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Mid-late Holocene temperature and precipitation variations in the Guanting Basin, upper reaches of the Yellow River

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ABSTRACT

The reconstruction of prehistoric temperature and precipitation variations in the upper reaches of the Yellow River is essential for understanding the cultural evolution of the region, but related information is sparse due to the limitations of the available proxies. Recent studies have shown that microbial glycerol dialkyl glycerol tetraethers (GDGTs) are promising tools for reconstructing mean annual temperature (MAT) and mean annual precipitation (MAP) in terrestrial deposits. In this study, we reconstructed mid-late Holocene climatic changes using GDGT distributions in a loess-paleosol sequence in the Lajia Ruins of the Neolithic Qijia Culture, Guanting Basin, in the southwestern end of the Chinese Loess Plateau. Our GDGT records show that MAP decreased from ca. 600 mm to 430 mm, while MAT decreased from 11.9 °C to 8.0 °C, during the past ca. 7000 yr, and a drastic decline in MAP (70 mm), accompanied by a 0.8 °C decline in MAT, occurred at 3800–3400 yr BP. Our results provide direct evidence supporting a hypothesis that the flourishing (4200–4000 yr BP) and decline (4000–3600 yr BP) of the Qijia culture (mainly based on millets cultivation) and subsequent rise of the Xindian/Kayue culture (3600–2600 yr BP), based on mixed agriculture of sheep husbandry and millets cultivation were triggered by climate change.

1. Introduction

The impact of climate change on cultural evolution is an important issue in Quaternary research and has attracted substantial attention (e.g., Cullen et al., 2000; Brenner et al., 2001; DeMenocal, 2001; Huang et al., 2002; Huang and Su, 2009; Li et al., 2014; Hou et al., 2017; Naudinot and Kelly, 2017; Griffiths and Robinson, 2018). Climatic conditions have been considered to play an especially important role in the evolution of prehistoric cultures, when economic productivity was relatively low (e.g., Weiss et al., 1993; Weiss and Bradley, 2001; Wu and Liu, 2004; Staubwasser and Weiss, 2006). For example, the collapses of the Mayan civilization, the Old Kingdom in Egypt, and the Akkadian Empire in Mesopotamia, have been attributed to a climatic event at about 4000 yr BP (Weiss et al., 1993; Hodell et al., 1995, 2001; Peiser, 1998; Cullen et al., 2000; DeMenocal, 2001; Haug et al., 2003; Stanley et al., 2003; Drysdale et al., 2006). Similarly, a cold event at about 4000 yr BP may also have caused changes in prehistoric subsistence patterns along the Yellow River, in China (e.g. Shui, 2001; An et al., 2003, 2004; Liu et al., 2005; Zhang et al., 2008).

The Guanting Basin, Qinghai Province, China, is an ideal locality for studying prehistoric cultural evolution and its relationship with climatic change. Located in the upper reaches of the Yellow River (Yang et al., 2003), the Guanting Basin was occupied and extensively cultivated by settled communities since the Neolithic (e.g., Dong et al., 2012; Huang et al., 2013a; b; Ma et al., 2014). To date, more than 50 prehistoric ruins, including those of the Majiayao culture (6000–4200 yr BP), the Qijia culture (4200–3600 yr BP), the Xindian culture (3400–2700 yr BP) and Kayue culture (3600–2600 yr BP), have been discovered in the region (Yang et al., 2004; Dong et al., 2012; Huang et al., 2013a). In modern times the Guanting Basin has experienced relatively harsh environmental conditions, while during prehistoric periods the ancient cultures who occupied the region are likely to have been more susceptible to changes in climatic conditions (An et al., 2003, 2004, 2005; Hou and Liu, 2004; Liu et al., 2005; Hou et al., 2009, 2012). Temperature and precipitation are the two principal factors controlling the distribution of living organisms (including crop

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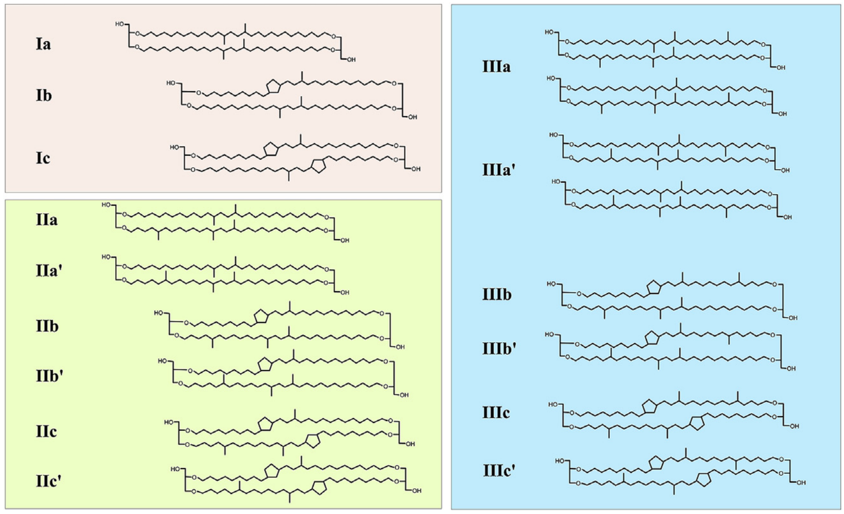

Fig. 1. Chemical structures of brGDGTs discussed in the text (after De Jonge et al., 2014).

plants), and therefore we hypothesized that they may have played an especially important role in influencing the evolution of prehistoric cultures in the region. However, effective temperature and precipitation records for prehistoric periods are lacking for the Guanting Basin, potentially hampering our understanding of the regional climatic background and its influence on cultural evolution.

