Quaternary sediments in Scoresby Sund, East Greenland: their distribution as revealed by reflection seismic data

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Introduction

The world's largest fjord system, Scoresby Sund, is located centrally along the East Greenland coast between 70°-72°N and 20°-28°W. It comprises the shallow Scoresby Sund and Hall Bredning and a number of deep and narrow fjords extending far inland (Fig. 1). Three different main geological units surround this fjord system. The westernmost block includes the Precambrian and Caledonian metamorphics which make up most of Milne Land, Renland and Scoresby Land (Larsen 1984; Fig. 1). During the Mesozoic rift phase (Permian to Jurassic) a deep sediment basin (Jameson Land) was formed which is separated from the eastern (Liverpool Land) and western metamorphics by a set of normal faults (Surlyk & Clemmesen 1983; Surlyk *et al.* 1983). The western NNE-SSW striking fault system is proposed to extend into Hall Bredning (Larsen 1984).

The area south of Scoresby Sund, the Geikie Plateau, is covered by at least 2,000 m of early

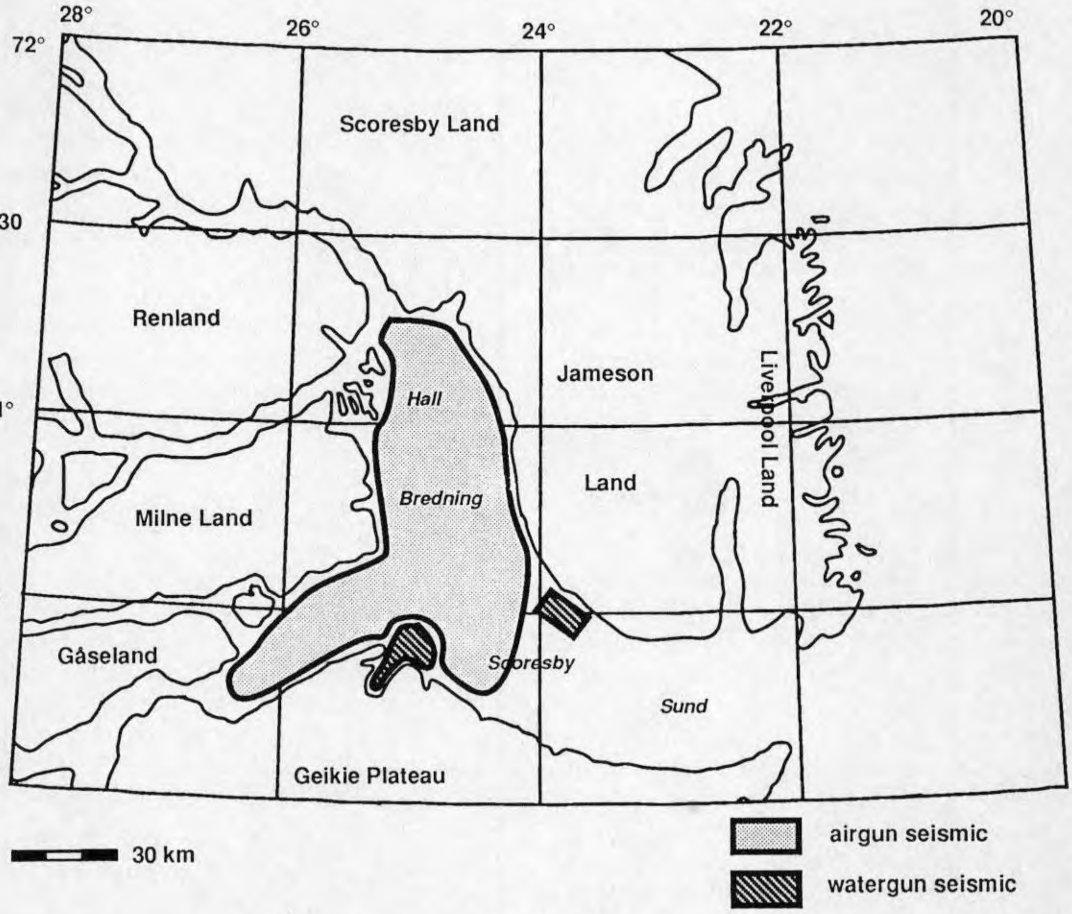


Fig. 1. Map of investigated areas in Scoresby Sund. Shaded area = airgun seismics, hatched area = watergun seismics.

Tertiary basalts (Larsen 1984) which result from the prominent North Atlantic Thule volcanism (Larsen & Watt 1985). Those Paleogene basalts probably covered parts of Milne Land and Jameson Land as well, even if to a minor degree (Larsen 1984; Larsen & Watt 1985) but have clearly been eroded. This erosion continued stratigraphically much farther down into the underlying Mesozoic sediments (Larsen 1984).

In the Neogene a major eastward flowing river system took up the position of the present Scoresby Sund and transported the erosional detritus from the crystalline basement in the west and Jameson Land towards the east (Larsen 1984).

The Quaternary in the Scoresby Sund region was generally a period of erosion, except for the valley mouths, high mountain plateaus and the coast of Jameson Land where thick deposits are preserved (Funder 1990). Several glacial-interglacial cycles characterize the distribution of Quaternary sediments. The oldest sediments (Lodin Elv formation) found on land are of Pliocene/Pleistocene age. The Scoresby Sund Glaciation documents the most expanded glaciation around 200,000 BP (Funder 1972, 1984, 1989).

