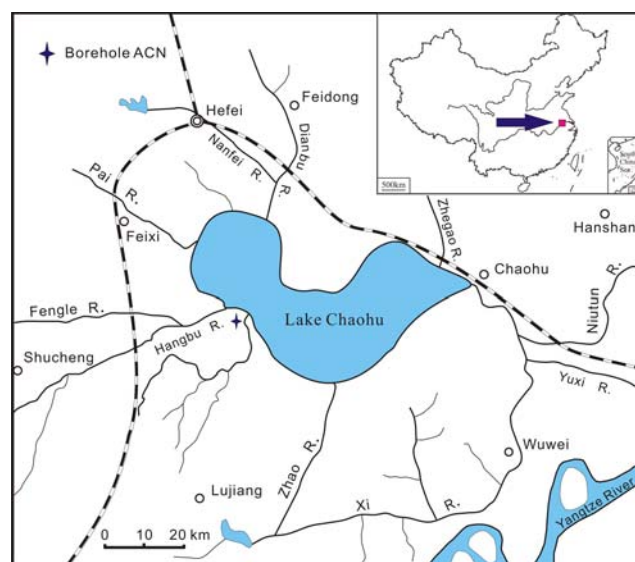

Fig. 1 Map showing location of study site and water system around the lake Chaohu area

from 27.5 to 28.5°C. Annual precipitation is between 800 and 1,200 mm.

The vegetation of the area is characterized by northern subtropical evergreen and deciduous mixed broad-leaved forest. As its geographical position is close to the warm temperate zone, some transitional features are recognizable in the flora. The principle constituents of the vegetation are evergreen and deciduous Fagaceae. Because of the long-lasting human influence, the vegetation displays stronger secondary features. Rebirth and renovation in the evergreen trees are generally weak, while deciduous trees become dominant. *Quercus acutissima* and *Q. variabilis* are the common dominant deciduous species, together with *Q. fabric*, *Q. glandulifera* var. *brevipetiolata*, *Q. aliena*, *Q. chienii*, *Castanea seguinii*, *Liquidambar formosana*, *Platycarya strobilacce*, *Albizia kalkora*, *Dalbergia hupeana* and *Pistacia chinesis* among the deciduous broad-leaved trees. Among the evergreen broad-leaved trees are mainly *Castanopsis sclerophylla* and *Cyclobalanopsis glauca*, along with *Ilex chinesis*, *Ligustrum lucidum* and *Photinia serrulata*. Some extensive tussocks, mainly consisting of *Themeda triandra* var. *japonica*, *Cymbopogon goeringii*, *Imperata cylindrica* var. *major*, *Miscanthus sinensis*, *Artemisia japonica*, *Dendranthema indicum* and *Solidago decurrens* are distributed on hillocks. *Pinus massoniana* widely forms a secondary forest in this area, together with *P. thunbergii* and *Platycladus orientalis*. The local agriculture is mainly double cropping rice and rape, together with triple cropping wheat. Other economic crops include cotton, hemp, tobacco, peanut etc. (Wu 1995).

Materials and methods

The field survey and sample collection were made by colleagues from East China Normal University in Shanghai. A total of 1,650 cm of sediments were recovered from the Borehole ACN.

All together 63 samples with a weight of 10–20 g were taken, 53 at an interval of 15 cm from 0 to 800 cm, and 10 from 810 to 1,420 cm at an average interval of 61 cm. Beneath 1,420 cm, no sample was taken because only limited sediments were recovered from the base part of the core. All samples were analyzed at the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGP, CAS). Procedure for pollen analysis followed the standard method (Faegri and Iversen 1989; Moore et al. 1991). Prior to the HF, tablets of *Lycopodium* were added for concentration measurements after being fully dissolved. The samples were finally cleaned with an ultra-sonic cleaner using a 10 μm mesh size sieve.

