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Paleoceanography of northeastern Fram Strait since the last glacial maximum: Palynological evidence of large amplitude changes

Jade Falardeau [a, *], Anne de Vernal [a], Robert F. Spielhagen [b, c]

[a] GEOTOP-UQAM, CP 8888 Montréal, H3C 3P8, Canada
[b] GEOMAR Helmholtz Centre for Ocean Research, 24148 Kiel, Germany
[c] Academy of Sciences, Humanities and Literature, 55131 Mainz, Germany

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ABSTRACT

Sea-surface conditions in northeastern Fram Strait since the last glacial maximum (LGM) were reconstructed from cores MSM5/5-712-2 and PS2863/1–2 based on palynological assemblages, ecological preferences of dinocysts and application of the modern analog technique. Dinocyst in LGM sediments are sparse, but their assemblages reflect mild summer conditions. Given the regional context and evidence from other tracers, the dinocyst assemblages of the LGM could relate to regional fluxes of dinocysts during exceptional mild summers. From 19 to 14.7 ka, dinocyst data suggest very cold conditions with extensive sea-ice cover, while abundant reworked palynomorphs indicate intense glacial erosion. An abrupt transition at 14.7–14.5 ka was marked by a peak in summer temperatures coinciding with a rapidly deposited sediment layer related to a regional meltwater plume event in western Svalbard. From 14.7 to 12.6 ka, large seasonal temperature contrasts with mild summers and cold winters together with low salinity indicate continuous melting of the Svalbard Barents Sea ice sheet fostered by warm climate. At 12.6 ka, the regional onset of the Younger Dryas was marked by cooling and increased salinity. On a regional scale, the 12.6–12 ka interval corresponds to an important transition involving enhanced circulation of Arctic waters around Svalbard and establishment of coastal fronts along its northern and western margins. Modern-like oceanic conditions with relatively high salinity and low seasonal temperature contrast developed at about 7.6 ka. Since then, a slight cooling is observed, especially in winter. This study offers a comprehensive picture of the deglacial phases in eastern Fram Strait with unique data on the sea-surface salinity, which controls surface water stratification and plays an important role in ocean circulation.

1. Introduction

The Norwegian Atlantic Current and its northernmost derivatives reach the Arctic Ocean notably through the Fram Strait, which is the main gateway between the Atlantic and the Arctic oceans (Fahrbach et al., 2001; Maslowski et al., 2004; Schauer, 2004). Hence, these currents are an important heat source to the Arctic Ocean shaping the northern limit of the regional sea-ice margins, which in turn plays an important role for the energy budget at the Earth's surface. Furthermore, as the Atlantic Water (AW) flows northward in eastern Fram Strait, heat loss to the atmosphere accompanied with surface water cooling leads to increased density of surface waters, thus potentially contributing to both the strength of the Atlantic Meridional Overturning Circulation (AMOC) and the rate of North Atlantic Deep Water (NADW) formation. Therefore, the oceanography of the Fram Strait is critical not only for the climate in the Arctic realm but also for the global thermohaline circulation. In this context, the objective of the present study is to document changes in sea-surface conditions in the northeastern Fram Strait since the last glacial maximum (LGM; 23–19 ka; Kucera et al., 2005) to assess the role of northward heat flux from AW advection on deglaciation and climate variations during the postglacial.

Many studies have investigated the changes in AW inflows in Fram Strait during the LGM and the deglaciation. Most of them are based on planktic and/or benthic foraminifer assemblages and stable isotope analyses of foraminifer shells (cf. Hebbeln et al., 1994; Sarnthein et al., 1995, 2003; Nørgaard-Pedersen et al., 2003; Hald

* Corresponding author.
E-mail address: falardeau.jade@courrier.uqam.ca (J. Falardeau).

