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Postglacial Sedimentary History of Scoresby Sund, East Greenland

By Peter Marienfeld*#

Summary: Reconstruction of the postglacial palaeoenvironmental evolution was the main objective of marine geological investigations in the Scoresby Sund fjord system. For this purpose, samples of marine sediments, taken on RV *Polarstern* cruises ARK-V/3b and ARK-VII/3b in 1988 and 1990, have been analysed.
All investigated fjord sediments are paratills. However, remarkable changes in sediment fabric and composition occur with depth in cores. They are attributable to different modes of sediment deposition. Therefore, a subdivision of the postglacial palaeoenvironmental history into periods of considerably different sedimentary conditions is feasible.
The change of sedimentary facies with time is interpreted by deposition under changing climatic conditions during the postglacial. Displacements of cyclonic and anticyclonic centers in the atmosphere change amount of precipitation at the east coast of Greenland. Precipitation strongly influences extension of local ice caps of coastal areas and duration of coverage of the fjords by sea ice. These factors again control the sedimentary regime in the fjord system.

Zusammenfassung: Die Rekonstruktion der postglazialen Sedimentationsentwicklung des Scoresby Sundes an der Ostküste Grönlands war das wichtigste Ziel der maringeologischen Arbeiten auf den Forschungsfahrten ARK-V/3b und ARK-VII/3b der FS *Polarstern* in den Jahren 1988 und 1990. Zu diesem Zweck wurde der Fjord intensiv mit Kastengreifern und Schwereloten beprobt.
Obwohl alle untersuchten Fjordsedimente Paratills sind, weisen die Sedimentkerne deutliche Veränderungen des Gefüges und der Sedimentzusammensetzung auf. Diese Veränderungen beruhen auf unterschiedlichen Formen des Sedimenteintrages. Die postglaziale Entwicklung kann daher in Perioden sehr unterschiedlicher Sedimentationsbedingungen unterteilt werden.
Der Wechsel der Sedimentfazies mit der Zeit ist auf unterschiedliche klimatische Bedingungen innerhalb des Postglazials zurückzuführen. Die Veränderung von Ausdehnung und Bewegungsbahnen von Hoch- und Tiefdruckgebieten hat starken Einfluß auf die Höhe der Niederschläge an der Ostküste Grönlands. Die Niederschläge bestimmen die Ausdehnung lokaler Eiskappen der Küstenregionen und die Dauer der Meereisbedeckung der Fjorde, die wiederum die Sedimentationsbedingungen in den Fjorden kontrollieren.

INTRODUCTION

The fjord system of Scoresby Sund is one of the largest fjord systems of the world. It is situated at 70° to 72° N, 22° to 29° W at the east coast of Greenland (Fig. 1). Geological reconnaissance of the Scoresby Sund Region, East Greenland, began at the end of the last century (BAY 1896, NATHORST 1901, NORDENSKJÖLD 1907). Beginning with the expeditions of Grønlands Geologiske Undersøgelse (GGU) in 1968-1972, terrestrial Quaternary deposits have been intensively studied (FUNDER 1972a, 1989, WEIDICK 1976). Due to degree of preservation of sediments, emphasis of investigations was put on the last glacial-interglacial cycle and the Holocene (FUNDER 1972b, 1978, 1984, FUNDER & HJORT 1973, HJORT & FUNDER 1974, HJORT 1979). They have shown that sedimentary processes in the Scoresby Sund area are predominantly influenced by extent of the Greenland Ice Sheet, calving of icebergs, meltwater input, and other factors, all controlled by climate. Furthermore they have shown the amount and speed of climatic changes during glacial-interglacial cycles and differences among previous glaciations.

To link the terrestrial glacial-interglacial record with the marine record, marine geological and geophysical work in the fjord system of Scoresby Sund was carried out in 1988 and 1990 during two cruises of RV *Polarstern* to the east coast of Greenland (DOWDESWELL et al. 1991, MARIENFELD 1991a, MARIENFELD 1991c, UENZELMANN-NEBEN et al. 1991). The aim of this study is the reconstruction of sedimentary processes through Late Quaternary time, and to show, whether only Postweichselian sediments can be found in Scoresby Sund, or if valley glaciers were not grounded during the Weichselian and even Eemian sediments are still preserved in the fjord. Of special interest are changes of sedimentary facies during the Postweichselian which can be interpreted by deposition under changing climatic conditions.

* Dr. Peter Marienfeld, Alfred Wegener Institute for Polar and Marine Research, D-W-2850 Bremerhaven, FRG.
# Present address: Prakla-Seismos GmbH, Buchholzer Straße 100, D-W-3000 Hannover, FRG.
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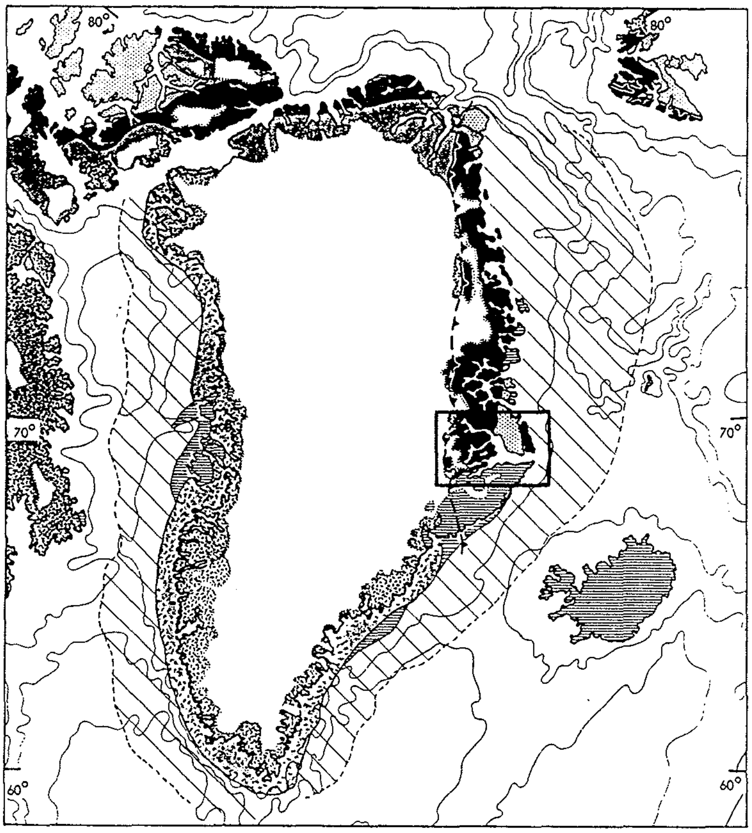

Fig. 1A: Geology of the ice-free areas of Greenland and Scoresby Sund fjord region (framed). Important geological units for the Scoresby Sund region are Tertiary basalts (hatched), Mesozoic sedimentary rocks (dotted) and Caledonian magmatic and metamorphic rocks (black); modified after FUNDER (1989).

Abb. 1A: Geologischer Aufbau der eisfreien Gebiete Grönlands und des Scoresby Sunds (Rechteck). Die wichtigsten geologischen Einheiten der Scoresby-Sund-Region sind tertiäre Basalte (gestreift), mesozoische Sedimentgesteine (gepunktet) und kaledonische Magmatite und Metamorphite (schwarz), modifiziert nach FUNDER (1989).

