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Scoresby Sund, East Greenland: Structure and Distribution of Sedimentary Rocks

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Summary: A reflection seismic investigation of the Scoresby Sund allowed a refined interpretation of the Mesozoic and Cenozoic sedimentary evolution of this area. A synsedimentary subsidence is suggested for the western part of the Jameson Land Basin. Two seismic sequences document the strong erosion which took place during the Cretaceaous/Tertiary. Further erosion resulted from the development of several glacial phases in the Quaternary leading to a very thin (below 12 m, in shallow areas below 5m) cover of Quaternary sediments. It is inferred that the most recent glacial developed during the Late Weichselian built up a grounded glacier.

Zusammenfassung: Durch eine reflexionsseismische Untersuchung des Scoresby Sundes konnte eine verfeinerte Interpretation der mesozoischen und känozoischen sedimentären Entwicklung erreicht werden. Für den westlichen Teil des Jameson Land Beckens wird eine synsedimentäre Absenkung angenommen. Zwei seismische Einheiten dokumentieren die in der Kreide/ Tertiär aufgetretene starke Erosion. Verschiedene Glaziale führten zu weiterer Erosion und so zu einer extrem dünnen Bedeckung (unter 12 m, in flachen Gebieten sogar unter 5 m) von Quartärsedimenten. Die Untersuchung hat ergeben, daß das letzte Glazial unter Ausbildung eines Gletschers mit Grundkontakt in der Spät-Weichsel stattfand.

INTRODUCTION

The Scoresby Sund, one of the world´s largest fjord systems, is located on the central East Greenland coast between 70° - 72° N and 20° - 28° W. It comprises two shallow outer fjords, Scoresby Sund (sensu strictu, E-W striking outer part opening into the polar North Atlantic) and Hall Bredning (N-S striking inner part) and a number of deep and narrow fjords extending far into the continent (Fig. 1).

The fjord system cuts through three different geological units: the oldest unit consists of Precambrian and Caledonian metamorphic rocks found in the west (Scoresby Land, Renland, Milne Land, Gåseland) and on Liverpool Land (LARSEN 1984). The central part is build up by the deep Jameson Land Basin, which is a result of a Paleozoic rift. This riftphase lasted until the Late Carboniferous/Early Permian and formed a number of west inclined nearly N-S striking halfgrabens in East Greenland (SURLYK & CLEMMENSEN 1983; SURLYK et al. 1986). An Upper Triassic uplift of the western border and northern Jameson Land shortened the deposition area to the Jameson Land Basin. In the north the basin has been bound by the Kong Oscar Fjord Fault, in the east by the Liverpool Land Slope and in the south by the Scoresby Sund Fracture Zone (SURLYK 1990). The location of the western boundary is unknown.

Extensional tectonic movement and subsidence continued into the Late Cretaceous. A Cretaceous/Tertiary riftphase resulted in the opening of the Norwegian-Greenland Sea east of Liverpool Land. A large amount of basaltic lavas was extruded during the initial opening (HINZ et al. 1987; MUTTER et al. 1988). Those lavas can be found on the Geikie Plateau (Fig. 1) with a thickness of at least 2000 m, there forming the third geological unit surrounding Scoresby Sund. 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 sedimentary rocks (LARSEN 1984). Indications for Tertiary intrusions into Jameson Land sediments are found in data gathered during a deep seismic sounding experiment (MARCUSSEN & LARSEN 1991). A major eastward flowing riversystem developed in the present Scoresby Sund region during the Neogene and transported erosional detritus from the crystalline basement in the west and Jameson Land to the east (LARSEN 1984).

In Scoresby Sund, the Pleistocene was a time characterized by erosion. Thicker deposits can be found only at the valley mouths, high mountain plateaus and the coast of Jameson Land (FUNDER 1990). The occurrence pattern of Quaternary sediments

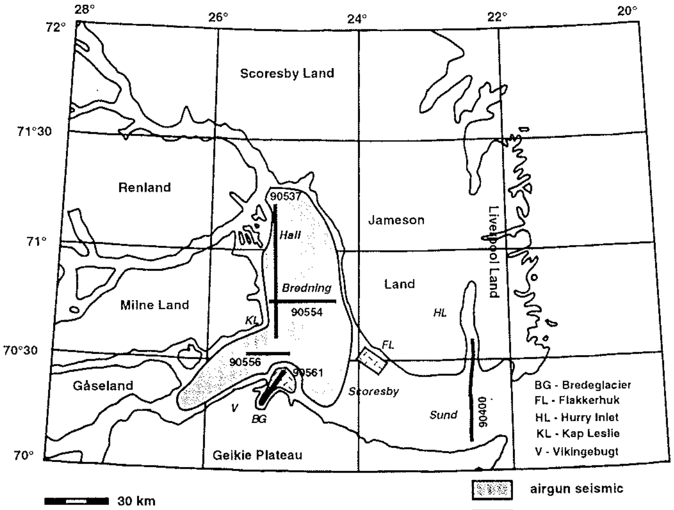

Fig. 1: Map of seismic investigated area in Scoresby Sund. Shaded area = airgun seismics, hatched area = watergun seismics. The thick lines show the locations of the profiles referred to in the text. During the whole experiment Parasound data were recorded.

Abb. 1: Karte des seismisch untersuchten Gebiets im Scoresby Sund. Schattiertes Gebiet = Airgun Seismik, schraffiertes Gebiet = Watergun Seismik. Die dikken Linien zeigen die Lage der im Text besprochenen Profile. Während des gesamten Experiments wurden Parasound Daten erfaßt.

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documents a number of glacial-interglacial cycles. The oldest sediments (Lodin Elv formation) found on land are of Pliocene/Pleistocene age. The most expanded glaciation, the Scoresby Sund Glacial, occurred around 200 ka (FUNDER 1972, 1984, 1989) and represents an important stratigraphic marker (HJORT & MÖLLER 1991; HJORT & SALVIGSEN 1991).

