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Neoglacial Glacier Changes around Storstrømmen, North-East Greenland

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Summary: Early Holocene recession of the ice cover over Germania Land in North-East Greenland 7.5 ka B.P. brought the Inland Ice margin back to a position close to the present. Continued recession after that time lead to the formation of a „Storstrømmen Sound" which separated Germania Land from mainland Greenland in the period from about 6 to 1 ka B.P. The present filling of the approximately 100 km long sound by the glaciers of Storstrømmen and Kofoed-Hansen Bræ must therefore have taken place during the Little Ice Age. In an archaeological sense this implies deterioration of the living conditions of Neo-Eskimos compared to those of Palaeo-Eskimos.

The neoglacial re-formation and present existence of the glaciers as a Little Ice Age relict may imply a present-day instability in their dynamics, as demonstrated by the pulsations (surge-like behaviour) in the last part of the 20th century. An earlier Little Ice Age advance might possibly have had the same amplitude as that documented from the 20th century but its exact age and character is not known.

The glacio-isostatic response of the earth's crust to the variations in the Holocene glacier load implies a relatively slow and slight emergence and subsequent submergence. The shift from emergence to submergence must have taken place between about 2 and 1 ka B.P.

Zusammenfassung: Während des frühholozänen Rückzugs der Vereisung auf Germania Land, erreichte der Eisrand dort bis ca. 7.5 ka vor heute eine Position, die der heutigen sehr ähnlich ist. Der sich anschließende weitere kontinuierliche Rückgang der Vereisung führte zur Ausbildung eines „Storstrømmen Sund", der dann Germania Land in der Zeit von ca. 6 bis 1 ka vor heute vom Grönländischen Festland trennte. Die erneute Auffüllung des Sunds durch die Gletscher Storstrømmen und Kofoed-Hansen Bræ bis zum heutigen Stand muß demnach während der Kleinen Eiszeit stattgefunden haben. Aus archäologischer Sicht ergibt sich daraus eine Verschlechterung der Lebensbedingungen für die Neo-Eskimo im Vergleich zu den Paläo-Eskimo in diesem Gebiet.

Aus der Tatsache der neoglazialen Wiederbildung und der heutigen Existenz der Gletscher als ein Relikt der Kleinen Eiszeit kann man auf eine gegenwärtige Instabilität ihres dynamischen Verhaltens schließen. Hinweise darauf sind auch die surge-artigen Schwankungen am Ende des 20. Jahrhunderts. Ein früherer Vorstoß während der Kleinen Eiszeit könnte möglicherweise die gleiche Stärke erreicht haben, wie sie für das 20. Jahrhundert dokumentiert ist. Es ist jedoch nichts über die Zeit und Art dieses Ereignisses bekannt.

Die isostatische Reaktion der Erdkruste auf die Veränderungen der holozänen Eisauflast schließt eine verhältnismäßig langsame und geringe Hebung und nachfolgende Absenkung ein. Der Übergang von Hebung zu Senkung muß etwa zwischen 2 und 1 ka vor heute stattgefunden haben.

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INTRODUCTION

The content of this paper is a part of a glaciological project concerning former climate oscillations and variations of Storstrømmen, an outlet from the Inland Ice in North-East Greenland.

The ice cover of North and North-East Greenland is considered to be very sensitive to climatic change (e.g. BØGGILD et al. 1994) and the lack of glaciological data, therefore, imposes certain restrictions on mass balance models of Inland Ice changes. Glaciological investigations of the Storstrømmen area have consequently been made since 1989 by the Alfred-Wegener-Institute (AWI), Germany, the Geological Survey of Greenland (GGU) and the Danish Polar Center (DPC), both Denmark, (REEH et al. 1994), for the purpose of establishing a long and continuous record of ice margin changes and related local fluctuations of relative sea level. Here as elsewhere in Greenland the problem of the present glaciation is apparent. The early Holocene recession of the ice cover and the connected emergence of land is known from the investigations of the present ice-free land, whereas evidence of the late Holocene (Neoglacial) changes of ice cover and sea level is largely buried by the expanding ice cover and the submergence of land. The fragmentary evidence available is scattered and of different provenance (geophysical, geological, archaeological and historic). The following treatise is, therefore, an attempt to make a best fit of this scattered information.

GEOLOGICAL AND GLACIOLOGICAL SETTING

The area of study covers the Inland Ice margin at Germania Land, i.e. a part of the north-eastern slope of the Inland Ice with its margin situated between 76° 30' N and 77° 30' N. The present Inland Ice margin of the area is drained by the major outlets of L. Bistrup Bræ and Storstrømmen (including Kofoed-Hansen Bræ), which surround the nunatak complex of Dronning Louise Land (Fig. la).

Towards the east Storstrømmen/Kofoed-Hansen Bræ abut Germania Land. The appreciable heights of both Dronning Louise Land (peaks of 2000 to 1000 m a.s.l.) and Germania Land (800 to 600 m a.s.l.) combined with the major north-south running bedrock structures of the area (e.g. FRIDERICHSEN et al. 1990, 1991, STRACHAN et al. 1991), act as extensive barriers against ice movements from the west. L. Bistrup Bræ, Storstrømmen and Kofoed-Hansen Bræ (Fig. la) are situated in a trough formed along these structures. Radar measurements of the ice thickness of Storstrømmen (N. GUNDESTRUP, pers. comm.) indicate that the deepest parts of this trough are located at the southwestern part

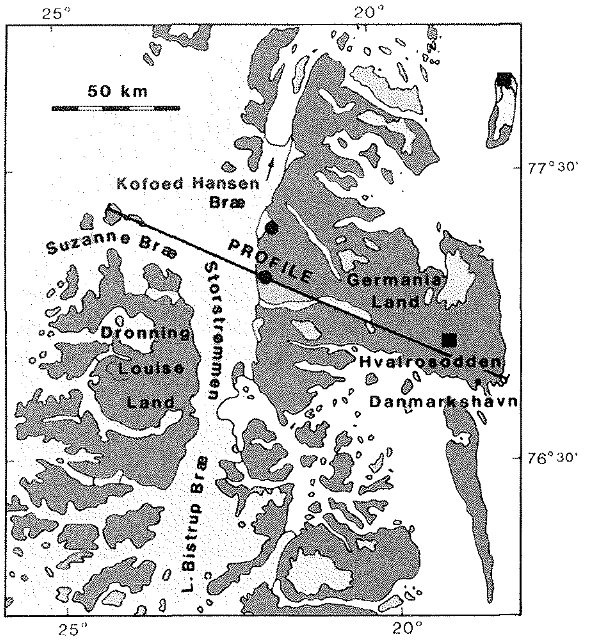


Fig. 1a: Situation of a profile through Germania Land and Storstrømmen, shown in Fig. lb. Also shown is location of interglacial and interstadial deposits, as located by LANDVIK (1994, square) and in this paper (circles).

Abb.1a: Lage des in Abb.1b dargestellten Profilschnittes durch Storstrømmen und Germania Land. In die Abbildung sind die Fundstellen interglazialer und interstadialer Ablagerungen, die von LANDVIK (1994, Quadrate) und in dieser Arbeit (Kreise) beschrieben werden, eingetragen.

of Storstrømmen, where they reach depths of over 400 m below present sea level (Fig. 2). According to the soundings Kofoed-Hansen Bræ must be considered as a northern overspill of Storstrømmen crossing a threshold of 0 to 200 m below present sea level (Fig. 2).

The height of the present glaciation limit (Fig. la) in the northern parts of Dronning Louise Land is estimated at about 1000 m a.s.l., an estimate comparable to the measured equilibrium line in the same region of 1100 m a.s.l. (REEH et al. 1993a,b). Towards the outer coast the glaciation limit decreases to 400-600 m a.s.l.

Climatological conditions must be based on the weather records from Danmarkshavn on the outer coast of Germania Land which extend back to 1949. The average temperature provided by the Danish Meteorological Institute for 1961-70 is: January -24.4 °C, July +3.6 °C, and for the year -12.5 °C; average precipitation is 109 mm a^{-1}.

