

LATE HOLOCENE NATURAL AND HUMAN-INDUCED ENVIRONMENTAL CHANGE RECONSTRUCTED FROM PEAT RECORDS IN EASTERN CENTRAL CHINA

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ABSTRACT. We present a high-resolution multiproxy record (geochemistry, macrofossil, and pollen) from a peatland in the Dajihu Basin in eastern central China. The chronology of the 120-cm peat profile was controlled by 6 accelerator mass spectrometry (AMS) ¹⁴C dates on plant remains, including 2 post-bomb dates. The age model was based on linear interpolations of calibrated ages. Plant macrofossil results indicate a major transition around 3600 cal BP from *Sphagnum* section *Subsecunda* and *Drepanocladus* sp. to *Sphagnum imbricatum* dominance, followed by the disappearance of *S. imbricatum* at 700 cal BP. These changes suggest a general sequence of local environment changes from a wet fen, through a *Sphagnum*-dominated peatland, to a dry sedge-dominated marsh, which are also reflected by change in peat lithology and composition. The drying trend after 3600 cal BP is in general agreement with the speleothem isotope record from this region and other paleoclimate records from east China, indicating a weakening summer monsoon resulting from a decrease in summer insolation. The shift to a dry environment at 700 cal BP might have been caused by human activities. Appearance of *Cerealia* pollen at 3600–3200 cal BP suggests the first introduction of crop farming in the region, while its absence at 3200–2000 cal BP could be attributed to abandonment of farmland. The increase of Ti and Si since 1300 cal BP may be related to agricultural activity and landscape erosion. A 2-step increase in Pb concentration at 1600 and 600 cal BP suggests 2 phases of industrial pollution intensity.

INTRODUCTION

The East Asian summer monsoon plays an important role in the hydrologic cycle and energy budget in southeast China (An et al. 2000). At the orbital timescale, monsoon intensity follows the precession-driven change in seasonal insolation, resulting in maximum monsoon intensity in the early Holocene and a subsequent weakening trend (Kutzbach 1981; COHMAP members 1988). In particular, there has been a general dry trend since ~4000 cal BP due to a weakening summer monsoon (e.g. Hong et al. 2000; Junmei et al. 2006; Wang et al. 2005). In the middle and lower reaches of the Yangtze River, lake-level and pollen records show that the Holocene moisture optimum period occurred around 7000–4000 cal BP (An et al. 2000; He et al. 2004).

Peat deposits provide a readily available natural archive of past environmental change. Recently, many studies using peat cores as paleoenvironmental archives have been carried out in China (e.g. Hong et al. 2000; Xie et al. 2002; Xu et al. 2002; Zhou et al. 2002). Here, we present a high-resolution multiproxy record from the Dajihu Basin (DJH) covering the last 4700 yr. The objectives of our study were to use radiocarbon dates to establish peat chronology; to reconstruct the local vegetation and environmental change; to investigate peat accumulation and development; and to detect the environmental impact from human activities, using lithology, plant macrofossil, pollen, and geochemistry data.

STUDY SITE

The Dajihu Basin is situated in central China (31°24′–31°33′N, 109°56′–110°11′E) (Figure 1), a region that is strongly influenced by the East Asian summer monsoon. The basin is at 1700 m above

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sea level (asl) is surrounded by mountains of up to 3053 m in elevation. The mean annual temperature is 7.4 °C at Dajiuhu meteorological station (at 1800 m asl), with a maximum monthly temperature of 17.1 °C in July and a minimum of −2.4 °C in January (based on data from 1975–2001). Mean annual precipitation is 1528.4 mm.

