GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT Nr. 92

The Geological Survey of Greenland
Report No. 92

Geology of the continental shelf off West Greenland between 61°15′N and 64°00′N:

an interpretation of sparker seismic and echo sounder data

by

Miodrag M. Roksandić

KØBENHAVN 1979

Grønlands Geologiske Undersøgelse

(The Geological Survey of Greenland)

Øster Voldgade 10, DK-1350 Copenhagen K

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1 map in pocket

1979

Abstract

Five types of sea floor have been recognized by the analysis of sparker seismic sections, echograms and bathymetric maps. Seismic facies analysis has made it possible to distinguish several geological units: postglacial channel fill, lateral moraines, ground moraines, proglacial stratified drift, preglacial fluvial deposits, stratified deposits of marine(?) origin and crystalline basement.

Deposition of the marine(?) stratified deposits was interrupted due to a regression. The fluvial deposits were formed on the emerged land area. The ice margin must have advanced over the fluvial deposits and at its maximum extent the ice covered the area of the 'strandflat.' In the marginal and transverse channels and on parts of the banks proglacial stratified drift was deposited. Later the transverse channels became the sites of glacial lobes. The proglacial stratified drift was partly removed by glacial erosion, while lateral and ground moraines were formed. It is possible that the offshore banks have been at least partly covered by the ice sheet during a more recent glaciation.

The postglacial channel fill is the youngest unit described and there is probably still deposition of these sediments in the Frederikshåb Dyb.

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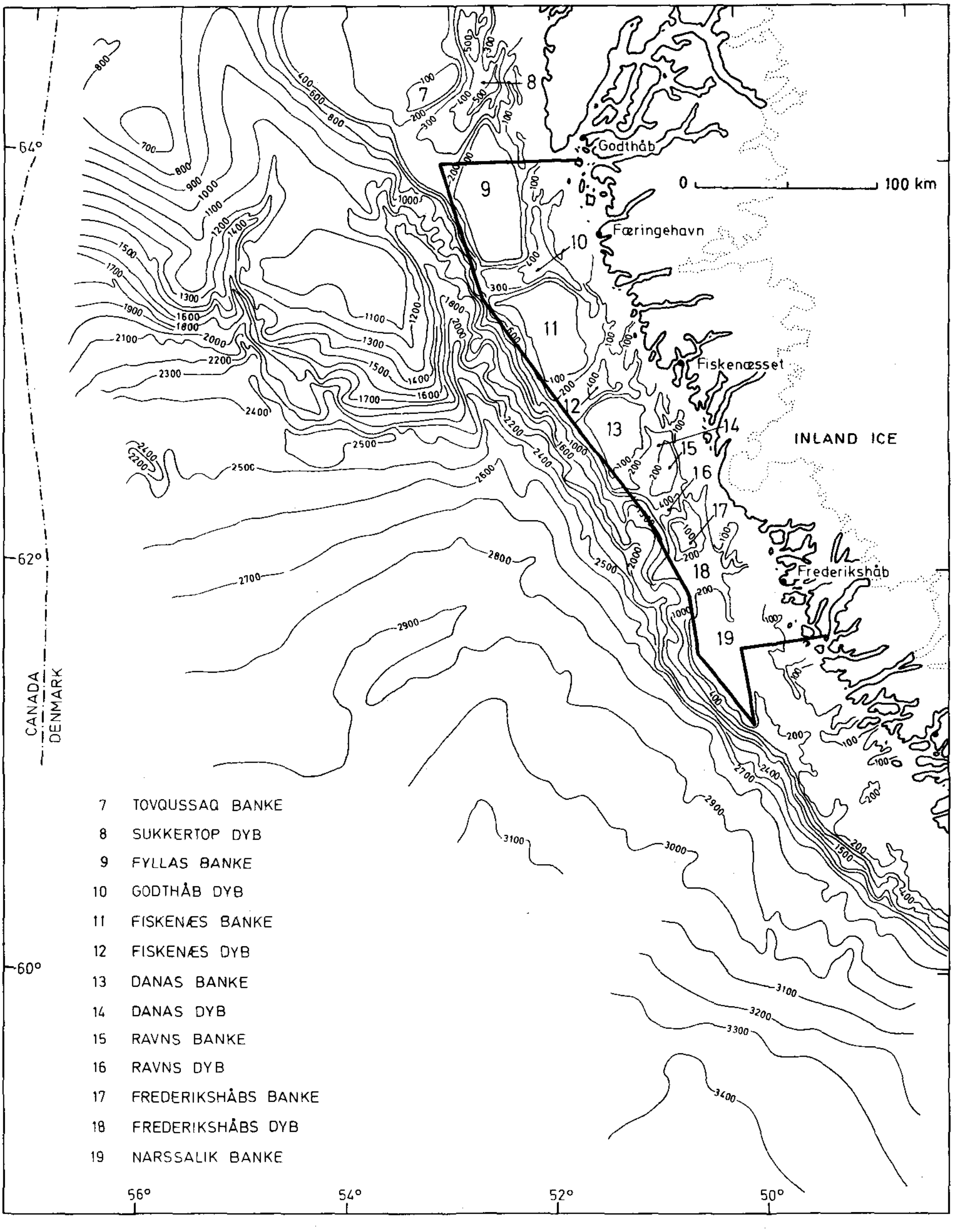

Fig. 1. Bathymetry of the West Greenland continental margin between 59°00′N and 64°30′N (according to Henderson, 1975) with the area of the map framed.