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et al., 2001, 2007; Ślubowska-Woldengen et al., 2007, 2008; Rasmussen et al., 2007, 2012; Werner et al., 2011, 2013; 2016; Aagaard-Sørensen et al., 2014a,b, Chauhan et al., 2014; Zamelczyck et al., 2014; Bartels et al., 2017; Consolaro et al., 2018). Other studies are based on sedimentological data (Andersen et al., 1996; Forwick and Vorren, 2009; Jessen et al., 2010). However, as most of these studies document paleoceanographical conditions in sub-surface and bottom waters, there is still little information on the surface water conditions. To date, reconstructions of past sea-surface conditions mostly document sea-ice cover using the organic biomarker IP_{25} (Müller et al., 2012; Müller and Stein, 2014; Bartels et al., 2017) and sea-surface temperature estimated from alkenones during the LGM (Rosell-Melé and Comes, 1999) and the Early Holocene (Calvo et al., 2002; Marchal et al., 2002; Risebrobakken et al., 2011). Data documenting variations of seasonal temperatures and sea-surface salinity off western Svalbard since the LGM remain rare.

Here we present two new dinoflagellate cyst (or dinocyst) records from northeastern Fram Strait covering the last 23,000 years. The data were used to apply the modern analog technique for quantitative reconstruction of several sea-surface parameters, including winter and summer sea-surface temperatures (SSTs) and sea-surface salinities (SSSs), along with sea-ice cover extent (month/yr) and productivity (gC/cm^2yr), simultaneously. Hence, our data provide information on freshwater inputs from glaciers and seasonal gradients of temperatures (Rochon et al., 1999; de Vernal et al., 2001, 2005; 2013; Grøsfjeld et al., 2009), which are critical parameters in ice-ocean dynamics, especially during phases of ice retreat. Core sites MSM5/5–712 and PS2863 are located on the western and northwestern continental slopes of Svalbard (Fig. 1; Table 1). Previous studies from site MSM5/5–712 (Spielhagen et al., 2011; Werner et al., 2013; Aagaard-Sørensen et al., 2014a; Zamelczyk et al., 2014) have provided a stratigraphic framework with multidecadal temporal resolution in which biomarkers and stable isotopes have illustrated qualitative changes of the AW inflow and sea-ice cover extent (Werner et al., 2011, 2013; Müller et al., 2012; Müller and Stein, 2014; Spielhagen et al., 2014; Zamelczyk et al., 2014). In addition to developing a more detailed portrait of the surface water conditions from the LGM to present, our study of the two above mentioned sites aims at contributing to a better understanding of the AW modifications along its pathway, from the relatively confined channel of the eastern Fram Strait to the open Arctic Ocean north of Svalbard, where strong ocean-atmosphere heat transfer presently occurs.

2. Regional hydrography

There are two main currents in the Fram Strait (Fig. 1; Fahrbach et al., 2001; Schauer, 2004; Rudels et al., 2005; Schauer et al., 2008). In the west, the East Greenland Current (EGC) flows southward and transports cold and fresh waters from the Arctic Ocean, thus playing a major role in iceberg and sea-ice export to the North Atlantic. In the east, the West Spitsbergen Current (WSC) circulates northward along the western continental slope of Svalbard and carries relatively warm and saline Atlantic waters towards the Arctic Ocean. It originates from two distinct branches in the Nordic Seas: the Norwegian Atlantic Slope Current (NwASC) and the Norwegian Atlantic Current (NwAC), further named the WSC western branch. Parts of the NwASC turns east at the surface into the shallow Barents Sea (Rudels et al., 1999), where it is responsible for significant heat transport (5.07 Sv; 106 TW; Maslowski et al., 2004) while the rest of the water masses continues north as the WSC core. Parts of the WSC western branch bifurcate to the west without extending further than 80–81°N (Rudels et al., 2000) through the Return Atlantic Current (RAC) following topographical features, to finally turn south with the EGC (Gascard et al., 1995). The two main branches converge into the WSC core around 78°N due to the bottom topography (Walczowski and Piechura, 2007).