Sediments deposited during the Langelandselv Interglacial (Eemian/Sangamonian, 120,000 BP, Funder 1990) have so far been found only along the SW coast of Jameson Land. According to Funder (1989) the early/middle Weichselian/Wisconsin Glacial showed no glaciation of the outer eastern fjord areas.

During the Flakkerhuk Glacial (Late Weichselian/Wisconsin according to Funder 1990) a fjord glacier extended onto the shelf while Jameson Land stayed uncovered by ice. Along the south coast of Jameson Land a lateral moraine can be observed (Funder 1972). Funder (1989) suggested a floating glacier in Scoresby Sund, grounded only on the shallow shelf. The Flakkerhuk glaciation has been redefined to be an Early Weichselian glaciation and the Late Weichselian glaciation is named "Glaciation 4" (Funder *et al.* 1991, this volume).

The Milne Land Stage (11,000-9,500 BP) represents a period when thick glaciers terminated at the mouths of the western fjords into Hall Bredning (Hjort 1979). After a continous retreat of the glaciers a standstill followed during the Rødefjord Stage (Funder 1971). The end of this phase resembles the ice extension at present.

But, while the glacial history has been investigated intensively on land, little is known about the sediment distribution and the Quaternary development in the marine environment. The glacial evolution can give detailed information on the climatic variations during that period. In order to gather those informations, which is the objective of the European PONAM project, we first need to determine thickness and distribution of Quaternary sediments in the Scoresby Sund area. To infer the actual expansion of the glaciers we need to map the extension of subaerial moraines into the marine environment.

Thus, the Alfred-Wegener-Institute for Polar and Marine Research together with the Renard Centre of Marine Geology carried out a reflection seismic survey as part of the PONAM project in Scoresby Sund in late summer 1990. The general sediment distribution, especially of Quaternary sediments near river mouths and in front of glaciers and the extension of a few moraines were to be mapped. Preliminary results will be discussed here.

Data acquisition

Two different seismic sources were used to solve the slightly different problems. To develop an idea on the general sediment distribution a tuned airgun array of 20.2 liters total volume was used allowing a deeper penetration. The main frequency of the transmitted signal was around 70 Hz theoretically resulting in a seismic resolution of layers thicker than 12 m. Shots were fired every 15 s corresponding to a shot distance of 37 m (5 kn ship's speed).

A more detailed mapping of Quaternary sediments require a higher resolution. Thus, an 0.25 liter watergun was used, leading to higher frequency signals (around 140 Hz) and a theoretical resolution of 6 m. A shooting intervall of 3 s led to a shot distance of 7.5 m.

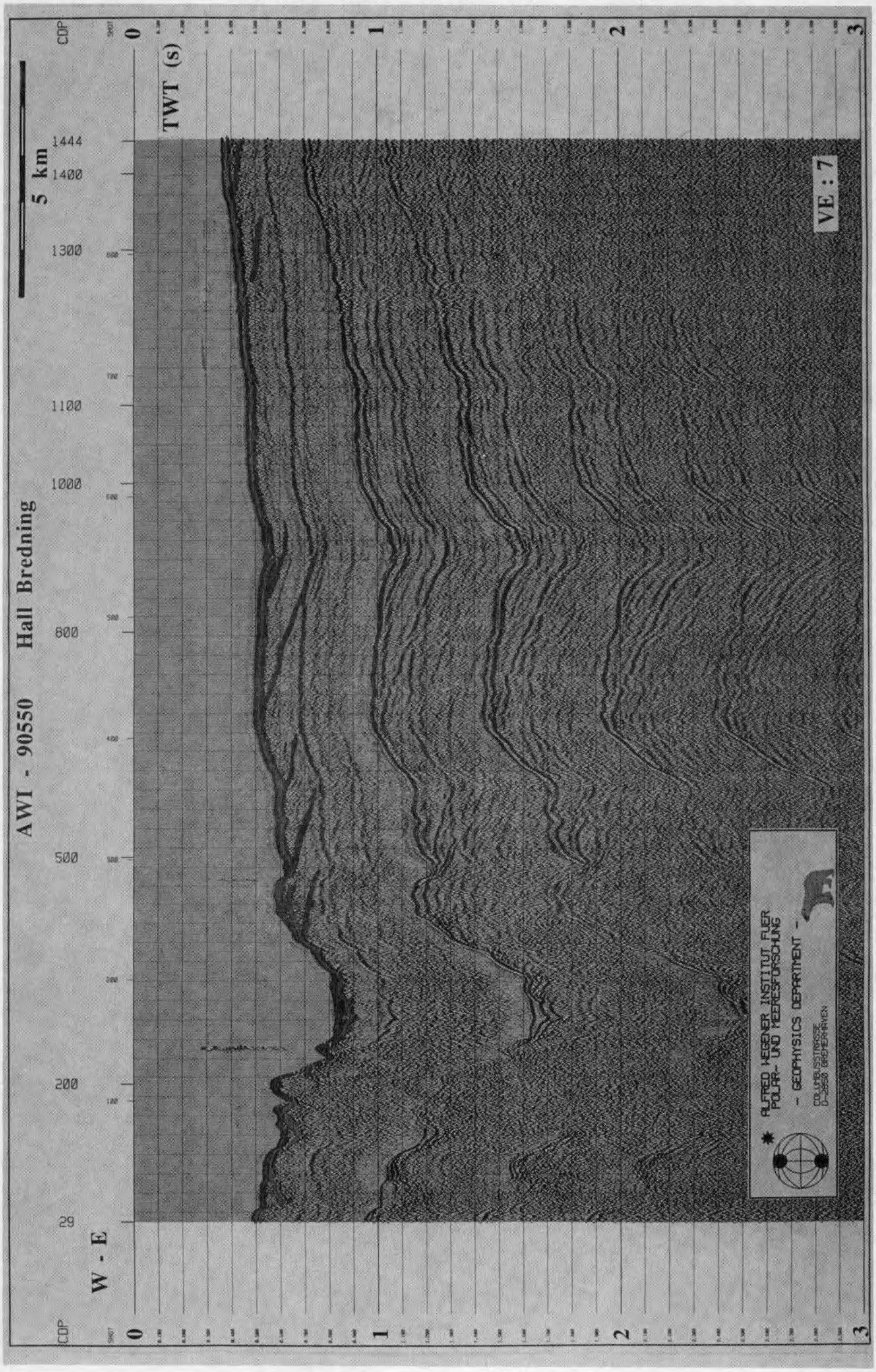
Together with the airgun array a 600 m long streamer (200 m lead-in cable, 24 channels) was used. A 100 m streamer (37 m lead-in cable, 12 channels) was employed in combination with the watergun.

