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Branched GDGT-based paleotemperature reconstruction of the last 30, 000 years in humid monsoon region of Southeast China

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ABSTRACT

The use of bacterial branched glycerol dialkyl glycerol tetraethers (brGDGTs) to reconstruct mean annual air temperatures (MAATs) and environmental pH from soils has sparked significant interest in the terrestrial paleoclimate community. However, the reconstruction of these climate proxies from peat bogs is rare in monsoonal regions of the East Asia. This research was carried out on a core from the Shuizhuyang (SZY) peat bog located in Fujian Province. Branched GDGT (brGDGT) indexes were used for reconstructing the paleoclimate of the last 30 cal ka. The aim was to evaluate quantitatively the MAAT and pH values since the Last Glacial Maximum (LGM) in the subtropical zone of China. Results show that the CBT-MBT′-derived MAAT at MIS 3 is about 15.6 °C on average, which is followed by a significant fall at the LGM (11.7–12.1 °C). The temperature difference between the LGM and the present-day value is as high as 5.8 °C. The synchronous variation of biomarker and pollen proxies indicates that replacement of subtropical evergreen broadleaved forests by cold-tolerant, deciduous broadleaved forests was driven by the significant drop in air temperature. Our results also indicate that the Younger Dryas event lasted from about 12.9 to about 11.3 cal ka, and cooling event at 3.2 cal ka in the late Holocene was detected, showing the sensitivity of peat bogs to rapid cooling. Our pH reconstructions indicate that the pH of the bog rose during Heinrich 1 and Bølling-Allerød periods, probably due to low precipitation, and were lowest in the Holocene thermal maximum between 8 ka and 2.5 ka, probably due to higher precipitation. The decoupling of reconstructed MAAT and pH during particularly deglaciation and YD periods supports the hypothesis that the variations in temperature and precipitation are not always synchronous.

1. Introduction

Important insights into paleoclimatic changes in China and other parts of eastern Asia have been obtained from quantitative reconstructions of air temperatures and other environmental variables based on analyses of various proxies (Farrera et al., 1999; Herzschuh, 2006; Herzschuh et al., 2014; Lu et al., 2007). Pollen and many other data from lacustrine sedimentary archives have become the proxies most used to quantify climate changes that occurred in the late Quaternary in China (Zheng et al., 2016). In the last decade, the use of bacterial branched glycerol dialkyl glycerol tetraethers (brGDGTs) to reconstruct mean annual air temperatures (MAATs) from soils has sparked significant interest in the terrestrial paleoclimate research community (Schouten et al., 2013; Weijers et al., 2007a, 2007b). The membrane lipids are widespread in soils (Weijers et al., 2007b, 2011a; Huguet et al., 2010a; Kim et al., 2011), lake sediments (MacGregor et al., 1997; Schouten et al., 2008; Powers et al., 2004) and peat bogs (Liu et al., 2010; Huguet et al., 2010b; Weijers et al., 2011b). As quantitative climate proxies, the cyclisation ratio of branched tetraethers (CBT) and a combination of the methylation index of branched tetraethers (MBT) have been successfully used for MAAT reconstruction, and CBT has been applied for soil pH reconstruction (Weijers et al., 2007b; Peterse et al., 2012).

The majority of previous studies concerning quantitative climate reconstruction in China are primarily based on the composition of lake sediments (Sun et al., 2011; Wang et al., 2015; Hu et al., 2015; Cao et al., 2014; Lu et al., 2011; Wang et al., 2014a; Chen et al., 2014). In southeastern China, however, due to the lack of natural lakes, the peat bogs are considered to be a suitable material for such studies of the Quaternary. The southeast of the subtropical zone in China is considered a key region for revealing the climate variability during glacial-interglacial transition, because of its location on the path of the East Asia Summer Monsoon (EASM). Furthermore, a number of natural peat bogs have been found in the mountain ranges, many of which have

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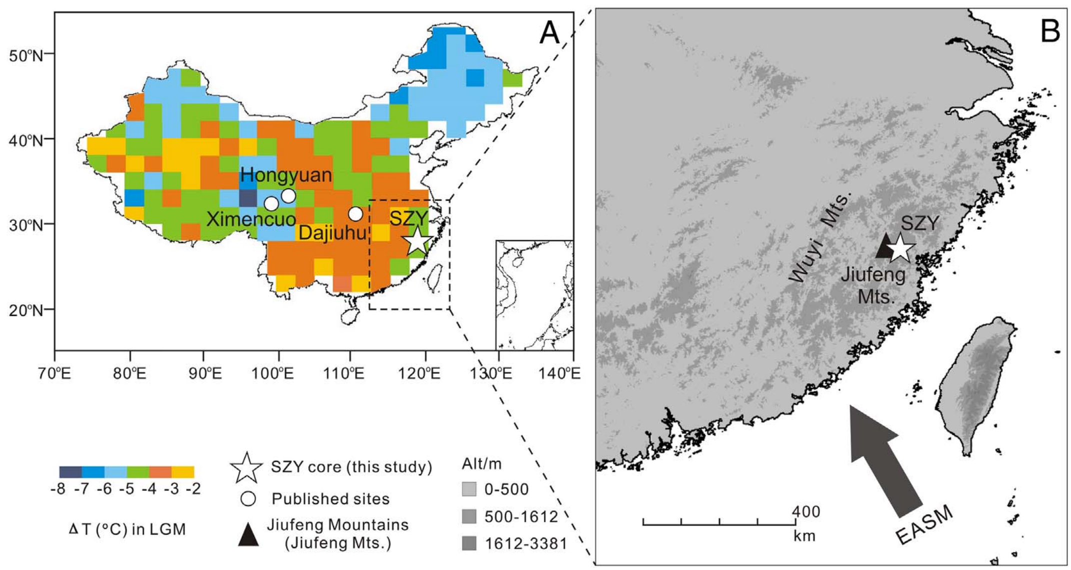