Over 300 pollen grains of AP and herbs including hygrophytes were counted for each sample with an average of 464. Most of them were between 400 and 600 grains (maximum 1,196 grains, without ferns and algae). Pollen identification followed references for spore and pollen flora in China (Zhang et al. 1990; IB and SCIB 1982; Wang et al. 1995), along with modern pollen keys collected in the NIGP, CAS. Pollen grains of Poaceae were divided into three ranges based on their sizes, i.e. <35 μm, 35–45 μm and >45 μm. Charcoals over 10 μm were also counted for each sample. The results were finally calculated and the diagram was made using the programs TILIA and TILIA.GRAPH (Grimm 1990). Zonation was corroborated by CONISS.

Results

Stratigraphy

The deposits in the core comprised various sedimentary facies, including diluvial, alluvial, lacustrine, alluvial,

**Table 1** Sediment stratigraphy of borehole ACN

Unit 1 (0–90 cm)	Yellowish brown clayey fine sand to fine sand, loose and clumped without any layering, accompanied by plant roots
Unit 2 (90–270 cm)	The top part (90–150 cm) consists of grayish brown clayey fine sand without distinct layer, including many plant residues. The lower part (150–270 cm) is interbedded with yellowish brown coarse sand, fine sand and silty clay. Its color becomes gradually blacker downward. Contains thin flat-bedding
Unit 3 (270–375 cm)	Caesious clay and silty clay, with occasional shell and plant residues
Unit 4 (375–960 cm)	Very soft caesious clay with a few charcoal and oval iron-manganese concretions
Unit 5 (960–1,020 cm)	Yellowish brown fine sand, with occasional concretions and shell fragments
Unit 6 (1,020–1,260 cm)	Yellowish brown fine sand and medium sand, interbeded with thin black mud
Unit 7 (1,260–1,400 cm)	Caesious and black-gray silty clay. The sediments contain a lot of peat grains, charred wood fragments and a few shell fragments
Unit 8 (1,400–1,650 cm)	Gray silt and sand
Unit 9 (1,650 cm and below, not penetrated)	Mottled sandy gravel. The gravel is generally sharp

Table 2 Radiocarbon dates of borehole ACN

Lab. code	Depth (cm)	Material	^{14}C age (B.P.)	Cal age (B.P.) (1σ range)
LUG 04248	115	Charcoal	1,074 ± 105	1,001 ± 167
LUG 04250	151	Plant fragment	1,401 ± 100	1,295 ± 112
LUG 04246	200	Plant fragment	1,868 ± 130	1,623 ± 163
LUG 04247	280	Plant fragment	2,182 ± 110	2,197 ± 135
LAMS 05–22	392	Clay	3,602 ± 150	3,922 ± 221
LUG 04249	490	Clay	4,907 ± 120	5,680 ± 198
LUG 04251[a]	770	Clay	8,176 ± 140	9,198 ± 204
LUG04252	990	Shell fragment	7,472 ± 140	8,246 ± 170
BA 04106	1,150	Charcoal	7,949 ± 121	8,727 ± 180
LUG 04253	1,260	Shell fragment	8,266 ± 135	9,260 ± 168
LAMS 05–23	1,550	Clay	9,916 ± 140	11,448 ± 244

Calibrated ages after Reimer et al. (2004)

[a] Sample, which is considered not reliable
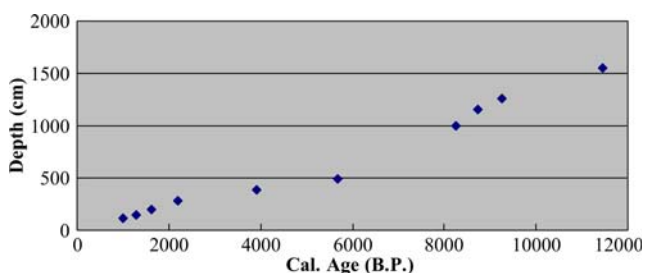
Fig. 2 Age–depth diagram of borehole ACN

fluvial, lacustrine (deep water), lacustrine (shallow water), deltaic and manual fillings in ascending order, and can be divided into nine corresponding sedimentary units, which are described in descending order in Table 1.