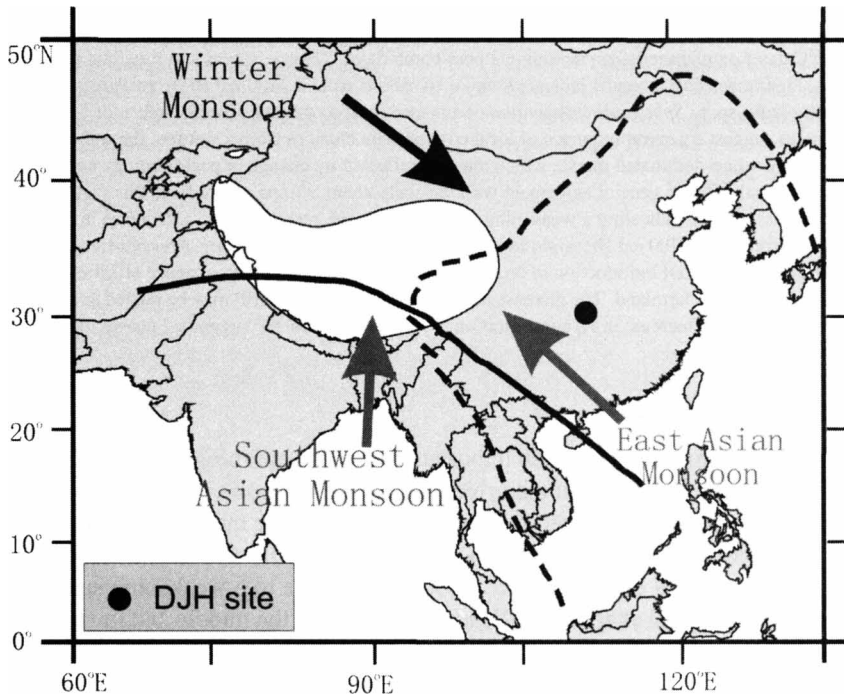


Figure 1 Location of the Dajiuhu Basin (black dot) in central China. The dashed line shows the present limit of the SE Asian summer monsoon influence, while the solid black line is the northern limit of the SW Indian monsoon.

The vegetation surrounding the basin is mainly composed of coniferous and deciduous broad-leaved forest. Above the elevation of 2000 m, *Pinus henryi*, *P. armandii*, and *Abies fargesii* are dominant tree species. At the elevation of 1700–2000 m, the common trees are *Quercus aliena*, *Q. variabilis*, *Q. acutissima*, *Castanea henryi*, *Fagus engleriana*, *F. lucida*, *Betula luminifera*, *Carpinus codata*, *Juglans regia*, *Pterocarya insignis*, *Platycarya strobilacea*, *Rhus verniciflua*, *Rhus chinensis*, *Abies chinsiensis*, *Ilex chinensis*, and *Acer givaldii*. The vegetation growing along the mountain slope facing the basin is mainly deciduous broad-leaved forest dominated by *Fagus* (Li and Yao 1993).

The Dajiuhu basin is about 16 km² in area, with 62.5% of the area covered by marsh. There are several small inflowing streams that eventually disappear into an underground karst cave network, and the basin has no outlet. Within the basin, marsh is dominated by *Carex* sp., *Sanquisorba officinalis*, *Juncus* sp., and *Gentiana pseudo-aquatica*. *Sphagnum* sp. is only found in the center of the marsh. The soil pH is about 4.8–5.7 (Lang et al. 1983).

METHODS

A peat profile (120 cm long) was taken in July 2000 in the southeast part of the marsh. The peat core was sliced into 1-cm intervals and was stored at 4 °C. Pollen, plant macrofossil, and geochemistry analyses were carried out at 2-cm intervals.

Six samples of plant macrofossils were picked and dated using accelerator mass spectrometry (AMS) at Leibniz-Labor for Radiometric Dating and Stable Isotope Research (Kiel, Germany) and the AMS Dating Laboratory at Beijing University (Beijing, China) (Table 1). The plant macrofossils in the samples are mostly *Sphagnum* leaves or Cyperaceae leaves or stems, which would yield reliable ¹⁴C dates (Nilsson 2001). All dates were calibrated to calendar years before present (AD 1950) using the program CALIB v 5.01 (Stuiver and Reimer 1993) with the IntCal04 data set (Reimer et al. 2004). Two post-bomb dates were calibrated with the CALIBomb program (<http://calib.qub.ac.uk/CALIBomb/frameset.html>). The age-depth model was based on linear interpolations of median calibrated ages. All discussion below is based on calibrated ages. In addition, the peat is acidic with a pH value of 4.8–5.7, so there is no dating or chronology problem related to peat acidity. The reliable chronology provides the basis of all discussions on the environmental change and human impact.

