GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT Nr. 87

The Geological Survey of Greenland
Report No. 87

Project Westmar
A shallow marine geophysical survey on the West Greenland continental shelf

by

C. P. Brett and E. F. K. Zarudzki

KØBENHAVN 1979

Grønlands Geologiske Undersøgelse
(The Geological Survey of Greenland)
Øster Voldgade 10, DK-1350 Copenhagen K

Reports

No. 68 Estimates on the mass balance changes of the Inland Ice since Wisconsin-Weichsel. 1975 *by* A. Weidick. D.kr. 12.00
No. 69 Results of geological and geophysical work in central West Greenland in 1972. 1975. D.kr. 20.00
No. 70 Quaternary geology of the area between Frederikshåbs Isblink and Ameralik. 1975 *by* A. Weidick. D.kr. 12.00
No. 71 Mineralogy and geochemistry of two Amîtsoq gneisses from the Godthåb region, West Greenland. 1975 *by* B. Mason. D.kr. 6.00
No. 72 Tension structures related to gliding tectonics in the Caledonian superstructure of Canning Land and Wegener Halvø, central East Greeenland. 1976 *by* R. Caby. D.kr. 14.00
No. 73 Second progress report on the geology of the Fiskenæsset region, South-West Greenland. 1976. D.kr. 45.00
No. 74 Igneous stratigraphy of Archaean anorthosite at Majorqap qâva, near Fiskenæsset, South-West Greenland. 1975 *by* J. S. Myers. D.kr. 12.00
No. 75 Report of activities, 1974. 1975. D.kr. 38.00
No. 76 Radiometric survey between Scoresby Sund and Hold with Hope, central East Greenland. 1976 *by* B. Leth Nielsen & L. Løvborg. D.kr. 21.00
No. 77 West Greenland coal deposits, distribution and petrography. 1976. *by* E. J. Schiener. D.kr. 12.00
No. 78 Late Precambrian acritarchs from the Eleonore Bay Group and Tillite Group in East Greenland. A preliminary report. 1976 *by* G. Vidal. D.kr. 10.00
No. 79 Results of geological work in central West Greenland in 1973–1974. 1977. D.kr. 27.00
No. 80 Report of activities, 1975. 1976. D.kr. 45.00
No. 81 Volcanic geology of native iron bearing rocks from west Disko, central West Greenland. 1977. D.kr. 56.00
No. 82 Cambrian-Silurian stratigraphy of Børglum Elv, Peary Land, eastern North Greenland. 1977 *by* R. L. Christie & J. S. Peel. D.kr. 24.00
No. 83 Precambrian and Tertiary geology between Kangerdlugssuaq and Angmagssalik, East Greenland. A preliminary report. 1978 *by* D. Bridgwater *et al.* D.kr. 14.00
No. 84 The migmatites, granites and metasediments of Danmark Ø and adjacent areas of Milne Land and Gåseland, East Greenland Caledonian fold belt. 1979 *by* K. Bucher-Nurminen.
No. 85 Report of activities, 1976. 1977 D.kr. 40.00
No. 86 The Quaternary geology of the Narssaq area, South Greenland. 1979 *by* S. Funder. D. kr. 22.00
No. 87 Project Westmar – A shallow marine geophysical survey on the West Greenland continental shelf. 1979 *by* C. P. Brett & E. F. K. Zarudski.
No. 88 Report on the 1978 geological expedition to the Peary Land region, North Greenland. 1979.
No. 89 Nagssugtoqidian geology. 1979.
No. 90 Report of activities, 1977. 1978. D.kr. 70.00

GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT Nr. 87

Project Westmar
A shallow marine geophysical survey on the West Greenland continental shelf

by

C. P. Brett and E. F. K. Zarudzki

1979

Abstract

An extensive shallow geophysical survey has been carried out on the West Greenland continental shelf between 64° and 69°30′N. Preliminary interpretation of the data reveals that between 64° and 67°30′N at least, the entire shelf was glaciated to its western margin during the Pleistocene, the glaciation processes leaving a variable (< 20–200 m thick) cover on the Tertiary sedimentary wedge underlying the shelf. A morphological relationship exists between the degree of sea floor roughness and the types of glaciation forms. The distribution and contacts of the three main shallow bedrock units in the area (Precambrian gneisses, Lower Tertiary volcanics and Tertiary sediments) are delineated. Widespread prograding is observed in sediments along the shelf margin. Extensive iceberg scouring of the sea floor is observed north of 67°30′N reaching a maximum water depth of 340 m.

CONTENTS

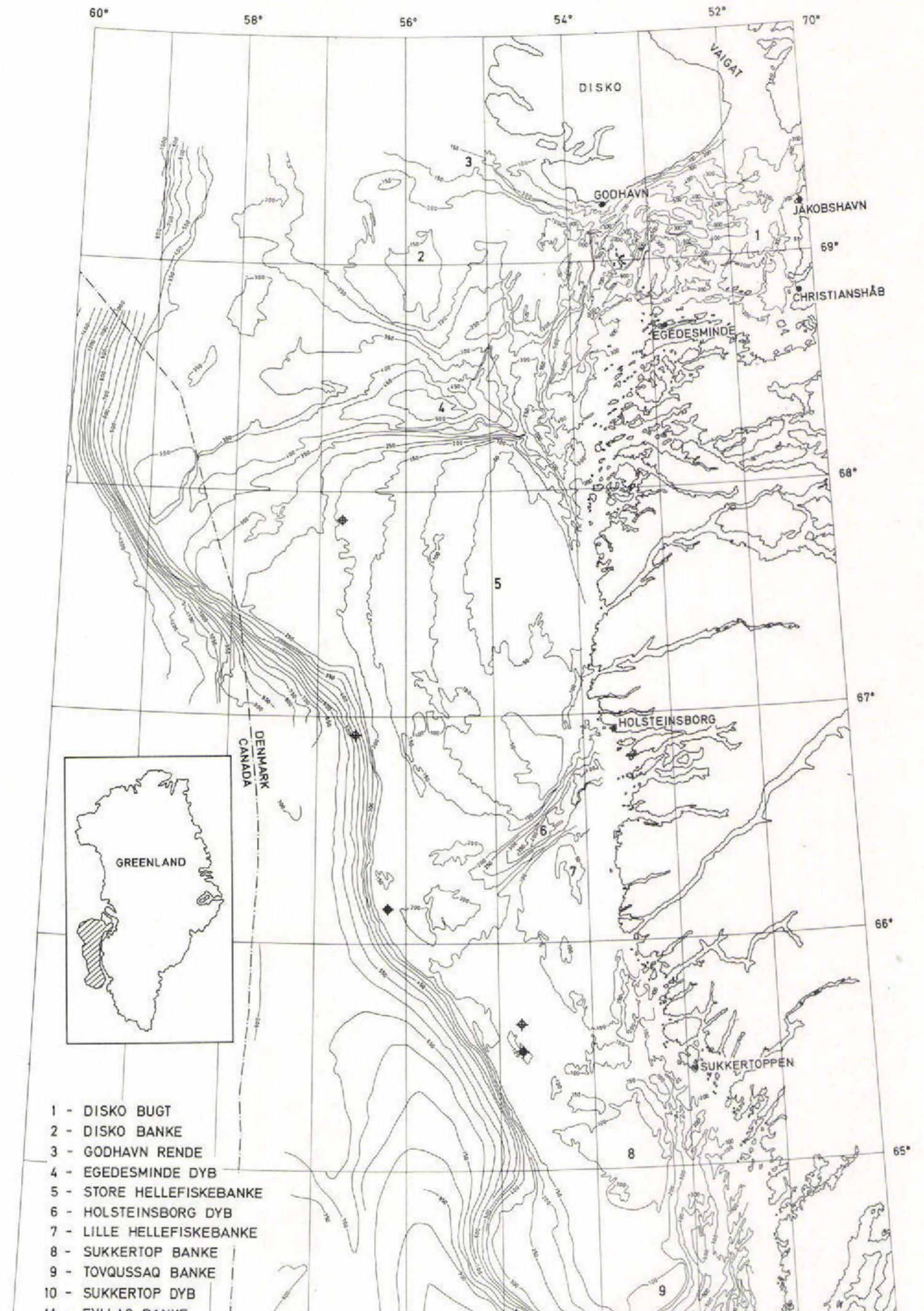


Fig. 1. The West Greenland continental shelf in the region 64°–70°N.

INTRODUCTION

Since 1962 several marine geophysical surveys of a purely scientific character have been undertaken on the West Greenland shelf area by foreign research institutes (Rvachev, 1964; Keen *et al.,* 1972; Ross & Henderson, 1973; Grant, 1975; Falconer, 1977) and by GGU in and north of Disko Bugt (Denham, 1974). However, a far greater amount of work, with more comprehensive cover has been done for oil companies in connection with hydrocarbon exploration, particularly deep seismic surveys in the region 64°–70°N. The continuing exploration activity off West Greenland demanded that supervisory or other generally involved authorities obtain a more thorough knowledge of the existing geological and geotechnical conditions of larger and more continuous shelf areas.

With these considerations as a background GGU prepared a proposal for shallow marine geological investigations of the shelf area between 64° and 69°30′N. This proposal was accepted by the Danish Ministry for Commerce and financed as Project Westmar under their energy-related research programme. This initial report on the project covers the 1978 geophysical survey together with a preliminary interpretation of the data obtained.

PHYSIOGRAPHIC SETTING

The location and bathymetric features of the survey area are shown in fig. 1. The topography, with the exception of Disko Bugt, was derived from the GGU series of bathymetric maps reported by Henderson (1975) who also discussed the physiography of the West Greenland shelf. The bathymetry of Disko Bugt was obtained by interpretative re-contouring of marine charts 1500, 1511, 1512 and 1513, published by the Royal Danish Hydrographic Office.

The morphology of the shelf in the survey area is deceptively simple. A broad, gently westward dipping platform of the shallow banks extends from near the coastline to the shelf-break. The greatest width of 230 km occurs just north of 68°N, and the shelf narrows southward to 85 km off Godthåb. The shelf-break occurs at a greatest depth of 400 m at 69°N, shallowing to 200 m at 64°N; it forms three lobate convexities within the survey area. Large areas of the banks lie in depths less than 50 m, but they are separated from the mainland by a chain of depressions which reach 600 m depths and run parallel to the coast. Holtedahl (1970) collectively calls them a 'marginal channel'. The shelf is divided into individual banks by a series of deep transverse channels, three of which occur in the survey area. By far the largest of them exits westward from Disko Bugt and is referred to in this report as Egedesminde Dyb*. These channels are most likely a final product of the Quaternary glaciation of the banks and display the main characteristics of glacial valleys. Between the coast and 'marginal channel' lies an area of very rugged topography – the 'strandflat' (Holtedahl, 1970; Henderson, 1975). Disko Bugt has the most rugged sea floor in the whole area and is also traversed by a branching system of deep (up to 990 m) valleys, incised by large southwestward flowing glaciers.

