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The Geological Survey of Greenland
Report No. 63

Offshore geology of northern West Greenland (69° to 75°N)

by

Leslie R. Denham

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Offshore geology of northern West Greenland (69° to 75°N)

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2 plates in pocket

1974

Abstract

A continuous basin is present offshore, with a maximum thickness varying with latitude from less than 2 km to more than 10 km. The age of the sediments is unknown, but they probably range from Tertiary down to at least Jurassic, and there is some evidence for Palaeozoic ages. The offshore basin is separated by a basement ridge from the onshore basin, and the offshore extension of the Tertiary volcanics is smaller than previously thought. Petroleum potential of the area is good, but limited by a scarcity of structural traps and by severe ice conditions.

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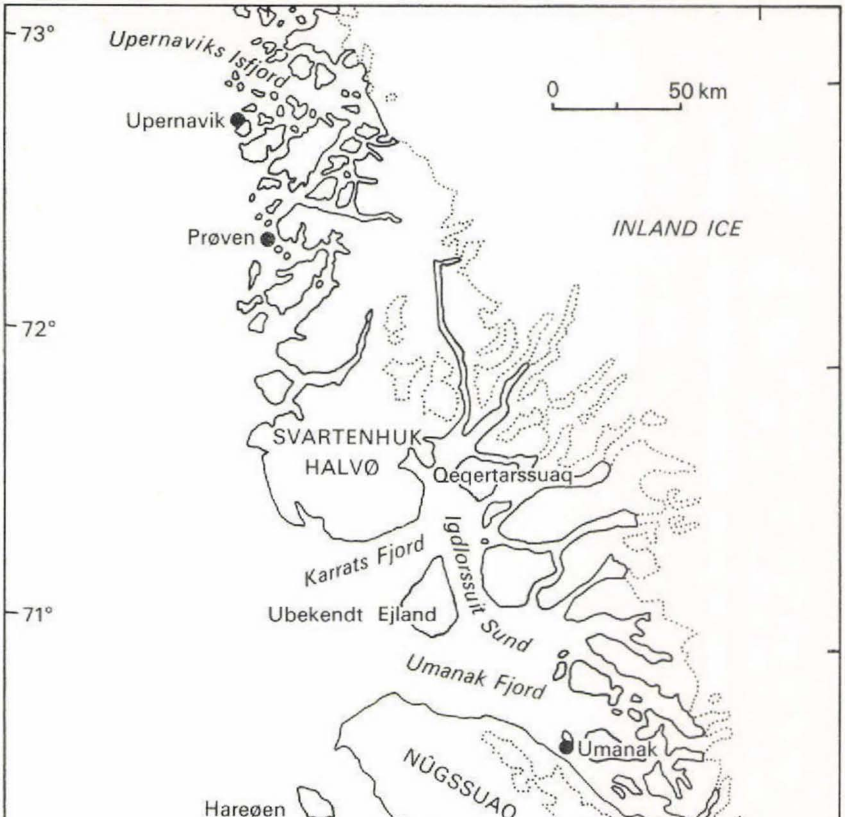

Fig. 1. Outline map of area.

SCOPE OF REPORT

The West Greenland continental shelf north of 69°N has been investigated in recent years by the Bedford Institute, and several papers have been published covering these operations; Ross & Henderson (1973) give the most recent data, plus a bibliography covering earlier Bedford operations. However, these authors have generally concentrated on the large scale geotectonic implications of their results, and the evaluation of various hypotheses on the origin and development of Baffin Bay and Davis Strait. Additional marine geophysical data collected by GGU during 1972 has considerably clarified the geology of the northern half of the West Greenland continental shelf. This report attempts to build up a picture of the geology of the continental shelf north of Egedesminde, with emphasis on the distribution, thickness and structure of the sedimentary rocks, and their economic potential as petroleum producers.

PREVIOUS GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS

The land areas north of Egedesminde have been studied in more or less detail for many years. The Cretaceous to Tertiary sediments and volcanics on Nûgssuaq and north Disko have been given particular attention (Rosenkrantz & Pulvertaft, 1969; Henderson, 1969a). In this area a sequence of at least 2 km of marine and non-marine sediments is known, ranging in age from Lower Cretaceous to Danian (lowermost Paleocene). The sediments are overlain by a Lower Tertiary volcanic pile which is in some areas several kilometres thick.

Outside the Disko-Nûgssuaq area geological mapping has been only of a reconnaissance nature (Rosenkrantz *et al.*, 1942; Henderson & Pulvertaft, 1967; Henderson 1969b; Escher & Pulvertaft, 1968). North from Holm Ø mapping is almost non-existent until the North Star Bugt area (around Thule Air Base) is reached, which has been mapped in some detail (Davies *et al.*, 1963). The basalts and sediments of Nûgssuaq continue north as far as Prøven, where outliers of basalt lie on Precambrian basement. Volcanics cover most of Svartenhuk Halvø, and according to Pulvertaft & Clarke (1966) are at least 8 km thick in the southern part of the peninsula; the thickest anywhere in West Greenland.

North from Prøven the rocks outcropping on the islands and peninsulas along the coastline are crystalline rocks of Precambrian age. From Prøven to Upernavik the outcrop is dominantly a coarse grained granite. North of Upernavik the granite is underlain by gneiss of granulite facies. This is significant from the point of view of interpretation of offshore magnetic data in that it contains significant quantities of magnetite (A. Escher, pers. comm.), unlike the granite, which appears to be essentially non-magnetic. North of 73°45′ the character of the gneisses changes, but the northern limit of the magnetite-bearing gneiss is not known.

The rocks of Kap York consist of deformed basic intrusives of Precambrian age; these contain only small quantities of magnetite. However, immediately to the north a 'gneissic magnetite vein' occurs at Magnetit Bugt (on the west end of Kap Atholl, 100 km north-west of Kap York). This vein, 6 to 15 m wide, contains about 50 % magnetite. Also in the area north of Kap York Precambrian sediments are intruded by dolerite dykes and sills containing abundant magnetite.

Offshore geophysical measurements in the area under consideration were carried out in the 1960s by various Canadian icebreakers, in 1970–71 by CSS *Dawson,* CSS *Hudson* and CSS *Baffin,* and in recent years, south of 72°N, by various commercial companies (this last work is not available for publication).

The early work by the Canadian vessels is summarized by C. E. Keen *et al* (1972). This was only magnetic profiling essentially on 'ships of opportunity', so the coverage is based on operational considerations, not on geological requirements. However, these data give a valuable background to fill in between the more complete measurements made in 1970 and 1971. A reasonably dense grid of magnetic profiles was obtained over the whole of the continental shelf outside Greenland territorial waters.

Three Canadian ships – *Baffin, Hudson* and *Dawson* – carried out surveys in Davis Strait, Baffin Bay, and Melville Bugt in 1970. The *Dawson* (M. J. Keen *et al.,* 1972) concentrated on detailed surveying south-west of Disko, but completed two traverses more or less parallel to the coast in Melville Bugt, very approximately 70 and 100 km from the coast. *Hudson* (C. E. Keen *et al.,* 1972) made one traverse which crossed part of the Greenland shelf at about 72°N, recording seismic, gravity and magnetic data. *Baffin* (C. E. Keen *et al.,* 1972) made a traverse into Melville Bugt and some more detailed traversing over the edge of the continental shelf in the outer part of Melville Bugt; gravity and magnetic measurements were made along these traverses.