Radiocarbon dating

In order to obtain a time scale for the core, 11 AMS radiocarbon dates were carried out in the Radiometric Dating Laboratory of the Shanghai Institute of Applied Physics, Chinese Academy of Sciences. The radiocarbon dates (Table 2) were calibrated using the CALIB REV 5.0.1 program (in conjunction with Stuiver and Reimer 1993) and the IntCal04 Terrestrial Radiocarbon Age Calibration data-set (Reimer et al. 2004). All data except sample LUG 04251 were consistent in age. Thus ten ^{14}C dates were used for the time–depth diagram (Fig. 2).

General features and pollen zonation

Altogether more than 60 palynomorphs including pollen, spore and algae are identified. They are grouped into different ecological groups (Fig. 3). AP are dominant below 382 cm, and are represented by *Cyclobalanopsis*, *Quercus*

and *Pinus*, together with small amounts of other taxa (less than 5.0%), such as *Betula*, *Liquidambar*, *Pterocarya*, *Ulmus*, Euphorbiaceae, *Fagus*, *Castanea*, *Alnus* and *Juglans*. Terrestrial herbs are frequent in the upper 382 cm, although there are some short intervals where terrestrial herbs also show marked rises below this depth. There is a majority of Poaceae, along with a small proportion of *Polygonum*, *Artemisia*, *Urtica* type, Caryophyllaceae, Asteraceae and *Humulus* type. Hygrophilous herbs consist of Cyperaceae, *Typha* and *Nymphoides* with low values throughout the core. Fern spores are generally divided into Polypodiaceae and trilete type, and mainly occur in the upper 250 cm. Of the algae only *Concentricystes* is identified primarily from the middle and upper part of the core with a small presence.

Pollen concentrations in the core are mostly between 5,000 and 15,000 grains/g, with an average of 6,772 grains/g. Large amounts of charcoals were counted in the upper part of the core, but charcoal concentrations also display peaks in the middle part of the core (Fig. 3). Based on changes in the main palynomorphs in the pollen diagram, corroborated by CONISS clustering via Tilia 2.0, seven local pollen assemblage zones (PAZ) were distinguished.

PAZ 1 (1,420–1,095 cm): This zone is dominated by AP including (average values) *Cyclobalanopsis* (30.2%), *Quercus* (13.9%), *Pinus* (11.8%), *Betula* (4.4%); and terrestrial herbs represented by Poaceae (16.8%), *Artemisia* (2.9%) and *Humulus* type (2.1%). A decline in *Cyclobalanopsis* and *Quercus*, and an increase in Poaceae are recognized at the upper part of the zone. Its boundary with PAZ 2 lies between the samples showing a significant increase in AP especially *Cyclobalanopsis*, and a decrease in terrestrial herbs, especially Poaceae.

PAZ 2 (1,095–855 cm): AP in the zone reaches its maximum (85.5%) of the core, mainly indicated by

(average values) *Cyclobalanopsis* (37.2%), *Pinus* (27.9%) and *Quercus* (8.5%), while terrestrial herbs Poaceae (7.7%), *Artemisia* (0.8%) and *Humulus* type (1.7%) decline. Values of the pollen components in the zone are more or less stable compared with other zones. Its boundary with PAZ 3 lies between the samples where *Cyclobalanopsis* displays a significant decrease.

PAZ 3 (855–563 cm): This zone is marked by *Pinus* and the fluctuating occurrence of *Cyclobalanopsis* and *Quercus* in lower values. At the top of the zone, *Pinus* show a significant decline, while terrestrial herbs, especially Poaceae, show a major rise. Consequently two subzones are recognizable. The average values of some main pollen types include *Pinus* (38.5%), *Cyclobalanopsis* (19.4%), *Quercus* (12.0%), Poaceae (9.4%) and *Liquidambar* (1.5%) in PAZ 3a (855–638 cm), and Poaceae (35.3%), *Cyclobalanopsis* (13.2%), *Pinus* (13.1%), *Quercus* (7.7%) and *Liquidambar* (1.0%) in PAZ 3b (638–563 cm). Its boundary with PAZ 4 lies between the samples showing a significant increase in AP especially *Cyclobalanopsis* and *Quercus*.

