

# SOIL-DERIVED BACTERIAL REMAINS AS TRACER OF TERRESTRIAL ORGANIC MATTER IN MARINE SEDIMENTS

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The flux of organic matter from land to sea is an important link in the global carbon cycle and of importance to global climate change. Reconstructing this flux in the past provides information on past changes in the carbon cycle and past changes in river activity. Most of the molecular tracers (biomarkers) used for these purposes are derived from higher plants and thus vulnerable to vegetation changes. We developed a new approach by looking for biomarkers derived from organisms thriving in soils which are thus more specific tracers of soil organic matter in marine sediments. We show that this new method is able to trace soil organic matter in marine sediments in front of the Congo River outflow and in reconstructing the past activity of one of the largest European rivers that ever existed at the end of the last Ice Age.

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Most tracers used up till now to distinguish between terrestrial and marine organic matter in marine sediments are either non-specific bulk parameters, e.g. the carbon isotopic composition of organic matter, or plant derived biomarkers which are, in contrast, highly specific for vegetation but vulnerable for changes in the vegetation composition and tend to neglect soil organic matter. An alternative and additional approach is to use biomarkers derived from microorganisms living in soils. In this context we developed a method based on branched glycerol dialkyl glycerol tetraether (GDGT) membrane lipids, i.e. molecules making up the cell membrane of micro organisms, from bacteria living in soils and peat bogs (Fig. 1). These molecules are, upon soil erosion, transported by rivers to the marine environment and settle down to the

ocean floor. Marine crenarchaeota, ubiquitous pelagic archaea thriving in the oceans, synthesise a similar type of membrane molecule called crenarchaeol (Fig. 1), which eventually also gets buried in the marine sedimentary archive. The

ratio between these two types of molecules, called the Branched vs. Isoprenoid Tetraether (BIT)-index (Fig. 1), gives information on the relative fluvial input of soil organic matter. Analysis of a diverse suit of soils showed that branched

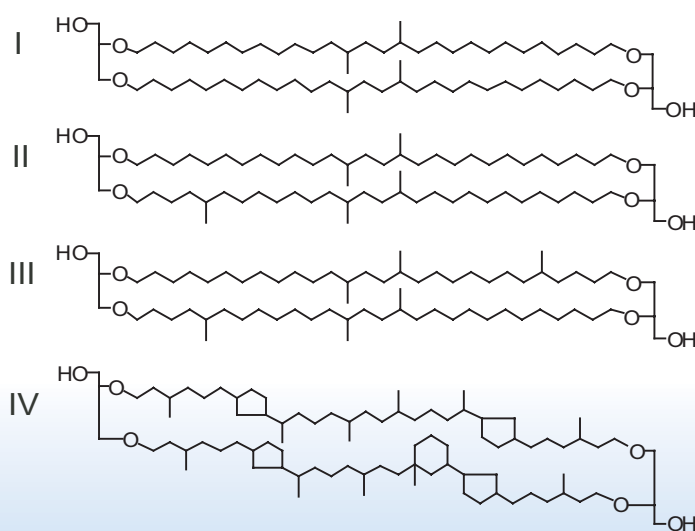
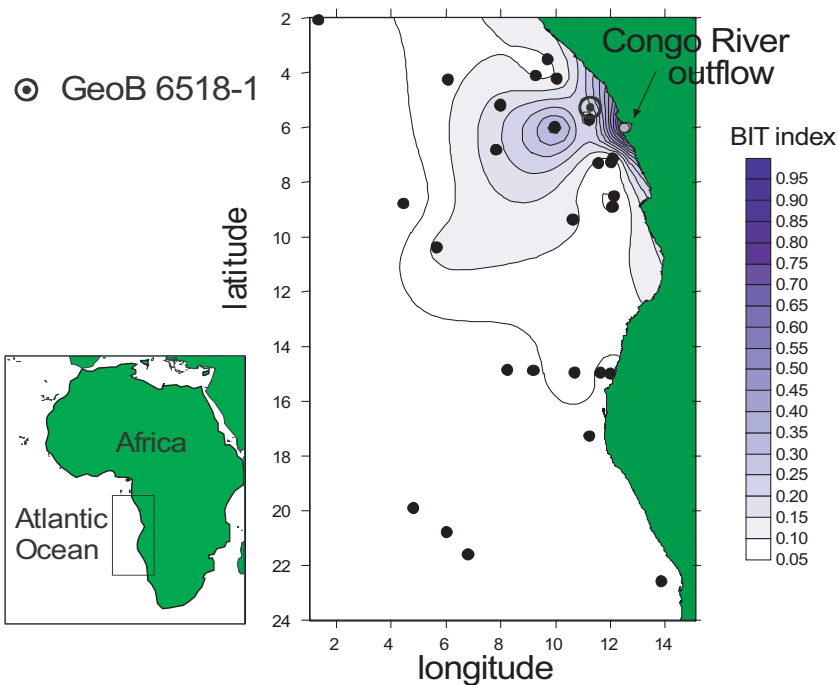


