



Impact of riverine suspended particulate matter on the branched glycerol dialkyl glycerol tetraether composition of lakes: The outflow of the Selenga River in Lake Baikal (Russia)



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ABSTRACT

Branched glycerol dialkyl glycerol tetraethers (brGDGTs) are bacterial membrane lipids found in several environments, including soils, rivers and lakes, whose distribution varies with temperature and pH, although this dependence is apparently not the same for the different environments. Mixing of brGDGT sources may thus complicate palaeoenvironmental reconstruction. The extent to which brGDGTs in a lake outflow reflect the distribution delivered by upstream rivers was studied for Lake Baikal (Russia), one of the largest freshwater lakes worldwide. Fifteen brGDGTs in suspended particulate matter (SPM) of the Selenga River and its outflow from the lake were quantified. The river and lake SPM had rather different distributions. The riverine distribution was still apparent in the SPM of the lake surface water 5 km from the river mouth, but shifts in the distribution were already apparent in the SPM of the surface water after 1 km. Based on the brGDGT distributions of the SPM of the Selenga outflow and that of the lake, conservative mixing between the river and the lake brGDGT distributions could not fully explain the observed shifts in distributions. Both preferential degradation and in situ production of brGDGTs in the surface and, especially, bottom water of the river outflow were potentially responsible. This implies that a riverine lipid distribution delivered to a lake can be modified prior to being transported downstream. The lacustrine brGDGT distribution, that possibly could have reflected a mixture of mountainous and Selenga River SPM, was not recognized in downstream Yenisei River SPM. The watershed of Lake Baikal thus does not seem to contribute to the brGDGTs transported to the marine system. As many large rivers have major lakes in their watershed, this has implications for palaeoclimate reconstruction from river fan sediments globally.

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1. Introduction

Branched glycerol dialkyl glycerol tetraethers (brGDGTs) are bacterial membrane lipids found in a variety of settings: soils, lacustrine and marine suspended particulate matter (SPM) and sediments and hot springs. Their source organisms probably fall within the Acidobacteria, based on environmental (Weijers et al., 2009; Peterse et al., 2010) and culture studies (Sinninghe Damsté et al., 2011, 2014). Their main application is as palaeoclimate proxies. In a dataset of global soils, the structural diversity of brGDGTs was shown to correlate with the prevailing soil pH and mean annual air temperature (MAAT; Weijers et al., 2007a). Nine were described as possessing 4 to 6 methyl substituents (branches) on

the linear C₂₈ alkyl chain (Sinninghe Damsté et al., 2000) and containing up to two cyclopentyl moieties formed by internal cyclization (Fig. 1; Schouten et al., 2000; Weijers et al., 2006). The cyclization of branched tetraethers (CBT) and methylation of branched tetraethers (MBT) are two brGDGT indices (Weijers et al., 2007a) that have been successfully applied to reconstruct the palaeoclimatic changes in palaeosoils (e.g. Peterse et al., 2011), speleothems (Blyth and Schouten, 2013), lake sediments (e.g. Niemann et al., 2012), but initially in marine sediments (e.g. Weijers et al., 2007b; Bendle et al., 2010). Prior to their incorporation into marine and lacustrine sediments, they were understood to be eroded from soils and transported by rivers through upstream lakes. The brGDGT distribution was thus assumed to reflect the distribution in watershed soils and to remain unaltered during this process.

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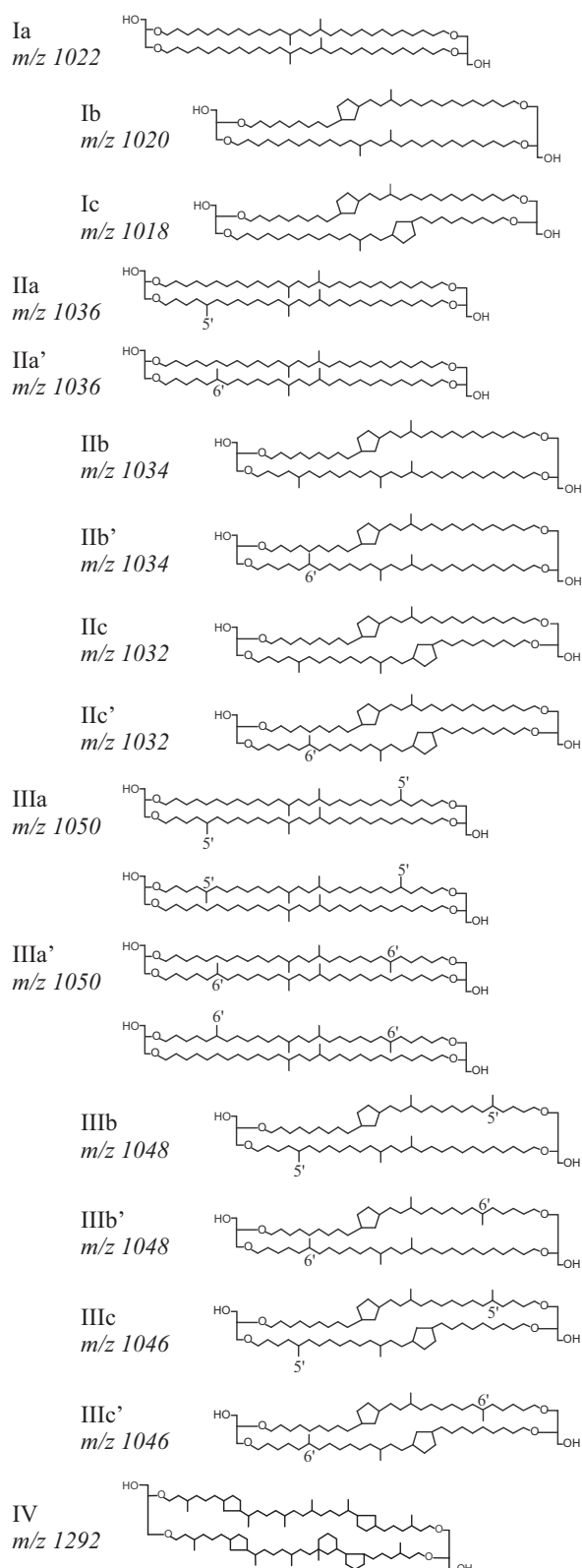


