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Records of East Asian monsoon activities in Northeastern China since 15.6 ka, based on grain size analysis of peaty sediments in the Changbai Mountains

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ABSTRACT

Peatlands provide a widespread terrestrial archive for Holocene study. However, little is known about the grain-size characteristics of peaty sediments and their environmental significance. In order to study these phenomena in detail, two sections from the Hani and Gushantun peatlands in the Changbai Mountain Area were cored and sub-sampled. Based on reliable calibrated AMS ^{14}C ages, we established grain size variations in the peat cores since 15.6 ka cal. BP. Our results showed that the peaty sediments in the Changbai Mountains are mainly composed of silt. Moreover, the grain size component, which is related to paleoclimate variables, can be classified into three groups based on the "Grain size class *vs.* standard deviation" method. These sensitive grain size components are <37.0 μm (Component 1 or C1), 37.0–497.8 μm (Component 2 or C2) and >497.8 μm (Component 3 or C3). C1 comprises the finest silt in the peaty sediment and is mainly conveyed by the East Asian winter monsoon (EAWM), whereas C2 is transported into the peatland by surface runoff related to the enhancement of the East Asian summer monsoon (EASM). C3 is conveyed in saltation and bed-load mode by strong surface runoff linked to high-energy flow caused by a strong EASM, and perhaps is an indicator of extreme rainfall events in the Changbai Mountains. Our results suggest that the study region was dominated by a cold/dry environment during the late-glacial period under a strong EAWM. However, there was a marked climatic shift from an EAWM-dominated cold/dry climate to an EASM-dominated more mesic environment during the early Holocene. Increased percentage of C2 in peat cores during the Holocene Optimum (9.0–4.5 ka) indicates abundant rainfall in the study region (even with extreme rainfall events) as a result of a significant enhancement of the EASM. Weak monsoon events occurred at 10.5 ka, 9.2 ka, 8.2 ka, 7.2 ka, 6.2ka, 5.5 ka and 4.2 ka shown by sharp decreases in C2, agreeing with the stalagmite $\delta^{18}O$ records in China. The results obtained from environmentally sensitive grain-size component records are largely consistent with other palaeoenvironmental records in the East Asian monsoon area, substantiating the regional climate patterns and monsoon evolution since late-glacial time. Because intensity of the East Asian monsoon is likely responsible for the grain-size change in the peat samples, the grain size components in peat samples may be used for reconstructions of past environmental conditions and of variability in the East Asian monsoon.

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1. Introduction

Peatlands provide a widespread archive of Holocene environmental change. Because the sampling of peat is relatively simple, the range of paleoclimate evidence and proxies is wide, and dating methods have become more accurate, such that peatlands have great potential for Holocene research (Chambers and Charman, 2004) and particularly for palaeoclimate reconstruction (Chambers et al., 2012), exemplified variously by studies in Europe (Barber et al., 2003), North America (Klein et al., 2013), South America (Chambers et al., 2014) and Siberia (Smith et al., 2004). Increasingly, there has been use of peat archives in China (e.g. Makohonienko et al., 2004; Ma et al., 2009; Zhou et al., 2010; Zhao et al., 2011, 2014; Gao et al., 2014). Indeed, Northeastern (NE) China is one of the most important peat distribution regions of the world (Chai, 1990). Up to now, several Holocene paleoclimate reconstructions have been carried out using peat deposits in the Changbai Mountains, and many proxies have been used as indicators to study Holocene environment change, including pollen (Liu, 1989; Xu et al., 1994; Xia and Wang, 2000; Makohonienko et al., 2004), phytolith (Zhang et al., 2007; Guo et al., 2012), stable isotopes (Hong et al., 2009, 2010), testate amoebae (Li et al., 2009), chemical element (Zhang et al., 2011) and biomarkers (Zhou et al., 2010). However, the inorganic mineral composition of peat deposits has been overlooked, yet grain size is recognized as an important paleoenvironmental proxy in other depositional environments (Liu, 1985; Ding et al., 1998; Lu and An, 1998; Sun et al., 2003; Huang et al., 2011; Qiao et al., 2011). There are relatively few published studies using the grain size of mineral clasts in peat as a paleoenvironmental indicator to reconstruct Holocene climate change (Wang et al., 2003; Yu et al., 2006; Bao et al., 2010; Zhang et al., 2014); indeed, there has been a lack of systematic study of the grain-size characteristics of peaty sediments and their environmental significance.