STUDY AREA

The fjord system can be subdivided into two major areas. The western, or inner fjord system consists of narrow and, with a maximum of 1.5 km, extremely deep fjords. Scoresby Sund (*sensu stricto*) and Hall Bredning make up the eastern, or outer fjord system (Fig. 1b). In this paper, the term Scoresby Sund is only used for the broad part of the eastern fjord system. The western fjord system is strongly overdeepened relative to fjords of the outer system.

Sedimentary processes and patterns in Scoresby Sund and Hall Bredning are controlled by morphology, geology, and glaciology of the surrounding areas. Archean to Caledonian magmatic and metamorphic rocks form Gåseland, Milne Land and Renland in the west and Liverpool Land in the east. These mountainous areas reach heights of 1,500-2,000 m. The up to 2,000 m high Geikie Plateau south of Scoresby Sund consists of Tertiary plateau basalts. Mainly Mesozoic sedimentary rocks, which are covered by glacial sediments, compose Jameson Land. This region, situated north of Scoresby Sund, rises gently to heights of less than 800 m.

Due to elevation, local ice caps cover Geikie Plateau, Gåseland, Milne Land and Renland. The ice cap of Geikie Plateau is drained by numerous, mostly small glaciers into Scoresby Sund (Fig. 1b). At the western ends of the

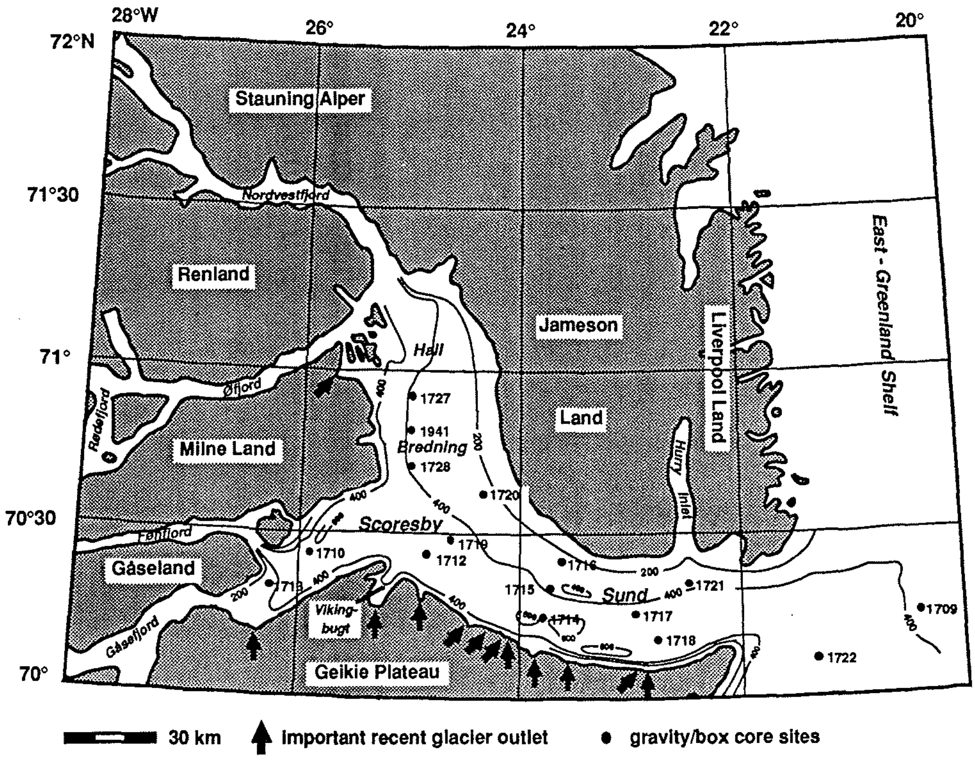

Fig. 1B: Scoresby Sund fjord system, East Greenland, with the position of box and gravity cores. Arrows mark the position of important modern glacier fronts.

Abb. 1B: Das Scoresby-Sund-Fjordsystem an der Ostküste Grönlands mit den Positionen der bearbeiteten Kastengreifer und Schwerelotkerne. Pfeile markieren die Positionen wichtiger rezenter Gletscherfronten.

fjords of the inner fjord region huge and highly productive outlet glaciers of the Greenland Ice Sheet are situated. Two of them, Daugaard-Jensen Gletscher and Vestfjord Gletscher, have an annual ice discharge of 11.2 km^3 and 6.5 km^3, respectively (OLESEN & REEH 1969, REEH 1985). Therefore, thousands of icebergs drift through the narrow western fjords into Scoresby Sund and Hall Bredning and from there into the East Greenland Sea. Because most of the year the fjords are covered by sea ice, icebergs can float unimpededly only during the short period of July through beginning of October (KOCH 1945).

MATERIALS AND METHODS

16 box cores and 14 gravity cores have been analysed for this study (Fig. 1b). All cores were collected during cruises ARK-V/3b and ARK-VII/3b of RV *Polarstern* in the years 1988 and 1990 (MARIENFELD 1991a).

For obtaining informations on the modern mode of sedimentation the uppermost 1 cm of the box cores was sampled and analysed for grain-size, carbonate, organic carbon, and sulphur contents and composition of the 125-250 µm fraction. Prior to opening of the gravity cores, magnetic susceptibility of the sediments was measured. X-radiographs were made from all cores for determination of biogenic and nonbiogenic sedimentary structures (MARIENFELD 1990) and contents of coarse ice-rafted debris (IRD) >2 mm (GROBE 1987). Depending on changes of lithology and sediment fabric, all cores were sampled at intervals of 10-15 cm. Subsamples have been analysed for grain-size, carbonate, organic carbon, and sulphur contents and composition of the 125-250 µm fraction.

$\partial^{18}O$ and $\partial^{13}C$ ratios were determined on benthic foraminifera *Cassidulina teretis* from samples of cores PS1927 and PS1941. Radiocarbon ages were measured at 7 samples to date characteristic changes of sediment composition and fabric of 4 cores (MARIENFELD 1991b).

SEDIMENTARY FACIES

All investigated glaciomarine sediments from Scoresby Sund and Hall Bredning are paratills. However, investigation of X-radiographs reveals remarkable changes in sediment fabric with depth in cores. Five characteristic facies could be distinguished (MARIENFELD 1990). The prominent features of these facies are described and summarized in Table 1.

Sediments of Facies 1 to 3 form when the fjords are not covered by sea ice for longer periods (probably several years to decades) and icebergs can drift unimpededly. Strong and continuous sedimentation mostly by icebergs leads to formation of sediments of Facies 1 and 2 with the main difference being the smaller IRD content of Facies 2. Coarse grained layers or lenses of Facies 3 may be the result of sedimentation-"events" overprinting background sedimentation of Facies 1 and 2. VORREN et al. (1983) and POWELL (1981) explain the genesis of similar sediments by turnover of icebergs and sudden release of sediment which had accumulated on their surfaces.

