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Geochemical signatures of sediments documenting Arctic sea-ice and water mass export through Fram Strait since the Last Glacial Maximum

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ABSTRACT

Elemental (Ca, Zr, Th, etc.) and radiogenic isotope (Pb, Nd, Sr) measurements in leachates and residues from deep-sea sediments of core MC16 (WarmPast Program) in central Fram Strait were used to document the geochemical signatures of outflowing Arctic water masses and ice rafted debris (IRD) since the Last Glacial Maximum. In addition, the elemental distribution among the three main sedimentary fractions (terrigenous, biogenic and authigenic) was quantified. Elements dominated by the terrigenous fraction display a change at ~13 ka assigned to an early Younger Dryas (YD) event. In the authigenic fraction, migration of the redox front, perhaps spurred by discontinuous delivery of organic matter to the sediment, has led to the mobility of elements such as Mn. Fe contents display lesser variability within the sediment suggesting that Fe experienced only minor redox-related redistribution. Authigenic Pb and Nd, thought to be hosted primarily by Fe-oxyhydroxides, also show little evidence of mobility, suggesting that their isotopic compositions should reliably record the isotopic compositions of past bottom water.

We have broadly identified the isotopic signatures of the three major source areas of IRD, the Russian, Canadian and Greenland margins. The elemental and isotopic residue records from core MC16 display distinct trends prior to and after the YD. The pre-YD interval, with ε_{Nd} values between −10.1 and −13.2, and $^{87}Sr/^{86}Sr$ ratios from 0.715 to 0721, reflects a mixture of IRD from the Russian and Canadian margins. The YD episode stands out with sediments originating mostly from the Canadian end-member, displaying the lowest ε_{Nd} values and highest $^{87}Sr/^{86}Sr$ ratios. This suggests enhanced sea-ice production and/or drifting along the Beaufort Gyre at that time. The post-YD interval, i.e. the Holocene, is characterized by a less variable mixture of IRD material, with ε_{Nd} values and $^{87}Sr/^{86}Sr$ ratios centred at −12.2 and 0.718 respectively. This material was derived from several sources including northwestern Canada (Mackenzie River), the western Arctic, the East Siberian/Chukchi Seas, and the more proximal Greenland margin.

The isotopic compositions of leachates are mostly linked to boundary exchange processes near major meltwater and freshwater source areas. Due to its longer residence time relative to Pb, Nd preserves the isotopic signature of more distal areas where high-density particulate fluxes may occur. In the studied core, Nd-isotope leachate data illustrate the influence of the western Russian margins prior to the YD event and that of the East Siberian and Chukchi Sea margins following this event. This study illustrates that complementary information on IRD sources and water-mass histories can be obtained from isotopic analyses of inherited (residual) and exchangeable (leachable) fractions in deep Arctic Ocean sediments. Higher resolution cores are now needed to illustrate more rapid variations of paleo sea-ice and water mass circulation.

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1. Introduction

The Arctic Ocean, though of small size, has a disproportionately large influence on the world's climate system (Holland et al., 2010; Jakobsson et al., 2010; Miller et al., 2010; Koenigk et al., 2011). Exports of freshwater and sea-ice may influence deep-water formation in the Greenland, Iceland and Norwegian (GIN) Seas and consequently the Atlantic Meridional Overturning Circulation (AMOC), which in turn strongly affects heat exchange with the atmosphere (Broecker, 1991; McManus et al., 2004; Peltier et al., 2006). Sea-ice is a key feature of the Arctic climatic system notably because of its strong albedo which provides a positive feedback mechanism by reflecting solar irradiation and hence preventing heat transfer to the ocean surface, maintaining a highly stratified water column (Miller et al., 2010; Polyak et al., 2010). The role of the Arctic with respect to changes in the AMOC can be examined by documenting water mass exchanges through Fram Strait using geochemical and sedimentological records from deep-sea cores (Fagel et al., 1997, 2002; Darby et al., 2002; Birgel and Hass, 2004; Fagel et al., 2004; Fagel and Hillaire-Marcel, 2006; Carignan et al., 2008; Gutjahr et al., 2008). Fram Strait is the major Arctic gateway for freshwater and sea-ice export and the only gateway for deep-water mass exchange between the Arctic and the North Atlantic (Jones et al., 1995; Fahrbach et al., 2001; Jones, 2001; Rudels et al., 2004). During glacial times, Fram Strait was also the only passage permitting exchange between the Arctic Ocean and the GIN Seas (Tütken et al., 2002; Darby et al., 2006). Atlantic waters enter the Arctic as the West Spitsbergen Current, in the eastern Fram Strait, and form the subsurface Atlantic waters present throughout the Arctic Ocean. In the western part of Fram Strait, the outflowing water masses are i) at the surface, the Modified Atlantic Water; ii) in the upper subsurface, the Arctic Atlantic Water; iii) at greater depths, the Arctic intermediate Water; and iv) at the seafloor, the Canadian Basin Deep Water and Eurasian Basin Deep Water (Fig. 1) (Rudels et al., 2000, 2005; Dickson et al., 2007; Langehaug and Falck, 2012). Changes in freshwater and sea-ice supplies within the Arctic are primarily linked to river discharge and to ice-sheet margin dynamics, related to the drainage of glacial lakes and/or ice-surges, calving and release of icebergs (Tütken et al., 2002; Tarasov and Peltier, 2005; Darby and Zimmerman, 2008). In addition, the inception of low-salinity water inflow from the Pacific through Bering Strait during deglaciation likely played a role that still remains poorly understood. Our aim is to document paleo sea-ice circulation and water mass exchange from Lateglacial to modern times.