Fig. 1. Chemical structures of the branched glycerol dialkyl glycerol tetraethers (GDGTs) (I to III) and crenarchaeol (IV). The BIT-index is defined as  $[I+II+III] / [I+II+III+IV]$ . Thus, BIT indices approaching 0 indicate a pure marine source and BIT indices approaching 1 indicate a pure terrestrial source.

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organic matter allowed us, by using a three end-member mixing model, to quantify the terrestrial organic matter input in the Congo deep sea fan over the last 20,000 years. It appeared that on average 45% of the organic matter at this site is of terrestrial origin. Additionally, tentative carbon burial budget calculations show that the amount of terrestrial carbon buried in this Congo deep sea fan varied over this time interval from 2 to  $10 \times 10^{11}$  gC yr<sup>-1</sup>, and is strongly related to variations in Congo River discharge. In general, based on these calculations, approximately 3 to 5% of the fluvial terrestrial organic matter discharge by the Congo River seems to have been buried eventually in marine sediments, while the remainder is

Fig. 2. Contour plot of the BIT index based on analyses of surface sediments from the eastern equatorial Atlantic Ocean (black dots). The high BIT indices near the Congo River outflow are indicative of relative high input of terrestrial organic matter. These decrease with increasing distance from the river mouth.

GDGTs are present in every soil analysed so far and that the BIT index in soils is high, between 0.9 and 1.0. Calculating the BIT-index in surface sediments in the western equatorial Atlantic Ocean in front of the Congo River shows a river plume pattern with decreasing BIT indices with increasing distance from the river mouth (Fig. 2). This indicates that the branched tetraether membrane lipids indeed originate from land and that the BIT-index can be used to trace soil organic matter in marine sediments.

Application of the BIT-index in a marine sediment core (GeoB 6518-11; Fig. 2) from the Congo fan in conjunction with the stable carbon isotopic composition and the carbon over nitrogen ratio of

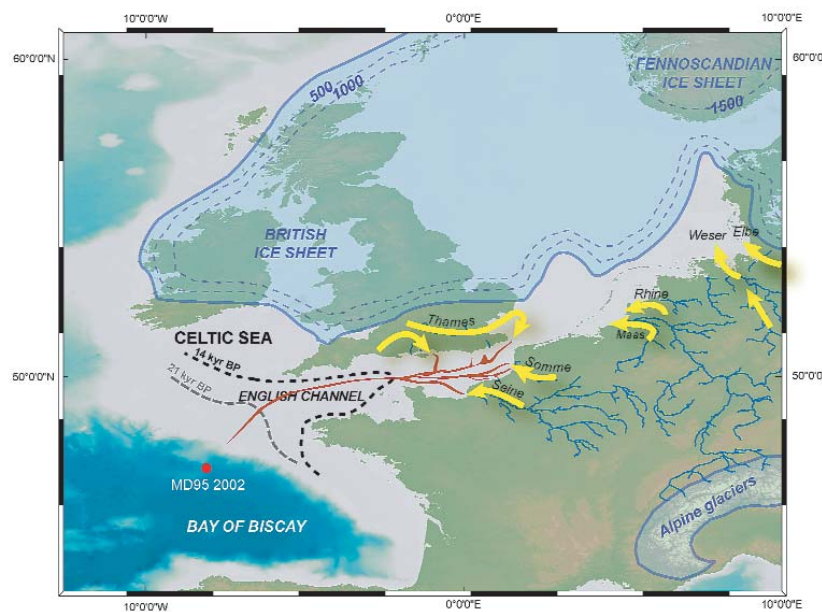


Fig. 3. Map showing the environmental conditions during the Last Glacial Maximum in north-western Europe. The British and Scandinavian ice sheets coalesced above the northern North Sea basin and forced river waters and ice sheet melt waters to flow across the dry North Sea basin and Channel basin. This river, known as the Channel River, was one of the largest rivers known in Europe and discharged into the Bay of Biscay (orange lines). The dashed grey and black lines indicate the position of past shore lines and the red dot indicates the core location.