Fig. 1. (A) LGM minus pre-industrial values of annual temperatures for the medians of the PMIP phases 1 and 3 (PMIP1/2) models, with regionally-averaged values over China given in parentheses (the dotted areas represent regions where at least 70% of the models share the same sign of anomaly) (modified from Tian and Jiang, 2016). The yellow circles mark sites of the published studies – Hongyuan peat bog (Zheng et al., 2015), Dajiuhu peatland (Zhu et al., 2008) and Ximencuo Lake (Herzschuh et al., 2014) – cited in this study. The yellow star indicates the site of the SZY core used in this study. (B) Location of the SZY core (red star), to the southeast of the Wuyi Mountains (Wuyi Mts.). The light and dark gray shading indicates altitude. The black arrow indicates the direction of the East Asia Summer Monsoon (EASM). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

been proven to be highly sensitive to Quaternary environmental changes (Zhong et al., 2010a; Huang et al., 2014; Huang et al., 2013; Zheng et al., 2015; He et al., 2015; Xie et al., 2013). However, there are few measurements from them that extend to the LGM (Li et al., 2013; Yue et al., 2012; Man et al., 2016; Zhong et al., 2010b; Liew et al., 2006).

The use of brGDGTs to reconstruct MAAT is an important method when using peat bog materials. MBT/CBT was first used for air temperature reconstruction from a Pliocene peat sediment from the North Pole by Ballantyne et al. (2010). Later, MBT/CBT-inferred air temperature estimates from the peat bogs were increasingly studied (Weijers et al., 2011a; Huguet et al., 2013; Zheng et al., 2015). From the above results, it can be seen that the brGDGT index has great potential for the quantitative reconstruction in peatlands. However, care should be taken when using brGDGTs as proxies for paleoclimate reconstruction due to proven risks of overestimating temperatures and bias in pH values. Recently, a new study based on 470 samples from 96 peatlands all over the world (Naafs et al., 2017) shows that the large artefacts should be avoided by means of the peat-specific brGDGT-derived pH and temperature calibrations. This demonstrates that there is clear potential to use GDGTs in peatlands to reconstruct past terrestrial climate. So far, brGDGT-derived MAAT reconstruction from peat sediments is still in early stages, and such work in East Asia is still lacking (Zheng et al., 2015; Weijers et al., 2011b; Zhou et al., 2011).

Knowledge of the temperature drop during the Last Glacial Maximum (LGM) in tropical and subtropical regions of the world is crucial for climate simulations. Although models and paleoclimate data are in agreement on the direction and spatial pattern of the large-scale features of climate change (Braconnot et al., 2012; Schmidt et al., 2014; Izumi et al., 2013), there are still discrepancies in the amplitude of the simulated changes (Harrison et al., 2014). For example, CLIMAP (1976) showed a 1–2 °C decrease during glaciation of tropical areas. The set of coupled ocean-atmosphere simulations using state-of-the-climate models from the Paleoclimate Modeling Intercomparison Project (PMIP2) (Harrison et al., 2002) suggested that the continental cooling during LGM in the tropical regions was between − 2 and − 5 °C (Braconnot et al., 2007). Harrison et al. (2014) also suggested that all models overestimate the reconstructed summer cooling of the tropics at the LGM. In tropical and subtropical China, both temperature and precipitation paleoclimate data for the LGM remain inconsistent and/or controversial. Oxygen-isotope records in Chinese stalagmites have offered valuable data for interpreting the strength and intensity of the EASM over the past few decades (Wang et al., 2001; Cheng et al., 2016; Zhou et al., 2008; Yuan et al., 2004), while their quantitative correlation with temperature and precipitation is still open to question (Cheng et al., 2005; Tan, 2011). There is a good deal of quantitative temperature reconstruction research into LGM conditions from southwest China (especially the Tibetan Plateau) (Shi et al., 1997; Tang et al., 1998; Herzschuh, 2006; Herzschuh et al., 2010; Farrera et al., 1999; Zhang et al., 1995). In southeast China, most researches are based on the comprehensive qualitative indexes (Zheng et al., 1998; Farrera et al., 1999; Cook et al., 2011; Yue et al., 2012; Li et al., 2013), which hardly present specific values (e.g. temperature degrees or pH values) of the proxies.

To address this deficiency, this paper presents a core from the Shuizhuyang (SZY) peat bog, located in the southeast of the Jiufeng Mountains in Fujian Province. BrGDGT indexes were used for evaluating the paleoclimate of the last 30 cal ka. The focus was to reconstruct quantitatively the MAAT and pH values from the LGM to present day in the subtropical zone of China. Coupled with the published pollen data from the SZY peat bog (Yue et al., 2012), this work on brGDGTs offers a quantitative result for the region that will help to test the regional modeling simulation, and provides a better understanding of the driving mechanism of climate change, in particular for the period of the LGM.

2. Regional setting and material

2.1. Regional setting

The SZY core is composed of peat and clay sediment from a mountain wetland (1007 m a.s.l. 26°46′N, 119°02′E; Yue et al., 2012) in Pingnan County, northeastern Fujian Province (Fig. 1B). Pingnan County is located to the southeast of the Jiufeng mountains, the first mountain barrier in the path of the EASM moving from the ocean to inland areas. This significant location e.g. the first mountain range inland from the coast, receives heavy rainfall during the summer monsoon (Chen, 2007). The mean annual and monthly temperatures