INTRODUCTION

In 1970 O. Holtedahl published a paper on the morphology of the West Greenland shelf based on the published charts from the Royal Danish Hydrographic Office. Holtedahl distinguished:

(1) an inner zone with irregular surface which corresponds to the 'strandflat' of Norway;
(2) a system of marginal channels;
(3) transverse channels, and
(4) banks.

A few years later Henderson (1975) gave a regional description of the submarine topography offshore West Greenland between 59° and 69°30′N based on new bathymetric maps prepared by the Geological Survey of Greenland.

In 1975, the author produced an interpretation of a part of the continental shelf off West Greenland using industry sparker seismic data and published bathymetric data. However, the sparker seismic data were confidential at the time and, because of that, only a brief report without map and sections could be published (Roksandić, 1976).

The purpose of this paper is to present more completely the results of geological interpretation of seismic and bathymetric data from a part of the West Greenland shelf.

REGIONAL SETTING

The area studied is situated off West Greenland between 60°15′N (i.e. west of Ivigtut) and 64°00′N (i.e. west of Godthåb) and contains a series of fishing banks separated by deep channels, as well as the 'strandflat' between these features and the coast (fig. 1).

The onshore area between Ivigtut and Godthåb belongs to the Archaean gneiss complex which "has remained unaffected by major metamorphic, tectonic and magmatic events during the last 2500 m.y." (Escher & Watt, 1976, p. 12). The Archaean complex is chiefly composed of granitoid quartzo-feldspathic orthogneisses with concordant intercalations of metavolcanic amphibolites, metasedimentary gneisses and units of meta-anorthosite and associated metabasic igneous rocks (Bridgwater *et al.*, 1976; Escher & Watt, 1976).

The present surface of the Archaean gneiss complex shows many signs of glacial erosion. It is sporadically covered by ground moraines, but in some areas ground moraines are widespread (Graff-Petersen, 1952; Weidick, 1975 a,b). Ice margin deposits have also been found. Glaciofluvial, ice lake, marine and aeolian deposits are also developed.

SOURCES OF INFORMATION AND METHOD OF INTERPRETATION

Sparker seismic data obtained from a geophysical survey conducted for Greenland Exploration Management Co. in 1970, original echograms recorded by the Royal Danish Hydrographic Office and new bathymetric maps prepared by the Geological Survey of Greenland (Henderson, 1975) were the sources of information.

The most important source of information was the sparker seismic sections. The quality of seismic sections obtained during the geophysical survey is variable and often poor. Seismic control has also been variable. In addition the positioning has sometimes not been sufficiently good for precise work. All these factors have made the interpretation difficult, and in parts of the area, impossible. Nevertheless, the sparker seismic sections contain a lot of interesting and useful geological data and are well worth interpreting.

The seismic facies analysis approach (for discussion of principles involved see Roksandić, 1978) was used for interpretation of sub-bottom geology. Penetration and sea floor multiples were factors which limited the depth of interpretation.

The new bathymetric maps made it easier to locate features recognised on the seismic sections.

Comparison between the seismic sections and the bathymetric maps facilitated the geological interpretation of the latter and made it possible to extrapolate seismic data sometimes relatively far from the seismic lines.

The resolution of the sparker seismic method used did not allow the sea floor geology to be deduced from available seismic data, except where the sea floor geology and the sub-bottom geology are the same. However, a comprehensive analysis of the sea floor based on sparker seismic sections, echograms and the bathymetric maps made it possible to identify several types of sea floor corresponding to different sea floor geological conditions.

TYPES OF SEA FLOOR

In a previous paper (Roksandić, 1976) six types of sea floor were described which could be recognised on seismic sections and echograms. Five of those six types have been found in the area covered by the map (Plate 1).

Type 1 is characterised by a very uneven sea floor consisting of numerous features such as highs, channels, lows etc. The wavelengths of sea floor forms vary from a few tens of metres to several thousand metres, but are most frequently between 500 m and 2500 m. Variations of amplitudes are very large, from a few metres to several hundred metres, but amplitudes are usually less than 200 m.

Type 1 is restricted to the inner part of the continental shelf, i.e. to the strandflat. Holtedahl (1970) compared the forms of the West Greenland, Norwegian and Labrador shelves and pointed out that the outer margin of the strandflat, including the marginal channels, marks the boundary between the old rock masses of the land block and young sedimentary deposits. Henderson (1975, p. 762) is of the opinion that "the outer margin of the inner irregular submarine zone offshore West Greenland represents the limit of the ice sheet and that the transverse channels are the sites of former glacial lobes from this sheet".