Sediments deposited during the Langelandselv Interglacial (Eemian 120 ka, FUNDER 1990) can be found only along the southwestern coast of Jameson Land. This interglacial showed higher temperatures than the present and can be correlated with isotopic stage 5e (BÖCHER & BENNICKE 1991). The first two Early Weichselian glacials (Glaciation 1 and 2 during the Jameson Land Marine Episode) showed neither an ice cover of the outer fjord areas (FUNDER 1989) nor of Jameson Land (FUNDER et al. 1991). During the Flakkerhuk Glacial (late Early Weichselian, FUNDER et al. 1991) a thick floating glacier extended out onto the shelf while Jameson Land stayed uncovered (FUNDER 1989, 1990). Glaciation 4 (Late Weichselian, FUNDER et al. 1991) commenced about 20 to 13 ka. Until present, it has been considered to be a minor glacial stage.

Thick glaciers terminated at the mouths of the western fjords into Hall Bredning and Scoresby Sund during the Milne Land Stage (11 - 9.5 ka, HJORT 1979). After a continuous retreat of the glaciers a standstill followed during the Rødefjord Stage (FUNDER 1971). The end of that phase resembles the present ice extent.

Both the complex Paleozoic-Mesozoic as well as the glacial development of the Scoreby Sund area have been mapped carefully on land where accessible and not covered by ice. However, until recently little was known about the sedimentary record in East Greenland´s fjords. The objectives of this paper are: i) to identify the western boundary of the sediment basin which is still under discussion in the Scoresby Sund area while it has been defined clearly north of the sound; ii) to describe the structures and distribution of the sedimentary record; iii) to develop an idea on the glacial fluctuations within the fjord system during the Late Quaternary. Especially the distribution of younger sediments is considered as a contribution to the European Science Foundation (ESF) programme on the Late Cenozoic Evolution of the Polar North Atlantic Margins (PONAM).

DATA ACQUISITION AND PROCESSING

In order to acquire a complete sedimentary record and to map the Quaternary sediments we used different seismic sources: two airgun arrays of 5.7 l and 20.2 l total volume, a 32 l airgun and a 0.25 l watergun. Although the single airgun has a rather large volume, the signal showed strong amplitudes up to 50 Hz which allowed a vertical resolution of 15 m. The highresolution watergun was used to resolve even thin layers of Quaternary sediments. Those profiles are located directly in front of a glacier and the prominent Flakkerhuk Moraine (Fig. 1). Apart from that we shot a relatively tight grid of lines in Scoresby Sund. In total, we gathered 2439 km of reflection seismic data.

The data were recorded employing a 24 channel streamer (600 m active length). In combination with the watergun we used a 100 m Ministreamer (12 channels). Recording and storage were performed by an EG&G Geometrics ES 2420 multichannel digital recording system. Shots were fired every 10-20 s corresponding to 25-50 m with a ship´s speed of 5 knots. For the watergun profiles the shot intervall was changed to 3 s (~8 m). Positioning was done by GPS (Global Positioning System) assisted by the on board INDAS (Transit Satillite) system.

Parallel to the seismic measurements continuous recordings with the sediment echosounding system Parasound™ were carried out. This system has a resolution of layers some 10 cm thick while penetrating the upper 50-150 m of the sedimentary column. Thus, a good controll on the overall occurrence of Quaternary sediments was achieved.

The reflection seismic data were demultiplexed, a CMP geometry (CMP intervall 25 m) was defined and a detailed velocity analysis (every 3rd CMP) was carried out on the lower frequency data. The watergun data were not suited for this due to the short streamer employed. Amplitude losses as a result of spherical divergence were compensated by the application of an automatic gain control window of 200 ms length. An adaptive filter was used on some lines to suppress ocean bottom multiples (Rosenberger, 1992). The data were stacked after NMO correction. A vertical stack was carried out on the higher frequency data.

DISCUSSION OF OBSERVATIONS

In general, the seismic records show two seismic sequences which can be distinguished clearly. Fig. 2 shows line AWI-90537 which crosses Hall Bredning from north to south. The lower sequence is bound by a top reflector of strong amplitude and good continuation. The top reflector lies up to 200 ms TWT below seafloor (160 m with v_p=1600 m/s), in most of the cases reaching up to seafloor. This sequence shows nearly no internal structures. On some profiles shallow internal reflectors can be observed whose amplitudes are weak compared to the top reflector´s (Fig. 3). Those internal reflectors are generally slightly inclined towards the south. East-west profiles show an easterly dip in the west for these reflectors, while they appear horizontal in the centre (Fig. 3). Here, the seafloor dips to the west, leading to a wedge out of the internal reflectors towards the seafloor. In the east, a westerly dip of the internal reflectors can be observed.

A base reflector could not be resolved for this lower sequence although the energy of the seismic sources should have been sufficient to achieve a deep penetration. This may infer that the sequence comprises rocks characterized by a strong absorption coefficient or that the impedance contrast to the underneath lying sequence is very small. The weak internal reflectors indicate either an intensive post-sedimentary homogenization (e.g. strong compaction or intensive cementation) or a massive magmatic body (SANGREE & WIDMIER 1979). A massive magmatic

