Available online at www.sciencedirect.com

ScienceDirect

Geochimica et Cosmochimica Acta 126 (2014) 49–69

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

Correlations between microbial tetraether lipids and environmental variables in Chinese soils: Optimizing the paleo-reconstructions in semi-arid and arid regions

Huan Yang [a,b], Richard D. Pancost [b], Xinyue Dang [a], Xinying Zhou [c], Richard P. Evershed [b], Guoqiao Xiao [a], Changyan Tang [a], Li Gao [d], Zhengtang Guo [e], Shucheng Xie [a,*]

[a] State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences, Wuhan 430074, China
[b] Organic Geochemistry Unit, Bristol Biogeochemistry Research Centre and The Cabot Institute, School of Chemistry, University of Bristol, Cantock's Close, Bristol BS8 1TS, UK
[c] Laboratory of Human Evolution, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, China
[d] Department of Geological Sciences, Brown University, Providence, RI 02912, USA
[e] Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China

Received 9 December 2012; accepted in revised form 27 October 2013; available online 8 November 2013

Abstract

The bacterial membrane lipid-based continental paleothermometer, the MBT/CBT or MBT′–CBT proxy (methylation index of branched tetraethers/cyclization of branched tetraethers), results in a large temperature deviation when applied in semiarid and arid regions. Here we propose new calibration models based on the investigation of >100 surface soils across a large climatic gradient, with a particular focus on semiarid and arid regions of China, and apply them to a loess–paleosol sequence. As reported elsewhere, MBT values exhibit a much higher correlation with MAAT than with summer temperature, suggesting a minimal seasonality bias; however, MBT is apparently insensitive to temperature <5 °C or >20 °C. Additional complexities are apparent in alkaline and arid soils, which are characterized by different relationships to climatic parameters than those in the complete Chinese (or global) dataset. For example, MBT and CBT indices exhibit a negative correlation in alkaline and arid soils, in contrast to their positive correlation in acid soils. Moreover, the cyclization ratio of bGDGTs (CBT), previously defined as a proxy for soil pH, is apparently primarily controlled by MAAT in these alkaline soils. Thus, we propose (1) a local Chinese calibration of the MBT–CBT proxy and (2) an alternative temperature proxy for use in semi-arid and arid regions based on the fractional abundances of bGDGTs; the latter has a markedly higher determination factor and lower root mean square error in alkaline soils than the Chinese local calibration and is suggested to be preferred for paleotemperature reconstruction in Chinese loess/paleosol sequences. These new bGDGT proxies have been applied to the Weinan Holocene paleosol section of the Chinese Loess Plateau (CLP). The fractional abundance calibration, when applied in the Weinan Holocene paleosol, produces a total Holocene temperature variation of 5.2 °C and a temperature for the topmost sample that is consistent with the modern temperature. Previously, we showed that the ratio of archaeal isoprenoid GDGTs to bGDGTs ($R_{i/b}$) increases at MAP < 600 mm, and elevated $R_{i/b}$ values (>0.5) in the CLP suggest the presence of enhanced aridity in the late Holocene in North China. In combination, the high $R_{i/b}$ ratios (>0.5) and the associated low MBT values (<0.4) reveal the co-occurrence of dry and cold events, especially in the latest Holocene, in the loess–paleosol sequences in CLP, and probably also in cold and arid regions outside of CLP.

* Corresponding author. Tel.: +86 18986111936.
E-mail address: xiecug@163.com (S. Xie).

0016-7037/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.gca.2013.10.041

1. INTRODUCTION

The Chinese loess plateau (CLP) in northwestern China is particularly sensitive to climate change (Liu and Ding, 1998), and the 2.6-Ma loess–paleosol sequences (LPS) have proven to be important continental paleoenvironmental archives. One of the most important records derived from loess/paleosol sequences is the Quaternary reconstruction of the Asian monsoons (An et al., 1990; Liu and Ding, 1998); this is documented by a range of geochemical and mineralogical proxies, e.g. the chemical weathering index (Guo et al., 1996), hydrogen and carbon isotopes of organic matter (Zhang et al., 2003; An et al., 2005; Liu and Huang, 2005; Zhang et al., 2006), the Carbon Preference Index (CPI) and Average Chain Length (ACL) of *n*-alkanes derived from the epicuticular wax of plant leaves (Zhang et al., 2003, 2006), magnetic susceptibility (Zhou et al., 1990; Deng et al., 2006) and grain size (Ding et al., 1994). However, reconstruction of paleotemperature and rainfall on the CLP has been less rigorous because most of the aforementioned proxies are controlled by both precipitation and temperature and are generally qualitative.