Glaciological investigations of the area were initiated by the Danish expeditions of 1906-08 and 1912-13 (KOCH & WEGENER 1911, 1930), and continued by the British North Greenland Expedition 1952-54 (LISTER & WYLLIE 1957, LISTER & TAYLOR 1961, HAMILTON & ROLLITT 1957) and the Danish-German operations since 1989 (BØGGILD et al. 1994, REEH et al. 1993a, b).

The investigations since 1989 have been undertaken by GGU/DPC (Geological Survey of Greenland/Danish Polar Center, Copenhagen) and AWI (Alfred Wegener Institute for Polar and Marine Research, Bremerhaven) as part of an EU-sponsored programme on „Climatic Change on a Century Time Scale".

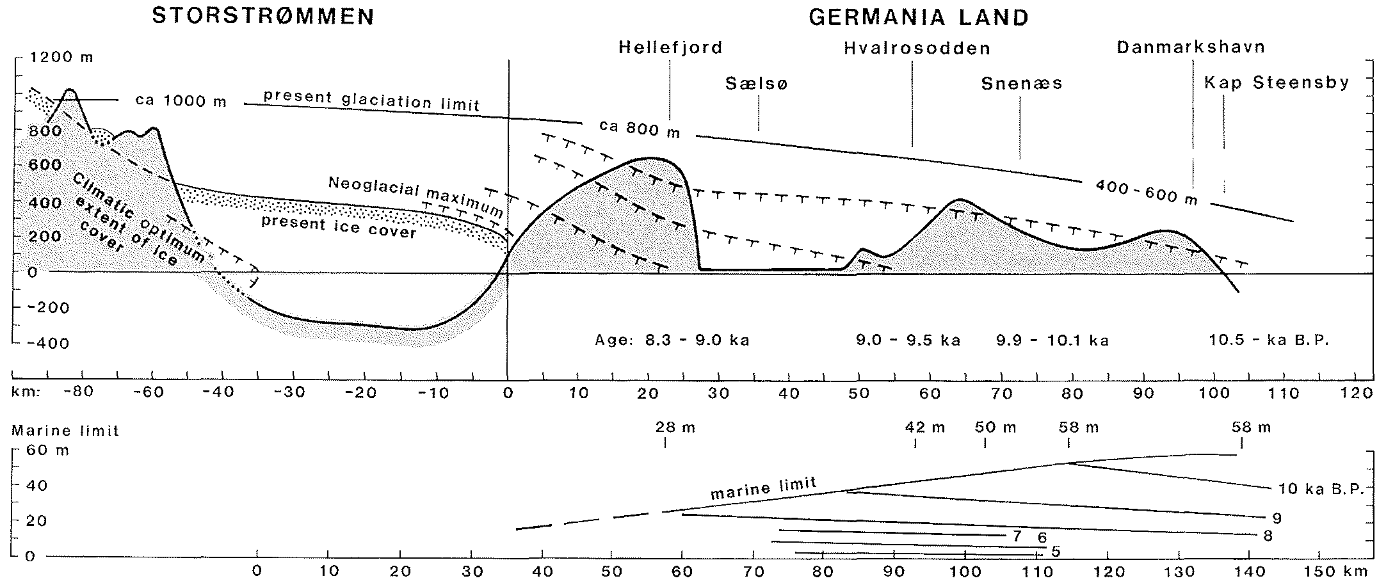


Fig. 1b: Profile through Germania Land and Storstrømmen (locationsee Fig. 1a) showing the early Holocene stages of the ice sheet recession (Kap Steensby to Hellefjord) based on LANDVIK (1994). Also shown are the subsequent ice margin positions of the climatic optimum west of „Storstrømmen Sound" and at the neoglacial maximum (latest: A.D. 1900). Simplified outline of the marine limit and the suggested trend of strandlines. The height of the present glaciation limit.

Abb. 1b: Profilschnitt durch Storstrømmen und Germania Land (Lage s. Abb.1a), der die frühen holozänen Stadien des Inlandeisrückgangs (von Kap Steensby bis Hellefjord) darstellt (basierend auf LANDVIK, 1994). Außerdem sind die späteren Positionen des Eisrandes, während des klimatischen Optimums westlich des „Storstrømmen Sunds" und zum neoglazialen Höchststand (spätestens um 1900 A.D.), dargestellt. Weiter sind in die Abbildung ein vereinfachter Umriß der marinen Grenzen und der vermutete Verlauf von Strandlinien sowie die Höhe der gegenwärtigen Vereisungsgrenze eingetragen.

Among the results of the investigations is the conclusion that the summer temperatures at the ice margin are lower than at the outer coast, in contrast to West Greenland localities, and that the observations of frontal change in volume and frontal position of Storstrømmen are indicative of surging behaviour. Rates of movement are extremely variable, with records of between a few hundred and two thousand m a^{-1} (REEH et al. 1994).

Initial observations on the Quaternary geology of Germania Land were made by KOCH & WEGENER (1930) and glacial geological features in the northern part of Dronning Louise Land were described by LISTER (1958) and LISTER & WYLLIE (1957). A detailed chronology of early Holocene events has been given by LANDVIK (1994) and this chronology forms the basis for the evaluation of the age of subsequent mid-Holocene (hypsithermal) and neoglacial events in the area discussed here.

The events are given in a schematic transect through Germania Land and northernmost parts of Dronning Louise Land (Fig. lb). The approximate age of stages indicates an average rate of recession of c. 40 m a^{-1}. If this average rate continued after the Hellefjord event (c. 8.3 ka B.P.), it implies that the Inland Ice margin reached approximately its present position at around 7.7 ka B.P. and attained a minimum position at around 6.8 ka B.P. This also gives an estimated age for the opening of a „Storstrømmen Sound", isolating Germania Land from mainland Greenland. However, the estimate of the average rate of recession must be crude, since it depends on local topography and drainage of the ice margin.

The idea of an earlier fjord or sound, now filled by the glaciers of Storstrømmen and Kofoed-Hansen Bræ, had been suggested by KOCH (1916: 445-446) and KOCH & WEGENER (1911: 47). Their conclusions were based on the presence of shells in the moraines around these glaciers, and the fact that the lower layers of water in Sælsø were salt.

THE EARLY AND MID-HOLOCENE DEPOSITS AT STORSTRØMMEN AND KOFOED-HANSEN BRÆ

This description covers the interior (western) part of Germania Land and northern parts of Dronning Louise Land (Fig. 1a), which for the sake of convenience are dealt with separately.

Western part of Germania Land

The roughly 25 km wide strip of Germania Land bordering Storstrømmen and Kofoed-Hansen Bræ can be divided into three zones: the easternmost and largest of hilly upland with sporadic moraine cover, a lowland inner moraine zone with extensive cover of ground moraine and south-north trending ice margin features, and closest to the ice margin and transitional to it a zone of neoglacial ice-cored moraines (Fig. 2).

The hilly eastern uplands reaching 600-800 m a.s.l. at their highest part are covered by autochthonous boulder fields or by local ice caps. The boulder fields designate the nunatak areas during the late Weichselian glaciation (LANDVIK 1994). These high surfaces are transected by fjords and deep valleys mainly with east-west or south-east/north-west trending directions. The major valleys are occupied by the lakes Annekssøen and Sælsø. The complex relief mainly shows deposition of scattered and isolated ice-marginal features along the shores of the fjords and lakes or at their heads. The occurrences of these deposits are too sparse to establish a relative morphological chronology of events and the deglaciation of the area must to some extent be regarded as a down-wasting of the ice cover rather than the corresponding recession of the ice margin through the fjords. The morphology around Annekssøen and Sælsø illustrate to some degree the lapse of deglaciation.

