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Peatland GDGT records of Holocene climatic and biogeochemical responses to the Asian Monsoon

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ABSTRACT

Branched and isoprenoidal glycerol dialkyl glycerol tetraether (GDGT) membrane lipids have been widely used to reconstruct past climate and environmental change. They are not, however, widely applied to peat deposits and the controls on their distributions in peats remain unclear. Here, we present a high resolution record of branched and isoprenoid GDGT concentrations and distributions from a peat core from the Tibetan Plateau that spans the last 13 kyr, a period characterised by distinct dry and wet periods in the region. The lowest concentrations of total branched glycerol dialkyl glycerol tetraethers (brGDGTs) occurred during a presumably dry interval in the mid-Holocene, suggesting that brGDGTs-producing bacteria are less productive under such conditions, perhaps reflecting their putative anaerobic ecology. The mean annual air temperature (MAT) estimates derived from the methylation index of brGDGTs and cyclisation ratio of brGDGTs (MBT′/CBT) are higher than present mean annual temperature in the region and closer to summer temperatures, perhaps due to seasonal production of brGDGTs. The downcore distributions of isoprenoidal and branched GDGTs are dominated by GDGT-0 and brGDGT II, respectively. The high fractional abundances of GDGT-0 in warm and especially wet intervals suggest that these conditions are favourable for some groups of methanogenic archaea. The mid-Holocene dry interval is associated with an increase in the fractional and absolute abundance of crenarchaeol, which could be indicative of enhanced ammonia-oxidising archaeal-mediated nitrogen cycling under these conditions. Taken together, variations of GDGT concentrations in peats appear to document the response of microbial processes to climate change and variations in the biogeochemical environment.

1. Introduction

Glycerol dialkyl glycerol tetraether (GDGT) membrane lipids are widespread in natural settings, including marine settings (Schouten et al., 2000, 2002), soils and peat bogs (Weijers et al., 2006a,b, 2007; Peterse et al., 2012), lakes (Sinninghe Damsté et al., 2009; Tierney et al., 2012), and rivers and estuaries (Kim et al., 2010a, 2012a; Zhu et al., 2011). Isoprenoidal GDGTs (iGDGTs; See Schouten et al. (2013) for structures) are synthesized by a wide range of archaea (e.g., Koga et al., 1993), whereas soil bacteria are thought to be the primary producers of branched GDGTs (brGDGTs; see Schouten et al. (2013) for structures) (e.g., Weijers et al., 2007). Proxies based on GDGTs are widely used in paleo-reconstructions in both marine and terrestrial environments (see review of Schouten et al. (2013)). For example, variations in the cyclisation of brGDGTs (CBT-index) in soils correlates with soil pH, and the methylation index of brGDGTs (MBT) correlates with both soil pH and overlying mean annual air temperature (MAT) (Weijers et al., 2007; Peterse et al., 2012; De Jonge et al., 2014).

GDGT-0 is a widespread iGDGT produced not only by the pelagic non-thermophilic Thaumarchaeota, but by a large variety of other archaea including methanogenic archaea (e.g., Schouten et al., 2000; Pancost et al., 2000a; Blaga et al., 2009). Methanogens are likely the predominant source of GDGT-0 in lake (Naeher et al., 2013) and peat sediments (Weijers et al., 2006a). Another iGDGT found in terrestrial settings is crenarchaeol, a unique iGDGT with a cyclohexane moiety that occurs in a variety of natural settings including marine and lacustrine waters and sediments (Powers et al., 2010; Kim et al., 2010b), hot springs (Pearson et al., 2004; Schouten et al., 2007a), peat bogs and soils

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(Gattinger et al., 2003; Leininger et al., 2006; Weijers et al., 2006a; Huguet et al., 2010). Little is known, however, how crenarchaeol concentrations (or relative abundance) respond to past climatic variations in terrestrial ecosystems and whether concentration variations in peats are linked to environmental changes (e.g., Wang et al., 2013).

Despite the fact that (br)GDGTs are extremely abundant in peatlands (Weijers et al., 2006a) and are now commonly used in paleoclimatic investigations, the behaviour of GDGTs in peat ecosystems – and especially high-altitude wetlands – has not yet been widely investigated. Weijers et al. (2011a) investigated the applicability of the MBT–CBT proxy from a Holocene-spanning peat core obtained from a raised bog in the Swiss Jura mountains. That work highlighted both the potential and limitations of using brGDGTs and MBT/CBT proxies in peats and advocated the need for additional studies. Here we focus on a peat spanning the Holocene from the Tibetan Plateau (Fig. 1).

Peat deposits are widespread on the Tibetan Plateau and represent a truly unique setting, characterised by continuous deposition in a low temperature, mid/low-latitude, high altitude geographical regime, and a close connection with the climatic zone of permafrost formation on the Qinghai–Tibetan Plateau (Large et al., 2009). Crucially, the hydrology of these settings is controlled by the Indian and East Asian Monsoon systems, meaning that these deposits are long term, high resolution recorders of past changes in these important climate systems (Zheng et al., 2007, 2014; Zhou et al., 2010; Seki et al., 2011). Here we determine abundances as well as distributions of branched and isoprenoid GDGTs in a peat core spanning the last 13 kyr from the Tibetan Plateau, compare these to known climatic events and evaluate the response of GDGTs to past changes in climate and microbially mediated biogeochemical processes.

