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Abstract

The timing of the waxing and waning of the East Asian summer monsoon during the Holocene is still under debate. In present study, we present the high-resolution grain-size and LOI records from a well-dated mud/peat profile to reveal the lake-wetland transition in the Sanjiang Plain and discuss its significance to Holocene monsoon evolutions. The results show that the shallow-water lakes have developed in low-lying areas of the plain before 4600 yr BP, corresponding to the Holocene monsoon maximum. Thereafter, the wetlands began to initiate with the extinction of the paleolakes, marking a lake-shrinking stage with the relative dry climate. Considering the prevalent monsoon climate in the Sanjiang Plain, we suggest the lake-wetland transition at 4600 yr BP indicate a sharp decline of the summer monsoon rather than the basin infilling process. Such a remarkable monsoon weakening event has been widely documented in northern China, and we associated it with the ocean–atmosphere interacting processes in low-latitude regions.

1 Introduction

The East Asian monsoon as an integral component of atmospheric circulation system plays a significant role in global hydrologic and energy cycles (Kutzbach, 1981; Ding et al., 1995). In China, monsoon climate, especially monsoon-associate precipitation has been widely considered as a key driver for evolution of biocommunity, maintenance of living environment and progress of human civilization in populous regions of East Asia (Wang et al., 2005; Chen et al., 2006; Zhao et al., 2011). So, it is an interesting question as to study the monsoon changes and their impacts on geo-biosphere, not only for the geologic past, but also for the prediction of future changes in terrestrial ecosystems.

During last decades, a large quantity of paleoclimate records with various proxies has been investigated to reveal Holocene monsoon variation (Hong et al., 2003; Xiao

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et al., 2004; Zhou et al., 2005; Chen et al., 2006). It was initially proposed that the strongest monsoon with a maximum precipitation induced by peak summer isolation occurred in early Holocene, and this hypothesis has been confirmed by a series of records from cave deposits, lake sediments, eolian deposits and peat accumulations (Hong et al., 2003; Li et al., 2004; Xiao et al., 2004; Jiang et al., 2008; Makohonienko et al., 2008). Comparing with the records in low-mid latitude regions, a few records from higher-latitude locations also suggest a much enhanced summer monsoon prevailed during mid-Holocene (Hong et al., 2001; Xiao et al., 2004; Jiang et al., 2006; Wen et al., 2010), and both early- and mid-Holocene (Zhou et al., 2002; Feng et al., 2004). Although a time-transgressive model has been developed to interpret these space–time discrepancies (An et al., 2000), there are still a few records showing no accordance with the model, especially for those from the mid-high latitude regions, which suggest a much later monsoon maximum (Hong et al., 2001; Jiang et al., 2006; Makohonienko et al., 2008; Wen et al., 2010). Therefore, a comprehensive and integrative view of East Asian monsoon evolution during Holocene is still under debate. Solutions to this problem require high-quality proxy records from more climatically sensitive and regionally representative locations.

Comparing with the low-mid latitude locations of the existing records on paleomonsoon evolution, the Sanjiang Plain located in northeast China, is more sensitive to climate changes for its mid-high latitudes and monsoon marginal locations (Sun and Chen, 1991; An, 2000). In this paper, we present a well-dated peat/mud profile in the Sanjiang Plain, to reconstruct wetland developing history during the Holocene and discuss its significance to the East Asian monsoon evolutions.

2 Regional setting

The Sanjiang plain (129°11′20″ ~ 135°05′26″ E, 43°49′55″ ~ 48°27′40″ N) is located in the northeastern China (Fig. 1). It is a huge alluvial plain related to three large rivers (Heilong River, Wusuli River and Songhua River), with a total area of 10.88×10^6 ha,

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an altitude of 55–95 m and a slope grade of 0.1–0.6‰. The present climate belongs to the temperate humid or sub-humid continental monsoon climate. The mean annual temperature ranges from 1.4 to 4.3 °C, with average maximum of 22 °C in July and average minimum –18 °C in January. The mean annual precipitation is 500–650 mm and 80 % of rainfall occurs between May and September (Fig. 2) (Liu, 1995).

In addition to the warm and wet climate, such an area of low-relief is favorable for development of wetlands (Ma et al., 1993). A recent survey shows that over 70 % of the plain has been dominated by freshwater wetlands, and it has been well known for the largest area of the freshwater wetlands in China (Song et al., 2008). Most of these wetlands are situated in shallow depressions originated from the glacial movements during the Last Glacial stage. During the Quaternary, the sand, mud and peat deposits exceeding 15 m have accumulated overlaying the Proterozoic granite (Yin, 1987) (Fig. 3).

3 Material and methods

3.1 Sampling and lithology

The studied profile HE (47°35.096' N, 133°30.006' E, 71 m a.s.l.) with a thickness of 160 cm was collected using a Russia Peat Corer from a dish-like depression in the Sanjiang Plain. The depression is roughly spherical in shape with a diameter of ~ 2000 m and a mean water depth of 0.5 m. It is dominant by herbs vegetation in its low-lying areas and surrounded by deciduous broadleaved forests. There is no inflowing and outflowing rivers within its catchments and all its water supply is via atmospheric precipitation. The According to lithological properties, the profile can be subdivided into two parts: blackish-grey oozy mud sediments in lower parts and the overlying brownish peat layers (Fig. 3). All samples were collected with 1-cm-thick interval and 160 samples in total were taken.

3.2 Chronology

10 bulk samples were collected according to lithological changes of the HE and dated with an accelerator mass spectrometry (AMS) system at Xi'an Institute of Earth Environment, Chinese Academy of Sciences. The AMS ^{14}C dates of all the samples were calibrated into calendar ages before present (0 yr BP = 1950 AD) using the CALIB Rev. 7.0.1 program (Stuiver and Reimer, 2006) (Table 1). Chronology of the HE was established based on the 3rd polynomial curve using the mean values of 2σ ranges of the calibrated ages (Fig. 4).

