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# Geochemical and isotopic tracers of Arctic sea ice sources and export with special attention to the Younger Dryas interval

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ABSTRACT

Radiogenic isotopes (Sr, Nd) in Ice Rafted Debris (IRD) sediments from the Lomonosov Ridge and Fram Strait Arctic areas are used to document changes in Arctic sea-ice sources and trajectories since the Last Glacial Maximum (LGM). The two records provide evidence for enhanced sea-ice production in the Beaufort Sea and its subsequent export through Fram Strait during the Younger Dryas (YD) interval. This pattern, exclusive to the YD, followed an LGM–Bølling–Allerød interval, when multiyear and/or reduced sea-ice mobility resulted in sedimentary hiatuses in the Central Arctic. Meanwhile, IRD from Svalbard–Barents ice-sheet margin source were still deposited in the Fram Strait area. The "isotopic excursion" of the YD points to enhanced sea-ice production in the Beaufort Sea, which we link to the Lake Agassiz (?)/Laurentide ice sheet drainage event through the Mackenzie route. Following this event, the Holocene depicts a 5-fold reduction in IRD rates with a shift towards prominent sea-ice production along Russian shelves. From a methodological viewpoint, we demonstrate that radiogenic isotopes must be used in a multi-proxy approach to better constrain IRD and sea-ice sources and routes. From a paleoceanographic perspective, we conclude that an Arctic freshwater/sea-ice export route should now be seen as the most likely mechanism for an AMOC reduction during the YD in accordance with more recent improved model experiment.



## 1. Introduction

Freshwater and sea-ice export from the Arctic Ocean via Fram Strait exerts a direct control over salinity conditions in the Greenland–Iceland–Norwegian (GIN) seas, thus on the Atlantic Meridional Overturning Circulation (AMOC). Enhanced fluxes from this area might have been involved in the AMOC-slowdown which occurred during the Younger Dryas (YD; McManus et al., 2004), i.e., during the latest of the large amplitude millennial scale cooling events which interrupted the last deglaciation, as proposed by Tarasov and Peltier (2005), Peltier et al. (2006) and Peltier (2007) from model experiments. Land-based investigation by Teller et al. (2005) and Murton et al. (2010) confirmed that a meltwater runoff did occur through the Mackenzie delta region into the Arctic Ocean during the YD period, which they assigned to a northwestward drainage stage of glacial Lake Agassiz. More recently Condron and Winsor (2012) used a high resolution ocean general circulation model to test the sensitivity of such a meltwater release location and confirmed the effectiveness of an Arctic meltwater event in impacting the AMOC.

Poore et al. (1999) and Hall and Chan (2004) had inferred a major melting episode in the Canadian Arctic, during the YD interval, from Ba/Ca and $\delta^{18}O$ measurements in planktic foraminifers in Mendeleev Ridge cores. Later, Not and Hillaire-Marcel (2012) suggested an enhanced sedimentary flux and a change in sea-ice regime corresponding to the YD-period based on mineralogical and U-series isotope analyses of a sedimentary core from the central Arctic. Further south, into the Fram Strait, Knies et al. (2007) interpreted stable isotope excursions in planktic and benthic foraminifers as the result of freshwater pulses that occurred during the last deglaciation. More recently, based on geochemical tracers and lead isotopes in a Fram Strait sedimentary sequence, Maccali et al. (2012) documented significant Ice Rafted Debris (IRD) supplies from the northern Laurentide Ice Sheet (LIS) margin during this interval. All these studies evoke a major meltwater/lake drainage event along the NW LIS-margin, in the Mackenzie River area. This freshwater event would have resulted in an enhanced supply of material from the northern LIS margin across the Arctic and

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eventually towards Fram Strait then into the GIN seas, likely through a more dynamic Beaufort Gyre (Fig. 1) and subsequent ice-rafting deposition along the Trans-Polar Drift route, as already suggested by Not and Hillaire-Marcel (2012).

From this viewpoint, the Arctic Ocean remained characterized by very specific sediment transport and deposition mechanisms during most of the late Cenozoic (O'Regan et al., 2011). Sea-ice that forms over shallow margins uploads coastal and suspended material (Darby et al., 2006; Stein, 2008) and disperses it from the source region. Today, the sea-ice circulation pattern is dominated by i) the Beaufort Gyre (BG), which follows an anti-cyclonic movement over the Amerasian basin and ii) the Trans-Polar Drift (TPD), circulating from the Siberian margin towards Fram Strait (Fig. 1; Rigor et al., 2002). Under full glacial conditions, these sea ice circulation patterns might have been strongly modified due to considerably reduced shelves and instabilities along ice-sheet margins, mostly on the Barents–Svalbard ice-sheet and the LIS margins (Bromwich et al., 2004; Griffiths and Peltier, 2008, 2009; O'Regan et al., 2011). Similarly, variable atmospheric synopses (e.g. Arctic Oscillation) might have been responsible for large-scale changes in the relative role of all circum-Arctic sea-ice "factories" and subsequent IRD patterns (Otto-Bliesner et al., 2006; Polyak et al., 2009; Darby et al., 2012). Very low sediment accumulation rates are usually observed in the central Arctic Ocean under such IRD supplies (Sellén et al., 2009; Not and Hillaire-Marcel, 2012). They limit the temporal resolution that can be achieved in deep-sea core records, aside problems linked to the use of an appropriate reservoir age when establishing $^{14}C$-stratigraphies (Hanslik et al., 2010). Nevertheless, radiogenic isotopes and elemental compositions of Arctic Ocean sediments can be used to document unequivocally sea-ice production areas and paleocirculation patterns (Winter et al., 1997; Darby, 2003; Darby et al., 2012). New radiogenic isotope (Nd, Sr) data in sedimentary sequences from the Fram Strait and Lomonosov Ridge areas, already investigated by Maccali et al. (2012) and Not and Hillaire-Marcel (2012) are presented here. These new data illustrate unequivocally the singularity of the YD "isotopic excursion" and thus provide robust complementary information on the source and export of IRD from the Arctic during this critical interval.

