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Glacial freshwater discharge events recorded by authigenic neodymium isotopes in sediments from the Mendeleev Ridge, western Arctic Ocean

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ABSTRACT

The freshwater budget of the Arctic Ocean is a key component governing the deep water formation in the North Atlantic and the global climate system. We analyzed the isotopic composition of neodymium (ε_{Nd}) in authigenic phases of marine sediments on the Mendeleev Ridge in the western Arctic Ocean spanning an estimated time interval from present to about 75 ka BP. This continuous record was used to reconstruct the ε_{Nd} of the polar deep water (PDW) and changes in freshwater sources to the PDW through time. Three deviations in ε_{Nd} from a long term average of −10.2 were identified at estimated 46–51, 35–39 and 13–21 ka BP. The estimated 46–51 ka BP event can be traced to bursting of ice-dammed lakes accompanying the collapse of the Barents–Kara Ice Sheet, which would have released radiogenic Nd to the eastern Arctic Ocean. The cyclonic surface circulation in the eastern Arctic Ocean must have been stronger than at present for the event to be recorded on the Mendeleev Ridge. For the 35–39 and 13–21 ka BP events, it is likely that the Laurentide Ice Sheet (LIS) supplied the unradiogenic freshwater. The configuration of the anticyclonic circulation in the western Arctic was probably similar to today or expanded eastward. Our simple mass balance calculations suggest that large amounts of freshwater were released but due to significant deep water formation within the Arctic Ocean, the effect on the formation of NADW was probably minor.

1. Introduction

In the modern Arctic Ocean, the primary freshwater sources are the riverine discharge, Pacific inflow through the Bering Strait and precipitation (Serreze et al., 2006). The largest sink is the flow into the North Atlantic through Fram Strait and Canadian Arctic Archipelago. The freshwater outflow from the Arctic Ocean may weaken the Atlantic meridional overturning circulation (Peterson et al., 2002; Tarasov and Peltier, 2005) and disrupt global climate. The Great Salinity Anomaly (1968–1982) (Dickson et al., 1988) is a recent example of a salinity depletion event in the North Atlantic caused by ice export from the Arctic Ocean (Aagaard and Carmack, 1989), and it possibly triggered the reduction of NADW in 1978–1982 (Schlosser et al., 1991). Therefore, reconstructing freshwater discharge events in the Arctic Ocean and tracing their origins are important for understanding paleoclimatic evolution and predicting future climate change.

To reconstruct past freshwater discharge events, light $\delta^{18}O$ and $\delta^{13}C$ values of planktonic foraminifera or occurrences of ice-rafted debris (IRD) have been used (Darby et al., 2006; Knies et al., 2007; Poore et al., 1999; Stein et al., 1994a, 1994b). Due to the semi-enclosed nature of the Arctic Ocean, low and stable Arctic surface water temperatures and diverse freshwater sources, the $\delta^{18}O$ distribution of its surface waters reflects regional salinity variations rather than global temperature or ice volume changes (Spielhagen and Erlenkeuser, 1994; Stein et al., 1994b). Although the full picture is more complicated, $\delta^{13}C$ depletion, if accompanied by $\delta^{18}O$ reduction, is also interpreted as stratified and less productive surface waters (Poore et al., 1999). However, $\delta^{18}O$ and $\delta^{13}C$ values cannot pinpoint the source of the freshwater, and their variability can be muted in areas of low sedimentation rate because of the short residence time (~10–30 yr) of the Arctic surface waters (Macdonald and Bewers, 1996). The abrupt increase in IRD accompanies collapsing ice sheets (Darby et al., 2006) but probably not outburst of ice dammed lakes from distal areas.

Neodymium (Nd) isotope ratios, expressed as $\varepsilon_{Nd} = [(^{143}Nd/^{144}Nd)_{sample}/(^{143}Nd/^{144}Nd)_{CHUR}-1] \times 10^4$, where $(^{143}Nd/^{144}Nd)_{CHUR}$ is 0.512638 (Jacobsen and Wasserburg, 1980), can be

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a useful provenance proxy of freshwater discharge events to complement the stable isotope ratios and IRD. During partial melting of silicate minerals, the daughter element Nd preferentially partitions into the melt phase whereas the parent element Sm tends to stay in the residual solid (Faure and Mensing, 2005). Thus, old continental crust develops unradiogenic ε_{Nd} values and young mantle rocks radiogenic values. The short residence time (200–1000 yr) of Nd in seawater (Tachikawa et al., 1999) allows the oceanic water masses to conserve the distinct ε_{Nd} value of the source regions (e.g. Piotrowski et al., 2009; Rutberg et al., 2000). The ε_{Nd} value of a water mass is in turn recorded in authigenic minerals such as the Fe–Mn oxyhydroxides which precipitate upon the surface of biogenic and detrital material from ambient water. Therefore, past variations in the water masses can be reconstructed through changes in ε_{Nd} (e.g. Frank et al., 2002; Piotrowski et al., 2009; Rutberg et al., 2000; Spivack and Wasserburg, 1988). Here we analyzed authigenic Nd isotopes of marine sediments from the Mendeleev Ridge in the Amerasian Basin of the Arctic Ocean at the depth of the Polar Deep Water (PDW) and reconstructed past ε_{Nd} variations of and the contribution of freshwater to the PDW over the past ~75 kyr.

The water column of the Arctic Ocean is highly stratified, featuring the fresh Polar Mixed Layer at the surface, the cold Halocline Layer, the warm and saline Atlantic layer (AL) at approximately 200–850 m, the cooler and saltier Upper Polar Deep Water (UPDW) extending to 1700 m and the PDW (Porcelli et al., 2009). The average depth of the Lomonosov Ridge is ~1700 m and divides the PDW into the western Amerasian (subdivided into Canada and Makarov basins) and eastern Eurasian (subdivided into Amundsen and Nansen basins) basins (Fig. 1).