Graphic Characterization of Lithology	Facies type	Fabric/Sedimentary Structures		Statistical Parameters	IRD Content	Ranking of Importance
		nonbiogenic	biogenic			
	1	homogeneous	slight bioturbation (*Planolites* and *Chondrites*)	very poorly sorted; mean grain size 4.4-8.5 Φ	much to very much coarse and angular IRD(>5 pebbles/cm depth in core)	prominent facies in the fjord; represents the recent sedimentary facies
	2	homogeneous	slight to moderate sometimes even strong bioturbation (*Planolites, Chondrites*)	very poorly sorted; mean grain size 4.5-8.5 Φ	few to intermediate IRD; pebbles smaller than in facies 1; (<5 pebbles/cm depth in core)	second important facies
	3	Lenses or layers (thickness 1-3 cm) with sharp contact to surrounding sediment	none	coarse grained layers/lenses dominantly composed of coarse sand to gravel; gravel mostly angular		randomly intercalated in facies 1 and 2; can be found in all cores
	4	laminated (mm)	none	two groups of laminae: 1) poorly sorted;mean 2-5 Φ 2) very poorly sorted;mean 7.5-9.5 Φ	isolated small pebbles	only in deeper sections of the cores of the deeper parts of Scoresby Sund and Hall Bredning
	5	layered (mm to cm)	none	very poorly sorted; mean grain size 5.5-8.5 Φ	few to intermediate IRD; (<5 pebbles/cm depth in core)	underlying facies 2 in deeper parts of Scoresby Sund and Hall Bredning

Table 1: Characterization of sedimentary facies of the fjord sediments. Biogenic and nonbiogenic sedimentary structures and content of coarse ice-rafted debris (IRD) have been determined at X-radiographs. Statistical sediment parameters are result from detailed grain-size analysis. Number of facies and their graphical depiction are as in Figure 4.

Tabelle 1: Charakterisierung der Fazies der Fjordsedimente. Biogene und nichtbiogene Sedimentstrukturen und der Gehalt an grobem eistransportiertem Material (IRD) wurden an Radiographien bestimmt. Die statistischen Sedimentparameter wurden nach detaillierter Korngrößenanalyse berechnet. Nummer und graphische Charakterisierung der Sedimentfazies wie in Abb. 4.

For formation of laminated sediments of Facies 4 the fjord has to be covered for longer periods by sea ice. Sea ice stabilizes the termini of tidewater glaciers and reduces the drift rate of icebergs (DOWDESWELL 1989, HIGGINS 1988, HIGGINS 1990). In this way input of coarse ice-rafted debris is drastically reduced and dominantly fine grained material settles out of suspension below the ice cover. A sea ice cover, which is stable for a longer period, causes reduced benthic life. Therefore, sediments accumulating under such conditions are not bioturbated. Facies 5 represents the transition between homogeneous and laminated sediments. Sedimentation by icebergs in the fjord is not continuous, but relatively often interrupted by periods of longer-lasting sea ice coverage.

THE SEDIMENTARY SEQUENCE

Sediments of Scoresby Sund and Hall Bredning are, without exception, poorly to very poorly sorted (sorting 2.0-4.1). Despite the sediment is mostly composed of silt and clay (mean grain-size 5.2-9.7 Phi), sand and even coarse gravel and boulders occur everywhere in the fjord (Figs. 2, 3 and 4). The 125-250 µm fraction of all investigated fjord sediments are mainly composed of terrigenous components. Because of the very short distances of transport, rock fragments are of major importance (Figs. 2, 3 and 4). Biogenic components of the 125-250 µm sediment fraction consist mostly of marine benthic microfossils. Calcareous foraminifers clearly dominate the benthic community. The sediments of Scoresby Sund and Hall Bredning are generally very soft and uncompacted (Figs. 2, 3 and 4).

After definitions of DOMACK et al. (1980), KURTZ & ANDERSON (1979) and ANDERSON (1977), all glaciomarine sediments of Scoresby Sund and Hall Bredning are „paratills": the surface sediments are uncompacted, pebbles have horizontal to subhorizontal orientation, the sediments are fossiliferous and show indications of biogenic activity (traces). The characteristics are indicative for marine processes in a polar environment. According to fabric, grain-size distribution, fossils content and degree of compaction (ANDERSON et al. 1980), a differentiation between „compound glaciomarine sediments" and „residual glaciomarine sediments" is feasible. Residual glaciomarine sediments can be found in shallow parts of Scoresby Sund and Hall Bredning, where scouring icebergs resuspend the sediment and the fine grained sediment fraction is winnowed. Compound glacialmarine sediments form in deeper parts of the fjord, where sediment is deposited from icebergs and out of suspension. Part of the fine grained material which is resuspended in the shallow parts of the fjord will probably settle in the deeper parts, where icebergs do not reach the fjord floor or the rate of scouring is at least very low.

Water depth, transport paths of icebergs and hydrographic conditions (mainly pattern of surface water circulation) are the factors for distinction of two sedimentary environments in Scoresby Sund and Hall Bredning (MARIENFELD in press). In shallow parts of the fjord, less than about 400 m deep, sediments are strongly scoured by icebergs. VORREN et al. (1983) call such sediments „iceberg turbates". With increasing water depth the intensity of sediment reworking by ploughing icebergs decreases. Therefore, cores PS1714, PS1718, PS1719, PS1728 and PS1941 (Fig. 1b) from the deeper parts of Scoresby Sund and Hall Bredning (more than about 400 m deep) are suitable for reconstructing changes of sedimentation and sedimentary facies. These changes are prominent features, which have regional extent and can be correlated throughout the entire east/west-extension of the fjord. Sediment parameters of core PS1718 (Fig. 2) and PS1719 (Fig. 3) are shown as examples. The most characteristic features, shown by all cores from the deeper parts of Scoresby Sund and Hall Bredning, are summarized in Figure 4.

The IRD and facies logs of Figures 2, 3 and 4 clearly demonstrate the dominance of IRD-rich homogeneous sediments of Facies 1 and 2 in the fjord. It should be emphasized, that sediments of Facies 1, which have the highest content of IRD, occur always at the top of the cores. Coarse-grained layers or lenses of Facies 3 are randomly intercalated in sediments of Facies 1 and 2. They result from local sedimentation „events" and therefore cannot be correlated between the cores. Laminated and layered sediments of Facies 4 and 5 appear always in deeper parts of the cores. The transition from laminated sediments of Facies 4 to overlaying homogeneous sediments of Facies 1 and 2 coincides with remarkable changes in various sediment parameters (Figs. 2, 3 and 4). This change enables to subdivide the sediment sequence into two distinctly different core sections. Magnetic susceptibility of the lower core section (Section A) is much lower than magnetic susceptibility of the upper core section (Section B, Figs. 2, 3 and 4). This is caused by a significant change of the sediment composition. Core