In 1971 *Hudson* returned to the Greenland shelf and recorded seismic, gravity and magnetic data from the Melville Bugt area and off Umanak Fjord. Magnetic and gravity data were collected on a traverse into Umanak Fjord as far as Umanak island (Ross & Henderson, 1973).

These geophysical investigations were all used by Ross & Henderson (1973) to present an interpretation of the offshore geology of the northern half of the West Greenland continental shelf. They identified two zones in the offshore extension of the basalts of Disko and Nûgssuaq, an inshore zone of dipping basalts at shallow depth, and an outer zone of horizontal basalts overlain by sediments of increasing thickness to the west and to the south (cf. M. J. Keen *et al.*, 1972, fig. 7 and 8). Further north, in Melville Bugt, a major continuous coast-parallel trough was estimated to contain 7 to 12 km of sediments, and was identified as a graben (following Hood & Bower, 1970; Barrett & Manchester, 1969, and later authors). To the landward side of the trough is a gravity high associated with high amplitude, high frequency magnetic anomalies, and a very irregular sea floor with a seismic velocity of 5.8 km/sec. West of the trough is a broad area of relatively high gravity and magnetic anomalies, which in part is covered by at least a few hundred metres of sediments. This area is bounded to the west by the continental slope.

MARINE GEOPHYSICAL SURVEY, 1972

As there were still unexplained discrepancies in the interpretation based on the existing data (Ross & Henderson, 1973) GGU carried out a marine geophysical survey using the M. S. *Brandal* in the 1972 field season. This survey was intended principally to fill the gaps caused by fjords in the onshore mapping of the Cretaceous-Tertiary basin, to map the close inshore area (mainly from 68°N to 72°N), and to relate this to both the onshore geology and to the previous geophysical work offshore. It was thought that the basin known from outcrops would be a key to the geology of the offshore area, so both the detailed structure of the onshore basin and its relationship to the shelf areas were important.

Brandal was equipped with a seismic reflection system and a magnetometer. The reflection system consisted of a single trace recorder and an airgun energy source. The hydrophone streamer consisted of four 50 element active sections, each 10 m in length, separated by 10 m inactive sections and connected to the ship by a 60 m cable. A preamplifier was incorporated in the outboard end of the cable. The signal from the streamer was fed via frequency filters and amplifiers to both a graphic recorder and an FM tape recorder. The signal source most commonly used was a single 20 cubic inch (0.328 1) airgun running at a pressure of about 100–120 atmospheres, and firing every six seconds. A telemetry receiver was carried to allow the use of expendable sonobuoys. The magnetometer was a modern proton precession instrument with a nominal accuracy (in the configuration used) of ± 1 gamma, recording on a 125 mm chart.

Navigation was accomplished by a combination of dead reckoning and radar fixes on coastal features. This was satisfactory when close inshore, but was increasingly inaccurate as the coast was left behind. However, as little work was done far offshore the errors in navigation are small relative to the distances between lines of traverse.

The traverse lines completed are shown in Map 1. A reasonably close grid of lines was completed in Disko Bugt, Vaigat, Umanak Fjord, and Igdlorssuit Sund, with less dense coverage over the coastal waters from Egedesminde to Svartenhuk Halvø, from close to the coast to about 40 km offshore. Traverses of a purely reconnaissance nature were carried out between Svartenhuk and Upernaviks Isfjord, with the furthest north traverse continuing west for 120 km from the outermost skerries. A detailed survey was carried out in Upernaviks Isfjord to study Quaternary sedimentation.

The magnetometer data collected are generally unaffected by magnetic storms, and have been used for interpretation without correction for diurnal variation and without reduction to a geomagnetic reference field. Because the anomalies used are of short duration (usually less than 30 minutes) and because the shape of anomalies is more important in this study than the absolute values of the field, these simplifications have not had a significant effect on the interpretation.

Seismic reflection data recorded generally show an effective penetration of up to 500 metres where sedimentary rocks are known to be present. Elsewhere, penetration varies from none at all to about 500 metres. With the single channel mode of recording, no velocity information was normally recorded; even the method described by Allen (1972) was rarely applicable, because structural variations within the sediments were difficult to separate from the time anomalies caused by sea bed topography, and because the sea floor was generally smooth and regular where sediments were present.

The southern limit of the study presented here is approximately the southernmost line of the 1972 survey, but to the north the study has been extended to include most of the 'graben' described by Barrett & Manchester (1969) and later writers, because the interpretation was substantially changed after one of the 1972 traverses crossed near its southern end.

PROBLEMS OF INTERPRETATION

After examining the data collected in 1972, together with some of the previously recorded seismic and magnetic profiles, it became apparent that the picture of the geology of the continental shelf presented by Ross & Henderson (1973) was not consistent with the new total of information available. In normal geological mapping, the first job is to establish the areas of outcrop of various mappable units. Similarly, in this area the first priority was to establish the areas of outcrop of the major geological units on the sea bed. This was attempted, ensuring as far as possible that the total picture was not inconsistent with any of the known geophysical, geological or geomorphological data.

From the 1972 survey the following geophysical information was available:

(1) Total magnetic intensity profiles, uncorrected for any diurnal variation or regional field;
(2) Reflection seismic profiles, which gave detailed bathymetry, and, in some places, reflections from within the rocks underlying the sea floor.

Because the seismic profiles showed no sub-bottom reflections over more than half the distance traversed, the magnetic data were used as a primary indicator of sub-sea rock type, and the seismic data used as a subsidiary criterion. The first attempt at division into geological units was made on the basis of general character of the magnetic profile. On the basis of known onshore geology it was decided that the shelf should be divided into three principal geological divisions: Precambrian basement, pre-Quaternary sediments and Tertiary volcanics. The Quaternary sediments were of limited extent and thickness, and easily identified on the seismic sections, so they were initially ignored.

The subdivision of the geology on the basis of magnetic profiles was not without problems, as fig. 2 illustrates. Here are shown some typical profiles across geological units where there is no reasonable doubt of their identification: either the line runs so close to land that the onshore geology can be reliably extrapolated, or the combination of magnetic and seismic data leaves no doubt of the rock type.

If short wavelength anomalies of several hundred gammas amplitude are present, as in profiles 1, 3 and 5 of fig. 2, the depth (or rather, the maximum depth) of the source of the anomaly can be calculated by, for example, Peters' Method (Dobrin, 1960, p. 312). If this depth is approximately equal to the depth of water, as it is in many cases, the source of the anomaly is on the sea floor (or perhaps covered by a thin layer of sediment); i. e. there is a contact on the sea floor between two materials of significantly different susceptibility or remanent magnetization, and this contact is approximately vertical. Where the calculated depth is greater than the water depth, the implication is a non-magnetic layer overlying the magnetic basement, and if reflections are present on the seismic section it is reasonably certain that this is so. The difference between the calculated depth to magnetic basement and the water depth is the thickness of sediments underlying the sea floor.

There is uncertainty about the sea floor geology when magnetic variations occur on the sea floor. Three possibilities exist: (1) magnetic material intruded into sediments in the form of dykes or sills; (2) a continuous section of more or less magnetic material, i. e. volcanics; and (3) a crystalline basement containing unevenly distributed magnetic material.