Table 1 AMS ¹⁴C dates from a peat core in Dajiuhu Basin, central China.

Lab nr ^a	Sample depth (cm)	Material dated	¹³ C (% VPDB)	¹⁴ C date ± standard deviation (BP)	2-σ range (cal BP) ^b	Median age (cal BP) ^b
KIA24683	4	Plant remains	-28.4	Post-bomb (119.8 pMC)	-33 to -35	-34
KIA24680	12	<i>Sphagnum</i> leaves	-25.1	Post-bomb (119.4 pMC)	-9 to -11	-10
LAMS05052	28	<i>Sphagnum</i> leaves	-24.4	990 ± 40	795–964	880
LAMS05051	54	Plant remains	-26.1	1720 ± 40	1538–1713	1626
KIA24681	74	Plant remains	-22.8	3085 ± 20	3312–3360	3336
KIA24682	118	Plant remains	-26.6	4074 ± 25	4511–4625	4568

^aKIA is Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research (Kiel, Germany); LAMS is AMS Dating Lab at Beijing University (Beijing, China).

^bCalibrated based on CALIB v 5.01 (Stuiver and Reimer 1993) using IntCal04 calibration data set (Reimer et al. 2004). Two post-bomb samples were calibrated with the program CALIBomb (<http://calib.qub.ac.uk/CALIBomb/frameset.html>).

Subsamples of ~3 g were oven-dried at 105 °C to estimate moisture content and then combusted at 550 °C for 12 hr to estimate organic matter content (Dean 1974). The ash-free bulk density was calculated from the measurements of sample volume and organic matter. The peat accumulation rates were calculated by multiplying ash-free bulk density and vertical peat-growth rates, assuming constant vertical growth rates between pairs of dates in the age model.

Oven-dried samples were homogenized for elemental analysis. Subsamples (~0.1 g) were used to determine nitrogen (N) concentrations (Allen 1974). Milled subsamples (~0.2 g) were used to determine lead (Pb) by inverse voltammetry and phosphorus (P) by flow-injection analysis (Allen 1974).

Titanium (Ti) was determined by a continuous-flow photometric system with Tiron after ~0.1-g subsamples were ashed in a quartz crucible at 550 °C. Another aliquot of ~20 mg was fused with sodium hydroxide for silicon (Si) determination by colorimetry using the molybdenum blue method (Allen 1974).

Pollen subsamples of 2 g were treated with a modified standard acetolysis method (Faegri and Iversen 1989), including KOH and acetolysis treatments. About 600 pollen grains were counted for each sample and were used as pollen sum for pollen percentage calculations. Subsamples (~1 g) were used for plant macrofossil. Macrofossil percentages were based on all the macroremains counted. Unidentifiable debris represents mostly leaves, stems, and roots of Cyperaceae, along with fine debris.

RESULTS

The analyzed core covered the last ~4700 yr based on the age-depth model (Figure 2). It appeared that there was a shift from a constant deposition around 3.3 kyr, but unfortunately we have only 1 data point. However, this uncertainty would not change the general time sequence of the environmental change discussed below. Two post-bomb samples at 4 cm and 12 cm were calibrated to AD 1984 (–34 cal BP) and AD 1960 (–10 cal BP), respectively, based on their ^{14}C contents of 119.77 and 119.40 pMC and their sequence in the peat core.

