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Insights into continental temperatures in the northwestern Black Sea area during the Last Glacial period using branched tetraether lipids

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ABSTRACT

In the continental realm, continuous quantitative temperature reconstructions spanning the Last Glacial are rare, especially in central and eastern Europe. Here, we provide a reconstruction from the northwestern Black Sea catchment, spanning 40 to 9 ka BP, from a study of the relative distribution of branched glycerol dialkyl glycerol tetraethers (brGDGTs) in Black Sea lacustrine sediments. First, the origins of brGDGTs are discussed. The comparison of geochemical proxies from the same core supports a dominant terrestrial origin for brGDGTs during the Last Glacial, and a strong decrease in the soil derived brGDGT proportion toward the Holocene. Since the lowering of soil vs. lacustrine derived brGDGTs is prone to bias the temperature signal that is reconstructed using a soil calibration, a correction for in situ-production is applied. The corrected signal is compared to independent discrete temperature records from the study area. The brGDGT-temperature relative evolution reconstructed in this work provides additional insight regarding millennial-scale climate variability in central and eastern Europe. Notably, the imprints of Heinrich event cold spells and Lateglacial climatic oscillations are consistent with other regional paleorecords from the Northern Hemisphere.

1. Introduction

The Last Glacial period was marked by millennial-scale climate oscillations that were first detected in Greenland and the North Atlantic. Such climate oscillations coincided with environmental and climate changes in many regions around the globe (see Clement and Peterson, 2008, for a review). The continental climate response to these major climatic events is still poorly understood, in part due to the scarcity of well-dated continuous terrestrial records with a sufficiently high resolution (e.g. Voelker, 2002), especially those that make quantitative temperature reconstructions useful for model-data comparisons (e.g. Van Meerbeeck et al., 2011). Groundwater recharge temperatures, obtained from dissolved atmospheric noble gases (the noble gas temperature, NGT), are often employed for estimating multi-centennial temperature variations on an aquifer scale (e.g. Beyerle et al., 1998; Aeschbach-Hertig et al., 2002). While this method provides major temperature shifts, dispersion and dating difficulties hamper abrupt climate variability reconstructions. Pollen, coleoptera, chironomids, and plant macrofossil remains are frequently used to infer paleotemperatures (Atkinson et al., 1987; Bartlein et al., 2011). However, such records remain particularly scarce in certain areas, as for central and eastern Europe. To our knowledge, thus far, no continuous temperature reconstruction spanning more than the last deglaciation has been attempted for this portion of Europe. New paleorecords for this transition zone, that potentially undergoes Atlantic, Mediterranean, and continental influences, could help to evaluate the accuracy of climate models (Braconnot et al., 2012) and contribute to understand abrupt past and future climate change.

Branched glycerol dialkyl glycerol tetraethers (brGDGTs) are membrane lipids produced by bacteria that thrive in soils (Weijers et al., 2006a) and are transported by rivers to sediments. As a result, brGDGT based proxies measured within the sediment archives recovered at the mouth of major river systems can record changes in river drainage basin conditions in response to climate changes. Parallel measurements of the amount of crenarchaeol, an isoprenoid GDGT synthetized by aquatic Archaea, enable the tracing of soil organic matter inputs through the BIT index (Hopmans et al., 2004). Additionally, brGDGTs show promise for reconstructing high-resolution continental past temperature and soil pH. Indeed, variations in the relative distribution of brGDGT compounds (associated with structural changes) have been shown to be linked to temperature and to soil pH changes (Weijers et al., 2007b). To quantify these relationships, Weijers et al. (2007b) have defined the methylation index of branched tetraethers (MBT), and the

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cyclization ratio of branched tetraethers (CBT), and they have developed the first calibrations of the MBT and CBT that enable mean annual air temperature (MAT) and soil pH reconstructions, from a set of globally distributed soils. Since the time of the successful use of the MBT/CBT proxy in marine sediment cores to reconstruct past MATs (e.g. Weijers et al., 2007a; Schouten et al., 2008), the calibration of the MBT/CBT proxy has been revised and based on an extended set of soils (Peterse et al., 2012). In addition to global calibrations, regional calibrations have also been proposed (e.g. Bendle et al., 2010). The application of MBT and CBT indexes to lacustrine environments has also been investigated (e.g. Tierney and Russell, 2009; Bechtel et al., 2010; Blaga et al., 2010; Tierney et al., 2010; Tyler et al., 2010; Zink et al., 2010; Sun et al., 2011; Tierney et al., 2012). Most of these studies have suggested that brGDGT production in lake water columns and/or sediments can occur, and when it does, it complicates the application of calibrations that are based on soil datasets. As such, new calibrations of brGDGT proxies in lake sediments have been established (e.g. Tierney et al., 2010; Sun et al., 2011). Hence, the application of brGDGT proxies in ancient lake sediments is promising for reconstructing MATs, especially if a specific lacustrine calibration is used (e.g. Sinninghe Damsté et al., 2012), or if constraints on brGDGT origin are provided (e.g. Niemann et al., 2012).