THE SURVEY

The survey was carried out by GGU personnel during June and July 1978, aboard the vessel M/V *Dana* (under charter to GGU) using a multi-systems approach. A track spacing of 20 km was adopted, which called for a planned total coverage of 8 000 line km in a survey area of approximately 100 000 km^2.

The primary survey systems used were:

(a) A single channel analogue sparker seismic system. The maximum power available was 8 kJ at a firing interval of 2 sec., but over the banks the system was generally used at 3.5 kJ with a firing interval of 1 sec. Recording was made on a dry paper facsimile recorder, usually at a sweep rate of 0.5 sec.

(b) A deep-tow dual-channel side-scan sonar system (100 kHz) combined with a sub-bottom profiler (10 kW, 1.5–3.5 kHz) in the same tow fish. The length of tow cable available (600 m) gave a maximum tow depth of approximately 180 m at normal survey speed (5 knots). The winch (with a slip-ring assembly) was operated remotely from the laboratory allowing the tow fish depth to be adjusted without interrupting data acquisition. Recording was made on a digital three-channel dry paper facsimile recorder displaying either side-scan or sub-bottom data, or both simultaneously.

(c) A proton precession marine magnetometer (1 gamma sensitivity) with a strip chart recorder and a digital display which was noted manually at five-minute intervals. The magnetometer recording cycle was triggered externally by the same pulse that fired the sparker. This ensured that the magnetometer sensor was being polarised at the time the sparker was fired, thus eliminating interference between the two systems.

(d) A 50 kHz precision depth sounder, with wet paper strip recorder, the water depth being noted manually at five-minute intervals.

The normal mode of operation was continuous survey with all of the above systems with the exception of the side-scan sonar. The latter was deployed as continuously as possible within the water depth limitations imposed by the tow cable length, and the restrictions imposed by the extremely rugged, and not well charted, topography of the inner shelf area, which normally prevented towing the fish near the sea bed.

In addition to the above systems two secondary (back-up) seismic systems were carried:

(a) A completely independent shallow sub-tow boomer system with a maximum power of 500 J at a firing interval of 0.5 sec. The power modules and facsimile recorder were identical

* This deep channel is not officially named, but following the trend of naming the deeps after the nearest major town, Egedesminde Dyb is adopted throughout this report.

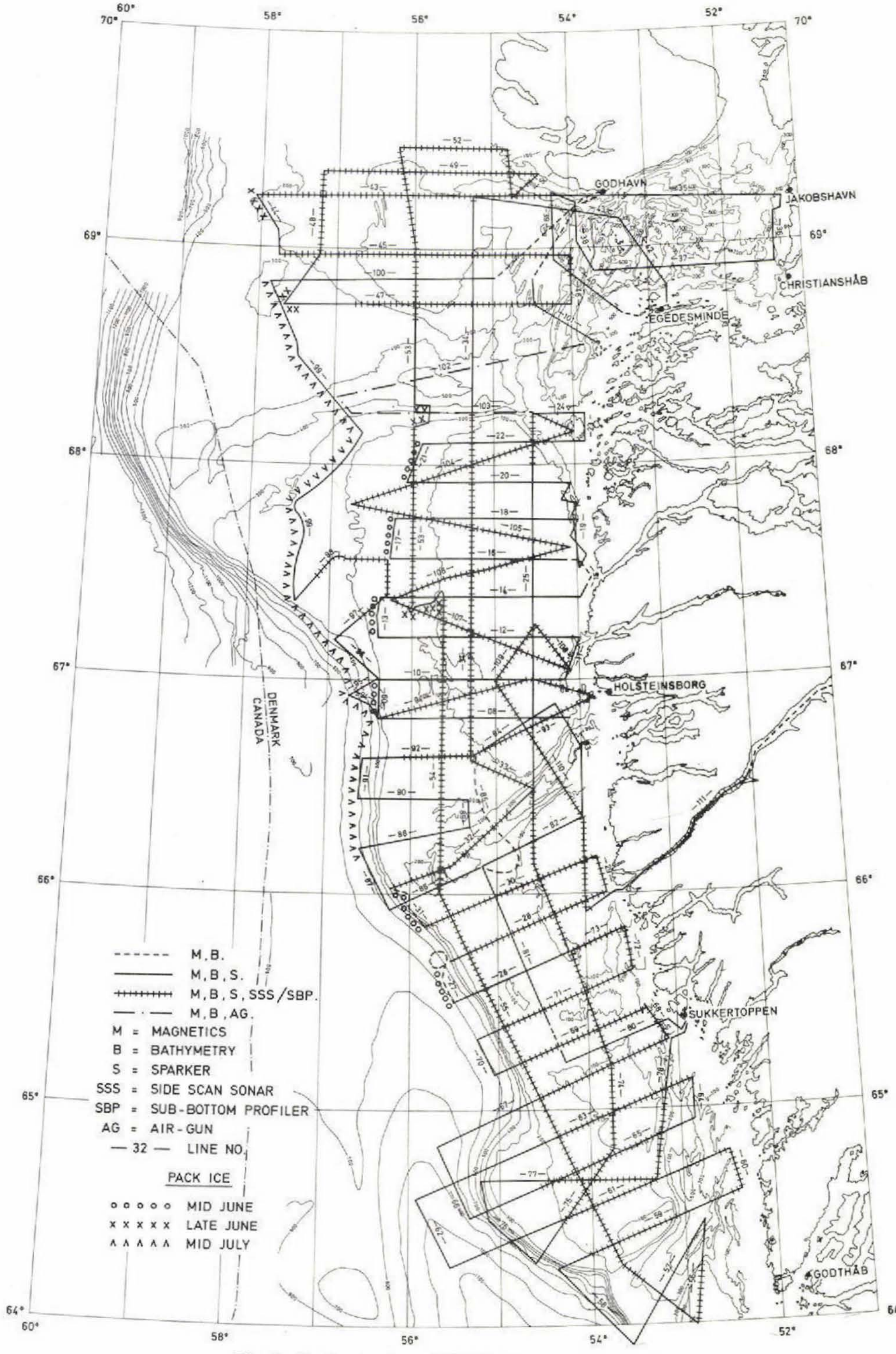


Fig. 2. Cruise track and distribution of data types.

to those in the sparker system. The boomer was not used in conjunction with the primary systems since it interfered seriously with the sparker whilst giving no significant improvement on the data acquired by the sparker/sub-bottom profiler combination. However, the power modules were used as plug-in spares for the sparker system, thus minimising its down time. The recorder was usually incorporated in the sparker system resulting in dual recording at different filter setting and/or sweep speed.

(b) A small (up to 40 in^3) air-gun system foreseen as a deep-water alternative seismic source to the sparker, but using the same recording system. The air-gun was used on two profiles; along both the axis and the southern margin of Egedesminde Dyb.

Further details of the survey systems are given in Appendix 1.

Continuous accurate position fixing was achieved using a fully integrated navigation system incorporating a dual-channel satellite navigator, doppler sonar velocity log and gyro compass. The doppler sonar was equipped with a thermistor for measurement of water temperature and an inclinometer enabling the central computer to correct the doppler information for the variation of sound velocity in water and for the pitch/roll of the vessel, respectively. The gyro compass had an incorporated auto-torquing facility, that is, the computer controlled, automatically, the corrections applied to the gyro compass to compensate for latitude, velocity north, acceleration and velocity east. These features, together with the frequency of satellite passes at our working latitudes (generally less than one hour between good updated satellite fixes) resulted in a continuous positional accuracy well within 100 m, with the doppler sonar in bottom-track mode. Bottom-track was achieved down to a maximum water depth of 510 m in calm weather before the doppler sonar switched to water track resulting in greater positional inaccuracy. On a few occasions, notably in very calm conditions, the doppler sonar was unable to water-track, presumably due to the clarity of the water off West Greenland and in such situations manual speed input had to be used. The co-ordinates of start and end points of each line were input to the system which then computed the track to be steered, distance along track, distance to end of track and deviation from the track as the survey proceeded. This information together with position and

Table 1. Summary statistics

A total of 39.5 days in the period 9th June – 28th July1978, were spent at sea surveying with the following data obtained:

System	*Time operating hours*	*Distance covered km*
Sparker	854	7 880
Magnetic	922	8 454
Bathymetry	925	8 474
Side-scan sonar	420	3 894
Sub-bottom profiler	270	2 530
Air-gun	28	271
Boomer	9	80

speed was continuosly relayed to the bridge by a remote video display enabling the helmsman to make the necessary adjustments to maintain the desired track. The ship's track was continuously recorded on a simple incremental plotter. At five-minute intervals all navigation data were logged on a twin magnetic tape cassette unit and the system supplied a simultaneous event mark to all the survey recorders. Further details of the navigation system are given in Appendix 2.

The survey was carried out largely as planned but with some modifications enforced by the continued presence of 'West Ice' in the area after an unusually late onset of Spring. As shown on the track-chart (fig. 2) this prevented the ship entering the extreme northwest of the area in which it had been intended to run reconnaissance lines at a 40 km spacing. However, the time thus saved was spent profitably by increasing the coverage (particularly side-scan sonar) over Store Hellefiskebanke. Cruise statistics regarding the data obtained are summarised in Table 1.

The weather was generally good throughout the survey, with 82 per cent of the data being collected in sea state 3 or lower, resulting in a high record quality. However, very poor weather on the passage to Greenland and on arrival in the area delayed the start of the survey by six days. Two more days were lost to weather during the survey.