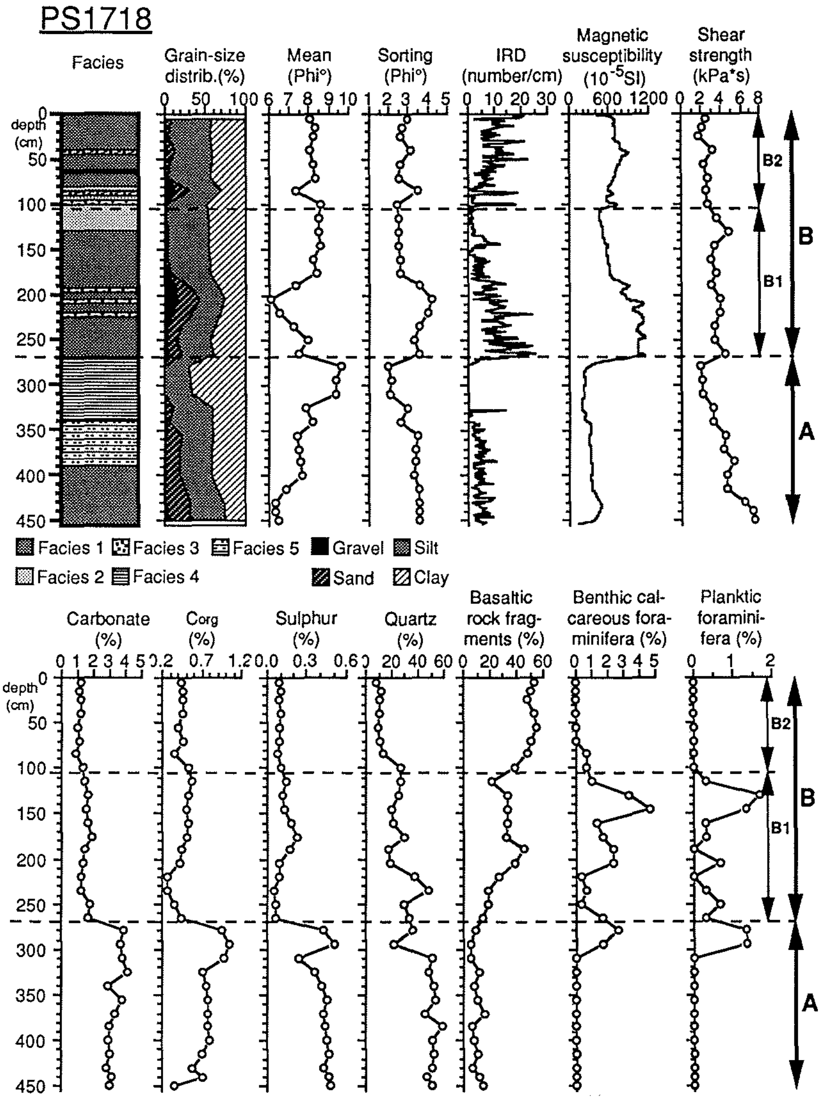

Fig. 2: Parameter of compound glaciomarine sediments of Core PS1718. Sedimentary facies and content of IRD are result of the analysis of X-radiographs. Percentages of terrigenous and biogenic components refer to their proportion in the 125-250 µm fraction. A, B, B1 und B2 mark facies units as discussed in text.

Abb. 2: Sedimentparameter im Kern PS1718 („compound glaciomarine sediment"). Sedimentfazies und Darstellung des IRD-Gehaltes beruhen auf der Auswertung von Radiographien. Die Prozentangabe terrigener und biogener Komponenten bezieht sich auf ihren Anteil an der Fraktion 125-250 µm. A, B, B1 und B2 kennzeichnen die im Text diskutierten Abschnitte unterschiedlicher Fazies.

Section A is mainly composed of quartz and nonbasaltic rock fragments. Furthermore, this core section has a relatively high content of terrigenous carbonate and organic carbon in its fine fraction. The terrigenous origin of the carbonate can be inferred from the fact, that carbonate content of sediments and distribution of calcareous microfossils of the 125-250 µm fraction, as for example benthic foraminifers (Figs. 2, 3 and 4), do not correlate. Recently performed investigations of the organic carbon fraction of PS1718 by using Rock-Eval pyrolysis support this interpretation. The organic sediment fraction of Section A is predominantly of terrigenous origin, whereas the one of Section B is of marine origin (STEIN et al. in press). The terrigenous components of Section

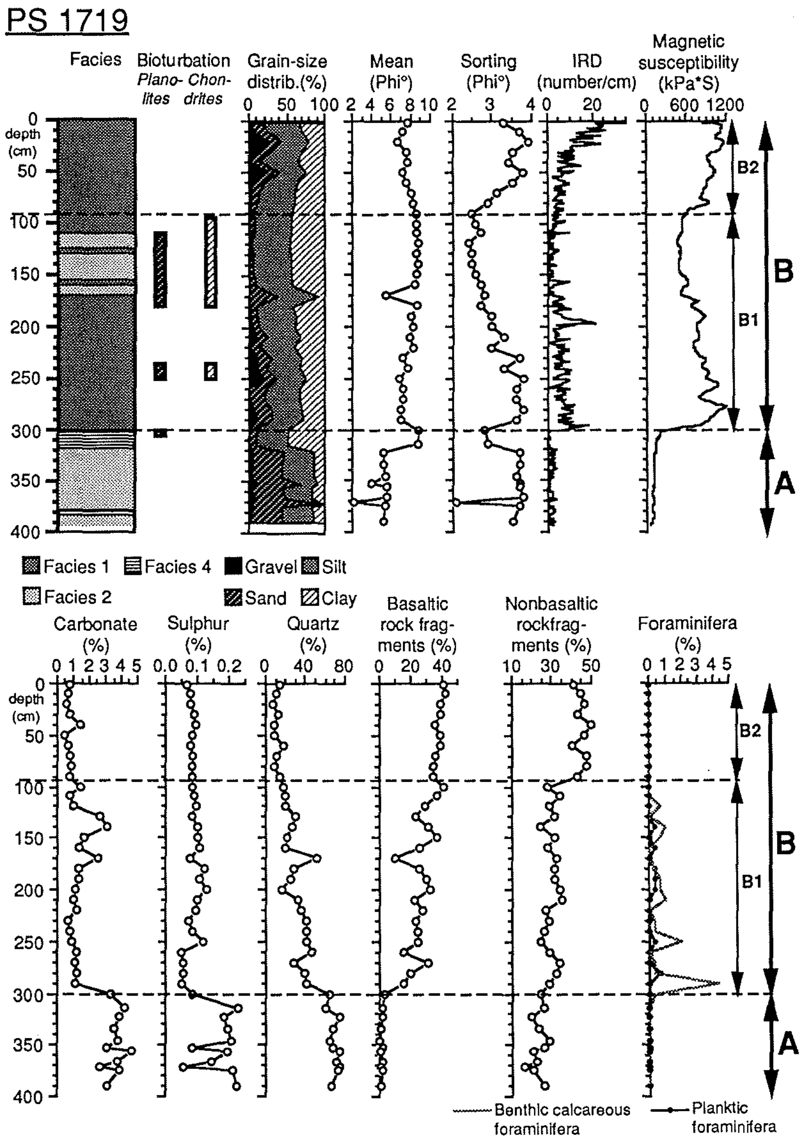

Fig. 3: Parameter of compound glaciomarine sediments of Core PS1719. Sedimentary facies and content of IRD are result of the analysis of X-radiographs. Percentages of terrigenous and biogenic components refer to their proportion in the 125-250 µm fraction. A, B, B1 und B2 mark facies units as discussed in the text.

Abb. 3: Sedimentparameter im Kern PS1719 („compound glaciomarine sediment".) Sedimentfazies und Darstellung des IRD-Gehaltes beruhen auf der Auswertung von Radiographien. Die Prozentangabe terrigener und biogener Komponenten bezieht sich auf ihren Anteil an der Fraktion 125-250 µm. A, B, B1 und B2 kennzeichnen die im Text diskutierten Abschnitte unterschiedlicher Fazies.

A have their source areas in the north and west of Scoresby Sund and Hall Bredning. The much higher magnetic susceptibility of sediments of Section B is caused by a much greater proportion of basaltic rock fragments (Figs. 2, 3 and 4). The source area of this component is Geikie Plateau south of Scoresby Sund.