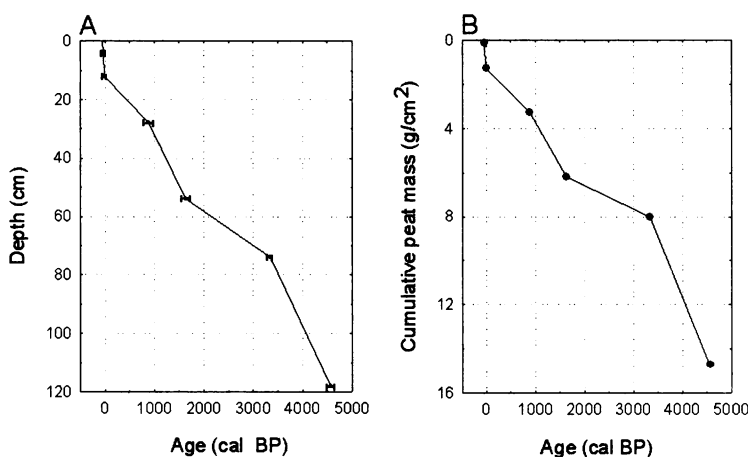


Figure 2 Age model and chronology. A) Age-depth model; B) Age-peat mass plot of the DJH peat profile at Dajiu Basin, eastern central China, based on median calibrated ages.

The water content of the peat core is 80–90% (Figure 3A) and organic matter is ~80% of dry peat mass (Figure 3B). The ash-free bulk density varies mostly between 0.1 and 0.15 g/cm³ (Figure 3C). Increases in water content and organic matter at 3400 cal BP correspond with a sharp decrease in ash-free bulk density. Peat accumulation rate averages 115.3 g m⁻² yr⁻¹, with the highest rate of 359 g m⁻² yr⁻¹ after the 1960s and the lowest rate of 11.9 g m⁻² yr⁻¹ in *S. imbricatum*-dominated peat between 3300 and 2000 cal BP (Figure 3D). The age versus depth (measured as cumulative peat mass from the surface downward) curve shows curvature, but is inconclusive about whether this is a concave or convex pattern (Figure 2B).

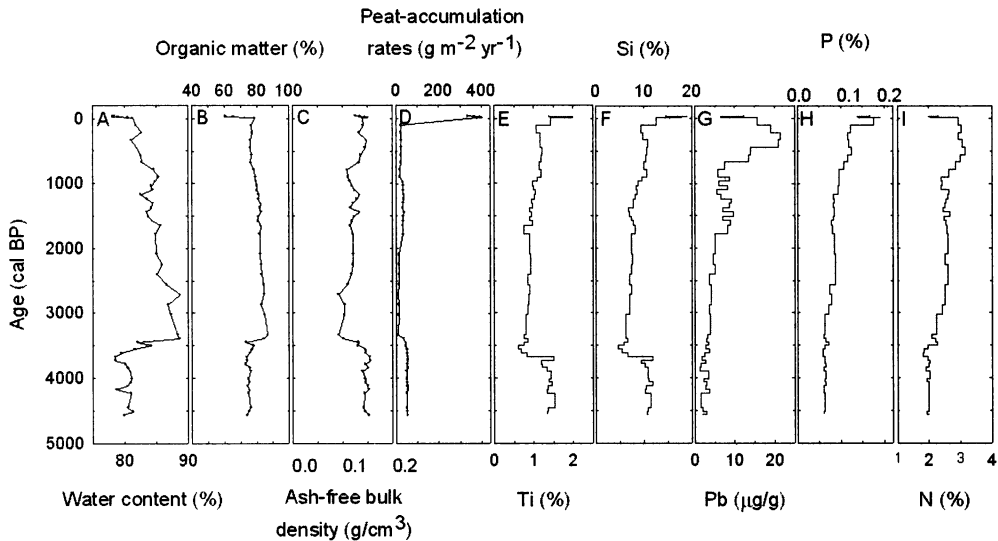


Figure 3 Peat composition and elemental concentrations: A) water content; B) organic matter content; C) ash-free bulk density; D) peat accumulation rates; E) titanium; F) silicon; G) lead; H) phosphorus; and I) nitrogen.