PAZ 4 (563–382 cm): This zone shows a constant rise in *Cyclobalanopsis* and *Quercus*. Two subzones are identified based on a rise in Poaceae, and a decrease in *Pinus* at the upper part of the zone. The average values of some main pollen types include *Cyclobalanopsis* (24.7%), *Quercus* (22.2%), *Pinus* (19.2%), Poaceae (9.0%), *Liquidambar* (1.6%) and *Artemisia* (2.6%) in PAZ 4a (563–443 cm), and Poaceae (35.6%), *Cyclobalanopsis* (15.7%), *Quercus* (13.9%), *Pinus* (11.4%), *Liquidambar* (1.1%) and *Artemisia* (3.3%) in PAZ 3b (443–382 cm). Its boundary with PAZ 5 lies between the samples with a major decline in *Cyclobalanopsis* and *Quercus*.

PAZ 5 (382–250 cm): A sharp decline in *Cyclobalanopsis* (4.9%) and *Quercus* (2.2%) is recognized in this zone. There is also some increase in the terrestrial herbs, such as Poaceae (45.1%) and *Polygonum* (8.8%), and *Artemisia* (3.0%). Its boundary with PAZ 6 lies between the samples where a decline in Poaceae is recognizable.

PAZ 6 (250–90 cm): This zone is characterized by the enrichment of ferns (33.7%) and fresh water algae (3.9%). Other main elements include Poaceae (24.3%), *Pinus* (6.9%), *Cyclobalanopsis* (5.0%), *Polygonum* (4.9%) and *Quercus* (1.7%). It is divided from PAZ 7 by a significant rise in *Fontanesia* and *Fraxinus*.

PAZ 7 (90–0 cm): This zone is characterized by abundant *Fontanesia* (24.0%) and *Fraxinus* (4.9%). Other AP percentages stay lower, including *Pinus* (6.3%), *Cyclobalanopsis* (2.0%) and *Quercus* (0.6%). Poaceae of sizes between 35–45 μm rise to 7.9%. Ferns decline to 15.6% and algae are present occasionally. The material of this zone was redeposited through human activity.

The above pollen zonation is more or less comparable with the result of CONISS analyses, but there are still some differences. This is mainly caused by the fact that CONISS analysis is based on all the elements in the pollen diagram, while the zonation described places more emphasis on changes between AP and terrestrial herbs.

Interpretation and discussion

Vegetation and environment history

Changes in Holocene vegetation have resulted in the formation of the modern flora. The pollen flora from Borehole ACN exhibits well the Holocene vegetation and environment history around the Lake Chaohu area in seven stages which correspond to the above mentioned pollen zones.

Stage 1 (ca. 10500–8550 cal B.P.): This stage predominantly features *Cyclobalanopsis* and *Quercus*, with the low occurrences of *Betula*, *Ulmus* and *Liquidambar*. *Cyclobalanopsis* is currently one of the main components in the subtropical evergreen forest (Zheng and Lei 2000; Xiao et al. 2000; Zheng 2000). *Quercus* often occurs with *Cyclobalanopsis* and *Castanopsis* in the north subtropics (Li et al. 1993). In the late part of this stage, a temporary decline in *Cyclobalanopsis* and *Quercus*, and a rise in *Pinus* and terrestrial herbs are recognized. As this happened only in one spectrum, it is hard to say whether it is a real situation or a casual bias. We will leave it undiscussed in this paper. Meanwhile, the depositional environment also changes from lacustrine to alluvial facies at that time, expressed by a distinct sand layer. The overall vegetation of the stage was evergreen and deciduous mixed broad-leaved forest.

Stage 2 (ca. 8550–7550 cal B.P.): AP in the pollen flora reaches the maximum for the Holocene, and includes *Cyclobalanopsis*, *Pinus*, *Quercus*, *Liquidambar*, *Pterocarya* and *Castanea*, while terrestrial herbs decrease to their lowest level. Besides *Cyclobalanopsis*, *Liquidambar* is a deciduous but frequently occurring element in the subtropical forest (Zheng 1991; Li et al. 1995). It indicates a fully developed evergreen and deciduous mixed broad-leaved forest. This stage might represent the beginning of the Holocene Maximum warm climate condition, while the local sedimentary facies gradually changed from fluvial to lacustrine (deep water). This stage is also in accordance with the Holocene maximum marine transgression in China, which occurred at this time (Hong 1989).