Annekssøen with a length of about 35 km has its present surface at 38 m a.s.l. (J. NEVE, pers. comm. 1993) but the lake level can vary by 1-2 m according to the season (KOCH 1917: 447-448). The greatest depth of the lake is 90 m (ibid., 447), i.e. well below sea level. The most prominent feature along Annekssøen is a marked terrace level with a height of 60 m a.s.l. (J. NEVE, pers. comm. 1993) and since the thresholds in both ends of the lake are lower than this height, its formation must be referred to a period of ice damming of both ends of the lake. The terrace cannot be followed beyond the south-east end of Annekssøen due to slumping of deposits along the sides of the valley connecting this lake with Sælsø.

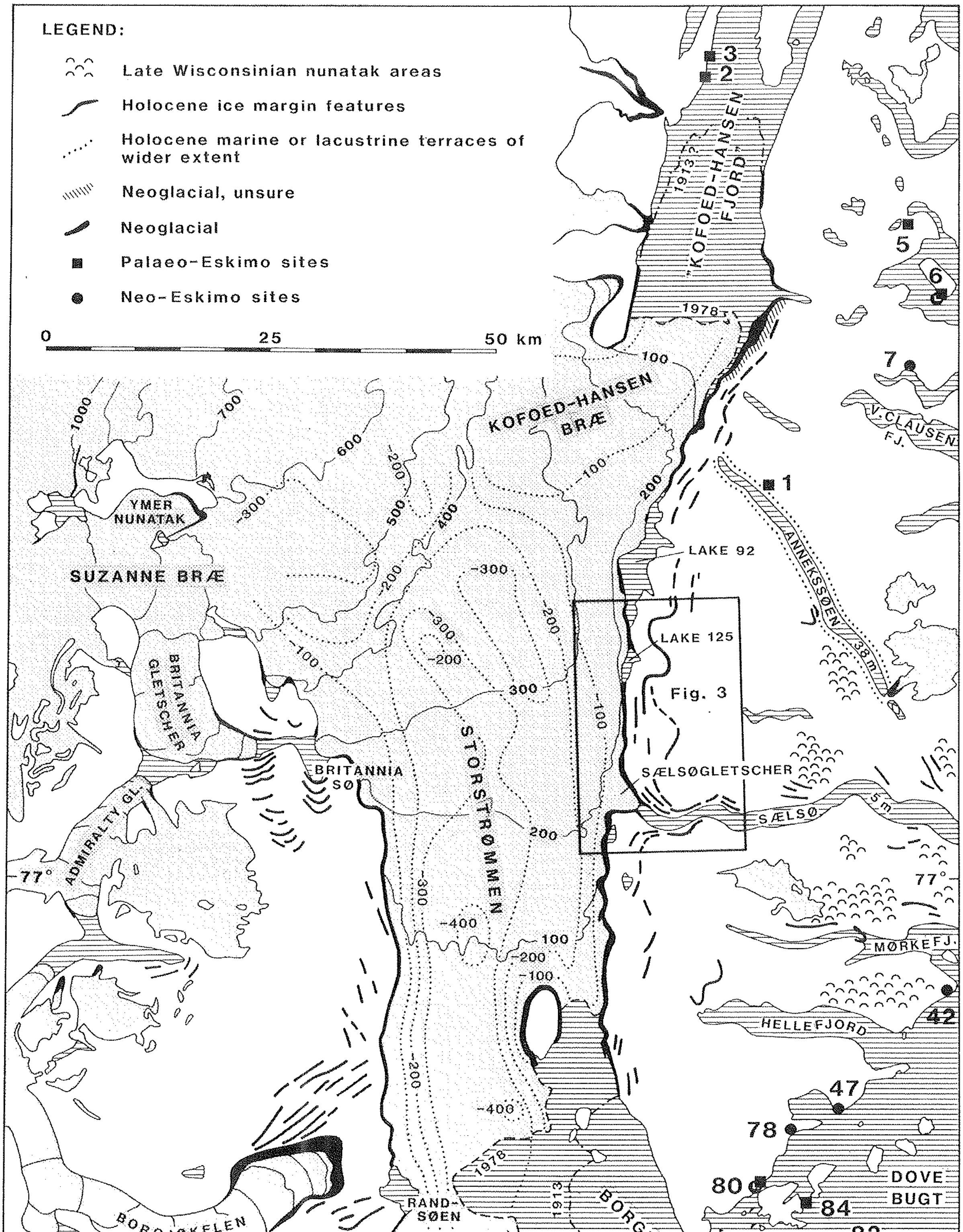
Sælsø extends 50 km from its eastern end at Hvalrosodden to its western end blocked by the present outlet from Storstrømmen, Sælsøgletscher. At times Sælsøgletscher (Fig. 3) calves into the lake which indicate substantial depth of the lake at the glacier front (Fig. 4). The lake surface is only 5 m a.s.l. and like Annekssøen, its surface height may vary 1-2 m according to the season. Soundings of the central part of the lake gave a depth of 116 m and at a depth of 60 m the water became salt, which was taken as evidence of a former connection with the sea (KOCH 1917: 445). Recessional moraine fragments border the shores of the lake but their relation to lake or marine levels can only be photogrammetrically measured at the inner part (J. NEVE, pers. comm. 1993) where the inner moraine zone (see below) is connected with fragments of alluvial plains at altitudes of 40 m a.s.l.

At the western 25 km of the lake, terraces are sparse and closely related to the present deltas. Towards the eastern end these terraces increase in frequency and height ending with the marine terraces of 42-43 m a.s.l. (local marine limit) in the Hvalrosodden area, described and dated by LANDVIK (1994).

Further south moraine fragments have been described from the central parts of Mørkefjord (KOCH 1917) and Hellefjord (LANDVIK 1994), of which the latter marks an event at 8.3 ka B.P.

The inner moraine zone is characterised by extensive coverage of ground moraine (e.g. FRIDERICHSEN et al. 1991) with numerous ridges of low marginal moraines (often only a few metres high). Major parts of the landscape are situated only 100-400 m a.s.l. and the landscape generally forms low hills sloping down to Storstrømmen.

The consistent and parallel formation of the ice margin features (Figs. 1 and 2) are in contrast to the outer zone and both features express a transition from a period of essentially down-wasting of the glacier parts in the highland to a gradual recession of an ice margin over a lowland. Possible errors in interpretation of the influence of bedrock structures running parallel to the ice margin cannot be excluded. Both north of Kofoed-Hansen Bræ



and south of Storstrømmen the moraine features of this zone (Fig. 2) do not seem to reach close to the present coast or to have connections to raised marine deposits.

The sediments of the inner zone are essentially comprised of silt, sand and gravel, and at the westernmost parts of this zone a marine origin can be concluded from the presence of shells, all having interglacial or interstadial ages (Tab. 1, Fig. 3). The interglacial or interstadial fossils of the morainal zone are collected either in silt underlying moraine or in gravelly/silty till. Shells of these ages have so far not been found in the neoglacial moraines. The occurrence of the interglacial or interstadial material seems to have an eastern analogue in the interglacial deposits of interior Germania Land north of Danmarkshavn (see Fig. la) where the original material is believed to have been redeposited by glacier erosion or fluviatile deposition during the early Holocene (LANDVIK 1994). The finite dates of the Storstrømmen material are all derived from the same locality. The first date was here Ua-3352 (33 ka B.P.), the location of which is given in Fig. 3. In order to confirm the age of the assemblage three other shells from the same locality were dated. These dates (Ua-4569, -4570 and -4571) have ages ranging from 28 to 25 ka B.P. (Tab. 1). The dates show that the ice sheet had an extent more reduced than at present during parts of the younger Weichselian. In Svalbard, 800 km east of Storstrømmen, the Kapp Ekholm interstadial (MANGERUD & SVENDSEN 1992) is also indicative of much reduced ice cover. This together with the isotopic climatic record from the ice margin of Storstrømmen (REEH et al. 1993a,b) and information from marine records (e.g. HEBBELN et al. 1994), indicate warm spells during the period between 50 and 20 ka B.P. However, in the light of the discussion on rapid temperature oscillations related to the Heinrich events (e.g. BOND et al. 1993) and the problem of exact age of finite ^{14}C-dates (HJORT 1981), the age of a „Storstrømmen interstadial" of 25 to at least 33 ka B.P. must be given with reservation.