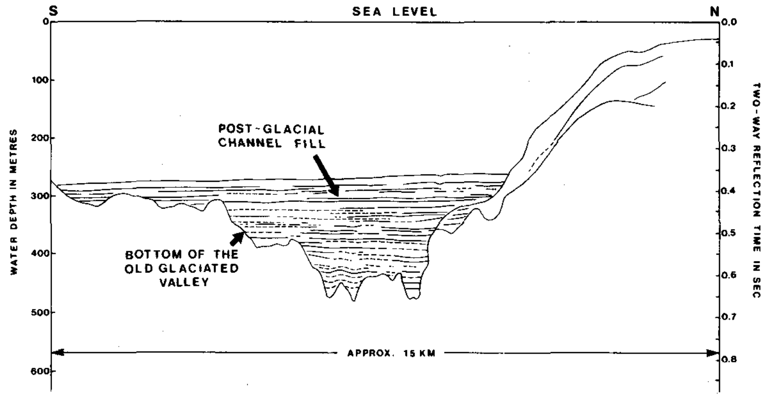

Fig. 2. Interpreted sparker seismic section showing the postglacial channel fill (for location see the map).

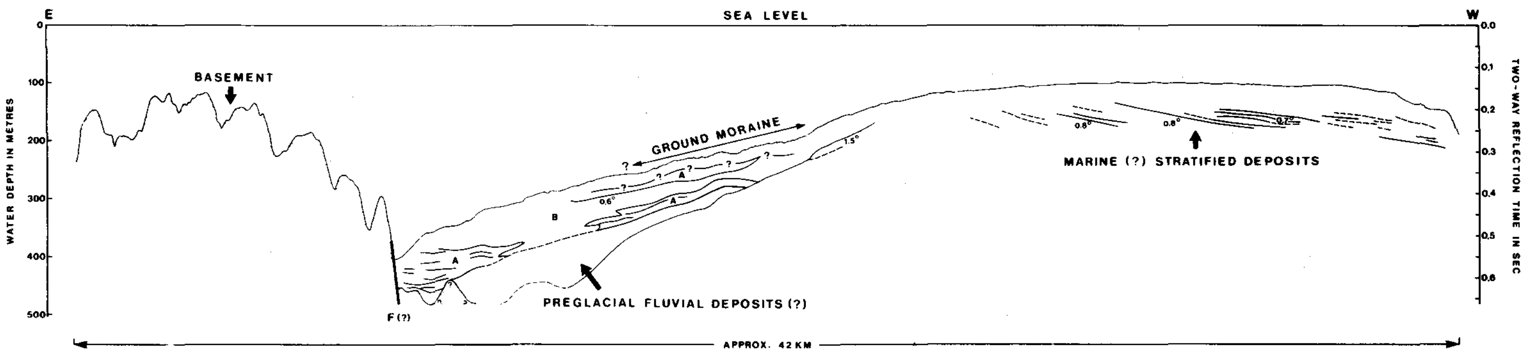

Fig. 3. Interpreted sparker seismic section (for location see the map). Five seismostratigraphic units could be distinguished: basement, marine(?) stratified deposits, preglacial fluvial deposits, proglacial stratified drift (with two facies: A – probably alternations of the different clastic deposits; B – probably uniform sediments) and ground moraine.

The study of sparker seismic and bathymetric data has shown that:

(a) the sea floor of the inner irregular part of the continental shelf (strandflat) is acoustic basement;

(b) the sea floor morphology is very similar to that in the onshore area;

(c) younger deposits cover the acoustic basement in the marginal channels (fig. 3).

Sea floor of type 1 is thus considered to consist of basement rocks which have been glacially eroded.

Sea floor of *type 2* occurs in the area composed of sedimentary rocks. It is characterised by relatively high microrelief, amplitudes usually ranging up to 20 m, and in some places even more. The wavelengths are usually between 200 m and 2000 m but may exceed this in places. Some features are asymmetrical. Locally a higher frequency microrelief (with wavelengths usually less than 300 m and amplitudes up to 6 m) is superimposed on it.

There is only one seismic line on Narssalik Banke, but, judging from bathymetric data, most of it is characterised by sea floor of type 2. In addition, type 2 has been recognised in one part of Fiskenæs Banke.

Interpretation of type 2 is somewhat problematical. Certain similarities between types 1 and 2 suggest that they may have similar origin. Because type 1 is caused by glacial erosion, type 2 might be its counterpart in the areas consisting of sedimentary rocks.

Type 3 is characterised by high frequency microrelief with wavelengths from less than 50 m (not measurable on the seismic sections) to 300 m, sometimes even more, while amplitudes usually range up to 6 m, rarely more. In the area studied this type of sea floor has been found mostly in the channels (Godthåb Dyb, Fiskenæs Dyb, Danas Dyb, Ravns Dyb), but also on some banks (Fyllas Banke, Ravns Banke, Frederikshåbs Banke).

