Quaternary Science Reviews 92 (2014) 269–279

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Oceanographic regimes in the northwest Labrador Sea since Marine Isotope Stage 3 based on dinocyst and stable isotope proxy records

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ARTICLE INFO

Article history:
Received 25 February 2013
Received in revised form
9 December 2013
Accepted 12 December 2013
Available online 7 January 2014

Keywords:
Dinoflagellate cysts
Foraminiferal stable isotopes
Labrador Sea
Late Pleistocene
Sea ice
Sea surface conditions

ABSTRACT

Sea surface temperature (SST), salinity and density gradients in the upper water column of the northwest Labrador Sea have been reconstructed based on high resolution analysis of a core (HU2008-029-004PC) spanning the last ~36 ka, raised off Hudson Strait. The modern analogue technique was applied to dinocyst assemblages and combined with stable isotope data from *Neogloboquadrina pachyderma* left-coiled (Npl) for this purpose. Three oceanographic regimes were identified, broadly corresponding to the "glacial", "deglacial" and "postglacial" intervals. The site remained under the direct influence of the Laurentide Ice Sheet (LIS) margin until the postglacial and did not record the Bølling-Allerød warming and weakly recorded the Younger Dryas event. The "glacial" regime lasted until ~12.2 cal ka BP. It was characterized by generally low concentrations of dinocysts within an assemblage indicative of quasi-perennial sea ice. The "deglacial" regime (ca 12.2–8.3 cal ka BP) was marked by increased biogenic fluxes and more diversified dinocyst assemblages and possibly an enhanced subsurface inflow of North East Atlantic Deep Water. Warm summer (~11 °C) but low winter (~0 °C) sea surface temperatures, sea ice cover during about 3 months per year, and low summer salinity (~28) suggest strong stratification in the upper water layer in relation to meltwater supply from the LIS. Following the final drainage of glacial Lake Agassiz through Hudson Strait, which is dated here at ~8.3 cal ka BP, and the subsequent LIS collapse, increased summer salinity (up to ~35) was accompanied by a reduced seasonal gradient of sea surface temperature from winter (~3.8 °C) to summer (~8.6 °C) suggesting enhanced penetration of North Atlantic Water. Weakened stratification of the surface water layer then allowed for winter convection and Labrador Sea Water formation, which is consistent with increased Npl-$\delta^{13}C$ values in response to higher ventilation of the subsurface water layer.

1. Introduction

Labrador Sea Water (LSW) is an important component of the modern Atlantic Meridional Overturning Circulation (AMOC). The cold winter surface air temperatures above the Labrador Sea cool a western branch of the saline North Atlantic Drift, which sinks due to increased density and forms the intermediate LSW (Lazier, 1973) and contributes to North Atlantic Deep Water (NADW) (Yashayaev and Loder, 2009 and references therein). The rate of LSW formation is variable and responds to both changes in atmospheric circulation and salinity, which affect stratification and therefore convective mixing. As such, periods of warmer climate with increased freshwater flux can inhibit LSW formation. Over one third of Arctic freshwater export presently flows via the Canadian Arctic Archipelago and Nares Strait into the Labrador Sea (Serreze et al., 2006), making Hudson Strait and Davis Strait very important Arctic freshwater pathways (Curry et al., 2011). Therefore any change in temperature and freshwater outflow from the Arctic may modify the LSW production rates as during the Great Salinity Anomaly (e.g., Gelderloos et al., 2012). It may also modify the strength of the AMOC as suggested from modeling experiments (Goosse et al., 1997; Wadley and Bigg, 2002; Cheng and Rhines, 2004). In this context, it is relevant to investigate the past history of water masses and sea ice formation, in relation to freshwater fluxes through the northern Labrador Sea to quantify the potential impacts of future freshwater fluxes and increasing sea surface temperature on the formation of LSW.

