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Baffin Bay paleoenvironments in the LGM and HS1: Resolving the ice-shelf question

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A B S T R A C T

Core HU2008029-12PC from the Disko trough mouth fan on the central West Greenland continental slope is used to test whether an ice shelf covered Baffin Bay during the Last Glacial Maximum (LGM) and at the onset of the deglaciation. We use benthic and planktic foraminiferal assemblages, stable isotope analysis of planktic forams, algal biomarkers, ice-rafted detritus (IRD), lithofacies characteristics defined from CT scans, and quantitative mineralogy to reconstruct paleoceanographic conditions, sediment processes and sediment provenance. The chronology is based on radiocarbon dates on planktic foraminifers using a ΔR of 140 ± 30 ^{14}C years, supplemented by the varying reservoir estimates of Stern and Lisiecki (2013) that provide an envelope of potential ages. HU2008029-12PC is bioturbated throughout. Sediments between the core base at 11.3 m and 4.6 m (LGM through HS1) comprise thin turbidites, plumites and hemipelagic sediments with Greenlandic provenance consistent with processes active at the Greenland Ice Sheet margin grounded at or near the shelf edge. Abundance spikes of planktic forams coincide with elevated abundance of benthic forams in assemblages indicative of chilled Atlantic Water, meltwater and intermittent marine productivity. IRD and IP_{25} are rare in this interval, but brassicasterol, an indicator of marine productivity reaches and sustains low levels during the LGM. These biological characteristics are consistent with a sea-ice covered ocean experiencing periods of more open water such as leads or polynyas in the sea ice cover, with chilled Atlantic Water at depth, rather than full ice-shelf cover. They do not support the existence of a full Baffin Bay ice shelf cover extending from grounded ice on the Davis Strait. Initial ice retreat from the West Greenland margin is manifested by a pronounced lithofacies shift to bioturbated, diatomaceous mud with rare IRD of Greenlandic origin at 467 cm (16.2 cal ka BP; $\Delta R = 140$ yrs) within HS1. A spike in foraminiferal abundance and ocean warmth indicator benthic forams precedes the initial ice retreat from the shelf edge. At the end of HS1, IP_{25}, brassicasterol and benthic forams indicative of sea-ice edge productivity increase, indicating warming interstadial conditions. Within the Bølling/Allerød interstadial a strong rise in IP_{25} content and IRD spikes rich in detrital carbonate from northern Baffin Bay indicate that northern Baffin Bay ice streams were retreating and provides evidence for increased open water, advection of Atlantic Water in the West Greenland Current, and formation of an IRD belt along the W. Greenland margin.

1. Introduction

Last Glacial Maximum (LGM) climatic and oceanic conditions in Baffin Bay are currently poorly known, but according to the temperature reconstructions from the Greenland Ice Sheet borehole (Dahl-Jensen and Al, 1998) and ice-core data (Buizert et al., 2014), summit temperatures were ~20 °C colder than present. Applying this temperature difference down to sea level using the adiabatic lapse rate,

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suggests that the annual temperature at the surface of Baffin Bay adjacent to Baffin Island would approach − 36 °C. Such cold temperatures support the argument that cold-based ice covered the forelands of eastern Baffin Island (Briner et al., 2003) with "Antarctic-like" conditions across Baffin Bay, which would also suggest that Baffin Bay was covered in perennial sea ice. At the LGM, confluent, Innuitian (IIS), Laurentide (LIS) and Greenland (GIS) ice sheets (England et al., 2006) blocked the channels that connect Baffin Bay to the Arctic Ocean (Dyke et al., 2002) and terminated in northern Baffin Bay as large ice streams (Li et al., 2011; Blake, 1977). The Greenland Ice Sheet reached the continental shelf edge via large ice streams off west Greenland (Ó Cofaigh et al., 2013a; Jennings et al., 2017; Slabon et al., 2016; Sheldon et al., 2016; Dowdeswell et al., 2014), but the outer limits of the ice on the Baffin shelf are not known.

