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11,000 yrs of environmental change in the Northwest Passage: A multiproxy core record from central Parry Channel, Canadian High Arctic

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ABSTRACT

Piston core 97022-004PC (74° 48.0′N 97°05.9′W; 267 m water depth) represents a rare paleoenvironmental archive from the understudied west-central Canadian Arctic Archipelago. Lithological, biogeochemical, and microfossil (dinoflagellate cysts, non-pollen palynomorphs, benthic and planktonic foraminifera) characteristics, in combination with a chronostratigraphy based on seventeen radiocarbon dates, show seven prominent paleoenvironmental episodes since the end of the last regional glaciation. The basal diamict (Zone I) records decoupling of previously grounded glacial ice, followed by ice-proximal conditions (Zone IIa) commencing at ~10.8 cal ka BP (age-depth model extrapolation). After an interval of pervasive sea-ice (Zone IIb), ice-distal conditions are established (Zone IIc). Although sparse microfossils are present in glaciomarine sediments (Zone II), noticeable biological activity with heightened abundances and diversities across all groups begins in the postglacial Zone III (10.3–10.0 cal ka BP) when planktonic foraminifera (*Neogloboquadrina pachyderma*) appear. As planktonics are excluded from the study area today (due to shallow inter-channel sills), this likely signals the inflow of relatively warm and saline Atlantic-derived Arctic Intermediate Water below 250 m, presumably facilitated by glacio-isostatically enhanced deglacial water depths. The subsequent Zone IV (10.0–7.0 cal ka BP), characterized by heightened biological productivity in both plankton and benthos and reduced seasonal sea-ice cover, may correspond to a previously proposed Holocene Thermal Maximum. This apparent amelioration ends by the mid Holocene (Zone V; 7.0–5.7 cal ka BP) when Arctic Intermediate Water is excluded from the study area and water depths approach modern values. High-Arctic conditions with seasonal sea-ice cover, a circulation dominated by Arctic Ocean Surface Water, and microfossil assemblages similar to modern are found from ~5.7 cal ka BP onwards (Zones VI–VII). As only minor environmental fluctuations are apparent during the late Holocene, shorter-term climatic episodes (e.g. Little Ice Age) are not recognized in this record.

1. Introduction

The Canadian Arctic Archipelago (CAA; Fig. 1A) occupies a fundamental role in global oceanographic circulation, freshwater budgets, and ecosystems (Melling, 2000; Munk, 2003; ACIA, 2005). Like other Arctic regions, marine and terrestrial CAA environments have shown recent shifts, including: sea-level rise, sea-ice decline, and increasing mean annual temperature (ACIA, 2005; IPCC, 2007). Longer term (pre-instrumental measurement) variability is also suggested by regional marine records (MacLean and Vilks, 1986; MacLean et al., 1989; Mudie et al., 2005; Richerol et al., 2008; Schell et al., 2008a; Scott et al., 2009; Vare et al., 2009; Belt et al., 2010; Gregory et al., 2010; Ledu et al., 2010a, 2010b; Pieńkowski et al., 2011; Melling et al., 2012; Pieńkowski et al., 2012), which provide a long-term context for current environmental changes (Bradley and England, 2008; England et al., 2008; Polyak et al., 2010; White et al., 2010). However, the spatial coverage of records from the marine CAA ("Northwest Passage" = NWP; Fig. 1) remains limited, and important deglacial–postglacial changes (Laurentide–Innuitian ice sheet decoupling, meltwater outflow, sea-level fluctuations) have been primarily terrestrially-derived (e.g. Hodgson and Vincent, 1984; Dyke and Prest, 1987; Bradley, 1990; Dyke et al., 1991; Gajewski, 1995; Dyke et al., 1996a, 1996b; Dyke, 2004; England et al., 2006, 2009).

To improve the spatial and temporal resolution of CAA marine data, we present a chronologically well-constrained, long-term record from west-central Parry Channel, extending to deglaciation (~11 cal ka BP), from a critical decoupling zone between Innuitian and Laurentide ice sheets (Dyke, 2004; England et al., 2006). Core 9722-004PC (Fig. 1) was studied for lithology, macro- and microfossils; previous work on this record includes a qualitative foraminiferal assay and eight ^{14}C dates (Blasco et al., 2005). This study elucidates the regional marine

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environmental changes, focusing on the deglacial to early postglacial interval, complementing and expanding the terrestrial record and advancing our understanding of the late Quaternary evolution of Arctic North America.

