Bathymetry, shallow seismic profiling and sediment coring in Sermilik near Helheimgletscher, South-East Greenland

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The Greenland ice sheet is one of the most significant contributors to the rising global sea level with a contribution of 0.5 mm per year (Rignot & Kanagaratnam 2006). Evidence is emerging that rising temperatures of subsurface ocean currents play a vital role in the recent acceleration of large fast flowing glaciers such as Jakobshavn Isbræ in West Greenland (Holland *et al.* 2008) and Helheimgletscher in South-East Greenland (Straneo *et al.* 2010). Important questions are whether these incursions of warmer water are part of a recurrent phenomenon and indeed exactly how they influence the glaciers. The Geocenter Denmark project SEDIMICE (Linking sediments with ice-sheet response and glacier retreat in Greenland) investigates past ice fluctuations in the Helheimgletscher region in South-East Greenland with regard to magnitude, possible causes and effects. One of the main tasks in this project is to analyse sedimentary deposits in the main fjord Sermilik (Fig. 1), which is influenced by the tidally affected Helheimgletscher that has a short floating tongue. By combining sediment studies with modern climate studies we aim to extrapolate meteorological data back in time.

In August 2009 the Geological Survey of Denmark and Greenland collected short sediment cores in Sermilik near Tasiilaq (Fig. 1). To select core sites and to understand the sedimentary processes, we also acquired data on the bathymetry and conducted shallow seismic profiling. This paper presents some results of the seismic survey, preliminary sediment core data and bathymetrical data from the fjord. Apart from a few isolated depth values, the bathymetry of Sermilik was unknown before the 2009 survey.

Setting

Sermilik is about 80 km long and 7–13 km wide. The terrain around the fjord is alpine with elevations of 300–600 m near the coast and up to 1000 m inland. Frequent glacial and geologically controlled fissure valleys dissect the area in a criss-cross pattern. The northern end of Sermilik branches into three fjords with calving glaciers. The westernmost – Helheimgletscher – is a fast flowing glacier and the third most prolific iceberg producer in Greenland (Rignot & Kanagaratnam 2006).

The climate of the region is low arctic and the weather conditions are influenced by lows moving north along the coast. The fjord is covered by sea ice from December to May. The hydrographic conditions in the fjord are influenced by a 10–20 m thick layer of glacial water, underlain by 100–150 m of

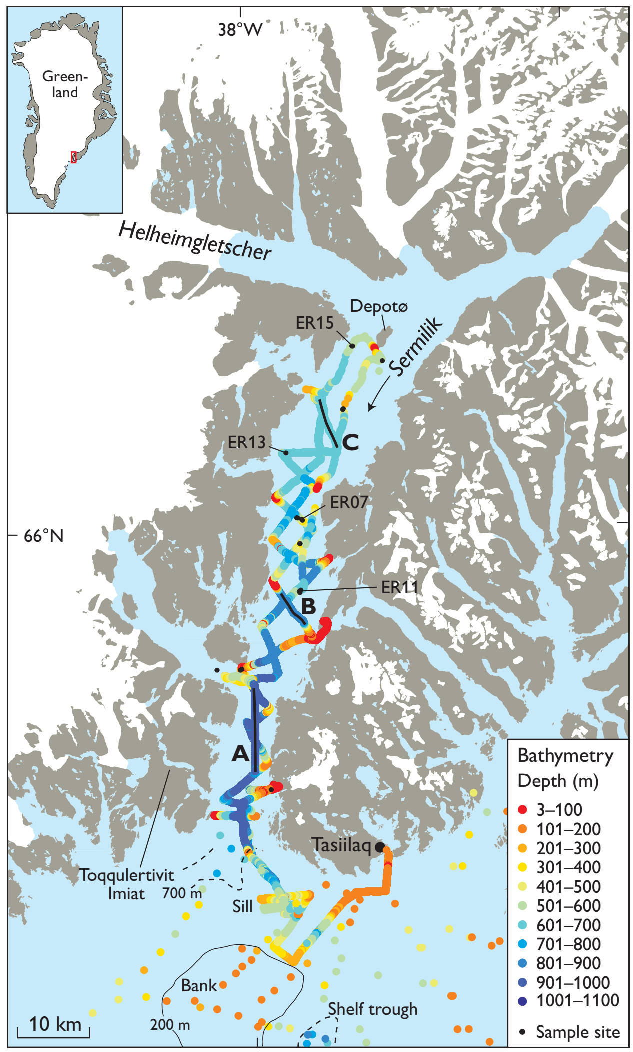

Fig. 1. Study area and bathymetrical data from Sermilik based on data collected in 2009. Depth data on the shelf south of the fjord mouth are from Clausen (1998) and this survey. The positions of the seismic lines A, B and C are indicated by black lines and sediment core sample sites are shown.

