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Paleo-environmental gateways in the eastern Canadian arctic – Recent isotope hydrology and diatom oxygen isotopes from Nettilling Lake, Baffin Island, Canada

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A B S T R A C T

Nettilling Lake is located on Baffin Island, Nunavut, Canada between the areas of past warming (Canadian High Arctic to the North) and climatic stability (Northern Quebec and Labrador region to the South). Despite being the largest lake in the Nunavut region with a postglacial marine to lacustrine transition history only a few paleo-environmental investigations were completed in this area. The oxygen isotope composition of diatoms ($\delta^{18}O_{diatom}$) can provide valuable insights into paleo-environmental conditions. Here, the recent (isotope) hydrology and hydrochemical data from the lake are presented to facilitate the interpretation of a $\delta^{18}O_{diatom}$ record from an 82 cm sediment core (Ni-2B).

The well-mixed lake ($\delta^{18}O_{water} = -17.4$‰) is influenced by a heavier (less negative) isotope composition (−18.80‰) from Amadjuak River draining Amadjuak Lake to the South and water of lighter (more negative) isotopic composition (−16.4‰) from the Isurtuq River originating from Penny Ice Cap in the North-East. From the $\delta^{18}O_{water}$ and $\delta^{18}O_{diatom}$ of the topmost sample of core Ni-2B a $\Delta^{18}O_{silica\text{-}water}$ of 1000 ln $\alpha_{(silica\text{-}water)} = 40.2$‰ for sub-recent diatoms of Nettilling Lake was calculated matching the known water-silica fractionation for fossil sediments well and thereby showing the general applicability of this proxy for paleo-reconstructions in this region.

Extremely large $\delta^{18}O_{diatom}$ variations in the core of more than 13‰ are mainly induced by changes in the isotopic composition of the lake water due to a shift from glaciomarine ($\delta^{18}O_{diatom} = +34.6$‰) through brackish (+23.4 to +27.2‰) towards lacustrine (+21.5‰) conditions (transition zones glaciomarine to brackish at 69 cm/7300 yr cal. BP and brackish to lacustrine at 35 cm/6000 yr cal. BP) associated with a shift in the degree of salinity. Our study provides the first evidence that paleo-salinity can be reconstructed by $\delta^{18}O_{diatom}$. Additionally, for the lacustrine section it could be demonstrated that $\delta^{18}O_{diatom}$ may serve as a proxy for past air temperature within the same core recording a late Holocene cooling of about 4 °C being consistent with other published values for the greater Baffin region.

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1. Introduction

Despite being the largest lake in the Canadian Arctic Archipelago, little is known about Nettilling Lake. The lake is located on south-central Baffin Island - an area between regions that experienced contrasting Holocene climate regimes since the last deglaciation: Extreme warming in the Canadian High Arctic to the North versus climatic stability of the Foxe Basin, Northern Québec and the Labrador region to the South (Jacobs et al., 1997; Pienitz et al., 2004; Smol et al., 2005).

The first field observations around Nettilling Lake were completed by Oliver (1964) in 1956. Jacobs and Grondin (1988) and Jacobs et al. (1997) focused on recent climate and vegetation characteristics of the southernmost part of the lake revealing relatively mild summers and cold winters. Although some Holocene paleoclimate reconstructions exist from Baffin Island (Axford et al., 2009; Briner et al., 2006; Joynt and Wolfe, 2001; Thomas et al., 2011, 2008) records from the southwestern part of the island are sparse but needed to refine the postglacial environmental history and past gateways in this remote region.

To reconstruct paleo-environmental conditions the isotope

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analysis of biogenic silica has become a useful proxy. Oxygen isotopes of biogenic silica are used to reconstruct past air temperatures (Chapligin et al., 2012b; Shemesh et al., 2001), paleohydrological settings (Mackay et al., 2008), paleo sea-surface temperatures (Labeyrie, 1974; Shemesh et al., 1992) or changes in air-mass sources (Shemesh et al., 2001). Overviews of the applications of the isotope analysis of biogenic silica are provided in Leng and Barker (2006) and Swann and Leng (2009).

However, before using this proxy a careful study of the recent isotope hydrology of the lake has to be performed (lake water, precipitation, inflow, outflow). These investigations were combined with a multi-proxy paleolimnological study of three sedimentary records retrieved from Nettilling Lake (Narancic et al., this issue). Within this project, our study aims (1) to assess the recent isotope hydrology and hydrochemistry of Nettilling Lake for delivering essential background information for palaeo-environmental interpretation, (2) to compare $\delta^{18}O$ values of sub-recent diatom samples to the oxygen isotope composition of the lake, and (3) to investigate the possibility of using $\delta^{18}O$ measurements in biogenic silica for recording changes in paleosalinity as the Nettilling Lake basin experienced a glaciomarine-lacustrine transition in the mid-Holocene. One additional goal was to observe whether $\delta^{18}O$ values of diatom silica could act as a proxy for two different parameters (hydrological changes, air temperature) in different sections of the same core.

