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Late Glacial–Holocene clay minerals elucidating glacial history in the SW Barents Sea

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ABSTRACT

Detailed investigations of the distribution of clay minerals of Late Glacial–Holocene sediments from the SW Barents Sea provide important new information about the provenance and transport paths of the sediments. This information leads to better understanding of the onset of the last deglaciation and subsequent advances/retreats of the Barents Sea- and Fennoscandian Ice Sheets. The results show interaction and changes in the Fennoscandian Ice Sheet and Bjørnøyrenna Ice Stream during the last deglaciation. High illite content and maximum kaolinite content (>18 700 cal yr B.P.) indicate glacial erosion from both the Fennoscandian Ice Sheet and Bjørnøyrenna Ice Stream (LGM II). The occurrence of a *C. reniforme* dominated benthic foraminiferal assemblage (~18 700 cal yr B.P.) indicates that the northern most cores site in Ingøydjupet had already been deglaciated and was probably situated in a glacier distal environment. In addition, smectite content reaching its highest level, concurrent with the presence of *Neogloboquadrina pachyderma* (sin) dominated planktic foraminifera can be related to the strengthening of the Atlantic Current. The inflow of the Atlantic Water may have triggered deglaciation of the Fennoscandian Ice Sheet (Bølling interstadial). A rapid increase in illite content, reflecting strong melting of the Fennoscandian Ice Sheet (~15 000 cal yr B.P.), indicates the onset of deglaciation in a core closer to the continent. Decrease of illite and IRD content, together with the deposition of laminated sediments during the Older Dryas stadial (15 000–14 000 cal yr B.P.) indicates colder conditions and formation of at least seasonal sea-ice. In addition, increased kaolinite content indicates increased glacial erosion of the Bjørnøyrenna Ice Stream. The highest values of illite content and increased IRD content (14 000–13 000 cal yr B.P.) can be related to strong melting of the Fennoscandian Ice Sheet. A slight indication of the Younger Dryas cold period is given by the decrease in illite and IRD contents. All clay contents are more stable during Holocene compared to LGM and the last deglaciation.

1. Introduction

The nature and timing of the Late Weichselian glaciations in the SW Barents Sea have been much debated during the past decades (e.g. Ottesen et al., 2001; Olsen, 2002; Dahlgren and Vorren, 2003; Nygård et al., 2004; Sejrup et al., 2005; Nygård et al., 2005; Ottesen et al., 2005a, 2005b; Hjelstuen et al., 2005; Lekens et al., 2005; Elverhøi et al., 1993). Most previous investigations of the glacigenic sediments in the study area have been based on two- and three dimensional (2D and 3D) seismic data and sediment cores (Solheim and Kristoffersen, 1984; Vorren and Kristoffersen, 1986; Vorren et al., 1986, 1988, 1990; Hald et al., 1990; Sættem et al., 1992, 1994; Andreassen et al. 2008; Ottesen et al., 2008; Knies et al., 2007; Winsborrow et al., 2010). During the Last-Glacial Maximum (LGM) the ice sheets reached the shelf break more than once in SW the Barents Sea. This occurred first at ca. 22 000 cal yr B.P. (19 000 ^{14}C yr B.P.) and second time at ca. 20 000 cal yr B.P. (ca. 18 000 ^{14}C yr B.P.) (Vorren and Laberg, 1996). According to Andreassen et al. (2008) the main contributors during LGM in the SW Barents Sea were ice streams flowing from Bjørnøyrenna and Ingøydjupet (Fig. 1). During the deglaciation between >15 700–14 000 cal yr B.P. (>13 300–12 000 ^{14}C yr B.P.) the Barents Sea became free of glacial ice (Hald et al., 1989; Vassmyr and Vorren, 1990; Vorren and Laberg, 1996; Murdmaa et al., 2006). Also at this time, the Bjørnøyrenna Ice Stream retreated from the shelf edge and an early readvance occurred (Andreassen et al., 2008). After this, glacial activity in the SW Barents Sea consisted of glaciers flowing northwestwards along the coast of Norway (Djuprenna) (Andreassen et al., 2008) (Fig. 1). These glaciers seem to have been sourced by an ice centre located farther east in the Barents Sea, in addition to input from the Fennoscandian Ice Sheet (Andreassen et al., 2008).