3.3 Organic matter contents and grain-size distributions

10 A total of 160 samples were prepared for loss-on-ignition (LOI), and grain-size analysis respectively. For LOI analysis, the samples with a volume of 2 cm^3 were sequentially combusted at 500 and 900°C in a muffle furnace to estimate organic matter and carbonate content following the method described by Schulte and Hopkins (1996). Samples for grain-size distribution were firstly burned in a muffle furnace at 550°C for more than 2 h to eliminate organic matter, and then the residues were pretreated with 10–20 mL of 30 % H_2O_2 and 10 mL of 10 % HCl successively to remove organic matter and carbonates. About 2000 mL of deionized water was added, and the sample solution was kept for ca. 24 h to rinse acidic ions before grain-size analysis with a Malvern Mastersizer 2000 laser grain-size analyzer. The Mastersizer 2000 has a measurement range of $0.02\text{--}2000\text{ }\mu\text{m}$ in diameter and a grain-size resolution of $0.166\text{ }\Phi$ in interval, thus yielding 100 grain-size fractions for each sample.

3.4 Identifying, fitting and partitioning of the grain-size components

It has been widely adopted that the grain-size distribution of unimodal clastic deposits follows the lognormal distribution, and the lognormal distribution function can give sufficient accuracy in describing unimodal grain-size distributions (Sun et al., 2002; Qin

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et al., 2005; Xiao et al., 2013). In the present study, the grain-size components of individual polymodal distributions were identified, fitted and partitioned using the log-normal distribution function method described by Qin et al. (2005), which is expressed as follows,

$$F(x) = \sum_{i=1}^n \left[\frac{C_i}{\sigma_i \sqrt{2\pi}} \int_{-\infty}^{\infty} \exp \left(-\frac{(x - a_i)^2}{2\sigma_i^2} \right) dx \right]$$

where n is the number of modes, $x = \ln(d)$, d is the grain size in μm . c_i is the percentage of the i th mode, σ_i is the variance of the i th mode, and a_i is the variance of the i th mode's logarithm grain size in μm .

The fitting residual is calculated as follows,

$$dF = \frac{1}{m} \sum_{j=1}^m (F(x_j) - G(x_j))^2$$

where m is the number of grain-size intervals. $F(x_j)$ is the fitted percentage of the j th grain-size interval. A lower value of dF indicates a better fitting result.

Fitting experiments on a certain sample are accomplished when the residual error reaches its minimum. Numerical partitioning of the unimodal components of a measured polymodal distribution can be achieved simultaneously through lognormal distribution function fitting because the parameters and the distribution functions of each component are determined during fitting. The modal sizes and relative percentages of each component are given as soon as the fitting is accomplished.

4 Results

The age-depth model of the HE indicates that the studied profile covers the last 8600 years, and the peat layers initiated at ~ 4600 yr BP. Accompanied by the lithological changes, both the variations of organic matter content and Md exhibit increasing

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trends at the mud-peat boundary. Additionally, the studied profile is also characterized by more clay fractions for its lacustrine deposits and more silt and sand fractions for its peat layers (Fig. 4).

The fitting and partitioning of the lognormal distribution function suggests that the polymodal grain-size distributions of samples from the studied profile is composed of four unimodal distributions, representing four grain-size components. According to the dominant range of modal size of each unimodal distribution, four components are designated C1 through C4 from fine to coarse modes in this study. As shown in Fig. 5, the four components can be easily determined for the lacustrine sections, comparing two components of C1 and C3 for the peat layers. The modal sizes of the components C1, C2, C3 and C4 vary primarily within ranges of 0.5–1.8, 2.5–8.6, 25.6–38.6 and 386.2–514.8 μm respectively. The relative percentages of the C1, C2, C3 and C4 vary primarily within ranges of 2.2–22.4, 9.8–76.5, 12.8–93.4 and 4.6–20.5 % respectively (Table 2).

5 Discussion

5.1 Depositional process of grain-size components and its links with the local environment changes

It has been widely accepted that the grain-size depositional process is closely linked to its sedimentary environment and the multimodal characters of the deposits represent different transport or depositional processes (McLaren and Bowles, 1985). In present study, the grain-size components of the HE were partitioned using a lognormal distribution function. The results show that the lacustrine deposits contain four distinct unimodal grain-size distributions named as C1 through C4 with their modal sizes ranging 0.5–1.8, 2.5–8.6, 25.6–38.6 and 386.2–514.8 μm respectively, while only the C1 and C3 were identified from the peat layers. Considering modal sizes variation and distribution of the four components in present study, together with the grain-

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size distributions of surface samples from modern lakes (Xiao et al., 2013), a model was proposed to illuminate the grain-size depositional process in the wetlands of the Sanjiang Plain (Table 2). The C1 is exceptional component with the smallest modal sizes ranging 0.7–1.6 μm , which appeared in a large majority of samples from the HE (Fig. 6). Such small grain-size particles in the C1 might belong to the long-term suspension component both in hydraulic and aeolian medium. The suspension component of modal size of < 2.6 microns was reported in modern dusts (Derbyshire et al., 1998; Sun et al., 2003). The C2 with the modal size ranging 2.5–8.6 μm and the C3 ranging 25.6–38.6 μm represent the offshore and nearshore suspension component respectively in a lake environment. The C4 as the coarsest component with the modal size ranging 380.2–529.6 μm is interpreted as a nearshore traction component, which is mainly transported by the surface flows to the basin.

Although the components of both the C1 and C3 have widely distributed in the studied profile HE (Fig. 6), only the C3 as the nearshore suspension component is sensitive to the environment changes. As shown in Fig. 7, comparing the other three components, the modal grain-size of the C1 shows only very slight variations during last 8600 years and there is no obvious signals even during the lake-wetland transition. In comparison, the C3 shows the more remarkable variations and should be more sensitive to the variation of local hydraulic conditions. Such a hypothesis is further supported by the grain-size distributions of surface sediments in modern lakes and a negative correlation has been revealed between the nearshore components and the water depth (Xiao et al., 2013). The findings paved the way for the subsequent works in reconstructing the water-level status and regional climate changes with the variations of the nearshore components from the lake and wetland sediments (Xiao et al., 2013; Zhang et al., 2014). Consequently, the C3 as a nearshore component in present study, its percentages can be used as a major indicator for the local water level variations, and in turn for the regional climate changes in geological history.