2. Material and methods

2.1. Study site

Nettilling Lake is the largest lake in the Canadian Arctic Archipelago and the sixth largest lake in Canada It is located on Baffin Island extending south and north of the polar circle (lake extension: 65°53.767′ N; 71°17.865′ W to 66°59.569′ N; 71°07.204′ W; Fig. 1; Oliver, 1964). The lake has two main inflows: (1) The Amadjuak River entering from the South (into Burwash Bay) which drains from Amadjuak Lake (64°55′ N, 71°09′ W; 113 m asl.) and Mingo Lakes and (2) Isurtuq River entering the North-East originating from Penny Ice Cap (67°15′ N, 65°45′ W; 1900 m asl.). The Penny Ice Cap is a remnant of the Laurentide Ice Sheet, which was once connected to the Foxe Dome (Fisher et al., 1998). The Koukdjuak River is the lake's main outflow in the West draining into Foxe Basin. The eastern part of the lake is shallow with several islands (mean depth 10–25 m) whereas the western part has a deeper basin with water depths up to ca. 65 m (mostly 40–60 m; Oliver, 1964). Geologically the region is characterised by Precambrian rocks in the North-East and Ordovician carbonate-rich sedimentary rocks to the West. The ice break-up starts between the middle and the end of July and the lake becomes free of ice between the end of July and the first week of August (Oliver, 1964 and pers. comm. Pat Rakowski, Canadian Wildlife Service; based on 5 yrs of observations in the camp). Water temperatures remain below 4 °C in summer in the deeper western part of the lake basin while rising above 4 °C (ca. 7–8 °C) in the island-rich and shallower eastern part (Oliver, 1964). In August 2014, all water profiles taken revealed a well-mixed lake and the absence of a thermocline. A Secchi disc depth of mostly greater than 10 m was observed (Oliver, 1964).

2.2. Sample material and age model

Lake water samples were taken at different water depths with a UWITEC water sampling device (UWITEC Corp., Austria), in most cases (apart from the water samples taken at the sediment cores' sites from the zodiac) directly from the helicopter in approx. 1–2 m water depth. Subsamples were taken from the water sampling device in the boat or helicopter for isotope and hydrochemistry analyses.

As the Global Network of Isotopes in Precipitation (GNIP) has only 3 stations in the Nunavut region and none in the South or Center of Baffin Island, there was a need for year-round precipitation sampling for isotope analysis which was performed at the Nunavut Research Institute (NRI) in Iqaluit since Sept 2013. Thirty samples in the year until Sept 2014 were taken for isotope analysis.

Climate (air temperature, …) data was recorded by a meteorological station with year-round automatic data acquisition at Nettilling Lake since 2010 which was set up by the Centre for Northern Studies at Laval University (Québec, Canada). Other climate data for Iqaluit was taken from http://www.iqaluit.climatemps.com/ and http://climate.weather.gc.ca/climateData/). Modelled isotope values were retrieved from the Online Isotopes in Precipitation Calculator, version 2.2. from http://www.waterisotopes.org (Bowen, 2015, based on Bowen and Revenaugh, 2003).

The core Ni2-B (82 cm) was taken from the north-eastern part of the lake (Fig. 1) at 14 m water depth using a 7 cm-diameter handheld percussion corer (Aquatic Research Instruments). At each coring site, the water depth was measured with a portable echosounder sonar (Lowrance).

A composite age-depth model was developed using four cores from the lake (Fig. 2, see details of the complete age model in Narancic et al., this issue). As these cores contain three recognizably concordant lithostratigraphic zones, the overlap of these zones was used to establish the composite core depth. The age-depth core chronology is based on 25 accelerator mass spectrometry (AMS) ^{14}C dates. For the three stratigraphic zones the following corresponding time intervals were defined: (1) the glaciomarine phase (ca. 8300 and 7300 yr cal. BP; 69–82 cm core depth), (2) the brackish water (transitional) phase and the beginning of basin isolation from marine influence (ca. 7300 and 6000 yr cal. BP; 35–69 cm depth) and (3) the lacustrine phase that marks the complete isolation of the basin from glaciomarine waters and the establishment of the present-day lake conditions (at ca. 6000 yr cal. BP, 35 cm depth). Since then, the lacustrine sedimentation (of the upper 0–35 cm of the core) occurred continuously to the present at very low and likely decreasing rates with a surface sample age of ca. 300 BP as suggested by paleomagnetic dating (Narancic and St-Onge, pers. comm).

The core was sampled at 0.5 cm intervals for isotope analysis. Pure biogenic silica samples are required to analyse for the oxygen isotope composition in diatoms (Leng and Sloane, 2008). Therefore, various chemical and physical preparation steps were performed to separate diatom frustules from sediment material (Morley et al., 2004; Chapligin et al., 2012a). The freeze-dried samples were treated with H_2O_2 (32%) and HCl (10%) to remove organic matter and carbonates and wet sieved into <10 μm and >10 μm fractions from which the <10 μm fraction was further used as the final amount of pure diatom material was sufficient for isotope analysis. Four multiple heavy liquid separation (HLS) steps with varying densities (from 2.25 to 2.15 g/cm^3) were then applied using a sodium polytungstate (SPT) solution before being exposed to a mixture of $HClO_4$ (65%) and HNO_3 (65%) for removing any remaining micro-organics.

2.3. Hydrochemistry

Water samples for major ion analyses were filtered through cellulose-acetate filters (Whatman™ CA; pore size 0.4 μm). Then, samples for the cation analyses were acidified with HNO_3 suprapure (65%) to prevent microbial conversion processes and adsorptive accretion. The cation content was analysed by inductively coupled plasma–optical emission spectrometry (ICP-OES, Perkin-

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