The first possibility can frequently be identified from the seismic sections: the sediments on each side of the magnetic feature frequently give reflections, while the more resistant igneous rock may show on the sea floor as a ridge. If the intrusions are isolated, the magnetic profiles will give the smooth character of 2 or 4 in figure 2 away from each intrusion. These anomalies almost invariably are negative, suggesting that igneous rocks have dominantly reverse remanent magnetism. This inter-

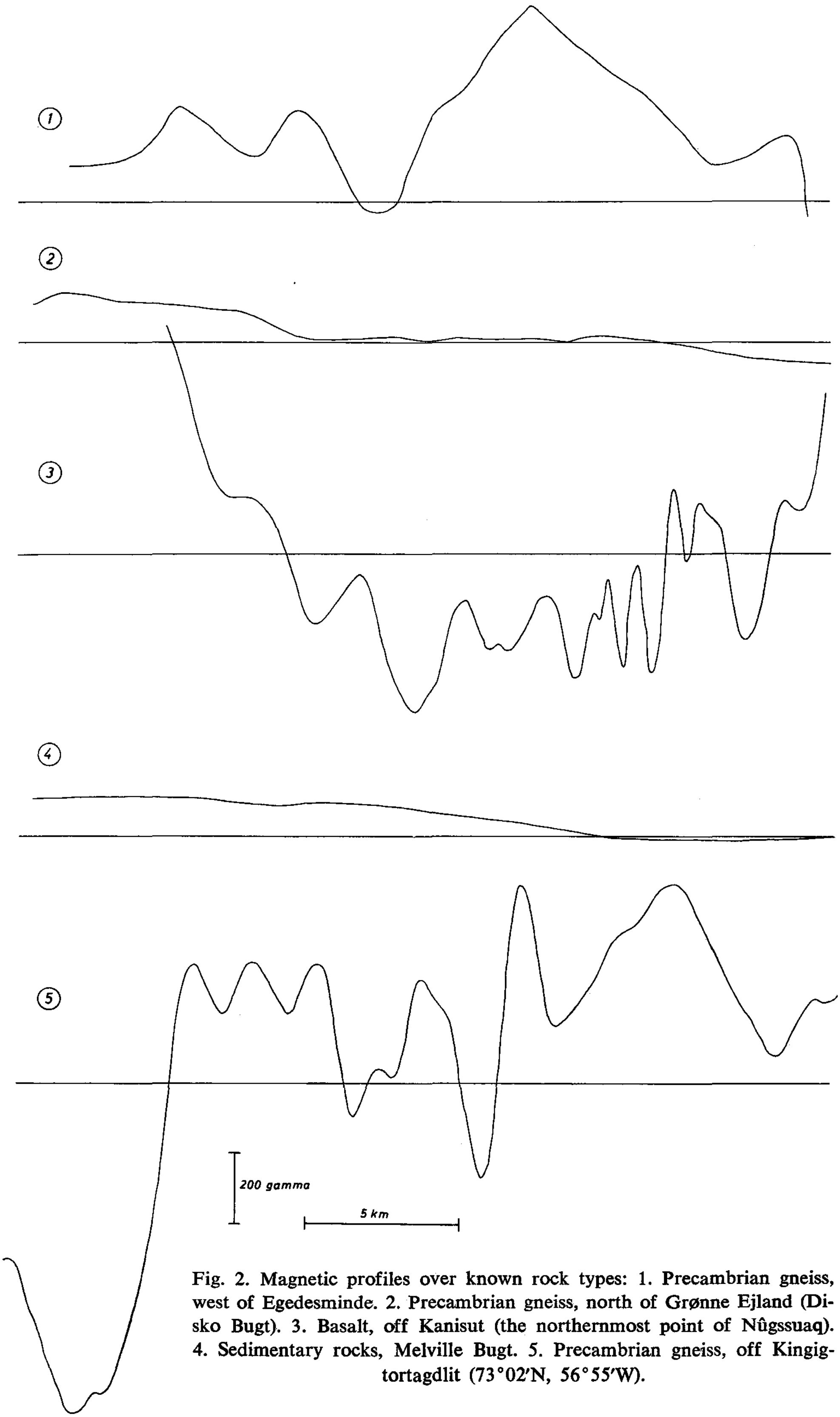

Fig. 2. Magnetic profiles over known rock types: 1. Precambrian gneiss, west of Egedesminde. 2. Precambrian gneiss, north of Grønne Ejland (Disko Bugt). 3. Basalt, off Kanisut (the northernmost point of Nûgssuaq). 4. Sedimentary rocks, Melville Bugt. 5. Precambrian gneiss, off Kingigtortagdlit (73°02′N, 56°55′W).

pretation is supported by Kristjansson & Deutsch (1973), who found that the Disko basalts were dominantly strongly magnetized with reverse polarity. While the intrusions we are considering are not definitely related to the basalts, a close connection is likely. If the source of the anomaly is assumed to be a plate-like body, the anomaly will be symmetrical if it is vertical and asymmetrical if it is dipping at a shallow angle – in this way a dyke can be distinguished from a sill. (This argument is only valid if the geomagnetic field is close to vertical, as it is in this part of Greenland, where the magnetic inclination is greater than 80°.)

It is difficult to distinguish between the second and third possibilities – which in the context of the regional geology are either Precambrian crystalline basement or Tertiary volcanics – as is shown by the general similarity of 1, 3 and 5 in figure 2. In each profile the anomalies consist of a large number of complex and overlapping highs and lows. Additional criteria are therefore necessary to distinguish the two types of geology. In most areas evidence is available from sea floor topography, seismic reflections or the lower frequency content of the magnetic profile. If the overall area of high frequency magnetic anomalies has a dominantly negative magnetic intensity relative to adjacent areas the implication is that the magnetic material is dominantly reversely magnetized and is probably Tertiary volcanics (see Kristjansson & Deutsch, 1973). It is almost axiomatic that seismic reflections cannot originate from within a granitic and metamorphic basement complex, but this is by no means so with a volcanic sequence consisting of distinct flows though reflections of good quality cannot be expected because the irregular flow surfaces and high reflection coefficients scatter most of the seismic energy, but some reflections are likely to be present. So if the seismic section shows any reflections in these magnetic areas the sea floor is probably Tertiary volcanics. Traverses in areas where the sea floor rock type is reliably known from nearby outcrops on land has shown distinct variations in style of sea floor topography which can be correlated with variations in rock type. While smooth, peneplaned surfaces are present in all rock types, where glacial valleys have been cut the profiles differ considerably. In the Precambrian areas it is quite common to find a vertical, or very near to vertical, rock face several hundred metres high, but in volcanic areas the steepest slopes are about 30°, except for local steps of up to a few tens of metres. The surface irregularities in the volcanics also have a shorter wavelength than surface features in the basement rocks. From a study of the sea floor topography as shown on the seismic sections, it is therefore often possible to decide whether a magnetic rock is Tertiary volcanics or Precambrian gneiss.

