Quaternary Science Reviews 79 (2013) 145–156

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

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

Quaternary history of sea ice in the western Arctic Ocean based on foraminifera

Leonid Polyak [a,*], Kelly M. Best [a,b], Kevin A. Crawford [a,b], Edward A. Council [c], Guillaume St-Onge [d,e]

[a] Byrd Polar Research Center, The Ohio State University, 1090 Carmack Road, Columbus, OH 43210, USA
[b] School of Earth Sciences, The Ohio State University, Columbus, OH 43210, USA
[c] Department of Geological Sciences, Wright State University, Dayton, OH 45435, USA
[d] Institut des sciences de la mer de Rimouski (ISMER), Rimouski, Quebec G5L 3A1, Canada
[e] GEOTOP Research Center, Quebec, Canada

ARTICLE INFO

Article history:
Received 27 July 2012
Received in revised form
20 December 2012
Accepted 22 December 2012
Available online 4 February 2013

Keywords:
Western Arctic Ocean
Foraminifers
Quaternary
Mid-Pleistocene Transition
Sea ice history

ABSTRACT

Sediment cores from the Northwind Ridge, western Arctic Ocean, including uniquely preserved calcareous microfossils, provide the first continuous proxy record of sea ice in the Arctic Ocean encompassing more than half of the Quaternary. The cores were investigated for foraminiferal assemblages along with coarse grain size and bulk chemical composition. By combination of glacial cycles and unique events reflected in the stratigraphy, the age of the foraminiferal record was estimated as ca 1.5 Ma. Foraminiferal abundances, diversity, and composition of benthic assemblages, especially phytodetritus and polar species, were used as proxies for sea-ice conditions. Foraminiferal Assemblage Zone 2 in the Lower Pleistocene indicates diminished, mostly seasonal sea ice, probably facilitated by enhanced inflow of Pacific waters. A gradual decrease in ice-free season with episodes of abrupt ice expansion is interpreted for the Mid-Pleistocene Transition, consistent with climatic cooling and ice-sheet growth in the Northern Hemisphere. A principal faunal and sedimentary turnover occurred near the Early–Middle Pleistocene boundary ca 0.75 Ma, with mostly perennial sea ice indicated by the overlying Assemblage Zone 1. Two steps of further increase in sea-ice coverage are inferred from foraminiferal assemblage changes in the "Glacial" Pleistocene by ca 0.4 and 0.24 Ma, possibly related to hemispheric (Mid-Brunhes Event) and Laurentide ice sheet growth, respectively. These results suggest that year-round ice in the western Arctic was a norm for the last several 100 ka, in contrast to rapidly disappearing summer ice today.

1. Introduction

As global climate conditions continue to shift toward a warmer planet, the Arctic Ocean is becoming increasingly vulnerable to warming and its associated effects, due to a set of positive feedbacks regarded as Arctic Amplification (Serreze and Barry, 2011). Sea ice is an integral factor that determines the magnitude of these feedbacks including the albedo in summer and insulation in winter. Knowledge of paleo-ice conditions is essential for understanding the trajectory of rapid retreat of sea ice in the Arctic (e.g., Stroeve et al., 2011) and related climatic and hydrographic changes affecting the global thermohaline circulation (Rashid et al., 2011).

Reconstruction of sea-ice extent in the Arctic is complicated by the lack of any one unequivocal proxy, and is further complicated by very low sedimentation rates and biogenic content in the areas of high sea-ice coverage (e.g., Polyak et al., 2010). Not surprisingly, reconstructions of paleo sea ice are being developed for marginal-ice areas such as the Fram Strait (Müller et al., 2009, 2012; Bonnet et al., 2010; Spielhagen et al., 2011), but not for the central parts of the Arctic Ocean.