2. Regional setting

Parry Channel, the main geographic NWP axis (Pharand, 1984), comprises several interlinked waterways. Barrow Strait is flanked to the west by Viscount Melville Sound and M'Clure Strait, and to the east by Lancaster Sound (Fig. 1A). Net circulation is southeastward from the western Arctic Ocean (Canada Basin) to Baffin Bay, though both Pacific- and Atlantic-origin waters occur within the CAA (Ingram and Prinsenberg, 1998; Michel et al., 2006). Modern circulation is controlled by numerous shallow sills limiting deep water inflow. The Lowther–Young islands sill (~125 m; Fig. 1B) permits Arctic Ocean Surface Water (AOSW; Melling, 2000; Melling et al., 2012) throughflow from Canada Basin but restricts entry of Arctic Intermediate Water (AIW; Atlantic origin, >200–250 m; Jones, 2001) to Lancaster Sound and M'Clure Strait (Jones and Coote, 1980; Coote and Jones, 1982; Tang et al., 2004). Pacific-derived AOSW occurs throughout Barrow Strait (Jones et al., 2003; Michel et al., 2006) whereas Atlantic water flows westward into Parry Channel (Baffin Bay Atlantic Water = BBAW; Leblond, 1980; Rudels, 1986), mixing with eastward-flowing Barrow Strait AOSW (BBAW/AOSW; Tang et al., 2004; Michel et al., 2006).

Piston core 9722-004PC was recovered in northwestern Barrow Strait adjacent to McDougall Sound (Fig. 1B). The site receives AOSW via Viscount Melville Sound (west) and Penny Strait (north), whose waters are more saline and colder (>32.8 salinity, −1.77 °C at 10 m depth; Prinsenberg and Bennett, 1987). Warmer, fresher water which flows in via Peel Sound (south; Fig. 1A) diverges eastward, around northern Somerset Island (Prinsenberg and Bennett, 1987). Strong tidal currents (50–150 cm/s) around shallow sills contribute to waters mixing *en route* to Baffin Bay (Melling, 2000). First-year fast ice dominates this region, with freeze-up in late September/early October and break-up by mid-July (Pharand, 1984; Barry, 1993; Michel et al., 2006). Open water allows multi-year pack-ice to enter western Barrow Strait via McDougall Sound (Melling, 2002), as observed recently (Michel et al., 2006; Howell et al., 2009).

3. Materials and methods

3.1. Core materials & sediment properties

Piston core 9722-004PC ("004PC"), retrieved at 74° 48.0′N 97°05.9′ W (267 m water depth; Fig. 1B) by the Geological Survey of Canada (GSC)-Atlantic (Hurlbut, 1997), consists of ~400 cm of massive silty clay overlying laminated clays (404–453 cm) and diamicton (453–523 cm; Fig. 2). Similar sediment sequences have been interpreted as i) massive, fine-grained postglacial sediments overlying; ii) ice-proximal to -distal laminated glaciomarine sediments deposited by a retreating grounded glacier and/or beneath ice shelves; and iii) "glacial drift" — till derived from grounded ice or ice-proximal deposition (MacLean et al., 1989; Andrews et al., 1991; Pieńkowski et al., 2012).

Magnetic susceptibility (MS), density and grain size (Beckman Coulter LS230 laser diffraction instrument; range 0.4–2000 μm) were measured at GSC-Atlantic. Percentages of lithoclasts >125 μm to 2 mm and >2 mm relative to total dry weight were used to determine coarse sediment input and ice rafting (either glacial or sea-ice). For biogenic silica (BioSil) content (%), oven-dried (45 °C) and powdered sediment samples (~2 g) were measured by the Pacific Centre for Isotopic and Geochemical Research (University of British Columbia) following Mortlock and Froelich (1989). Sedimentation rates were derived from the age-depth model (Section 3.3).