Here, we present a high-resolution record of brGDGT distributions in the lacustrine sediments of core MD04-2790, recovered from the northwestern Black Sea. The presented record spans the Last Glacial and the last deglaciation, from 40 to 9 cal ka BP. First, we assess the dominant origin of brGDGTs (in situ production vs. soil production) along the core using a comparison of geochemical proxies that trace the terrestrial inputs in sediments, the sedimentation rates, and evidence of lacustrine productivity. The suggested dominant soil origin of brGDGTs during the full glacial period enables us to reconstruct a realistic MAT signal using the recent global soil calibration of brGDGT proxies. However, the decrease in the soil derived brGDGT proportion that is suggested in the early Holocene sediments points to the need for a correction of the soil calibrated MAT. We, therefore, propose a correction method and test its sensitivity. The corrected MAT record is consistent with existing punctual records from central and eastern Europe. As a result, we provide further insights regarding European millennial scale climate variability.

2. Materials and methods

2.1. Study area: the Black Sea drainage basin

The Black Sea drainage basin (BSDB) spans a large portion of central and eastern Europe (from 8° to 48° in longitude and 37° to 57° in latitude), and is composed of extensive lowlands (in the Hungarian and Eurasian Plains) and several steep mountains, including the Alps and the Carpathians Mountains (Fig. 1). Major rivers draining the northern and western portions of the BSDB are the Don and Kuban (through the Sea of Azov), and the Dniepr, southern Bug, Dniestr, and Danube. These river drainage basins span nearly 1.9×10^6 km^2 and currently provide approximately 47% of the Black Sea annual sediment load (Panin and Jipa, 2002). Currently, the main river inputs to the Black Sea originate from the Danube. The Dniestr and the Dniepr are less significant sources (Panin and Jipa, 2002). However, their inputs were larger during the last deglacial period (Bahr et al., 2005; Soulet et al., 2013). Additionally, Black Sea Rim currents transport sediments cyclonically from north to west and favor the deposition of sediment on the slope and the deep western basin (Özsoy and Ünlüata, 1997; Oguz and Besiktepe, 1999). Therefore, the northwestern continental slope of the Black Sea is a suitable place for studying the terrestrial organic matter transported by northern and western Black Sea rivers and investigating organic proxies such as the MBT/CBT indexes.

From north to south, modern MATs in the BSDB vary from 6 to 12 °C, with the exception of mountainous regions (the Alps, the Carpathians, and the Balkans) where MATs are lower than 6 °C. Within the Danube Basin, modern MATs are between 10 and 12 °C. Within the Dniestr and the lower Dniepr Basins they are between 8 and 10 °C (Fig. 1).

2.2. MD04-2790 core sediments

Core MD04-2790 was recovered from the upper slope of the northwestern Black Sea in the direct axis of the mouth of the Danube River (44°13′N, 30°60′E) at a water depth of 352 m during the ASSEMBLAGE 1 cruise, aboard *Marion Dufresne* (Fig. 1). The typical marine Units I and II (Ross and Degens, 1974) were found within the core from the top to a core depth of 1.24 m (Soulet et al.,

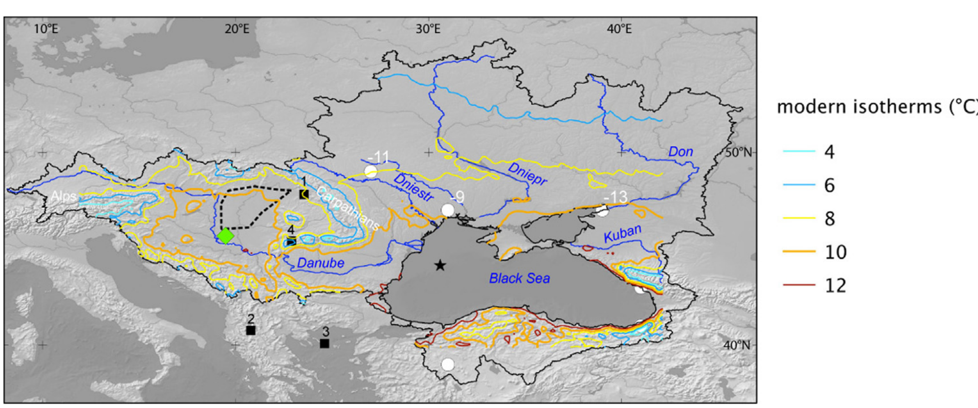

Fig. 1. Geographic setting of the study: the Black Sea Drainage Basin. The star symbol indicates the position of the MD04-2790 core and the black line outlines the modern Black Sea drainage basin limits (inferred using the CCM River and Catchment Database© of the European Commission, JRC 2007, Vogt et al., 2007). Colored lines indicate modern MAT isotherms inferred using the 1961–2000 CRU CL 2.0 10′ global climatology (New et al., 2002). The locations of the main archives providing the quantitative temperature reconstruction mentioned in the text are also provided. The white dots and the associated values are sites with the LGM MAT anomalies provided by Bartlein et al. (2011); the dashed line contains sites with noble gas temperature reconstructions (Stute and Deak, 1989; Varsányi et al., 2011); the black squares indicate sites with Lateglacial temperature reconstructions (1. Feurdean et al., 2008a; 2. Bordon et al., 2009; 3. Kotthoff et al., 2011; 4. Tóth et al., 2012; these reconstructions are based on pollen, with the exception of the one obtained from Tóth et al. (2012) study that is based on chironomids). The green diamond indicates a Serbian soil with known amounts of brGDGTs and crenarchaeol (Zech et al., 2012, see Fig. 5 for additional details). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)