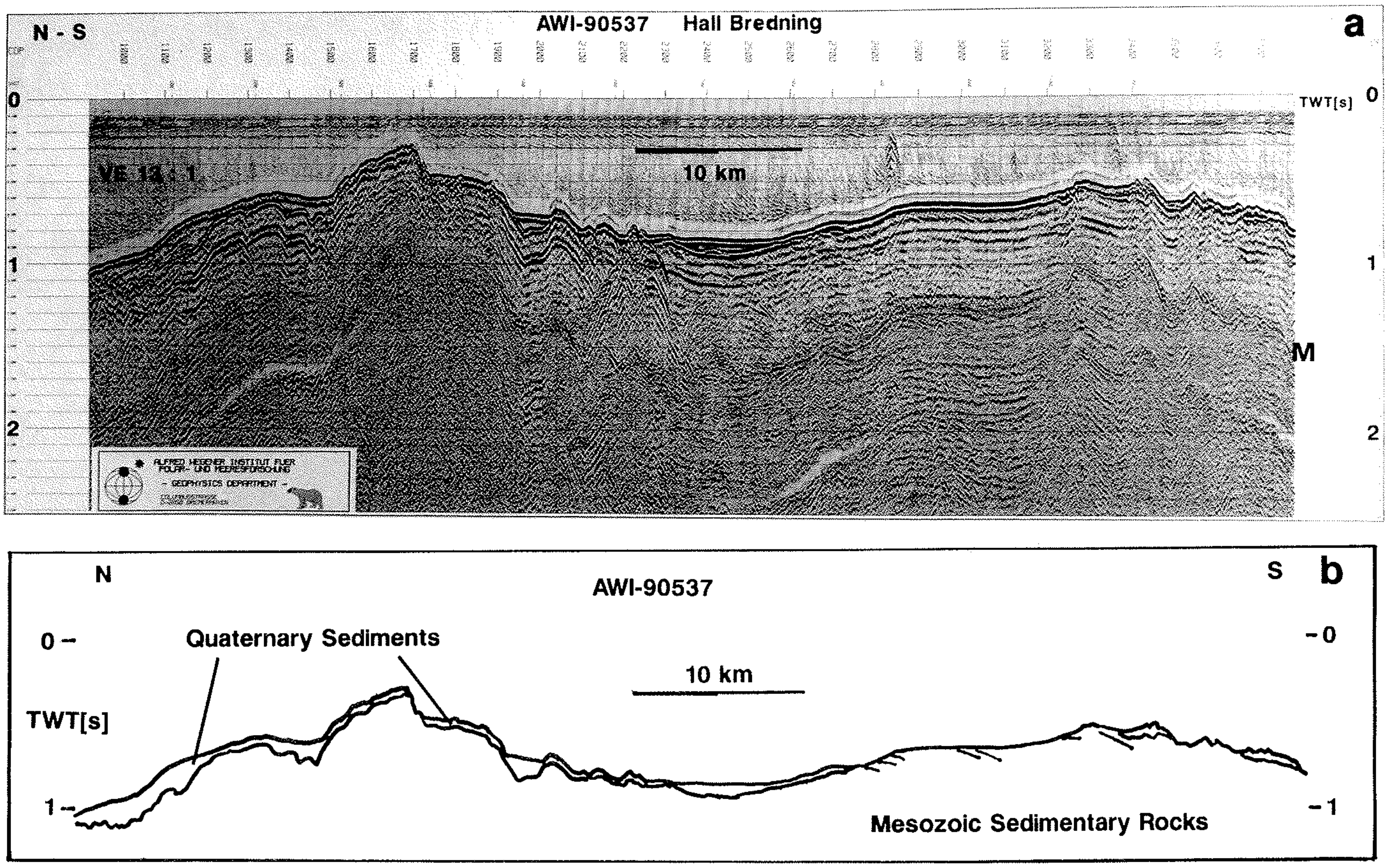

Fig. 2: a) Line AWI-90537 which crosses Hall Bredning from the north to the south. Notice the pockets in the centre and north of CDP 1500. The underneath lying rocks show nearly no internal strucures; in the southern part one can see weak internal reflectors near the top reflector. M = ocean bottom multiple. b) Line-drawing of line AWI-90537 showing the interpretation of the well consolidated unit to comprise Mesozoic sedimentary rocks and the material in the pockets to consist of Quaternary sediments.

Abb. 2: a) Profil AWI-90537, das Hall Bredning von Norden nach Süden durchquert. Man beachte die Taschen im Zentrum und nördlich von CDP 1500. Die darunter liegenden Gesteine zeigen nahezu keine internen Strukturen; lediglich im Süden sind schwache interne Reflektoren nahe der Oberfläche zu erkennen. M = Meeresbodenmultiple. b) Strichzeichnung von Profil AWI-90537, die die Interpretation der gut konsolidierten Schicht als mesozoische Sedimentgesteine und des Materials in den Taschen als quartäre Sedimente zeigt.

body appears unrealistic in this tectonic setting. Tertiary intrusions as observed in larger depths in Jameson Land (MARCUSSEN & LARSEN 1991) are a possibility. On Jameson Land, Jurassic sedimentary rocks are exposed. There, several kilometres thick Cretaceous and Cenozoic sediments were eroded (SURLYK & CLEMMENSEN 1983; LARSEN 1984; SURLYK et al. 1986). Quaternary glaciers led to an additional load and further compaction. Thus, I suggest that the lower seismic sequence consists of Mesozoic sedimentary rocks. Intensive cemented sedimentary layers would probably show more distinct internal reflectors representing the cementation horizons for which no indications can be seen in our seismic records. Another argument for the chronological classification is the strong amplitude of the sequence´s top reflector which documents the post Mesozoic erosion (LARSEN 1984). The computed interval velocities correspond to those of older compacted sedimentary rocks ($v_p \approx$ 2000-3000 m/s).

The different dip of internal reflectors correlating with different parts of Hall Bredning may be the result of a synsedimentary subsidence with lower subsidence rates of the borders. This led to a preservation of the basin structure (ALLEN & ALLEN 1990; PRICE & COSGROVE 1990). A sole post-sedimentary subsidence can be ruled out because this would lead to faults in the shallow sedimentary layers (PRICE & COSGROVE 1990). Another origin for the dip pattern might have been a thick above lying body, e.g. a glacier, whose axis corresponded to the area of horizontal internal reflectors. This would suggest a general N-S extending ice sheet, which does not follow the morphology of the Scoresby Sund. A possible event could have been the Scoresby Sund Glacial (200-130 ka), because a thick ice sheet developed during that glacial which covered Jameson Land as well and was not restricted to the sound (FUNDER 1972, 1984, 1989).

