Organic Geochemistry 79 (2015) 74–82

Contents lists available at ScienceDirect

Organic Geochemistry

journal homepage: www.elsevier.com/locate/orggeochem

Glacial–interglacial contrast in MBT/CBT proxies in the South China Sea: Implications for marine production of branched GDGTs and continental teleconnection

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ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form 7 December 2014
Accepted 17 December 2014
Available online 25 December 2014

Keywords:
br GDGTs
BIT
MBT
CBT
South China Sea
Glacial–interglacial cycles

ABSTRACT

Two proxies derived from branched glycerol dialkyl glycerol tetraethers (br GDGTs), the methylation index of branched tetraethers (MBT) and the cyclization ratio of branched tetraethers (CBT), are often used to reconstruct paleo mean annual air temperature (MAAT) and soil pH based on the premise that br GDGTs in the marine environment are mainly of terrigenous origin. However, mounting evidence indicates that br GDGTs can be produced in situ in oceanic settings, which may affect MAAT reconstruction and the use of other related paleoenvironmental proxies. We have determined br GDGT distributions in a sedimentary core (MD05-2896/7) from the southern South China Sea, which provided high resolution profiles of MBT and CBT indices as well as the branched and isoprenoid tetraether (BIT) index. BIT varied systematically with glacial–interglacial cycles, reaching much lower (< 0.1) values during the interglacial periods (MIS 1 and MIS 5) than during the glacial periods (MIS 2, MIS 3, MIS 4 and MIS 6). MBT/CBT-derived temperature showed, on the other hand, lower values during the interglacial periods but higher values during glacial periods. We hypothesize that the lower MBT/CBT-derived temperature during interglacial periods reflects bottom water temperature registered via br GDGTs produced under marine conditions, whereas the higher MBT/CBT derived temperature during glacial periods reflects terrestrial MAAT because of the overwhelming input of br GDGTs from land when the sea level was low. Similarly, the CBT-derived soil pH appeared to have been overprinted by marine br GDGT production during interglacial periods but responded to precipitation on land during glacial periods, showing patterns similar to, or as a positive response to, the southern hemispheric climate oscillation due to teleconnection. Our results demonstrate an unprecedented pattern of MBT/CBT variation constrained by glacial–interglacial cycles in the South China Sea. Under this constraint, MBT/CBT revealed deep water production of br GDGTs during interglacial periods and recorded changes in paleohydrology on land during glacial periods, providing a new perspective for paleoclimate studies using organic proxies.

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1. Introduction

Glycerol dialkyl glycerol tetraethers (GDGTs) have become a promising series of biomarkers, characterized by two major groups based on their structures and sources: isoprenoid GDGTs (iso GDGTs) and branched GDGTs (br GDGTs; Fig. 1). The iso GDGTs are produced by Archaea, which occur ubiquitously and have special applications in paleoclimate studies (Schouten et al., 2002, 2012; Wei et al., 2011; Jia et al., 2012; Wegwerth et al., 2014). The br GDGTs were originally thought to be produced by soil bacteria (Sinninghe Damsté et al., 2000, 2011; Weijers et al., 2006, 2009), leading to the development of two important proxies, the methylation index of branched tetraethers (MBT) and cyclization ratio of branched tetraethers (CBT; (Weijers et al., 2007c) that have been widely used to reconstruct terrestrial soil pH and mean annual air temperature (MAAT; Fawcett et al., 2011; Peterse et al., 2011; Damsté et al., 2012; Das et al., 2012; Gao et al., 2012; Zech et al., 2012; Jia et al., 2013). In addition, the predominance of iso GDGTs in marine sediments and of br GDGTs in soil allowed Hopmans et al. (2004) to propose a branched and isoprenoid tetraether (BIT) index for estimation of terrigenous input of organic matter (OM) to the ocean.

The MBT/CBT-derived MAAT and CBT-derived soil pH using marine sediments are based on the premise that br GDGTs in

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http://dx.doi.org/10.1016/j.orggeochem.2014.12.008
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marine settings are derived from a terrigenous source. Case studies include reconstruction of MAAT for Congo river fan deposits (Weijers et al., 2007a), MAAT variation in the Arctic region across the Paleocene–Eocene (P–E) boundary (Weijers et al., 2007b) and the Eocene–Oligocene (E–O) boundary (Schouten et al., 2008), as well as the early Eocene temperature change on the Antarctic continent (Pross et al., 2012) and the United States Gulf Coastal Plain (Keating-Bitonti et al., 2011). In a recent study of core sediments from the East China Sea, MBT/CBT was found to be decoupled from the TEX_{86}-derived sea surface temperature (SST) since ca. 9 ka (Ge et al., 2014). However, the application of MBT/CBT to lake systems has been less successful (Tierney and Russell, 2009; Tyler et al., 2010; Zink et al., 2010). These studies suggest that, compared with the continental environment, marine sediments could provide a well preserved and continuous record of the terrigenous OM for paleoclimate reconstruction.

Recently, the in situ production of marine br GDGTs has been increasingly observed (Peterse et al., 2009; Zhu et al., 2011; Hu et al., 2012; Weijers et al., 2014). This has raised concern that an increase in a marine component of br GDGTs may bias the reconstructed paleo continental temperature (Sanchi et al., 2014). Furthermore, the applicability of BIT as a terrigenous proxy is also compromised by in situ production of br GDGTs in the oceanic environment.