## 2. Material and methods

The central Arctic record corresponds to a 47 cm-long multicore (MC18) retrieved during the HOTRAX expedition (Darby

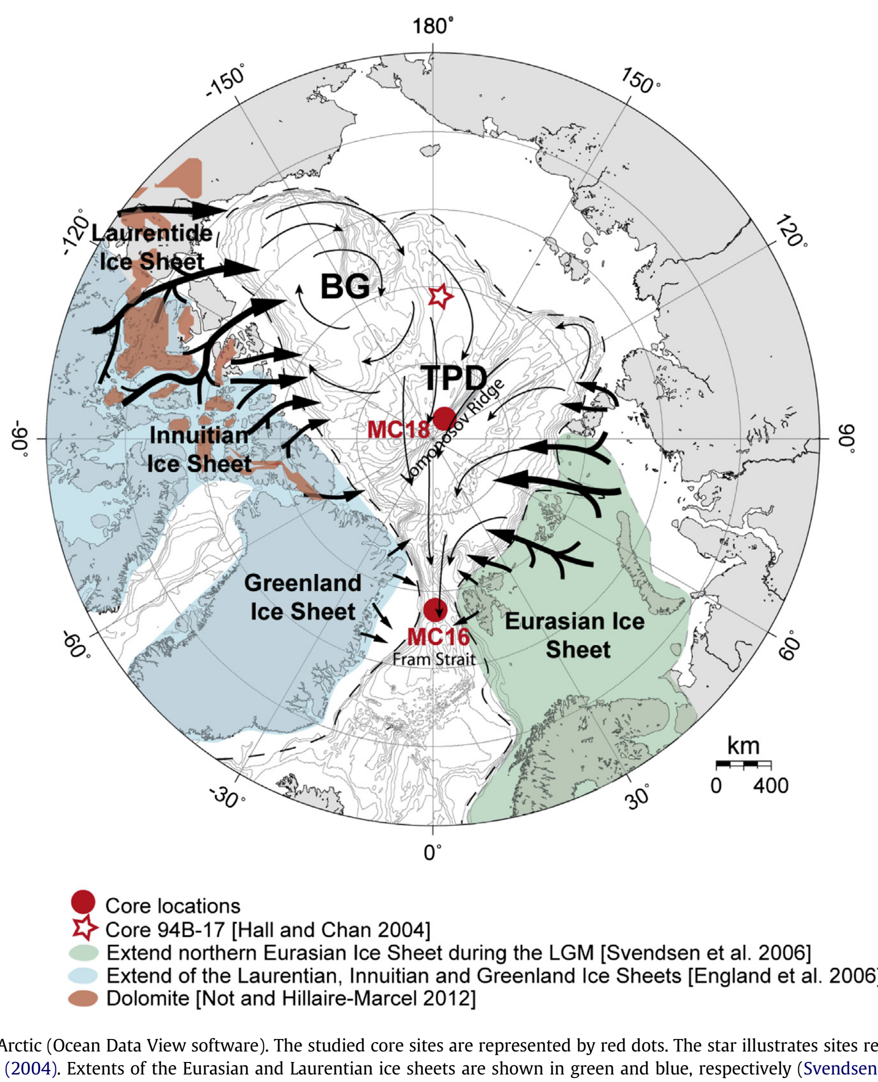


**Fig. 1.** Bathymetric map of the Arctic (Ocean Data View software). The studied core sites are represented by red dots. The star illustrates sites reported in earlier studies by Poore et al. (1999) and Hall and Chan (2004). Extents of the Eurasian and Laurentian ice sheets are shown in green and blue, respectively (Svendsen, 2004; England et al., 2006). The Laurentian ice sheet is displayed with its ~13 ka limits. However, as such limits have not yet been published for the Eurasian ice sheet, we use here its LGM limits. Red areas correspond to dolomitic bedrock occurrences (Not and Hillaire-Marcel, 2012). Bold black arrows represent paleo-ice streams (Stokes and Clark, 2001) and thin black arrows correspond to modern surface oceanic currents. The dashed line highlights shelf edges. BG = Beaufort Gyre; TPD = Trans-Polar drift. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)