2. Materials and methods

2.1. Study area

The Zoigê-Hongyuan peat is located on the eastern edge of the Tibetan Plateau and is the largest peatland in China (Chai, 1990), covering about 4500 km^2. The average elevation of the peatland is 3400 m above sea level and the Hongyuan Peat sampling site is 2 km southeast of Hongyuan County at 32°46′N, 102°31′E, with an altitude of 3507 m (Fig. 1). The area is characterised by cold and wet climate and a long period of frost (typically 5–6 months). The annual mean temperature is ~1 °C, with a January mean temperature of −11 °C and July mean temperature of +11 °C (Zhou et al., 2010). The annual mean precipitation is ~700 mm. The climate of this area is mainly controlled by the Asian Monsoon systems (Fig. 1; Zhou et al., 2010; Yu et al., 2011).

A continuous core of 754 cm was obtained using a peat corer. During the field sampling, pH was measured using pH indicator strips and varied between 5 and 6. Detailed AMS ^{14}C dating (see Zheng et al. (2014) for details) demonstrated that the core covers the past 13,000 years, extending back to the deglaciation. All AMS ^{14}C dates were obtained on plant fragments with a size ranging between 90–300 μm that were isolated from peat samples by wet sieving, and then pre-treated using the acid–alkali–acid (HCl–NaOH–HCl) method to obtain appropriate dating materials. The core consists of 584 cm of brown to dark brown acid peat containing a large amount of undegraded plant residue, underlain by 6 cm of dark brown mud and then 64 cm of dark brown peat. Below 654 cm depth, the sediment is grayish-green to dark brown mud, representing lacustrine depositional conditions (Zheng et al., 2014). The core was transported intact to the laboratory where it

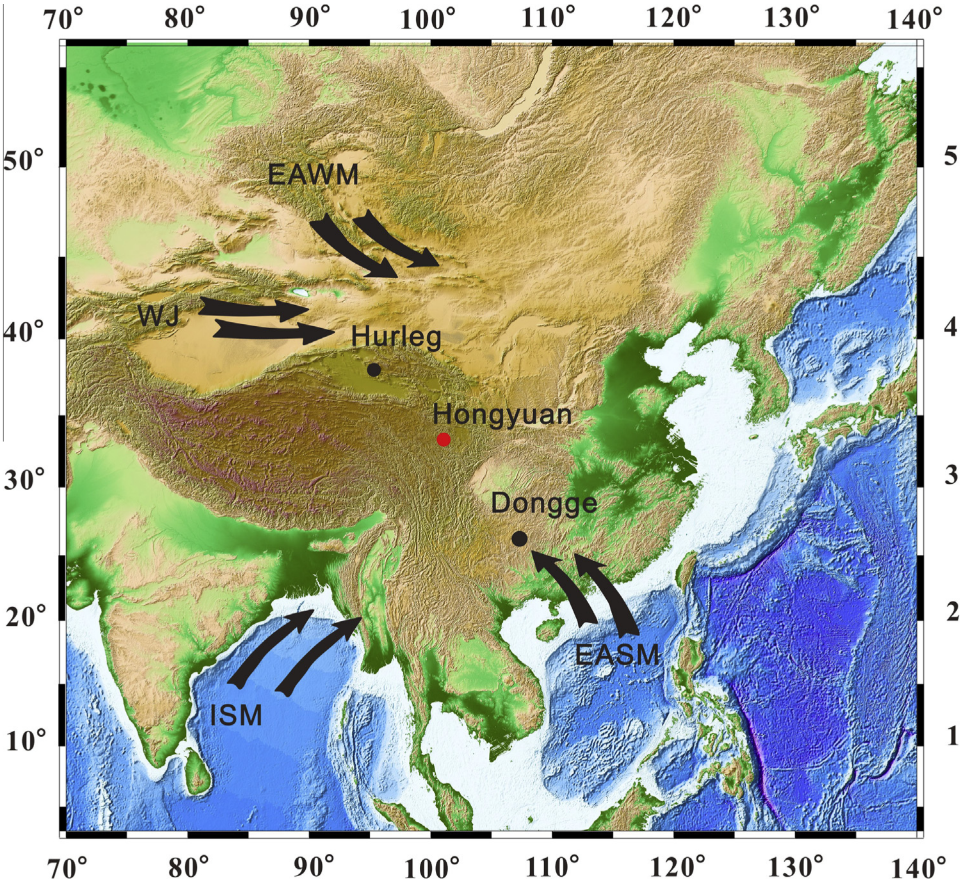

Fig. 1. Site location and atmospheric circulation. ISM – Indian summer monsoon, EASM – East Asian summer monsoon, EAWM – East Asian winter monsoon, WJ – Westerly jet.