Branched glycerol dialkyl glycerol tetraethers (brGDGTs; Fig. 1) are promising tools for reconstructing mean annual temperature (MAT) and mean annual precipitation (MAP). They are the membrane lipids derived from unknown bacteria (Weijers et al., 2006; Sinninghe Damsté et al., 2011) and are ubiquitous in soils (Hopmans et al., 2004; Weijers et al., 2007; Liu et al., 2013; Wang et al., 2017). Global and regional investigations of brGDGTs in modern surface soils have demonstrated that their distributions are sensitive to environmental parameters (Weijers et al., 2007; Peterse et al., 2011; De Jonge et al., 2014; Wang et al., 2014; Yang et al., 2014). A preliminary study of brGDGTs in > 130 globally distributed soils (Weijers et al., 2007) showed that soil pH and MAT can be reconstructed by the cyclisation ratio of branched tetraether (CBT) and the combination of methylation index of branched tetraether (MBT) and CBT, respectively. Using an improved analytical method, De Jonge et al. (2014) then developed several new indices, such as the MAT_{mr} index (a multiple linear regression index) and the Index 1 index (in the form of the common logarithm of a ratio of brGDGTs), that are more suitable for quantitative temperature estimates in arid and semi-arid regions. On the other hand, Wang et al. (2014) found that CBT is mainly controlled by precipitation rather than soil pH in alkaline soils from arid to sub-humid regions, and therefore it is a potential indicator for MAP in paleoclimatic reconstruction. In the past decade, these GDGT indices have been applied to several loess-paleosol sequences on the southern Chinese Loess Plateau (CLP) (Peterse et al., 2011; Gao et al., 2012; Jia et al., 2013; Wang et al., 2014; Yang et al., 2014; Lu et al., 2016; Tang et al., 2017).

In this study, we applied the recently developed brGDGTs paleotemperature and paleoprecipitation proxies (Index 1 and CBT) to a loess–paleosol sequence from Lajia Ruins of the Neolithic Qijia Culture, Guanting Basin, to examine temperature and precipitation variations in the basin. The Lajia site, located on the second terrace of the Guanting Basin along the upper Yellow River, was a typical settlement of the Qijia culture in Eastern and Central Asia. It is well-known for the Lajia Ruins, which have yielded much highly significant and well-preserved material for archaeological studies of Neolithic cultures (Fitzgerald-Huber, 1995, 2003; Ye, 2002, 2004; 2008; Xia and Yang, 2003; Lv et al., 2005; Huang et al., 2013a; Zhao et al., 2017). The occurrence of catastrophic events affecting these prehistoric cultures has attracted much research attention from a wide variety of fields, including archaeology, anthropology, geology and seismology (e.g. Fitzgerald-Huber, 1995, 2003; Ye, 2002, 2004; Lv et al., 2005; Wu et al., 2009, 2016; Yin et al., 2013; Huang et al., 2017; Zhang et al., 2017; Zhao et al., 2017). However, most of the studies have focused on the causes for the catastrophic formation of the Lajia Ruins (e.g. Xia et al., 2004; Wu et al., 2009, 2016; Huang et al., 2013a; Yin et al., 2013; Zhang et al., 2014b), while paleoclimatic information for this area is scarce. Our results potentially provide improved insight into the climatic background for interpreting the evolution and shift in ancient cultures during the mid-late Holocene in this environmentally sensitive region.

2. Geological setting and sampling

The Guanting Basin (35°49′–35°54′N, 102°36′–102°56′E) is situated in the arid/semi-arid zone on the boundary between Gansu and Qinghai Provinces in the upper reaches of the Yellow River (Fig. 2). Surrounded by the Laji Mountains to the northwest and the Jishi Mountains to the south (Hou et al., 2012), the area is about 53 km^2 and the average elevation is 1800 m above sea level (asl) (Yang et al., 2003; Huang et al., 2013a; Zhang et al., 2014b; Ma et al., 2014; Zhou and Zhang, 2015). According to the interpolation of meteorological data of the two nearest weather stations at Linxia (ca. 46 km away; MAT = 7.3 °C; MAP = 501 mm; alt. = 1917 m asl) and Minhe (ca. 54 km away; MAT = 8.3 °C; MAP = 338 mm; alt. = 1814 m asl), the MAT and MAP for the Guanting Basin are estimated to be 8.4 °C and 430 mm, respectively. The Yellow River flows through the southern part of the basin, from west to east. Many Neolithic sites have been excavated in the Guanting Basin (e.g., Yang et al., 2004; Huang et al., 2013; Ma et al., 2014; Zhang et al., 2014b), including those relating to the following cultures: Majiayao (5300–4500 yr BP), Qijia (ca. 4200–3600 yr BP), Xindian (3400–2700 yr BP) and Kayue (3600–2600 yr BP) of the same period (Yang et al., 2004; Hou et al., 2012; Zhang et al., 2014a).

Following detailed geomorphological, pedological, sedimentological and stratigraphic observations in the Lajia region in October 2015, a fresh and complete mid-late Holocene sediment profile, composed of three spliced sections and without human disturbance, designated the Shanglajia (SLJ) sequence (35°51′49.98″N, 102°48′27.51″E), was identified and sampled to the south of Shanglajia village along the Lvjiagou gully walls, to the northwest of the Lajia Ruins (Fig. 2). Detailed pedo-stratigraphic subdivision and descriptions of the profile were presented in Zhao et al. (2017) and Huang et al. (in press). Briefly, 0–60 cm is the modern soil, 60–100 cm is the late Holocene loess, and 100–320 cm is the mid-Holocene paleosol (S_0). Two red clay beds split