The upper Section B itself is not homogeneous and can be subdivided into subunits B1 and B2 (Figs. 2, 3 and

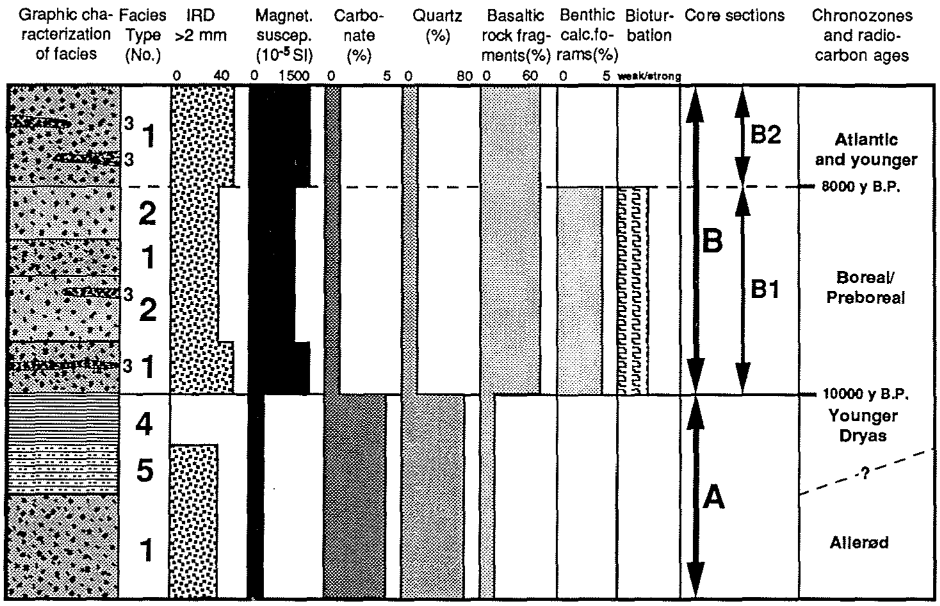

Fig. 4: Summary of main sediment features in an idealized sediment core from Scoresby Sund and Hall Bredning. Proportions of the components quartz, basaltic rock fragments and benthic calcareous foraminifers were counted in the 125-250 µm fraction. The content of IRD >2 mm was counted in X-radiographs. Determination of lithology, intensity and distribution of bioturbation structures are based on X-radiograph analysis. Numbers of sedimentary facies follow those used in Tab. 1. Facies 1 = homogeneous sediment, high content of IRD; Facies 2 = homogeneous sediment, low to moderate content of IRD; Facies 3 = coarse grained lenses or layers; Facies 4 = laminated, fine grained sediment; Facies 5 = layered sediment, moderate content of IRD (modified after MARIENFELD 1991a).

Abb. 4: Idealisiertes Schema mit den wichtigsten Merkmalen der Kerne aus Scoresby Sund und Hall Bredning. Die Anteile an Quarz, basaltischen Gesteinsbruchstücken und kalkschaligen benthischen Foraminiferen wurden an der Fraktion 125-250 µm bestimmt, die IRD-Gehalte an den Radiographien ausgezählt. Abiogene Sedimentgefüge und Art, Häufigkeit und Verteilung biogener Sedimentstrukturen beruhen auf der Auswertung von Radiographien. Die Kennzeichnung der Sedimentfazies wie in Tab. 1. Fazies 1 = Homogener, IRD-reicher Paratill, Fazies 2 = Homogener Paratill mit geringem bis mittlerem Gehalt an IRD, Fazies 3 = Grobkörnige Sedimentlagen oder -linsen, Fazies 4 = laminiertes feinkörniges Sediment, Fazies 5 = Geschichtetes Sediment mit mittlerem Gehalt an IRD (modifiziert nach MARIENFELD 1991a).

4). Microfossils of 125-250 µm fraction are concentrated in Subunit B1. Benthic calcareous foraminifers, which dominate the microfossil assemblage, have nearly the same species composition as described by MACKENSEN (1987) from the Iceland-Scotland Ridge in a much greater water depth. Additionally, Subunit B1 shows the highest degree of bioturbation with traces of *Chondrites* and *Planolites* (MARIENFELD 1990). Subunit B2 is characterized by higher contents of coarse ice-rafted debris, which mainly consists of basaltic rock fragments. Due to a greater proportion of basaltic components, magnetic susceptibility of Subunit B2 is generally higher compared with Subunit B1.

AGE OF SEDIMENTS

Seismic investigations in Scoresby Sund and Hall Bredning do not indicate large quantities of unconsolidated sediments (UENZELMANN-NEBEN et al. 1991). Throughout most of Scoresby Sund and Hall Bredning unconsolidated sediments covering bedrock have a thickness of only 5-15 m (DOWDESWELL et al. 1991), which is very thin for a fjord environment in a polar setting. Therefore, and supported by ^{14}C-ages, it is probable, that during Late Weichselian glacial maximum a valley glacier has eroded all older Quaternary sediments and the thin sedimentary record comprises exclusively the postglacial period (MARIENFELD 1991c). The ^{14}C-ages permit the subdivision of the sedimentary record (MARIENFELD 1991b). The base of Core Section B is dated with about 10,000 y B.P. (PS1715: 9,890±150 y B.P., PS1719: 9,930±190 y B.P., PS1728: 10,210±120 y B.P.) and represents the end of the Younger Dryas and/or beginning of the Preboreal. The transition of Subunits B1/B2 is dated with about 8,000 y B.P. (PS1728: 8,140±150 y B.P.) and represents the end of the Boreal or beginning of the Atlantic.

DISCUSSION

The sections on sedimentary facies and sedimentological investigations of the cores have shown that factors controlling sedimentation in Scoresby Sund and Hall Bredning have changed with time. Considering $\partial^{18}O$ and $\partial^{13}C$-data (MARIENFELD 1991c) and ^{14}C-ages (MARIENFELD 1991b), it is possible to divide the postglacial depositional history into four distinct phases of sedimentation. The changing conditions during postglacial sedimentation can be characterized as follows.

Evolution from the Allerød to the beginning of Younger Dryas

After the end of Weichselian glacial phase, the front of the valley glacier, draining the inland ice sheet and filling the whole fjord system, retreated westward (Fig. 5). Finally, Scoresby Sund and Hall Bredning were free of ice and termini of valley glaciers were situated at the mouths of Nordvestfjord, Øfjord, Fønfjord and Gåsefjord into Scoresby Sund and Hall Bredning. During the retreat of the ice, many icebergs, which dominantly contained sediment from the western fjord region, were released (Fig. 6). Poorly sorted glaciomarine paratills of Facies 1 and 2, which do not contain biogenic components, were formed. The absence of a marine biogenic sediment fraction could be caused by very high sedimentation rates, intense iceberg scouring, or unfavourable hydrographic conditions because of strong input of meltwater. However, results of reflection seismic and sediment echographic investigations (DOWDESWELL et al. 1991, UENZELMANN-NEBEN et al. 1991) do not indicate a thick sediment cover of the fjord floor. Hence, high sedimentation rates are unprobable during that period of deglaciation. After FUNDER (1972b) the Allerød, as the first period of deglaciation, ended at about 11,000 y B.P. in the Scoresby Sund fjord region.

Renewed decrease of temperature during Younger Dryas (about 11,000-10,000 y B.P.)

The renewed decrease of temperatures at the beginning of Younger Dryas happened quickly (MERCER 1969, DANSGAARD et al. 1989). During Younger Dryas glacier termini remained at the topographically favourable positions at the mouths of Nordvestfjord, Øfjord, Fønfjord and Gåsefjord into Scoresby Sund and Hall Bredning (FUNDER 1972a, 1972b). At these locations termini of glaciers were grounded on more or less pronounced sills.