Stage 3 (ca. 7550–6050 cal B.P.): The pollen flora maintained the main features of the former stage, but there occurred some marked fluctuations, mainly due to competition between *Quercus* and *Cyclobalanopsis*. Late in this period (ca. 6,450–6,050 cal B.P.), AP declined greatly and terrestrial herbs including Poaceae, *Polygonum* and *Artemisia* increased rapidly. Although there is no comparable
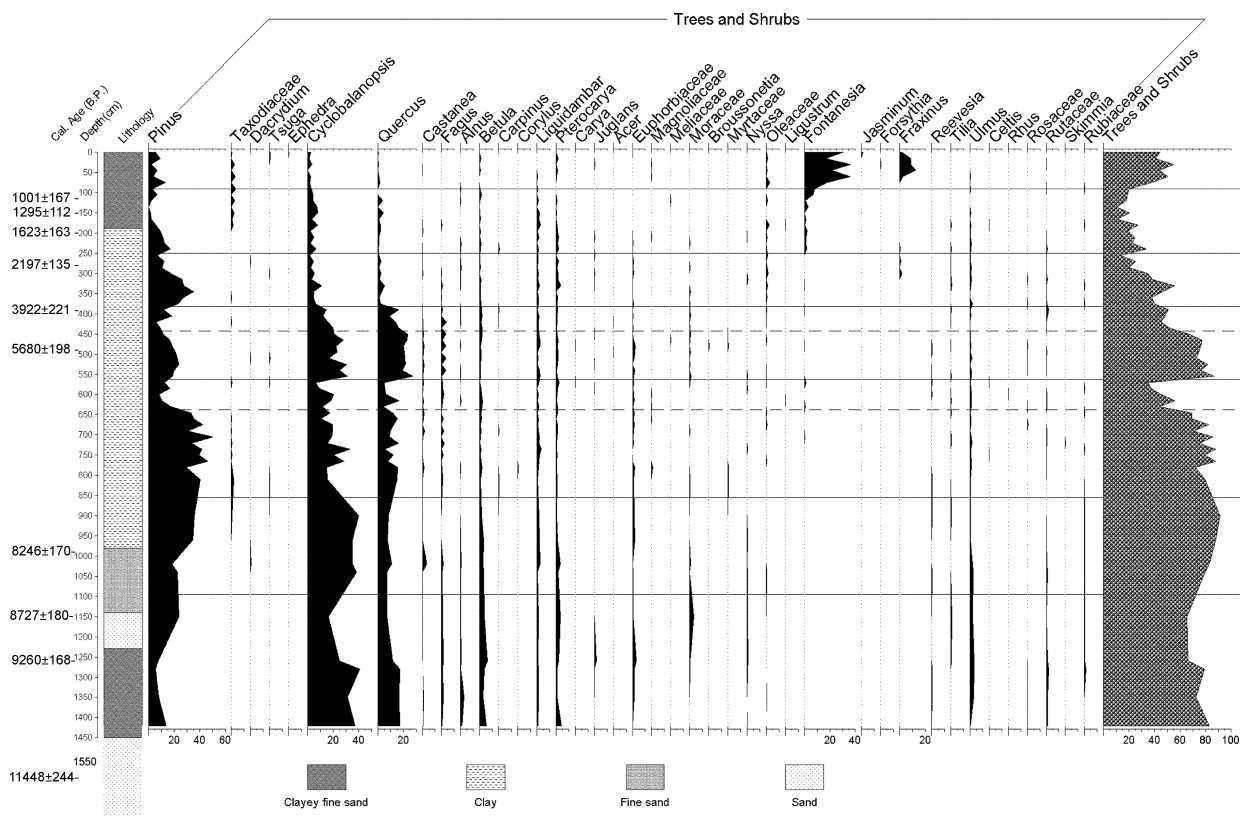
Fig. 3 Pollen-percentage diagram of trees, shrubs and herbs, together with the pollen sum, pollen concentration, charcoal sum, charcoal concentration and independent fern and alga percentages based on all the palynomorphs from Borehole ACN

record of Neolithic culture around the lake area, we do have the Houjiazhai culture (about 7,300–5,200 years ago) which was located some 100 km north of the lake in the same geographic region. Archaeological evidence shows that extensive human activities including paddy agriculture and house construction had already been initiated in several prehistorical culture sites (Ren and Zhang 2005). Changes in the forest composition indicated in the pollen profile might infer a distinct opening of the forest and point to considerable human interference, which took place simultaneously with the development of the Houjiazhai culture.

