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Change at the margin of the North Water Polynya, Baffin Bay, inferred from organic matter records in dated sediment cores

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ABSTRACT

The North Water Polynya (NOW) is one of the most productive marine environments in the Arctic. With Arctic sea-ice cover a prominent control in the production of marine organic matter (OM), polynyas are likely to be sentinels of the effects of recent change in ice climate. We collected six sediment cores from the NOW, dated them using ^{210}Pb, corroborated with ^{137}Cs where possible, and analysed down-core profiles of OM kerogen (Rock-Eval 6 analysis), total organic carbon (TOC), total organic nitrogen (TON), δ^{13}C and δ^{15}N. The down-core records were examined for evidence of recent (past 150 years) change.

Sediment OM bulk concentrations (TOC and TON) displayed exponential decreases with water depth reflecting water-column remineralization processes. Using a model to account for sedimentation rate and sediment surface mixing, we found that cores from the interior of the NOW showed no significant change between pre-1900 sediments and post-1900 sediments, and little variance among cores. In contrast, a core from the northwest boundary of the region showed evidence of increased marine organic carbon input, and two cores from the southeast boundary showed evidence of decreased terrigenous carbon input. In addition, the cores at the southeast boundary, on the slope off Greenland, witnessed a significant decline in sedimentation rate during the same time interval. We interpret the change in OM in the boundary cores in the context of change in regional ice climate and runoff. Our results suggest that the margin of this polynya is more vulnerable to change than the interior, and thus is a better location to seek evidence of change. Furthermore, the diversity of settings within NOW indicates that change must be understood at sub-regional scales.

1. Introduction

The Arctic is undergoing rapid change in ice climate (Stroeve et al., 2012) that will lead to changes in biogeochemical cycling (Bates and Mathis, 2009), but these secondary changes remain unclear and hard to predict. Polynyas, which are defined as ocean regions in the Arctic having predictably light ice and open water, are widespread around the Arctic and form special biological habitats sometimes thought of as 'oases' (AMAP, 1998; Tremblay et al., 2006). It appears, therefore, that such places would be especially vulnerable to change in ice climate and, perhaps, be the first regions in the Arctic seas to express such change.

The retreat and advance of sea-ice directly influence biotic and abiotic sedimentation in polar marine environments by altering irradiance levels, stratification and the habitat for primary producers (Nørgaard-Pedersen et al., 1998; Klein et al., 2002; Eicken et al., 2005; Mundy et al., 2005; O'Brien et al., 2006). Furthermore, change in ice affects nutrient supply and sediment transport (Nørgaard-Pedersen et al., 1998; Intergovernmental Panel on Climate Change (IPCC), 2001; ACIA, 2005; Mundy et al., 2005). Despite a rudimentary assumption that ice affects biogeochemical cycling, there remains a sparse body of evidence to infer exactly how change in ice cover might affect marine biological systems, or whether these systems may have already changed during the last century (Hamel et al., 2002). For the Baffin Bay region in particular, the discharge of freshwater and sediments associated with an increase in rate of loss of coastal glacial ice mass in Greenland (Lemke et al., 2007) provides another factor that could affect biogeochemical cycling in the NOW.

Arctic marine systems vary widely in seasonal ice cover, stratification, riverine influence and geographic setting, suggesting that the effect of climate change on annual primary production similarly varies (Slagstad et al., 2011). To predict the biogeochemical consequences of

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future variations in ice dynamics in Arctic marine regions, it is essential that we understand how large-scale changes in ice conditions will affect the production of labile carbon in the surface ocean and the export of organic matter (OM) to pelagic and benthic systems.

Significant progress has been made in the classification of OM sources using bulk properties like carbon and nitrogen stable isotope composition ($\delta^{13}C$, $\delta^{15}N$), elemental ratios (C/N), and specific biomarkers (e.g., Schubert and Calvert, 2001; Belt et al., 2007; Macdonald et al., 2008; Kuzyk et al., 2010). Though some researchers have catalogued the spatial distribution of OM in surface sediments in the North Water Polynya (NOW: 75–79°N, 68–80°W; Fig. 1) (Hamel et al., 2002), few have examined temporal changes of OM in modern and historical NOW sediments as reflected by multiple organic markers (e.g., Rock-Eval 6 determinations, and C and N concentrations and stable isotope ratios (e.g., see Vare et al., 2009)).

In this paper, we present evidence of recent change in the organic system associated with the NOW using organic markers in six marine sediment cores collected from sites ranging from the shallow northern portion of the polynya to the slope at its southern boundary. Sediments have been dated using ^{210}Pb and ^{137}Cs, and core sections analysed for kerogen (Rock-Eval 6), total organic carbon (TOC), total organic nitrogen (TON), and bulk stable isotopic composition for organic carbon ($\delta^{13}C$) and total nitrogen ($\delta^{15}N$). Changes observed at the century scale in some of the cores have been evaluated in the context of changes in sea-ice and runoff.