5.2 The lake-wetland transition and its associated environment changes

The lithofacies of local strata is one of the most direct indicators for paleo-environment. As shown in Figs. 4 and 8, the blackish-grey oozy mud layers have accumulated during the lower part of the studied profile. The layers are also characterized by low and stable values of accumulation rate ($0.5 \text{ cm } 100 \text{ yr}^{-1}$), organic matter content (7 %) and Md ($\sim 7 \mu\text{m}$). Such characters of the mud layer coincide well with those of the lake deposits in monsoon regions, China (Xue et al., 2003; Xiao et al., 2004), and it indicates a shallow lake had developed in the studied depression. Thereafter, the typical peat deposits defined by a high ratio of the organic matter contents began to accumulate, suggesting the wetlands began to develop after the extinction of the paleolake. While such a definition varies largely among different countries with the organic matter contents changing from 20 to 40 % (Ma et al., 1993). Here, a median value of 30 % of organic matter contents was employed as an indicator of the peatlands initiation, and we accordingly suggest the lake-wetland transition in the Sanjiang Plain occurred at 4600 yr BP.

Such a striking environmental change was further supported by the grain-size records. Based on the variations of C3 percentages of the HE, the local hydraulic conditions during the Holocene were tentatively reconstructed. During stage before 4600 yr BP, the percentages of the C3 show much lower values implying a deep-water environment in the low-lying areas of the Sanjiang Plain. While at 4600 yr BP, the sharp increases of the C3 percentages indicate a remarkable drying event corresponding to the lake-wetland transition. In addition to the studied areas, such a lake-wetland transition has been well documented in most basin-like topographic areas in the Sanjiang Plain (Ma et al., 1993; Liu, 1995). Given the relative lower water table in wetlands than that in lakes in the modern Sanjiang Plain, the lake-wetland transition indicates a remarkable drying event at 4600 yr BP.

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5.3 The sharp decline of the East Asian Summer monsoon during the mid-late Holocene

Considering the prevalent monsoon climate in the Sanjiang plain, the locally environmental variations in the Plain must be potentially linked with the monsoon variations during the Holocene. While in addition to climate changes, the local environmental changes may also be influenced by lake-infilling process, hydrological changes or tectonic-induced changes, so we need to consider all these factors before interpreting the monsoonal implication of the lake-wetland transition in the Sanjiang Plain.

During the development of the lakes, the depositional process will lead to a gradual adoption to terrestrialization, and eventually the extinction of the lake (Fang, 1991). This infilling action is usually accepted as a long-term and stable process on thousand-year time scale (Rhodes et al., 1996). Similarly, the tectonic activities are also a slow process and take gradually effects on local environment over much longer time scale (Jiang et al., 2008; Yang et al., 2011). Additionally, local hydrological changes, especially the channel changes of the neighboring rivers, may generate a direct effect on the extinction of a lake. However, the studied lake was broadly surrounded by low hills, and there are no big rivers affecting the basin directly. Therefore, all the three factors discussed above have only played a negligible role for the rapidly shrinking of the paleolake over several decades.

In comparison, the climate changes may exert a more important influence for the sudden drying event at 4600 yr BP. In view of the hydrologic and climatic conditions of the studied basin, the water supply in basin is mostly provided by atmospheric precipitations. Considering the prevailing monsoon climate in the studied region, most of the local precipitation is provided via summer monsoon circulations (Liu, 1995), thus this remarkable drying event should be driven by the sudden retreat of the summer monsoon. It has been demonstrated that the East Asian monsoon rains are linked with the interaction between warm moist southerly air masses and cold northerly airflows (An, 2000). It means that the stronger summer monsoon strength will generate more north-

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ern penetration of the rainfall belt, and the heavier precipitation in mid- and high-latitude regions. Accordingly, the humid and warm interval during the development of the paleolake before 4600 yr BP suggests the much enhanced summer monsoon circulation, corresponding to the Holocene monsoon maximum. While the ecologic lake-wetland transition at 4600 yr BP indicates a sudden retreat of the summer monsoon (Fig. 9).

Such a remarkable monsoon decline have been well documented in cave deposits, lake sediments, eolian deposits and peat accumulations in monsoon regions of China (Hong et al., 2003; Li et al., 2004; Xiao et al., 2004; Shen et al., 2005; Jiang et al., 2008; Sun and Huang, 2006; Wang et al., 2005). For the northeastern China, the alternations of sand accumulation and paleosol development in desert regions are regarded as the direct indicators for the monsoon circulations in the geological past. As the soil development requires a much wetter/warmer climate and better vegetation cover comparing with the drier climate during the aeolian sand accumulation, in this context, the alternations of aeolian sand and paleosols are mainly controlled by the changes of summer monsoon strength. During the interval before 4600 yr BP, the widespread shallow lakes in the Sanjiang Plain corresponds well to the well-developed soil sections in the Hulun Buir Desert before 4400 yr BP, in spite of a 200 yr discrepancy which is acceptable in view of the 400 yr error of the OSL dating at 4400 yr BP (Fig. 8). Such a good coincidence between the two independent proxies not only supports our conclusions for the timing of the monsoon retreating event, but also attributes them to the regional phenomena in northeastern China.