As already mentioned, the observed internal reflectors show no general westward inclination. This would be the expected dip in case of the riftbasin resembling a halfgraben as interpreted by SURLYK& CLEMMENSEN (1983). Refraction seismic investigations (FECHNER & MANDLER, pers. communication) imply an eastward inclinination of the basin, and deep seismic sounding data indicate a halfgraben dipping towards the east (MARCUSSEN & LARSEN 1991). Our reflection seismic data give no arguments for either dip direction. In contrast, the shallow sedimentary rocks seem to resemble a basin (Fig. 3). This may imply that this part of the Jameson Land Basin is separa-

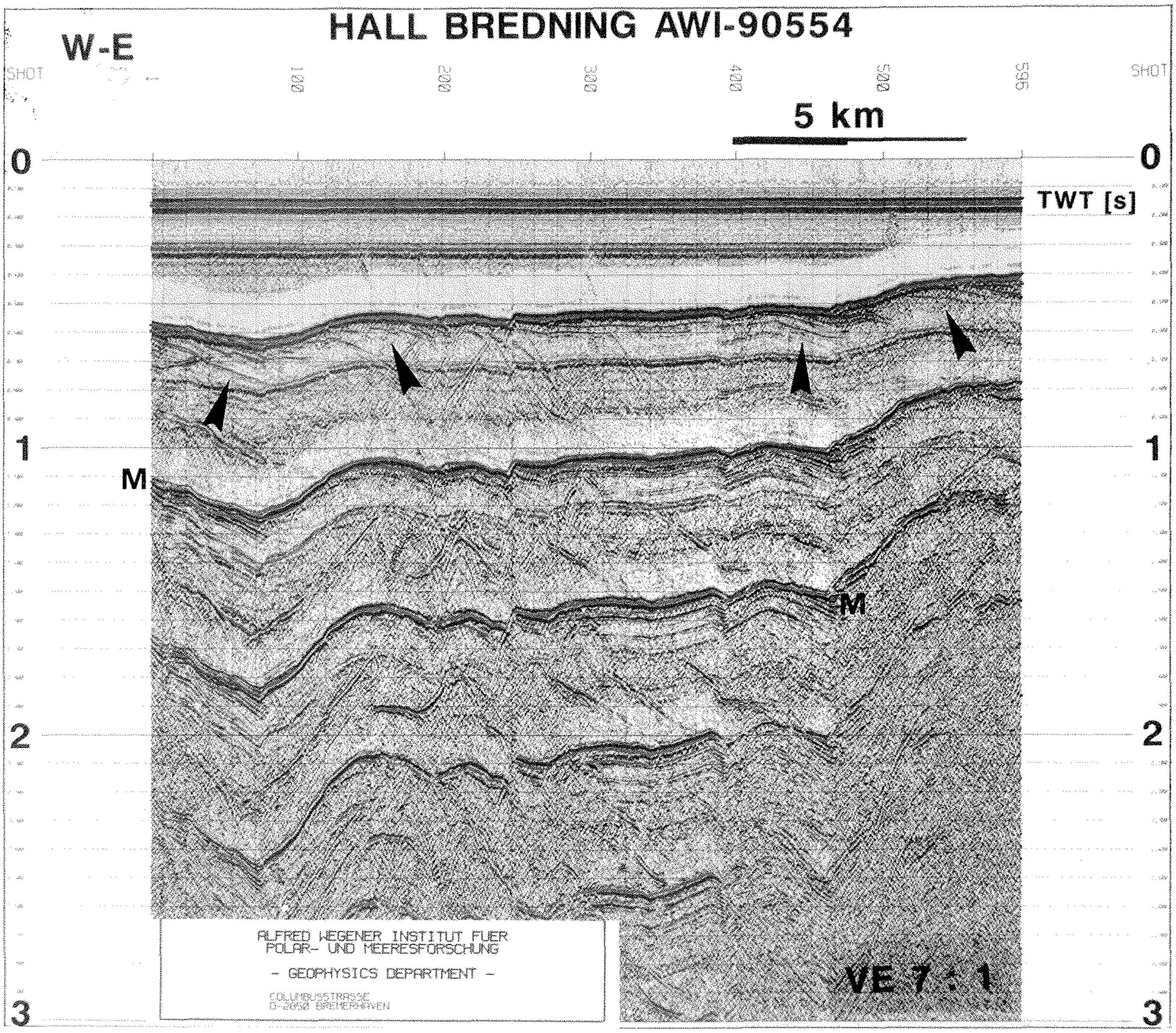

Fig. 3: Line AWI-90554. This profile crosses Hall Bredning from west to east. The arrows indicate dipping internal reflectors of the lower seismic sequence, whose amplitudes are small compared to the sequence´s top reflector. M = ocean bottom multiple.

Abb. 3: Profil AWI-90554. Dieses Profil durchquert Hall Bredning von West nach Ost. Die Pfeile deuten auf geneigte interne Reflektoren in der tieferen seismischen Sequenz, deren Amplituden relativ zu den des Topreflektors klein sind. M = Meeresbodenmultiple.

ted from the eastern part by a fault near the coast of Jameson Land. Another argument for this separation is the extremely deep basement in Jameson Land (up to 18 km, MARCUSSEN & LARSEN 1991) while basement depths only up to 9 km were computed for Hall Bredning (FECHNER & MANDLER pers. communication).

A N-S trending 10 km wide (400 m isobath) channel is located in western Hall Bredning (GEBCO, 1980). The channel´s western flank appears steeper than the eastern one which may be interpreted as a hint on a fault. This fault may coincide with the western boundary of the Mesozoic riftbasin. The Quaternary glacial load probably reactivated the fault and thus formed the channel. A branch of this channel turns off to the west south of Kap Leslie (Fig. 1). In this southwestern part of Hall Bredning a number of faults as well as diffractions and deeper structures (up to 2200 ms TWT, Fig. 4) can be observed. Refraction seismic data show that the faults correlate with the western shallower part of the sedimentary basin whereas the depth of the basin increases rapidly east of the faults (from ~4 km to ~9 km, MANDLER 1991). This could indicate that the southeastern Milne Land encloses a shallow part of the sedimentary basin, i.e. that the basin extends farther west that initially expected.