The neoglacial ice-cored moraines (Figs. 3 and 4) are clearly discernible at most places from the zone of recessional moraines mentioned above due to their content of dead ice and fresh appearance on the aerial photographs. At places there is an intermittent zone with gradation from fresh moraines to a landscape of recessional moraines, presumably where older phases of neoglacial advances (17th or 18th century?) have surpassed the early advance of 1900 (1850-1900?). Towards the present

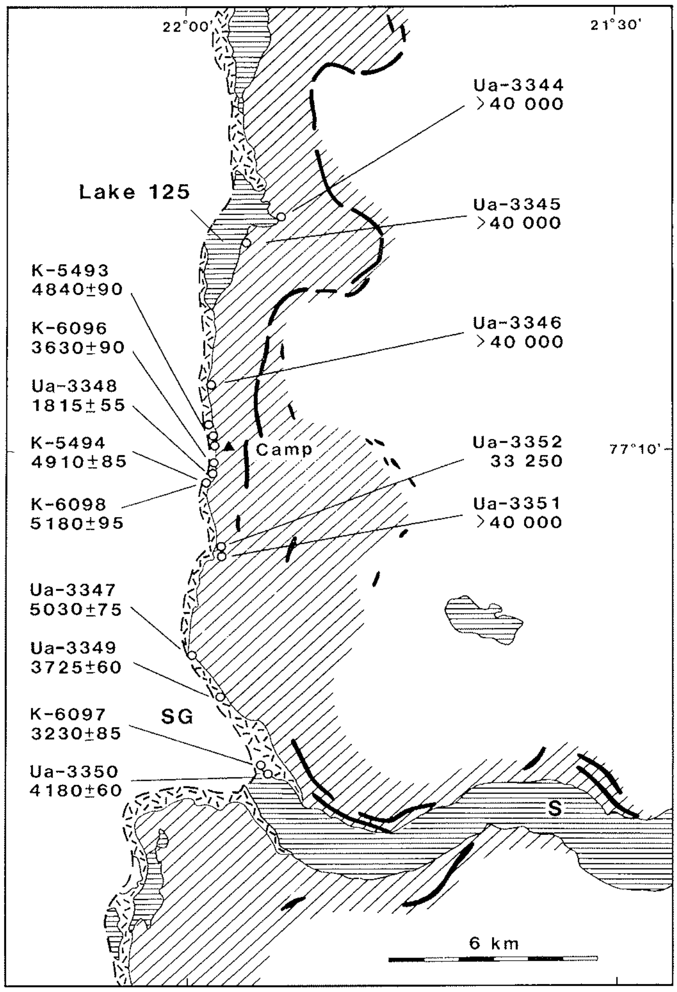


Fig. 3: Location of radiocarbon dated samples from the ice margin in central Germania Land between Lake 125 and Sælsøgletscher. Inner moraine zone (oblique hatched area). The narrow zone close to the present ice margin indicates the neoglacial moraines, often with pronounced dead ice features. Lakes shown by horizontal shading. Dates are given in radiocarbon years B.P. For location see Fig. 2., SG: Sælsøgletscher, S: Sælsø.

Abb. 3: Fundstellen von organischem Probenmaterial am Eisrand zwischen See 125 und Sælsøgletscher, das mit ^{14}C datiert wurde. Die schräge Schraffur kennzeichnet die innere Moränenzone. Der schmale Streifen unmittelbar am heutigen Eisrand stellt die neoglazialen Moränen dar, die oft noch mit ausgeprägten Toteiskörpern durchsetzt sind. Die Altersangaben sind Radiocarbonalter in Jahren vor heute. Zur Lage vgl. Abb. 2., SG: Sælsøgletscher, S: Sælsø

Fig. 2: Surroundings of Storstrømmen and Kofoed-Hansen Bræ (western Germania Land and eastern Dronning Louise Land). Boulder fields designating nunatak areas during Late Wisconsinian (LANDVIK 1994) and recessional systems close to present ice margin, preferentially designating mid Holocene recessional features. Neoglacial moraine areas around the present glaciers are shown in black. Position of archaeological sites after ANDREASEN & ELLING (1992). Surface contours (100 m interval) on the glaciers after map sheet by GGU (based on aerial photographs and aerotriangulation by KMS, Copenhagen). Subsurface contours in metres below sea level are based on measurements by GUNDESTRUP (pers. comm.) are shown for major parts of Kofoed-Hansen Bræ and Storstrømmen (dotted lines). Outlined area position of Figure 3.

Abb. 2: Umgebung von Storstrømmen und Kofoed-Hansen Bræ (westliches Germania Land und östliches Dronning Louise Land). Gekennzeichnet sind die Lage von Geröllfeldern, die Nunatakgebiete während der späten Weichseleiszeit (Wisconsin) ausweisen sowie Rückzugsstrukturen nahe dem heutigen Eisrand, die vorzugsweise Rückzugsstrukturen des mittleren Holozän zuzuordnen sind. Neoglaziale Moränengebiete in der Umgebung der heutigen Gletscher sind schwarz dargestellt. Lage von archäologischen Fundstätten nach ANDREASEN & ELLING (1992). Höhenlinien (100-m-Intervall) für vereiste Gebiete nach einem Kartenblatt von GGU, basierend auf Luftbildern und Luftbildvermessung von KMS, Kopenhagen). Höhenlinien des Gletscheruntergrundes in Metern unter Meeresspiegel, basierend auf Messungen von N. GUNDESTRUP (pers. Mitt.), sind für weite Teile des Storstrømmen und Kofoed-Hansen Bræ (gepunktete Linie) eingetragen. Das umrandete Gebiet kennzeichnet die Lage des in Abb.3 dargestellten Ausschnitts.

Lab. no	Material / Species	^{14}C age B.P.	Res. corr.	Calculated age (ka) B.P.	Calibration according to
Ua-3344	s: *Hiatella arctica*	>40 000	-		
Ua-3345	s: *Mya truncata*	>40 000	-		
Ua-3346	s: *Mya truncata*	>40 000	-		
Ua-3351	s: *Hiatella arctica*	>40 000	-		
Ua-3352	s: *Hiatella arctica*	33 250 ± 815		-	
Ua-4569	s: *Hiatella arctica*	27 905 ± 370		-	
Ua-4570	s: *Mya truncata*	26 665 ± 300		-	
Ua-4571	s: *Astarte borealis*	24 930 ± 275		-	
K-6098	s: *Mya truncata & Hiatella arctica*	5180 ± 95	5030	5.8 - 5.9	Stuiver & Pearson 1993
K-5494	s: *Mya truncata*	4910 ± 85	4760	5.5 - 5.6	Stuiver & Pearson 1993
K-5493	s: *Mya truncata*	4840 ± 90	4690	5.3 - 5.5	Stuiver & Pearson 1993
Ua-3347	s: *Hiatella arctica*	5030 ± 75	4480	5.2 - 5.5	Stuiver & Pearson 1993
Ua-3350	s: *Hiatella arctica*	4180 ± 60	3630	3.9 - 4.0	Pearson & Stuiver 1993
K-6096	b: *Balaenoptera physalus*	3630 ± 90	3480	3.7	Pearson & Stuiver 1993
Ua-3349	s: *Hiatella arctica*	3725 ± 60	3175	3.4	Pearson & Stuiver 1993
K-6097	s: *Hiatella arctica & Mya truncata*	3230 ± 85	3080	3.3	Pearson & Stuiver 1993
Ua-3348	s: *Hiatella arctica*	1815 + 55	1265	1.2 - 1.3	Stuiver & Pearson 1993

Tab. 1: Age of biogene material from the ice margin, Kofoed-Hansen Bræ and Storstrømmen; s: = shells; b: = bone.