Recording and storage was performed by an EG&G Geometrics ES 2420 multichannel digital recording system. Positioning was carried out using GPS (Global Positioning System) assisted by the on-board INDAS (Transit Satellite) system.

Discussion of observations

The Hall Bredning and and more easterly parts of Scoresby Sund were investigated using the airgun array as a seismic source (Fig. 1, shaded area). Here, information on the general sediment distribution and on the continuation of the western fault system bordering Jameson Land were to be gathered. The older sediments will be discussed elsewhere (Miller *et al.* in prep.) and only the

Fig. 2. Common offset section of line AWI-90550. This airgun-line crosses the central part of Hall Bredning from West to East.


AWI - 90550 Hall Bredning
W - E
TWT (s)
5 km
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CDP
29
200
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- GEOPHYSICS DEPARTMENT -
COLUMBUSSTRASSE D-2850 BREMERHAVEN

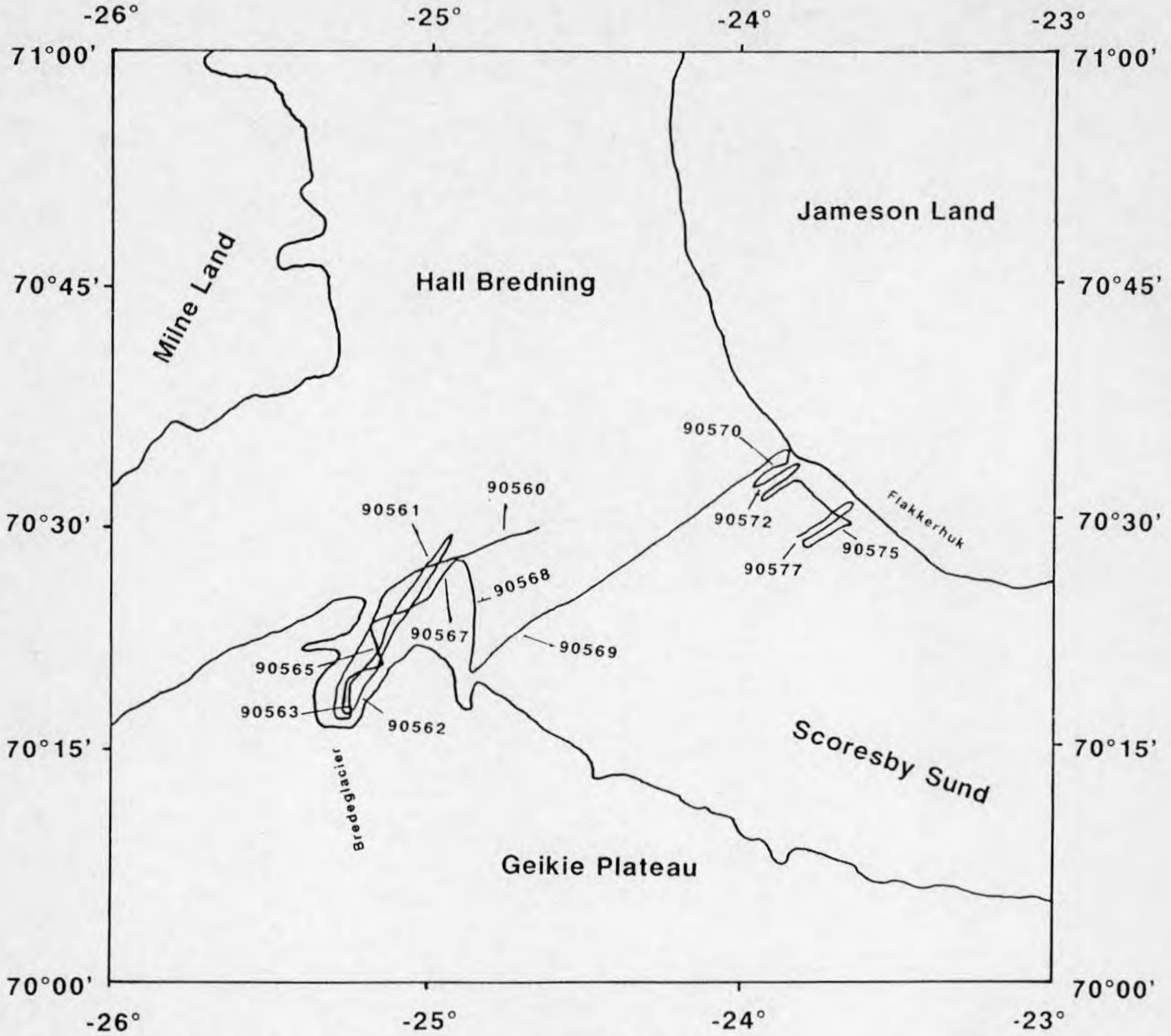


Fig. 3. Location of watergun-profiles in Vikingebugt and near the southwestern coast of Jameson Land.

Quaternary deposits shall be dealt with in this paper.

Fig. 2 displays line AWI-90550 as an example of the data, crossing Hall Bredning from West to East. A strong reflector can be identified, sometimes up to 100 ms TWT (corresponding to 80 m assuming a seismic velocity of 1600 m/s) below seafloor, more often reaching up to seafloor. We suggest that this reflector represents the top of the Mesozoic sedimentary rocks. The sedimentary rocks show only few internal reflections indicating rather small impedance contrasts beneath the reflector, which might be due to well consolidated material.

