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Svalbard ice-sheet decay after the Last Glacial Maximum: New insights from micropalaeontological and organic biomarker paleoceanographical reconstructions

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ABSTRACT

A marine sediment core retrieved from the middle continental slope of the northwestern Barents Sea was analyzed for its geochemical (alkenones) and micropalaeontological (diatoms, coccolithophores and dinocyst) content in order to reconstruct the evolution of upper ocean conditions and ice-sheet dynamics during the last 25 kyr. Additionally, quantitative reconstructions of sea surface conditions (temperature, salinity and sea-ice cover extent) were conducted based on the best analogue technique applied to dinocyst assemblages and on the alkenone unsaturation index. The sediment core contains a post Last Glacial Maximum depositional sequence unaffected by stratigraphic discontinuities. Low salinity and laminated sediments after 20 cal kyr BP, indicate a massive settling of meltwater sediment-laden plumes from the initial melting of the Svalbard-Barents Sea Ice Sheet on Western Svalbard. First record of measurable alkenones, together with a drop of the number of months of sea-ice cover and increase in SSTs suggests an intensification of the influx of Atlantic waters into the study area at ~15 cal kyr BP representing the termination of the last glacial period and onset of the Bølling interstadial. The first occurrence of diatoms and increase in the abundance of all microfossils marked the onset of the Holocene at 11.2 cal kyr BP when modern-type sea surface conditions were rapidly established in Western Svalbard. Reconstructions based on dinocyst data and alkenone unsaturation index suggest relatively warm and stable temperatures between 9.9 and 8.9 kyr BP and a decrease of SSTs from 4.2 cal kyr BP to present coinciding with the Holocene Thermal Maximum and the decrease of summer insolation in the high latitude northern hemisphere, respectively.

1. Introduction

The Atlantic meridional overturning circulation (AMOC) carries warm and saline Atlantic waters (AW) into high northern latitudes and returns cold deep waters southward towards the Equator. The inflow of warm and saline Atlantic waters across the Greenland-Scotland Ridge represents the major source of heat and salt to the Nordic Seas and Arctic Ocean (Aagaard et al., 1985), playing a pivotal role in the formation of the densest and deepest waters of the North Atlantic thermohaline circulation. The transport of heat by the North Atlantic Current (NAC) flowing north to Fram Strait causes a dramatic reduction of the sea-ice extent via the warming of the intermediate water layers contributing to the fresh water input into the Greenland, Iceland and Norwegian Seas (Serreze et al., 2003; Seidov et al., 2015). Indeed, most evidence indicates that the inflow of Atlantic surface waters has played a key role in the growth and decay of ice sheets and climate changes in the Nordic Seas during the last deglaciation (Kristensen et al., 2013; Telesiński et al., 2015).

The front of the Svalbard-Barents Sea Ice Sheet on Western Svalbard (Fig. 1) underwent pronounced advances and retreats during the last glacial-interglacial cycle associated with fluctuations in the strength of the NAC flux (Martrat et al., 2003; Rasmussen et al., 2007; Jessen et al., 2010). The Storfjorden, in the southwestern Svalbard continental margin (Fig. 1), represented the western limit of this large ice sheet during

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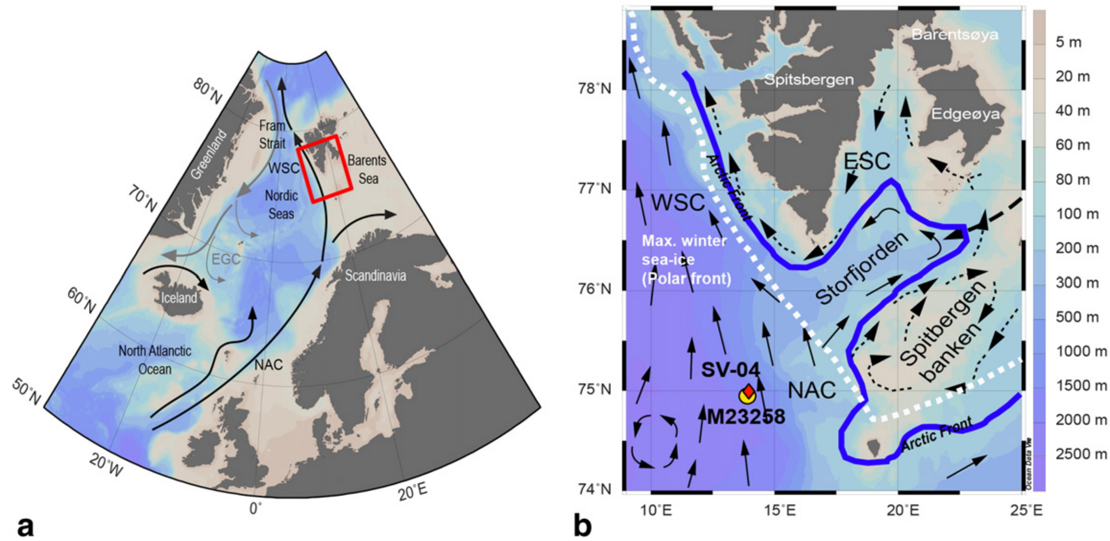