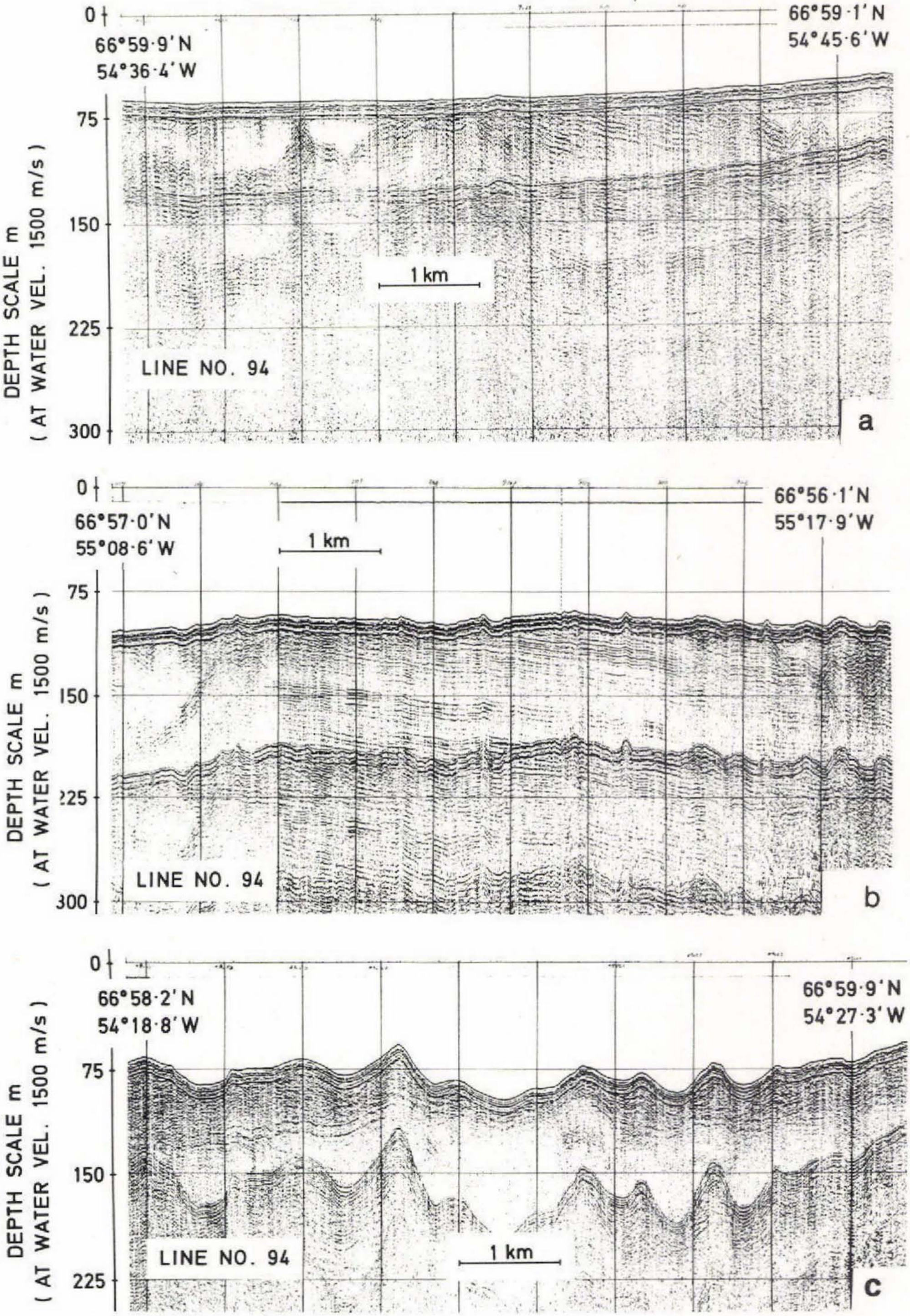
PRELIMINARY INTERPRETATION

The interpretation presented here was largely carried out aboard ship as the survey proceeded, and on revision has received only minor alterations. Three general aspects of the area are considered here:

(a) Sea floor types
(b) Shallow bedrock units
(c) Iceberg scouring

Discussions of topics (a) and (b) are largely based on the sparker seismic data. Due to the uncertainties resulting from large diurnal variation and frequent magnetic storms, the magnetic data have not been used except as a check on the basalt–gneiss boundary (discussed later), which was not always clear on the sparker records. The magnetic data will be corrected subsequently and incorporated in future work.

Whilst the side-scan sonar and sub-bottom profiler data can contribute greatly to a detailed understanding of the surface geology of the banks, this data has not been used extensively in the preliminary interpretation. Again, it will be incorporated in future work to fill in the details which may not be apparent on the sparker records. The one exception to this is the topic (c),i.e. iceberg scouring, which, as one of the most striking features of the side-scan sonar records, is discussed below.



DEPTH SCALE m
(AT WATER VEL. 1500 m/s)
0
75
150
225
300
66°59·9'N
54°36·4'W
66°59·1'N
54°45·6'W
1 km
LINE NO. 94
a
DEPTH SCALE m
(AT WATER VEL. 1500 m/s)
0
75
150
225
300
66°57·0'N
55°08·6'W
66°56·1'N
55°17·9'W
1 km
LINE NO. 94
b
DEPTH SCALE m
(AT WATER VEL. 1500 m/s)
0
75
150
225
66°58·2'N
54°18·8'W
66°59·9'N
54°27·3'W
1 km
LINE NO. 94
c

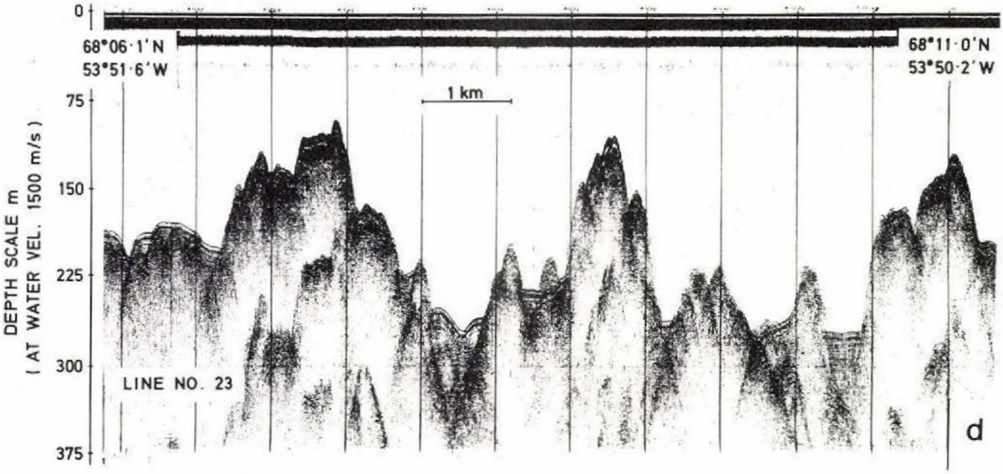


Fig. 3. Sparker record examples of sea-bed roughness types: (a) Very smooth, (b) Smooth, (c) Rough, (d) Very rough.

(a) Sea floor types

From analysis of the sparker records the degree of surface roughness of the sea floor has been used to define four sea floor types: very smooth, smooth, rough and very rough.

Three parts of line 94 (for location, see fig. 2) have been chosen to illustrate the types of sea floor over the banks and their relation to physiography and surface geology.

The very smooth surface (fig. 3a) is associated with an overall smoothing effect of sea currents, tides and waves acting on parts of the banks lying above the 100 m isobath (as shown here), with sediment ponding in depressions over the banks and with undisturbed sediments of the continental slope. The small and rare surface irregularities range from 1 to 5 m in height.

The smooth bottom type (fig. 3b) includes broader, undulating physiographic features such as ridges, swells, hummocks etc., whose low relief may be further subdued by infilling with fine, unconsolidated sediments transported by the winnowing action of currents, tides and waves. The relative relief rarely exceeds 20 m.

The rough sea floor type (fig. 3c) is usually associated with one of the many morainic forms found over the banks. Some frontal or push moraines exceed 100 m in height but, more commonly, the net build up is in the region of 20–80 m. The disintegration and ground moraines also fall into this same general category, though their relief tends towards lower values. This rough type of sea floor occurs over about 20 per cent of the banks. A similar degree of roughness exists on eastern Disko Banke. However, this is not due to morainic material but to ridges of hard rock, mainly volcanics, underlying and distorting thin Quaternary sediments.

The very rough sea floor (fig. 3d) is principally found in regions where the Precambrian rocks, heavily glaciated, outcrop or form the entire sea floor. This occurs in a narrow belt parallel to the coastline and throughout Disko Bugt.

A characteristic sparker profile over both a terminal and a disintegration moraine is shown, together with its interpretation in fig. 4. The example of the former (to left of

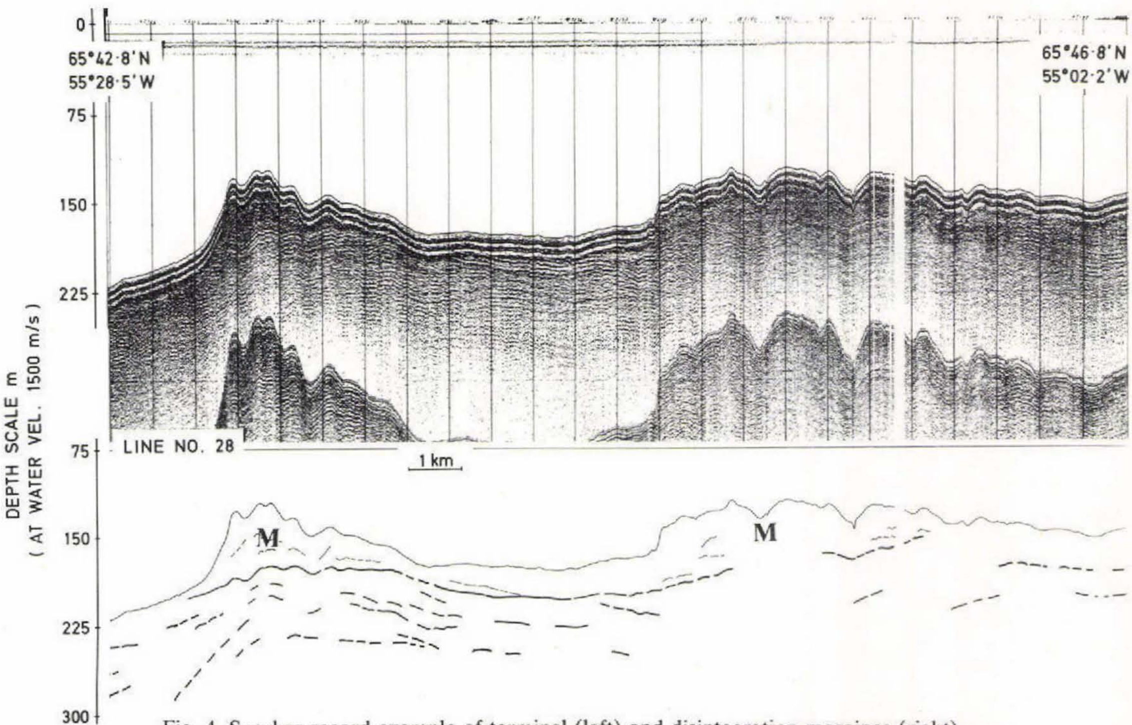
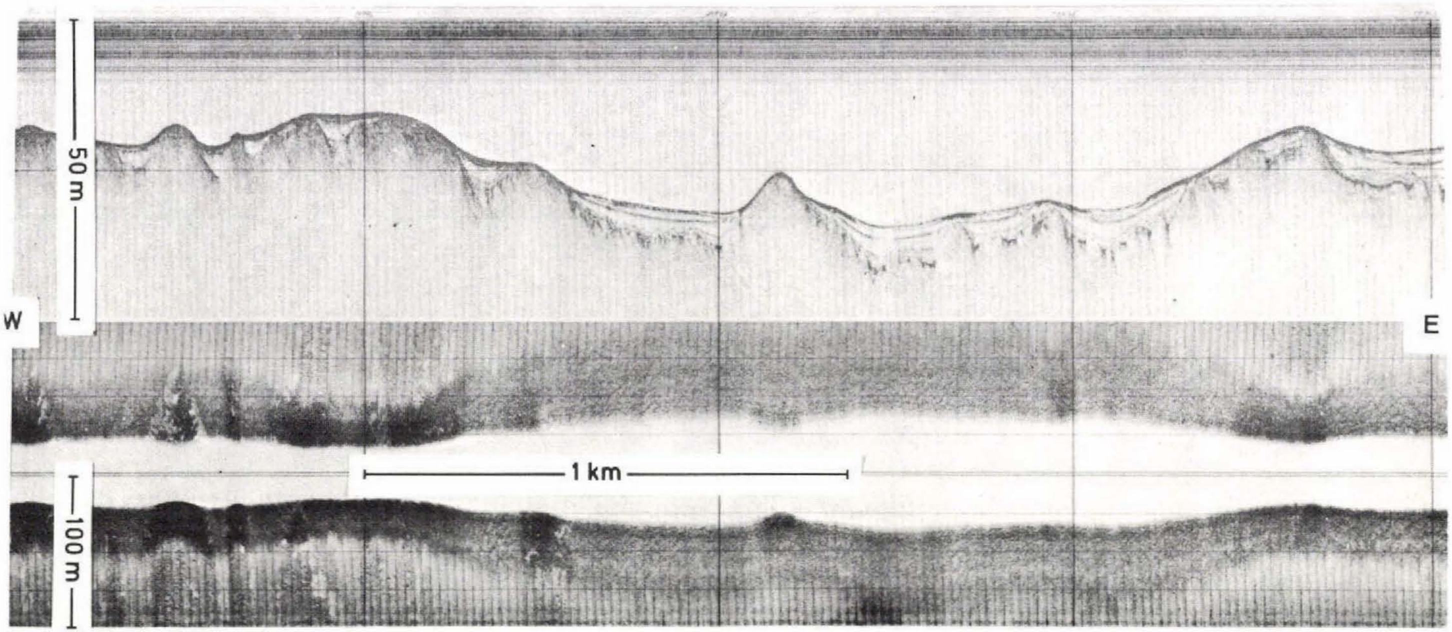