Tab. 1: Altersbestimmungen an biogenem Material vom Kofoed-Hansen-Geltscher und Storstrømmen. s = Molluskenschalen, b = Knochen.

ice margin a gradation is frequently encountered from fresh neoglacial moraine over dead ice zones to shear moraine formation in the present ice margin (Fig. 4).

Dronning Louise Land

The west side of Storstrømmen (Dronning Louise Land) also exhibits a triple zonation into a western highland (over approximately 400 m a.s.l.), a moraine covered lowland (400-100 m a.s.l.) and, adjacent to the present glacier, an (often narrow) rim of neoglacial moraines.

The highland areas can be subdivided into several morphological units (Lister & Wyllie 1957) but in this context it is essential that the landscape is transected by several large outlets of the Inland Ice (Fig. 2) of which the northernmost ones, Borgjøkelen and Britannia Gletscher ceased to act as tributaries to the Storstrømmen glacier during the Holocene recession (Fig. 2). The plateaus over 1000 m a.s.l. are covered by local ice caps and autochthonous block fields have not been reported.

The lower zone of extensive moraine areas and ice contact features has its main extent between 400 and 100 m a.s.l. (Lister & Wyllie 1957, „low glaciated hills"). However, in contrast to the eastern side of Storstrømmen, where the recessional moraines indicate the history of a recession and thinning of this glacier, major parts of the recessional moraine systems of Dronning Louise Land (Fig. 2) relate to events in the recession of Borgjøkelen and Britannia Gletscher.

The system of marginal recessional moraines around Britannia Sø (Fig. 2) has been investigated in detail by Lister & Wyllie (1957), who distinguish six moraine stages, all of neoglacial age. Those of stages 1 to 3 were laid down in the period A.D. 300-1400; stage 4, with a large size of moraine, indicates the only marked readvance (A.D. 1650), whereas stage 5 moraines with a core of dead ice and fresh appearance are related to A.D. 1850 and stage 6 is the mapped delineation of glaciers A.D. 1954. The dating, based on varve chronology, is given with reservation. All phases indicate a total thinning of several hundred metres in a nearly continuous process.

The marginal recessional moraines between Britannia Sø and Borgjøkelen further to the south (Fig. 2) are scarce and fragmentary but indicate a gradual thinning of Storstrømmen. It is conceivable that the recessional moraines around Britannia Sø (Lister & Wyllie's stages 1-3) are a part of this recession and therefore related to the early or mid Holocene rather than to late Holocene. This would also better explain a general total thinning of the ice sheet of 300 m or more from then to now.

In this context the large system of recessional moraines around Borgjøkelen (Fig. 2) should also be considered. The moraines reach close to the present Storstrømmen ice margin near Randsøen i.e. down to estimated heights of 30-50 m a.s.l. Terrace levels up to 21 m a.s.l. at Randsøen are of lacustrine origin (Landvik 1994) and the negative evidence of marine deposits so far fits the recessional story of the eastern side of Storstrøm-

Fig. 4: Storstrømmen: front of the outlet Sælsøgletscher towards the lake Sælsø. The glacier is thinning and neoglacial moraines of the ice margin can be seen proximal to the dotted lines and their continuation. Route no. 6986 (July 28, 1950), reproduced by permission from Kort- og Matrikelstyrelsen, Danmark (A. 200/87).

Abb. 4: Front des Sælsøgletschers, der in den Sælsø abfließt. Der Gletscher dünnt aus und neoglaziale Moränen des Eisrandes sind entlang der gepunkteten Linie und ihrer Verlängerung sichtbar. Luftbild Flug Nr. 6986 (28. Juli 1950), wiedergegeben mit Erlaubnis von Kort- og Martikelstyrelsen, Dänemark (A 200/87).

men where attainment of the present situation of the glacier at 7.7 ka B.P. would be expected with a relative sea level less or equal to about 10 m a.s.l. The Borgjøkelen moraines may be witness of a period close to this level when Borgjøkelen from being a tributary to Storstrømmen was converted to the present land-based glacier lobe with a consequent slowdown in recession.

DATING OF THE HYPSITHERMAL ICE RECESSION

Biogenetic material was collected at the eastern margin of Storstrømmen at the marginal zone towards Germania Land (Fig. 3). The Holocene material occurs in the neoglacial fresh moraines with dead ice. Description of the occurrences was given by Koch & Wegener (1911: 47) in which the authors describe the shell bearing moraine and dead ice from the terrain at the margin of Kofoed-Hansen Bræ near the north-western end of Annekssøen.

The dates given here (Tab. 1) are from material on a 15 km long stretch of the central part of the ice margin of Germania Land, i.e. at the highest points (150 m at the ice divide between Kofoed-Hansen Bræ and Storstrømmen). This implies that the ages given must refer mainly to times of the existence of a „Storstrømmen Sound“, separating Germania Land from mainland Greenland. Locations of the dated samples are shown in Fig. 3 and the quoted ages are listed in Tab. 1. The quoted ages also include a correction for reservoir effect of 550 years, as recommended for the region by Hjort (1993) and Tauber & Funder (1975). The calibration of the ^{14}C ages is according to the references listed in the table. The species of the dated material are given in Tab. 1; they all represent species now living in the region. The oldest date of approximately 6 ka fits fairly well with a continued rate of recession of the ice margin of 40 km ka^{-1} from Hellefjord as given above.

The dates obtained are clustered around 6-5 ka B.P. (K-6098, K-9494, K-5493, Ua-3347), and 4-3 ka B.P. (Ua-3350, K-6096, Ua-3349, K-6097) with a single date as late as 1.2 ka B.P. (Ua-3348).

It is doubtful whether lack of datings for the intervening periods (5-4 and 3-1.2 ka B.P.) can be taken as evidence for closing of the sound by glaciers, although at least the period of 3-2 ka B.P., according to the Camp Century ice core record (Dansgaard et al. 1984, Weidick et al. 1990), was one of relatively cold spells. The occurrence of Palaeo-Eskimo sites (4-2 ka B.P.) around Kofoed-Hansen Bræ (Fig. 2) points to better hunting conditions than today, i.e. the existence of a „Storstrømmen Sound" at this period. The very young date of 1.2 ka B.P. for minimum age of existence of the sound is remarkable in the sense that it indicates a refilling of the sound by glaciers which may first have taken place during the Little Ice Age, and shows that the present glaciers of Storstrømmen and Kofoed-Hansen Bræ must be considered to be in an unstable state. In general the dates point to a long period of existence for a „Storstrømmen Sound" throughout the last part of the climatic optimum and neoglacial time. During this long period of existence considerable sedimentation and deposition of material must be expected from the reduced Storstrømmen (Suzanne Bræ) into the sound, material that with its fauna subsequently formed major parts of the neoglacial moraines of Germania Land.