Stage 4 (ca. 6050–3750 cal B.P.): A major recovery of AP is recorded in this stage, represented by *Quercus*, *Cyclobalanopsis*, *Fagus*, Euphorbiaceae etc. In the later part of the stage (ca. 4,850–3,750 cal B.P.), terrestrial herbs came in again, with a preponderance of Poaceae and *Polygonum* developing. It seems the landscape became more and more open, and human activities intensified in the later part of the stage. According to the archaeological data from the low ground by the Yuxi River (Fig. 1) to the east of the lake, the Lingjiatan site indicates the first prehistorical culture such as paddy agriculture, with settlement traces and finds of jade artefacts near the lake. Radiocarbon dating results from the plant ash in the lower red baked soil

layer and the charcoal from the graveyard are 5,560 cal B.P. and 5,290 cal B.P., respectively (Ren and Zhang 2005), comparable with this stage. Meanwhile, the water of Lake Chaohu gradually became shallow.

Stage 5 (ca. 3750–2000 cal B.P.): The beginning of this stage marks a great increase in terrestrial herbs, combined with a steep decrease in the *Quercus* and *Cyclobalanopsis* curves. The sudden clearance of the broad-leaved forest might mean extensive land use for agriculture and human habitation. This is well documented by historical records that a state called Juchao (Chao) was established from the Shang Dynasty (16th century B.C.) to the Han Dynasty (A.D. 220) in the study area, and by the archaeological discovery of the ruins of an ancient city in the Tangjiazui lowlands of Lake Chaohu. The state was between Wu and Chu (two ancient states in the Yinzhou dynasty) (Ren and Zhang 2005; Wang et al. 2005). From this time the broad-leaved forest never recovered fully because of the intense human impact. At the beginning of this anthropogenic era some secondary reforestation took place as can be seen from the *Pinus* curve. This tree, however, is possibly overrepresented in the diagram due to its high pollen production.