King (1967) found a similar type of sea floor on the Scotian shelf and, correlating it with the data from textural analyses of sea floor samples, determined that it consisted of glacial till. Sea floor of this type has been interpreted in the same way in the Gulf of St Lawrence (Shearer, 1973; Loring, 1975), on the northern, eastern and western sides of the Flemish Cap and on the northern and eastern edge of the Grand Banks (Monahan & Macnab, 1975). Such an interpretation is in good accordance with the seismic data dealt with here and the conclusion has been drawn that type 3 corresponds mainly to glacial till.

Type 4 is flat. In the area studied such a type of sea floor exists in Frederikshåb Dyb (in the transverse channel lying between Frederikshåbs Banke and Narssalik Banke as well as in its branches) and on some banks (Fyllas Banke, Fiskenæs Banke, Danas Banke, Ravns Banke and Frederikshåbs Banke). On the banks this type of sea floor is often developed on the inner and the shallowest parts of the banks. Here gentle undulations are associated with the flat bottom.

According to Monahan & Macnab (1975, p. 215), the smoothness of the bottom "may indicate regions where sedimentary processes are or have been active". This is obviously true for Frederikshåbs Dyb, but on the banks this type of sea floor might also be a consequence of erosion by sea currents.

Type 5 is characterised by small or moderate amplitudes (usually not greater than 5 m) and very variable wavelengths (from being unmeasurable on available seismic sections to more than 2000 m but mostly between 300 and 1500 m). It may be considered as a transition between types 2, 3 and 4.

Sea floor of this type is widespread in the area and especially on the banks (Fyllas Banke, Fiskenæs Banke, Danas Banke, Ravns Banke, Frederikshåbs Banke). It is difficult to explain its origin because in all probability, it may be of mixed kindred. One possibility is that it is the results of reworking of types 2 and 3, either by erosion or sedimentation.

SUB-BOTTOM GEOLOGY

Seismic facies analysis has made it possible to recognise several seismostratigraphic units which correspond to different lithostratigraphic units. The substratum to all the sedimentary units, the crystalline basement, outcrops in the strandflat.

Postglacial channel fill

Frederikshåbs Dyb and some of its branches are partly filled by a sequence characterised by a seismic facies different from others in the area studied (fig. 2). An even-layered parallel reflection configuration is characteristic of that seismic facies. Reflections are usually continuous, but their amplitudes can be changeable. Some reflections have high amplitudes, the others moderate or low. Lateral variations of amplitudes are also noticeable, but only occasionally conspicuous.

The sequence under consideration covers unconformably the older rocks of which the bottom of the older channel is made. On the strandflat and partly in its transverse part, the channel is incised into basement rocks, while the greatest part of the transverse channel is cut into sedimentary rocks. The configuration of the channel bottom shows that this is an old glaciated valley.

The present sea floor of the channel under discussion is flat and, as already mentioned, belongs to type 4.

In shallow parts of the sequences beds are parallel to the sea floor which has meant that it has been possible to calculate the true dip of the series in spite of the fact that seismic data are scarce. In the tranverse channel the dip is approximately 0.2°. This must be a primary sedimentary dip. The deepest parts of the sequence can be slightly undulating antiforms being above ridges on the underlying old valley floor and synforms above lows (fig. 2). The undulation is believed to be due to compaction of sediments.

So far the postglacial channel fill has been revealed by seismic survey only along a restricted length on two seismic lines. However, it has been possible to extrapolate seismic data and to determine with a good approximation the area covered by this sequence using bathymetric data, because a sea floor type corresponding to it has been identified.

The thickness of the postglacial channel fill varies very much depending on the channel bottom morphology and loction. On the sections available the maximum thickness is about 270-290 m (fig. 2).

From all available data it can be deduced that the sequence is a postglacial, well stratified sequence deposited in a submarine channel. It is made up of lithologically different layers; some of them may change laterally in composition, but only slightly. In all probability, the series is predominantly composed of clay, silt and sand (fine sand ?).

It is interesting to note that the northern branch of Frederikshåbs Dyb reaches the neighbourhood of the glacial lobe, Frederikshåbs Isblink. Because of that it is the author's opinion that the origin of the channel fill is closely connected with meltwater, i.e. the material has been brought (and is still being brought) by meltwater and has been deposited (and is being deposited) in the submarine channel. Similar sequences can be expected in other submarine channels as well as in fjords where there has been or is influx of meltwater.

Lateral moraine

Holtedahl (1970) interpreted some features on the flanks of certain channels as probable remains of lateral moraines. Henderson (1975) found features strongly suggestive of lateral moraines on both flanks of Sukkertop Dyb and Godthåb Dyb and on the south flank of Fiskenæs Dyb.