Fig. 1. Structures of brGDGTs (I–III) and crenarchaeol (IV). The structures of the hexa- and pentamethylated brGDGTs with cyclopentyl moiety(ies) IIb', IIc', IIIb' and IIIc' are tentatively assigned.

Contrasting brGDGT distributions between rivers, lakes and their surrounding soils provided the first indications for in situ production in freshwater aquatic systems (e.g. Tierney and Russell, 2009). Although the temperature dependence is different from that

in soils, the distribution of aquatic brGDGTs in lakes also varies with prevailing MAAT, and to some extent with depth and pH (e.g. Tierney et al., 2010; Pearson et al., 2011; Sun et al., 2011; Loomis et al., 2012, 2014a). There is thus a growing body of evidence supporting in situ production of brGDGTs in lakes, but the niche of the source organism(s) has not been constrained. The concentration of lacustrine brGDGTs was shown to increase below the lake thermocline, pointing toward a preference for environments with low O_2 concentration (e.g. Sinninghe Damsté et al., 2009; Buckles et al., 2014a). However, a recent study of brGDGTs in a temperate lake (Loomis et al., 2014b) found that they were produced throughout the water column. Further possible mechanisms influencing the distributions are shifts in bacterial community, possibly prompted by a large shift in nutrients or by the transition between river and lake biomes (Loomis et al., 2014b and references therein). Although in situ production of brGDGTs has been described to occur in rivers (e.g. Kim et al., 2012; Zell et al., 2013, 2014; De Jonge et al., 2014a), a lacustrine in situ produced distribution may be significantly different from that of its inflowing river (Tierney and Russell, 2009; Buckles et al., 2014b). As large lakes are often present in large river drainage basins, lacustrine in situ production may result in the introduction of lacustrine brGDGTs in downstream rivers and ultimately in marine sediments. Large lakes in the drainage basin of river systems may thus have an effect on palaeoclimate brGDGT reconstruction from river fan marine sediments.

The aim of this study was to investigate the extent to which the brGDGT distribution delivered by a river can propagate in a large lake and to compare any effect with the brGDGT distribution exported from the lake by river outflow. Furthermore, we tried to constrain the environmental parameters that influence lacustrine in situ production of brGDGTs. Although such production of in lakes has been extensively documented (e.g. Tierney and Russell, 2009; Loomis et al., 2011, 2014b; Buckles et al., 2014a), this is the first study to evaluate the delivery and export of riverine brGDGTs to and from a lake system. Furthermore, the above studies are all based on a dataset of nine brGDGTs, as the analytical procedure used did not allow separating the recently described 6-Me brGDGTs (De Jonge et al., 2013). The abundance of these novel brGDGTs was recently shown to be high in a Siberian River system (De Jonge et al., 2014a) and to be highly variable in a set of globally distributed soils (De Jonge et al., 2014b).

This study describes the full suite of fifteen brGDGTs in a major river (Selenga River) that drains northern Mongolia and southern Siberia before and after its inflow to the world's largest freshwater lake (Lake Baikal). We evaluate the brGDGT concentration and distribution in the Selenga River outflow, where in situ production and preferential degradation could possibly affect the lacustrine brGDGT distribution. Furthermore, the distribution exported from the lake was compared with the brGDGT distribution in both the Selenga River and the mountainous Irkut River, to evaluate whether or not riverine brGDGTs alone could explain the lacustrine brGDGT signature exported.

2. Geographical setting

The Selenga River originates in the mountainous parts of Mongolia, draining large parts of Mongolia and southern Siberia (442,000 km²; Fig. 2b). It is the main tributary of Lake Baikal, with a drainage area 82% of the total drainage area of the lake. It transports 57.8 km³/yr of water, which accounts for ca. 50% (Votintsev, 1985) of the total water input to the lake. Furthermore, it contributes ca. 80% of the total suspended solids delivered by the tributaries to the lake (Votintsev, 1985). The other tributaries (Fig. 2b) drain the steep, mountainous watershed that borders

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