Because of the complex bathymetry of the Fram Strait, the WSC core splits into three branches (Manley, 1995): a western branch (RAC), a central branch called the Yermak Branch (YB), which flows north and reaches the Arctic Ocean along the western and northern shelf of the Yermak Plateau (YP), and the Svalbard Branch (SB). This branch flows east following the northern Svalbard shelf and continues by circulating south of the Yermak Plateau.

Arctic waters circulate southward through the East Spitsbergen Current (ESC) and follow the east Svalbard coast in the Barents Sea (Loeng, 1991). The ESC is renamed as the South Cape Current (SCC) after passing the Storfjorden, in south Svalbard, and follows the western coast of Svalbard carrying freshwater from glaciers melt and river runoff in summer (Skogseth et al., 2005).

The WSC transports about 11.6 Sv at 78°50′N corresponding to 70.6 TW of heat (Walczowski et al., 2005). Previous studies from moored instruments obtained similar values with mean annual transport of 9 ± 2 to 10 ± 1 Sv (Schauer, 2004) and a monthly mean average of 9.5 ± 1.4 Sv (Fahrbach et al., 2001). The regional sea-ice cover extent is mainly controlled by the advection of warm AW. Site MSM5/5–712 is located under the path of the WSC on the western continental slope of Svalbard and it is therefore largely influenced by AW. Site PS2863 is located 200 km north of MSM5/5–712 downstream of the WSC and is thus under distal influence of AW and close to the limit of mean sea-ice extent in summer which corresponds to the Polar Front.

At site PS2863, the mean sea-surface temperature and salinity in summer are 2.3 ± 2.3 °C and 33.3 ± 0.9 psu, respectively (1900–2001 data from the World Ocean Atlas, 2001; Conkright et al., 2002, Table 1). The sea-ice cover is highly variable at the core site since it is located close to the sea-ice margin. Hence, the sea-ice cover with concentration >50% varied between 0 and 11 months/yr from 1954 to 2003, with an average of 3.7 ± 3.2 months/yr (data provided by the NSIDC in Boulder). At site MSM5/5–712, the mean-sea surface temperature and salinity in summer are 4.9 ± 1.4 °C and 34.73 ± 0.43 psu, respectively (Conkright et al., 2002, Table 1). Sea-ice cover with concentration >50% varied between 0 and 6 months/yr from 1954 to 2003, with an average of 1.2 ± 1.7 months/yr (data from NSIDC, 2003).

3. Methods

Gravity core PS2863-1 (80°33.46′N, 10°17.96′E; water depth 808 m) was collected in 1997 during the *RV Polarstern* expedition ARK-XIII/2 (Stein and Fahl, 1997). The core is 580 cm long. The uppermost 184 cm were subsampled at 4 cm intervals for palynological analyses. Box core PS2863-2 from the same location is 41 cm long. It was subsampled at a 1 cm interval (Table 1). The results from the two cores were combined into a composite record referred to as PS2863 (see detailed counts of palynomorphs in Falardeau, 2017).

Sediment core MSM5/5-712-2 (78°54.94′N, 6°46.04′E; water depth 1487 m) was retrieved from *RV Maria S. Merian* in 2007 (Budéus, 2007). The kastenlot core has a total length of 950 cm. Palynological results from this core (hereafter MSM5-712) are presented at 4 cm intervals for the uppermost 283 cm and at 8 cm intervals down to 777 cm (Table 1).

Samples were prepared for palynological analyses in the micropaleontology laboratory of GEOTOP according to standard procedures (de Vernal et al., 2010). In short, approximately 5 cm^3 of sediment were wet sieved at 10 and 106 μm after measurement of their volume and their weight (wet and dry). One capsule of *Lycopodium clavatum* with a known number of spores was added for further palynomorph concentration calculations (Matthews, 1969). The 10–106 μm fraction was treated with hydrochloric acid