Series of paleoceanographic data have been utilized to reconstruct past changes in the ocean circulation and climate of the Nordic Seas (Hald et al., 1989; Koç et al., 1993; Sarnthein et al., 1995; Hald and Aspeli, 1997). Time slice reconstructions of the inflow of Atlantic

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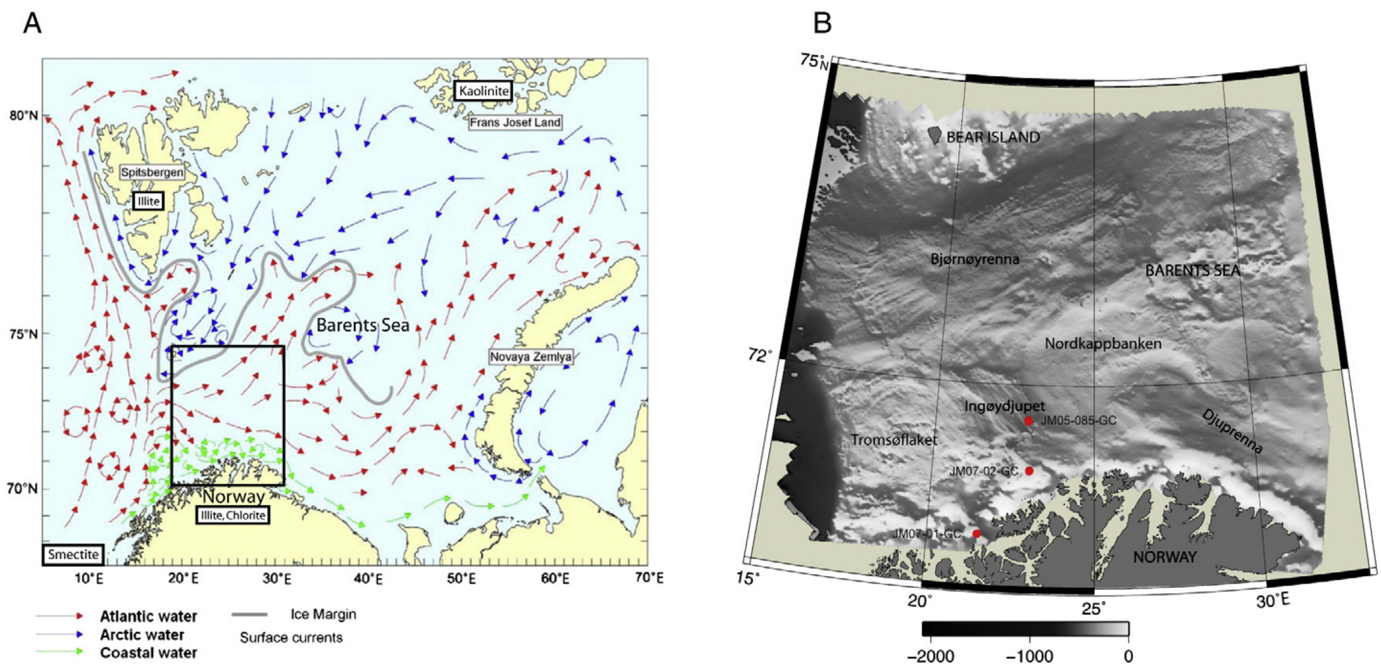

Fig. 1. A) Map of the study area including ocean currents and the approximate location of the marginal ice zone during winter season (modified after Sakshaug and Skjoldal, 1989) and also clay mineral sources (Wahsner et al., 1999; Vogt and Knies, 2009). B) Map of the Barents Sea showing the core locations as well as the locations of Bjørnøyrenna, Djuprenna and Ingøydjupet troughs (Andreassen et al., 2008). Bathymetry is obtained from Statoil, compiled by E. Mauring at the Norwegian Geological Survey in 2003 and is based on picks of the seismic seafloor reflection on 2D seismic data.

Water to the Barents Sea based on benthic foraminifera fauna analysis show the earliest sign of subsurface warming between 16000–15000 cal yr B.P. (Ślubowska-Woldengen et al., 2008).