Where no obvious magnetic anomalies are present it is usually necessary to rely on the seismic sections. It can reasonably be assumed that the Tertiary volcanics always contain significant magnetite, so they are not present where there are no magnetic anomalies. Therefore any reflections recorded in these areas indicate sedimentary rocks on the sea floor. In the absence of magnetic anomalies, and in view of the very limited penetration of the seismic system, the thickness of the sediments is usually unknown, except where it can be estimated by normal geological methods. The absence of both sub-bottom reflections and magnetic anomalies leaves the rock type in doubt. Some areas can immediately be designated as basement from the sea floor topography, but this is not always diagnostic. The absence of reflections must generally be regarded as a strong indication of the absence of sediments, as everywhere sediments are known to be present there are at least poor quality reflections. The section known on land is generally a well bedded

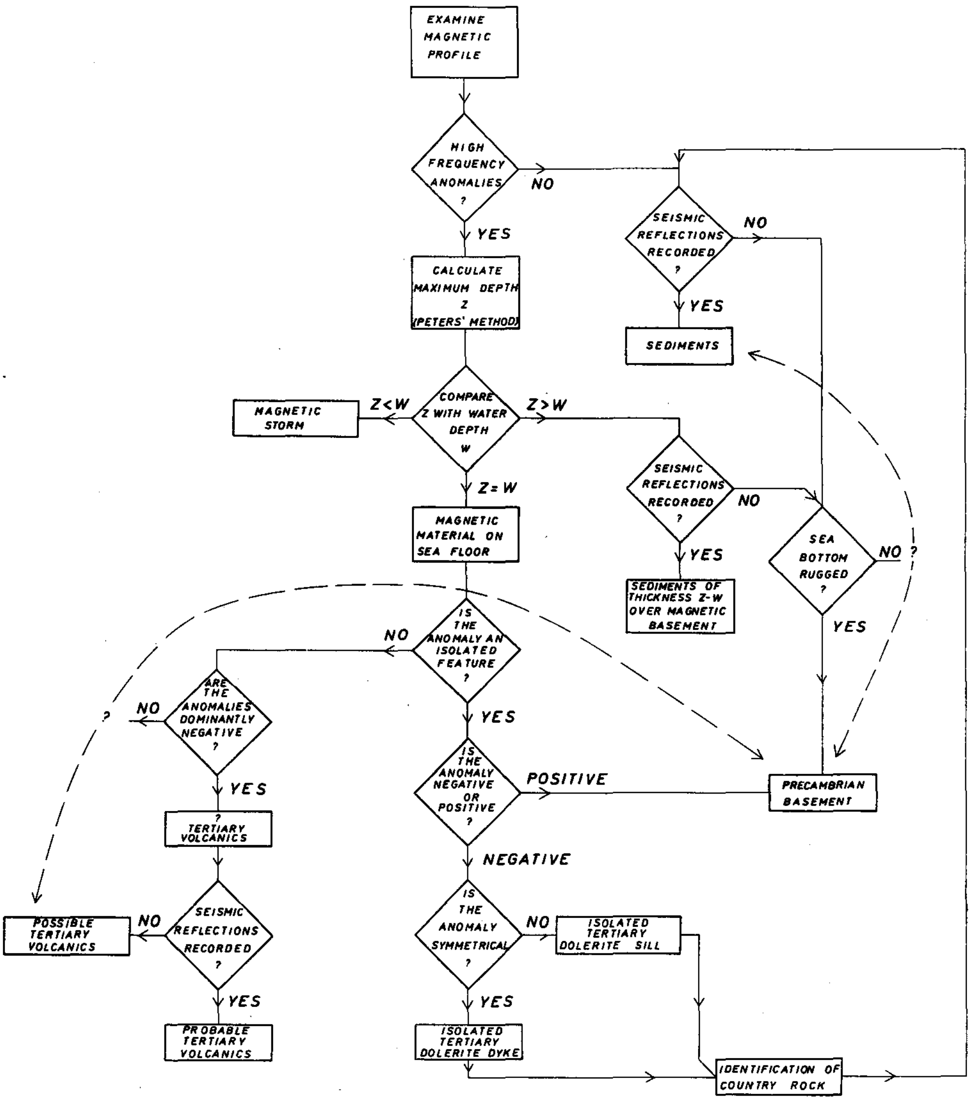

Fig. 3. 'Flow chart' illustrating the logic used in deducing sub-sea geology from the survey data.

alternation of sandstone and shale with a number of coal seams, so reflections could be expected to be present wherever this section is present.

Low amplitude magnetic anomalies, such as on profile 2 (fig. 2) are reasonably interpreted as indicating basement at shallow depth, possibly on the sea floor (this can be checked by a depth calculation using Peters' Method).

The arguments detailed above for identification of sea bed rock types are summarized in the interpretation flow chart (fig. 3). This illustrates the underlying logic used to interpret the geophysical data collected in 1972, as well as other available data, but as geology is still an art as much as a science, the chart is very much a simplification of the thought processes used: at each stage other data which are difficult to evaluate objectively were used. This includes ideas on the overall reasonableness of the total geological picture being built up.

The geology of the continental shelf from Egedesminde to the northern end of Melville Bugt has been mapped on the principles discussed above, and is shown on the accompanying map. Onshore geology has been taken, with modifications, from the map by the Geological Survey of Greenland (1970) and Rosenkrantz & Pulvertaft (1969). The geology is discussed in detail in the following sections of this report.

GEOLOGY OF THE CONTINENTAL SHELF FROM EGEDESMINDE TO SVARTENHUK HALVØ (68°30'N to 72°00'N)

The gneiss ridge known from outcrops on Disko has been shown to be continuous, as expected, with the Precambrian rocks in the Egedesminde area, which also extend over the greater part of Disko Bugt. In view of the general feeling (e.g. Ross & Henderson, 1973) that the Precambrian rocks in this general area were essentially non-magnetic it was rather surprising to find high amplitude magnetic anomalies in the area north-west of Egedesminde. However, these can be explained as originating from an extension of the Precambrian supracrustal rocks described by Ellitsgaard-Rasmussen (1954) north-east of Egedesminde and reported to extend to Hunde Ejland and probably to Rotten (A. Escher, pers. comm.). A brief examination of the outcrop of Rotten would clarify this. No magnetic measurements have been made on these rocks. Ellitsgaard-Rasmussen described them as containing significant and variable, but unspecified, quantities of 'ore minerals' which included magnetite, haematite, pyrrhotite and ilmenite, so large amplitude magnetic anomalies might expected over this area.

West of this gneiss ridge is an area of volcanics very similar to that shown by M. J. Keen *et al.* (1972). The eastern boundary of the volcanics may be depositional – controlled by topography of the Precambrian rocks at the time of deposition of the volcanics – or fault controlled. The complex tectonic interrelation of the volcanics and the basement ridge is not clear, but it is likely that both faulting and topography are involved. The volcanics may be underlain by sediments of Cretaceous to Danian age. There is no evidence other than the presence in west Disko of contaminated lavas (A. K. Pedersen, pers. commun.) that these volcanics are underlain by sediments, but sediments similar to those underlying the volcanics on north-east Disko are probably present. The volcanics show some evidence of consistent westerly dips, continuing the general structure known from outcrops onshore, but dips appear to be mainly less that 10°. On some lines there is evidence of a dip reversal to give a synclinal structure (fig. 4).