On the basis of modeling, it has been proposed that Baffin Bay was blocked at its southern end by an ice shelf extension of the Hudson Strait ice stream that grounded across Davis Strait to reach southern Greenland, thus sealing Baffin Bay from the Labrador Sea (Hulbe, 1997; Álvarez-Solas et al., 2010; Marcott et al., 2011). This ice shelf was the starting point for modeling the processes that produce Heinrich events (Hulbe, 1997; Álvarez-Solas et al., 2010; Marcott et al., 2011), but physical evidence for it has not been recovered. An ice shelf of this scale would have environmental consequences that should be recorded in Baffin Bay sediments. Firstly, grounding of a Labrador Sea ice shelf along Davis Strait would prevent seawater exchange between Baffin Bay and the Labrador Sea, excluding advection of organic matter into Baffin Bay. It also would shut down in situ primary marine productivity in Baffin Bay so that planktic and benthic organisms, their biomarkers, and bioturbation would be absent in the sediment. Secondly, ice shelves and even extensive sea-ice cover are known to restrict the movement and export of icebergs (Reeh et al., 2001; Domack and Harris, 1998). Thus iceberg rafting and mixing of sediments of various provenances in Baffin Bay would be reduced. Using these concepts, we test the LGM Baffin Bay ice-shelf hypothesis by studying the sedimentological and biological characteristics of sediments in HU2008029-12PC from the continental slope off western Greenland, a core that extends from the LGM into the Younger Dryas (YD) and that recorded retreat of the Greenland Ice Sheet during deglaciation (Jennings et al., 2017).

2. Setting of core HU2008029-12PC

Detailed studies of LGM and deglacial environments in Baffin Bay have been hampered by relatively slow sediment accumulation rates and poor calcium carbonate preservation (cf. Aksu, 1985; de Vernal et al., 1992; Simon et al., 2012). HU2008029-12PC (hereafter called 12PC) was raised from the northern side of the Disko trough mouth fan (TMF) from acoustically stratified sediments with continuous parallel reflections on the eastern side of Baffin Bay (68°13.69′ N; 57°37.08′ W; 1475 m water depth; Campbell and de Vernal, 2009) (Figs. 1 and 2). This site on the trough mouth fan has higher sediment accumulation than sites in the deep basin of Baffin Bay that have variable sedimentation rates that range between 3 and 35 cm/ka (Andrews et al., 1998; Hillaire-Marcel et al., 1989; Hillaire-Marcel and de Vernal, 2008; Simon et al., 2012, 2014) (Fig. 1).

The Disko TMF was built throughout the Quaternary by rapid sediment deposition in front of the fast flowing Disko ice stream (Fig. 1) when the GIS margin was extended on the shelf, and from hemipelagic sedimentation during and after ice retreat (Ó Cofaigh et al., 2013a, 2013b; Jennings et al., 2017; Hofmann et al., 2016). An ice sheet grounded at or near the shelf edge delivers abundant sediments directly to the continental slope in the form of sediment gravity flows, including turbidity currents that form graded sand layers, stratified sand/silt beds, and glacigenic debris flows (Ó Cofaigh et al., 2013a, 2013b; Lucci and Rebesco, 2007). Turbid meltwater plumes released from the ice front produce plumites, which are finer grained than the turbidites as the sand is dropped near the ice front and the silt and clay continue offshore in suspension (Hesse et al., 1997; Lucci and Rebesco, 2007). Depending on sea surface conditions such as perennial sea ice and/or ice shelves, icebergs would also deliver sediment to the slope as they melted during their transit in Baffin Bay (Andrews et al., 1998, 2014; Jennings et al., 2014; Simon et al., 2012, 2014, 2016; Sheldon et al., 2016).