polar water. Below the polar water towards the bottom warmer Atlantic water of subtropical origin with temperatures of 3.5–4°C is found (Straneo *et al.* 2010). The inflow of warmer waters into Sermilik takes place via deep troughs in the shelf.

Glacial history of the region

A study from the Toqqulertivit Imiat valley (Fig. 1) shows that a glacier flowed through this valley and most likely coalesced with a glacier flowing south in Sermilik and out over the continental shelf during the Last Glacial Maximum (Roberts *et al.* 2008). Exposure ages of 11.8–9.9 ka (kilo-annum, 10^3 years BP) from bedrock surfaces at high elevations (683–740 m a.s.l.) provide minimum ages for the last deglaciation (Roberts *et al.* 2008). These ages from Toqqulertivit Imiat support the 'maximum' model of a large Last Glacial Maximum ice sheet extending to the shelf break in South-East Greenland (Stein *et al.* 1996; Kuijpers *et al.* 2003). Evidence from the shelf south of Sermilik indicates that the ice margin retreated to the inner shelf around 15.7–14.6 calibrated (cal.) ka (Kuijpers *et al.* 2003). In the Kangerlussuaq region farther north the ice-sheet margin retreated from the outer shelf around 15.5 cal. ka and reached the present outer coast around 13.6–10 cal. ka (Jennings *et al.* 2006). This is in accordance with surface exposure ages from lower Toqqulertivit Imiat indicating that ice retreated to the mouth of Sermilik between 11.1 and 9.7 ka (Roberts *et al.* 2008). These data are further supported by a minimum age of 11 cal. ka for the formation of the local marine limit (at 69 m) and thereby local ice retreat near Tasiilaq (Long *et al.* 2008).

Methods

We used the locally hired motor boats *Erik den Røde* and *Puite* for the work. An Innomar SES-2000 Medium sub-bottom echo sounder from Innomar Tecnologies, Rostock, Germany, was used for bathymetrical and sub-bottom sediment profiling. This parametric device is designed for water depths down to about 2000 m and has the ability to resolve sediment layers a few decimetres thick and penetrate down to about 50 m below the sea floor. The transducer was mounted on a vertical steel tube attached to the side of the boat and a motion sensor was used to compensate for movements of the boat. Additional bathymetrical data were recorded in the inner fjord from the echo sounder of *Erik den Røde* during the sediment coring cruise. Comparisons of depth recordings obtained by the two methods showed that the results are compatible to within a few metres. Sediment coring was performed with a Rumohr lot corer with up to 1.5 m long core liners.

Bathymetrical data from Sermilik

The southern part of Sermilik Fjord is an up to 920 m deep and flat basin (Fig. 1). The bathymetry of the fjord mouth can be described as terminating into a SE-directed trough and a SW-directed trough separated by a broad bank with water depths of less than 200 m. The bathymetry of the SW-directed trough is very uncertain. The shallowest part of the SE-directed trough forms a *c.* 550 m deep sill between the deep fjord and the 800–900 m deep trough that stretches the entire shelf towards the Irmiger Sea.

The deep fjord basin extends up to 40 km northward from the fjord entrance into the middle part of Sermilik where several bathymetrical highs (400–550 m) narrow the connection to the northern part of the fjord. Towards the northern part of Sermilik, the basin floor rises steadily to a depth of about 600–650 m just south of Depotø. The fjord bottom in the inner part is more irregular with channel systems more than 100 m wide and up to 20 m deep. During the survey we could not measure water depths in the inner east–west-trending fjord arm leading up to Helheimgletscher due to semi-permanent sea ice extending tens of kilometres