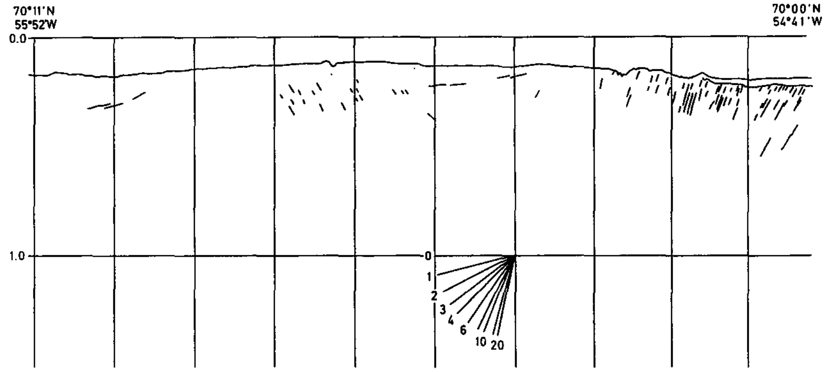

Fig. 4. Plotted seismic section, from 70°00'N, 54°41'W to 70°11'N, 55°52'W. Reflection time scale is in seconds two-way time, and dip scale in degrees. Vertical lines are at 30 minute intervals.

M. J. Keen *et al.* (1972) interpreted the western boundary of the volcanics as being a zone across which the volcanics dip under an increasing cover of sediments, with up to 6 km of sediments overlying the basalt. However, the data now available suggest that the boundary is actually a fault: in particular, the very sharp change in character of the magnetic profiles supports this interpretation. This fault can be traced on the magnetic profiles north to a point west of Ubekendt Ejland. To the west of the fault (in the south) there is a zone of longer wavelength magnetic anomalies which give estimated depths increasing westwards to at least 4 km in a few tens of kilometres. That this indicates sediments overlying the magnetic material is supported by sonobuoy measurements west of Disko (Ross & Henderson 1973) which give velocities of 2.1–2.3 km/sec for the uppermost layer, and 3.7–4.4 km/sec at a deeper level. The age of these sediments is unknown, but three points can be made: it is not geologically probable that 4 to 6 km or more of sediments would have accumulated in this area since the end of the Eocene (the probable age of the uppermost basalts; see Rosenkrantz & Pulvertaft, 1969); the velocities measured, particularly in the deeper layer, are rather high for Tertiary sediments; and the character of the magnetic anomalies suggests they originate from a Precambrian basement rather than from the Tertiary basalts. For these reasons I consider the major part of the sediments is probably older than the basalts, and separated from them by a fault downthrown to the east. This concept is shown in plate 1.

The age of the sediments must still be regarded as unknown. There is almost everywhere a cover of Quaternary deposits, reaching a thickness of several hundred metres in some glacial valleys (e. g. Vaigat). It is conceivable that the sedimentation in some areas has been continuous since the early Tertiary, giving the thickness of up to 1000 m of material with a seismic velocity of 2.1–2.3 km/sec recorded by the Bedford Institute (Ross & Henderson, 1973). If this is so, the base of the lower velocity section could mark the unconformity represented on land by sub-aerial deposition of the upper part of the volcanic sequence, and the higher velocity rocks would be the sediments older than the volcanics. This interpretation is weakened by two points: the lower velocity sediments are slightly higher in velocity than would be expected for post-Eocene sediments which have never been deeply buried, and the higher velocity rocks are distinctly higher in velocity than the Cretaceous sediments underlying the volcanics on land (see Sharma, 1973).

An alternative interpretation is that the post-Eocene to Quaternary sediments are a thin veneer which has not been identified on the sonobuoy profiles, and the 2.1–2.3 km/sec layer is the equivalent of the Cretaceous-Danian section seen on land. The higher velocity rocks would then be a sedimentary sequence older than that known on land. The age of this is unknown, but a Jurassic fossil was described last century (Haughton, 1860) from a dredge haul by M'Clintock "off Lievely" [Godhavn]. There appears to be no record of the exact location of this dredge station, but from M'Clintock's narrative a position about 68°N, 56°W seems likely (M'Clintock, 1959). Efforts to find Haughton's specimen to check the determination have been unsuccessful. However, the rather tenuous existence of a Jurassic fossil from the area, plus the high velocities, add up to a definite probability that sediments older than Cretaceous are present in the area. The velocities suggest an Upper Palaeozoic age (Dobrin, 1960, p. 22).

Whichever interpretation is accepted, it can be reasonably accepted that the lowest sediments present in the western offshore area are at least as old as the lowest sediments known on Nûgssuaq, and possibly older. The upper part of the section may be Cretaceous, Tertiary, or Tertiary-Quaternary.

To the north, the section west of the fault thins until west of Mellemfjord basement outcrops on the sea floor. The area of basement outcrop widens to the north until it is cut off against the Svartenhuk volcanics, probably by a fault downthrown to the north. This area of basement outcrop on the sea floor includes a magnetic body which is the source of an unusually large positive anomaly. This feature lies across the entrance to Umanak Fjord, and is about 30 km long and 6 km wide, striking NE-SW.

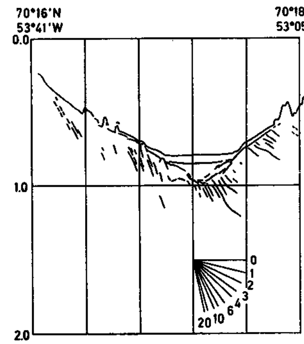

Fig. 5. Plotted seismic section, from 70°18'N, 53°05'W to 70°16'N, 53°41'W. A section across Vaigat. Note the sea floor irregularities at about 300–400 m water depth each side of the channel. These appear to be lateral moraines left by the glacier which formerly occupied the valley. Same scale as fig. 4.

The geology of the area further east is a logical extension of the onshore geology described by Rosenkrantz & Pulvertaft (1969) and Henderson (1969a). The fault along Vaigat suggested by Bridgwater *et al.* (1973) does not appear to be present in the sediments (fig. 5). Several seismic sections across Vaigat show no sign of faulting, and dips are generally in agreement with those measured in outcrops along the coasts of Nûgssuaq and Disko.

SVARTENHUK TO MELVILLE BUGT

The volcanics on Svartenhuk Halvø are a major problem in the general geology of West Greenland. The total thickness of them has been estimated to be at least 8 km in the southern part of the peninsula (Pulvertaft & Clarke, 1966), but they appear to be quite limited in their offshore extension to the south and west. The same problem of accommodating unlikely thicknesses of volcanics in a geological interpretation is present on Ubekendt Ejland, and to a lesser extent on Nûgssuaq. Similar thicknesses of volcanics have been suggested in the past on the west coast of Disko, but recent field work by A. K. Pedersen (pers. comm.) has shown that repetition of flows by faulting gives an apparent thickness much greater than the actual thickness, which he estimates to be about 2 km on the northern part of the west coast of Disko. Similar faulting has been suggested on Ubekendt Ejland and Svartenhuk Halvø, but no field evidence has been found of antithetic faulting on a scale large enough to significantly reduce the apparent measured thickness (G. Henderson, pers. comm.). Calculations of the thickness of the volcanics on Svartenhuk Halvø from measurements by Münther (1972) give inconsistent results: the addition of measured sections along the east coast of Svartenhuk Halvø gives a total of 11.25 km while the addition of measured sections along the north coast only gives a total thickness of 4 km.