Even though the glacial history of the SW Barents Sea has been studied quite excessively, knowledge of the late glacial drainage pattern is limited, in particular pathways, sources and mineral assemblages of the glacial sedimentary products. The overall goal of this paper is to advance knowledge of the onset of the deglaciation and subsequent advances/retreats of the ice streams in the Barents Sea (cf. Andreassen et al., 2008). This will be done by studying the distribution, pathways and sources of clay minerals in Late Glacial–Holocene sediments which are currently poorly investigated. Previous clay mineral studies integrated with other paleoclimatological proxies have provided reliable data on glaciations and paleoceanography in the Nordic Seas, Barents Sea and Arctic Ocean (Vogt and Knies, 2009; Knies et al., 2002; Junttila et al., 2008; Elverhøi et al., 1995; Vogt et al., 2001; Vogt and Knies, 2008; Wahsner et al., 1999; Forsberg et al., 1999; Fagel et al., 2001;Fagel and Hillaire-Marcel, 2006; Müller and Stein, 2000; Winkler et al., 2002; Polyak and Solheim, 1994; Murdmaa et al., 2006; Krylov et al., 2008). Sediment analyses, including clay mineral analysis, represent an integrated input function over time which will provide a chronological record of glacial history and paleoclimate. In addition, the clay mineral data will be integrated with other proxies including i.e. determination of ice rafted debris (IRD). Objectives of this study are the following: 1) to study the changes in the clay mineral distribution during the deglaciation and Holocene in southwestern Barents Sea and 2) identify main source areas and transport pathways for the clay minerals and 3) to relate/compare changes in clay mineral contents to changes in the ice sheets during Late Glacial/deglaciation as well as in the paleoceanographic development during Late Glacial–Holocene.

2. Regional settings

The epicontinental Barents Sea covers one of the widest continental shelves in the world (Fig. 1). The major geomorphologic feature of the SW Barents Sea is the Bjørnøyrenna cross-shelf trough (Andreassen et al., 2008) (Fig.1). It is 750 km long, 150–200 km wide and the water depth varies between 300 and 500 m. Bjørnøyrenna (Bear Island Trough) is bounded by shallow banks to the south. These shallow banks, Tromsøflaket and Nordkappbanken, have water depths around 300–200 m (Andreassen et al., 2008) (Fig. 1). Two southeast–northwest-trending troughs just off the coast of Norway Ingøydjupet (Ingøy Deep) and Djuprenna (Deep Trough) reach water depths around 400 m (Andreassen et al., 2008) (Fig. 1).

The western and northern continental margins of the Barents Sea–Svalbard area are characterized by fan shaped protrusions located at the mouth of cross-shelf troughs and are therefore named 'trough mouth fans' (TMFs; Vorren et al., 1988; Vorren and Laberg, 1997). The TMFs are depocentres of sediments that accumulated in front of ice streams of the former Fennoscandian–Barents Sea–Svalbard Ice Sheets (Vorren and Laberg, 1997; Vorren et al., 1998; Sejrup et al., 2003; Dahlgren et al., 2005).The main bathymetric feature of the investigated area is the Ingøydjupet trough, which is more than 400 m deep and is bordered by two bank areas to the east and to the west (Fig. 1). To the north the Ingøydjupet trough terminates in the eastwest running Bjørnøyrenna (Vassmyr and Vorren, 1990).

Water masses in the study area consist of Atlantic water in the Nordkapp Current, an extension of the Norwegian Current, lower saline water in the Norwegian Coastal Current and mixed water masses in the north-east, where the Atlantic, the Norwegian Coastal and Arctic water masses meet (Fig. 1). The sea-ice distribution in the Barents Sea varies throughout the year (Vinje, 1977). The minimum ice cover occurs in August and September, when the areas north of ca. 77° N and east of Spitsbergen are covered by pack ice. The maximum ice cover occurs in March–April when the Barents Sea north of 74° N and areas west of Spitsbergen are covered by pack ice.

3. Geological setting and sources for clay minerals

The bedrock in the northernmost Norway comprises of Archaean and Palaeoproterozoic complexes of the Fennoscandian Shield and