MARINE GEOLOGICAL AND GEOPHYSICAL OBSERVATIONS IN DAVIS STRAIT

by

Ian G. Park

Submitted in partial fulfilment of
the requirements for the Degree of
Master of Science
at
Dalhousie University
Halifax, Nova Scotia
July, 1971

Table of Contents

Acknowledgements

I am especially grateful for the help and guidance of my supervisor, M.J. Keen, Chief Scientist on the first two legs of the cruise, during all phases of this work. I thank R.D. Hyndman for his able supervision as Chief Scientist during the third leg of the cruise and for advising me on the latest geophysical aspects of continental drift between Canada and Greenland. Without the help of Barrie Clarke, resident expert on the volcanics and sediments of the Davis Strait area, many aspects of this thesis could never have been undertaken.

I would also like to thank Bob Gerstein, director of operations for the cruise and Jim Johnson for providing the technical expertise which produced the excellent seismic records. Many stimulating discussions with Norman Lyttle, on and off-topic, were a great help. The assistance provided by many of the other graduate students should not go unrecognised. The Marine Geophysics staff at the Bedford Institute of Oceanography are to be thanked for the loan of the magnetometer and for their willingness to give advice and to provide technical assistance in the computer processing of the magnetic data.

Gilroy Henderson and the Greenland Geological Survey are to be thanked for keeping me informed of the latest geological results and reports from West Greenland. H.C. Palmer at the University of Western Ontario kindly consented to do the magnetic property analyses of the dredge samples and L. Kristjansson provided the magnetic data for the Baffin Island samples. C.R. Angell at Edinburgh University kindly performed the chemical analyses.

Thanks also go to Mrs. Norma Ewen for typing the thesis. Mrs. Heather Cross helped with the drafting of many of the illustrations. My wife Pamela typed parts of the first draft, helped with several illustrations and provided the much needed moral support.

I especially wish to express my appreciation for the kindness and interest shown in our work by the late Captain Vieau, before his tragic death at sea. The co-operation of Captain Wagner, officers and crew of the C.S.S. DAWSON as well as the members of the scientific party is also appreciated.

The financial support of Dalhousie University has made this research possible.

Abstract

Geophysical surveys and dredging in Davis Strait have shown that the Tertiary volcanics of the West Greenland basin continue offshore for many tens of kilometres. The offshore sequence is similar in structure to the terrestrial volcanics, and is composed of shallow westward dipping basalt flows which underlie, on the west, younger sediments and abut against Precambrian gneisses on the south and east. The eastern margin is fault bounded, a seaward continuation of the faulted margin of Cretaceous-Tertiary sediments on land. Several magnetic profiles have established a northern boundary of the offshore province 100 km north of the northernmost occurrence of volcanics on land.

Geochemical analyses and petrographical examinations of the dredge samples have confirmed that the offshore series is composed of subaerial feldspar-phyric basalts similar to the feldspar-phyric volcanics in the West Greenland basin. Opaque petrography and magnetic property examinations show that the volcanics have Q ratios ranging from 2 to 20 and an opaque mineralogy similar to many previously described volcanics.

The bathymetry of the West Greenland shelf was examined with respect to the "marginal channel" problem. The prominent north-south trending channels southwest of Egedesminde and north of Upernavik may delineate the offshore extension of the eastern faulted margin of the West Greenland basin. However, their tectonic origin and their continuity with the more typical marginal channels in Melville bay and to the south near Godthaab are evidence in favor of an initial structural origin of marginal channels on the West Greenland shelf.

An area of weak magnetic characteristics, northwest of Nugssuaq peninsula may show an offshore continuation and substantial thickening of the sediments of the West Greenland basin. The presence of hydrocarbons and potential source rocks on Nugssuaq peninsula, the absence of basalts overlying these offshore sediments and the thickened sequence make the area attractive for petroleum exploration.

Finally, the results of this survey are added to previous geological and geophysical studies in the Baffin Bay-Labrador Sea regions to formulate a model for the geological development of Baffin Bay and Davis Strait.

Initial structural weaknesses were developed in the Late Precambrian by rifting without sea-floor spreading. This Hadrynian rifting formed northwest trending grabens on Baffin Island, and in proto-Baffin Bay. The area appears to have been a stable cratonic block for 500 my. Sediments may have been continuously deposited in Baffin Bay in the interval between the Lower Palaeozoic and the Jurassic. Limnic and fluviatile sediments were deposited in the West Greenland area in the mid-Cretaceous. Marine trangressions affected the area in the Late Cretaceous-early Tertiary. Volcanic activity began in the early Tertiary in the Davis Strait area and halted further marine sedimentation. The initial extrusives were subaqueous breccias and subaerial olivine basalts and were deposited on either side of the Baffin Bay graben. Later the continental crust was severed in this graben and the volcanic activity in the form of feldspar-phyric basalts greatly extended the West Greenland province. This activity was entirely confined to the west of the Baffin Bay graben. The separation of Greenland and Canada probably ceased at about 47 my, while the extrusive volcanism declined and stopped. Younger sediments have since been deposited on the West

Greenland shelf to the west of the offshore volcanic sequence and in Baffin Bay.