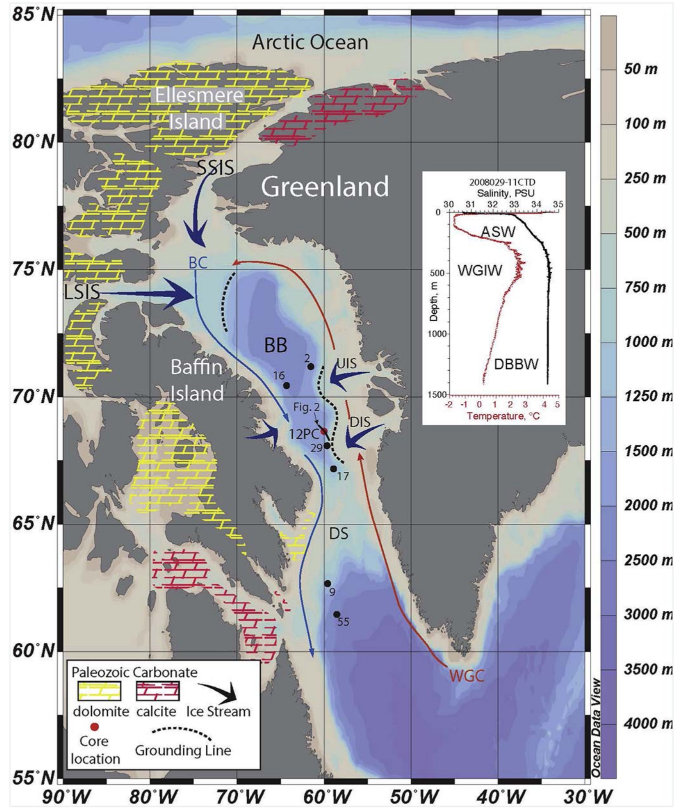

Fig. 1. Bathymetric map centered on Baffin Bay (BB) showing the location of core HU2008029-12PC (12PC) and other cores mentioned in the text, the distribution of Paleozoic carbonate bedrock, mapped ice margin positions in northern Baffin Bay (Li et al., 2011) and central west Greenland (Ó Cofaigh et al., 2013a) and major ice streams. UIS = Uummannaq ice stream; DIS = Disko ice stream; SSIS = Smith Sound ice stream; LSIS = Lancaster Sound ice stream. Northward flowing West Greenland Current (WGC) is shown as the thin red line and the southward flowing Baffin Current (BC) is shown as a thin blue line. The position of the acoustic profile in Fig. 2 is shown as a black line. HU2008029-016PC = 16; HE006-4-2PC = 2; JR175-VC29 = 29; HU77029-017PC = 17; HU75009-IV-055PC = 55 and HU87033-009 LCF = 9. Inset plot shows the salinity and temperature against water depth at from the same location as 2008029-12PC. ASW = Arctic Surface Water; WGIW = West Greenland Intermediate Water; DBBW = Deep Baffin Bay Water. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The modern sea ice edge extends southeast to northwest within Baffin Bay and sea ice cover is greater in the western than in the eastern half due to the influence of the relatively warm and saline West Greenland Current that enters Baffin Bay from the southeast (Tang et al., 2004; Münchow et al., 2015) (Fig. 1). The boundary between lower salinity, sea-ice bearing, Arctic Surface Water (ASW) that passes from the Arctic Ocean through the channels of the Canadian Arctic Archipelago into Baffin Bay and Atlantic Waters of the West Greenland Current (WGC) moving northward along West Greenland is oriented NE-SW and migrates through the year. The relatively warm, saline Atlantic Water submerges beneath the ASW (Buch, 2000a, 2000b) and forms the West Greenland Intermediate Water (WGIW) (Fig. 1 inset) (Tang et al., 2004). During the LGM, however, the circulation regime in Baffin Bay would have been different because the southward flow of ASW into Baffin Bay was blocked by confluent ice sheets grounded in the channels of the Canadian Arctic Archipelago until the early Holocene (England, 1999; Zreda et al., 1999; Jennings et al., 2011;