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Research paper

A multi-proxy reconstruction of oceanographic conditions around the Younger Dryas–Holocene transition in Placentia Bay, Newfoundland

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A B S T R A C T

A marine sediment core from Placentia Bay off the south coast of Newfoundland was studied to reconstruct past oceanographic conditions based on a multiproxy approach, including diatoms, benthic foraminifera, grain size analysis, IP_{25}, X-Ray fluorescence, calcium carbonate and total organic carbon content. Based on 6 radiocarbon dates, the 513.5 cm long core spans the age interval from ca. 13 to 10 cal kyrs BP and thus captures the transition from the Younger Dryas stadial into the Holocene at sub-decadal resolution. The Younger Dryas was characterized by cold Arctic water taxa of diatoms and benthic foraminifera and a stratified water column with high sea ice cover and low productivity due to strong influence of the Labrador Current. During the second half of the Younger Dryas, after ca. 12.2 cal kyrs BP, the influence of the Labrador Current gradually decreased and sea ice conditions became more variable. The transition towards the Holocene is characterized by a sequence of events starting with turnovers in the biogenic proxies followed by an abrupt retreat of sea ice and a rise in productivity. These events are believed to be related to a northward migration of the Gulf Stream–Labrador Current oceanic front. The Younger Dryas termination is directly followed by a detrital carbonate layer associated with the final phase of the Heinrich 0 event, linked to Laurentide Ice Sheet dynamics. During the early Holocene productivity remained high, with minimal sea ice cover, reduced stratification and stronger influence of warmer, Gulf Stream-derived waters.

1. Introduction

The period of transition from the last glaciation into the present Holocene between ca. 14 and 10 cal kyrs BP was characterized by climatic instability with many abrupt fluctuations. The most extreme of these climatic events, in both magnitude and duration, was the Younger Dryas interval, a period of rapid cooling in the Northern Hemisphere between ca. 12.8 and 11.6 cal kyrs BP (Rasmussen et al., 2006). The event is one of the best studied climatic intervals and its origin has been a subject of debate for many years (de Vernal et al., 1996; Alley, 2007; Carlson et al., 2007; Broecker et al., 2010). The cold interval has been proposed to have been triggered by a large freshwater outburst coming from lake Agassiz, disrupting the thermohaline circulation and allowing sea ice to be formed much further south than normal (Broecker, 2006; Murton et al., 2010). Recent studies have indicated that during the course of the Younger Dryas, the Atlantic overturning circulation gradually picked up strength, resulting in a mid-Younger Dryas shift with more unstable conditions during the second half of the interval (Bakke et al., 2009; Lane et al., 2013; Pearce et al., 2013). The termination of the Younger Dryas and transition into the Early Holocene was even more abrupt than the Younger Dryas onset with a change in air temperatures and atmospheric circulation within just a few decades according to Greenland ice core records (Rasmussen et al., 2006).

Analysis of high resolution marine sediment cores from areas sensitive to these changes can be used for detailed reconstruction of past oceanic conditions and to identify the aforementioned variability in circulation patterns. The coastal waters off eastern Newfoundland provide an ideal location for studying such variability. In the north and east this area is influenced by water masses from the North Atlantic subpolar gyre, while in the south it is within reach of the northern extremity of the North Atlantic subtropical gyre. Both gyres play an important role for the climate of the North Atlantic region. The northern sector of the large heart-shaped subpolar gyre is marked by the presence of the East and West Greenland Currents entraining both Polar and Atlantic-derived water masses, whereas the cold Labrador Current transports cold, ice-loaded Polar water south along the Canadian east coast. The warm Gulf Stream–North Atlantic Current and Irminger Current systems characterize the subpolar gyre in the South and East, respectively (Fig. 1). The North Atlantic Current also forms the boundary zone separating the subpolar gyre from the subtropical gyre further to the south (Fig. 1). Our study site is thus located where the cold, relatively fresh Labrador Current water masses meet warm, relatively saline Gulf

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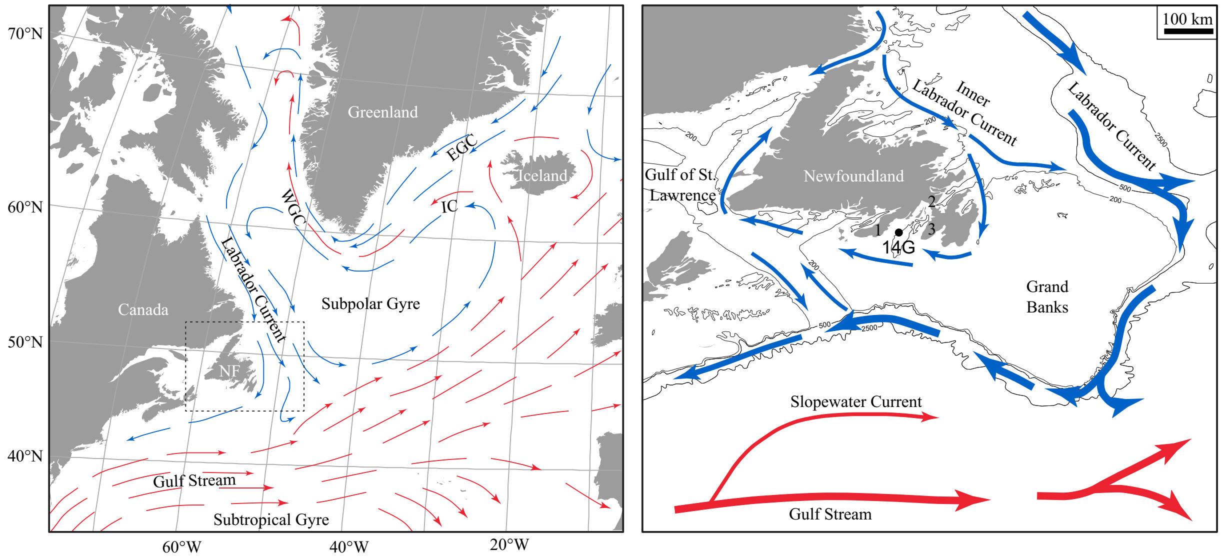