The second observed sequence does not form a continuous layer in this area but the sediments are accumulated in pockets which are up to 200 ms TWT thick. This sequence is characterized by a number of diffuse internal reflectors as can be seen clearly on

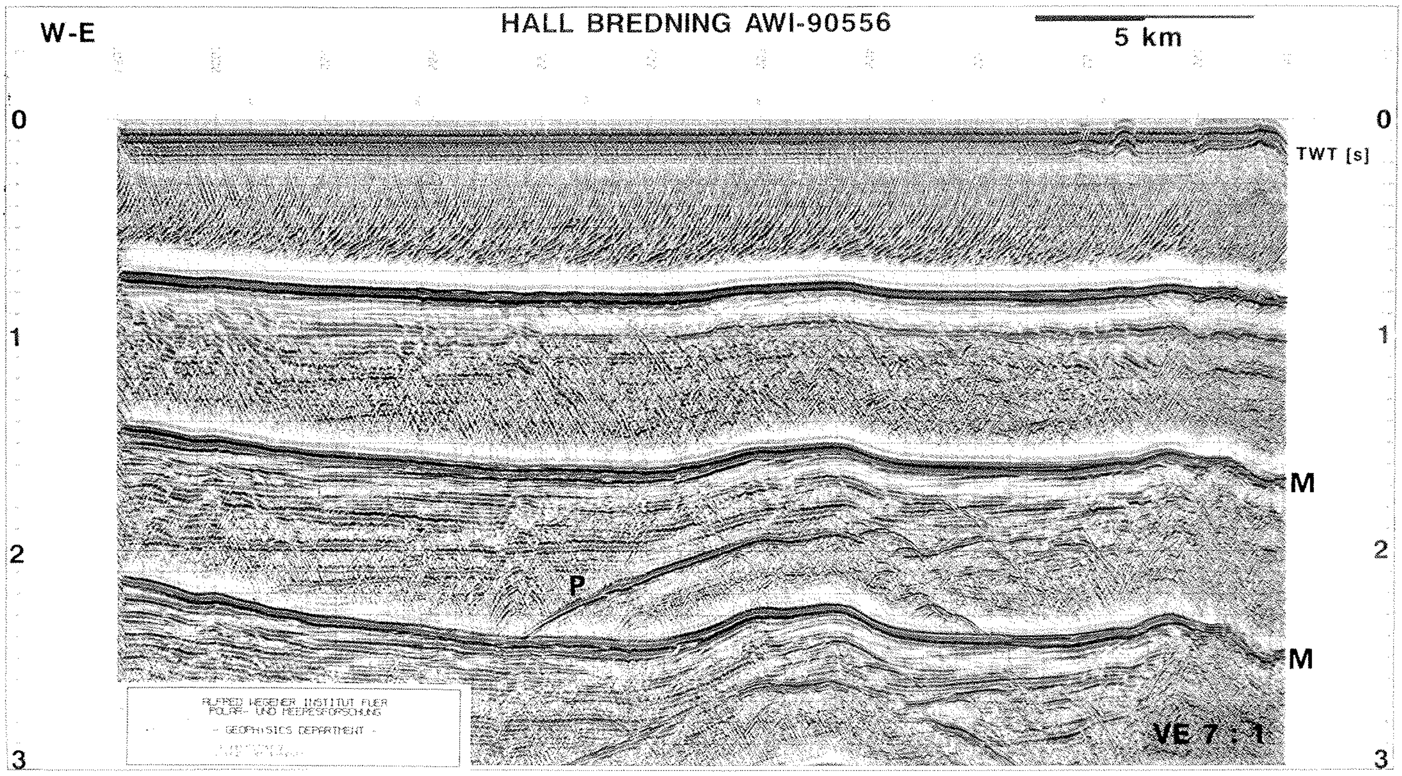

Fig. 4: Line AWI-90556 from southwestern Hall Bredning. Here, some deeper structures can be observed in the Mesozoic sequence (between CDP 700 and 100). Those structures may indicate tectonic movements which are restricted to the southwestern part of Hall Bredning and may thus correlate with the western boundary of the Jameson Land Basin. P = primary reflection, M = ocean bottom multiple.

Abb. 4: Profil AWI-90556 aus dem südwestlichen Hall Bredning. Hier können Strukturen in der mesozoischen Sequenz erkannt werden (zwischen CDP 700 und 100). Diese Strukturen deuten wahrscheinlich auf tektonische Bewegungen, die auf das südwestliche Hall Bredning beschränkt sind und mit der westlichen Grenze des Jameson Land Beckens korreliert werden können. P = Primärreflexion, M = Meeresbodenmultiple.

the lines shot with the high resolution watergun (UENZELMANN-NEBEN et al. 1991). The structure of this sequence indicates Quaternary deposits.

In the Vikingebugt a strong reflector forms the base of a sedimentary infill in front of the Bredeglacier (Fig. 5). This reflector probably constitutes an older glacier-generated erosional surface cut into the assumed Mesozoic sedimentary rocks. On top of this sequence we find little consolidated Quaternary sediments. To the north this depositional sequence is bound by a mound consisting of a number of lenticular structures (Fig. 6). The base reflectors of those structures are very strong and show different dips for each lense. Those lenticular units can be interpreted as moraines which document the different glacial stages. The lowest moraines were probably deposited during glaciations when the glacier extended farther into Hall Bredning. On top and nearest to the basin we find at least one push moraine as inferred by its complex internal structure (Fig. 6; RICHTER 1980); this push moraine documents the last advance of the glacier. During each stage the glacier overrode the old moraines at least partly, thereby slightly reworking the material. This accumulation of Quaternary material forms a fan into Hall Bredning which has a restricted extension. In other places, e.g. the Hurry Inlet, the Quaternary sediments are structured in a similar way as shown clearly in line AWI-90400 (Fig. 7). Here, we observe a moraine which initially was built up from the north and later overprinted by ice movement from the south.

An isopach map of Quaternary sediments (Fig. 8) shows that the upper seismic sequence can be found primarily in front of fjord mouths, along the coasts of Milne Land and the Geikie Plateau and in southwestern Hall Bredning. This occurrence pattern correlates very well with areas of larger waterdepths. Thus, the distribution of Quaternary sediments follows the bathymetry: in shallow regions the cover is too thin to be resolved by seismic or Parasound techniques (see also DOWDESWELL et al. 1991, submitted), in deeper regions some ten metres thick. This indicates that the sedimentation has not been undisturbed for a long time, but that active grounded ice cleared the sound in Late Weichselian times.