A continous layer on top of this reflector could not be detected. This is true for the whole set of lines. Deposits of probably younger age were only observed at a few locations (Fig. 2). Those pockets are up to 50 ms TWT thick and are mainly found in the western Hall Bredning: at the bottom of a deep N-S striking channel and west of it.

In order to get an idea on the sedimentation in front of a glacier terminus and the distribution of sediments in front of creeks, several profiles were shot with a high shooting rate with the high-resolution watergun in front of the Bredegletscher (Vikingebugt) and near the mouths of Aucellaelv and Langelandselv on southern Jameson Land (Fig. 1, hatched areas; Fig. 3).

The lines in the Vikingebugt area display at least two distinguishable layers. The top of the lower layer is marked by a strong reflector. Directly in front of the glacier this reflector forms a basin (Fig. 4) with a hummocky reflector appearance. The material beneath this reflector appears well consolidated, showing only few internal structures. Several hundred ms TWT below this reflector another reflection might be suspected. We propose that this reflector constitutes an older glacier-generated erosion surface cut into the Mesozoic sediments, and that the upper layer consists of loose Quaternary deposits.

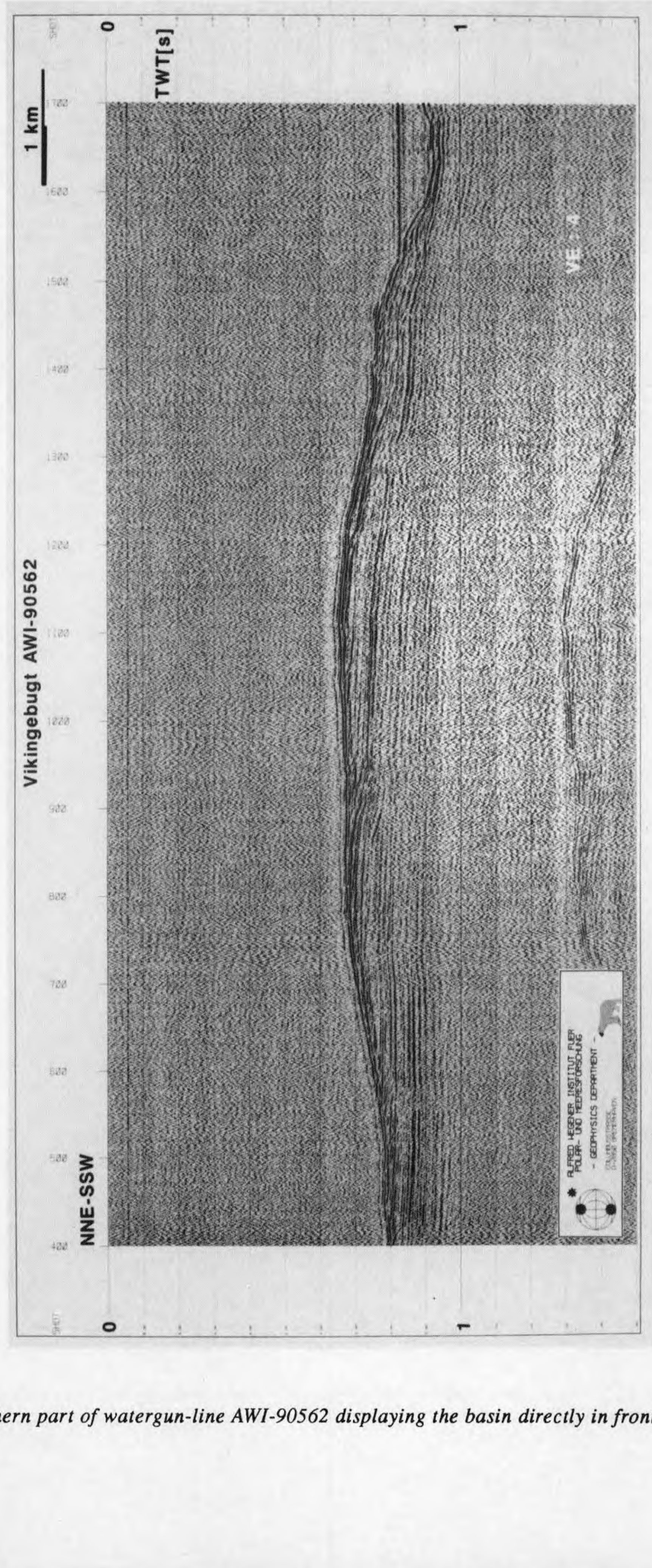


Fig. 4. Southern part of watergun-line AWI-90562 displaying the basin directly in front of Bredeglacier.