Fig. 4. Sparker record example of terminal (left) and disintegration moraines (right).

section) is part of a narrow chain of terminal moraines which follow closely the shelf-break for over 150 km between 64°20′N and 66°45′N, and possibly further north. These moraines are only 4 km wide and over 50 m high with five to seven characteristic, narrow ridges. The moraine sole is clearly visible on the seismic record and there are some signs of internal layering suggesting subaqueous deposition. A narrow (3 km) shelf to westward of the moraine frequently displays signs of slumping origin. Behind, and following for nearly the full length of the long terminal moraine, is a broad, over 20 km wide disintegration moraine, which is parallel to the frontal moraine but is more subdued and probably partially reworked. The depositional sole of this moraine is not visible and there are no traces of internal layering. A 5–7 km wide, flat-bottomed, sediment filled depression separates the two moraines.

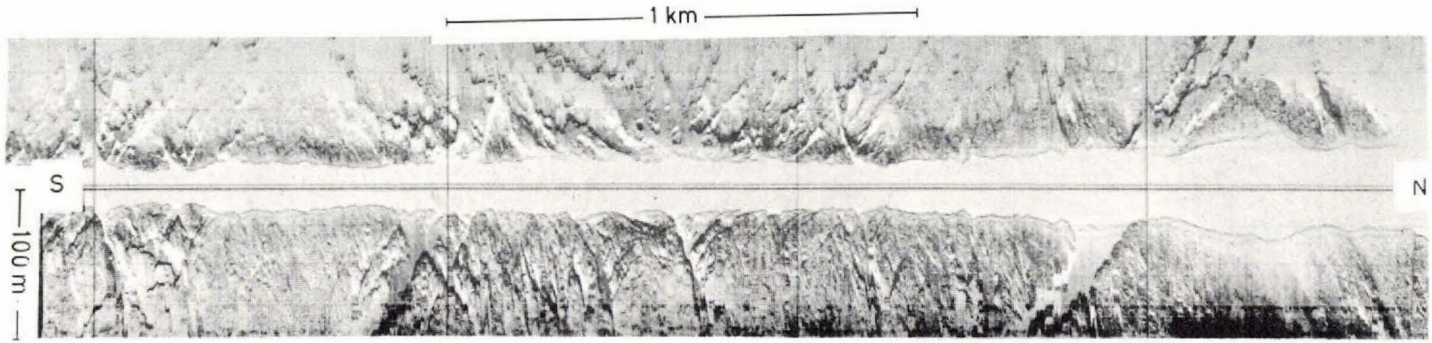
Two more views of the previously described sea floor types are illustrated by the side-scan sonar records of fig. 5 and 6.

Fig. 5 shows a combined side-scan sonar (lower) and sub-bottom profiler (upper) record taken from the eastern end of line 107 (fig. 2) and represents the smooth sea floor type. The sub-bottom profiler record reveals that the depressions in the harder Pleistocene material are filled in with softer, differentially compacted Holocene sediments. Multiple Holocene layering testifies to numerous sedimentation episodes. The Pleistocene till outcrops on the tops of gentle topographic ridges, the side-scan sonar record shows numerous boulder and gravel patches associated with such outcrops. This suggests that the soft sediments filling in the hollows may have been partly derived from the Pleistocene till by winnowing action of currents and waves.



Line no. 107 Centre Co-ords. 67°04·5′N, 54°14·2′W Water depth 75–90 m Tow speed 4·8 kts

Fig. 5. Combined side-scan sonar (lower) and sub-bottom profiler (upper) record showing Holocene muds and clays overlying Pleistocene till.



Line no. 60   Centre Co-ords. 64°44·2′N, 52°27·3′W   Water depth 30–40 m   Tow speed 4·8 kts

Fig. 6. Side-scan sonar record over Precambrian sea-bed.

An example of a side-scan sonar record over the very rough (Precambrian rock outcropping) sea floor is shown in fig. 6. This is a rare recording over the 'strandflat' since the very high topographic relief normally prevented the safe use of side-scan sonar in such areas. The record clearly shows the outcropping hard rock, with small amounts of recent sediments occurring in the depressions. The intense NW–SE fracturing and NE–SW foliation in the Precambrian rocks have been exploited and emphasised by Quaternary glaciation.

The distribution of the four main sea floor types is shown in fig. 7. In about 60 per cent of the survey area the sea floor is either very smooth or smooth. The remaining 40 per cent is nearly equally divided between the rough and very rough bottom types. The very smooth bottom type is found on the continental slope, on tops of the banks and in the transverse valleys. The most widespread smooth sea floor is of a transitional character, mostly due to ground or other moraine forms eroded or smoothed out with reworked Quaternary materials. An exception to this is the very narrow, sickle-shaped smooth band occurring below the shelf-break between 64°20′N and 65°30′N. This is interpreted as a system of slump scars in the very smooth sediments of the continental slope.

The rough sea floor on the outer banks is associated with various types of relict moraines (designated M in fig. 7). The N–S running frontal moraine ridges are particularly well preserved close to the shelf-break between 64°40′N and 66°20′N. Further eastward, on the banks, other front moraine ridges merge with chaotic disintegration moraines: this is particularly evident between 66°30′N and 68°20′N. Some moraine ridges also follow the landward flank of the banks.

The rough sea floor type on eastern Disko Banke and in Disko Bugt is, on the other hand, due to the hard volcanic rock ridges showing through a thin layer of soft sediments.

The very rough bottom is characteristic of a strongly irregular, jagged, glaciated and sediment free Precambrian rock surface. It occurs mainly in Disko Bugt though a narrow zone is found on the submerged 'strandflat' parallel to the coast and designated R in fig. 7.

(b) Shallow bedrock units

Three main shallow bedrock units have been identified in the survey area; Precambrian basement, Lower Tertiary volcanics and Tertiary sediments, together with a very limited occurrence of Upper Cretaceous sediments, confined to parts of Disko Bugt. Before discussing the distribution of the units some sparker record examples of their contacts and characteristics are presented.

An example of the contact between the Precambrian and the Tertiary sediments (with Quaternary cover) is shown in fig. 8. The Precambrian (PC) rocks dip gently westward under the Tertiary sediment (TS) wedge of Sukkertop Banke. A smoothed, Quaternary ground moraine (Q) covers the contact (arrow in fig. 8) of the Precambrian and Tertiary sediments. The roughness of the Precambrian surface decreases westward under the Tertiary sediments.

An example of the contact between the Lower Tertiary basalts and the Precambrian is shown in fig. 9. In this example the Tertiary basalts to the west (left of section) onlap the flank of an arch in the Precambrian gneisses (right of section) which outcrop on the sea floor south of Godhavn. The contact (arrow in fig. 9) is based largely on the morphology of the two rock types, which have been subjected to a similar erosional intensity during the

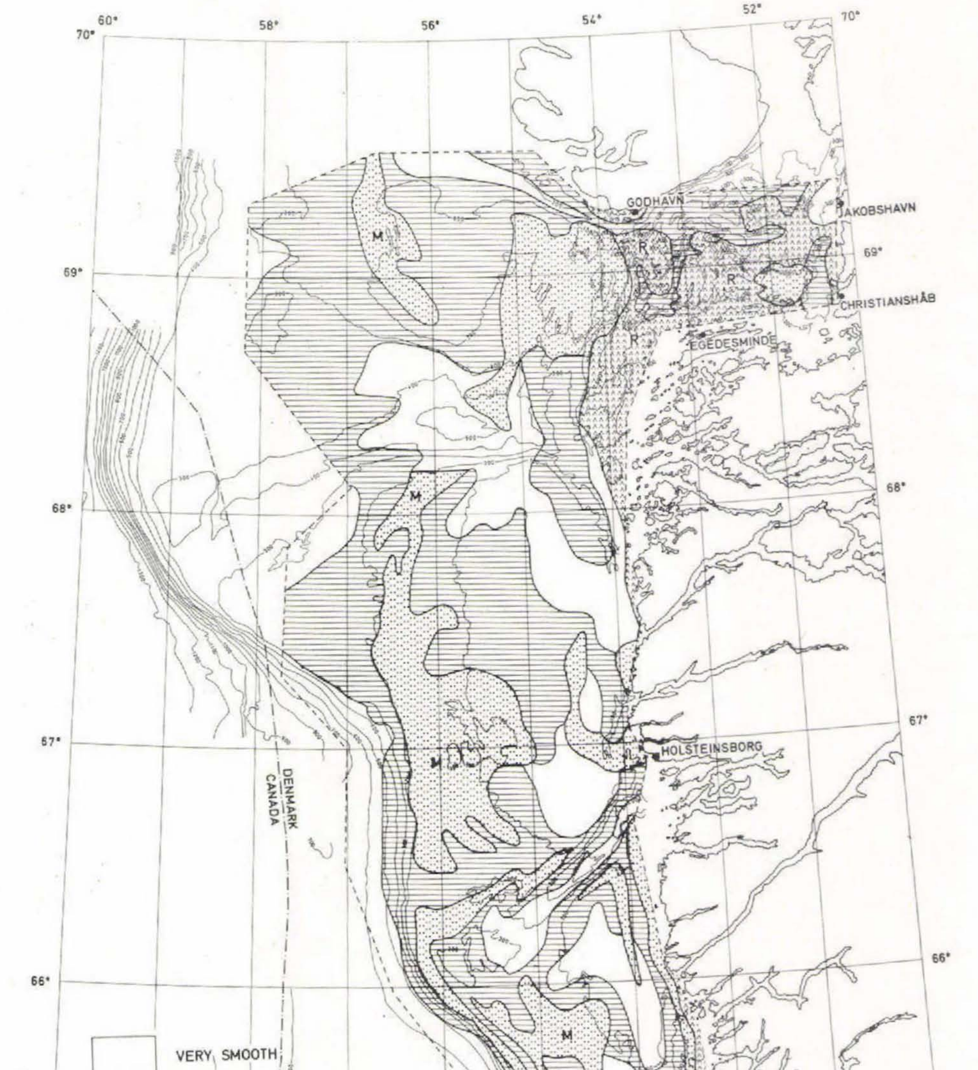


Fig. 7. Distribution of sea floor types, moraines and rock outcrops.