RELATIVE SEA LEVELS

Dates related to former shorelines are sparse for the area. The information which has been applied for determination of the emergence trend for the central Germania Land and Storstrømmen area is given in Tab. 2. The following comments concern this information:

- Dates related to a 42 m level are given by Landvik (1994) for the area between the west end of Sælsø and Hvalrosodden in the central part of Germania Land. Oldest is a shell date of 8495±90 ^{14}C years B.P., i.e. calibrated to approximately 9.5 ka B.P. (Kromer & Becker 1993).
- The subsequent height of 28 m is related to the Hellefjord stage in the western parts of Germania Land (Fig. lb) with an age of approximately 7500 ^{14}C years B.P. (Landvik 1994), here converted to 8.3 ka B.P. (Pearson et al. 1993).
- The dating of a 5 m level is also given by Landvik (1994) from ^{14}C dates on shells from Hvalrosodden, central southern part of Germania Land. The ^{14}C age of 5270±80 years B.P. is given as 6.0-6.2 ka B.P. according to Stuiver & Becker (1993) and the 5 m level must be considered as a minimum height for this age (it could be slightly higher).
- Palaeo-Eskimo sites recorded by Andreasen & Elling (1992) from the area occur at levels varying from 20 to 2 m a.s.l.; their locations are shown in Fig. 2. In the context of related former sea level only the minimum levels are of interest. The low levels are concentrated in Penthiévre Fjord north of V. Clausen Fjord (Fig. 2, ruin sites 5-7), whereas elsewhere 8-5 m seems to be the dominant minimum level for this culture. There is no record of „drowned" Palaeo-Eskimo sites, so relative sea levels in this long archaeological period (4 to 2 ka B.P.) may be estimated to be somewhere between 5 and 0 m a.s.l., presumably moving from the upper to the lower end of this estimate during the period.
- With respect to levels below the present sea level, Andreasen & Elling (1992, 9) have one site (no. 47, Fig. 2) of a Neo-Eskimo ruin with its entrance placed on the present beach, which must be taken as evidence of periods with a relative sea level just below the present at a time of Neo-Eskimo settlement, i.e. between 0.9 and 0.1 ka B.P. Elsewhere in North-East Greenland records of drowned ruins, all of Neo-Eskimo age, are known from Peary Land at 82° N (Bennike 1987) and between Ymer Ø (73° N) and Hochstetter Forland (76° N) (Hjort 1981).

Height m a.s.l.	Correct. age B.P. (ka)	Locality	Reference
42 m	9.5	Hvalrosodden	Landvik 1994
28 m	8.3	Hellefjord	Landvik 1994
~5 m	6.0-6.2	Hvalrosodden	Landvik 1994
0-5 m ?	4-2	Pentiévre Fjord	Andreasen & Elling 1992
≤ 0 m ?	0.9-0.1	Dove Bugt	Andreasen & Elling 1992

Tab. 2: Age estimate of relative sea level around Storstrømmen.

Tab. 2: Geschätzte Alter der relativen Meeresspiegelstände im Bereich Storstrømmen.

On the basis of the information given above a trend of emergence and submergence can be shown for inner Germania Land (Fig. 5). The age of the marine limit must decrease from east to west; its age is based on Landvik's age determination. The related local emergence trends are believed to be a family of curves and the estimated emergence curve is here applied for construction of the conceptual equidistant strandline diagram in Fig. lb. The tilt of a 9.4 ka B.P. strandline measured by Landvik (1994) at Hvalrosodden fits into this concept.

The evidence gives no clear information of age and height of minimum relative sea level, since the archaeological sites so far are referred to cultural periods, not specific radio-carbon datings. Present sea level might have been reached about 3 ka B.P., decreasing to a height only a little below the present. Trends are the same as in other areas of Greenland (e.g. Weidick et al. 1992) but specific for the region are the low marine limits, low rate of early Holocene emergence and possibly low rate of neoglacial submergence.

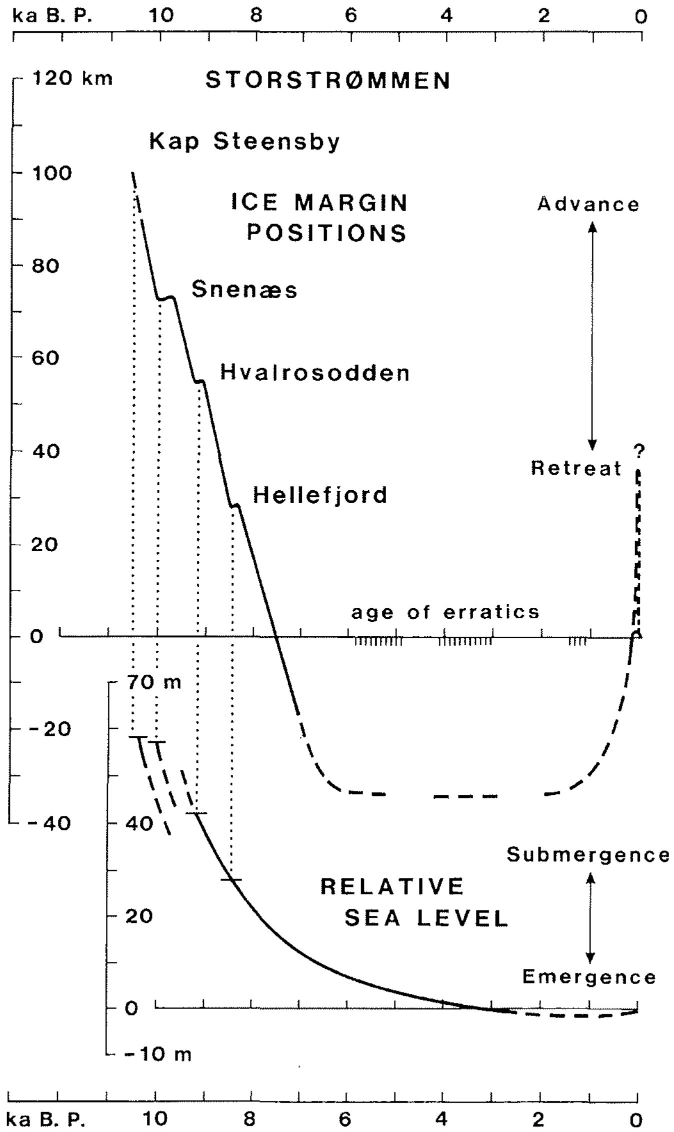


Fig. 5: Germania Land. Top: Ice marginal change in Holocene time over Germania Land and Storstrømmen. Age of erratic biogene material designating the time of the existence of a „Storstrømmen Sound". Bottom: Conceptual emergence and submergence trends of the interior part of Germania Land (Hvalrosodden to Storstrømmen), based on the data of ANDREASEN & ELLING (1992) and LANDVIK (1994).

Abb. 5: Germania Land. Oben: Veränderungen der Lage des Eisrandes während des Holozäns in Germania Land und am Storstrømmen. Alter von erratischem biogenem Material, die die Perioden, in denen der „Storstrømmen Sund" geöffnet war, bezeichnen. Unten: Hebungs- und Senkungsphasen des inneren Teils von Germania Land (von Hvalrosodden bis Storstrømmen), basierend auf Daten von ANDREASEN & ELLING (1992) sowie LANDVIK (1994).

HISTORICAL CHANGE OF ICE COVER

Although historical information only extends back to 1908 (KOCH & WEGENER 1911) the extensive description of the area from this expedition (the Denmark Expedition) and its successors: The Danish Expedition of 1912-13 (KOCH & WEGENER 1930), British North Greenland Expedition 1952-54 (HAMILTON 1958) and the glaciological investigations since 1989 by AWI and GGU/DPC have produced a wealth of information on glacier changes in the area. This data can be supplemented with information from the Danish North-East Greenland Expedition 1938-39 (KNUTH 1942) and from a series of vertical and oblique aerial photographs taken by the Geodetic Institute (now KMS, National Survey and Cadastre, Denmark) since 1950 and augmented over the last decade by satellite information.

These sources, together with mass-balance and ice-movement studies, have been used in compilation of a history of the development of the Storstrømmen front (REEH et al. 1993a,b, 1994, BØGGILD et al. 1994). It was concluded that this major drainage glacier experienced a general retreat of the front between 1913 and 1978 of 9-12 km, after which it suddenly advanced more than 10 km down the fjord between 1978 and 1984. Following this surge-like behaviour the front is again slightly retreating. For comparison the behaviour of other major outlets of the Inland Ice from Kofoed-Hansen Bræ in the north to Soranerbræen in the south are given here (Fig. 6). The information is homogenised in the sense that the approximate distance of the central part of the glacier front from a supposed glacial maximum extent is plotted for each year of observation. The following comments are given for the individual glaciers.