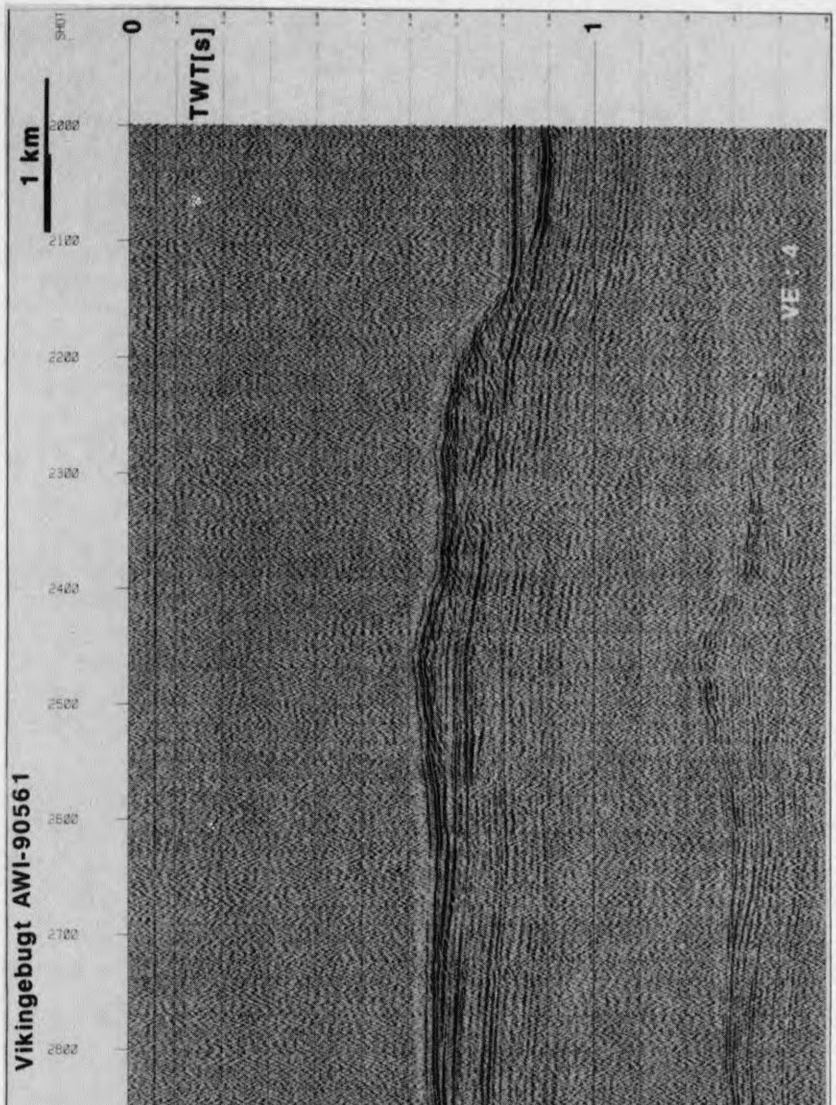


Fig. 5. Central part of watergun-line AWI-90561 showing the set of moraines stuck onto each other at the northern end of the basin.

In central Vikingebugt this reflector rises almost to seafloor (Fig. 4). A mound can be observed at the northern boundary of this basin. The mound seems to be built-up of at least three sediment lenses which show distinct base reflectors whose dips decrease with depth (Fig. 5), i.e. the lowest is flatlying whereas the base reflector of the top lense is strongly inclined. The base reflectors are truncated at the top of the mound, indicating erosion. Those observations lead to the interpretation of the lenses as end moraines, representing different stages of glaciation. We infer that the lowest moraine was deposited first and that the uppermost moraine documents the youngest glaciation.

The lines AWI-90560, -90561, -90562, -90567 and -90568 (see Fig. 3 for location) document that the set of moraines extends into Scoresby Sund, forming a kind of fan, while no indications for a moraine can be found on line AWI-90569. North of the moraines the lower reflector parallells the seafloor.

The observed upper layer fills up the basin in front of the glacier (Fig. 4). Its thickness inceases towards the glacier (maximum thickness around 250 ms TWT). Very faint subparallel reflectors can generally be observed, indicating a low sedimentation rate after basin formation. Thus, we suggest that those sediments have been deposited after the latest glacial retreat. A beautiful pattern of rotational slumps was observed at the sea bed directly in front of the glacier, indicating poorly consolidated material.

This layer of recent sediments was found to thin out towards the set of moraines. North of the moraines the layer reappears, now showing a continous thickness of 20 ms TWT. We presume that the sediments consist of glaciofluvial material transported by meltwater from the glacier sole.