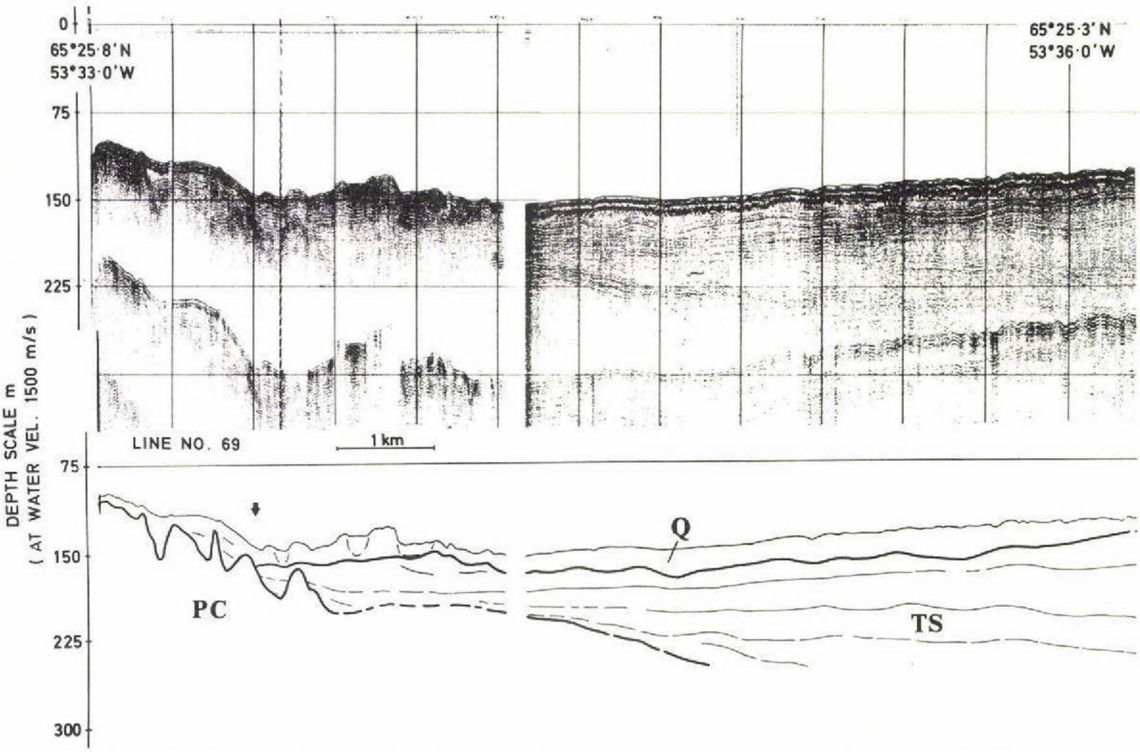


Fig. 8. Sparker record example of the contact (arrow) between the Precambrian (PC) and Tertiary sediments (TS) beneath Quaternary cover (Q).

Quaternary glaciation. It is also supported by a marked change in magnetic signature (Ross & Henderson, 1973, figs 2 & 3; Denham, 1974, fig. 2), which has been used in conjunction with the seismic data to define the boundary between the Precambrian basement and Tertiary basalts. Note the characteristic gentle westward slope of the basalt layers interrupted by short, steep, eastward facing scarps. Near the centre of the section the basalts forming Disko Banke are downstepped steeply, northeastward, into a deep, broad depression, the Godhavn Rende. This structure suggests a NW–SE trending, major fault zone vigorously exploited by a glacier. The Precambrian gneisses have a much more jagged appearance, due, most likely, to close jointing and greater resistance to glacial erosion.

A characteristic E–W sparker profile across western Disko Banke is shown in fig. 10. Eroded and/or faulted multilayer basalt flows (TB) dip gently (maximum 2°) westward under the onlapping Tertiary sediments (TS). The feather edge contact (arrow) is concealed under 25–30 m thick Quaternary ground moraine (Q) which fills the depressions in the basalt. To the east and west of the central depression in this section the surface cover is disturbed by intense iceberg scouring (discussed later). Note the strong top basalt reflector which displays throughout Disko Banke the characteristic structure of gentle westerly dips and steep, short scarps to the east (to left in fig. 10). These seem to be mainly erosional features but some faulting may also be involved.

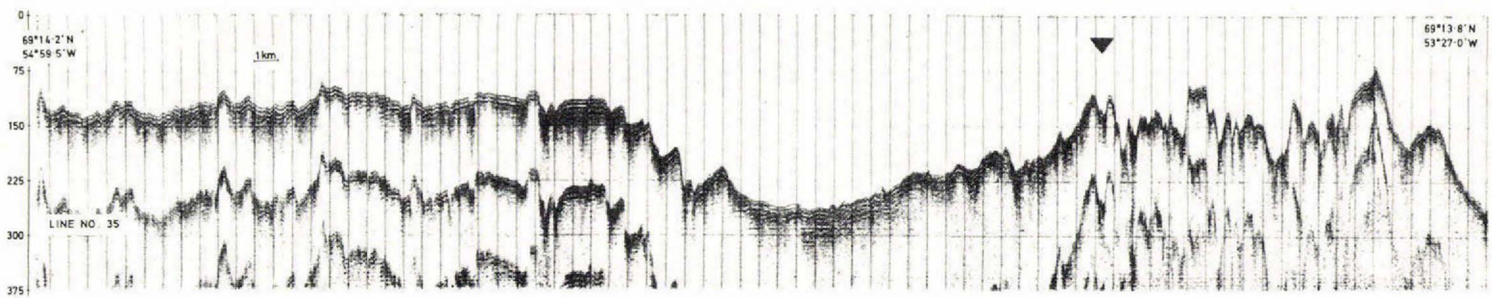


Fig. 9. **Sparker record** example of the contact (arrow) between the Precambrian (to the right) and Tertiary basalts (to the left). (Depth scale in metres at water velocity 1500 m/s).

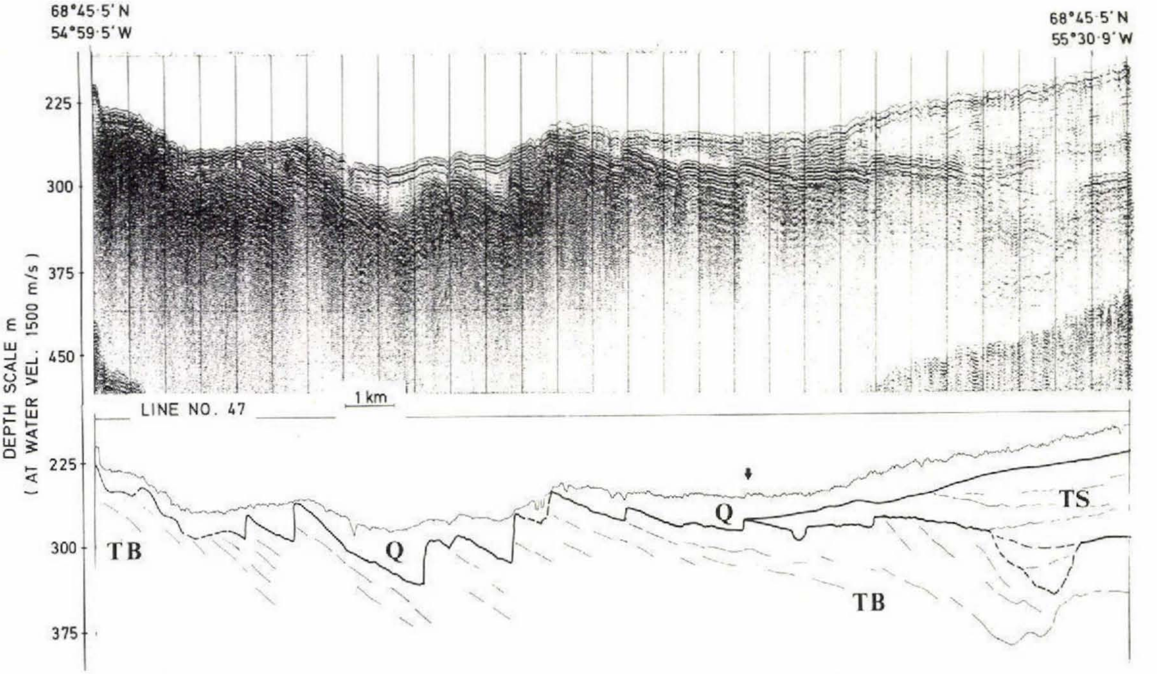


Fig. 10. Sparker record example of the feather edge contact (arrow) between Tertiary basalts (TB) and Tertiary sediments (TS) beneath Quaternary cover (Q)'.

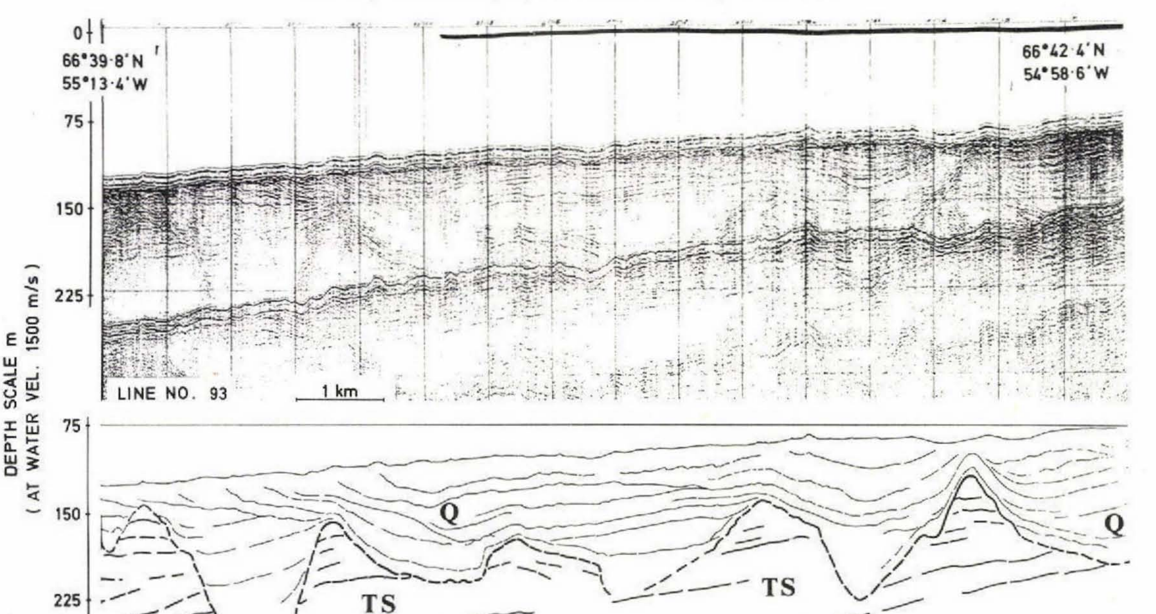


Fig. 11. Sparker record example of 'cut-and fill' structure in Tertiary sediments (TS), the fill being Quaternary sediments (Q).