However, on present data a thickness of at least 4 km of volcanics and sediments must be allowed in southern Svartenhuk Halvø. This implies a major east-west feature, probably a fault, running through Karrats Fjord and limiting the southern extent of the Svartenhuk volcanics, as shown on the map. The edge of the volcanics is not well defined, as it is mostly based on magnetic data where the distinction between volcanics, Precambrian basement rocks and thin sediments over basement is never very clear. There is also poor coverage of this area by both the GGU traverses and the Bedford Institute traverses.

To the west and north-west of Svartenhuk Halvø the limit of the volcanics is rather unsatisfactorily defined by magnetic data. From the general setting of the volcanics it seems probable that this boundary is an erosionally modified depositional limit. It is probably far more complex than is shown on the map, where it has been crossed by only one GGU traverse and three Bedford traverses. At the boundary the volcanics overlie either Precambrian basement rocks or basement covered by a thin (2 km or less) sedimentary section.

West of Upernavik an outlier of volcanics is shown, on the basis of a single dredge sample (M. J. Keen *et al.,* 1972) and a rather speculative interpretation of one GGU and several Bedford Institute magnetometer traverses. This area of volcanics is poorly defined and probably only one of several in the general area.

On the GGU traverse west from Upernaviks Isfjord, and on the Canadian traverses in Melville Bugt, the eastern boundary of the sedimentary basin described by various authors (Barret & Manchester, 1969; M. J. Keen *et al.,* 1972; Ross & Henderson, 1973, and others) is marked by a definite topographic scarp (fig. 6) of about 300 metres, to the east of which is the rugged topography typical of glaciated crystalline rocks, and to the west of which is a much smoother and deeper sea floor. The scarp can be traced on navigational charts with little difficulty, and has been used to extend the sediment-basement boundary north to about 75°30′.

The structure within the basin is taken directly from the interpretation by Ross (Ross & Henderson, 1972) modified to fit the basin edge determined from sea bed topography, and to accomodate the new GGU data. No attempt has been made within this study to determine the western limits of the sedimentary basin.

Uncertainties in interpretation

Errors in the map accompanying this report are of two types: incorrect interpretation of the geophysical data, and incorrect interpolation between data points. The probability of the second type of error can be judged from the density of traverses shown on the map, except that the mapping in Melville Bugt uses some Canadian traverses not shown on the map. Incorrect interpretation of the geophysical data is most likely to occur where 'magnetic' basement and Tertiary volcanics can be confused: west of Egedesminde, and along the western edge of the volcanics from about 69°45′ northwards.

In particular, the interpretation is uncertain in the area west of Ubekendt

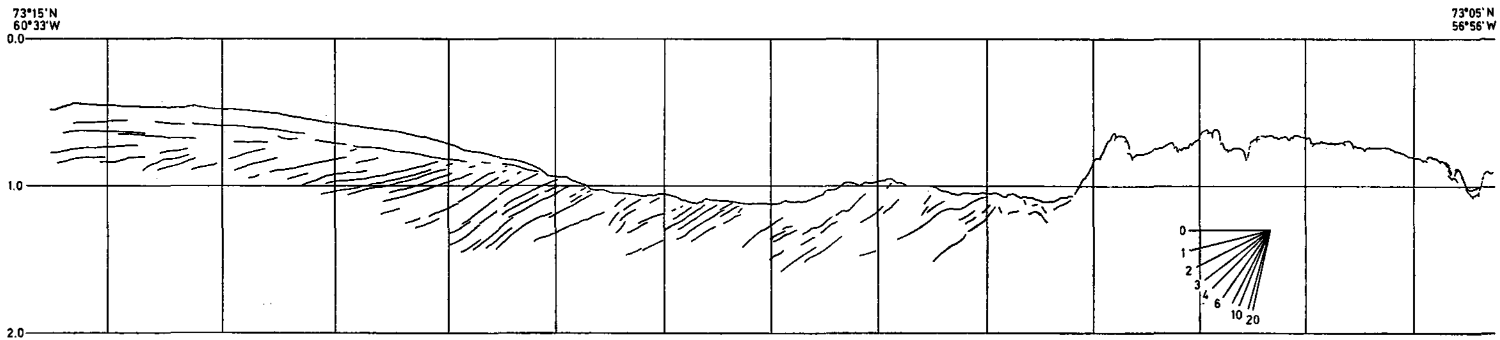

Fig. 6. Plotted seismic section, from 73°05'N, 56°56'W to 73°15'N, 60°33'W. Same scale as fig. 4.

Ejland and Svartenhuk Halvø, and it is likely that future geophysical work will substantially alter the map in this area.

In parts of Disko Bugt and the fjords north of Nûgssuaq the distinction between 'non-magnetic' basement and sediments is not clear, so the distribution of the sediments in this area is possibly incorrect.

The contours shown on the map are of estimated depth to Precambrian basement (in kilometres below sea level). They are based on magnetic basement depth estimates, measured dips (both in outcrop and by seismic methods), seismic refraction depths, and depths based on gravity interpretation in Melville Bugt (after Ross & Henderson, 1973). They should not be regarded as being of great accuracy.

REGIONAL SUMMARY

In the area studied there is a continuous sedimentary basin underlying most of the continental shelf. The evidence available suggests that the youngest sediments are not older than Danian, and the oldest sediments are at least low in the Cretaceous. Although the basin is extensive, the thickness of sediment varies greatly – from a maximum of less than 2 km at latitude 72°30′ to about 10 km at 73°30′ or 5 km at 69°00.

Except in Melville Bugt (M. J. Keen *et al.,* 1972), the western margin of the basin underlying the continental shelf has not been seen. Keen & Barrett have demonstrated the presence of 4–7 km of sediments across the middle of Baffin Bay, and these sediments are probably continuous with the shelf sediments described in this study. Although Keen & Barrett (1973) argue on geophysical grounds that the crust underlying Baffin Bay is 50–80 m. y. old, there are quite strong geological reasons for saying it is much older (Henderson, 1973). One reason is simply the thickness of sediments – it is not an impossible thickness, but it is unlikely for such a short time.

A study of accumulation rates in ocean basins was made by analysing results of the JOIDES drilling (sites 195–258 as summarized in *Geotimes,* April 1972 to March 1973, and results of sites 111 to 119 from a summary of Leg 12 issued by the Scripps Institution of Oceanography). The depth reached in each hole was divided by the age of the deepest sediments to give an average accumulation rate. Expressed in centimetres per 1000 years, this rate ranged from about 0.05 to 40. These are not useful figures, but if the lowest and highest 10 % of values are discarded, the range is reduced to 0.1 to 4 cm/1000 yrs. The 4 km of sediments overlying basement in the middle of Baffin Bay may on these figures represent a time span of between 100 and 4000 million years. The second figure is meaningless, but the first figure gives a reasonable minimum age for Baffin Bay. If the JOIDES data are representative of ocean deposition rates in general, the median accumulation rate for all sites will give the most probable rate for Baffin Bay – about 1 cm/1000 yrs, giving an age for the basin of 400 million years. In view of the published hypotheses about rifting of Greenland this seems improbable, but there is no real evidence against it. Also, the velocities recorded for Keen & Barrett's 'consolidated' sediments seem unusually high for sediments less than 80 m. y. old with no history of tectonic disturbance or deep burial. The recently released report on the Leif E-38 well on the Labrador shelf (the closest deep drilling to West Greenland) gives an Oligocene to Lower Miocene age for the deepest section penetrated, indicating an average accumulation rate since then of 3.0 cm/thousand years (Daneliuk & Bell, 1973).