The available sparker seismic data revealed lateral moraines on the south flank of Sukkertop Dyb (the northern flank is outside the area mapped) and on the south flank of Godthåb Dyb. In addition moraines have been found on the south-west side of the marginal channel lying north-east of Fiskenæs Banke, but from the data available it is not quite clear whether those are lateral moraines or perhaps marginal (terminal) moraines.

The moraines are usually reflection free, but in some places may have chaotic and/or discontinuous reflection configuration. The Godthåb Dyb moraine is the largest and thickest (fig. 4). Using a treatment similar to that described by Allen (1972), it has been found that the velocity of the Godthåb Dyb lateral moraine is approximately 2050 m/s. With this velocity (which might be underestimated), the maximum thickness of the moraine is about 120 m. The bottom of the moraine dips towards the channel.

The maximum thicknesses of the other two moraines are about 50-60 m.

Ground moraine

A reflection free sequence (except for some point reflections) has been found in the following transverse channels: Sukkertop Dyb, Godthåb Dyb, Fiskenæs Dyb (fig. 4) and Danas Dyb (fig. 3). The type of sea floor associated with such sequences is always type 3.

From the seismic characteristics and sea floor type, it can be deduced that the reflection free sequences are unstratified and made up of clastic components with coarse grained sediments predominating at least in some places. Such properties of the sequence and its location in transverse channels (which are glaciated valleys) are reasons for interpreting it as ground moraine. The ground moraine is thickest in Fiskenæs Dyb (up to about 60 m) while its thickness in other transverse channels is:

Sukkertop Dyb	about 30 m
Godthåb Dyb	about 40 m
Danas Dyb	about 45 m

Proglacial stratified drift

A sequence which is interpreted as being composed of proglacial stratified deposits is developed on some banks and in some marginal channels. It is best known on Fiskenæs Banke and in the surrounding channels (fig. 4) where seismic control is best. The sequence is