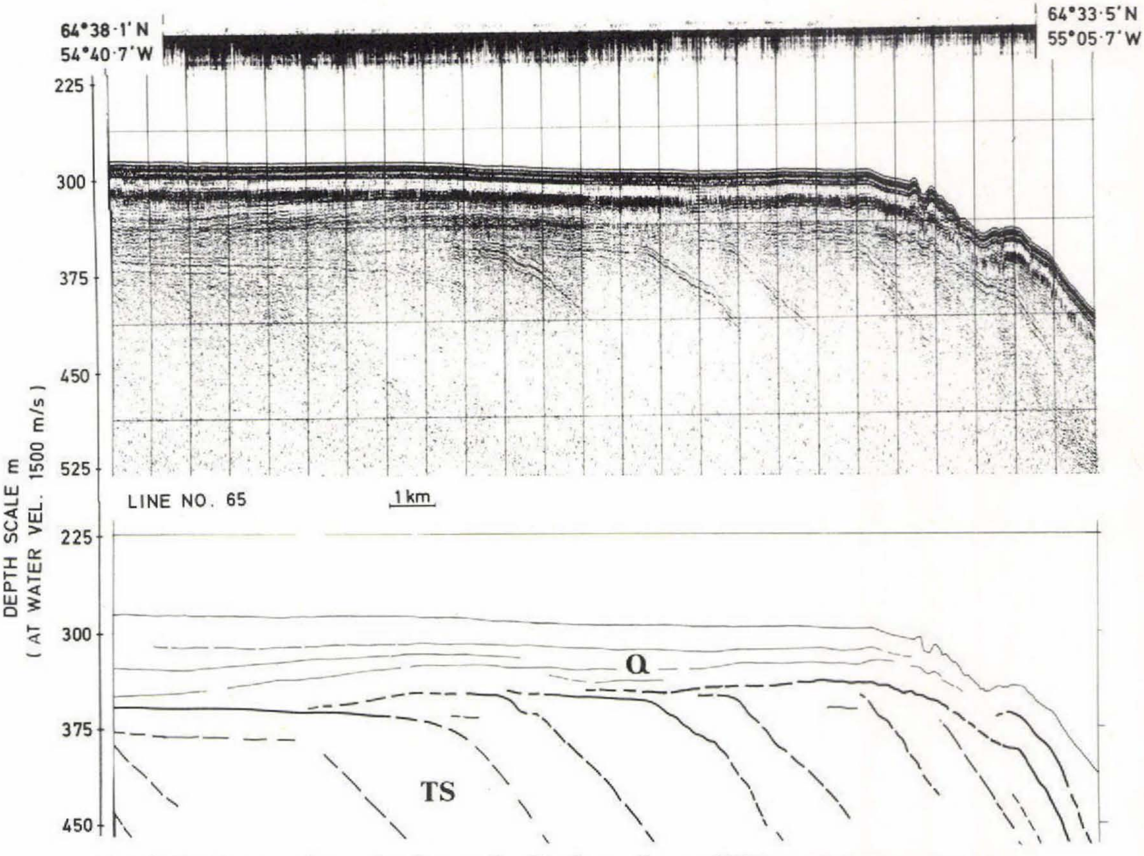


Fig. 12. Sparker record example of prograding Tertiary sediments (TS) beneath Quaternary cover (Q).

On the banks, two types of shallow structure within the Tertiary sediments were observed, a 'cut-and-fill' structure (fig. 11) and prograding (fig. 12). As shown in fig. 11, the sub-horizontal Tertiary sediments in the shallow parts of the banks were deeply cut into and subsequently filled, presumably during the Quaternary glaciation. The cuts, as illustrated, often exceed depths of 100 m and widths of several kilometres, their fill lying characteristically discordant with the Tertiary beds of the uncut banks. The 'cut-and-fill' structures were repeatedly re-cut and refilled. They may represent development of under ice channels carrying meltwater and transporting the glaciers' bed load.

The edge of the continental shelf prograded considerably westward since its original deposition during the Tertiary. Such prograding in presumably Tertiary (TS) and Quaternary (Q) sediments is shown in fig. 12, an example from the western part of line 65 (for location see fig. 2). Note the slump scar immediately below the shelf-break referred to in the earlier discussion of sea floor types.

The boundaries of the aforementioned bedrock units as derived largely from the sparker profiles are shown in fig. 13. Starting from the east, the crystalline complex of Precambrian age dips gently westward under the Tertiary sediment wedge of the banks. The topmost Tertiary strata dip gently WSW over the banks, continuing at an increased dip rate down the

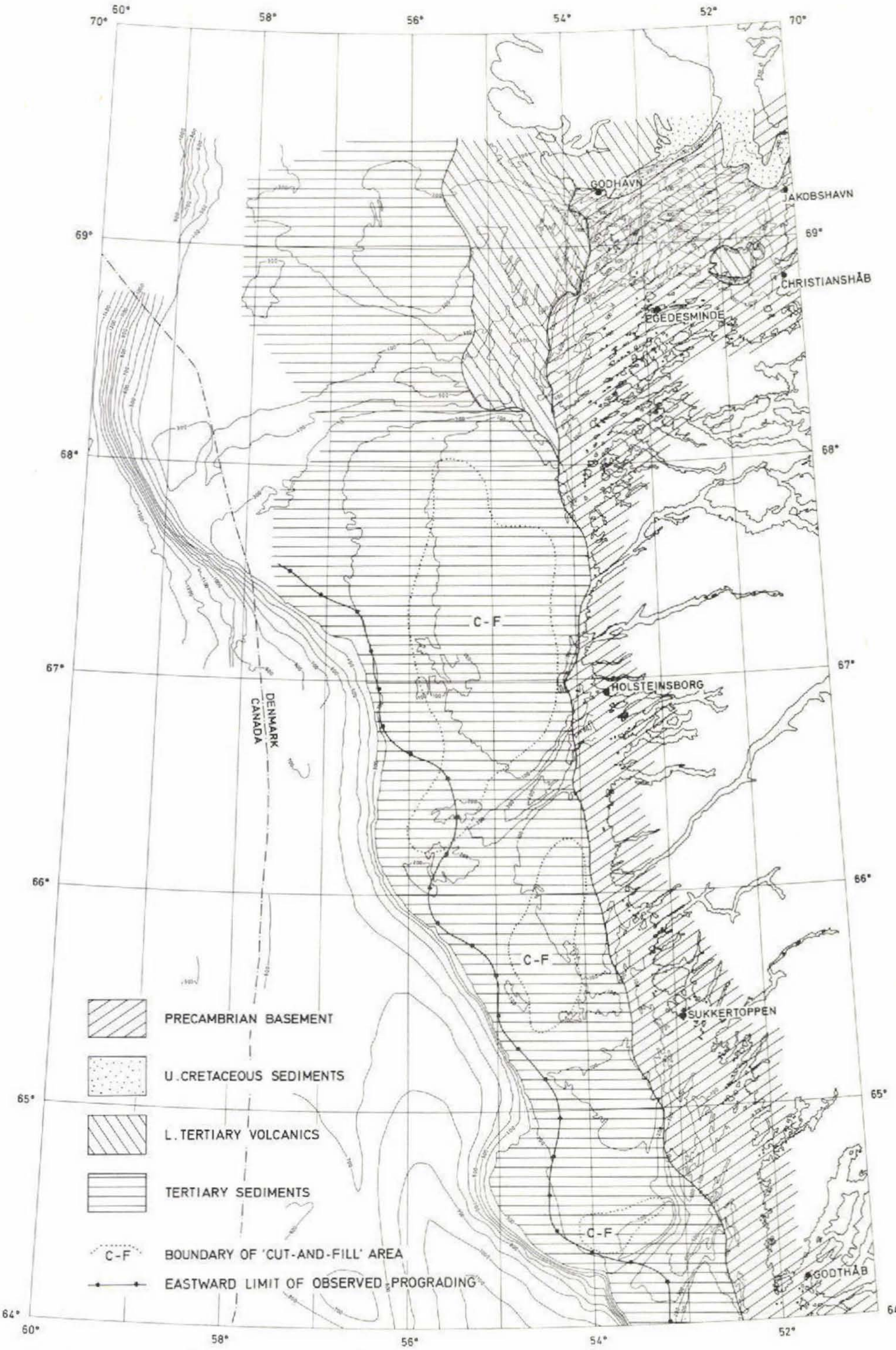


Fig. 13. Shallow bedrock units, 'cut-and-fill' distribution (C–F) and eastermost limit of observed prograding.

continental slope. At the surface the layers are heavily glaciated showing widespread 'cut-and-fill' structure (C–F), with Quaternary materials filling these deep cuts and moreover, creating an overall 20–200 m thick cover of the banks. The areas of the 'cut-and fill' are most widespread over Store Hellefiskbanke, decreasing in extent southward to Tovqussaq Banke; they are found on the higher parts of the banks. The western boundaries of either Precambrian basement or the Tertiary sediments are not known. Presumably they continue westward, well past the shelf-break. The present continental shelf edge lies westward of the older edges now buried under successively prograding sediments. One position of such an older (Tertiary?) shelf-break is shown in fig. 13.