Stage 6 and 7 (from cal 2000 B.P. onwards): In this upper part of the pollen diagram there are only small traces of the
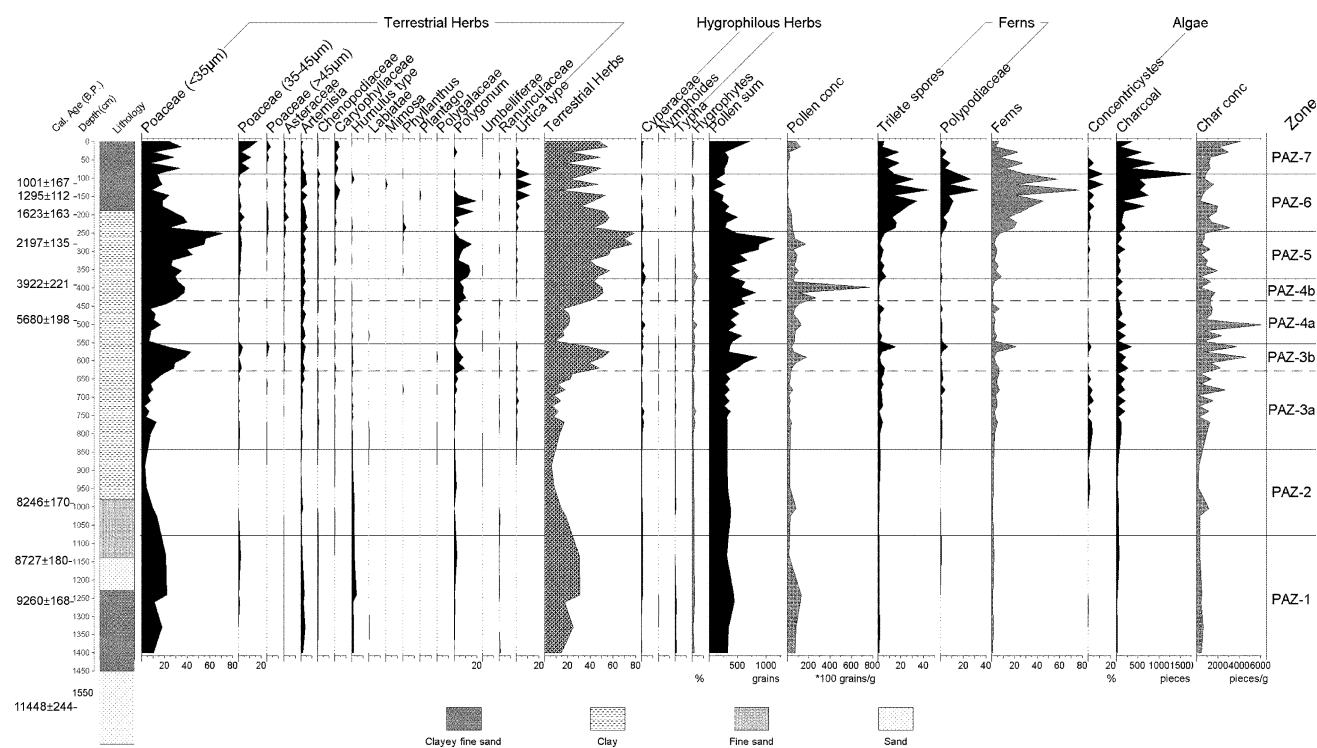
Fig. 3 continued

natural forest vegetation, as the whole landscape was now formed by the activities of man with the area around the lake being almost open. Archaeological data show that the site in the Tangjiazui lowland was abandoned about 1,800 years ago, which seems to coincide with a legend about the sinking of the Chaozhou State into the lake in A.D. 239. Historically, there is no mention of the state after the Han Dynasty (Wang et al. 2005). According to the historical record, Chao County, established in the Qing Dynasty (B.C. 221–206), was abandoned in the Sanguo (triple states) period (A.D. 220–280) because of war, and was reoccupied in the Xijin (West Jin) Dynasty (A.D. 265–316) (Shou et al. 2006). In other words this area had not only experienced natural disaster soon after the Han Dynasty, but also suffered from war in the Sanguo period (Shou et al. 2006). Among the dominant elements in Stage 7 is *Fontanesia*, which is currently used as a popular local shrub for fencing (JIB 1982). Poaceae with a size range between 35 and 45 μm also increased, which might indicate the intensified agriculture.

Human impacts

It is sometimes difficult for the palynologist to extract signals of human activities in the pollen diagram from those of natural origin. This is especially the case for China, because studies related to this are just in their initial stages. Anthropogenic indicators in the pollen diagrams have been established for many studies in Europe (e.g. Behre 1981, 1986). This is mostly based on progress in some detailed pollen morphological studies (Beug 2004; Tweddle et al. 2005). In many cases, charcoals are also employed (Marziani and Citterio 1999; Kangur 2002).

We have made some similar efforts in the current study to separate cereal from wild Poaceae, and to distinguish other possible anthropogenic indicators in the pollen diagram through pollen morphology, but so far the result is not satisfactory. Anyhow, it is still revealed that Poaceae pollen grains with size ranges between 35 and 45 μm can more probably be assigned to cereal (mainly *Oryza sativa*) than other size ranges in the study area. Much of the pollen material we obtained from the Holocene profile in the middle and lower reaches of the Yangtze Rive area shows that most Poaceae pollen grains recorded are of a size <35 μm, while size ranges between 35 and 45 μm increase up the core and sometimes predominate at the top. Pollen grains with a size >45 μm are generally sparse, and occur mostly in the upper part. Meanwhile, we counted charcoals as a supplement to the pollen data. As there was no major damage to the local flora in the glaciations, Holocene vegetation in the study area is more complicated than that in Europe. In the present status of the study, the data we used for discussing human impacts are largely based on the result of a comprehensive consideration rather than definite anthropogenic indicators.