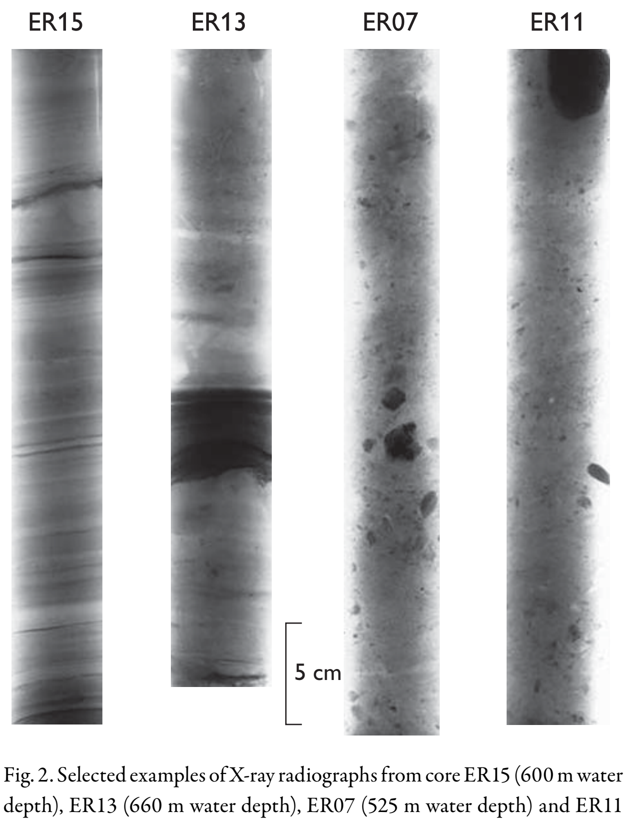

Fig. 2. Selected examples of X-ray radiographs from core ER15 (600 m water depth), ER13 (660 m water depth), ER07 (525 m water depth) and ER11 (600 m water depth) that document different sedimentation regimes. Note the dark sand layer in core ER13 with a lower erosive boundary; this unit is interpreted to be a turbidite. Core sites are shown in Fig.1.

from the Helheimgletscher calving front. However, according to the skipper of *Erik den Røde* (Sigurdur Petursson), water depths up to 800 m are found north-west of Depotø.

Sediment cores

Altogether 19 cores with lengths ranging from 30 to 150 cm were retrieved during the sediment coring cruise. The full sediment core data (sedimentology, geochemistry and chronology) will be presented elsewhere. However, preliminary inspection of cores ER07, ER11, ER13 and ER15 documents the variable sediment regimes that characterise the fjord (Figs 1, 2), and X-ray radiography of the cores show diamicton facies, laminated mud facies and sand layers with erosive lower boundaries. These lithofacies are similar to lithofacies described from sediment cores from Kangerlussuaq (Smith & Andrews 2000) and Scoresby Sund (Dowdeswell *et al.* 1994; Ó Cofaigh & Dowdeswell 2001). For example, core ER15 consists of laminated mud with variable content of pebbles, which is interpreted as ice-proximal glaciomarine sediments mainly deposited by suspension settling from turbid overflow plumes and turbidity currents and occasional iceberg rafting. In contrast, cores ER07 and ER11 are characterised by massive diamicton facies with abundant pebbles, which is interpreted as the result of iceberg rafting. Core ER13 has a unit of diamicton facies above a unit of laminated mud facies. This may reflect an environmental change from a long-lasting sea-ice cover in the fjord prohibiting iceberg passage to a period with increased passage and melting of icebergs. As also suggested by Jennings & Weiner (1996) variable inflow of Atlantic water may influence the melting and traversing of icebergs.

^{210}Pb dating of the upper decimetres of the cores show sedimentation rates >1 cm/yr in ER15, 0.4 cm/yr in ER13 and 0.2 cm/yr in ER11. The decreasing sedimentation rates with increasing distance to the present front of the calving glaciers reflect the decreasing influence from meltwater plume sedimentation.

Seismic profiles

The seismic profile (Fig. 3A) shows an outer flat, deep basin in Sermilik with an upper 4–6 m thick, transparent seismic unit overlying a well-stratified section (>15 m thick) that is characterised by strong, continuous, parallel reflectors. There is no distinct boundary between the two seismic units, as weak, discontinuous, parallel reflectors characterise the uppermost *c.* 2 m of the stratified section. On vertically extremely exaggerated sections, wide lenticular units and stratigraphical onlap structures are visible in some parts of the lower seismic unit. To the north, the transparent upper unit disappears and well-stratified sediments, with some channel features, dominate the seismic profiles (Fig. 3B). The profiles of the bathymetrical highs in the middle part of the fjord are dominated by overlapping diffraction hyperbolae. The inner, shallower part of the fjord is characterised by large channel and levee structures, and broad flank units showing well-stratified sediments in the north-western part of the seismic survey area (Fig. 3C).