3.2. Chronostratigraphy

Seventeen AMS (Accelerator Mass Spectrometry) ^{14}C dates were obtained (Table 1; eight pre-existing, nine new dates) and all were calibrated in CALIB 6.0 (Stuiver et al., 2013), using Marine09 (Reimer et al., 2009), and a CAA ΔR of 335 ± 85 yrs (Coulthard et al., 2010). Dates older than the Last Glacial Maximum (LGM; >18 ^{14}C ka BP) fall beyond, and hence preclude the use of, the Marine09 curve.

Seven radiocarbon dates were based wholly or partially on identified deposit-feeding molluscs (*Yoldiella* spp., *Yoldia* sp.; Ockelmann, 1958), which suffer non-systematically from enhanced apparent age effects ('Portlandia Effect') due to uptake of 'old' detrital carbon from carbonate bedrock (cf. Forman and Polyak, 1997; England et al., 2012). As expected, most of these dates plot older than the age-depth curve, and were excluded from age-depth model construction; nonetheless, they are plotted (Fig. 2) for comparison with non-Portlandia Effect samples. At 395–397 cm depth, dates on detrital-feeding molluscs and benthic and planktonic foraminifera allow direct comparison between different materials (Table 1). The two *Yoldiella fraterna* dates are consistently older than foraminiferal dates (as expected) though a ~380 cal yrs difference exists between benthic and planktonic foraminiferal dates, the benthic *Islandiella norcrossi* appearing older. Such differences may arise from time averaging, species-specific effects, or watermass ventilation histories (depth-variable ΔR).

For further comparisons of the 004PC chronology with regional (raised marine) ages, previously published dates were calibrated using the same protocol (above). Where appropriate, such land-based dates were first "de-corrected" for prior reservoir correction (GSC dates post 1992; Coulthard et al., 2010). Dates originally normalized to δ^{13}C of 0‰ were converted to the equivalent conventional radiocarbon age (normalized to −25‰ δ^{13}C; sensu Stuiver and Polach, 1977) by adding 400 ^{14}C yrs (Coulthard et al., 2010). Marine mammal dates were calibrated using the above methodology, with a ΔR of 170 ± 95 yrs for bowhead whale (*Balaena mysticetus*; Furze et al., submitted for publication) and a ΔR of 335 ± 85 yrs for walrus (*Odobenus rosmarus*) given their molluscan diet (cf. Coulthard et al., 2010). Molluscan ages >10.5 ^{14}C ka BP were provisionally calibrated using ΔR of 1000 yrs due to presumably limited Arctic Ocean ventilation during, and prior to, the Younger Dryas (Hanslik et al., 2010).

3.3. Age-depth model

A best-fit (fourth-order polynomial) curve was plotted through CALIB 6.0 median probability ages and associated 95.4% probability age ranges against core depth (Fig. 2). The curve excluded all samples with the Portlandia Effect; a previously dated mixed sample on deposit-feeding bivalves and a predatory opisthobranch gastropod (Beta-115389); and four considerably older (>37,000 ^{14}C yrs) basal dates incorporating reworked pre-Late Wisconsinan material (Fig. 2; Table 1).

Beyond the ages obtained on the uppermost and lowermost (post-glacial) non-deposit feeder samples, the polynomial curve is extrapolated. Towards the core base, linear extrapolation to the boundary between laminated (glaciomarine) and diamictic (~glacial) facies provides an age of ~11.8 cal ka BP for deglaciation, older than the well-constrained chronologies from adjacent island coastlines (Dyke, 1993; Bednarski, 2003). The lithology of the basal core units (ice-proximal rhythmites, diamictons) suggests elevated sedimentation rates (Cowan et al., 1997) and thus steepening of the age-depth curve, consistent with fourth-order polynomial extrapolation. Towards the core top, the only date available (44 cm; Beta-115388; 870 cal yrs BP) is on a deposit-feeding mollusc. Given the propensity of deposit-feeding molluscs for enhanced age effects (England et al., 2010), this date should be regarded with caution, but can be used as a maximum age. Projection of the age-depth model (Fig. 2) defines a core-top age range between 0 yrs BP (youngest possible age) and