5.4 The possible driving mechanism for the East Asian monsoon variation

The East Asian monsoon is primarily controlled by the thermal contrast between the Asian landmass and tropic Pacific Ocean, and it is characterized by the seasonal alterations of northward-moving moist summer monsoon air and a northern mass of cooler winter monsoon air (An, 2000). Modern meteorological studies indicate that the moisture brought by the East Asian summer monsoon to the eastern China derives from low latitudes of the west Pacific where is characterized by a large pool of warm sur-

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face water, having the warmest global SST $> 29^{\circ}\text{C}$ (De Deckker et al., 2003). Through ocean–atmosphere coupling this warm pool plays an important role in transporting humid air masses from the tropical Pacific to inland China. Since northwestern Pacific summer SST, like summer air temperatures, highly depend on summer insolation (Terada and Hanzawa, 1984), the low-latitude solar forcing should serve a driving role in modulating the east Asian summer monsoon by controlling the SST and the West Pacific warm pool (Terada and Hanzawa, 1984; Sun and Huang, 2006). During the early Holocene, the higher insolation in tropical regions may generate much more moistures for the north-moving summer monsoon air mass with higher SST temperatures in the West Pacific regions (Figs. 8 and 10), and in turn producing a much wetter climate corresponding to the monsoon maximum in East Asia. While during the mid-late Holocene, the gradually declined solar insolation would lead to a weakening summer monsoon with the decrease of the moisture supply caused by the decline of the SST in the west tropical Pacific (Stott et al., 2004). Thus, we suggest the sharp decline of the East Asian summer monsoon during the mid-Holocene is related to the retreatment of the summer monsoon front which is primarily controlled by decreased solar insolation in low latitudes.

6 Conclusions

Based on the high-resolution LOI and grain size records from a well dated peat/mud profile in the Sanjiang Plain, a detailed environmental change has been well reconstructed during the last 8600 yr. During the interval before 4600 yr BP, a shallow-water lake had developed in the studied basin, implying a much warm and humid climate corresponding to the Holocene monsoon maximum or climate optimum. After 4600 yr BP, a typical wetland began to develop suggesting a remarkable drying event. Considering the prevailing monsoon climate in the Sanjiang Plain, we attribute the lake-wetland transition to the influence of the sudden decline of East Asian summer monsoon dur-

ing the mid-Holocene, which is initially controlled by the ocean–atmosphere interacting processes in low-latitude regions.

Acknowledgements. This study was financially supported by the National Basic Research Program (No. 2012CB956100), the National Natural Science Foundation of China (No. 41 201 083, 41 271 209 and 41 271 106), and the Knowledge Innovation Program of Chinese Academy of Science (No. KZCX2-EW-319).

References

- An, Z. S.: The history and variability of the East Asian paleomonsoon climate, *Quaternary Sci. Rev.*, 19, 171–187, 2000.
- An, Z. S., Porter, S. C., Kutzbach, J. E., Wu, X. H., Wang, S. M., Liu, X. D., Li, X. Q., and Zhou, W. J.: Asynchronous Holocene optimum of the East Asian monsoon, *Quaternary Sci. Rev.*, 19, 743–762, 2000.
- Chen, F. H., Cheng, B., Zhao, Y., Zhu, Y., and Madsen, D. B.: Holocene environmental change inferred from a high-resolution pollen record, Lake Zhuyeze, arid China, *Holocene*, 16, 675–684, 2006.
- De Deckker, P., Tapper, N. J., and Van Der Kaars, S.: The status of the Indo-Pacific Warm Pool and adjacent land at the Last Glacial Maximum, *Global Planet. Change*, 35, 25–35, 2003.
- Derbyshire, E., Meng, X. M., and Kemp, R. A.: Provenance, transport and characteristics of modern aeolian dust in western Gansu Province, China, and interpretation of the Quaternary loess record, *J. Arid Environ.*, 39, 497–516, 1998.
- Ding, Z. L., Liu, T. S., Rutter, N. W., Yu, Z. W., Guo, Z. T., and Zhu, R. X.: Ice-volume forcing of East Asian winter monsoon variations in the past 800,000 years, *Quaternary Res.*, 44, 149–159, 1995.
- Fang, J. Q.: Lake evolution during the past 30,000 years in China, and its implications for environmental change, *Quaternary Res.*, 36, 37–60, 1991.
- Feng, Z. D., An, C. B., Tang, L. Y., and Jull, A. J. T.: Stratigraphic evidence of a Megahumid climate between 10,000 and 4000 years BP in the western part of the Chinese Loess Plateau, *Global Planet. Change*, 43, 145–155, 2004.
- Hong, Y. T., Wang, Z. G., Jiang, H. B., Lin, Q. H., Hong, B., Zhu, Y. X., Wang, Y., Xu, L. S., Leng, X. T., and Li, H. D.: A 6000-year record of changes in drought and precipitation in

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northeastern China based on a $\delta^{13}\text{C}$ time series from peat cellulose, *Earth Planet. Sc. Lett.*, 185, 111–119, 2001.

Hong, Y. T., Hong, B., Lin, Q. H., Zhu, Y. X., Shibata, Y., Hirota, M., Uchida, M., Leng, X. T., Jiang, H. B., Xu, H., Wang, H., and Yi, L.: Correlation between Indian Ocean summer monsoon and North Atlantic climate during the Holocene, *Earth Planet. Sc. Lett.*, 211, 371–380, 2003.

Jiang, W. Y., Guo, Z. T., Sun, X. J., Wu, H. B., Chu, G. Q., Yuan, B. Y., Hatté, C. T., and Guiot, J.: Reconstruction of climate and vegetation changes of Lake Bayanchagan (Inner Mongolia): Holocene variability of the East Asian monsoon, *Quaternary Res.*, 65, 411–420, 2006.

Jiang, W. Y., Leroy, S. A. G., Ogle, N., Chu, G. Q., Wang, L., and Liu, J. Q.: Natural and anthropogenic forest fires recorded in the Holocene pollen record from a Jinchuan peat bog, northeastern China, *Palaeogeogr. Palaeoclimatol.*, 261, 47–57, 2008.

Kutzbach, J. E.: Monsoon climate of the early Holocene: climate experiment with the earth's orbital parameters for 9000 years ago, *Science*, 214, 59–61, 1981.

Li, X. Q., Zhou, J., Shen, J., Weng, C. Y., Zhao, H. L., and Sun, Q. L.: Vegetation history and climatic variations during the last 14 kaBP inferred from a pollen record at Daihai Lake, north-central China, *Rev. Palaeobot. Palynol.*, 132, 195–205, 2004.

Liu, X. T.: *Wetland and Its Rational Utilization and Conservation in the Sanjiang Plain*, Jilin Science Technology Press, Changchun, 108–117, 1995.