Fig. 1. Left: Surface ocean circulation patterns in the North Atlantic Ocean, dotted rectangle shows area of detailed map around Newfoundland (NF). IC: Irminger Current, EGC: East Greenland Current, WGC: West Greenland Current. Right: Map of coastal waters around Newfoundland with 200, 500 and 2500 m isobaths and location of sediment core AI07-14G in Placentia Bay. 1: Burin Peninsula, 2: Isthmus of Avalon, 3: Avalon Peninsula. Red Arrows: warm surface currents, blue arrows: cold surface currents. For a color figure, the reader is directed to the online version of this manuscript.

Stream-derived water masses. The atmospheric circulation around Newfoundland is characterized by the meeting of cold, polar winds from northerly directions and warmer, southerly winds of subtropical origin (Drinkwater, 1996). The air mass frontal zone between the northerly and southerly winds has been shown to have varied significantly over time (Jessen et al., 2011). This position in the boundary region of large-scale oceanic and atmospheric circulation systems thus makes eastern Newfoundland an ideal location for studying past climatic variability (Jessen et al., 2011; Solignac et al., 2011; Weckström et al., 2013).

The aim of the present study is to provide a detailed reconstruction of variations in the oceanography of this boundary zone during the period ~13–10 cal kyrs BP. Our study is based on multi-proxy investigations of a marine sediment core from Placentia Bay, SE Newfoundland, making it the first marine record of this region to cover the late glacial to Holocene transition at such high resolution. Initial results have been provided by Pearce et al. (2013), but here we show a more detailed reconstruction including significant additional proxy data with special focus on the response of the micropalaeontological communities to the changes in climate and ocean circulation. Hence, to achieve a reliable reconstruction of past environmental variables this study combines several micropaleontological, geochemical and sedimentological analyses on the same sediment record. The applied proxies in the present study include both surface and bottom water indicators (diatoms and benthic foraminifera), grain size measurements, the sea ice biomarker IP_{25}, and several other geochemical parameters.

The molecular biomarker IP_{25}, an organic compound that is biosynthesized only by diatoms living in the sea ice, is resistant to degradation in sediments and is thus a useful indicator of past seasonal sea ice presence (Belt et al., 2007; Belt and Müller, 2013). It has been previously applied in the same area where it was proven to be a reliable sea ice indicator when compared with local instrumental observations (Weckström et al., 2013). Absolute abundances of microfossils (diatoms and benthic foraminifera) in combination with calcium carbonate and total organic carbon measurements are used here as paleoproductivity indicators. Diatoms have been used in many studies in the North Atlantic as indicators of past sea surface conditions as temperature and sea ice cover, owing to their high abundance in surface waters and generally good preservation in sediments (Lapointe, 2000a, 2000b; Jiang et al., 2002; Jensen et al., 2004; Koç et al., 2013). The presence of freshwater or brackish diatom taxa in the marine environment can also be used to indicate freshwater output from land or melting ice. To examine bottom water conditions, benthic foraminifera are excellent proxies, often used in paleoceanographical studies and can provide further information on ice proximity and nutrient availability and can be characteristic of water masses, ocean currents and various physical properties (e.g. Murray, 1991, 2006; Rytter et al., 2002; Seidenkrantz, 2013). Using a combination of both planktonic and benthic proxies can thus provide a more complete reconstruction of past oceanic conditions.

2. Regional setting

Placentia Bay is located in the southeast of the island of Newfoundland. It is bordered by the Avalon Peninsula to the east, the Burin Peninsula to the west and the 5 km narrow Isthmus of Avalon to the North (Fig. 1). The bay is approximately 130 km long and 100 km wide at its seaward opening in the south. Water depth in the bay locally exceeds 400 m, and the bathymetry is characterized by glacial features such as drumlins, flutes and mega-lineations (Brushett et al., 2007; Shaw et al., 2013). Following the last glacial maximum, relative sea level in eastern Newfoundland initially fell and subsequently rose to modern level (Liverman, 1994). The hydrography of Placentia Bay is dominated by the cold Inner Labrador Current flowing south over the Labrador Shelf, although the bay does also receive some input of relatively warm and saline Gulf Stream-derived waters from the Slopewater Current (Petrie and Anderson, 1983; Csanady and Hamilton, 1988; Catto et al., 1999, 2003; Pickart et al., 1999). Drift material originating from the Gulf Stream is commonly found in the bay (Catto et al. 1999) and recent studies have suggested that during the early Holocene Placentia Bay may have been more influenced by the Gulf Stream than today (Shaw et al., 2013). Surface water circulation in the bay is cyclonic with northward flow along the eastern edge and southward flow along the west (Schillinger et al., 1999). The climate of Placentia Bay is classified as mid-boreal, with mean air temperatures of −4 °C in January and 16 °C in July. Winds are strongest during winter, coming from the west to north-west, compared to calmer westerly to south-westerly winds in summer (Drinkwater, 1996). Sea surface temperatures in Placentia Bay show very strong seasonality and vary between 0 and 15 °C (Locarnini et al., 2010), and sea ice is rare and only present during the coldest winters (Canadian Ice Service, 2014). Although sea