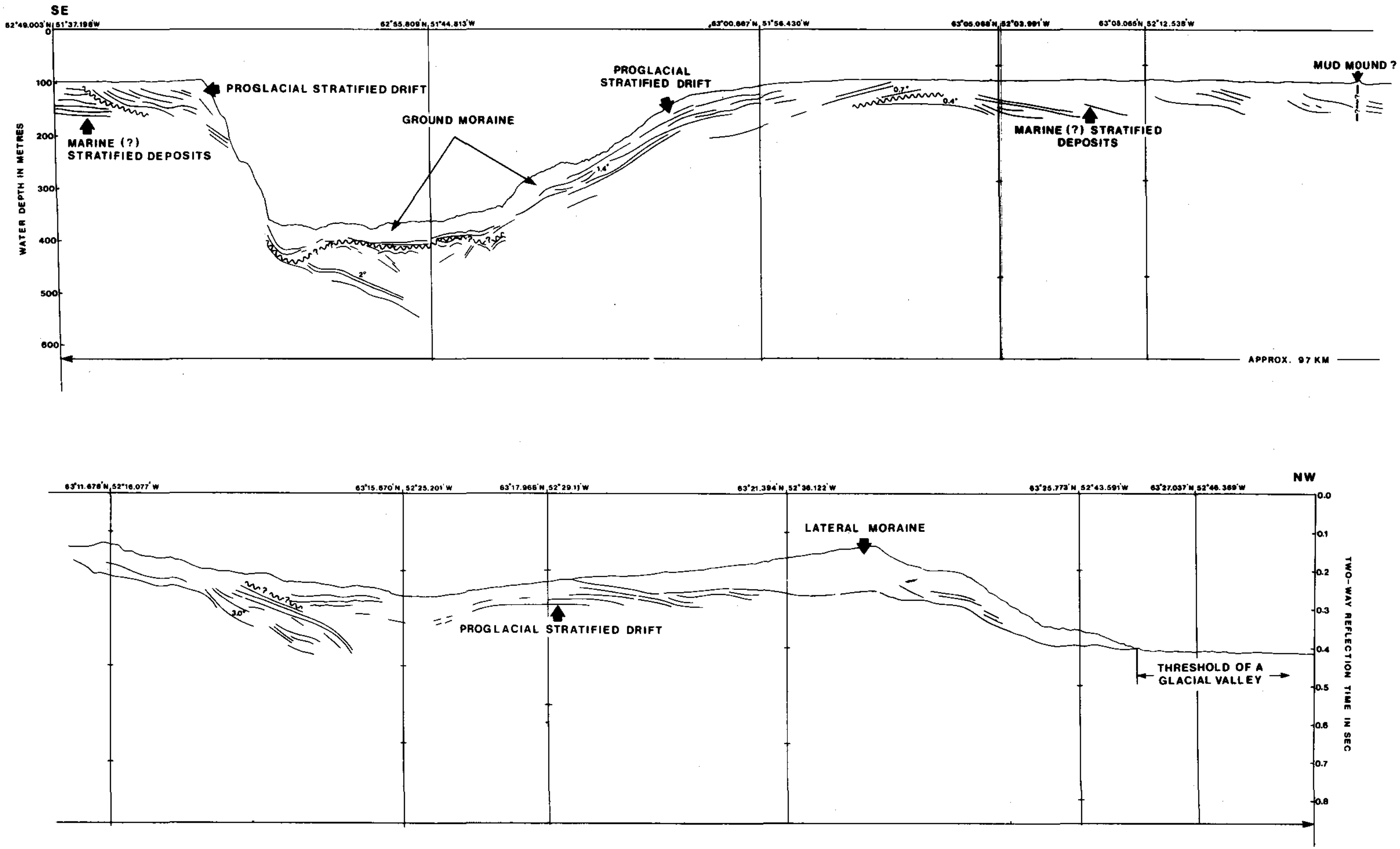

Fig. 4. Interpreted sparker seismic section (for location see the map).

present also on the south-eastern part of Fyllas Banke, Danas Banke (fig. 3), Ravns Banke, the eastern portion of Frederikshåbs Banke and their adjoining marginal channels. The same sequence probably also exists in Ravns Dyb, on the western part of Frederikshåbs Banke and on Narssalik Banke.

Judging from the reflection configuration the sequence is usually made up of stratified deposits with some intercalations of unstratified sediments. Lateral variations may be pronounced.

On the banks the deposits discordantly overlie the older sediments, often with an offlap as on Fiskenæs Banke. In the marginal channels or on their north-east flanks the sequence discussed covers the basement rocks, usually with an onlap.

In the transverse channels and on their flanks the deposits have been partly removed by glacial erosion and afterwards locally covered by younger moraines.

The sequence dips without exception towards the neighbouring channels, the dip being usually less than 2°. This dip is believed to be a primary sedimentary feature.

Locally small faults separate the deposits from the basement rocks (fig. 3).

By applying the method proposed by Allen (1972), it has been found that the velocity of the sequence in the north-west part of Danas Banke is about 2170 m/s. This result cannot be of great accuracy.

All available data (stratified sequence with intercalations of unstratified sediments, pronounced lateral variations, primary dip towards the neighbouring channels, restricted area of sedimentary basin(s), relationship with other lithostratigraphic units) suggest that the sequence was laid down in a water environment in the vicinity of the ice margin. The retreat of the ice margin caused the change in the position of the sedimentary basin now marked by the offlap on the banks and by the onlap to the east-north-east.

Preglacial fluvial deposits

On the two neighbouring sections in Danas Dyb, fluvial deposits were found below ground moraines. Unfortunately, the sections are of poor quality and the noise level is very high. Because of that the interpretation can only be tentative.

In some of the areas concerned there is a compound channel-like feature incised into older sedimentary rocks (fig. 5). Its width is 17-18 km. Two river channels filled with sandy

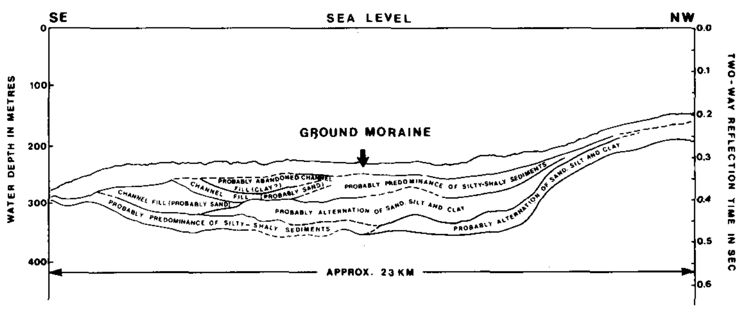

Fig. 5. Facies of the preglacial fluvial deposits interpreted from sparker seismic data. The preglacial fluvial deposits are covered by the ground moraine. For location see the map.

deposits could be recognised. An abandoned river channel filled with clayey deposits marks the top of the younger channel. However, most of the area is probably made up of flood plain deposits.

About 10 km further to the north-north-east, a channel-like feature with a width of about 8.5 km, can be seen on a seismic section (fig. 3). There are no reflections from within the feature, but its form and location suggest that it is a continuation of the above-mentioned preglacial fluvial complex. Here it is covered by proglacial stratified drift.

Stratified deposits of marine(?) origin

A sequence characterised by parallel, fairly continuous reflection configuration with variable, often high amplitudes is probably developed on all banks and in all transverse channels from Sukkertop Dyb in the north to Narssalik Banke in the south (figs 3 and 4). Its bottom cannot be seen on the sparker seismic section studied, while it is topped by preglacial fluvial deposits, progalcial stratified drift, postglacial channel fill or moraines. Generally, it dips towards the south-west, i.e. towards the sea. In some places it outcrops on the sea floor or is covered only by a thin veneer of recent sediments.

Judging from available data the sequence was laid down in a water environment, in a depositional basin of considerable extent. This fact, the reflection configuration and the general dip towards the sea lead to the conclusion that the sequence discussed is of marine origin.