Ma, X. H., Liu, X. T., and Wang, R. F.: China's wetlands and agro-ecological engineering, *Ecol. Eng.*, 2, 291–301, 1993.

Makohonienko, M., Kitagawa, H., Fujiki, T., Liu, X., Yasuda, Y., and Yin, H. N.: Late Holocene vegetation changes and human impact in the Changbai Mountains area, Northeast China, *Quatern. Int.*, 184, 94–108, 2008.

McLaren, P. and Bowles, D.: The effects of sediment transport on grain-size distributions, *J. Sediment. Res.*, 55, 457–470, 1985.

Qin, X. G., Cai, B. G., and Liu, T. S.: Loess record of the aerodynamic environment in the east Asia monsoon area since 60,000 years before present, *J. Geophys. Res.*, 110, B01204, doi:10.1029/2004JB003131, 2005.

Rhodes, T. E., Gasse, F., Lin, R., Fontes, J. C., Wei, K., Bertrand, P., Gibert, E., Mélières, F., Tucholka, P., and Wang, Z.: A Late Pleistocene-Holocene lacustrine record from Lake Manas, Zunggar (northern Xinjiang, western China), *Palaeogeogr. Palaeoclimatol.*, 120, 105–121, 1996.

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Schulte, E. E. and Hopkins, B. G.: Estimation of soil organic matter by weight loss-on-ignition, *Soil organic matter: analysis and interpretation*, SSSA Special Publ. 46, Madison, , 21–31, 1996.

Shen, J., Liu, X. Q., Wang, S. M., and Ryo, M.: Palaeoclimatic changes in the Qinghai Lake area during the last 18,000 years, *Quatern. Int.*, 136, 131–140, 2005.

Song, K. S., Liu, D. W., Wang, Z. M., Zhang, B., Jin, C., Li, F., and Liu, H. J.: Land use change in Sanjiang Plain and its driving forces analysis since 1954, *Acta Geographica Sinica*, 63, 93–104, 2008 (in Chinese).

Stuiver, M. and Reimer, P. J.: Extended (super 14) C data base and revised CALIB 3.0 ^{14}C age calibration program, *Radiocarbon*, 35, 215–230, 2006.

Sun, D. H., Bloemendal, J., Rea, D. K., Vandenberghe, J., Jiang, F. C., An, Z. S., and Su, R. X.: Grain-size distribution function of polymodal sediments in hydraulic and aeolian environments, and numerical partitioning of the sedimentary components, *Sediment. Geol.*, 152, 263–277, 2002.

Sun, D. H., Chen, F. H., Bloemendal, J., and Su, R. X.: Seasonal variability of modern dust over the Loess Plateau of China, *J. Geophys. Res.-Atmos.*, 108, 1–10, 2003.

Sun, J. M. and Huang, X. G.: Half-precessional cycles recorded in Chinese loess: response to low-latitude insolation forcing during the Last Interglaciation, *Quaternary Sci. Rev.*, 25, 1065–1072, 2006.

Sun, X. J. and Chen, Y. S.: Palynological records of the last 11,000 years in China, *Quaternary Sci. Rev.*, 10, 537–544, 1991.

Terada, K. and Hanzawa, M.: Climate of the North Pacific Ocean, in: *Climates of the Oceans*, edited by: Van, H., 15, 431–477, *World Survey of Climatology*, Elsevier, New York, 1984.

Wang, Y. J., Cheng, H., Edwards, R. L., He, Y., Kong, X., An, Z., Wu, J., Kelly, M. J., Dykoski, C. A., and Li, X.: The Holocene Asian monsoon: links to solar changes and North Atlantic climate, *Science*, 308, 854, 854–857, 2005.

Wen, R. L., Xiao, J. L., Chang, Z. G., Zhai, D. Y., Xu, Q. H., Li, Y. C., and Itoh, S.: Holocene precipitation and temperature variations in the East Asian monsoonal margin from pollen data from Hulun Lake in northeastern Inner Mongolia, China, *Boreas*, 39, 262–272, 2010.

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Xiao, J. L., Fan, J. W., Zhou, L., Zhai, D. Y., Wen, R. L., and Qin, X. G.: A model for linking grain-size component to lake level status of a modern clastic lake, *J. Asian Earth Sci.*, 69, 149–158, 2013.

Xiao, J. L., Xu, Q. H., Nakamura, T., Yang, X. L., Liang, W. D., and Inouchi, Y.: Holocene vegetation variation in the Daihai Lake region of north-central China: a direct indication of the Asian monsoon climatic history, *Quaternary Sci. Rev.*, 23, 1669–1679, 2004.

Xue, B., Qu, W. C., Wang, S. M., Ma, Y., and Dickman, M.: Lake level changes documented by sediment properties and diatom of Hulun Lake, China since the late Glacial, *Hydrobiologia*, 498, 133–141, 2003.

Yang, X. P., Scuderi, L., Paillou, P., Liu, Z. T., Li, H. W., and Ren, X. Z.: Quaternary environmental changes in the drylands of China-A critical review, *Quaternary Sci. Rev.*, 30, 3219–3233, 2011.

Yin, H. N.: The Depositional Environment and Physicochemical Characteristics of the Peat Deposits in Huachuan (in Chinese), Shanxi People's Publishing House, Xi'an, 1987.

Zhang, Z.Q, Xing, W., Lv, X. G., and Wang, G. P.: The grain-size depositional process in wetlands of the Sanjiang Plain and its links with the East Asian monsoon variations during the Holocene, *Quatern. Int.*, 349, 245–251, 2014.

Zhao, Y., Yu, Z. C., and Zhao, W. W.: Holocene vegetation and climate histories in the eastern Tibetan Plateau: controls by insolation-driven temperature or monsoon-derived precipitation changes?, *Quaternary Sci. Rev.*, 30, 1173–1184, 2011.

Zhou, W. J., Lu, X. F., Wu, Z. K., Deng, L., Jull, A. J. T., Donahue, D., and Beck, W.: Peat record reflecting Holocene climatic change in the Zoige Plateau and AMS radiocarbon dating, *Chinese Sci. Bull.*, 47, 66–70, 2002.