Kofoed-Hansen Bræ front
The maximum extent of 1907 probably does not, as indicated on contemporaneous maps, reach up to the island of Weinschenk Ø 30 km north of the 1978 position of the front (Fig. la). Neoglacial moraines along the fjord sides show a maximum extent of 25 km north of the 1978 position would be more realistic. It is likely that the floating lobe at its maximum position showed a saw-tooth appearance, such as can still be observed with its northern neighbours Zachariae Isstrøm and ''Nioghalvfjerdsbræ'' (Fig. 6) and some of the other large outlets in North Greenland (HIGGINS 1991). Subsequent recession and thinning of Kofoed-Hansen Bræ continued to at least 1989, although at a decreasing rate. The very fast initial rate of recession must be due to fast dispersion of a floating front, followed by the present well defined front. In spite of its size the glacier must be considered an overspill of Storstrømmen over a subglacial threshold situated 20 km behind the present front (Fig. 2).

Kofoed-Hansen Bræ, western and eastern flanks
Pronounced trimline zones and the fresh appearance of the surface of the nunataks closest to the western flank and front may indicate strong thinning of the glacier lobe in this century but there is no documentation of the recessional history of this area.

On the eastern side of the glacier (Germania Land) the recession had taken place prior to 1960, but then turned to advance. Profiles over the ice margin show an increase in thickness and advance (very slow over land, fast over the ice-dammed „Lake 92") since the 1960s.

Storstrømmen, front
Fig. 7 indicates the gradual recession in the first half of the 20th century and the subsequent surge-like advance from 1978-84 (REEH et al. 1994) at two points of the front. The curve of the old position of the front (1913) is based mainly on the description and mapping of KOCH & WEGENER (1930). However, in the

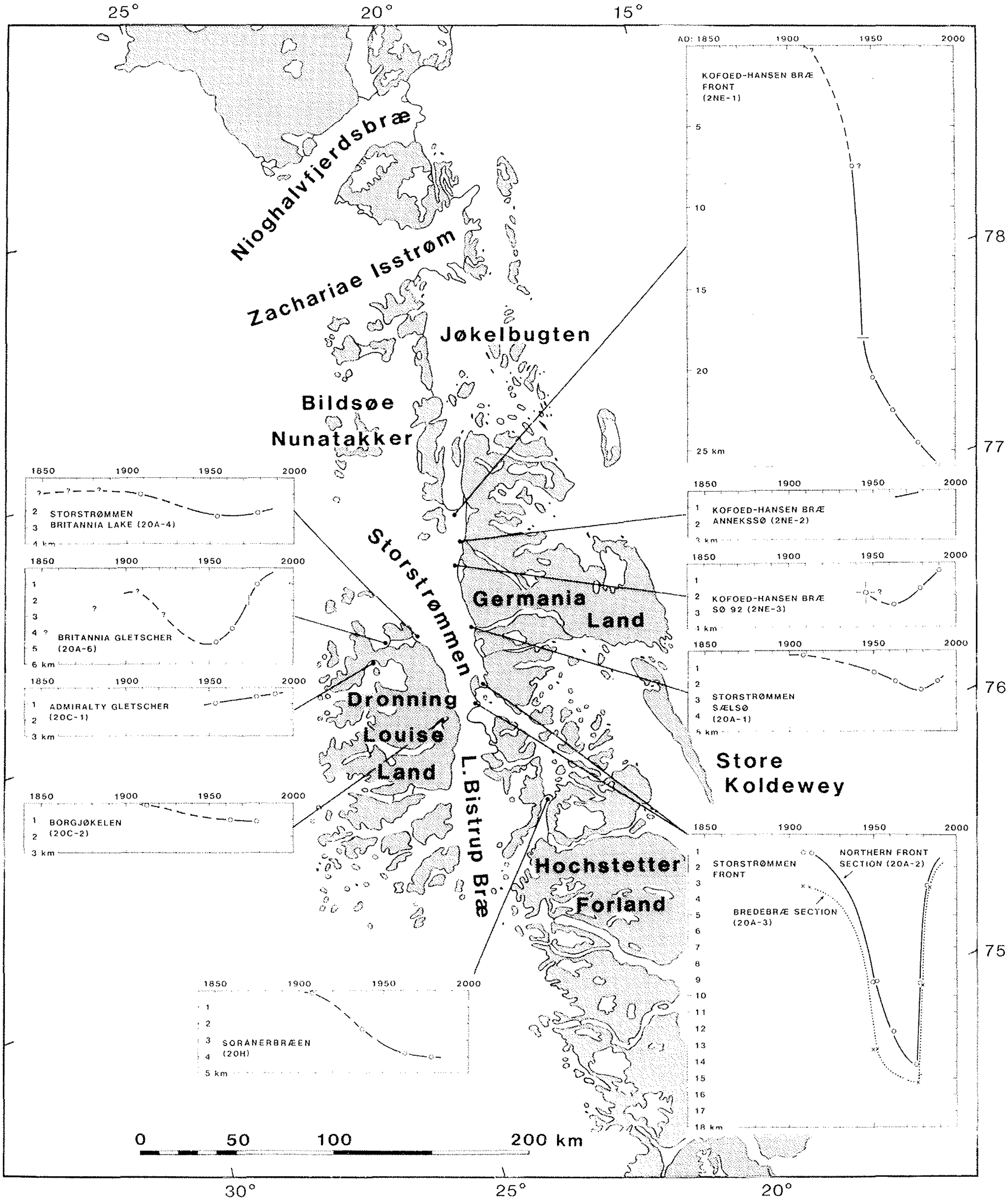


Fig. 6: Fluctuation of glacier margins and -fronts around Storstrømmen this century. Downward trend: recession; upward trend: advance. Units in kilometres.

Abb. 6: Veränderungen der Lage des Eisrandes und der Gletscherfront mehrerer Gletscher in der Umgebung des Storstrømmen während des 20. Jahrhunderts. Fallend = Rückzug, steigend = Vorstoß, Einheiten in Kilometern.

same treatise (Fig. 3, 27) the glacier front is given at Kap Stop, i.e. 10 km south-east of the position otherwise given and shown here in Fig. 2. This illustration might show a detached part of the front proper.

Storstrømmen, eastern flank

Sælsøgletscher, an outlet from Storstrømmen to lake Sælsø, can be found in continuation of the eastern margin of Kofoed-Hansen Bræ (Fig. 6). The oldest descriptions and photographs from 1908 (Koch & Wegener 1911, Figs 13-16) show that the glacier was still advancing. The subsequent thinning and recession continued to around 1980, but as late as 1978 the front was still receding whereas the glacier surface 4 km behind the front was growing in thickness.

Storstrømmen, western flank (Dronning Louise Land)

In spite of repeated visits to the lower parts of Storstrømmen glacier around Randsøen, little is known about the marginal

Fig. 7: Dronning Louise Land, seen from north-west. Foreground left: Britannia Gletscher, and to the right: Admiralty Gletscher. Admiralty Gletscher is under advance (steep front) whereas Britannia Gletscher at the time (1950) is thinning and receding. The surrounding zone of dead ice and neoglacial moraines at its front might therefore be from the (middle?) of the 19th century. A subsequent readvance of Britannia Gletscher has now transformed the clay plain between Britannia Gletscher and Admiralty Gletscher to an ice dammed lake. Route 656 E no. 2807 (August 15, 1950), reproduced by permission from Kort- og Matrikelstyrelsen, Danmark (A. 200/87).

Abb. 7: Dronning Louise Land, von Nordwesten aus gesehen. Im Vordergrund links der Britannia Gletscher und rechts davon der Admiralty Gletscher. Der Admiralty Gletscher befindet sich im Vorstoß (steile Front) während der Britannia Gletscher zu diesem Zeitpunkt noch ausdünnt und sich zurückzieht. Das Gebiet mit Toteis und neoglazialen Moränen vor seiner Gletscherfront könnte deshalb aus dem 19. Jahrhundert (Mitte 19. Jh. ?) stammen. Ein neuerlicher Vorstoß des Britannia Gletschers hat mittlerweile die lehmige Ebene zwischen Britannia Gletscher und Admiralty Gletscher in einen eisgestauten See verwandelt. Luftbild Flug 656 E no. 2807 (15. August 1950), wiedergegeben mit Erlaubnis von Kort- og Martikelstyrelsen, Dänemark (A.200/87).

changes in this area. The ice margin is surrounded by a narrow trimline zone and for the period 1963 to 1978 local signs of expansion of the ice can be observed. About 50 km northeast of the front Storstrømmen forms an unnamed outlet into the lake of Britannia Sø (surface elevation 238 m a.s.l). Observations reach back to 1908 and suggest here a thinning and slight recession to 1960 followed by stability and local minor readvance. Comparative photographs of the front in 1908 and 1953 are given by LISTER (1958).