Chapter 1 Introduction

Interest in the Canadian Arctic has been prevalent for a number of years, ever since early workers such as Taylor (1910), and Wegener (1924) published their theories on continental drift and suggested that Canada and Greenland were once joined and have since moved apart. However, the accumulation of knowledge seems to have undergone several stages of advancement. Wegener's contribution began a vigorous controversy, and it took many years to accept the concepts of continental drift. With the advent of studies of palaeomagnetism in the late 1950's, geophysicists and geologists began to realise that not only has continental drift occurred, but it has occurred on a scale of world-wide proportions.

The suggestion of sea-floor spreading by Hess (1960) and Wilson's hypotheses concerning the presence of median ridges in between drifted continents and the mechanism of transform faulting (Wilson, 1963 and 1965) are the basis for much of the present day studies of the ocean basin. One of the examples put forward by Wilson was that a branch of the Mid-Atlantic ridge extended through the

Labrador Sea and Baffin Bay to terminate at Nares Strait, considered by Wilson to be a transform fault.

Drake et al. (1963), initiated the geophysical studies in the Labrador Sea by demonstrating the possible existence of a buried ridge in the southern Labrador Sea. Clarke (1965), recognised that the only major geological features younger than Precambrian in the area between Canada and Greenland were the Cretaceous-Tertiary sediments and volcanics on either side of the Davis Strait. Their age, and geographical separation today link them intimately to the spreading history of Baffin Bay and the Labrador Sea. Clarke's subsequent studies of the volcanics of Baffin Island and Svartenhuk have shown, on the basis of geological and geochemical evidence, that these two provinces may be related to a single petrogenetic scheme. Hood and Godby (1964) began to compile, on the basis of aeromagnetic profiles across the Labrador Sea, evidence for continental drift and sea floor spreading in the form of the linear anomaly patterns which are characteristic of mid-ocean ridges.

The theory of plate tectonics (Le Pichon, 1968) brought about another revolution in scientific knowledge concerning the phenomena of continental drift and sea floor spreading. The use of the Heirtzler et al. (1968) time scale has enabled the determination of chronological sequences of events in areas where sea floor spreading has occurred.

Both these principles have now been applied to the history of opening of the southern Labrador Sea and the North Atlantic. Increased geophysical activity in these two areas, in the form of magnetic surveying, seismic reflection profiling, and drilling (JOIDES, Leg 12) have allowed workers such as Le Pichon et al. (in press) and Laughton (in press) to provide the most up-to-date interpretation of the tectonics of the opening of the Labrador Sea.

What had not been determined until recently, was the relationship between the history of development of the Labrador Sea and the development of Baffin Bay. Although a large volume of data had been collected in this region prior to 1970, none of the structures usually associated with mid-ocean ridges had been identified. There appeared to be no magnetic lineations or a central ridge in Baffin Bay, nor had the crust of the Bay been shown to be oceanic.

Not only has there been a great interest in the

Canadian Arctic with respect to the aspects of continental drift, but the area has recently aroused a special interest from the viewpoint of economics and mineral resources. As the petroleum reserves in the classical continental locales of the Canadian West and the United States become depleted, oil companies have been forced to consider the possibility that hydrocarbons may have accumulated in offshore areas, such as the continental shelf off Nova Scotia, and in the remote northern regions of North America. Fostered by the discovery of vast reserves in the North Slope area of Alaska, and the two successful Imperial Oil wells in the Mackenzie delta area, oil companies have begun to investigate many other areas in the Arctic Archipelago. This has also been extended to the associated offshore regions of the Beaufort Sea, Lancaster Sound and the shelves off Baffin Island and Labrador, where thick sedimentary sequences are thought to exist.

The cruises of three ships, C.S.S. DAWSON, C.S.S. HUDSON and C.S.S. BAFFIN to the Baffin Bay area in the summer of 1970 were to provide some of the answers to the problems of continental drift, but have also delineated areas which merit further investigation in the realm of offshore petroleum exploration. The preliminary results of HUDSON and BAFFIN are summarised in Chapter 2.

The cruise of the C.S.S. DAWSON to Baffin Bay from August to September 1970 was significant in that it was the first voyage by one of the Bedford Institute's non-icebreaking ships to the Arctic, and the first major scientific cruise to the Arctic to be organised by a Canadian University.