Ti and Si concentrations showed very similar changes over the past 4700 yr (Figures 3E–F), with high values of 1.5% Ti and 10% Si at 4700–3400 cal BP. A sharp decrease in both elements occurred at 3400 cal BP, followed by a gradual increase until the 1960s, when both elements increased sharply to the highest concentrations. Pb showed a gradual increase from 3400 to 1500 cal BP and 2-step sharp increases at 1500 cal BP and at 700 cal BP (up to 22 $\mu\text{g/g}$) (Figure 3G). Both P and N showed a gradual increase during the last 4700 yr (Figures 3H and 3I).

Macrofossil diagram was divided into 3 zones (Figure 4). *Sphagnum imbricatum* was the only *Sphagnum* species in Subzone 1a (4700–4200 cal BP), with some leaves of *Drepanocladus* sp. In Subzone 1b (4200–3600 cal BP), *Sphagnum* section *Subsecunda* appeared, at only <10%. Zone 2 (3600–700 cal BP) was dominated by *S. imbricatum* (up to 95%), while both *Sphagnum* section *Subsecunda* and *Drepanocladus* sp. disappeared. *Sphagnum* cf. *balticum* and *S. cuspidatum* were only found at 1 sample each in Subzone 2a. In Zone 3 (700 cal BP–present), *S. imbricatum* decreased sharply and disappeared. The *Sphagnum*-dominated peat had the lowest bulk density (Figure 3C).

Pollen results showed that over the last 4700 cal BP, upland vegetation was dominated by *Quercus* (up to 38%), *Betula* (up to 24%), *Fagus* (up to 13%), *Corylus* (up to 12%), and *Castanea* (up to 11%), while Cyperaceae dominated the local vegetation (up to 40%). At 4700–3000 cal BP, *Juniperus*, *Rumex*, and *Potamogeton* was continuously present, and *Polypodium* was abundant (up to 6%). Cerealia-type pollen appeared at 3600 cal BP, but almost disappeared at 3000–1200 cal BP (Figure 5).

DISCUSSION

Peatland Development History During the Late Holocene

Plant macrofossil results indicate a major transition around 3600 cal BP from *Sphagnum* section *Subsecunda* and *Drepanocladus* sp. to *Sphagnum imbricatum* dominance. *S. imbricatum* is a peat moss species that occurs over a wide range of water-table depths, while *Sphagnum* section *Subse-*

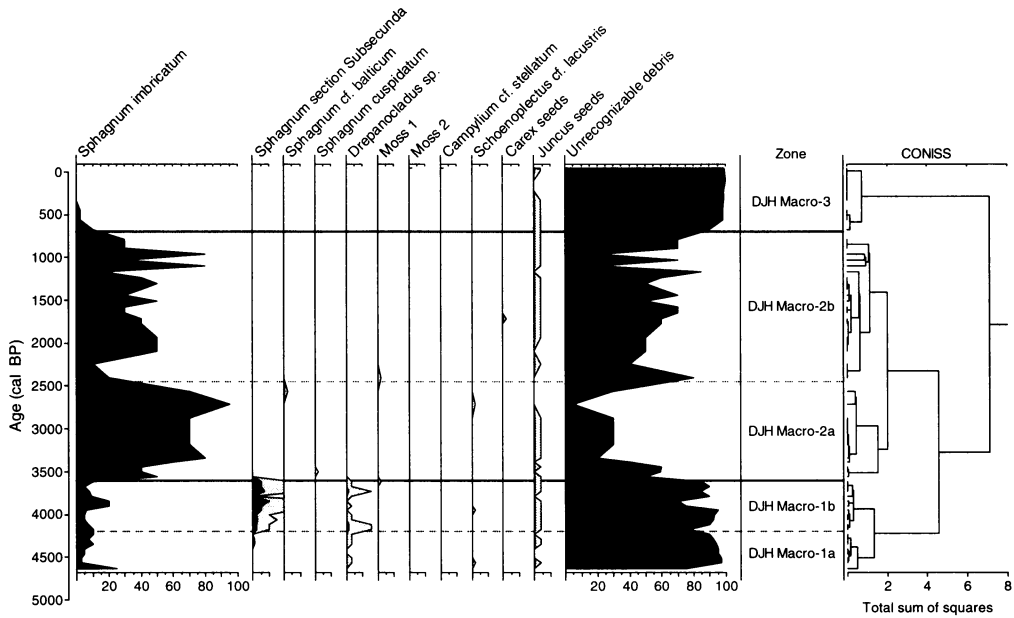


Figure 4 Percentage macrofossil diagram from the DJH peat profile at Dajihu Basin, eastern central China