Line AWI-90569 was shot across Scoresby Sund (Fig. 3). Again, a basin can be observed in front of the south coast which, however, is not as deep and large as in Vikingebugt (Fig. 6). No end- or lateral moraines were found. Instead, we observed several step faults with displacements of 20 ms TWT to 50 ms TWT. Those step faults may be the surface expression of a fault system separating the sediment basin of Jameson Land in the North from the volcanic Geikie Plateau in the South.

Larsen (1984) described a transform zone, the Scoresby Sund Fracture Zone, located at or just south of the mouth of Scoresby Sund which separated two different tectonic provinces off the East Greenland Continental Margin. We suggest that this fault system extends into Scoresby Sund at least as far as Vikingebugt. Indications for a westward continuation of those faults were found on reflection seismic lines shot east of Danmark Ø (Miller *et al.* in prep.).

The central part of line AWI-90569 reveals a zone where penetration suddenly amounts to about 100-200 ms TWT below seafloor. This zone shows internal reflectors wedging out via an erosional truncation in the northern central part of the profile. In the northern part of the profile the in-

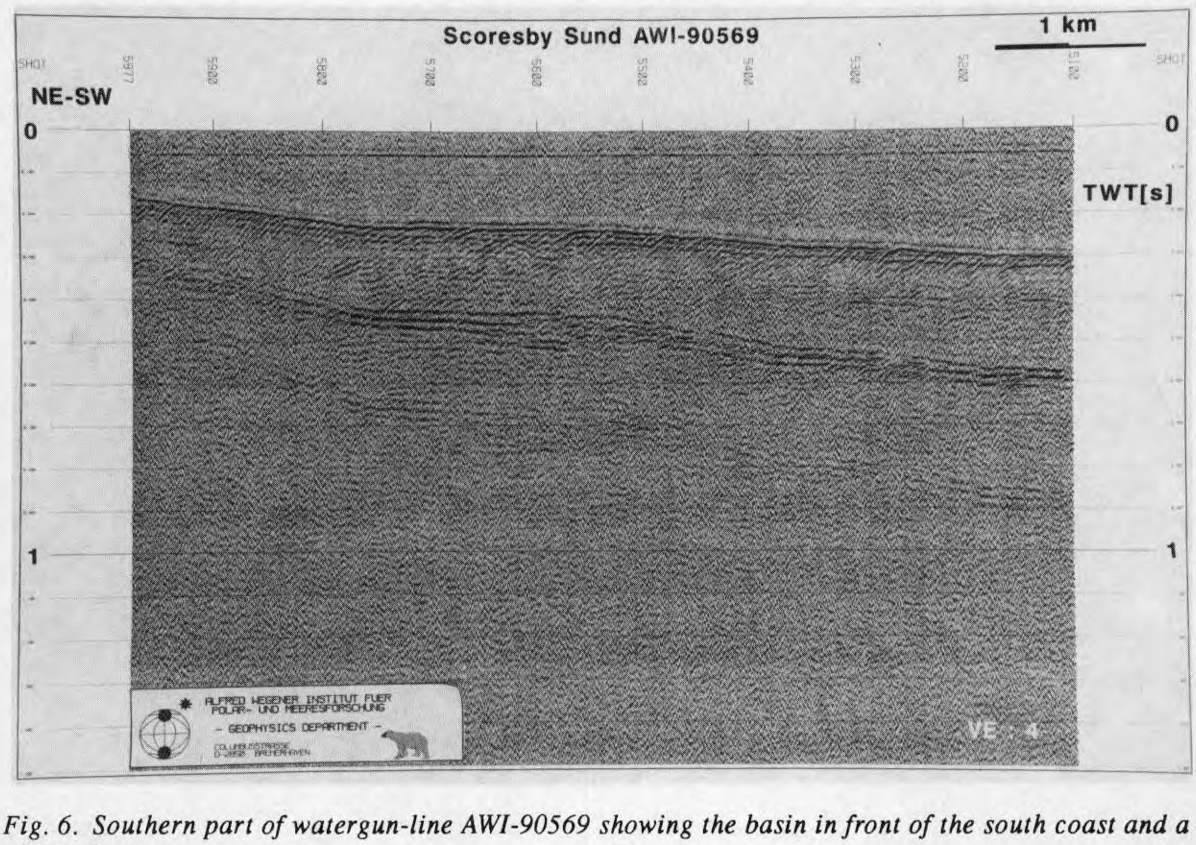


Fig. 6. Southern part of watergun-line AWI-90569 showing the basin in front of the south coast and a set of step faults.

ternal reflectors have vanished. Two sites here (Aucellaelv and Langelandselv) were, amongst others, selected by the terrestrial PONAM groups coordinated by S. Funder, C. Hjort and J. Landvik. The objective was to look for delta deposits that are presently deposited in front of the rivers or that had formed during lower sea level stands, in order to make a comparison with a series of raised deltas of presumed Early Weichselian age that were identified on land (Funder, personal communication). However, near the mouths of Aucellaelv and Langelandselv, no loose Quaternary deposits

