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Multi-proxy study of primary production and paleoceanographical conditions in northern Baffin Bay during the last centuries

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ABSTRACT

As polynyas are often used around the globe as a window on tomorrow's marine polar ecosystems, this study presents reconstructions of primary production and sea-surface conditions near the North Water polynya, since ~1560 CE from palynological, isotopic and biomarker analyses of a sediment core. Quantitative reconstructions of sea-surface conditions (temperature, sea-ice cover and production) were derived from the Modern Analogue Technique (MAT) applied to dinoflagellate cyst assemblages. Production was also qualitatively estimated from the stable isotope composition of organic carbon and nitrogen and the concentration of organic biomarkers (IP_{25}, dinosterols). The results show relatively stable oceanographic conditions but suggest a slight warming accompanied by an increase in productivity after 1860 CE. The comparison of MAT reconstructions and the organic biomarker data suggests that IP_{25} provides information about primary production associated with sea-ice but does not unequivocally reflect sea-ice concentration in this regional setting, which is marked by dense seasonal sea ice except during the short summer season.

1. Introduction

Because polynyas are sensitive to regional changes resulting from global changes, they are sometimes compared to the 'Canaries in Coal Mines' regarding the forthcoming global warming (Barber et al., 2001a). These areas of open water or thin ice cover surrounded by the pack ice, which reappear annually, are sensitive to the changing conditions in the atmosphere and the ocean (Smith et al., 1984). Not only are they interesting cases of ocean setting, but they are also important for the health of high-latitude marine ecosystems (Stirling et al., 1981). The reduced ice cover in polar regions allows for more sunlight to reach the ocean and thereby enhances primary production and facilitates the feeding of marine mammals and seabirds (Melling et al., 2001). These important features explain why systematic studies have been undertaken on polynyas around the globe as a window on tomorrow's marine polar ecosystems.

In northern Baffin Bay, North Water Polynya was the target of a research project (NOW) between 1990 and 2002 within the scope of the International Arctic Polynya Program (IAPP). Several studies summarized by Tremblay et al. (2006) show that the North Water is one of the most productive regions of the Arctic. For example, the region is subject to massive diatom blooms in the spring (Lewis et al., 1996). The possible causal link between the high primary production in the region and the presence of the megafauna (Dunbar, 1981), as well as the fate of the organic carbon produced in surface waters, were the main focus of the NOW program. Results have shown that the high plankton productivity in the polynya supports the pelagic herbivore fauna, but the fate of dissolved organic carbon (DOC) derived from biological production in surface waters of the North Water Polynya and its subsequent transformations remains uncertain (Tremblay et al., 2006).

The paleoceanographic campaign HU-2008-029 was undertaken in the summer of 2008 in Baffin Bay, notably in order further explore these issues. Samples of the water column and sediments were collected with the specific objectives of (i) quantifying the relationship between particle fluxes (biogenic and detrital) to the sea floor and ocean conditions (productivity, current, temperature, salinity, etc.), (ii) developing proxies for the reconstruction of changes in sea-surface conditions and currents, and (iii) evaluating changes in climate and ocean conditions in the eastern Canadian Arctic at time scales ranging from hundreds to thousands of years. In this paper, we report on the analysis of a 46 cm-long box core collected close to the western edge of the North Water region where high sediment accumulation rates ranging around 0.05 to 0.19 cm $year^{-1}$ (Hamel et al., 2002; Mudie et al., 2006) permit high temporal resolution analyses. The box core was analyzed for its organic biomarkers content (IP_{25}, sterols, and alkanes), dinocyst assemblages and isotopic composition ($\delta^{15}N$ and $\delta^{13}C$) in order to characterize the evolution of sea-surface conditions and primary production in the region over the last 500 years.

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2. Regional setting

The North Water polynya in the North Water region (Fig. 1) is characterized by earlier ice-free waters from early April to September, by contrast to adjacent waters of the Canadian Archipelago where ice-free conditions occur between mid-July and mid-August (Fortier et al., 2002). The southern extend of the polynya, tightly coupled with the atmospheric conditions and the timing of formation of a ice bridge at the northern limit of Smith Sound, varies between Jones sounds and the southern limit of Devon Island (Barber et al., 2001c). The August sea surface temperature (SST) near the sampling site is about 2.3 °C. The mean sea ice cover (SIC) is about 7.9 months year^{-1} within the polynya, whereas it is about 11.2 months year^{-1} in the remaining Canadian Arctic Archipelago (Tremblay et al., 2006). The prevailing winds and currents from the north lead to the development of an ice bridge, and less importantly, the warmer water from the West Greenland Current (WGC) and upwelling in the eastern part of the polynya are all responsible for the rapid opening of the sea-ice in spring (Barber et al., 2001b; Melling et al., 2001).

3. Material and method

3.1. Sampling

The box core 2008-029-040 BC (46 cm long) was collected at 580 m water depth close to the western edge of the North Water region in northern Baffin Bay (75.58° N, 78.63° W; Fig. 1) during the sampling campaign HU2008–029 (Campbell and de Vernal, 2009). According to the remote sensing monitoring of the region between 1979 and 1976 analyzed by Barber et al. (2001a, 2001b, 2001c), the sampling site, located outside the initial small size of the polynya, is generally rapidly annexed (in May) and might allow to record its extent over time. The core was subsampled at 1-cm intervals. Each subsample was divided into three for palynological, isotopic and organic geochemical measurements. The subsamples were stored at 4 °C except those for analyses of biomarkers which were stored at −20 °C.