Zhou, W. J., Xie, S. C., Meyers, P. A., and Zheng, Y. H.: Reconstruction of late glacial and Holocene climate evolution in southern China from geolipids and pollen in the Dingnan peat sequence, *Org. Geochem.*, 36, 1272–1284, 2005.

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Table 1. AMS radiocarbon dates of samples from the HE in the Sanjiang Plain.

Lab number	Depth (cm)	Dating material	$\delta^{13}\text{C}$ (‰)	AMS ^{14}C age (^{14}C yr BP)	Calibrated ^{14}C age (2σ) (cal yr BP)
XA7572	38	Plant residues	−32.12	578–652	615 ± 37
XA7573	60	Plant residues	−30.91	1172–1265	1219 ± 47
XA7574	80	Plant residues	−31.54	2306–2353	2330 ± 24
XA7575	94	Plant residues	−41.63	2494–2597	2546 ± 52
XA7576	108	Plant residues	−29.89	2780–2925	2853 ± 73
XA7577	125	Plant residues	−30.40	3546–3636	3591 ± 45
XA7560	135	Organic matter	−29.38	4460–4521	4491 ± 31
XA7578	140	Organic matter	−31.76	5992–6192	6092 ± 100
XA7579	148	Organic matter	−29.89	6451–5901	6512 ± 61
XA7568	160	Organic matter	−27.39	8543–8658	8601 ± 58

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Table 2. Characteristics of the four grain-size components recognized on the polymodal distributions of samples.

Component	Number of Samples	Modal size (μm)		Dominant range of modal sizes (μm)	Percentage		Dominant range of percentages	Description of the Components
		Min.	Max.		Min.	Max.		
C1	178	0.5	1.8	0.7–1.6	2.2	22.4	2.6–10.2	Long-distance suspension with wind and water
C2	45	2.0	13.6	2.5–8.6	9.8	76.5	12.8–68.6	Offshore suspension
C3	160	16.2	43.3	25.6–38.6	12.8	93.4	36.9–94.8	Nearshore suspension
C4	23	234.6	512.8	386.2–514.8	4.6	20.5	5.1–16.5	Alluvial material

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Figure 1. Digital elevation model of the Sanjiang Plain. The solid triangle in black color indicates the sampling site. In inset figure, the current northern limit (dashed line) of the East Asian Summer monsoon with its direction indicated by the arrows, the locations of the Sanjiang Plain (highlighted in black area) and the HLB profile (solid circles) mentioned in the text are shown.

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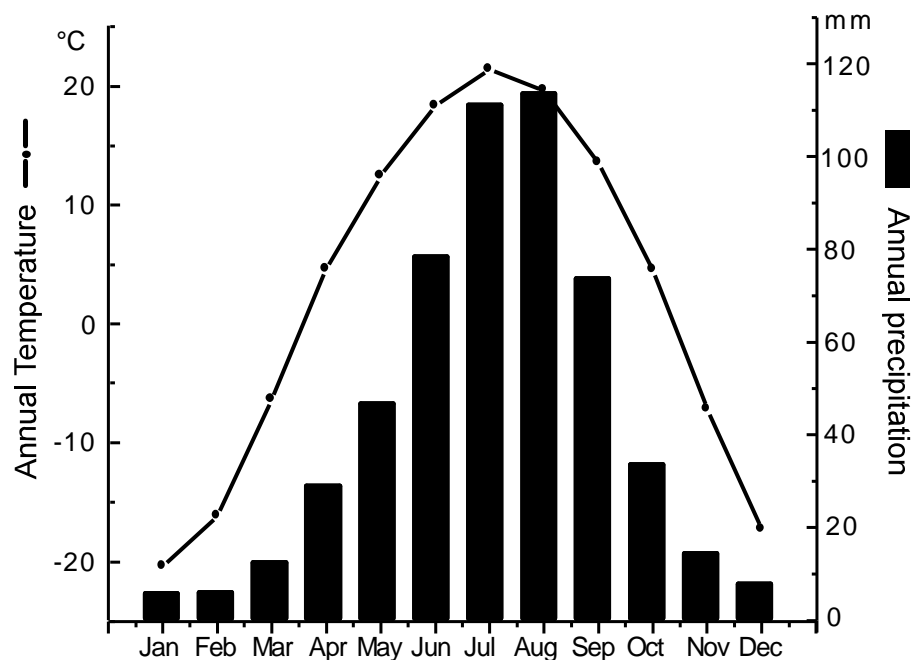


Figure 2. Climate diagrams showing monthly temperature and precipitation in the Sanjiang Plain. All data were from climate normal for the period 1957–2000 at meteorological stations in the Sanjiang Plain.

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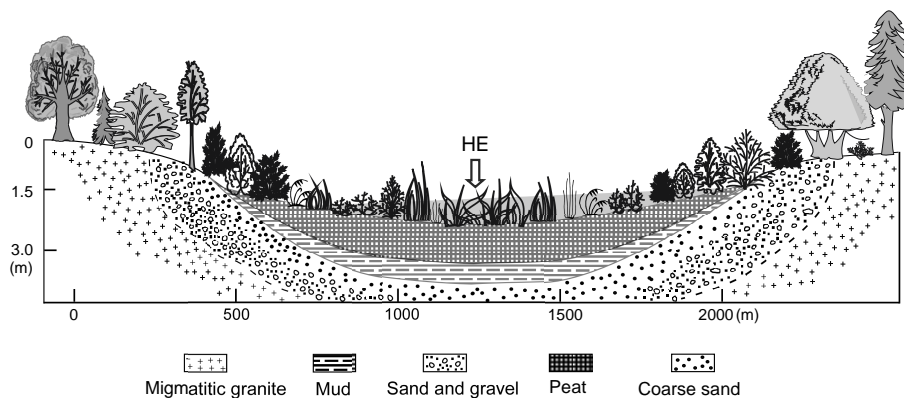


Figure 3. A simplified configuration of the Quaternary strata in the studied basin with the location of HE profile.