This paper aims to reconstruct Quaternary sea-ice conditions in the western Arctic based on a foraminiferal record from the Northwind Ridge, western Arctic Ocean (Fig. 1), where modern sea-ice retreat is especially pronounced (Stroeve et al., 2011). Unlike most sediment cores from the Arctic Ocean, where calcareous material is preserved only in the Late and, partially, Middle Pleistocene (e.g., Jakobsson et al., 2001; Spielhagen et al., 2004; Polyak et al., 2009; Stein et al., 2010), the record under study has abundant calcareous microfossils going back into the Early Pleistocene, estimated ca 1.5 Ma. Pronounced changes in benthic foraminiferal assemblages, along with lithostratigraphic proxies, allow for the first-time characterization of the Quaternary history of sea ice in the western Arctic Ocean, the most ice-covered oceanic region of the world.

* Corresponding author. Fax: +1 614 2924697.
E-mail address: polyak.1@osu.edu (L. Polyak).

0277-3791/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.quascirev.2012.12.018

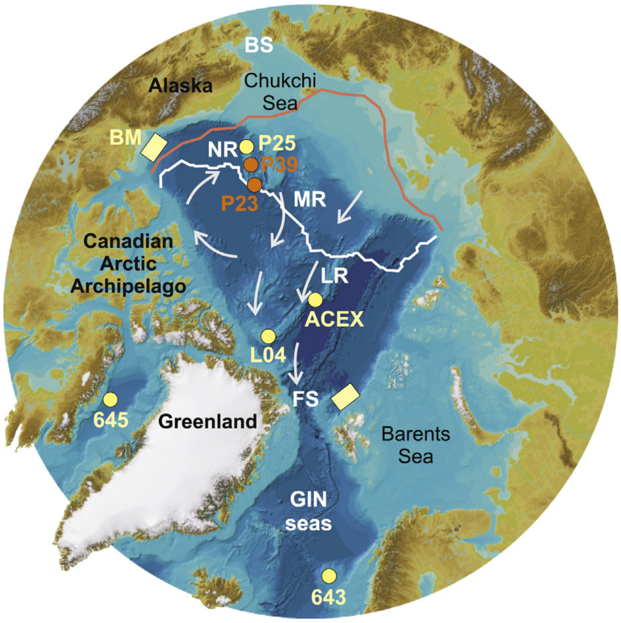

Fig. 1. Index map with location of cores P23 and P39 (red circles) and other sites discussed in the paper (yellow circles). Arrows show Transpolar Drift and Beaufort Gyre circulation. Pink line – climatological late-20th century summer ice extent (15% concentration), white line – 2007 summer ice extent (historical minimum). Yellow boxes – sites of earlier paleo-sea-ice studies based on benthic foraminifers. NR, MR, and LR – Northwind, Mendeleev, and Lomonosov ridges, respectively. FS and BS – Fram and Bering straits. BM – Beaufort–Mackenzie area. GIN seas – Greenland–Iceland–Norwegian seas.

2. Paleoceanographic context

A cyclic character of lithological, geochemical, and paleobiological proxy changes has been identified from recent detailed studies of sediment cores from various parts of the Arctic Ocean (e.g., Jakobsson et al., 2000; Spielhagen et al., 2004; O'Regan et al., 2008; Adler et al., 2009; Polyak et al., 2009; Stein et al., 2010). Although not all proxies are completely deciphered, the general interpretation recognizes that these changes have been caused by alternation of full-glacial, deglacial (iceberg dominated), and interglacial/major interstadial environments of the Late to Middle Quaternary. Glacial–interglacial contrasts are most pronounced in the hydrographically more isolated western Arctic Ocean due to its remoteness from the deep-water connection with the Atlantic and the gyre-type surface circulation (Beaufort Gyre) (Polyak and Jakobsson, 2011). Early Pleistocene to pre-Quaternary history of the Arctic Ocean has been partially investigated only in the ACEX deep borehole (Fig. 1) representing the Transpolar Drift-dominated environments and suffering from poor preservation of paleontological remains (Backman et al., 2006; O'Regan et al., 2008).

