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Peatland development and climate changes in the Dajiuahu basin, central China, over the last 14,100 years

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ABSTRACT

Peatlands are one of the optimal archives for paleoclimate research and their records contain a detailed history of climatic and environmental variations during their formation. Here we collected a peat profile from the Dajiuahu basin in central China and analyzed several geochemical proxies, such as Total Organic Carbon (TOC), Total Nitrogen (TN), Titanium (Ti) and Aluminum (Al), to investigate the history of peat development. The results show that the peat growth was initiated after around 12.8 cal ka BP at the sampling site and the TOC and TN contents kept stable during the Holocene except during the periods of 10.5–9.0 cal ka BP and recent 1.5 cal ka BP. However, compared with other TOC records in the Dajiuahu basin, the history of peat development varied greatly in different sampling sites, indicating that the peat development in the Dajiuahu basin probably responds to both climate changes and local geological and hydrological conditions. Investigations of the interactions between climate change and peat development record in this study suggest that peat development presented significant responses to the large and rapid decreases in East Asian Summer Monsoon intensity, such as the 9.2 ka monsoon weakening event. However, the obvious long-term decreasing trend of monsoon precipitation during the mid-late Holocene did not lead to the degradation of the Dajiuahu peat, probably resulting from relatively stable temperature. In addition, the sharp decrease of TOC and TN values in the surface 15 cm of Dajiuahu peat was probably attributed to increased human activity.

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1. Introduction

Peatland is one of the largest pools of carbon in the terrestrial biosphere, representing nearly a third of organic soil carbon, and plays an essential role in the global carbon cycle and climate changes (Gorham, 1991). In recent decades, numerous studies have highlighted the potential of peatlands as paleoclimate archives due to the significant impacts of climate changes on the growth of vegetation and peatland formation, development and evolution (Chambers et al., 1997; Anderson, 1998; Chambers and Charman, 2004; Tarnocai and Stolbovov, 2006; Large et al., 2009; Yu et al., 2009; Langdon et al., 2012; Bezrukova et al., 2013; Charman et al., 2013; Hunt et al., 2013; Poto et al., 2013;

Horák-Terra et al., 2015; Korzeń et al., 2015; Leroyer et al., 2016; Xue et al., 2015). Usually, peatlands develop in stable sedimentary environments with high temporal resolution and may contain many potential proxy records such as humification, elemental contents, organic compounds contents, stable isotopes, pollen and fossils (Blackford, 2000; Chambers and Charman, 2004; Xu et al., 2006; Chambers et al., 2012; Guo et al., 2013; Poto et al., 2013; Xie et al., 2013; Huang et al., 2013a, 2013b, 2013c).

An understanding of the dynamics of peat development, as well as the contribution of different climate parameters (e.g. temperature, precipitation, solar irradiance and so on) to their formation and development, is essential before using peatlands as paleoclimate archives. Many studies have focused on the dynamics and factors affecting peat development, but the results can still be complex to interpret (Ovenden, 1990; Chambers and Charman, 2004; Charman et al., 2009; Yu et al., 2009; Jackson

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and Charman, 2010; Zhao et al., 2011; Klein et al., 2013; Garneau et al., 2014; Wang et al., 2014; Yu et al., 2014; Zhao et al., 2014; Charman et al., 2015; Margielewski et al., 2015). Many studies highlight the impacts of regional hydrothermal conditions and climate changes on peatland development (Wang et al., 2014; Yu et al., 2014; Zhao et al., 2014; Rowe, 2015). However, some studies have argued that the regional conditions may be less important in a waterlogged environment and the peatland growth is mainly related to the anaerobic environment, water table depth and moisture content, along with some local-scale controls (Yin and Lv, 2006; Swindles et al., 2009; Klein et al., 2013). A more complex situation occurs in Chinese monsoon climate areas where both temperature and precipitation can play an important role in initiation and development of peatlands (Wang et al., 2010, 2014; Xu et al., 2013; Huang et al., 2014a). It can be difficult to distinguish the contributions of temperature and precipitation on peat development due to the synchronous variations of rain and heat (Wang et al., 2010, 2014; Xu et al., 2013; Huang et al., 2014a). Overall, the climatic sensitivity is probably quite different for each peatland and testing the dynamics of peatland development is important for paleoclimate research.