Formation of fjord-bottom sediment structures

The sediment unit with a transparent pattern in the outer fjord basin indicates a uniform lithology that possibly origi-

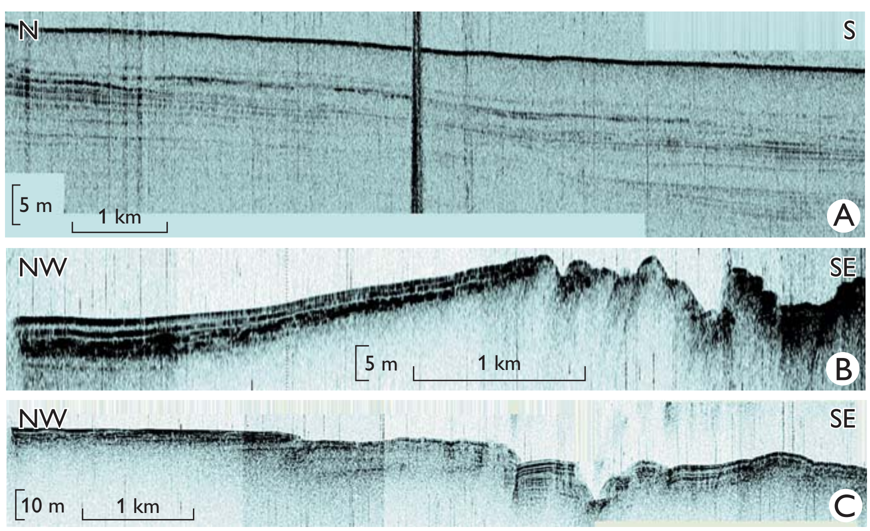

Fig. 3. Representative seismic sections that illustrate different structures in different parts of Sermilik (see text for description and Fig. 1 for location).

nates from suspension sedimentation (meltwater plumes) and ice-rafting during the main part of the Holocene (Fig. 3A). The lower stratified section is interpreted as glaciomarine sediments consisting of turbidites and mass-transport deposits interbedded with suspension-deposited sediments. The lower unit was possibly deposited during the final deglaciation of the main part of Sermilik at about 10 ka (cf. Roberts *et al.* 2008). Turbidite sedimentation typically creates very flat fjord basins with reflectors onlapping basin margins and structural highs. It is possible that the structural highs in the middle part of Sermilik could serve as anchor points for the retreating glacier, causing a stagnation of the fjord glacier front during the last deglaciation.

The inner basin with its apparent active channel and levee sedimentation and over-all fill geometry (Fig. 3C) can be characterised as a progradational–aggradational wedge of sediments with possibly very high sedimentation rates from turbidites and mass flows, as well as plume sedimentation. It is an open question whether the channel systems are directly fed by the Helheimgletscher source, or whether bedrock thresholds in the innermost fjord system prohibit bed transport of glaciogenic sediments. If a deeper sub-basin exists north of Depotø, we can only explain the seismic signature and large channel-levee systems of the inner basin by a very advanced position of Helheimgletscher to near Depotø during the late Holocene. Hopefully, future exposure ages from the land terrain near Depotø by our collaborators can show if the front of Helheimgletscher had a standstill near Depotø during the Little Ice Age.

In conclusion, the seismic survey has revealed a rather complex pattern of sub-bottom sediment structures (down to 50 m) in Sermilik reflecting the early Holocene retreat of Helheimgletscher, probably followed by a Holocene ice advance – perhaps during the Little Ice Age. Preliminary results from analyses of the sediment cores support the interpretation that the glaciomarine sediments in Sermilik is related to settling from meltwater plumes and iceberg rafting. Knowledge of the sediment depositional regime on the fjord bottom from seismic investigations is highly relevant for retrieval of sediment cores suitable for Holocene palaeoclimatic reconstructions. We hope to collect more and longer sediment cores in the fjord in coming years.

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