Despite a generally robust identification of glacial–interglacial cyclicity, changes in associated sea-ice conditions in the Arctic Ocean remain mostly unassessed. A notable exception is an elevated occurrence of subpolar planktonic foraminifers at some stratigraphic intervals including the estimated Last Interglacial (Nørgaard-Pedersen et al., 2007; Adler et al., 2009). Although more understanding is needed for the distribution of these foraminifers (local blooms vs. long-distance transport by currents, selective preservation, etc) and for the accurate age of these events, they clearly show the potential of paleobiological proxies for representing sea-ice conditions. In this study we capitalize on the stratigraphically longest calcareous foraminiferal record recovered thus far from the Arctic Ocean to gain insights into sea-ice history in the western Arctic. We especially focus on benthic foraminifers that have been thus far underutilized as paleo-sea ice proxies due to preservation and counting size issues (e.g., Cronin et al., 2008; Scott et al., 2008) and perennial sea ice predominance in recent Arctic history, which complicates identification of proxies related to lower ice extent.

3. Materials and methods

Piston cores 92AR-P39 and 93AR-P23 (hereafter referred to as P39 and P23) were collected on the 1992 and 1993 U.S. Geological Survey P1 cruises from the Northwind Ridge extending from the Chukchi Sea margin to the interior of the western Arctic Ocean (Fig. 1; Table 1). Both core sites are bathed by the Upper Polar Deep Water, with shallower P23 site being close to the lower boundary of the Arctic Atlantic Water (Rudels, 2009). The summer sea-ice margin was located south of the ridge in climatological data, but shifted to its northern edge in recent years (e.g., Stroeve et al., 2011), which makes the Northwind Ridge an area of choice for studying the history of sea ice in the western Arctic.

Two samples from core P23 investigated by Mullen and McNeil (1995) contained calcareous benthic foraminifers that had similarity to pre-Quaternary (Pliocene to Late Miocene) fauna from the Beaufort–Mackenzie Basin of Arctic Canada. However, stratigraphic and paleoceanographic context for this core remained uninvestigated. To test the earlier assessment of foraminiferal assemblages and utilize them for evaluating paleo-environments, we have performed a detailed study of core P23 along with P39 collected farther south on the Northwind Ridge (Fig. 1). Due to its more southern location, P39 represents overall lower long-term ice cover resulting in higher sedimentation rates and, thus, a higher-resolution record (Polyak et al., 2009; Crawford, 2010). Difference in water depths may also contribute to varying sedimentation rates as P23 site at the ridge top is more likely affected by currents.

Upon collection, cores have been stored in a refrigerated facility (USGS Menlo Park) and, other than partially drying out, remained in a very good condition. Due to a negligible amount of labile organic matter and strong oxic conditions on the central Arctic Ocean floor (e.g., Stein and Macdonald, 2004), carbonaceous material in these sediments is minimally affected by diagenetic dissolution caused by post-collection oxidation (unlike sediments from the continental margins). Cores have been sampled on several occasions for various analyses including discrete and u-channel samples. Earlier litho- and magnetostratigraphic results on a series of cores from the western Arctic Ocean including P23 and P39 have been described in Polyak et al. (2009). To detail earlier bulk chemical composition XRF measurements spaced at 2–6 cm, u-channels from core P23 were analyzed with the 0.5 cm resolution on the Itrax XRF scanner at the INRS-ETE (Quebec City). Foraminiferal counts along with coarse (>63 μm) grain content measurements were done at the Byrd Polar Research Center, with samples mostly taken at 2-cm intervals from subsections cut along the core length. Total planktonic and calcareous benthic foraminifers >150 μm were counted in almost all samples collected (Fig. 2; Suppl. 1), with sparser intervals in the unfossiliferous lower part of P39. Detailed counts of benthic foraminifers in 63–125 and >125 μm size fractions were primarily

Table 1
Sediment core information.

Core ##	Latitude N	Longitude W	Water depth (m)	Core length (cm)	Core diameter (cm)
P1-92AR-P39	75° 50.7′	156° 01.9′	1470	687	8
P1-93AR-P23	76° 57.3′	155° 03.9′	951	572	8