Fig. 1. (a) Map of the Nordic Seas and Barents Sea showing major surface currents. Red square highlights the study area. (b) Location of core SV-04 (red diamond) and M23258 (yellow circle) and trajectories of main oceanic surface currents after Loeng (1991) and Saloranta and Svendsen (2001). Abbreviations: NAC: North Atlantic Current; WSC: West Spitsbergen Current; ESC: East Spitsbergen Current; EGC: East Greenland Current.

the Last Glacial Maximum (LGM) and one of its main drainage pathways during the following deglaciation phase (see Ingólfsson and Landvik, 2013 for a review). Storfjorden is under the influence of both Atlantic and Arctic waters, and therefore, it is a highly sensitive area to global climate changes (Bauch and Weinelt, 1997; Landvik et al., 1998; Martrat et al., 2003; Rasmussen et al., 2007, among others). These characteristics make Storfjorden an ideal setting for studying the interactions between ice sheet dynamics, oceanography and climate (Jessen et al., 2010).

Analyses of the deep-sea sedimentary records of the Nordic Seas have provided important insights into the palaeoenvironmental and palaeoceanographic development of this region during the last glacial-interglacial cycle. Planktonic and benthic foraminifera (e.g. Bauch and Weinelt, 1997; Hald et al., 2004; Hald et al., 2007; Ślubowska-Woldengen et al., 2008; Andersson et al., 2010), coccoliths (e.g. Andruleit and Baumann, 1998; Giraudeau et al., 2010; Dylmer et al., 2013), diatoms (Koç et al., 1993; Justwan and Koç, 2008; Berner et al., 2011; Hoff et al., 2016), dinocysts (e.g. Matthiessen and Baumann, 1997; Van Nieuwenhove et al., 2016) and a variety of chemical biomarkers (e.g. Martrat et al., 2003; Massé et al., 2008; Berben et al., 2014) have resulted particularly useful tools for the reconstruction millennial-scale changes of the AMOC and the evolution of the ice-sheet dynamics in this climate sensitive area.

However, conclusions derived from these proxies often yield different results and magnitudes of the perceived climate variability in the region. This is most likely due to several biological, chemical and physical processes that complicate the interpretation of the sedimentary record. For example, the low species diversity and preservation issues of calcareous phyto- (e.g. coccolithophores) and zooplankton (e.g. foraminifera) often limit the interpretations on the fossil record (e.g. Solignac et al., 2008; Van Nieuwenhove et al., 2013). Moreover, silica dissolution of the diatom frustules in the water column and at the sediment-water interface largely alter the original diatom assemblages from their production in the surface layer until their eventual preservation in the fossil record (Ragueneau et al., 2000; Birks and Koç, 2002; Jordan and Stickley, 2010). In turn, dinoflagellate cysts have a proven potential for reconstructing surface ocean properties in the Nordic Seas and other cold oceanic regions. Due to their highly resistant organic walls, rich species diversity and good correlation with modern seas surface temperatures (SSTs), salinity (SSS) and sea-ice cover, dinocysts have been proven as one of the most reliable proxies for the reconstruction of environmental conditions in the Nordic Seas (see Van Nieuwenhove et al., 2016 for a review).

In order to contribute to the understanding of the evolution of the Svalbard-Barents Sea Ice Sheet margin, an oceanographic expedition was conducted in the Storfjorden sedimentary system in August 2007 in the framework of the Spanish project SVAIS as part of the International Polar Year (IPY) Activity NICE STREAMS (Neogene ice streams and sedimentary processes on high-latitude continental margins). Detailed multibeam bathymetric survey, shallow seismic (TOPAS), single channel seismic reflection and coring of 6 sediment records in the slope and in the shelf were performed during the cruise. Onshore studies on the recovered dataset comprised measurement of palaeomagnetic and rock magnetic parameters, sedimentological, biogeochemical, isotopic and micropaleontological analyses, and 9 AMS radiocarbon datings (Pedrosa et al., 2011; Sagnotti et al., 2011; Lucchi et al., 2013; Llopart et al., 2015; Lucchi et al., 2015).

In this study we present a reconstruction of the sea-surface conditions in the Storfjorden area during the last deglaciation phase until present based on analyses performed in the piston core SV-04 recovered from the middle slope of the SW Svalbard continental margin (Fig. 1). SST, SSS, and seasonal duration of sea-ice cover have been quantitatively reconstructed by applying the Modern Analogue Technique (MAT) to dinocyst assemblages (e.g. de Vernal et al., 1993; Rochon et al., 1998; de Vernal and Hillaire-Marcel, 2000; de Vernal et al., 2005). Furthermore, changes in the abundance and the assemblage composition of diatoms, coccolithophores and dinocysts, together with alkenone concentration and alkenone derived SSTs, are presented and discussed to further document the paleoceanographical reconstructions.

2. Oceanographic setting

At present, the Storfjorden area is influenced by two distinct surface water masses. In the west, the Atlantic-sourced Western Spitsbergen Current (WSC) flows poleward along the continental slope carrying relatively warm and saline waters towards the Fram Strait and the Arctic Ocean (Rasmussen et al., 2007) (Fig. 1b). The WSC continues its flow into the Fram Strait as a intermediate water mass below the sea-ice covered Polar surface Water (Aagaard et al., 1987). On the Eastern Svalbard shelf, the cold and low saline Eastern Spitsbergen Current (ESC) flows from the Arctic Ocean towards the western coasts of Spitsbergen