Within the sedimentary section there is widespread evidence of a significant unconformity between an upper sequence of up to 2000 m of almost completely horizontal sediments, and a lower sequence of very gently folded rocks. This unconformity is visible on the record section (fig. 6) from Melville Bugt, and is mentioned by M. J. Keen *et al.* (1972) and by Keen & Barrett in Baffin Bay. The rocks with seismic velocities of about 2.2 km/sec and about 3.5 km/sec, reported by Ross & Henderson both west of Nûgssuaq and in Melville Bugt, may correspond with the rocks above and below the unconformity. The age of this unconformity cannot be determined from the present data, but onshore there are only two major time breaks known: at the base of the preserved section (about basal Cretaceous) and at the top of the preserved section (post-Eocene). If it is assumed that the unconformity offshore is one of these (which it need not to be) it is most probably the basal Cretaceous unconformity. The velocities recorded for the lower sediments are consistent with an Upper Palaeozoic to Lower Mesozoic age.

The offshore sediments are bounded to the east by a basement high. North of Svartenhuk Halvø this is the Precambrian shield margin outcropping along the coast, but to the south it is an offshore ridge known only by inference from geophysical data. In this area a complex trough containing a thick section of Tertiary volcanics is known to extend from west of Egedesminde to the Svartenhuk area, including western Disko, Hareøen, western Nûgssuaq, and Ubekendt Ejland. This trough appears to be essentially fault bounded and resembles a rift valley (fig. 4). The volcanics may or may not be underlain by the Cretaceous to Danian sediments known further east. The trough consists of three distinct segments: south from Hareøen, Hareøen to Ubekendt Ejland, and Svartenhuk Halvø. The volcanics appear to have overflowed the trough to the east between Godhavn and Umanak Fjord, and again north of Qeqertarssuaq. The basalts only extend west of the trough north of 71°00'N.

East of the basalt filled trough, and separated from it by a fault in the north and a basement ridge in the south, is a shallow basin containing sediments ranging from Lower Cretaceous to Danian. Almost everywhere it is known in outcrop or from reliable seismic records the eastern limit of this basin is fault controlled. The nature of the southern boundary is unknown, but is probably erosional, and the northern limit of the sediments is concealed by the volcanics. Fig. 5 shows a typical seismic section in the area of sediment outcrop.

PETROLEUM POTENTIAL

Henderson (1969a) has assessed the petroleum potential of the area as it was known four years ago. Work since then has not improved the prospects for economic petroleum deposits in the onshore area, but a large offshore basin is now known where previously its existence was only surmised. The offshore area shown on the accompanying map as 'sediments' represents about 0.2×10^6 cubic kilometres of sedimentary rocks.

There are considered to be four prerequisites for petroleum accumulation: source rocks, reservoir rocks, opportunity for migration, and traps. As the onshore area has been shown to contain definite source rocks (Henderson, 1969a) even though depositional conditions were not favourable (E. J. Schiener, pers. comm.), the presence of source rocks in the postulated shelf environment offshore is more likely. The ridges of basement rocks separating the onshore area from the offshore basin appear to have been a source area for the sands of Disko and Nûgssuaq, and could be expected to have supplied coarse detritus to the west as well, thus providing potential reservoir rocks. There is no evidence offshore (in the form of oil seeps, etc.) of migration of oil, but the dips seen on seismic profiles (e. g. fig. 4) are commonly adequate to induce migration.

The weakest of the four prerequisites in this area is the requirement for traps. The small amount of seismic exploration available shows very little folding, and in the area covered by this study dips of 3° or less to the west dominate. The most promising features from the point of view of structural traps are the "folded and faulted sediments" of M. J. Keen *et al.* (1972) in Melville Bugt. These sediments, while hardly deformed (the maximum dip is 6–7°), show definite dip reversals which could indicate closed structural traps (see also Hyndman *et al.,* 1973, fig. 4). Elsewhere there is more chance of stratigraphic rather than structural traps, and in the areas where the sediment thickness increases rapidly to the west a number of potential traps could occur.

Overall, the potential for the existence of substantial petroleum pools in the area studied is good. The possibility of their exploitation being economically feasible will depend on the development of technology to handle very deep water (typically 500 metres) and a hostile evironment which includes icebergs in probably the densest concentration in arctic seas and in sizes up to hundreds of millions of tons. (An iceberg estimated to displace 200 million tons was seen during this survey, near the entrance to Upernavik Isfjord).

FUTURE WORK

The scope for additional geophysical and geological work is almost unlimited. However, there are several problems which deserve special attention: the basement ridge off Disko and Nûgssuaq (whose very existence is unproved); the trough in Melville Bugt; and the relationship of the Svartenhuk trough to the volcanics on Ubekendt Ejland.

The relationship of the probable basement ridge west of Disko with the sediments to the west and the volcanics to the east could best be solved by a more detailed version of the 1972 survey, with the addition of precision navigation and proper monitoring of diurnal magnetic fluctuations. A bottom sampling program in the sedimentary area might establish by palaeontology the age of the sedimentary rocks relative to the volcanics, but it is doubtful whether normal sampling methods could retrieve basement samples. Distinction of basement areas from basalt areas is probably possible only by careful study of detailed magnetic surveys.

The trough in Melville Bugt requires more traverses to establish its extent and, if possible, to outline some of its internal structure. The best approach to this is to survey (using similar methods to the 1972 survey) a series of traverse lines running from the skerries to the edge of the continental shelf at about 20 mile intervals from 73°N to Kap York. Again, bottom sampling in the sedimentary areas would be profitable.

The problem of the geological relationship between Svartenhuk Halvø and Ubekendt Ejland can only be solved by detailed marine magnetic surveying. An offshore survey would also yield a bathymetric chart of Karrats Fjord – something which does not now exist.

The whole of this suggested program could be completed in one summer by a ship similar to that used in 1972, with the same equipment, except for the addition of a better navigation system.

Acknowledgements

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REFERENCES

Allen, F. T. 1972: Some characteristics of marine sparker seismic data. *Geophysics* **37**, 462–470.

Barrett, D. L. & Manchester, K. S. 1969: Crustal structure in the Baffin Bay and Davis Strait region from magnetometer surveys (abstract). *Trans. Amer. geophys. Union* **50**, 135 only.

Bridgwater, D., Escher. A. & Watterson, J. 1973: Tectonic displacements and thermal activity in two contrasting Proterozoic mobile belts from Greenland. *Phil. Trans. R. Soc. Lond.* **A**, **273**, 513–533.

Daneliuk, B. A. & Bell, J. A. 1973: Well history report, Tenneco *et al.* Leif E-38. Resource Management and Conversation Branch, Dept. Energy, Mines & Res., Canada.

Davies, W. E., Krinsley, D. B. & Nicol, A. H. 1963: Geology of the North Star Bugt area, northwest Greenland. *Meddr Grønland* **162**, 12.

Dobrin, M. B. 1960: *Introduction to geophysical prospecting.* (2nd ed.) New York: McGraw-Hill.