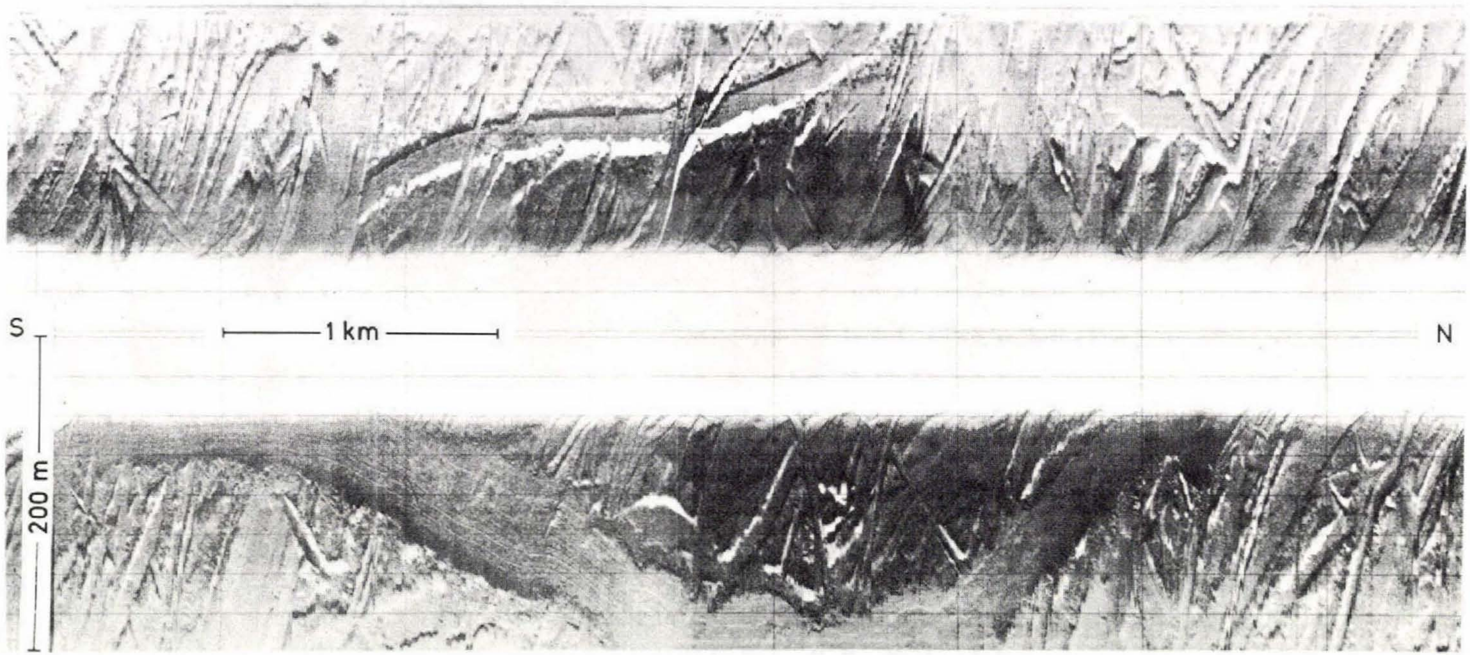
North of 68°N this rather simple stratigraphy becomes more complicated by the presence of a thick sequence of Lower Tertiary volcanics. They overlie directly the Precambrian gneisses along the axis of the basement arch between Egedesminde and Godhavn. On the eastern flank they overlie a wedge of Cretaceous–Tertiary sedimentary rocks which outcrop on eastern Disko and on the sea floor (Denham, 1974). A remnant of an extensive Tertiary dolerite sheet which protected a fragment of Cretaceous sediments forms the heavily glaciated platform of Grønne Ejland, in the southeast part of Disko Bugt. The eastern boundary of the volcanics south of Disko is fault controlled (Clarke, 1975). However, the western limit is speculative as its magnetic signature (Ross & Henderson, 1973) is unclear. The Tertiary sediments of Disko Banke onlap the basalts, the sedimentary wedge thickening and dipping westward.

(c) Iceberg scouring

The side-scan sonar data contribute greatly to a detailed understanding of the surface geology of the banks. However, one of the most striking features observed is that of iceberg scouring.

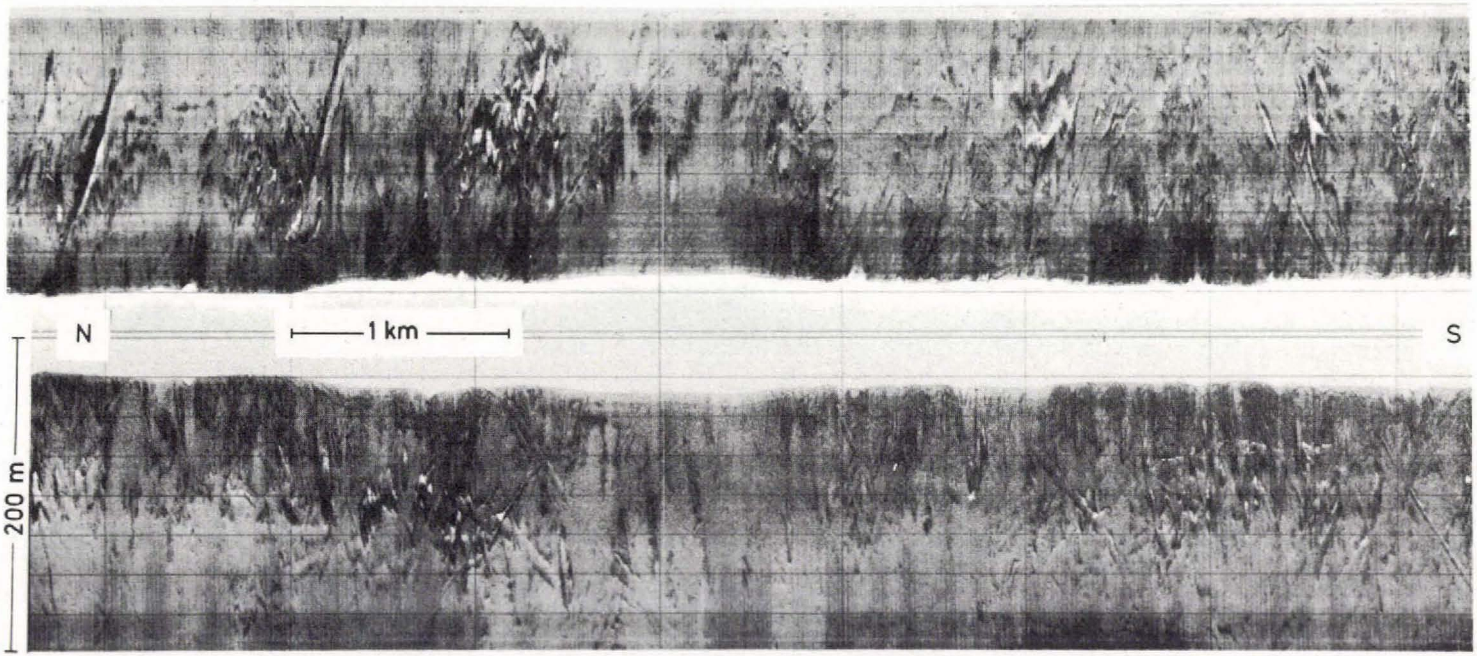
The degree of scouring observed has been divided into three grades, intense, moderate and none. The intense grade applies to areas where the entire sea floor is composed of scour marks and associated marginal deposits and is illustrated by the side-scan sonar record in fig. 14. Also visible on this record is one of the largest individual scours observed, being some 75 m wide and 4–5 km long. The moderate grade applies to areas where scour is present up to an intermediate level and is illustrated in fig. 15.

The distribution of the iceberg scouring is shown in fig. 16. The compilation of this map has been made largely from side-scan sonar records. Sparker data have been used also to extend the mapped area. There is a distinct correlation between the existence of scour (particularly when intense) observed directly with the side-scan sonar and its appearance on the sparker record as fine, hummocky surface with many small diffraction patterns. Such an example can be seen in fig. 10, particularly in the sediments towards the western end (right of section) of the profile shown. Using the sparker records, scour can be traced to a water depth of 340 m on either flank of Egedesminde Dyb, at which depth an abrupt cut-off occurs. A more thorough study of the ice scour patterns is planned, but at this stage it can be said that the contribution of the East Greenland ice, rounding Kap Farvel and carried northward along the continental shelf edge, is small. The scour distribution strongly suggests the vast majority of the scouring arises from icebergs calved in Disko Bugt (Jakobshavn Isbræ) and exiting from the bay via Egedesminde Dyb and Godhavn Rende. The age of the scours is not known at this stage but it is felt that some, dispite looking fresh, may date from



Line no. 48   Centre Co-ords. 69°19·2′N, 57°15·0′W   Water depth 215–220 m   Tow speed 4·3 kts

Fig. 14. Side-scan sonar record illustrating intense iceberg scouring.



Line no. 53 Centre Co-ords. 67°54·3′N, 56°02·1′W Water depth 125–130 m Tow speed 5·4 kts

Fig. 15. Side-scan sonar record illustrating moderate iceberg scouring.

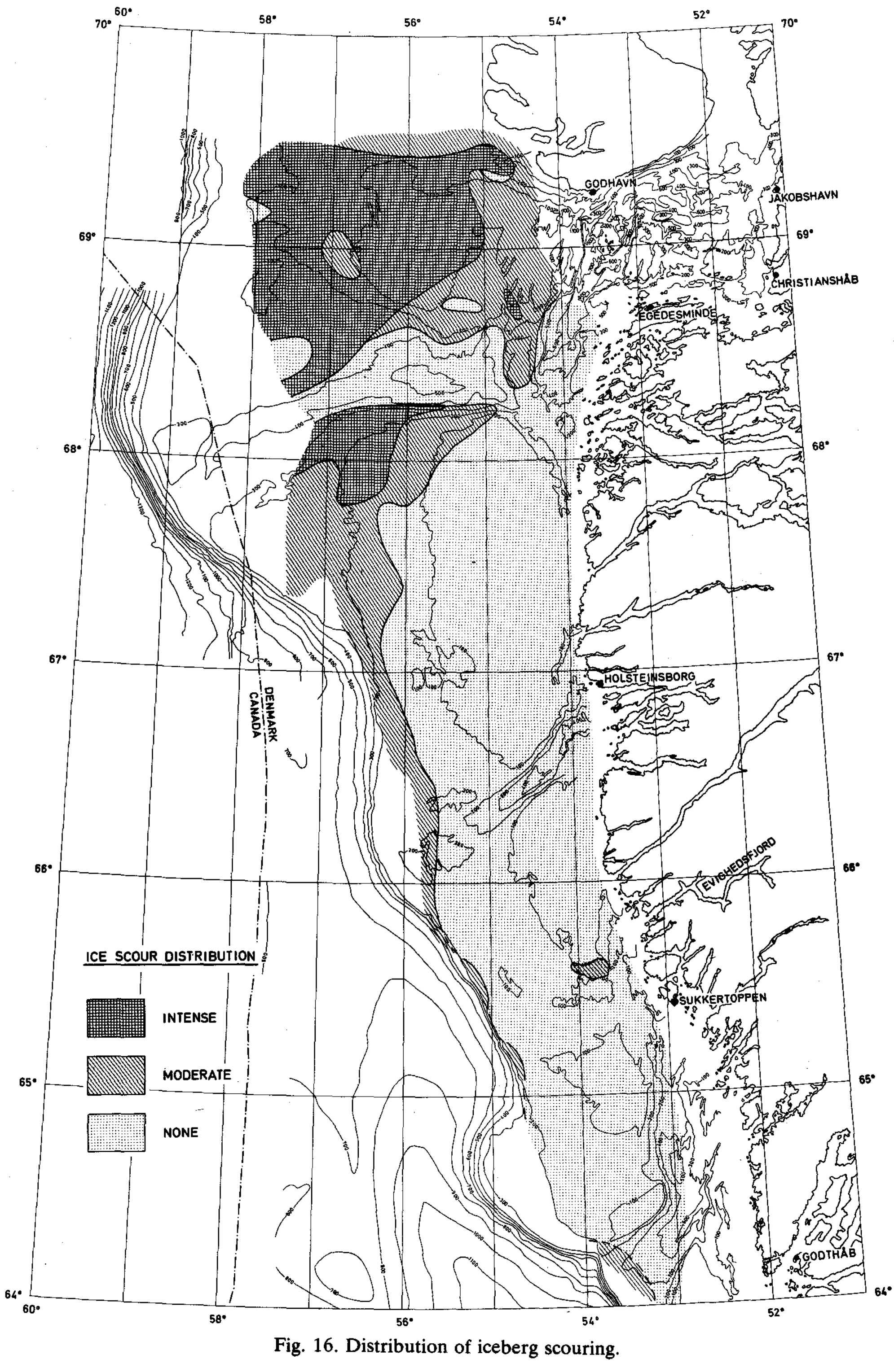


Fig. 16. Distribution of iceberg scouring.

the beginning of the last deglaciation of the shelf. This is supported by scouring being apparent to a depth of 340 m. Under present glacial conditions icebergs of that draft cannot exit from Disko Bugt since there is a 300 m deep basalt bar across the eastern end of Egedesminde Dyb, at approximately 54°30′W. It is felt that the deeper scour was created by icebergs calved in Egedesminde Dyb when the ice front, or tonque of ice in the Dyb extended west of this basalt ridge.

