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Paleoenvironments in the Fram Strait during Marine Isotope Stages 2–6 based on planktonic paleobiological and stable-isotope proxies and ice-rafted debris

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ABSTRACT

Two sediment cores from the Knipovich Ridge in the Fram Strait have been studied to examine paleoceanographic and climatic changes in the Polar North Atlantic during the late Middle and Late Pleistocene. As inferred from the data on foraminifers, nannofossils, diatoms, IRD, oxygen isotope values, and AMS ^{14}C ages, the recovered deposits span the interval of MIS 2–6. Several beds marked by a high productivity of microplankton and often by a great IRD content are recorded in MIS 2, MIS 5a, 5c, 5e, and MIS 6 suggesting a repeated occurrence of seasonally ice-free waters and strong meridional circulation in the eastern Fram Strait. The planktonic foraminifers *Globigerinoides ruber*, *Globorotalia scitula*, *G. crassaformis*, and pink-colored *Globigerina rubescens*, exotic for this latitude, were identified in three points of the section. A hiatus in one of the cores studied was revealed from comparison of IRD variations and the occurrence of *Pullenia bulloides*.

1. Introduction

The Fram Strait is a connecting link between the Atlantic Ocean and the Arctic and the main way for heat and water exchange between the Arctic basin and the world ocean. In this region, the interactions between warm Atlantic and cold Arctic waters and the southward sea ice export affect the world thermohaline circulation and cause global climate and paleoenvironmental changes (Holland et al., 2001; Moran et al., 2006). Paleoceanographic and climatic oscillations in the Polar North Atlantic are documented in bottom sediments of the Fram Strait. During the last decades several sediment cores from the Fram Strait were examined (e.g. Gard, 1987; Morris, 1988; Hebbeln, 1992; Hebbeln and Wefer, 1997; Spielhagen et al., 2004; Risebrobakken et al., 2007; Van Nieuwenhove et al., 2011) to reconstruct climatic variability and dynamics of Atlantic Water advection to the Arctic in the Pleistocene. However, their number is limited and each new core provides interesting information on the stratigraphy and paleogeography of this key area.

This study is focused on the interpretation of data from two sediment gravity cores located on the Knipovich Ridge slopes in the Fram Strait (Fig. 1) and derived during the 24th cruise of R/V Academician Strakhov in the context of the International Polar Year program. The stratigraphic interpretation of the sections is based on the studies of foraminifers and nannofossils, $\delta^{18}O$ records, and on the accelerator mass spectrometry (AMS) ages obtained for the upper part of the recovered sediments. The dynamics of paleoceanographic conditions is additionally represented by high-amplitude variations in the ice-rafted detritus (IRD) distribution.

2. Regional setting

The surface waters of the Fram Strait are dominated by the cold East Greenland Current transporting Arctic water to the Atlantic in the west and by the warm West Spitsbergen Current in the east. One of the branches of the warm West Spitsbergen Current runs directly over the studied area (Saloranta and Haugan, 2004). Distribution of sea ice in the Fram Strait is controlled by the interaction of polar and Atlantic water masses and strongly varied during the Pleistocene (Dokken and Hald, 1996; Hebbeln and Wefer, 1997; Spielhagen et al., 2004). The Knipovich Ridge extends for a distance of 550–600 km southwest of Spitsbergen. This morphostructure of still unclear origin underwent rifting and strike-slip shifts during the Pleistocene and is marked by high seismicity (Sokolov et al., 2014).

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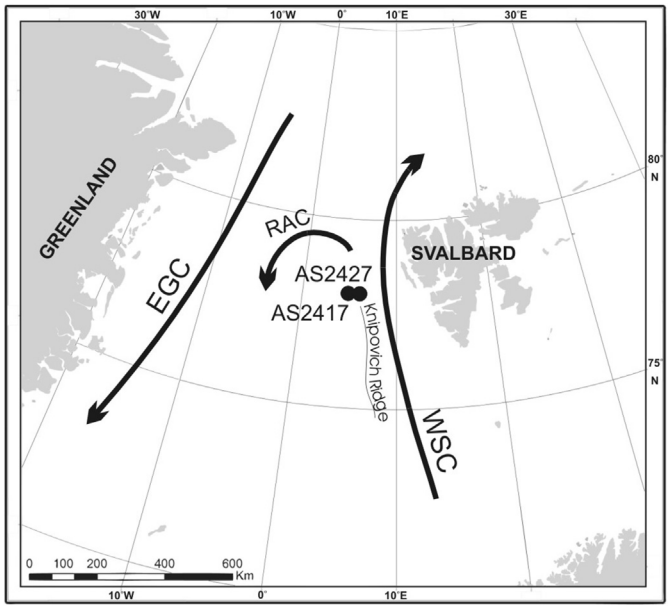

Fig. 1. Location of cores AS2417 and AS2427 in the Fram Strait. The arrows indicate surface currents: EGC, East Greenland Current; WSC, West Spitsbergen Current; RAC, Return Atlantic Current.