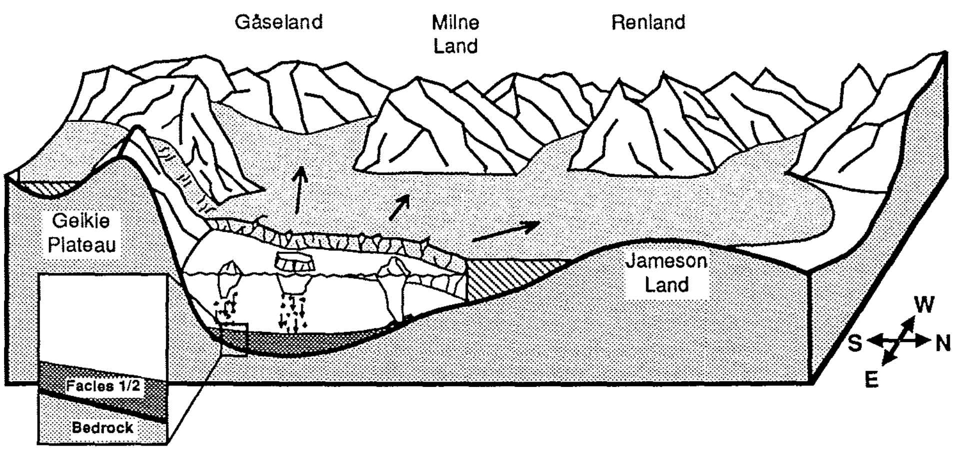

Fig. 5: Depositional model for the Allerød. In this period, the valley glacier, filling Scoresby Sund and Hall Bredning since the Weichselian glacial maximum, retreated westward. Sedimentation and sediment reworking took place by drifting icebergs. Glaciers of Geikie Plateau have only minor influence on sedimentation in the fjord.

Abb. 5: Sedimentationsverhältnisse während des Allerød-Stadiums. In dieser Phase zieht sich der Talgletscher aus Scoresby Sund und Hall Bredning nach Westen zurück. Sedimentation und Sedimentaufarbeitung erfolgt durch treibende Eisberge. Der Einfluß des Geikie Plateaus auf die Sedimentation im Fjord ist gering.

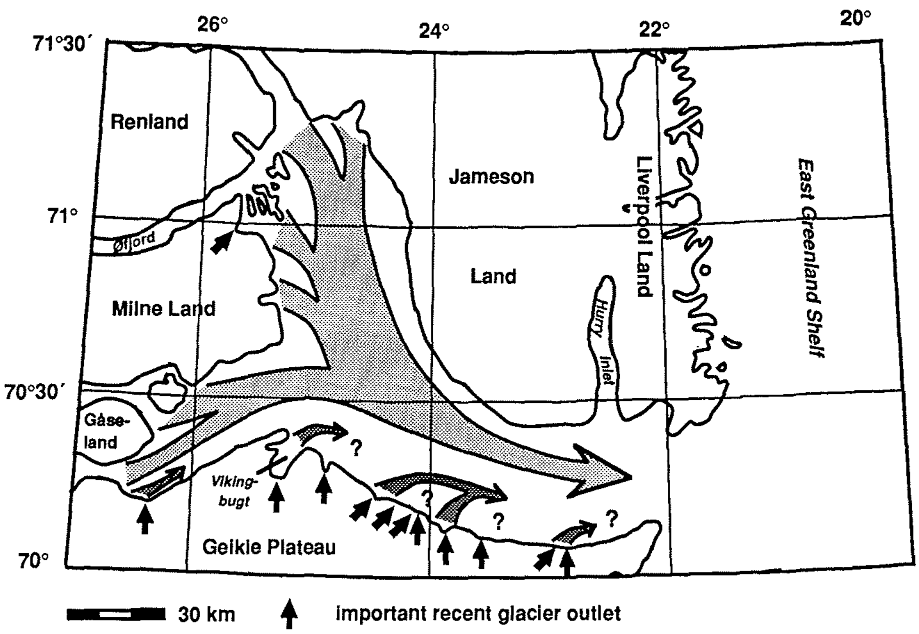

Fig. 6: Most of the sediments deposited during Allerød have their source in the western fjord region. The size of arrows symbolizes importance of the different source areas of terrigenous sediment components.

Abb. 6: Der größte Teil des im Allerød abgelagerten Sediments stammt aus der westlichen Fjordregion. Die Größe der Pfeile symbolisiert die Bedeutung der verschiedenen Herkunftsgebiete der terrigenen Sedimentkomponenten.

With beginning of the Younger Dryas a more and more stable sea ice cover was formed, which considerably reduced drift of icebergs and thus input of coarse ice-rafted material. Formation of layered sediments of Facies 5 is attributed to this period. Sediments still contain relatively high amounts of dropstones, but less than those of the foregoing period.

Continuous decrease of temperature then resulted in a persistent and stable sea ice cover of Scoresby Sund and Hall Bredning. It is assumed that during Younger Dryas the arctic anticyclonic center renewedly extended southward (LAMB & WOODROFFE 1970, HJORT 1979), resulting in less precipitation. As a consequence, less glacier ice was formed and flow velocity of glaciers was reduced. Additionally, a persistent sea ice cover stabilized glacier fronts and thus caused smaller calving rates of icebergs (DOWDESWELL 1989, HIGGINS 1988, HIGGINS 1990). Such conditions have favoured the formation of fine grained laminated sediments of Facies 4, barren of microfossils and nearly devoid of coarse ice-rafted material (Fig. 7).

As at the beginning of this interval, the climatic change at the end of Younger Dryas came relatively quickly (MERCER 1969, DANSGAARD et al. 1989). In the sediment cores this is shown by the abrupt change from laminated to homogeneous glaciomarine sediments, containing a high proportion of coarse ice-rafted material. The beginning of the Preboreal, following the Younger Dryas is ^{14}C-dated in three cores to about 10,000 y B.P. (MARIENFELD 1991b).

The period of climatically optimal conditions 10,000-8,000 (?) y B.P.

With the end of Younger Dryas a considerable change in the mode of sedimentation took place. Formation of laminated sediments was now followed by sedimentation of homogeneous paratills (Facies 1-3). During this period glaciers in the narrow fjords rapidly retreated westward (FUNDER 1989). The climatic amelioration caused intensive calving and drift of icebergs. Consequently, at first sediment containing a high proportion of coarse ice-

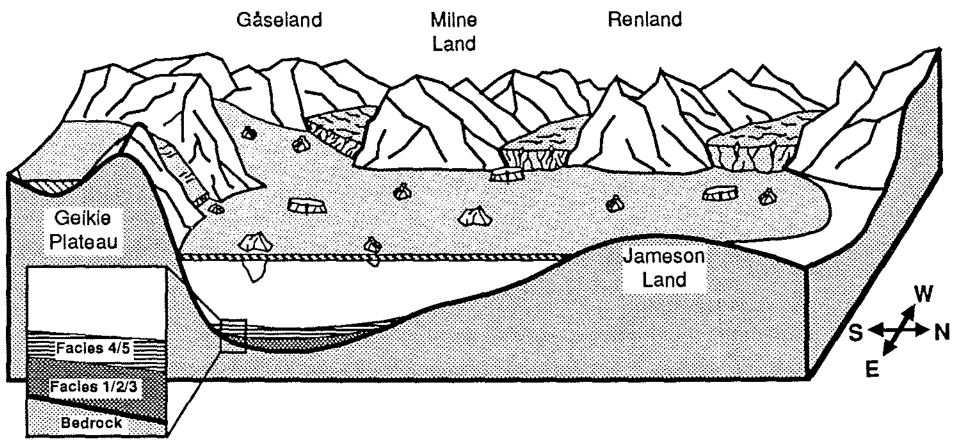

Fig. 7: Depositional model for the Younger Dryas. Glaciers have their termini at the mouths of fjords of the western fjord region. Scoresby Sund and Hall Bredning are covered by sea ice, which hinders calving and drift of icebergs and thus sedimentation of ice-rafted material.