Marin-geological investigations give sedimentation rates of 20-30 cm 1000 years for the last 10 ka (MARIENFELD 1991). If a floating ice shelf, rather than active and grounded glacier ice, had been present in Hall Bredning during the Middle/Late Weichselian deposition would be more likely than a removal of sediment from the fjord floor. A reworking of the Quaternary material to prevent a seismic detection appears unplausible (UENZELMANN-NEBEN, submitted). Glaciation 4 (FUNDER et al. 1991) was, therefore, characterized by the presence of grounded ice and not by the precense of an ice shelf. This is in agreement with DOWDESWELL et al. (1991) who infer that the last ice advance to the Scoresby Sund mouth was during oxygen isotope stage 2.

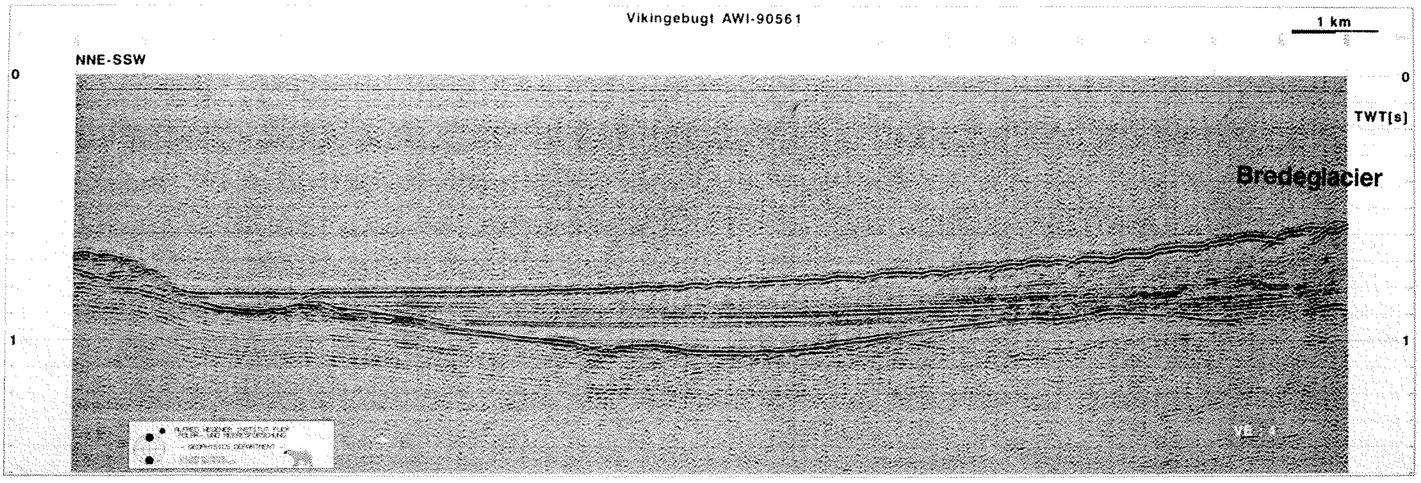

Fig. 5: Southern part of line AWI-90561 showing the depositional environment directly in front of the Bredeglacier. Notice the sedimentary infill with a strong base reflector resembling the top of the Mesozioic sedimentary rocks. The ocean bottom in front of the Bredeglacier (ssw part of the profile) is heavily disturbed due to iceberg scouring.

Abb. 5: Südlicher Teil des Profils AWI-90561, der das Ablagerungsgebiet direkt vor dem Bredegletscher zeigt. Man beachte das durch einen starken Basisreflektor geformte Becken, der vermutlich dem Top der mesozoischen Sedimentgesteine entspricht. Unmittelbar vor dem Gletscher ist der Meeresboden stark durch Abschleifung durch Eisberge gestört.