As the sedimentary material from borehole ACN is well dated, and is richer in pollen grains and has closer sample intervals compared to other related data from the lower reaches of the Yangtze River area, it allows us to explore the possible changes in the interface between vegetation and human activities all through the Holocene. Basically, human influence on the natural environment revealed in the pollen diagram seems weak at first. An evergreen and deciduous mixed broad-leaved forest existed between ca. 10,500 and 8,550 cal B.P., which became fully developed between ca. 8,250–7,550 cal B.P. Archeological documents show that some of the earliest cereal cultivation was initiated around ca. 9,000–8,000 cal B.P. in the middle and lower reaches of the Yangtze River. An example is the Pengtoushan Civilization (Du 2002), which is more or less parallel with the later Stage 1 and early Stage 2 of this study. A definite signal of human activities is first recognized between ca. 7,550 and 3,750 cal B.P., where notable changes in the pollen proportions of AP, terrestrial herbs and Poaceae (35–45 μm) might infer the definite opening of the forest and indicate considerable human interference on the natural environment. This might indicate, based on changes in the pollen diagram, that people including the Chao tribe of the ancient legend (Shou et al. 2006) might have already been living in the lake area. It is during this period that cereal agriculture developed greatly in the middle and lower reaches of the Yangtze Rive (Kong et al. 2003).

From ca. 3,750 cal B.P., the broad-leaved forest finally gave way to farmland and human habitation because of the expansion of organized farming and increasing population, and never recovered again. This coincides well with the establishment of the Shang Dynasty (16th century B.C.) in China, and the Juchao (Chao) state in the lake area (Ren and Zhang 2005; Wang et al. 2005). At the beginning of this anthropogenic era, the local vegetation seems to have been partly replaced by a secondary pine forest. Similar situations were also reported in some other places in East Asia. In Japan, Sakaguchi (1983) noted that *Pinus* (Diploxylon) pollen increased suddenly after A.D. 1806, and he considered that this phenomenon occurred possibly as a result of human deforestation, and the growth and spread of *Pinus* (Diploxylon) as a secondary forest. In China, a transition between oak and pine also occurred in the Lake Taihu area (Xu et al. 1996), the Lake Poyanghu area (Jiang and Piperno 1999), the Yangtze River Delta (Okuda et al. 2003), the Yellow River Delta (Yi et al. 2003a) etc. After ca. 2,000 cal B.P., with a decline in values for *Pinus*, it seems that the secondary pine trees were also largely destroyed. In addition, abundant charcoals were counted in the upper part of the core, but charcoal concentrations also display high peaks in the middle parts of the core (Fig. 3). This is supposed to be more or less connected with human activities.

Conclusions

Pollen data from the Borehole ACN provide a high-resolution proxy of Holocene human environmental interactions in the study area. Reconstructed vegetation suggests an evergreen and deciduous mixed broad-leaved forest dominated by *Cyclobalanopsis* and *Quercus* from ca. 10,500 cal B.P., and fully developing between ca. 8,250 and 7,550 cal B.P., which represents the beginning of the HCO. Human influence on the natural environment is clearly distinguished in the pollen diagram through fluctuations of the pollen content between AP, terrestrial herbs and other possible agriculture indicators, between ca. 7,550 and 3,750 cal B.P. This coincides with archaeological evidence including paddy agriculture and house construction from some nearby prehistorical culture sites (Ren and Zhang 2005). With the expansion of organized farming and increases in population, natural forest finally gave way to farm lands and expanded habitation from ca. 3,750 cal B.P. This is well in accordance with the establishment in the study area of the Juchao (Chao) state from the Shang Dynasty (16th century B.C.) to the Han Dynasty (A.D. 220).

Although the pollen data presented here reveal the Holocene vegetation history and the related human impacts in the study area well, further explanation of the detailed interaction between the environment and human activities is anticipated. This would include more accurate pollen identification, especially of cereal pollen, and high-resolution pollen study of the lower part of the deposits.

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