On this cruise it was discovered that:

1) a thick sedimentary basin occupies the northern part of Baffin Bay, resting on a crust which Hudson subsequently showed is oceanic;
2) the continental edge of Baffin Bay is marked by a magnetic edge effect;
3) there may be magnetic lineations associated with the crust of northern Baffin Bay which agree with a "pole of rotation" in Lancaster Sound;
4) heat flow over the central part of the buried mid-Labrador Sea ridge is normal, and that the heat flow in Baffin Bay is affected by bottom water temperature effects (Pye, 1971);
5) the gravity and magnetic lows in Melville Bay are due to the accumulation of a great thickness of sediments in a graben-like feature; and
6) the Tertiary basaltic province of West Greenland

extends many tens of miles offshore, and further north than had been known previously.

The purpose of this thesis is to report on the findings of a geophysical survey conducted offshore from the known occurrence of these Tertiary volcanics in the West Greenland basin. In addition, it will provide an opportunity to review the geological and geophysical evidence in favour of continental drift between Baffin Island and Greenland, and to formulate a model for the geological development of Baffin Bay.

Chapter 2 A Review
Geology, Geophysics and Continental Drift in the Labrador Sea and Baffin Bay

2.1 Introduction

This chapter presents a review of geological and geophysical observations in the Labrador Sea, Baffin Bay and their bordering lands, and the bearing of these observations on the problem of continental drift between Canada and Greenland. The most conclusive evidence for drift is based on the many studies conducted in the Labrador Sea, but a review of previous work in Baffin Bay and more recent studies will show that structures in that region are also consistent with the continental drift hypothesis.

In addition to the results of our recent geophysical survey in the Davis Strait, this review will provide a basis for the conclusions drawn in Chapter 5.

2.2 Precambrian Relations in Eastern Canada and West Greenland

The major tectonic and stratigraphic divisions in the Precambrian of southern West Greenland were first identified by Wegmann (1938), based on field relations in the Cape Farewell to Ivigtut area. Concurrent studies by Kranck (1939), on the Labrador coast suggested that the Precambrian areas of Eastern Canada and Western Greenland formed sections of the same shield. Berthelsen (1961), summarised the results of the 1:200,000 regional mapping programme in West Greenland (completed in 1956) which confirmed the earlier suggestions. Since that time, much of the area has been re-mapped at scales of 1:20,000 or 1:40,000 with particular reference to the infracrustal and supracrustal divisions first suggested by Wegmann. Due to the degree and number of cycles of metamorphism, these divisions are very difficult to recognise in the field. Consequently, the Greenland Geological Survey (GGU) has supplemented field observations with a reconnaissance K-Ar dating survey (Larsen and Moller, 1968). Similarly, the Geological Survey of Canada (GSC) has undertaken K-Ar dating of many rocks from Labrador and Baffin Island and these results are compiled yearly. The most recent compilation appears on the Isotopic Age Map of Canada (Map 1256A).

The ages for Precambrian rocks from West Greenland may be divided into groups corresponding to two main periods of plutonic activity, from

2700-2300 my and 1830-1500 my and one period of cratogenic magmatism from 1300 to 1000 my. The rocks affected by plutonic activity have been subdivided into three main structural units consisting of two younger fold belts, known as the Nagssugtoqidian and the Ketilidian, which lie respectively to the north and south of a central Archean basement gneiss complex (Fig.1). The youngest period corresponds to the Gardar cratogenic episode, during which the deposition of continental molasse-type sandstones was accompanied by basaltic and trachytic flows.

Keen et al. (1970), have compiled the radiometric ages from both Eastern Canada and Western Greenland, and have shown that the distribution of ages is consistent with the drift hypothesis. The oldest dates from the Eastern Nain province lie opposite the oldest dates from West Greenland and are a part of the Superior Province which has been affected by the Kenoran orogeny (Fig. 1). Additional dates and revisions to this compilation are listed in Larsen and Moller (1968) and Jorgensen (1967).

Figure 1

Structural Provinces in the Canadian-
Greenland Shield

(after Keen et. al.,1970)