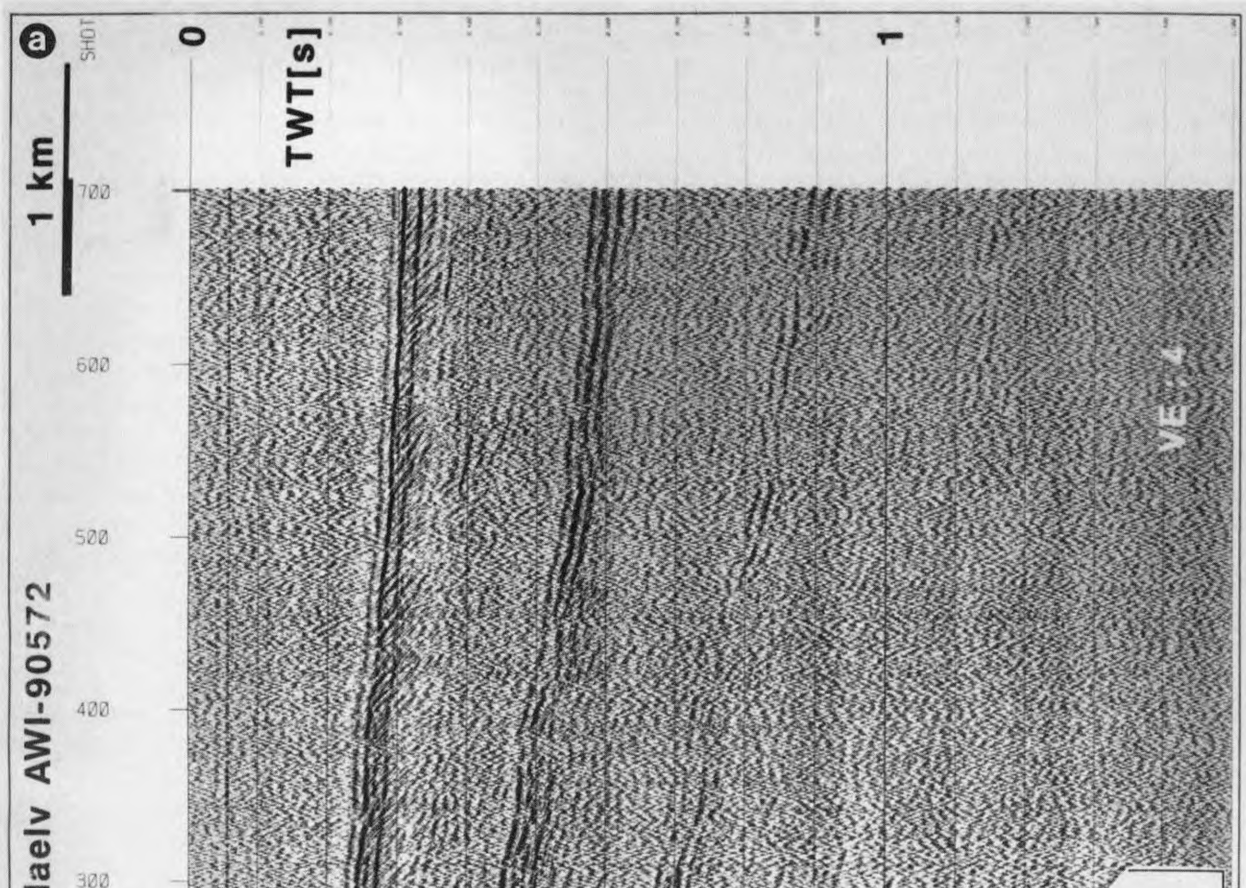


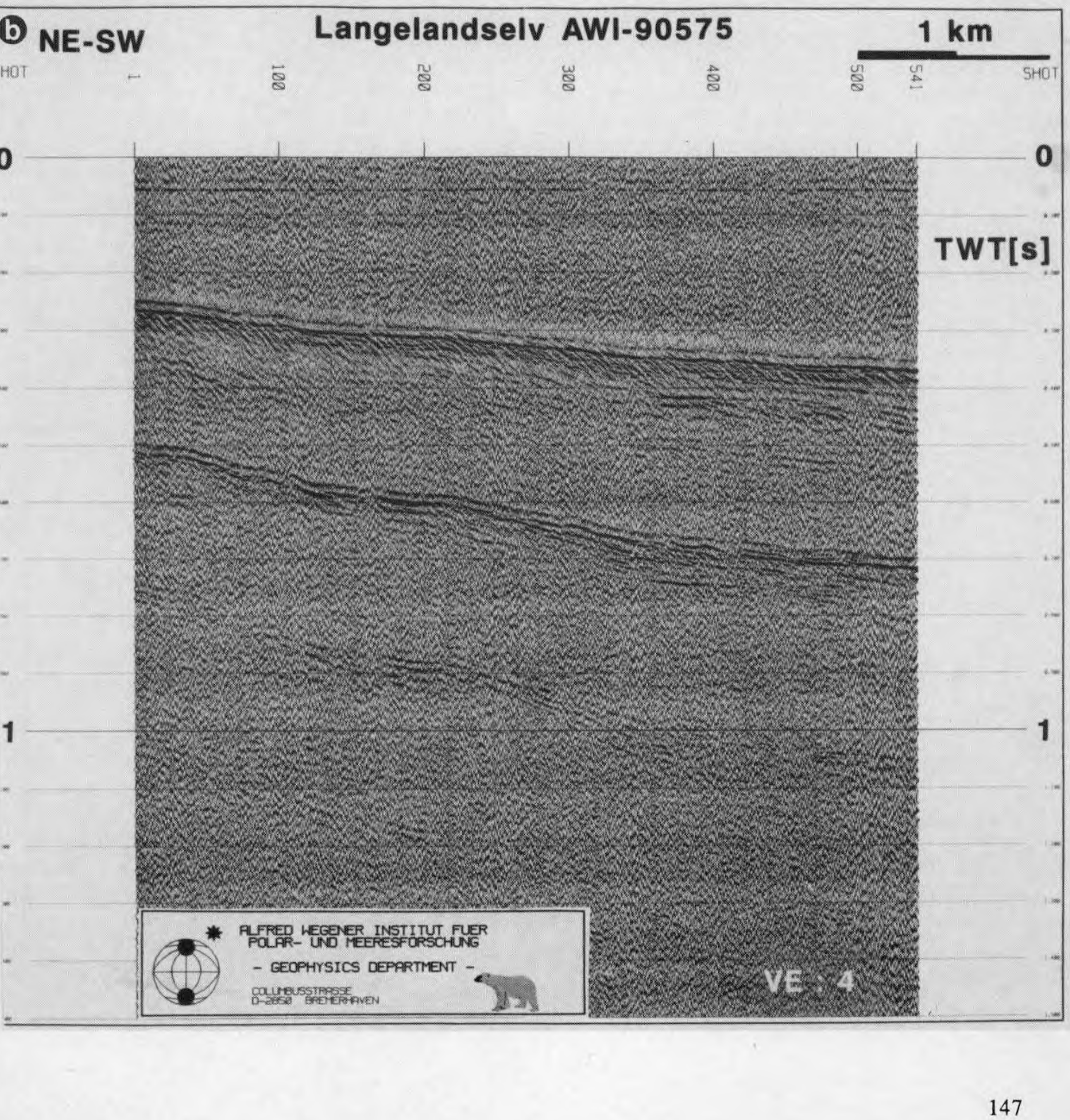
Fig. 7a. Watergun-lines AWI-90572 (a) and -90575 (b) near the southwestern coast of Jameson Land.