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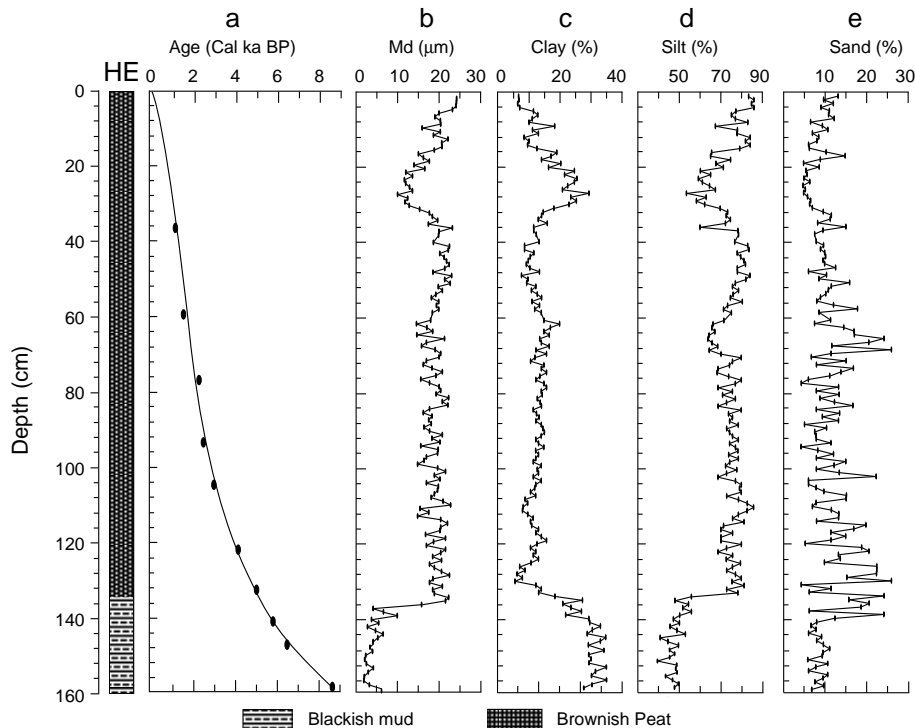


Figure 4. Lithology, age model (a) and grain-size analysis results (b–e) from the studied profile HE.

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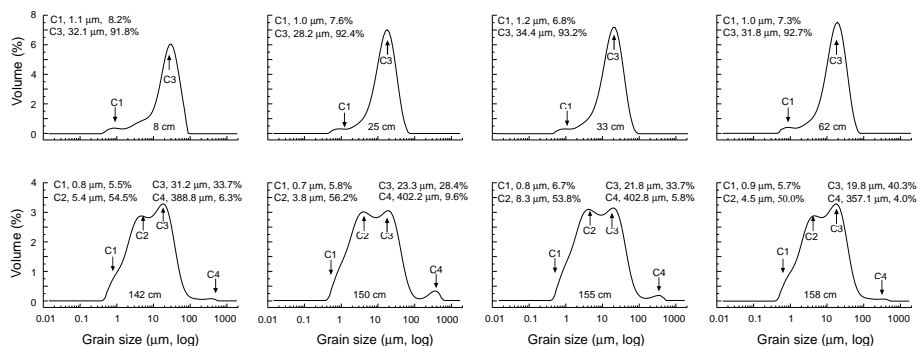


Figure 5. Representative frequency curves of the grain-size distributions of samples from the studied profile. Noting that the upper four curves are from the peat sections, while the lower four curves are from the lacustrine layers. In each diagram, the number with the unit “cm” marks the depth of the sampled horizon.

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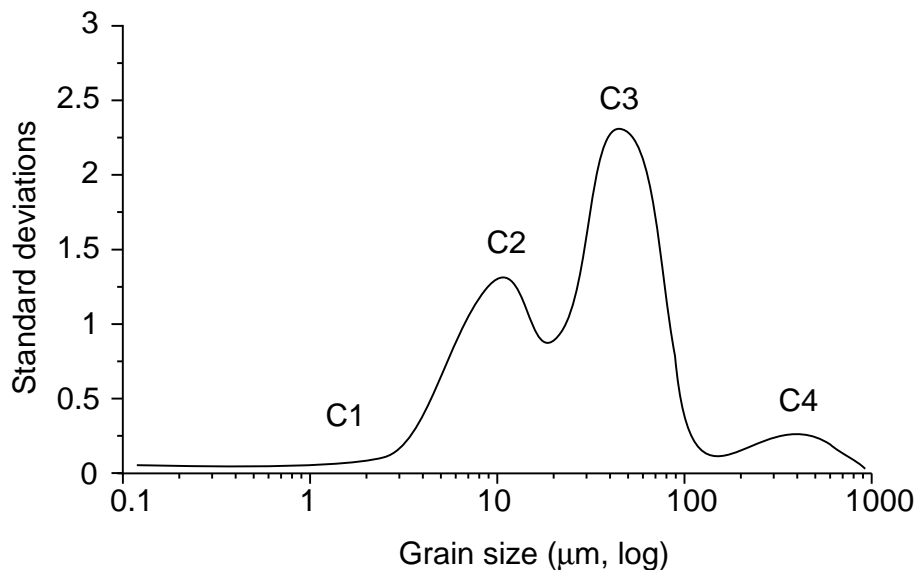


Figure 7. SDs of the percentages of the four grain-size components, C1 through C4, in samples from the HE. Noting that the C1 shows no apparent variation while the C3 exhibits the widest fluctuations responding to the climate changes.