2. Methods

2.1. Regional setting

The NOW, a region of seasonal light-ice cover spanning 50,000 km^2 to 80,000 km^2, is distinct from greater Baffin Bay (770,000 km^2), which is ice covered for much of the year. Generally, the NOW (Fig. 1a) begins to open in mid to late April, in weeks 16–20, as the Smith, Jones, and Lancaster Sound polynyas amalgamate (Mundy and Barber, 2001). The remainder of Baffin Bay is clear of ice by mid-September. Freeze-up proceeds principally as a mirror of break up, commencing along the Ellesmere Island coast in late October (Melling et al., 2001; Bâcle et al., 2002). The region also lies in the path of icebergs, which are shed predominantly from the Greenland continent and entrained into the WGC where they move northward and secondarily from Ellesmere Island where they move southward (Newell, 1993).

Water masses in the NOW and Baffin Bay derive from the Pacific, Arctic, and Atlantic Oceans and are modified by local sea-ice production and melt and by river runoff (Alkire et al., 2010). The distribution and structure of these water masses vary with surface forcing, topographically-induced mixing, and bottom water friction (Bâcle et al., 2002). Pacific water (via the Bering Strait) and Arctic Ocean water enter Baffin Bay through the Canadian Arctic Archipelago and Nares Strait, or may be delivered through Davis Strait within the West Greenland Current (WGC; Fig. 1a) (Cullen et al., 2001; Bâcle et al., 2002). Warmer Atlantic Ocean water also enters the Bay as a sublayer of the WGC, impinging on the NOW from the southeast (Fig. 1a). The supply of water and mixing of the various water masses within the NOW then influences nutrient source and availability, primary production, the delivery of terrigenous matter and, indirectly, the length and timing of the sea-ice seasons.

2.2. Sample collection

In the summer of 2008, as part of the ArcticNet Amundsen expeditions, sediment box cores were collected at 6 locations in the NOW and northern Baffin Bay (Fig. 1b). Cores were sub-sectioned aboard ship at 0.5 cm intervals for the first 10 cm and 1 cm intervals thereafter. Samples were frozen at −40 °C in Whirlpak™ bags until freeze-drying and sub-sampling for analysis at the University of Manitoba.

2.3. Radioisotope analysis

Profiles of ^{210}Pb, ^{226}Ra, and ^{137}Cs activity (Fig. 2) were determined at the Environmental Radiochemistry Laboratory, University of Manitoba, Winnipeg, Canada. The ^{137}Cs and ^{226}Ra were counted for 48 h on a Hyper-pure Germanium Crystal Gamma-Ray Spectrometer Detector to produce a counting error of ~7%.

Total ^{210}Pb activity was determined by leaching sediment samples with 6 N HCl in the presence of ^{209}Po and autoplated on a silver disc (Flynn, 1968). Supported ^{210}Pb activity was determined from the decay rate of ^{226}Ra (determined for 3 samples selected from the top, middle and bottom portions of the cores). The slope of the ^{226}Ra activity was used to assign an appropriate supported ^{210}Pb activity for each section of the core and this was subtracted from the total ^{210}Pb to provide the excess ^{210}Pb ($^{210}Pb_{ex}$).

Errors for ^{137}Cs and ^{226}Ra were estimated by analysing International Atomic Energy Agency (IAEA) (01 and 02) reference soil samples, and ^{209}Po tracers were calibrated against a ^{210}Po NIST standard (Isotope Product Laboratories, #6310) for ^{210}Pb. Reference values for ^{137}Cs averaged 0.12 ± 0 dpm g^{-1}. Reference values for ^{210}Pb, IAEA-01 and -02

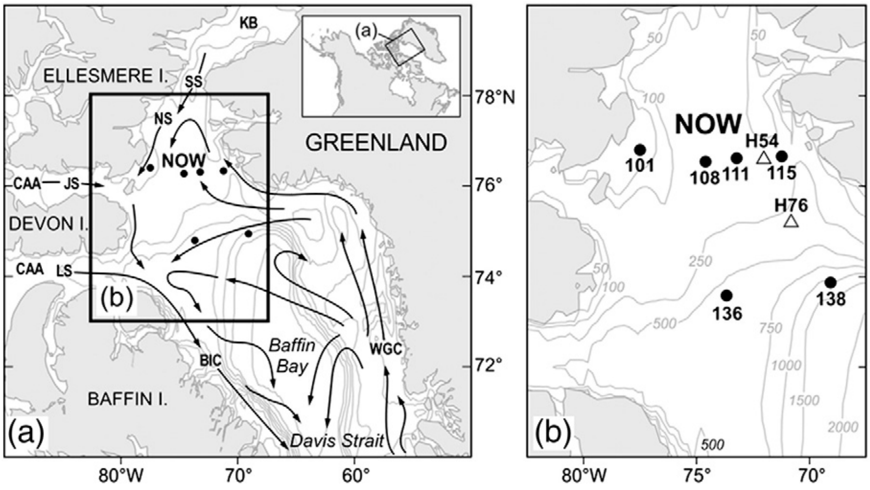

Fig. 1. Chart of the study area (a) and locations of sampling sites (b). Surface water circulation is indicated with black arrows and bathymetry with grey lines and text. Abbreviations: The North Water Polynya (NOW); Smith Sound (SS); Lancaster Sound (LS); Jones Sound (JS); Kane Basin (KB); Canadian Arctic Archipelago (CAA); West Greenland Current (WGC); and the Baffin Island Current (BIC). Open triangles (H54, H76) mark the two locations cored by Hamel et al. (2002) as discussed in the text.