Abb. 7: Sedimentationsverhältnisse während der Jüngeren Dryas. Die Gletscher enden an den Mündungen der Fjorde der westlichen Fjordregion. Scoresby Sund und Hall Bredning sind von einer Meereisdecke verschlossen, die Kalbung und Drift von Eisbergen und damit Sedimentation von eistransportiertem Material behindert.

rafted material was deposited (Fig. 4). With the retreat of glacier termini to the west and the increasing distance between calving fronts and Scoresby Sund and Hall Bredning, proportion of IRD in sediments of the eastern fjord region decreased.

The warming at the beginning of Preboreal resulted from a change in extension and location of the arctic anticyclonic center and the path of the west/east-moving cyclonic centers, respectively (LAMB & WOODROFFE 1970, HJORT 1979). With the northward extension of influence of cyclonic systems along the east coast of Greenland the amount of precipitation changed. After DANSGAARD et al. (1989), Greenland ice cores reveal a 50% increase in precipitation rate. Today, coastal areas are heavily glaciated as far north as the mouth of Scoresby

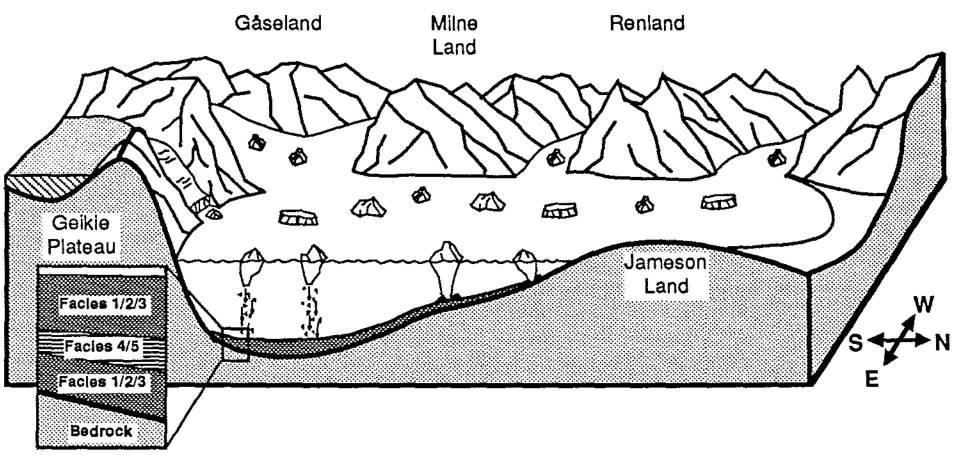

Fig. 8: Depositional model for the period between the end of Younger Dryas and present day. Fjords of the western fjord region are no longer occupied by glaciers. Sedimentation and sediment reworking take place by drifting icebergs. Numerous glaciers drain the local ice cap of Geikie Plateau, which has grown because of higher precipitation. A large number of icebergs transport a lot of basaltic rock fragments into Scoresby Sund.

Abb. 8: Sedimentationsverhältnisse vom Ende der Jüngeren Dryas bis heute. In den Fjorden der westlichen Fjordregion liegen kein Gletscher. Sedimentation aber auch Sedimentaufarbeitung erfolgt durch treibende Eisberge. Vom nunmehr stärker vergletscherten Geikie Plateau münden zahlreiche Gletscher in den Scoresby Sund. Die zahlreichen Eisberge transportieren viel basaltischen Gesteinsschutt in den Fjord.

Sund at 70° N. However, north of the mouth of Scoresby Sund, coastal areas are predominantly free of ice (REEH 1989). Consequently, it is a realistic assumption, that the local ice cap of Geikie Plateau and the numerous smaller glaciers draining this ice cap into Scoresby Sund, began to grow with beginning of the Preboreal. The changed glaciological situation during the Preboreal and younger periods is mirrored in the sediments by an increased input of basaltic rock fragments from the south and a reduced input from the west (Figs. 4, 8 and 9). The calculated sedimentation rates of the period of Preboreal until present are 20-30 cm/10^3 y for the deeper parts of Scoresby Sund (e.g. at Sites PS1719 and PS1728) and about 10 cm/10^3 y for the shallower parts of the fjord (e.g. at Site PS1715).

The decreasing influence of glaciers from the western fjord region on sedimentation in Scoresby Sund and Hall Bredning is not only caused by growing distance of glacier fronts relative to the eastern fjord region. Another important factor is the different bathymetric situation of the eastern and western fjord region. With a maximum of 1.5 km, Nordvestfjord, Øfjord, Fønfjord and Gåsefjord are about twice as deep as fjords of the eastern fjord region. Glaciers draining into them reach big ice thicknesses and calving icebergs have calculated keel depth of up to 700 m (DOWDESWELL et al. in press). Icebergs of great keel depth run aground at the mouth of these deep fjords into Scoresby Sund and Hall Bredning. Only after partial decay and, due to it, loss of part of basal sediment load, icebergs can resume to float to the east.

Climatic changes at the transition from the Younger Dryas to the Preboreal did not only influence the composition of the terrigenous sediment fraction, but also the biogenic fraction. Spreading of vegetation onshore, mainly on Jameson Land (FUNDER 1978), resulted in higher nutrient input into the fjord. More nutrients on the other hand favour spreading of planktic as well as benthic life, e.g. benthic foraminifers (Figs. 2, 3 and 4). An increase of benthic activity is indicated by stronger bioturbation of the fjord sediments (Figs. 3 and 4).