Over much of the bank areas south of Egedesminde Dyb there is no scour, the exception being the small area off Evighedsfjord, in which the scour is assumed to arise from local calving of icebergs in the fjord.

The undisturbed sediments of the banks frequently show fishing trawl marks, which are easily identifiable as pairs of narrow parallel furrows spaced 50 to 70 metres apart.

CONCLUDING REMARKS

The 1978 cruise was entirely successful with the acquisition of a wealth of geophysical data regarding the shallow structure of the West Greenland shelf. The preliminary interpretation has led to the following main conclusions.

Between 64° and 67°30′N the entire shelf area was glaciated to its western margin during the Pleistocene. This is particularly clear in the region 64°40′ to 66°20′N in which a narrow, frontal moraine some 50 m thick can be traced for 150 km running parallel and close to the shelf-break. The products of repeated glaciation and deglaciation appear as a cover of very variable thickness (20–200 m) on the Tertiary sediments underlying the shelf. A morphological relationship between the sea floor roughness and the types of glacial forms has been established. Many striking similarities can be observed between the surface and shallow continental shelf forms of West Greenland and Labrador (Grant, 1972; van der Linden *et al.,* 1976).

The contact of the Cenozoic sediments forming the banks with the coastal Precambrian rocks follows the 'marginal channel', roughly parallel to the coast. The contact of the Lower Tertiary Disko volcanics with the heavily glaciated Precambrian gneisses occurs, south of Godhavn, across the mouth of Disko Bugt. It follows a 500 m high escarpment southwards to the junction with the 'marginal channel' at approximately 68°N. The sparker profiles clearly show the contact between these volcanics and the overlying Neogene sediments of western Disko Banke. The sediments onlap the basalts which dip gently to the west with no sign of down-faulting of the basalts at shallow levels.

Widespread prograding is observed in the sediments along the shelf margin.

Extensive iceberg scouring of the sea floor is noted, particularly in the areas of Disko Banke and immediately south of Egedesminde Dyb. It is felt that this scouring is largely due to icebergs originating in Disko Bugt and exiting via Egedesminde Dyb and Godhavn Rende. Much of the scours appears fresh but some, particularly in deeper water is thought to have occurred at a time when the ice-front was to the west of Disko Bugt or when a glacier tongue was still present in Egedesminde Dyb. The limited scour occurring on the continental margin is possibly caused by icebergs from East Greenland rounding Kap Farvel and drifting northwards along the shelf margin.

It must be stressed that the interpretation presented here is somewhat generalised and is of a preliminary nature. More detailed work incorporating fully the side-scan sonar/sub-bottom profiler data together with the corrected magnetic data is in progress.

Acknowledgements

For the success of the survey we are indebted to Captain H. Rothe and the crew of M/V *Dana,* to the technical staff, P. Goymour (Oceonics Ltd), E. Hansen (GGU) and J. Boserup (GGU) and to the four scientific assistants, P. Askløf, H. Fredborg, T. Jensen and J.-O. Nielsen. We also wish to thank B. MacLean of the A.G.C., Bedford Institute of Oceanography (Canada) who accompanied us on part of the survey. His valuable assistance with onboard interpretation, particularly his work on the bedrock geology which led to the production of fig. 13, and his helpful discussions were much appreciated.

The project was conceived and initiated by E. J. Schiener (GGU) who has continued to give useful advice and support throughout. Finance was provided by the Danish Ministry for Commerce.

REFERENCES

Clarke, D. B. 1975: Tertiary basalts dredged from Baffin Bay. *Can. J. Earth Sci.* **12,** 1396–1405.

Denham, L. R. 1974: Offshore geology of northern West Greenland. *Rapp. Grønlands geol. Unders.* **64,** 24 pp.

Falconer, R. K. H. 1977: Marine geophysical and geological research in Baffin Bay and the Labrador Sea, CSS Hudson, 1976. *Pap. geol. Surv. Can.* **77–1B,** 255–260.

Grant, A. C. 1972: The continental margin off Labrador and eastern Newfoundland – morphology and geology. *Can. J. Earth Sci.* **9,** 1394–1430.

Grant, A. C. 1975: Structural modes of the western margin of the Labrador Sea. *Pap. geol. Surv. Can.* **74–30,** 217–231.

Henderson, G. 1975: New bathymetric maps covering offshore West Greenland 59°–69°30′N. 1975 Offshore Technology Conference Proc. **1,** 761–773.

Holtedahl, O. 1970: On the morphology of the West Greenland shelf with general remarks on the 'marginal channel' problem. *Marine Geol.* **8,** 155–172.

Keen, C. E., Barrett, D. L., Manchester, K. S. & Ross, D. I. 1972: Geophysical studies in Baffin Bay and some tectonic implications. *Can. J. Earth Sci.* **9,** 239–256.

Ross, D. I. & Henderson, G. 1973: New geophysical data on the continental shelf of central and northern West Greenland. *Can J. Earth Sci.* **10,** 485–497.

Rvachev, V. D. 1964: Relief and bottom deposits of the shelf of southwestern Greenland. *Deep Sea Res.* **11,** 646–653.

van der Linden, W. J., Fillon, R. H. & Monahan, D. 1976: Hamilton Bank, Labrador margin: origin and evolution of a glaciated shelf. *Pap. geol. Surv. Can.* **75–40,** 31 pp.

APPENDIX 1

Geophysical survey systems

(a) Sparker seismic system
EG & G 8 kJ Sparkarray system comprising:
(i) 2 × model 232A power supplies
(ii) 1 × model 231A triggered capacitor bank
(iii) 2 × model 233A capacitor banks
(iv) 1 × model 402/7 nine electrode Sparkarray
(v) 2 × model 265 hydrophones
Filter: Krohn-hite model 3700
Recorder: EPC 4100

(b) Deep-tow combined side-scan sonar/sub-bottom profiling system
Edo-Western model 515T/606 comprising:
(i) model 606A three channel digital recorder with integral side-scan transceiv
(ii) Model 248E/465 10 kW sub-bottom profiling transceiver
(iii) 2 × model 6315 self depressing combined tow wehicles, each with (a) model 250 low frequency (2.5 kHz) sub-bottom profiling transducer, (b) model 603 side-scan sonar (100 kHz) transducers and electronics
(iv) model 610 electric powered winch with slip-ring assembly and 600 m armoured tow cable.

(c) Magnetometer
Geometrics G803 marine proton precession magnetometer (1 gamma sensitivity)
Recording on Hewlett Packard HP 680 strip recorder.

(d) Echosounder
Simrad EK50 scientific sounder (50 kHz)
This was kindly lent by the Danish Institute for Fisheries and Marine Research

(e) Boomer system
EG & G model 240 sub-tow boomer system comprising:
(i) model 240 Uniboom sub-tow
(ii) model 231A triggered capacitor bank
(iii) model 232A power supply
Filter: Krohn-hite model 3700
Recorder: EPC 4100
The boomer system (excluding filter) was hired from the Danish Geotechnical Institute

(f) Air-gun system
2 × Bolt model 600B air-guns
1 Bauer K16DK compressor
Recording as for the sparker system

APPENDIX 2

Positioning system

Fully integrated satellite navigator/doppler sonar system comprising:

(i) Magnavox MX610 doppler sonar incorporating thermistor and inclinometer
(ii) Arma-Brown Mk 10 gyro compass with auto-torquing
(iii) Magnavox MX702 dual-channel satellite receiver with antenna and pre-amplifier.
(iv) Hewlett packard HP 21Mx computer with 16K memory and floating point
(v) Texas Instruments 733 ASR thermal printing terminal with twin magnetic tape cassette unit
(vi) Houston Instruments DP1 incremental plotter
(vii) Magnavox software and engineering including equipment event marker
(viii) Magnavox remote CRT display

A shematic of the system is shown in fig. 17.
The positioning system was hired from Oceonics Ltd. (U.K.).

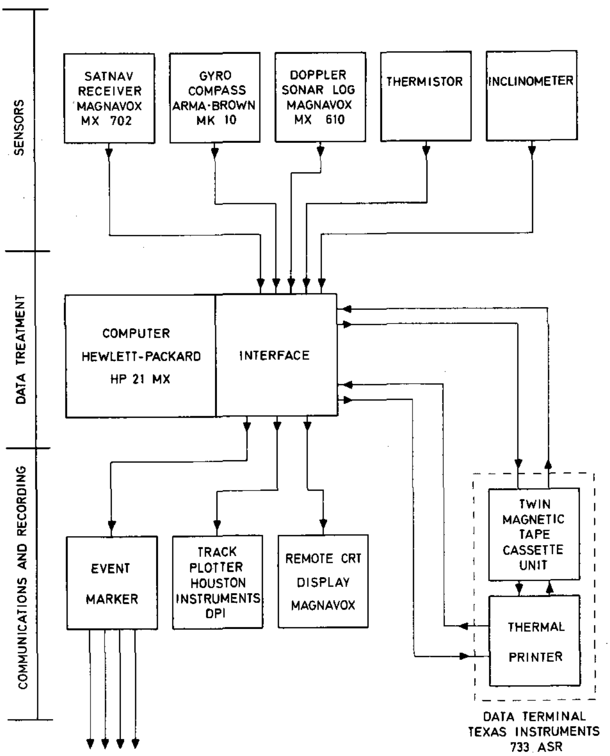


Fig. 17. Positioning system schematic.

Grønlands Geol. Unders., Rapport Nr. 87 (C. P. Brett & E. F. K. Zarudzki) 1979

ISSN 0418–6559

ANDELSBOGTRYKKERIET I ODENSE