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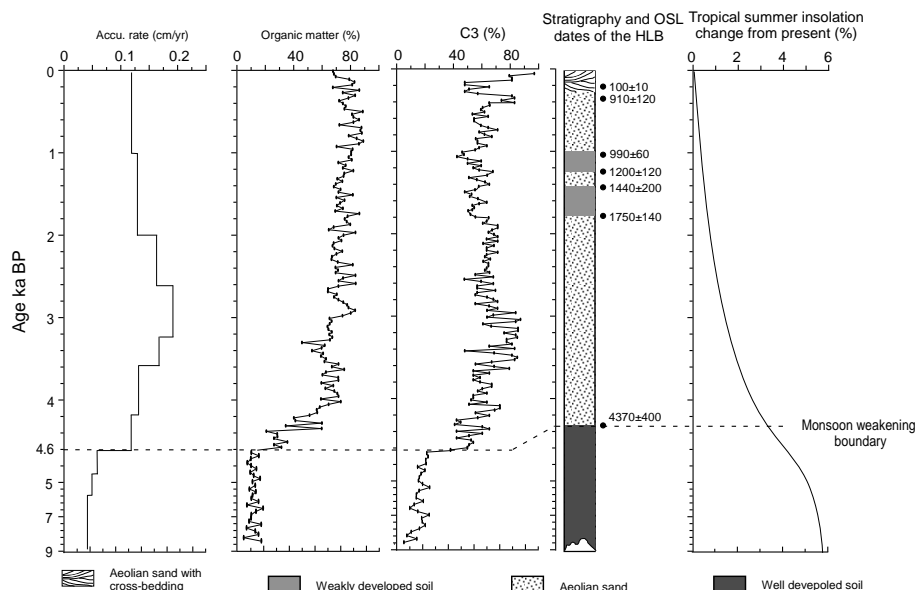


Figure 8. The accumulation rate (cm yr^{-1}), organic matter contents (%) and percentage variations of the C3 (%) from the HE, and their correlations with the well-developed soil section from the HLB profile (see location in Fig. 1) in the Hulun Buir deserts, and the tropical summer insolation changes during the Holocene.

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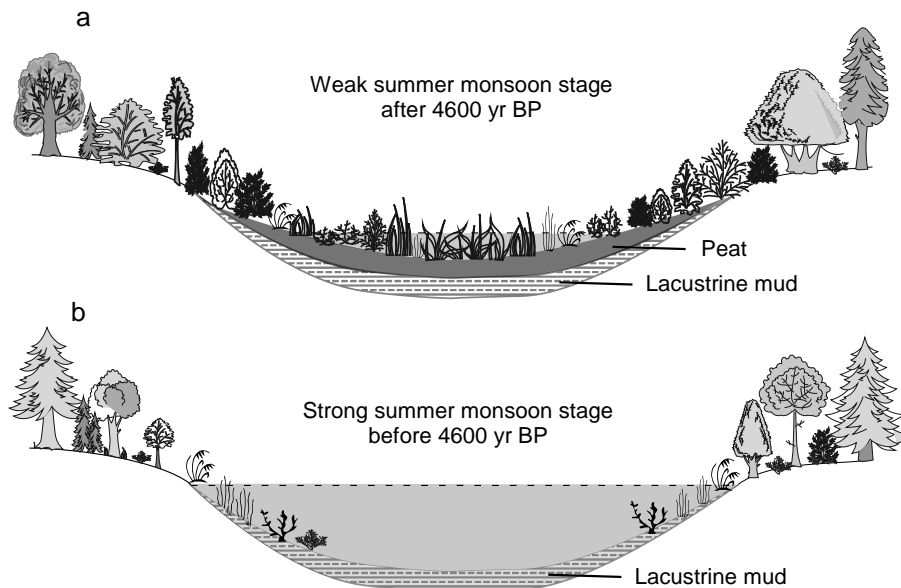
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Figure 9. Schematic figures indicating the decline of East Asian summer monsoon played a driving role in lake-wetland transition during Holocene.

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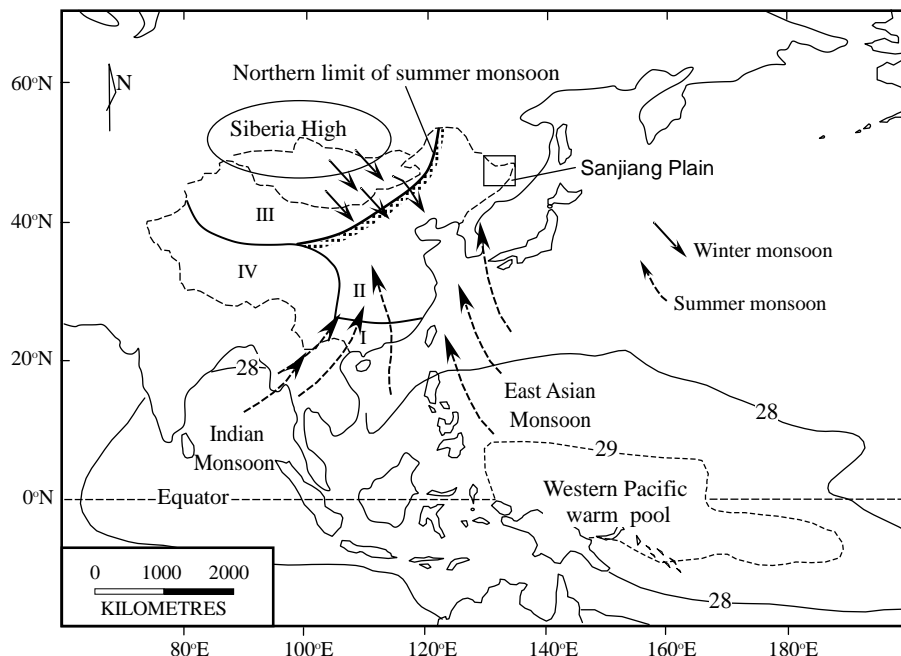


Figure 10. Schematic map showing the monsoon climate affecting China and the location of the modern Western Pacific warm pool (modified from Sum and Huang, 2006). Zone I is controlled by both the Indian monsoon and the east Asian monsoon; Zone II is mainly controlled by the east Asian monsoon; Zone III is controlled by the westerlies; Zone IV is located in the Tibetan Plateau with different climate. Noting that the East Asian summer monsoon plays an important role in transport of humid air masses from the western Pacific (especially from the warm pool) to the mid-high latitude regions of China, which is primarily controlled by the low-latitude solar radiation.

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