Throughout the last glacial cycle, the Labrador Sea has been marked by meltwater supplies from the northeastern margin of the Laurentide Ice Sheet (LIS). Sedimentological and paleoceanographic studies of marine cores from the shelf and slope off Labrador and eastern Baffin Island have permitted to identify phases of LIS margin advance, waning, retreat, and Heinrich Events (Hillaire-Marcel et al., 1994; Andrews et al., 1994b, 1998, 2012; Jennings

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http://dx.doi.org/10.1016/j.quascirev.2013.12.010

et al., 1998; Hillaire-Marcel and Bilodeau, 2000; Rashid et al., 2003; Rashid and Piper, 2007). However, the impact of changing climate and meltwater pulses on the oceanic conditions (temperature, salinity, sea ice cover, upper water mass stratification) has yet to be determined on a regional scale, especially in the northwest Labrador Sea and at the outlet of Davis Strait and Hudson Strait.

For this study, we had access to a new core (HU-2008-029-004) ideally located in the northern Labrador Sea. The core was recovered from mid-slope, about 200 nautical miles east of Hudson Strait and south of Davis Strait. It spans over 36 ka and provides detailed information on the impacts of meltwater pulses from the northeastern margin of the LIS on the regional ocean conditions and northwest North Atlantic circulation. Sea surface temperature (SST), sea surface salinity (SSS), seasonal cover of sea ice, and productivity (gC m^{-2}) were reconstructed from dinocyst assemblages (de Vernal et al., 2001, 2005, 2008, 2013; Radi and de Vernal, 2008). Subsurface dwelling planktonic foraminifera were analyzed for oxygen and carbon stable isotopes to provide complementary information about subsurface temperature and salinity, ventilation, variations in convective mixing and intermediate water formation (e.g., Ravelo and Hillaire-Marcel, 2007), and also information on major meltwater pulses and their impact on sea ice production rates (Hillaire-Marcel and de Vernal, 2008).

2. Modern hydrographic setting and location of core collection

The hydrography of the Labrador Sea is influenced by both relatively warm and saline waters flowing from the south and cold low-salinity waters flowing from the north (Fig. 1). Along the western Greenland margins, the West Greenland Current (WGC), which flows to the north, consists of a mix of the cool and low saline waters (temperature ~ −1.8 °C, salinity ≤ 34.5) carried through the East Greenland Current (EGC) along the shelf. The warm, saline North Atlantic waters (core at 200–700 m, temperature ~ 4.5 °C, salinity ≤ 34.95) that are transported via a western branch of the Irminger Current (IC) flow above the slope (Cuny et al., 2002). Along the Labrador Shelf, the Labrador Current (LC) flows southward. It is formed from the Baffin Island Current (BIC) (temperature ~ −1.5 °C, salinity ≤ 34) and outflow from the Hudson Strait, which both consist of cold and low saline Arctic waters. Along the upper slope, the LC overlies Irminger water that has circulated around Baffin Bay. Below the surface layer, the Labrador Sea Water (LSW; temperature ~ 3.0 °C, salinity ~ 34.9) is formed by vertical convection due to the sinking of dense waters cooled in winter (Lazier, 1973). LSW has depths reaching down to 2500 m above the North East Atlantic Deep Water (NEADW) and the Denmark Strait Overflow Water (DSOW) (Yashayaev, 2007).