In general, the circulation in the PDW is not well known. Because of the higher temperature and salinity in the deep Arctic basins and the structure of increasing salinity with depth, slope convection has been inferred for the different basins of the Arctic

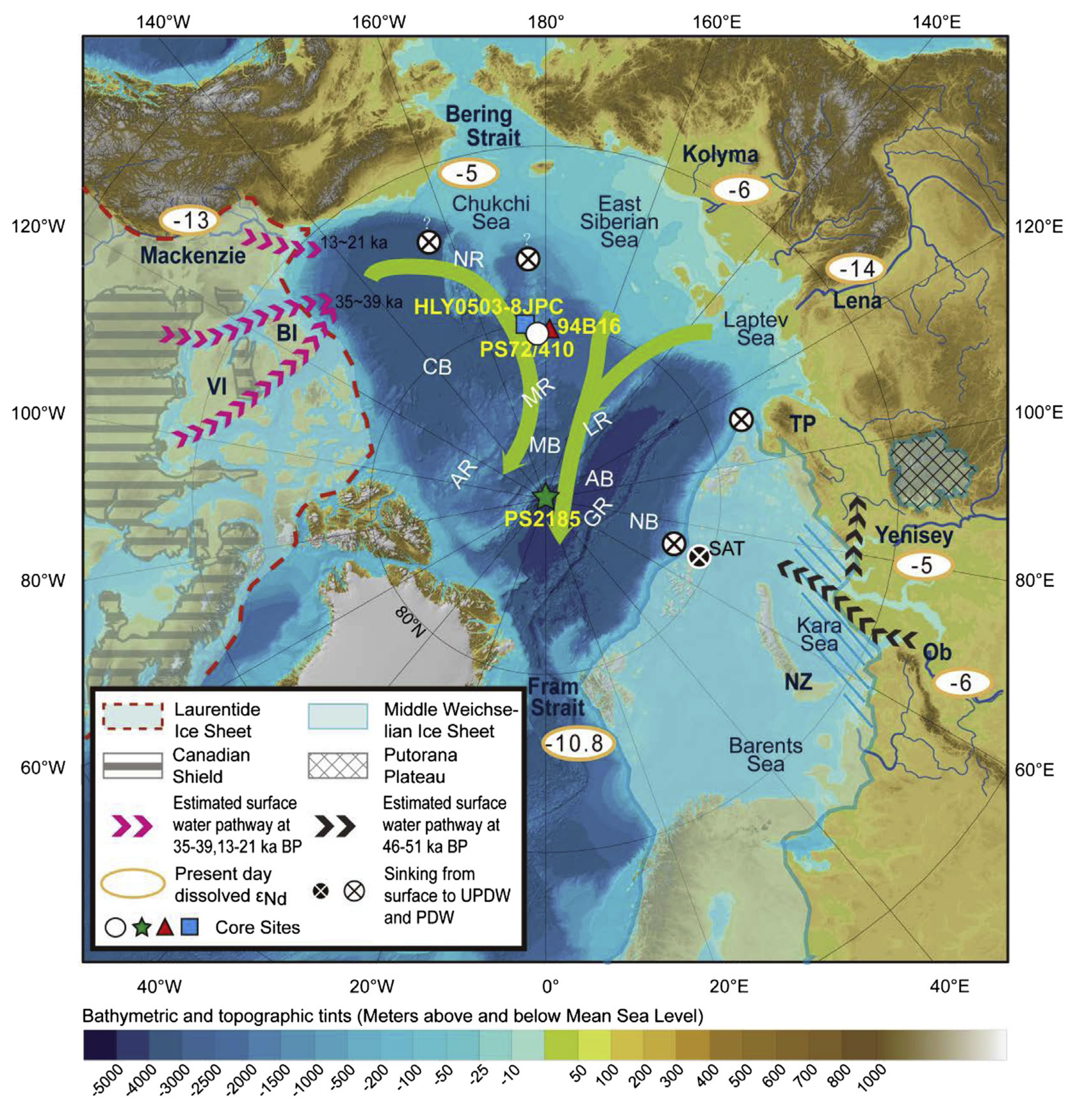

Fig. 1. Schematic map of the circum-Arctic showing core sites, ocean circulation and glacial ice sheet distribution. Yellowish green arrows mark the Beaufort Gyre and the Transpolar Drift. Sites are marked for core PS72/410 (white circle) and neighboring cores 94B16 (red triangle; Poore et al., 1999) and HLY0503-8JPC (blue square; Adler et al., 2009) on the Mendeleev Ridge and for core PS2185 (green star; Haley et al., 2007) on the Lomonosov Ridge. The ε_{Nd} values of major inflows into the Arctic Ocean are given inside yellow ellipses (Porcelli et al., 2009 and references therein). The full glacial Laurentide Ice Sheet margin (dashed red line) and the Barents–Kara Ice Sheet margin at 60 ka BP (blue line) are simplified from Svendsen et al. (2004) and Stokes and Clark (2003), respectively. Note that the Putorana Plateau was under ice in the Middle Weichselian. Estimated surface water inflows during different periods are shown with purple and dark gray arrows. AB: Amundsen Basin, AR: Alpha Ridge, BI: Banks Island, CB: Canada Basin, GR: Gakkel Ridge, MB: Makarov Basin, MR: Mendeleev Ridge, NB: Nansen Basin, NR: Northwind Ridge, NZ: Novaya Zemlya, SAT: St. Anna Trough, TP: Taimyr Peninsula and VI: Victoria Island. The base map is IBCAO-3 from Jakobsson et al. (2012). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)