Ellitsgaard-Rasmussen, K. 1954: On the geology of a metamorphic complex in West Greenland. *Bull. Grønlands geol. Unders.* **5** (also *Meddr Grønland* **136**, 6) 70 pp.

Escher, A. & Pulvertaft, T. C. R. 1968: The Precambrian rocks of the Upernavik-Kraulshavn area (72°–74°15′N), West Greenland. *Rapp. Grønlands geol. Unders.* **15**, 11–14.

Geological Survey of Greenland, 1970: Tectonic/Geological Map of Greenland. The Geological Survey of Greenland, Copenhagen.

Geological Survey of Greenland, 1971: Geologisk kort over Grønland, 1:500 000: Søndre Strømfjord – Nûgssuaq. The Geological Survey of Greenland, Copenhagen.

Haughton, S. 1860: On the fossils brought home from the arctic regions in 1859, by Captain Sir F. L. M'Clintock. *J. R. Dublin Soc.* **3**, 53–58.

Henderson, G. 1969a: Oil and gas prospects in the Cretaceous-Tertiary basin of West Greenland. *Rapp. Grønlands geol. Unders.* **22**, 63 pp.

Henderson, G. 1969b: Precambrian rocks of the Egedesminde-Christianshåb area, West Greenland. *Rapp. Grønlands geol. Unders.* **23**, 37 pp.

Henderson, G. 1973: The geological setting of the West Greenland basin in the Baffin Bay region. *Geol. Surv. Can. Paper* **71–23**, 521–544.

Henderson, G. & Pulvertaft, T. C. R. 1967: The stratigraphy and structure of the Precambrian rocks of the Umanak area, West Greenland. *Meddr dansk geol. Foren.* **17**, 1–20.

Hood, P. & Bower, M. E. 1970: Aeromagnetic profile from Cape Cargenholm, Baffin Island to Red Head, West Greenland. *Geol. Surv. Can. Paper* **70–1B**, 37–39.

Hyndman, R. D., Clarke, D. B., Hume, H., Johnson, J., Keen, M. J., Park, I. & Pye, G. 1973: Geophysical and geological studies in Baffin Bay and the Labrador Sea. *Geol. Surv. Can. Paper* **71–23**, 621–631.

Keen, C. E. & Barrett, D. L. 1973: Seismic refraction studies in Baffin Bay: an example of a developing ocean basin. *Geophys. J. roy. astr. Soc.* **30**, 253–271.

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.

Keen, M. J., Johnson, J. & Park, I. 1972: Geophysical studies in Baffin Bay and some tectonic implications. *Can. J. Earth Sci.* **9**, 689–708.

Kristjansson, L. G. & Deutsch, E. R. 1973: Magnetic properties of rock samples from the Baffin Bay coast. *Geol. Surv. Can. Paper* **71–23**, 545–563.

M'Clintock, F. L. 1859: *The voyage of the "Fox" in the arctic seas: a narrative of the discovery of the fate of Sir John Franklin and his companions.* London: J. Murray.

Münther, V. 1973: Results from a geological reconnaissance around Svartenhuk Halvø, West Greenland. *Rapp. Grønlands geol. Unders.* **50**, 26 pp.

Pulvertaft, T. C. R. & Clarke, D. B. 1966: New mapping on Svartenhuk peninsula. *Rapp. Grønlands geol. Unders.* **11**, 15–17.

Rosenkrantz, A., Noe-Nygaard, A., Gry, H., Munck, S. & Laursen, L. 1942: A geological reconnaissance of the southern part of the Svartenhuk Peninsula West Greenland. *Meddr Grønland* **135**, 3, 72 pp.

Rosenkrantz, A. & Pulvertaft, T. C. R. 1969: Cretaceous-Tertiary stratigraphy and tectonics in northern West Greenland. *Mem. Amer. Ass. Petrol. Geol.* **12**, 883–898.

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.

Sharma, P. V. 1973: Seismic velocity and sediment thickness investigations by refraction soundings in Nûgssuaq, West Greenland. *Rapp. Grønlands geol. Unders.* **54**, 22 pp.

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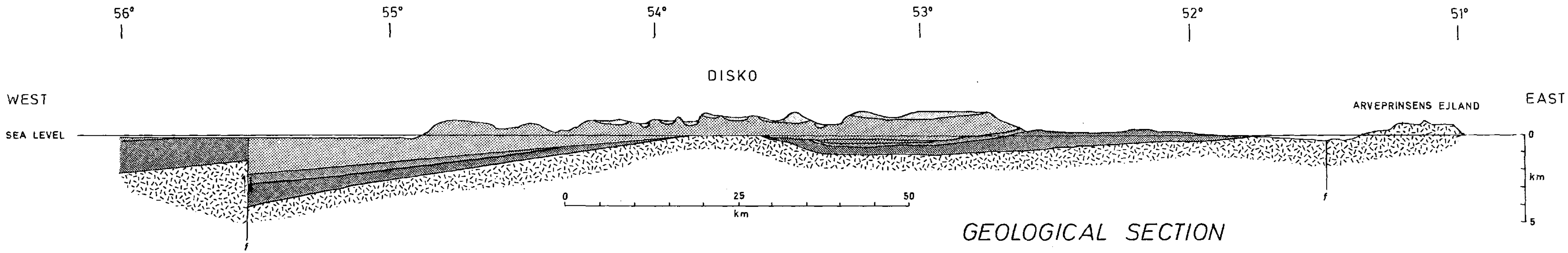
PLATE 1



GEOLOGICAL SECTION WEST GREENLAND BASIN

APPROX. LATITUDE 69°45′N

	Ice	
TERTIARY	*Basalt*	
	Pillow Breccias	
	Sandstone with coal	
CRETACEOUS	*Sandstone and shale*	
PRECAMBRIAN	*Gneiss*	


KAP YORK
MELVILLE BUGT
HOLMS Ø
UPERNAVIK ISFJORD
UPERNAVIK
PRØVEN
SVARTENHUK HALVØ
QEQERTARSSUAQ
KANGIGDLEQ
KANGERDLUGSSUAQ
KARRATS FJORD
UPERNIVIK Ø
UBEKENDT EJLAND
UMANAK FJORD
AGPAT
UMANAK
NÛGSSUAQ
HAREØEN
DAIRAIAGS FJORD
QUIDLORSSAT
VAIGAT
DISKO
MELLEMFJORD
TORSSUKATAK
ARVE PRINSENS EJLAND
GODHAVN
DISKO BUGT
JAKOBSHAVN
RITTEN
HUNDE EJLAND
GRØNNE EJLAND
EGEDESMINDE
CHRISTIANSHÅB
KANGATSIAQ
76°00'
75°00'
74°00'
73°00'
72°00'
71°00'
70°00'
69°00'
66°00'
64°00'
62°00'
60°00'
58°00'
56°00'
OFFSHORE GEOLOGY
68°N – 76°N WEST GREENLAND
0 10 20 30 40 50 km
Basic Volcanics Tertiary
Sedimentary Rocks Jurassic – Tertiary
Crystalline Rocks Precambrian
Geophysical Traverse GGU, Canadian
Basement Surface (C.I. 1km)
Rock unit Boundary
Probable Fault
L.R. Denham
December 1972