Several attempts have been made to quantitatively reconstruct the paleotemperature and rainfall variation in the CLP. Phytoliths have been used to reconstruct both parameters (Lu et al., 2006, 2007), but the low taxonomic resolution of phytoliths may widen the range of climatic tolerance and influence the sensitivity of the phytolith-based proxy to environmental change (Lu et al., 2006). Another approach for paleoprecipitation reconstruction is the carbon isotopic composition of bulk soil organic matter (SOM) via its reflection of the relative abundance of C_3 and C_4 plants (Ning et al., 2008). However, the distribution of C_3 and C_4 plants is also governed by temperature, complicating interpretation (Zhang et al., 2003; Sun et al., 2012).

A recently developed paleothermometer, the bacterial membrane lipid-based MBT–CBT proxy (methylation index of branched tetraether/cyclization ratio of branched tetraethers), was used by Peterse et al. (2011), Gao et al. (2012), Zech et al. (2012) and Jia et al. (2013) to reconstruct the paleotemperature in the loess–paleosol sequences in the semi-arid or arid regions. This proxy was established by Weijers et al. (2007a) based on the distribution of nine branched glycerol dialkyl glycerol tetraethers (bGDGTs, I–IIIc, Fig. 1) in global soils. The bGDGTs, widely occurring in peatlands (Weijers et al., 2006a; Liu et al., 2010), soils (Weijers et al., 2007a), stalagmites (Yang et al., 2011), and lake (Tierney et al., 2010; Pearson et al., 2011) and estuary sediments (Zhu et al., 2011), were proposed to be derived from the cell membrane of unknown bacterial species with a heterotrophic lifestyle (Oppermann et al., 2010; Weijers et al., 2010; Sinninghe Damsté et al., 2011). The methylation index of bGDGTs, expressed as MBT, was demonstrated to have a linear correlation with mean annual atmospheric temperature (MAAT) and soil pH, whereas the cyclization ratio of bGDGTs, CBT, appears to be governed solely by soil pH (Weijers et al., 2007a). The MBT/CBT index has been applied as a MAAT proxy in a wide range of studies spanning the Cenozoic (e.g. Weijers et al., 2007b,c; Schouten et al., 2008) and could also have promise in paleotemperature reconstruction of the CLP.

The MBT–CBT proxy yields paleotemperatures for the CLP that appear to track northern hemisphere insolation, but the temperatures reconstructed for the topmost layers of the Mangshan and Lantian loess section are ~10 and 5 °C greater than modern MAATs, respectively (Peterse et al., 2011; Gao et al., 2012). Moreover, the reconstructed Holocene temperatures vary by 10 °C (cf. Section MS 2008W, Peterse et al., 2011), which is much larger than the range determined by other approaches (cf. Lu et al.,

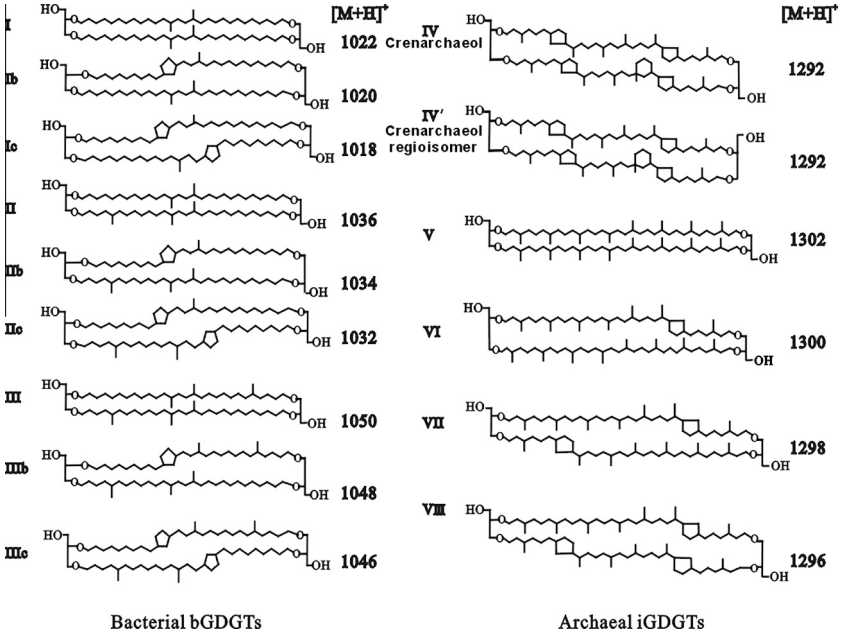

Fig. 1. The structures of GDGTs in Chinese soils and their protonated mass and charge ratios.