The geochemical compositions of deep-sea sediments are indicative of their sources, transport mechanisms, and in some cases, of diagenetic processes. Marine sediments are composed of three distinct fractions: detrital, biogenic and authigenic (which includes syn-depositional and early diagenetic components). The detrital fraction is derived from weathering of continental crust, including mechanical erosion by ice-sheets, as well as from volcanic

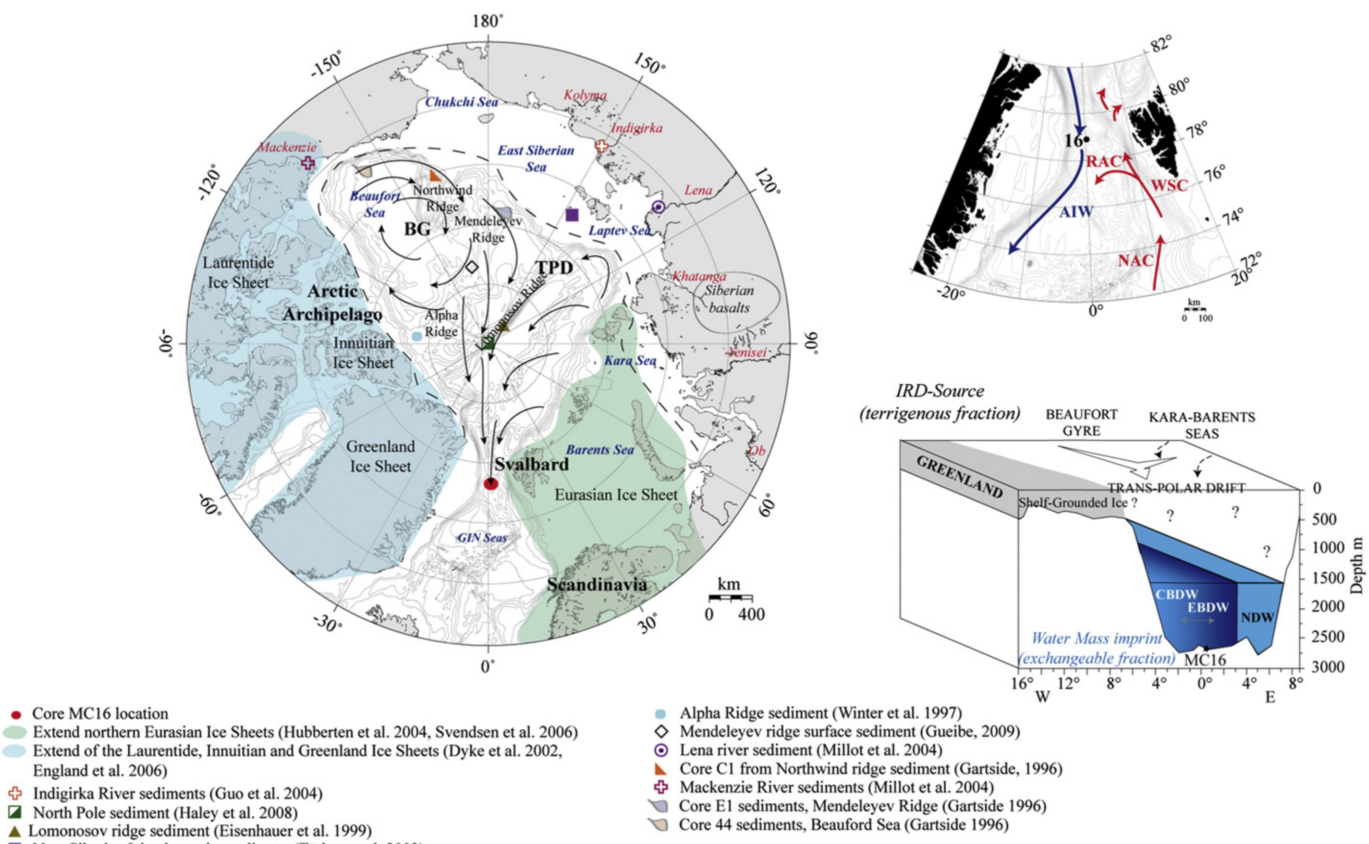

Fig. 1. Left: Map of the Arctic during LGM and early deglacial period showing core MC16 location (Red circle) and extent of ice-sheets. Italic Red: river locations; Bold-Italic blue: Arctic Seas; Bold Black: Land; Regular Black: Submarine ridges; Italic Grey: Arctic basins. Black arrows reflect the suggested sea-ice circulation patterns. The dashed line represents the assumed LGM sea-level. Top Right: Bathymetric map of the Fram Strait along with major currents and MC16 core location. NAC: North Atlantic Current; WSC : West Spitsbergen Current; RAC: Return Atlantic Current; AIW: Arctic Intermediate Waters 10 Bottom Right: Cross section of the Fram Strait showing deep water masses entering the Arctic (NDW: North-Atlantic Deep Water) and exiting the Arctic (CBDW: Canadian Basin Deep Water; EBDW: Eurasian Basin Deep Water). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)