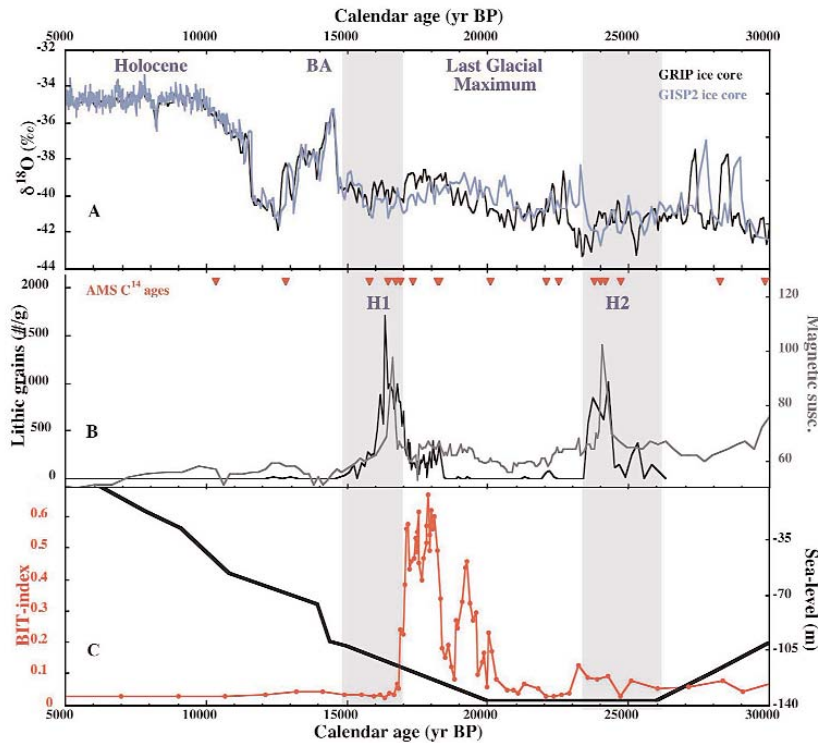


Fig. 4. (A) Greenland ice core records showing an initial warming at ca. 21,000 years ago; (B) Grain counts (black line) indicate the occurrence and timing of Heinrich event 1 (H1); (C) Sea level reconstruction (black line) showing the sea level low stand during, and recovery after the Last Glacial Maximum, and the BIT index (red line) indicating increasing fluvial activity from 21,000 years onward and an abrupt end at 17,000 years ago at the start of H1. (yr BP = years before present)

either remineralised or further dispersed in the ocean.

In cooperation with French colleagues from CEREGE (Aix-en-Provence, France), we also applied the BIT-index to sediments from a marine core in the Bay of Biscay. As during the last Ice Age the sea level was ca. 130m lower than today, the North Sea and Channel basins were dry causing the large European rivers (Rhine, Meuse, Thames, Seine etc.) to merge into one of the largest rivers ever on the European continent, known as the Channel River (Fig. 3). At that time, the location of this

core was near the mouth of this large river. Our results show a strong increase in BIT indices from 21,000 to 17,000 years ago, indicating increased terrestrial organic matter (and water) discharge by this large river system, coincident with the early warming in the Greenland air-temperature record (Fig. 4). Most striking is the sharp and abrupt drop in the BIT index at 17,000 years ago right at the start of Heinrich event 1 (Fig. 4), which is an event whereby large amounts of ice bergs calved off the large ice sheets around the North Atlantic Ocean and drifted over the ocean.

These ice bergs partly floated into the Bay of Biscay and their fresh melt water created a 'lit' of cold water on top of the saltier ocean water of the Bay of Biscay. This hindered the evaporation of water and thus cloud formation and caused a return to dryer (and probably colder) conditions on the European continent resulting in lower river runoff. The BIT-index did not return to higher values again in this record as due to the sea level rise this core site became located more distal from the river mouth.