3. Material and methods

Sediment cores AS2417 (78°14.79′ N, 05°45.75′ E, water depth 1568 m) and AS2427 (78°08.14′ N, 06°30.12′ E, water depth 1598 m) were taken with a gravity corer from an elevation on the western flank of the Knipovich Ridge (Table 1). These 350 and 262 cm long cores are composed of alternated brown and gray muds bearing ice-rafted detritus. Samples were taken at 2–3 cm intervals as 1-cm thick slices. The complete residues of washed samples were looked through in order to trace all rare species that can be overlooked on cursory examination. The number of foraminifers >100 μm per 1 g of dry deposit was counted and the dry weight % of material >100 μm was measured in each sample. In core AS2417 mineral grains >250 μm were additionally counted. Nannofossils and diatoms were also identified in the foraminifer-rich intervals.

Table 1
Position of sediment cores under study.

Core	Latitude (°N)	Longitude (°E)	Water depth (m)
AS2417	78°14,79′	05°45,75′	1568
AS2427	78°08,14′	06°30,12′	1598

AMS datings (Table 2) were carried out at Keck Carbon Cycle AMS Facility, University of California, using 500–1000 tests of *Neogloboquadrina pachyderma* sin. The radiocarbon datings were converted to calendar ages (cal. ka) by the CALIB Rev 7.0.2 calibration program using the "marine13" calibration dataset (Stuiver and Reimer, 1993; Stuiver et al., 1998). Age of the boundaries of marine isotope stages (MIS) is given according to Lisiecki and Raymo (2005).

Stable isotope ratios were measured on 25–30 specimens (200 μm average size) of the planktonic foraminifer *Neogloboquadrina pachyderma* sin per sample. The measurements were done at the Laboratory for Isotope Geochemistry and Geochronology, Geological Institute, Russian Academy of Sciences, with the Thermoelectron complex including a Delta V Advantage mass spectrometer and a Gas-Bench-II Device. The analytical accuracy of this system is ±0.2 and ± 0.1‰, for $\delta^{18}O$ and $\delta^{13}C$, respectively. All measurements were calibrated on the Pee Dee Belemnite isotope scale (PDB). The stratigraphic models of the sections studied are based on accelerator mass spectrometry (AMS) ^{14}C dates, oxygen isotopes, and the occurrence of *Pullenia bulloides*, an indicator of MIS 5a and/or MIS 5e intervals in the Polar North Atlantic (e.g. Haake and Pflaumann, 1989).

4. Results

4.1. Microfossils

The microfauna and flora content varies greatly in the sediments studied. Several high productive (HP) intervals separated by zones extremely impoverished in organic remains are recognized (Fig. 2). The bulk of foraminiferal assemblage consists of planktonic Arctic sinistral *Neogloboquadrina pachyderma* ranging from 1–2 specimens in a sample to several thousand tests per 1 g of sediment. In all HP beds the assemblage, in addition to abundant *N. pachyderma* sin, which proportion is never less than 96%, includes rare *N. pachyderma* dex and *Turborotalita quinqueloba* (not more than 2% each), and few or scarce *Globigerinita glutinata*, *Globigerina bulloides*, and *G. falconensis*. In the youngest HP interval of core AS2417, single specimens of *Globorotalia scitula* and juvenile *G. crassaformis* occurred. In a smear-slide for nannofossil identification at 268 cm core depth a juvenile *Globorotalia truncatulinoides* was encountered. Finally, at depths of 33 cm, 144 cm, and 348 cm of core AS2417 single tests of *Globigerinoides ruber* (Fig. 3), and at 340 cm, a pink-colored *Globigerina rubescens*, were found. Studies of the present-day planktonic foraminiferal composition in the Fram Strait showed that the modern assemblage consists of five species and, apart from dominating *N. pachyderma* and *T. quinqueloba*, includes only rare *Globigerina bulloides*, *Globigerinita uvula*, and *G. glutinata* (Carstens et al., 1997). *Globorotalia scitula* and *G. crassaformis* in the Pleistocene of the North Atlantic are regularly known as far north as 63°N (Krasheninnikov and Bylinskaya, 1994; Bylinskaya, 2005). Thus, the latter species and moreover *Globigerinoides ruber*, are exotic elements at the latitude of Spitsbergen. The northernmost occurrence of pink (more thermophilic) *Globigerina rubescens* in the Atlantic was recorded at 45°31′ N at Site 410 DSDP (Bylinskaya et al., 2002). Nevertheless, single findings of warm-water planktonic foraminifers in the Quaternary of the Polar North Atlantic and Arctic are reported in the literature. For instance, in the Yermak Plateau, Site 911 ODP (Spiegler, 1996), scarce *Globorotalia scitula*, *Orbulina universa* and single *Globigerinoides ruber* were found in the Lower Pleistocene. Quaternary deposits from the Alpha Rise in the Arctic Ocean yielded scarce exotic plankton including *Globorotalia crassaformis*, *G. inflata*, and juvenile

Table 2
AMS ^{14}C and calibrated ages.

Sediment core	Lab number	Depth in core (cm)	Radiocarbon age (yr BP)	Calendar age calculated with CALIB Rev 7.0.2
AS2417	76079	13	18415 ± 45	21820
AS2417	76080	21	20330 ± 50	23981
AS2417	76081	30	24080 ± 80	27764
AS2427	115927	27	22200 ± 80	26014
AS2427	115928	40	24450 ± 110	28071

The age determinations were performed at the Keck Carbon Cycle AMS Facility, UC Irvine, on tests of *Neogloboquadrina pachyderma* sin.

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