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Sources of organic matter in Changjiang (Yangtze River) bed sediments: Preliminary insights from organic geochemical proxies

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ABSTRACT

Insight into the content and composition of organic carbon (OC) in river systems contributes to our understanding of the global carbon cycle. The Changjiang (Yangtze River) plays a significant role in global carbon and hydrological cycles, as it is an important supplier of sediment, nutrients and OC to the East China Sea. To provide a preliminary insight into the source of OC transported by the Changjiang, we analyzed bulk (grain size, organic carbon content, $\delta^{13}C$), and molecular (lignin phenols, branched and isoprenoid GDGTs) characteristics of organic matter in bed sediments at eight locations along the river. The $\delta^{13}C$ values and lignin phenol composition indicate that the OC originates from a mixture of primarily soils and plants. Comparison between branched GDGT (br GDGT) distributions in riverbed sediments and those in the different soil types in the drainage basin indicate that the br GDGT signal in the upper reaches is largely derived from soils from the Qinghai-Tibet Plateau. Downstream changes in br GDGT distributions can be linked to subsequent input of local soil material. The observed variation in br GDGT composition along the river implies that a portion of the OC may be oxidized or replaced by the local input during transit. Although the relationship between $\delta^{13}C$ and lignin phenol composition indicates that the contribution of phytoplankton is limited, comparison of GDGT ratios (GDGT-0:crenarchaeol, iso GDGTs:br GDGTs, BIT index) for the sediments and surrounding soils indicates that at least part of the iso GDGTs has an aquatic origin. Overall, the downstream evolution of br GDGTs in the Changjiang implies that their use as paleoclimate proxy in downcore applications will likely yield a local, rather than a basin-integrated continental climate record.

1. Introduction

Over the last few decades, the importance of the role of rivers in the global carbon cycle has been increasingly appreciated (Hedges, 1992). On a global basis, rivers transport ca. 0.35–0.50 Pg organic carbon (OC) to the oceans per annum (Hedges et al., 1997; Lal, 2003). Rivers form a key connection between the terrestrial and marine carbon cycles, constituting the primary mode of carbon transport from continents to the ocean (Smil, 2007) and are thus key focal points in "source to sink" studies (Blair et al., 2004; Galy et al., 2007; He et al., 2013). Suspended particulate matter (SPM) is the most important carrier of particulate OC from continent to ocean. During the transport of SPM, riverbed sediment may also be important due to hydrodynamic mixing between suspended and bed sediments. Thus, the bed sediment plays a role as both source and sink of SPM in the river system. The properties and behavior of river-transported OC depend not only on geomorphic and hydrological properties of the basin, but also on the composition and provenance of the material. Hence, studying the sources and characteristics of OC within major river basins contributes to a better understanding of catchment dynamics and its role in the global carbon cycle. Bulk and molecular characteristics are commonly used to determine the composition, sources and the transformation processes of organic matter (OM) in river systems (e.g. Hedges et al., 1986; Wu et al., 2007; Galy et al., 2008a; Ponton et al., 2014). Asian Rivers are thought to be responsible for ca. 40% of global land-sea C transfer (Galy et al., 2008b; He et al., 2013). Within Asia, the Changjiang (Fig. 1) is one of the major transporters of sediments and thereby influences global geochemical cycles (He et al., 2013). Studies of the characteristics of particulate and dissolved material and their transport in the Changjiang system have indicated that soils are the main source of particulate OC (Wu et al., 2007; Bao et al., 2012b). However, the provenance

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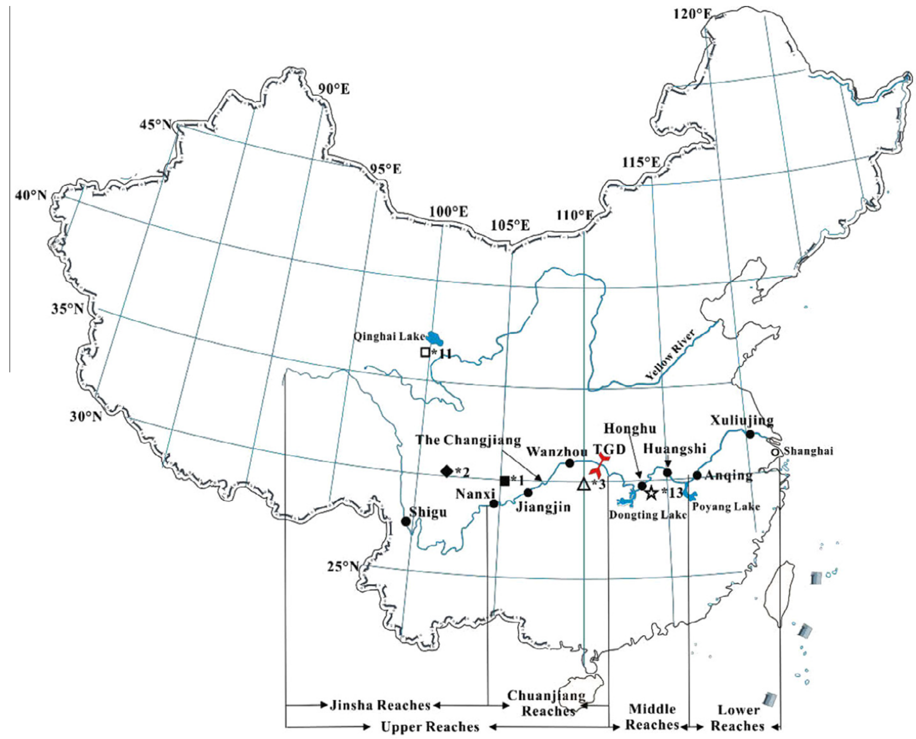