Britannia Gletscher and Admiralty Gletscher

LISTER & WYLLIE (1957) stated that during the period of observation (1952-54) Britannia Gletscher (Figs 7 and 8) was in a state of recession and thinning after a preceding advance (at A.D. 1850?), whereas the neighbouring Admiralty Gletscher was slowly advancing. Since then Britannia Gletscher advanced nearly 4 km into Britannia Sø and at the same time transformed the earlier clay plain between Britannia and Admiralty Gletscher into an ice dammed lake which in 1978 had a surface height of 326 m a.s.l.

Borgjøkelen and Soranerbræen

Both glaciers show continued recession throughout the 20th century although at a decreasing rate during recent decades. The intervening L. Bistrup Bræ, which is also covered by the same photographic sources of information as these outlets, show the same frontal variations as those recorded for Storstrømmen. These variations might be influenced by the dynamics of this glacier, and the very thin or absent trimline zone around L. Bistrup Bræ might be interpreted as an expression of an otherwise stable glacier tongue.

As a generalisation the early and continuous advance of Admiralty Gletscher (initiated prior to 1950), and the reversals to an advance initiated in upper Kofoed-Hansen Bræ in the 1960s, and at Sælsøgletscher and the frontal areas of Storstrømmen in the 1970s, could imply a dynamic development connected to the surge behaviour described by Reeh et al. (1993a, b). The distance from Lake 92 beside Kofoed-Hansen Bræ (Fig. 2) to the front of Storstrømmen is 50 km, implying an average movement of this reversal of 2 km a^{-1}.

The outlets from the Inland Ice surrounding this system are Kofoed-Hansen Bræ in the north and Borgjøkelen and Soranerbræen in the south. Although with different amplitudes, these glaciers indicate a recessive trend throughout the 20th century. Here as elsewhere in Greenland (WEIDICK et al. 1992) the local glaciers and ice caps must have been reduced to their present size very early in the Holocene; in Germania Land this is witnessed by the occurrence of recessional moraines from the ice sheet close to present ice caps. The maximum size of these glaciers in the late Holocene was apparently first reached in the latest parts of the Little Ice Age. Extensive trimline zones and moraine systems surround the lower reaches of many glacier lobes, especially in the region south of Germania Land and Dove Bugt. The best documented information exists for Søgletscher, a lobe of a local ice cap extending down to the south-eastern corner of Annekssøen. It was first described in March 1908

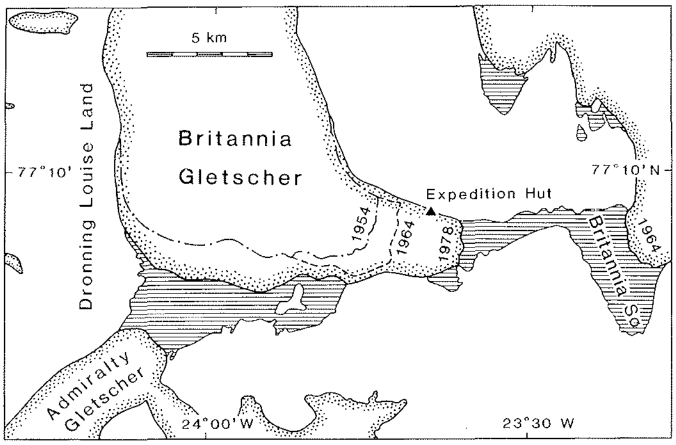


Fig. 8: Fluctuations of the Britannia Gletscher in western end of Britannia Sø, determined from aerial photographs by the National Survey and Cadastre.

Abb. 8: Veränderungen der Gletscherfront des Britannia Gletschers am westlichen Ende des Britannia Sø, bestimmt aus Luftbildern von Kort- og Martikelstyrelsen, Dänemark.

(KOCH & WEGENER 1911: 52-53) when its tongue ended 30 m above lake level (i.e. 70 m a.s.l. and close to the outer part of the present trimline zone). The recession since then is estimated as 0.8 km, with a front at about 200 m a.s.l. in early August 1978.

CONCLUDING REMARKS

The early Holocene deglaciation of Germania Land was initiated at 10.5 ka B.P. (LANDVIK 1994) and a rate of recession of approximately 40 m a^{-1} continued until the opening of a sound („Storstrømmen Sound") separating Germania Land from mainland Greenland.

During this recession a position of the ice margin corresponding to the present was reached at Storstrømmen and Kofoed-Hansen Bræ about 7.5 ka B.P. Based on the determination of the subglacial topography of the present Storstrømmen (Fig. 2) it is presumed that the glacier at the end of this recession, at 6.8 ka B.P., became grounded on a threshold on the west side of the sound and that the front was presumably located near this position during the following millennia.

The dates of the marine material of along „Storstrømmen Sound" taken from the neoglacial moraines on Germania Land, are clustered around the periods of 6-5 and 4-3 ka B.P. This could indicate several closures of the sound after the climatic optimum, and at least the period of 3-2 ka B.P. is known to be one of relatively cold spells according to the Camp Century ice core climatic record (DANSGAARD et al. 1984). However, the single young date of 1.2 ka B.P. indicates that the sound was open under climatic conditions close to these of the present and that the glacier filling of the sound first took place during the Little Ice Age. In this context the occurrence of Palaeo-Eskimo sites in the inner part of Jøkelbugten (ANDREASEN & ELLING 1992) at Kofoed-Hansen Bræ (Fig. 2) points to a less extensive ice cover of the area than now, i.e. a continuous existence of the sound in the period of 6-1 ka B.P. By contrast the occurrence of Neo-Eskimo sites in the outer and central parts of the region must be accounted for by the presence of glacial conditions like those of today, in an estimated period of 0.8-0.1 ka B.P.

This evidence indicates that the presence of the Storstrømmen/Kofoed-Hansen glacier complex is marginal under present climatic conditions. Hence, the glacier lobes must be close to a total break down and re-establishment of „Storstrømmen Sound" could be initiated at any time. The present surge-like behaviour of Storstrømmen glacier may be related to such unstable conditions. Furthermore the historic information of glacier changes this century point to a kind of kinematic wave which from the 1950s (upper reaches of the glacier system) to the 1970s (frontal parts of the Storstrømmen) gradually reversed a preceding period of recession.

Older neoglacial moraine terrain occurs locally at the present ice margin and may point to earlier advances in the Little Ice Age. According to modelling by HUYBRECHTS (1994), this area is situated in a zone of Greenland that has been thinning over the last 200 years. The concept generally holds true in the areas surrounding Storstrømmen (occurrence of wide trimline zones or fresh moraine areas) around the Inland Ice outlets. The dynamic instability of the ice margin in the Storstrømmen glacier complex seems to be a superimposed response pattern which veils the long-term trend of glacier response.

The glacio-isostatic effects of the change in glacier load during the Holocene deglaciation and reglaciation can only partly be determined from the results of geological (LANDVIK 1994) and archaeological (ANDREASEN & ELLING 1992) research. With some reservations in respect of the detailed trends, it can be concluded that the early Holocene emergence attained present sea level at about 3 ka B.P., and that submergence must have prevailed for the last millennium. The isostatic response of the area, both with regard to height of emergence (and possibly also subsequent submergence), has a relatively low amplitude. This must be connected both to the relatively small width of deglaciated land and to the wide possibilities for drainage to the sea during the Holocene deglaciation.

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