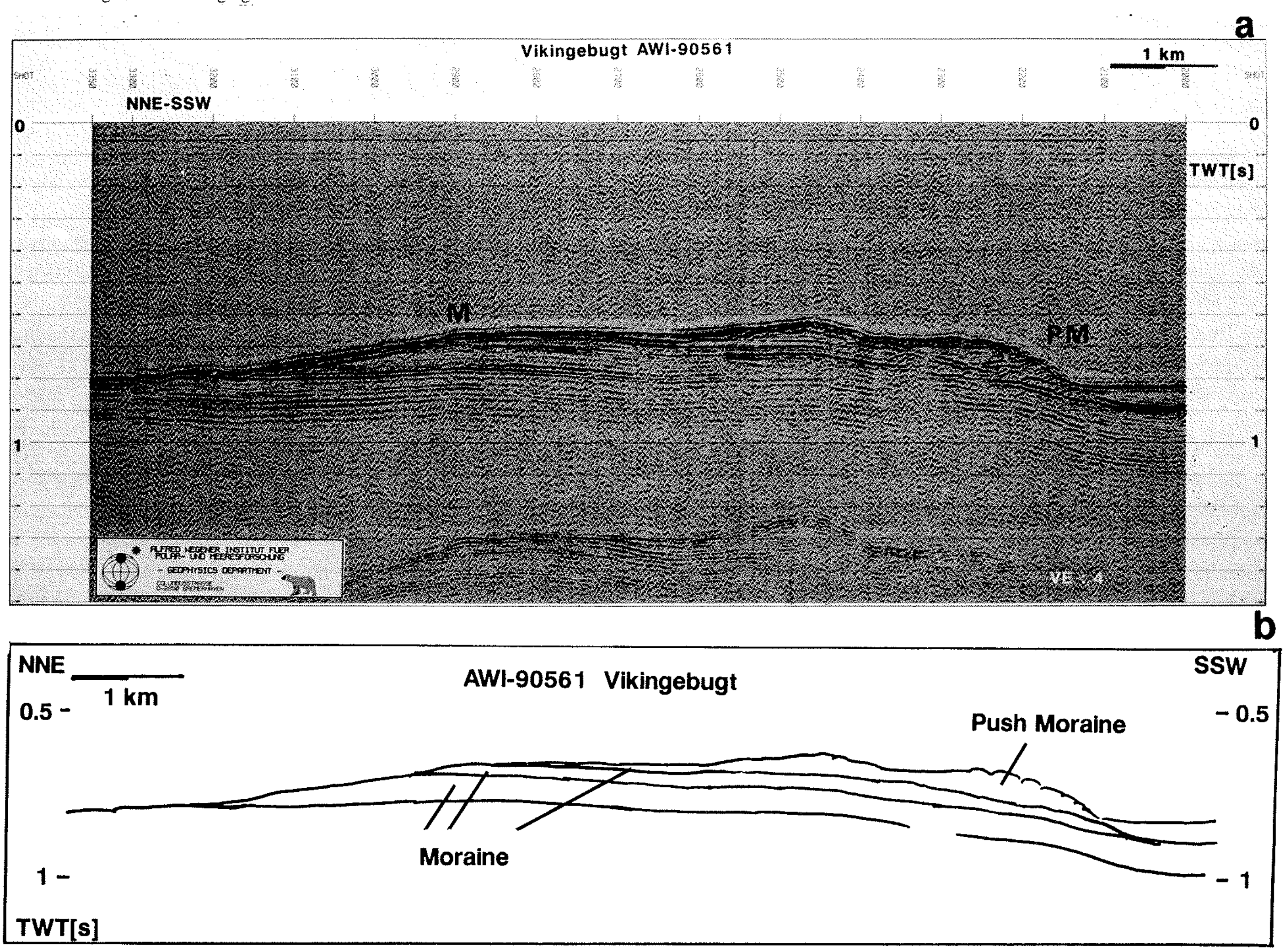

Fig. 6: a) Northern part of line AWI-90561. The mound is built up by a number of lenticular structures which are interpreted to represent moraines (M, PM). The push moraine (PM) probably documents the last ice advance. b) Linedrawing of line AWI-90561 (northern part). One can clearly see the moraines which were at least partly overrriden during the different ice advances.

Abb. 6: a) Nördlicher Teil des Profils AWI-90561. Der Hügel ist von einer Reihe linsenförmiger Strukturen aufgebaut, die als Moränen interpretiert werden (M, PM). Die Stauchendmoräne (PM) dokumentiert wahrscheinlich die letzte Eisausdehnung. b) Strichzeichnung des nördlichen Profils AWI-90561. Deutlich sind die Moränen zu erkennen, die sicherlich bei verschieden Eisausdehnungen vom Eis bedeckt wurden.

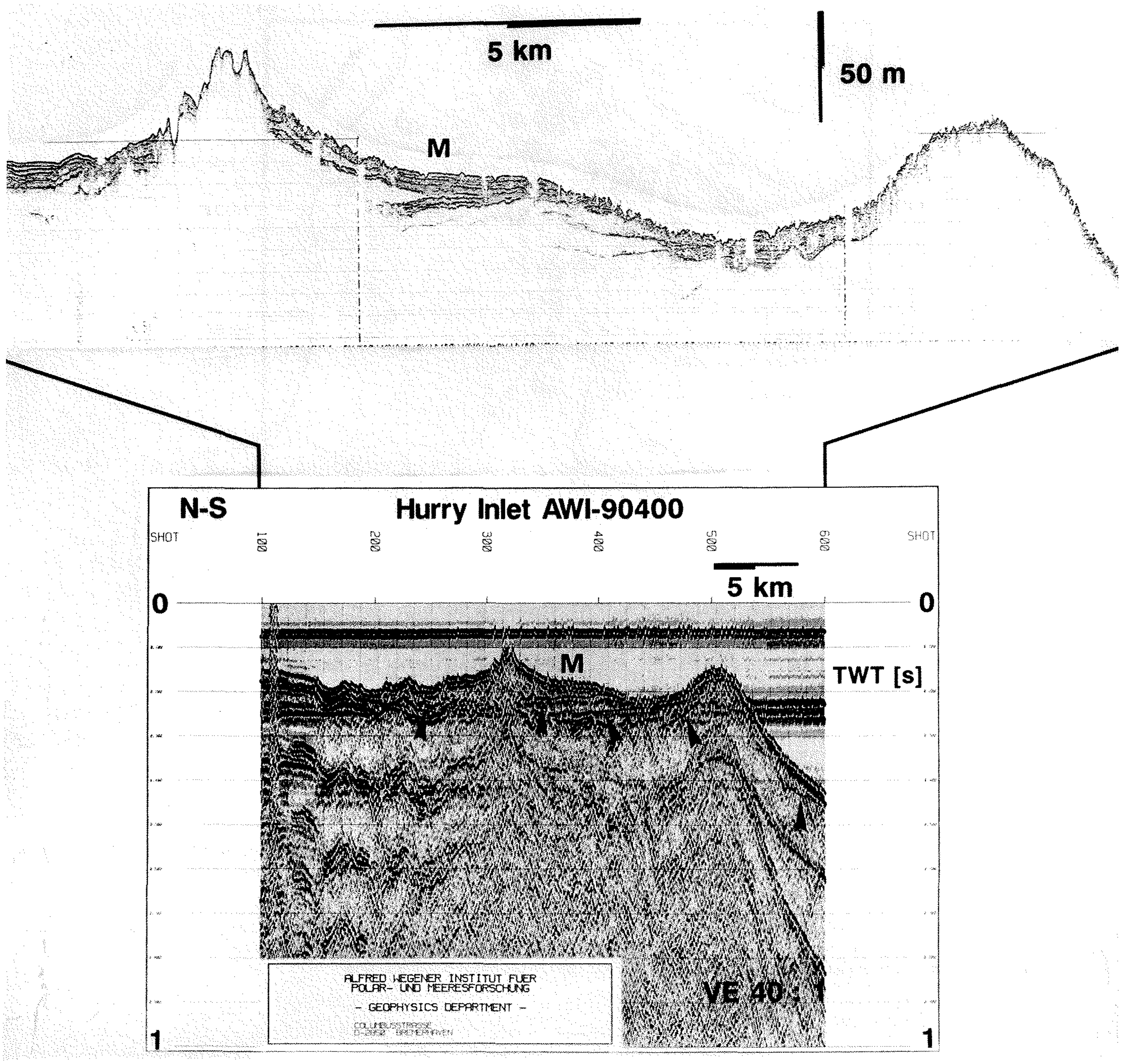

Fig. 7: Moraine structure (M) on line AWI-90400 in the Hurry Inlet. Parasound recording on top of seismic data. The base of the moraine can be clearly identified (Parasound and two left arrows in seismic record). The form of the structure suggests ice movements as well from the north as from the south.