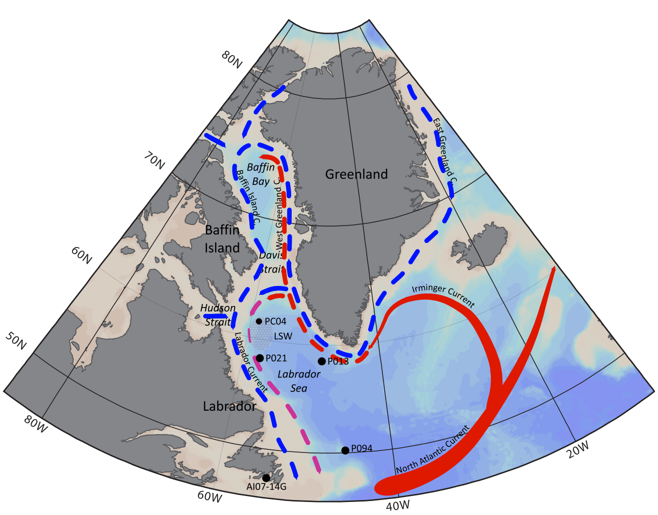

Fig. 1. Map indicating PC04 coring location (895 cm long piston core; 61.46 °N, 58.04 °W; 2163 m water depth), with surface currents (North Atlantic Current (NAC), Irminger Current (IC), East Greenland Current (EGC), West Greenland Current (WGC), Baffin Island Current (BIC), and Labrador Current (LC)). Neighboring cores P013, P021, P094 and AI07-14G are also displayed. Labrador Sea Water (LSW) is formed in the Labrador Sea approximately at the location indicated by the hatched oval.

Piston core HU-2008-029-004 (henceforth PC04) was collected in 2008 off the Southern Baffin Island shelf in the northern Labrador Sea (61.46 °N, 58.04 °W; Campbell et al., 2009) at a water depth of 2163 m (Fig. 1). At the coring site, summer surface waters are predominantly those carried by the WGC (Wu and Tang, 2011). The present mean winter and summer SSTs are 3.7 ± 0.5 °C and 7.3 ± 1.2 °C, respectively, and summer SSS averages 34.2 ± 0.3 (NODC 2001). Sea ice is occasional and occurs only once every 3 years on average. The 1953 to 2003 sea ice compilation using data provided by the National Snow and Ice Data Center (NSIDC) in Boulder CO indicates that the core site has a mean of 0.7 ± 1.3 months per year with more than 50% of sea ice, calculated with observations for 1–5 months per year for 15 years.

3. Methods

The core PC04 is 896 cm in length. Onboard measurements included magnetic susceptibility, spectrophotometry, and sedimentary descriptions, which can be found in the HU2008029 cruise report (Campbell et al., 2009) together with core photographs. The core was not showing any handling disturbance. The working half was sampled onboard at 1-cm intervals. For this study, subsamples were taken at every 4 cm throughout the core, for a total of 220 samples.

The chronostratigraphy of PC04 was established from radiocarbon dates of planktonic foraminiferal populations that consist of >95% *Neogloboquadrina pachyderma* left-coiled (Npl). Accelerator mass spectrometry (AMS) radiocarbon measurements were made at Lawrence Livermore National Laboratory and at the National Ocean Sciences AMS Facility of Woods Hole. Radiocarbon ages were calculated using the Libby half-life of 5568 years and normalized to a $\delta^{13}C$ of −25‰. The ages were converted to calibrated years and modeled using the Marine09 calibration curve (Reimer et al., 2009) with a marine reservoir correction of 400 years in OxCal 4.2 (Ramsey, 2008). No additional correction (ΔR) was made as it was the case for other ^{14}C-based chronologies from planktonic foraminifers in the area (see a discussion in Hillaire-Marcel et al., 2007; supplementary material). We have chosen to use the *p_sequence* model in OxCal, which relies on a Bayesian approach using information that includes the ^{14}C dates, their depths, and the changes in deposition rate for modeling the probability of each age (Ramsey, 2008). This approach was regarded as adequate considering the changes in sedimentary processes related to the dynamics of the LIS margin during glaciation and deglaciation, including Heinrich Events. The resulting age model assumes constant ^{14}C-carrier flux settling through the water column to the bottom, constant habitat (water depth) within and among Npl samples, and homogeneous mixed layer at the sediment–water interface (Berger and Johnson, 1978; Bard, 2001). The calibrated ages are reported as the modeled median cal. years BP (see Table 1).

For palynological preparations, 5 cm^3 subsamples were rinsed and sieved through 106 μm and 10 μm sieves. The dried >106 μm size fraction, which mostly contains detrital material, was weighed as a proxy for ice rafting deposition. It was also used to hand pick foraminifera for stable isotope analyses. The 10–106 μm size fraction was processed following the detailed methods described by de Vernal et al. (1999). The residual organic matter was mounted onto a slide with Kaiser's glycerol gelatin. Palynological analyses were