could be observed. This is true for the whole set of lines shot in this area (Fig. 7). It is not possible to identify different layers. We did not even observe pockets filled with different material resembling those in western Hall Bredning. Occasionally southeast-wards inclined reflectors can be suspected (Fig. 7).

Young deposits, if they occur, are obviously below our resolution (thickness 6 m) and the observed indistinct structures are probably old (Mesozoic). Those thickness constraints would give sedimentation rates of 7.5 $cm/10^3$ yr if the Scoresby Sund/Illinoian Glacial was assumed to represent the last full glaciation during which the glaciers eroded all sediments in Scoresby Sund (Funder 1989). P. Marienfeld (this volume) observed sedimentation rates of 30 $cm/10^3$ yr for the last 10,000 years. Taking into account that the period Eem-Weicheselian-Holocene includes an interglacial-glacial-interglacial cycle with a suggested floating glacier during the late Weichselian/Flakkerhuk Glacial (Funder 1989) we would expect deposition rather than erosion with sedimentation rates similar to those of the Holocene. Some 10.000 years of sedimentation would result in a sediment cover which is obviously not existing. So, for the Flakkerhuk Glaciation we suggest a glacier with ground contact, thus actively eroding in Scoresby Sund (see also Dowdeswell *et al.*, this volume).

Neither could an extension of the Flakkerhuk moraine be observed, thus the originating glacier probably reached up to the present-day shoreline of Jameson Land.

Apart from very small deltas, the river systems of southwestern Jameson Land do not extend far into Scoresby Sund. No indications of delta systems could be found, not even in water depths down to 10 m (the Langelandselv area). We speculate that the rivers on southwestern Jameson Land



are of Holocene age and transport little material. Furthermore, this material may be caught up by longshore currents and deposited parallel to the coast and not perpendicular.

Conclusions

The tight grid of reflection seismic data gathered in Hall Bredning, Scoresby Sund and Vikingebugt gives a good opportunity to map the distribution of Quaternary sediments.

Interpretation of the airgun seismics give thicknesses of Quaternary sediments in Hall Bredning and Scoresby Sund less than 12 m (seismic resolution of airgun array). Only in western Hall Bredning a few pockets filled with supposedly young material could be observed on top of well consolidated probably Mesozoic sedimentary rocks.

In Vikingebugt younger material could be observed on top of the ubiquitous strong reflector that is interpreted as the top of the Mesozoic sedimentary rocks of the Jameson Land basin. A well developed set of moraines can be found at the northern end of this glacier basin. The different moraines obviously document different stages of the deglaciation. This set of moraines extends 2 to 3 km into Scoresby Sund.

In the southern central part of Scoresby Sund indications for a deep reaching fault system was observed which might terminate the northern Mesozoic rift basin.

Close to the coast of southwestern Jameson Land only well consolidated sediments are found. The cover of Quaternary sediments is thinner than 6 m (seismic resolution of watergun), thus indicating a very low rate of deposition and/or erosion. Our observations seem to exclude a floating glacier during the last glacial advance, as suggested by Funder (1989), because this would result in deposition rather than erosion. Instead we propose a grounded glacier which eroded all older sediments.

Summarizing, we infer that the major areas of Hall Bredning and Scoresby Sund were subjected to erosion or non-deposition during glaciation up to the end of the Younger Dryas (c. 10,000 BP). Only sheltered areas such as Vikingebugt display a beautiful sequence of glacial deposits documenting the different glacial stages.

Acknowledgements

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