Fig. 1. Map of the Changjiang River and locations where the riverbed sediments were collected (black circles). Soil locations and number of soil samples per site used for cluster analysis are indicated with an open square (plateau soils), black diamond (purple soils), black triangle (yellow soil), open triangle (limey soils) and open star (paddy rice soils). Soil data are from Ayari et al., 2013; Wang et al., 2012; Yang et al., 2012, 2014. TGD, Three Gorges Dam (for interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article).

and properties of soil material transported by the river and discharged to the adjacent East China Sea have not been determined. Lignin phenol characteristics of SPM from the middle and lower reaches of the river indicated that the Three Gorges Dam (TGD; Fig. 1) traps particulate OC, modifying the influence of OC flux from the Dongting and Poyang lakes (Yu et al., 2011; Bao et al., 2012b). These observations suggest that the terrigenous C signal may be subject to extensive attenuation and modification along the course of the river.

The stable isotopic composition of OC ($\delta^{13}C$) is helpful for tracing the OC source in a river system (Raymond and Bauer, 2001). $\delta^{13}C$ values are generally used to identify vascular plant inputs from C_3 vs. C_4 vegetation, or to distinguish between OM of (higher plant) and aquatic origin. With respect to the latter, freshwater phytoplankton biomass tends to have lower $\delta^{13}C$ values than OC derived from higher plants and soils (Hamilton and Lewis Jr., 1992). Based on the $\delta^{13}C$ of SPM and bed sediments in the Ganga–Brahmaputra river system, Galy et al. (2008a) found that the contribution of C_4 plants was higher in the delta region than in the plateau region.

Additionally, biomarkers, such as lignin phenols and glycerol dialkyl glycerol tetraethers (GDGTs; Fig. 2), have been widely studied to trace sources of OC in fluvial sediments (Goñi et al., 2000; Walsh et al., 2008; Schouten et al., 2013). Lignin phenols are useful for tracing OM derived from the land surface, as they derive exclusively from the structural tissue of higher plants (Hedges et al., 1986; Yu et al., 2011). Lignin concentration, typically expressed as the total concentration of vanillyl (V), syringyl (S) and cinnamyl (C) phenols normalized to sediment mass ($\Sigma8$) or to OC ($\Lambda8$), are lower in soil than fresh plants, due to microbial degradation (Hedges et al., 1988). Additionally, information on plant type can be derived from the ratios of syringyl and cinnamyl phenols to vanillyl phenols (S/V and C/V, respectively). For example, angiosperm plants tend to have a higher S/V ratio (> 0.4) than gymnosperm plants, while woody plants have a lower C/V ratio (ca. 0) than plants with non-woody tissue (Hedges et al., 1986). The GDGTs have recently been introduced as an additional tracer for the input of soil OC to the aquatic environment (Hopmans et al., 2004; Kim et al., 2012). GDGTs are membrane lipids synthesized by archaea and bacteria (Langworthy et al., 1982; De Rosa and Gambacorta, 1988; Damsté et al., 2007) and can be divided into two groups: branched, and isoprenoid GDGTs (br GDGTs and iso GDGTs). The br GDGTs are thought to be produced primarily by anaerobic bacteria and are ubiquitous in soil (Weijers et al., 2007), lake sediments (Blaga et al., 2009; Powers et al., 2010; Pearson et al., 2011), peat (Weijers et al., 2004), and estuarine and ocean margin sediments (Hopmans et al., 2004; Zhu et al., 2011), as well as rivers (Kim et al., 2012; Yang et al., 2013; Zell et al., 2013; De Jonge et al., 2014). It has been reported that the degree of methylation (MBT index) of br GDGTs is related to mean air temperature (MAT) and soil pH and the degree of cyclisation (CBT index) is related to soil pH (Weijers et al., 2007). Changes in the distribution of br GDGTs throughout a sedimentary archive have consequently been used to reconstruct the MAT and soil pH in the environment of their producers (Weijers et al., 2007; Peterse et al., 2012; Yang et al., 2014). Iso GDGTs are produced by archaea and are prevalent in the marine environment (Schouten et al., 2013 and references therein), although they have also been detected in peat bogs (Weijers et al., 2004) and soil (Weijers et al., 2006; Wang et al., 2012). In the marine environment, pelagic Thaumarchaeota (previously termed Crenarchaeota) are considered the main source of iso GDGT lipids (Schouten et al., 2013). Given the general predominance of br GDGTs in soils and iso GDGTs in the oceans, their ratio has been proposed as a proxy for determining the relative input of riverine transported soil OM to a marine environment, quantified via the