SUMMARY OF GEOLOGICAL EVENTS

Although it is not possible to date the lithostratigraphic units revealed by the interpretation of available seismic data, the succession of geological events can be established.

Deposition of the marine(?) stratified deposits was interrupted and followed by a regression. The fluviatile deposits were formed on the emerged land. The ice margin must have advanced afterwards and at its maximum extent the ice probably covered the area of the strandflat. In the marginal and transverse channels and on some parts of the banks proglacial stratified drift was deposited. What is called in this paper 'proglacial stratified drift' probably corresponds, in different parts of the mapped area, to glaciofluvial, glaciomarine and, perhaps, glaciolacustrine deposits. Transitions between ice margin, glaciofluvial and glaciomarine sediments have been found in the onshore area discussed. The ice margin started to retreat thus causing some migration of the area of proglacial stratified drift deposition.

Later the transverse channels became the sites of glacial lobes. The proglacial stratified drift was partly removed by glacial erosion, while lateral and ground moraines were formed.

Again the ice margin retreated and the sea partly covered the area liberated from the ice sheet.

The postglacial channel fill found in Frederikshåbs Dyb is the youngest among the lithostratigraphic units described. In all probability, the deposition of that unit is still active.

Weidick (1975a, p. 6) interpreted the offshore banks "as marginal moraines laid down during the maximum extent of the Inland Ice". On the sparker seismic sections studied there is no evidence of marginal moraines, except in the south-east part of Fiskenæs Banke and on the flank towards the neighbouring marginal channel, but those moraines could be lateral moraines. It is worth noting that the author found evidence of marginal moraines on some banks outside the area mapped (e.g. on Store Hellefiske Banke between 67°37′N and 67°43′W). However, the types of sea floor indicative of glacial erosion or the presence of glacial drift suggest that the offshore banks, at least partly, might have been covered by the ice sheet during a more recent glaciation. The lack of marginal moraines may indicate that there were no important halts during the retreat of the ice sheet (Graff-Petersen, 1952).

Amongst other features seen on the seismic section the following are worthy of mention:

(1) At two places on Fiskenæs Banke mud mounds have been noticed above small faults (fig. 4). Such mud mounds have been interpreted elsewhere as gas seeps (Antoine, 1975).

(2) On the flank of Godthåb Dyb, near its connection with the marginal channel noth-east of Fiskenæs Banke, some features occur which were interpreted as slumps. The interpretation is based on the form of those features. The maximum inclination of the channel slope along the seismic line is about 6°. Judging from the bathymetric data slumping may even occur, at least locally, on slopes with an average inclination of about 3°.

Acknowledgements

The present study would not have been possible without sparker seismic data obtained from Greenland Exploration Management Co., original echograms recorded by the Royal Danish Hydrographic Office and new bathymetric maps prepared by the Geological Survey of Greenland. I am indebted to all those institutions. I wish also to thank G. Henderson who followed my work in all its phases and critically read the manuscript.