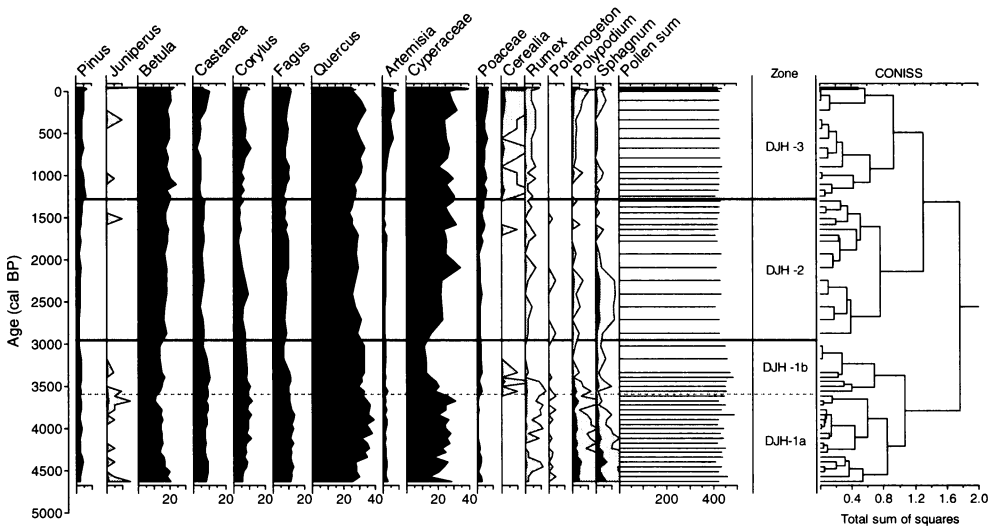


Figure 5 Percentage pollen diagram from the DJH peat profile at Dajihu Basin, eastern central China. Only selected taxa are shown.

cunda and brown moss *Drepanocladus* sp. prefer a wetter environment. Before 3600 cal BP, local vegetation comprised a rich (wet) fen, dominated by sedges, as indicated by abundant debris (likely from Cyperaceae), high Cyperaceae pollen, and some *Drepanocladus* sp. Between 3600 and 700 cal BP, a bog or poor fen was indicated by dominant *S. imbricatum*. After 700 cal BP, a marsh environment with fluctuating water table is supported by the disappearance of all *Sphagnum* species and dominance of Cyperaceae. *S. imbricatum* has not been recorded in the modern flora of this area (Li

and Si 1999). These vegetation changes suggest a general sequence of local environment changes from a wet fen, through a *Sphagnum*-dominated peatland, to a sedge-dominated marsh.

These major vegetation shifts are also reflected by changes in peat lithology and elemental composition. The wet minerotrophic fen period (4700–3600 cal BP) contains slightly lower organic matter and higher bulk density, suggesting input of inorganic material probably by streams. The elevated detrital input was also supported by high Ti and Si concentrations, which have been shown to be good indicators of soil erosion (Hölzer and Hölzer 1998). Ti rarely exists in plants, though Si can be found in plants such as Cyperaceae, *Equisetum*, or diatoms (Hölzer and Hölzer 1998). However, the strong correlation of Ti and Si in the DJH profile suggests that an increase in Si is likely caused by the erosion of mineral soils. High bulk density probably reflected elevated decomposition and compaction in this sedge-dominated minerotrophic fen. The gradual decrease in organic matter and increase in bulk density during the last 3400 yr correspond with a decrease in *S. imbricatum* and an increase in unrecognizable debris (probably Cyperaceae).