Here, we present a high resolution (ca. 243 yr/cm) profile of br GDGTs between glacial and interglacial cycles in a sediment core from the southern South China Sea (SCS), with the aim of evaluating the applicability of the br GDGT proxies for the reconstruction of terrigenous signals over the last two glacial–interglacial cycles.

2. Oceanographic setting

The SCS is the largest marginal sea between the largest continent (Asia) and largest ocean (the Pacific; Wang and Li, 2009; Fig. 2). The southern SCS lies in the western Pacific warm pool and is affected by the seasonally changing East Asian Monsoon. Over the Quaternary glacial–interglacial cycles, frequent changes in relative sea level and sea surface temperature together shaped the sedimentary patterns on shelf and slope, with the accumulation of fluvial terrigenous OM determined mainly by the distance between the paleo-river mouths (Fig. 2) and the offshore basins. As one of the largest rivers in the region, the Mekong River, for example, flows southward from the Tibetan Plateau through the Indochina Peninsula into the SCS. At present when the sea level is relatively high, the Mekong discharges ca. 160×10^6 t/yr suspended sediment into the southern SCS (Milliman and Syvitski, 1992) helping to shape a large delta at its mouth (Ta et al., 2002). However, the direction of the Mekong River sediment is strongly affected by seasonal changes in the monsoon, and the rapid growth of the delta to the southwest indicates net southwestward sediment transport during the winter monsoon season, in spite of the fact that release of sediment from the river occurs predominantly during the southwesterly summer monsoon (Tamura et al., 2010). Thus, the terrigenous OM derived from the river appears to be deposited mainly on the northern Sunda shelf rather than in the deep sea basin.

At low sea level stands, the Sunda shelf was exposed and the paleo-Sunda plain was drained by large river systems (Fig. 2), discharging the glacial fluvial sediment into the southwestern part of the semi-enclosed basin of the SCS (Hanebuth et al., 2003). Despite the distance between the river mouths and the deep water area being shortened considerably during the glacial periods, both of the paleo-Mekong River and paleo-Sunda River were still ca. 300 km from the study site, which is sufficiently far away to be defined as a distal marine environment. Based on the two topography sections in Fig. 2, the paleo-Mekong River might have discharged mainly into the deep sea basin down to ca. 2500 m (section A and B), while other paleo-rivers discharged their terrigenous load mainly into the flat basin (section C and D), where our site was located. Intensive mixing between terrigenous material

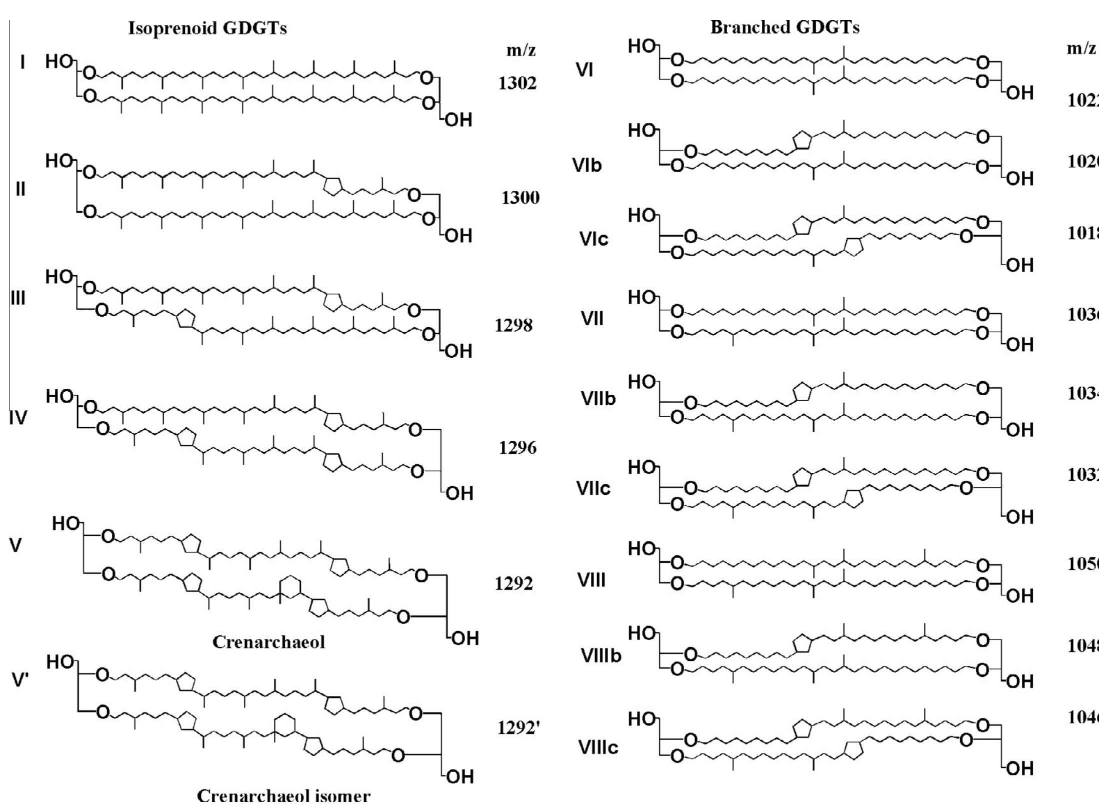

Fig. 1. Structures of iso GDGTs and br GDGTs.

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