The Changbai Mountains are located at the northern periphery of the East Asian summer monsoon (EASM). Since the Last Glaciation, paleoclimate fluctuations and the swings of the monsoon boundary (Wang et al., 2001, 2005a, 2005, 2008; Stebich et al., 2015) must have changed the sedimentary environments of peatlands, and these changes may be reflected in the grain size characteristics of peat deposits. Thus, peatland may have great potential to investigate the activities history of the EAM. In this study, two cores of peat that accumulated since the late-glacial time were taken from the Changbai Mountains, NE China. Combined with high-precision AMS ^{14}C dating, we focused on grain size characteristics of mineral clasts within the peat deposit and its environmental significance. To facilitate more reliable reconstructions, grain-size class *vs.* standard deviation was used to obtain environmentally sensitive components of the peat sediments. Based on the time sequences of these components, we present an inferred variation history of the EAM and paleoclimatic changes in the Changbai Mountains since the late-glacial time.

2. Regional setting

Hani (42°13′31.1″ N, 126°30′ 14.7″ E, 890m a.s.l.) and Gushantun (42°18′22.1″ N, 126°16′ 57.7″ E, 506m a.s.l.) peatlands are situated west of the Changbai Mountains (Fig. 1A and B) in the Longgang Volcanic Field, which is an area of active vulcanicity in China (Liu, 1988). There were intense Cenozoic volcanic activities in this region and these provided a geological basis for the development of peatland. The lake basin substrate of the Hani peatland is Early Pleistocene basalts (Isotopic Age of 2.6 ± 0.29 Ma (Qiao, 1993)). In the Late Pleistocene, the Hani River valley was dammed during the Nanping Period by volcanic ejecta. Since then, peat formed in the former lake basin (Qiao, 1993). The Gushantun peatland is also surrounded by Cenozoic basalt, with the peatland initiated in the Late Pleistocene on a former Maar Lake (Zhao and Hall, 2015). The average thickness of the peat is about 7 m.

The modern climate of NE China is controlled by the EAM, which shows strong seasonal variability. Dominating north-westerly winds in winter contribute aeolian material from the interior of the Eurasian land mass to the Changbai Mountains (Schettler et al., 2006a, 2006b, 2006c). In contrast, summers are dominated by humid air, transported by south-easterly winds from the Pacific. So the regional precipitation period is concentrated from June to August (Fig. 1C). The average annual temperature of Changbai Mountains ranges from −7.3 °C to 4.8 °C while the average annual rainfall ranges from 700 mm to 1400 mm (Wang, 1989). The landform type in the Changbai Mountains is diverse, with catenae of mountain, plateau, tableland and valley (Fig. 1B). The dominant soil in the study region is dark brown forest soil, but with meadow soils in valleys and lessive soil on high tableland. Moreover, the Changbai Mountains are situated in the modern temperate conifer−hardwood forest zone, representing one of the best preserved primeval forests in China.

3. Material and methods

3.1. Sampling and chronology

Peat sediment cores were taken from the Hani and Gushantun peatlands (Fig. 1) in the summer of 2009, using an Eijkelkamp peat sampler. The length of the Hani (HN) core was 350 cm while that from Gushantun (GST) was 750 cm. Both cores were sub-sampled at 1-cm intervals, resulting in 350 sub-samples from Hani and 750 from Gushantun. Reflecting changes in lithology, sixteen bulk organic samples were dated by accelerator mass spectrometry (AMS) radiocarbon dating at Peking University. All the radiocarbon ages were calibrated into calendar ages before present (BP) (Table 1) with the Intcal13 calibration data (Reimer et al., 2013) using the CALIB Rev. 7.0.4 program (Stuiver and Reimer, 1993) and chronologies were estimated with the Bacon v2.2 model (Fig. 2) (Blaauw and Christen, 2011). Meanwhile, in order to investigate the environmental significance of different components in peat, three dust samples were collected using a glass dust collection tank (15 cm in diameter and 30 cm in depth) from Nov., 2010 to May, 2011. The tank is located at Hani Automatic Weather Station and about 3m off the ground.

3.2. Grain size analysis

Peat samples were selected at 2-cm intervals for the Hani section and 10-cm intervals from the Gushantun section for grain size analyses. Before any further treatment, all samples were dried in a thermostatic drying chamber at 105 °C.

In advance of grain size measurements, *c.* 0.5 g dry peat samples were pretreated in a muffle furnace (550 °C) for 4 h to remove organic matter (Lewis, 1989), while dustfall samples were pretreated using 30% hydrogen peroxide (H_2O_2). Then, all samples were treated with 10% hydrochloric acid (HCl) to remove carbonates and with 10 mL 0.05 mol/L sodium hexametaphosphate ($(NaPO_3)_6$) to facilitate dispersion. The grain size distribution was determined with a MICROTRAC S3500 particle analyzer at Northeast Normal University. It automatically yields the percentages of the clay-, silt- and sand-size fractions and the median diameter over the range of 0.02−2800 μm. Replicate analyses indicated that the mean grain size has an analytical error of 2%.