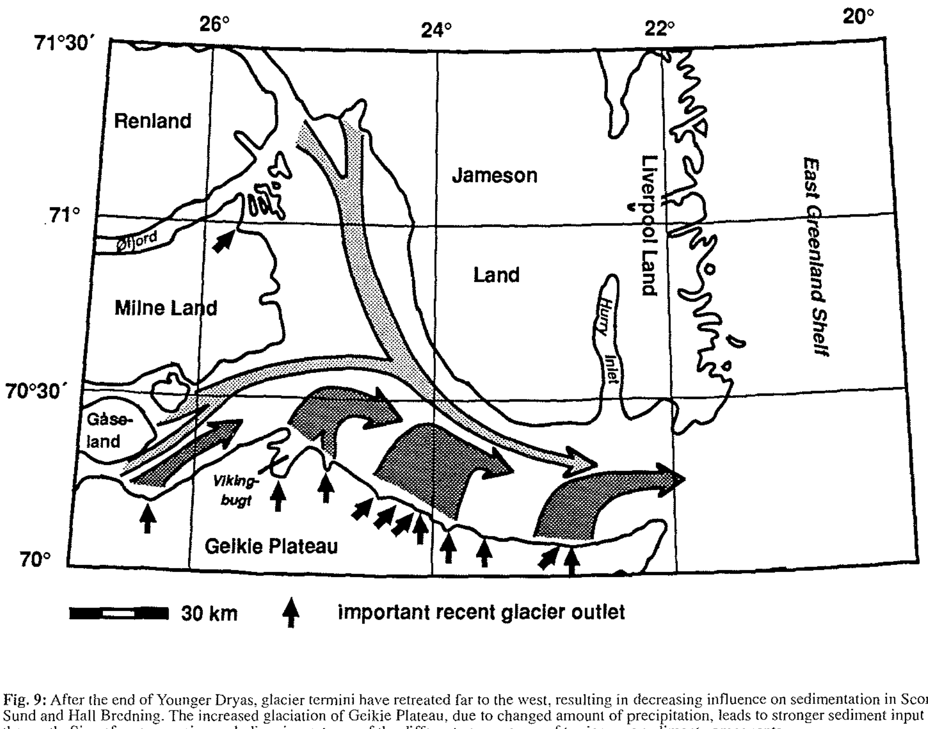

Fig. 9: After the end of Younger Dryas, glacier termini have retreated far to the west, resulting in decreasing influence on sedimentation in Scoresby Sund and Hall Bredning. The increased glaciation of Geikie Plateau, due to changed amount of precipitation, leads to stronger sediment input from the south. Size of arrows again symbolizes importance of the different source areas of terrigenous sediment components.

Abb. 9: Nach dem Ende der Jüngeren Dryas ziehen sich die Gletscher der westlichen Fjordregion weit nach Westen zurück. Ihr Einfluß auf die Sedimentation in Scoresby Sund und Hall Bredning wird dadurch geringer. Die stärkere Vergletscherung des Geikie Plateaus führt zu erhöhtem Sedimenteintrag von Süden. Die Größe der Pfeile symbolisiert die Wichtigkeit der verschiedenen Herkunftsgebiete der terrigenen Sedimentkomponenten.

The period of climatically optimal conditions, as defined by occurrence of microfossils and bioturbation of sediments, lasted until 8,000 y B.P., as dated by ^{14}C (e.g. core PS1728). This seems to be in contradiction to HJORT & FUNDER (1974) whose investigations on bivalves indicate climatically optimal conditions from 8,000-5,000 y B.P.. Their criterion is the immigration and extinction of *Mytilus edulis*. The disappearance of *M. edulis* correlates with the return of a poor, less dense arctic vegetation, as indicated by pollen analysis (HJORT & FUNDER 1974).

Evolution from 8,000 y B.P. to present

Since about 8,000 y B.P. input of mainly basaltic coarse ice-rafted material intensified in the southern parts of Scoresby Sund and Hall Bredning. The source area for this material is mainly Geikie Plateau. Conditions of life for benthic organisms deteriorated. The proportion of microfossils and intensity of bioturbation are much smaller than in the previous period. This change is most pronounced in the eastern part of Scoresby Sund.

The question arises, why conditions for benthic organisms became worse. An explanation could be that, because of renewed cooling, the fjord was covered by sea ice for a longer time during the year. Additionally, due to a less dense vegetation cover, input of nutrients into the fjord has been reduced. Alternatively, higher sedimentation rates could have influenced conditions of life for benthic organisms. The assumption of a climatic deterioration at 8,000 y B.P., however, is not consistent with results from investigations of bivalves (HJORT & FUNDER 1974) and pollen (FUNDER 1978). These authors have shown that at that time a further amelioration of climate took place, probably resulting in higher sedimentation rates because of increased input of ice-rafted debris from the numerous glaciers draining the local ice cap of Geikie Plateau. As at the transition from the Younger Dryas to the Preboreal, a moderate change in precipitation could have been sufficient for considerably influencing sedimentation in the fjord. A renewed displacement of cyclonic and anticyclonic centers to the north would result in higher precipitation at coastal areas further north and would cause growth of the local ice cap of Geikie Plateau. A higher number of glaciers draining this ice cap and a higher calving rate of icebergs would increase input of basaltic rock fragments into Scoresby Sund. Probably, the huge glaciers draining the inland ice cap into the fjords of the western fjord region released a higher number of icebergs. Thus conditions for benthic life would become worse due to higher sedimentation rates. Consequently, deterioration of conditions for benthic organisms at 8,000 y B.P. did not result from deterioration of climate and lower temperatures. This conclusion is supported by oxygen and carbon isotope ratios measured on benthic foraminifers, which do not show any change at the Boreal-Atlantic transition at 8,000 y B.P. Thus, there is no inconsistency between reduced density of benthic life in the fjord and onshore spreading of vegetation, which is better adopted to higher temperatures (FUNDER 1978).

Sedimentological and palynological investigations of lake sediments from Jameson Land indicate a decrease of temperatures in the Scoresby Sund region at about 5,000 y B.P. (FUNDER 1971, 1972b, 1978; HJORT & FUNDER 1974). This climatic change is not mirrored in fjord sediments. Beginning at 8,000 y B.P. and lasting until today, fjord sediments in the southern parts of Scoresby Sund and Hall Bredning show a steadily increasing influence of the Geikie Plateau as source area of sediments in Scoresby Sund.

CONCLUSIONS

1) The glacier advance during the Weichselian glaciation appears to have removed any Preweichselian sediments from the fjord floor of Scoreby Sund. The sedimentary sequence, comprising only Postweichselian sediments, has a thickness of 5-15 m of unconsolidated sediments.

2) All sediments are paratills and have been deposited under glaciomarine conditions. The poorly sorted sediments are dominated by terrestrial components; biogenic components are of minor importance. Sediment fabric and grain-size distribution, mainly the content of coarse ice-rafted debris, permits the distinction of five facies.

3) Each of five glaciomarine facies is attributable to distinct environmental conditions, such as intensity of iceberg rafting, intensity of sediment reworking by scouring icebergs, and degree of coverage of the fjord by sea ice.

4) The postglacial sedimentary record can be subdivided into four distinct periods, each characterized by a specific mode of sedimentation, sediment reworking, hydrographic and glaciologic conditions, source area of sediments, and distribution and abundance of planktic and benthic life.

5) Beginning with the end of the Weichselian glaciation, the valley glacier rapidly retreated in Scoresby Sund and Hall Bredning. Many icebergs were released and poorly sorted paratills were formed. At the end of this period, at about 10,000 y B.P., Scoresby Sund and Hall Bredning were free of glacier ice.

6) During the Younger Dryas, lasting about 11,000-10,000 y B.P., climate deteriorated and Scoresby Sund and Hall Bredning were covered by sea ice. Layered to laminated fine grained and unfossiliferous sediments were deposited below the sea ice cover.

7) An amelioration of climate at the beginning of the Preboreal period caused the sea ice cover to break up. An increase in precipitation resulted in intensified iceberg calving and the renewed deposition of coarse grained poorly sorted homogeneous paratills rich in coarse ice-rafted debris. Due to increased input of organic material from the areas surrounding Scoresby Sund and Hall Bredning, abundance of planktic and benthic life increased.

8) Beginning with the Atlantic period at about 8,000 y B.P. and lasting until today, precipitation probably renewedly increased, resulting in more intense iceberg calving, stronger input of IRD and more intensive sediment reworking by iceberg scouring. Due to changed hydrographic and glaciologic conditions, the conditions of life for benthic and planktic organisms deteriorated and their abundance and diversity remarkably decreased.

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