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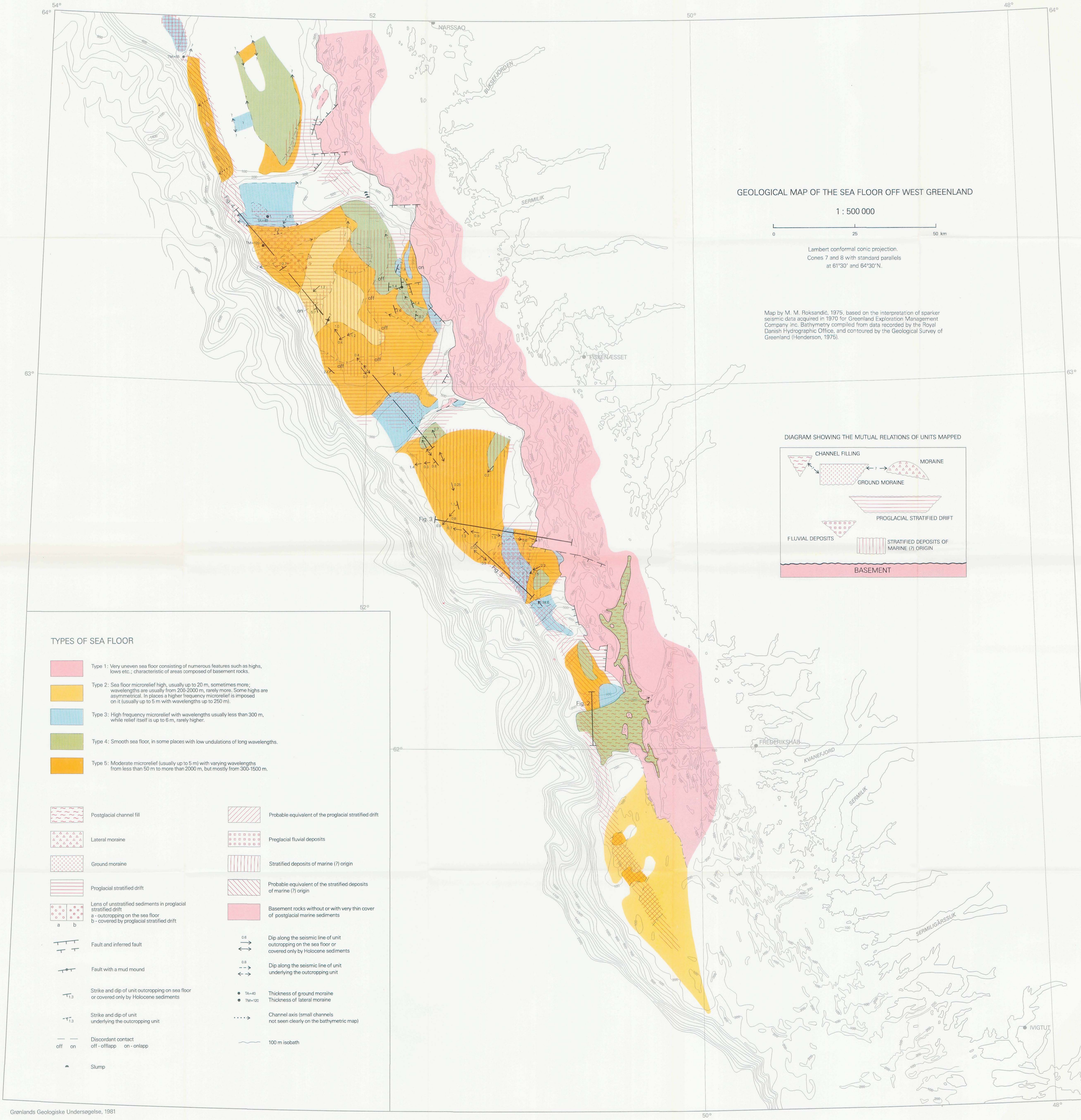
GRØNLANDS GEOLOGISKE UNDERSØGELSE

THE GEOLOGICAL SURVEY OF GREENLAND

Plate 1



GEOLOGICAL MAP OF THE SEA FLOOR OFF WEST GREENLAND

1 : 500 000

0 25 50 km

Lambert conformal conic projection.
Cones 7 and 8 with standard parallels
at 61°30′ and 64°30′N.

Map by M. M. Roksandić, 1975, based on the interpretation of sparker seismic data acquired in 1970 for Greenland Exploration Management Company Inc. Bathymetry compiled from data recorded by the Royal Danish Hydrographic Office, and contoured by the Geological Survey of Greenland (Henderson, 1975).

DIAGRAM SHOWING THE MUTUAL RELATIONS OF UNITS MAPPED

CHANNEL FILLING
MORAINE
GROUND MORAINE
PROGLACIAL STRATIFIED DRIFT
FLUVIAL DEPOSITS
STRATIFIED DEPOSITS OF MARINE (?) ORIGIN
BASEMENT

TYPES OF SEA FLOOR

Type 1: Very uneven sea floor consisting of numerous features such as highs, lows etc.; characteristic of areas composed of basement rocks.

Type 2: Sea floor microrelief high, usually up to 20 m, sometimes more; wavelengths are usually from 200-2000 m, rarely more. Some highs are asymmetrical. In places a higher frequency microrelief is imposed on it (usually up to 5 m with wavelengths up to 250 m).

Type 3: High frequency microrelief with wavelengths usually less than 300 m, while relief itself is up to 6 m, rarely higher.

Type 4: Smooth sea floor, in some places with low undulations of long wavelengths.

Type 5: Moderate microrelief (usually up to 5 m) with varying wavelengths from less than 50 m to more than 2000 m, but mostly from 300-1500 m.

- Postglacial channel fill
- Lateral moraine
- Ground moraine
- Proglacial stratified drift
- Lens of unstratified sediments in proglacial stratified drift
  a - outcropping on the sea floor
  b - covered by proglacial stratified drift
- Fault and inferred fault
- Fault with a mud mound
- Strike and dip of unit outcropping on sea floor or covered only by Holocene sediments (1.3)
- Strike and dip of unit underlying the outcropping unit (1.3)
- Discordant contact: off - offlapp, on - onlapp
- Slump
- Probable equivalent of the proglacial stratified drift
- Preglacial fluvial deposits
- Stratified deposits of marine (?) origin
- Probable equivalent of the stratified deposits of marine (?) origin
- Basement rocks without or with very thin cover of postglacial marine sediments
- Dip along the seismic line of unit outcropping on the sea floor or covered only by Holocene sediments (0.6)
- Dip along the seismic line of unit underlying the outcropping unit (0.8)
- TA=40 Thickness of ground moraine
- TM=120 Thickness of lateral moraine
- Channel axis (small channels not seen clearly on the bathymetric map)
- 100 m isobath