Relatively high peat accumulation rates between 4700–3400 cal BP in the DJH profile were most likely caused by high bulk density and high vertical growth rate, in a nutrient-rich fen environment. The slight increase in peat accumulation after ~2000 cal BP might be related to the change from *Sphagnum*-dominated peatland to sedge-dominated marsh, along with increases in nutrient supplies, such as P and N (Figure 3). The highest accumulation rate during the last 40–50 yr was probably due to less decomposition of fresh litter and new peat in the acrotelm. Peat accumulation appeared to show neither a concave age-depth pattern nor a convex pattern due to the lack of dating resolution in DJH (Figure 2B).

Impacts of Late Holocene Climate Change on Peatland Development

The multiproxy data presented above (plant macrofossil, peat lithology, elemental composition) suggest a general drying trend during the late Holocene around the Dajiuhe Basin (Figure 6). The transition from a wet to a dry environment at 3600 cal BP was probably in response to the general weakening of the East Asian summer monsoon as predicted by the insolation hypothesis (Kutzbach 1981; COHMAP members 1988). This pattern has also been documented by other proxy records from this region and in east China. The speleothem isotope record from the nearby Shennongjia region showed a general increase in oxygen isotope in the late Holocene due to the reduction in summer monsoon rainfall (Junmei et al. 2006). The $\delta^{18}\text{O}$ record from the Jinchuan peat marsh from northeast China also suggests a decrease in monsoon rainfall from ~3600 cal BP (Hong et al. 2000). Zhang et al. (2004) reported a colder and drier climate after 3800 cal BP from a 6000-yr high-resolution speleothem isotope record from Xiangshui Cave in Guilin. A dry climate in the late Holocene has been characteristic of many regions influenced by the SE Asian summer monsoon in central and east China (An et al. 2000; He et al. 2004).

History of Human Influences Derived from the Peat-Core Record

Findings of Cerealia-type pollen between 3600–3200 cal BP comprise paleobotanical evidence for the first introduction of crop farming and agriculture in the region (Figure 6). This interpretation appears to be consistent with archaeological evidence indicating that the ancient civilizations in central China developed between the Yangtze and Yellow rivers from about 4500–3500 cal BP (Shi et al. 1993). This is the region where the Sanxingdui culture has been documented at the end of Neolithic period (Xiao 2002), including rice and *Avena* planting and wine brewing (Yang 1980). However, it is not known with certainty what had caused the disappearance of Cerealia pollen between 3200 and 2000 cal BP. Could climate change or social changes be the principle reason? In

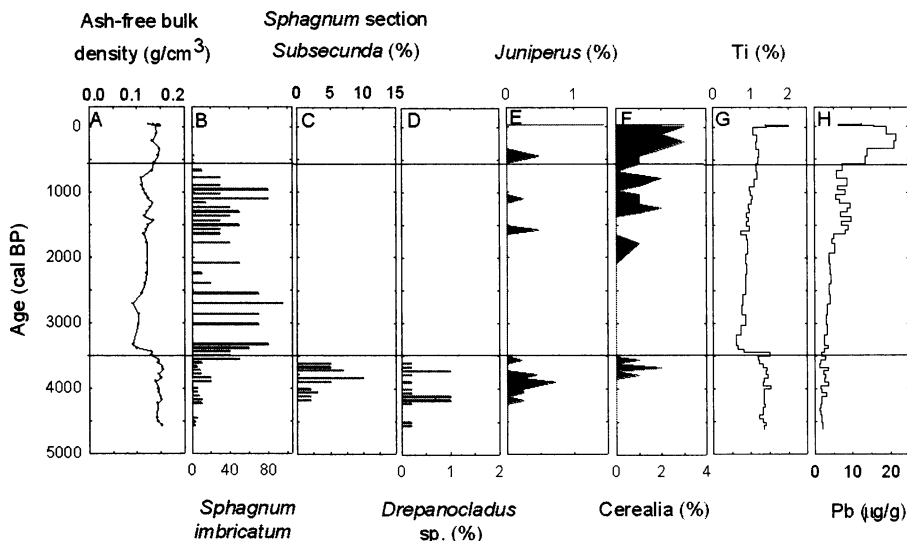


Figure 6 Multiproxy data from DJH peat core. A) Ash-free bulk density; B) *Sphagnum imbricatum* leaves; C) *Sphagnum* section *Subsecunda* leaves; D) *Drepanocladus* sp. leaves; E) *Juniperus* pollen; F) *Cerealia* pollen; G) Ti concentration; and H) Pb concentration.