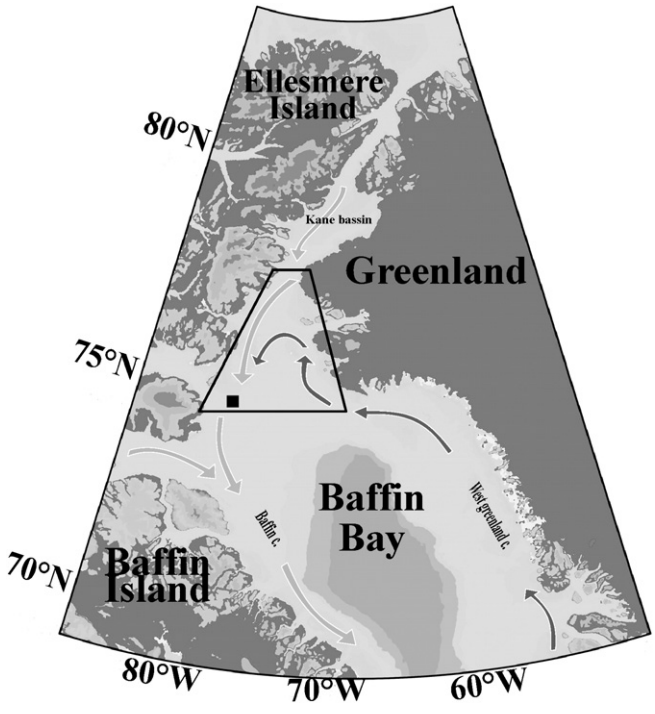

Fig. 1. Location of the study area in Baffin Bay. The black square indicates the location of the 46 cm-long core HU-2008-029-040 BC (75.58° N, −78.63° W, water depth = 580 m). The zone defined by the back line corresponds to the North Water region. The arrows represent the West Greenland Current and the Baffin Island Current.

3.2. ^{210}Pb and ^{14}C measurements

The chronostratigraphy of the studied sequence was determined from ^{210}Pb measurements performed at GEOTOP center and three AMS-^{14}C dates of carbonate shells were measured at the Lawrence Livermore National Laboratory. The total activity profile of ^{210}Pb ($^{210}Pb_{tot}$) in the sediments was inferred by measuring the daughter element, ^{210}Po, by α spectrometry.

3.3. Palynological analyses

3.3.1. Sample preparation and microscopy

Each sample was treated using a standardized palynological treatment method as described by Rochon et al. (1999). Approximately 5 cm^3 of wet sediment was sieved through two Nitex® membranes of 100 and 10 μm mesh size. A capsule of *Lycopodium clavatum* spores with a known concentration (12,100 ± 1892 spores/tablet: batch #414831) was added to the samples prior to sieving to assess the palynomorph concentrations, which are expressed as number of cyst per gram of dry sediment (cyst g^{-1} dry sediment). Percentage of water in the sediments throughout the core was estimated by weighing precisely the sediment before and after drying. The sediment fraction between 10 and 100 μm was treated with hot hydrochloric acid (HCl 10%, 4 times for 10 min) to dissolve carbonate particles, alternating with hot hydrofluoric acid (HF 49%, 2 times for 10 min and 1 time for 12 h) to dissolve silica particles. The residue obtained was sieved again on a 10 μm mesh size Nitex® membrane to eliminate the fine particles and fluorosilicates formed during the acid treatments. A few drops of phenol were added to the residue, for the preservation of the sample, which was then stored at 4 °C. Part of this fraction was mounted in glycerin gel for a systematic counting of at least three hundred palynomorphs with a transmitted light microscope (Leica® 5500B) at 400× magnification.

3.3.2. Dinoflagellate cyst nomenclature

Dinocyst taxa were identified using the identification keys in Rochon et al. (1999) and in Radi et al. (2013). The key in Radi et al. (2013) is particularly helpful for the identification of problematic round brown spiny cysts, such as *Echinidinium karaense* vs. *Islandinium* spp., which are abundant in arctic regions.

3.3.3. Paleoenvironmental reconstructions

Quantitative estimates of past sea-surface parameters were reconstructed from dinocyst assemblages using the Modern Analogue Technique (MAT) as described by Guiot and Goeury (1997) with the R software using the procedure described by de Vernal et al. (2005). MAT was performed using the GEOTOP's dinocyst reference database (n = 1429) (de Vernal et al., 2005). The best estimate of each reconstructed parameter that was calculated corresponds to the average weighted inversely to the distance for the five best analogues. Modern environmental data used for reconstructions are sea-surface temperature and salinity values at 10 m depth provided by the 2001 version of the World Ocean Atlas (Conkright, 2002). Seasonal duration of sea-ice cover, defined as the number of months per year with sea-ice coverage >50%, was compiled using the 1953–1990 data set provided by the National Climate Data Centre in Boulder, Colorado. Primary production was computed from satellite observations from the MODerate resolution Imaging Spectroradiometer (MODIS) program (observations from 2002 to 2005) as described in Radi and de Vernal (2008). Validation tests were performed on the 'n = 1429' database in order to assess the error of prediction by dividing the database into verification and calibration data sets. Relationships between estimates and observations are linear, with high correlation coefficients: August Sea-Surface