The Dajiuhu peatland is located in central China where high resolution Holocene paleoclimate records are few except for some stalagmite records. But the signal preserved in $\delta^{18}\text{O}$ records derived from speleothems may be complicated by the influence of multiple contributory factors, such as monsoon rainfall amount (Dykoski et al., 2005; Wang et al., 2005, 2008; Zhang et al., 2008) and moisture source (Maher, 2008; Pausata et al., 2011; Lee et al., 2012; Caley et al., 2014; Chiang et al., 2015). Some studies have focused on peat development and climate changes recorded in the Dajiuhu peat in recent decades and these works refer to diverse proxies such as pollen, magnetism, chemical element contents, stable carbon isotopes and some organic geochemical proxies (Ma et al., 2008, 2009; Zhu et al., 2008; Zhu et al., 2010; Li et al., 2013; Xie et al., 2013; Huang et al., 2013b, 2013c, 2014b, 2014c; He et al., 2015). However, controversies remain in explaining the results. For example, Zhu et al. (2008) and Huang et al. (2013b) reconstructed the temperature variations of the Dajiuhu basin during the Holocene by pollen and microbial lipid proxies, respectively. Both records showed similar long-trend temperature decrease since the early Holocene, but the millennial oscillations were slightly different in the two records. In addition, Xie et al. (2013) reconstructed the monsoon-driven precipitation changes since the last deglaciation by aerobic microbial biomarkers. It revealed three relatively long wet periods from 13.0 to 11.5 ka BP, 9.5–7.0 ka BP and 3.0–1.5 ka BP. However, Ma et al. (2009) argued that the precipitation was comparatively less during 9.2–7.5 ka BP, and the best moisture and thermal conditions occurred during 7.0–4.2 ka BP. The peat development records in the Dajiuhu basin during the Holocene also have been generated by several studies (Ma et al., 2008; Huang, 2009; Zhu et al., 2010; He et al., 2015), but the results present substantial inconsistency between the records from the different sampling sites, implying that the peat development in the Dajiuhu basin is probably influenced by the geography and hydrology conditions of sampling sites. Thus further investigation and comprehensive integration about the history and dynamics of peat development in the Dajiuhu basin is still necessary before the paleoclimate reconstructions.

In this study, we collected a sediment profile from the Dajiuhu basin and several geochemical proxies, such as TOC, TN, Ti and Al, were analyzed in order to test the dynamics of peat development since the last 14.1 cal ka BP and its relationship with regional and global climate changes.

2. Materials and methods

2.1. Study site and sampling

The Dajiuhu basin (109°56'E–110°11'E, 31°24'N–31°33'N) is located in the west of the Shennongjia Mountains, central China (Fig. 1). With an area of about 16 km², it is covered with thick peat and is a unique subalpine peatland in a mid-latitude subtropical region. Its climate has an unusual seasonal variability under the strong control of the East Asian Monsoon, which is marked by a short warm and wet summer and long cold winter due to its relatively high altitude (Ma et al., 2008). The average annual temperature is 7.2 °C with the highest monthly average 17.1 °C in July and the lowest –2.4 °C in January. The average annual precipitation is approximately 1500 mm with a maximal up to 3000 mm. The yearly rain days reach up to 150–200 days, mainly from April to October, and with the humidity over 80% (Ma et al., 2008). These climate conditions foster peat formation and its preservation as a whole.

Choosing a site with minimal disturbance by anthropogenic activities, we dug a pit and continuously collected 165 samples through a depth sequence of 205 cm at the center of Dajiuhu Basin (31°28'48.93"N, 110°00'6.65"E, 1753 m a.s.l.). The samples were collected at 1.2 cm intervals from 0 cm to 188 cm, 2 cm intervals from 188 cm to 198 cm, and about 2.3 cm depth intervals from 198 cm to 205 cm. The profile was described and photographed in the field. The upper part (0–177 cm) of the sediment was mainly composed of black peat with plant remains, and the lower part (177–205 cm) was grey clay sediment (Fig. 2).

2.2. Laboratory analysis

To obtain a high-resolution chronology for the sequence, ten bulk samples and two extractive pollen samples were taken for radiocarbon dating. In order to extract pure pollen, the peat samples had carbonate removed by diluted hydrochloric acid, then were added NaOH and NaClO₂ and sieved to remove coarse organic matters. After washing with deionized water and drying, the pollen samples were measured by the accelerator mass spectrometry in the Institute of Earth Environment, Chinese Academy of Sciences, Xi'an. The bulk samples were treated using the acid-base-acid technique. The AMS ¹⁴C ages were calibrated into 2σ calendar ages and obtained 12 median calibrated ages by the IntCal13 calibration curve (Reimer et al., 2013).

After drying for 48 h at 50 °C, all the samples were ground to homogeneity and sieved through a 150 μm Mesh. For TOC and TN analysis, for the grey clay samples hydrochloric acid (5%) was added to remove carbonate. Then they were adjusted to pH 7 with deionized water. Because of the high content of organic matter, the black peat samples were not pretreated with acid. All of the samples were placed into an elemental analysis instrument to determine TOC and TN after dry combustion (ISO, 1995). With three control standard samples, each of them was also measured four times and the standard deviations of the repetitions were <0.02% (TOC) and <0.002% (TN). For chemical element analysis, about 0.01 g of each sample was taken, and then weighed. Al and Ti were determined using the inductively coupled plasma-atomic emission spectrometry (ICP-AES) with method 200.7 (EPA, 2001) after digestion by HF–HNO₃–HClO₄. The detection limits of Al and Ti were 0.01 mg/g and 0.001 mg/g, meeting the demands of accuracy and precision. All of these experiments were conducted in the Lake Sediment and Environment Laboratory of Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences.

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