the Shennongjia region, the Sanxingdui culture moved westward around 3700–3500 cal BP for unknown reasons. The disappearance of the *Cerealia* could have been due to population decline and the abandonment of agriculture in the wake of this population movement. However, this hypothesis needs to be further tested with additional records from this region. During the Qin and Han dynasties (starting from ~2000 cal BP), the population of the Shennongjia region started to increase again because of incoming people due to government exile and war refugees (Shennongjia Chorography Group 1996). The increasing abundance of *Cerealia* after 2000 cal BP corresponded with the general increase in human population, especially after 700 cal BP when agriculture developed on a larger scale. The high Ti and Si concentrations in DJH profile after 1300 cal BP correspond with a continuous occurrence of *Cerealia* pollen, suggesting landscape instability and soil erosion after forest clearance and agricultural activities (e.g. Hölzer and Hölzer 1998). The dry conditions after 700 cal BP, as indicated by the plant macrofossil results, might have been due to human activities through peat mining and altered drainage. It is interesting to note that *Juniperus* appeared to follow *Cerealia* pollen presence (Figure 6). We hypothesize that *Juniperus* shrubs might grow along the farmlands or villages, either planted or as a weed; however, there is no direct archaeological or other paleobotanical evidence to support this suggestion.

In the DJH profile, over the past 4700 cal yr BP there were 2 phases of increase in Pb concentrations at 1600 cal BP and at 600 cal BP (Figure 6), probably suggesting 2 stages in the intensity of industrial pollution. Pb became an important metal early in human history. Peat bogs have been used as archives of atmospheric metal deposition (e.g. Küster and Rehfuess 1997; Shotyk et al. 1998). The main source for the atmospheric lead could be from sulfide ores and metal smelting processes (Renberg et al. 2001). The increase at 1600 cal BP corresponded to the Han Dynasty, when ironing and advanced smelting techniques had developed. The second increase at 600 cal BP corresponded with the large scale steel and ironing during the Ming and Qing dynasties. Alternatively, some Pb could come from increased soil dust inputs resulting from deforestation and agriculture (e.g. Küster and Rehfuess 1997), while higher Pb concentration after 1600 cal BP could be derived from downward movement of younger peat that contains higher Pb concentration (Damman 1978).

CONCLUSIONS

Plant macrofossil results indicated a major vegetation transition at 3600 cal BP in the Dajiuhu Basin in eastern central China, from *Sphagnum* section *Subsecunda* and *Drepanocladus* sp. to *Sphagnum imbricatum* dominance, followed by disappearance of *S. imbricatum* at 700 cal BP. These changes suggest a general sequence of local environment changes from a sedge- and brown-moss-dominated rich fen, through a *Sphagnum*-dominated bog, to a dry sedge-dominated marsh.

The drying trend after 3600 cal BP was likely in response to the general weakening of the East Asian summer monsoon due to a decrease in summer insolation. This pattern is in general agreement with many records from east and central China.

Cerealia pollen at 3600–3200 cal BP is interpreted as evidence for the introduction of crop farming and agriculture in the region. The disappearance of Cerealia from 3200 to 2000 cal BP might correspond to the emigration of the Sanxingdui culture and a decrease in population, as supported by archaeological records.

The high concentrations of Ti and Si after 1300 cal BP are correlated with continuous appearance of Cerealia pollen, suggesting elevated soil erosion following deforestation and agricultural activities. A 2-step increase in Pb concentration at 1600 and 600 cal BP suggests 2 more intense phases of industrial pollution in this region.

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