Abb. 7: Moränenstruktur auf Profil AWI-90400 im Hurry Inlet. Parasound Daten über einer seismischen Sektion. Die Moränenbasis kann deutlich identifiziert werden (Parasound und linke Pfeile in der seismischen Sektion). Die Form der Struktur deutet an, daß Eisbewegungen sowohl von Norden als auch von Süden stattgefunden haben.

CONCLUSIONS

The interpretation of reflection seismic data from the Scoresby Sund resulted in a characterization of two distinct seismic sequences (e.g. Fig. 2). The lower sequence, which is inferred to consist of Mesozoic sedimentary rocks, appears well consolidated probably due to a now eroded sediment load and the glacial burden. This unit was affected by a synsedimentary subsidence as concluded from the regional variable dip of internal reflectors. The general dip of the sequence towards the south (Fig. 2) is not consistent with directions observed in refraction and wide angle seismic data for the basin base (FECHNER & MANDLER, pers. comm.; MARCUSSEN & LARSEN 1991). This may indicate the existence of a fault between Hall Bredning and the eastern part of the Jameson Land Basin. Further hints for this are the different basement depths computed for both parts. The

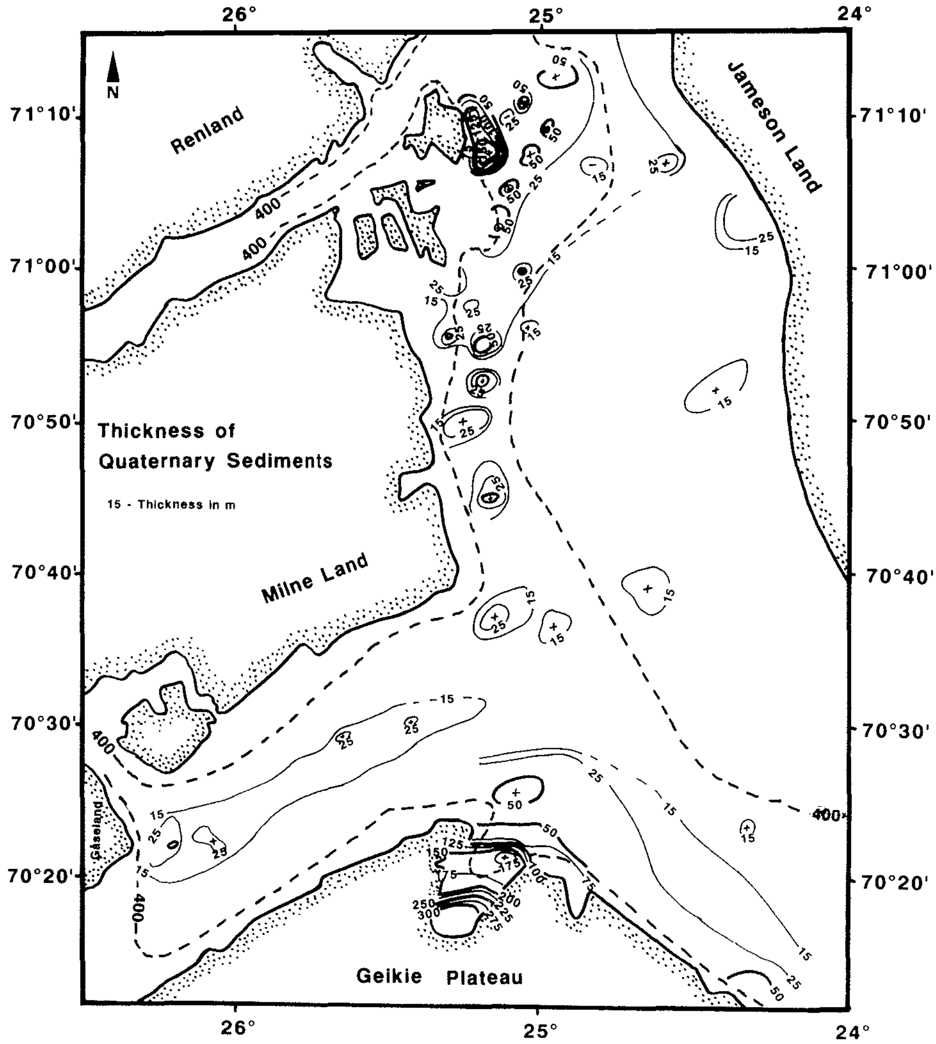

Fig. 8: Distribution map of Quaternary sediments. Sediments thicker than 15 m have been mapped (minimum vertical resolution of seismic data). Parasound data show that in most areas the cover is thinner than 5 m (DOWDESWELL et al. 1991). The dashed line represents the 400 m depth contour and shows that the thikker assemblages are restricted to the deeper parts of the sound.

Abb. 8: Karte der Quartärsedimentverteilung. Sedimentmächtigkeiten größer als 15 m wurden dargestellt (minimale vertikale seismische Auflösung). Parasound Daten zeigen, daß die Bedeckung in den meisten Gebieten dünner als 5 m ist (DOWDESWELL at al. 1991). Die gestrichelte Linie stellt die 400 m Tiefenlinie dar. Es wird deutlich, daß dickere Ansammlungen quartären Materials auf tiefere Gebiete des Sunds beschränkt sind.

western boundary of the sedimentary basin probably coincides with a N-S striking bathymetric channel in Hall Bredning whose western flank is steeper than the eastern and may indicate a fault zone. All in all, the basin appears to extend farther to the west than initially assumed.

On top of the Mesozoic sedimentary rocks Quaternary sediments are distributed in pockets and not in a prolonged layer (Fig. 2). Those pockets occur in areas with larger waterdepths and directly in front of glacier outlets (Fig. 8). The shallow areas have been cleared of most of the Quaternary material. This distribution gives rise to the interpretation that a grounded glacier developed during the Late Weichselian and removed the sediments from the shallower parts of the fjord floor but could not reach into the deeper areas. This shows the Late Weichselian Glacial to have been an active period in the Scoresby Sund area.

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