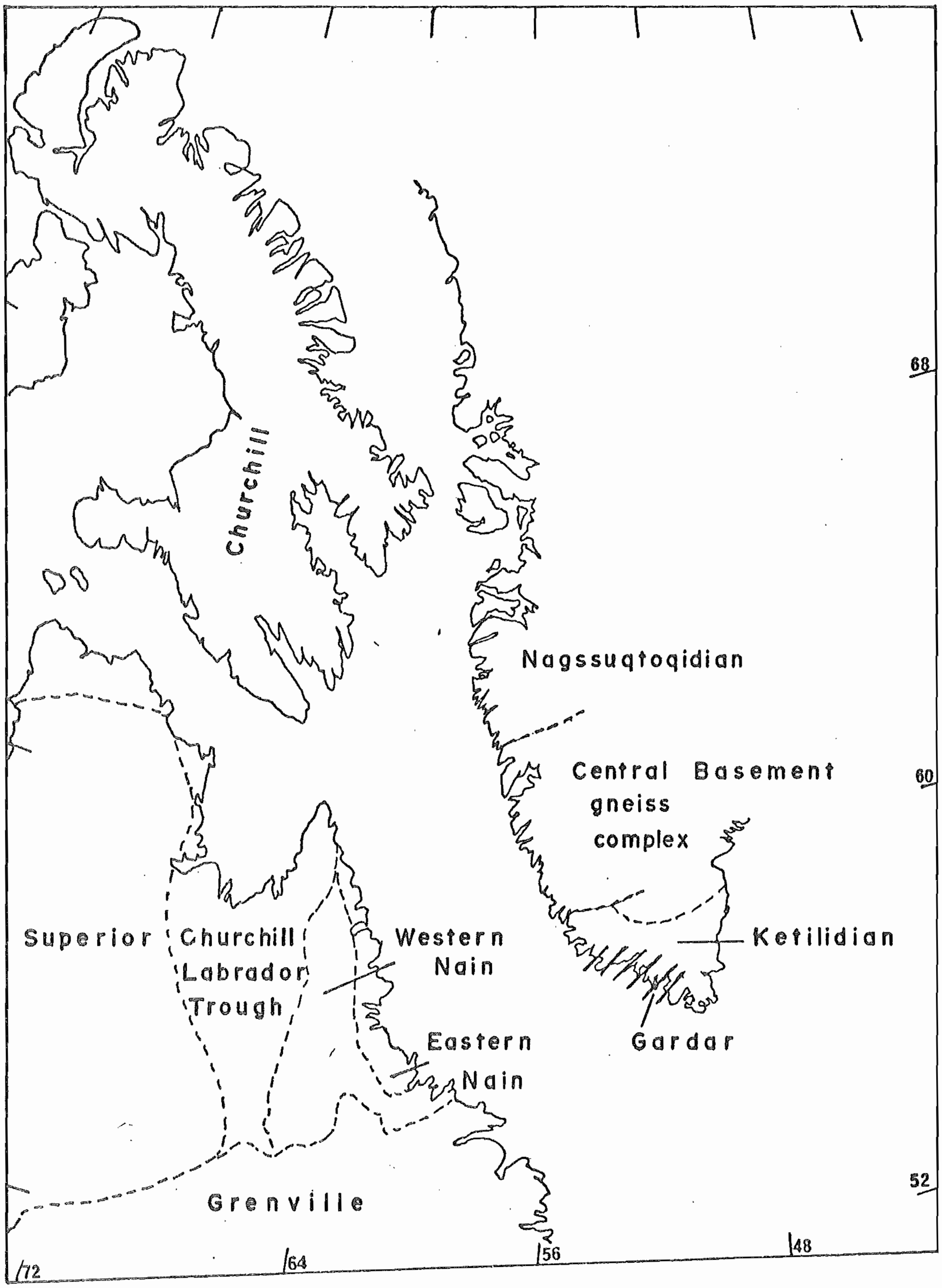

Churchill
Nagssuqtoqidian
Central Basement
gneiss
complex
Superior
Churchill
Labrador
Trough
Western
Nain
Ketilidian
Eastern
Nain
Gardar
Grenville
68
60
52
72
64
56
48

FIG. I

Precambrian Chronology

Archean

In Greenland, Archean rocks, unaffected by younger regional metamorphic events, extend from Ivigtut to Sondre Stromfjord. The rocks of the Eastern Nain occupy only a small coastal strip in Labrador stretching from Makkovik to the vicinity of Cape Chidley. No Archean ages have yet been recorded from Baffin Island; however, several whole rock Rb-Sr isochrons showing Archean affinities have been noted by Bridgwater et al. (1971), suggesting that the rocks are most likely updated Archean gneisses. The rocks of this time period are dominantly quartzo-feldspathic gneisses exhibiting predominantly granulite facies metamorphism with very complex structural patterns. The Kenoran orogenic event (2480 my) has affected these gneisses but several ages in Greenland are older than 3000 my.

Faulting in the late stages of Archean metamorphism show two differing trends:

1) in Labrador and southern Greenland, N-S to NNE-SSW
2) on Baffin Island and in the northern part of Greenland, the main fault direction is ENE-SSW to E-W, but southeast trends of presumed Archean faults on Baffin Island are also common (Bridgwater et al. 1971).

Proterozoic

Lower Proterozoic sedimentary and volcanic sequences were deposited on the Archean basement and both were subsequently deformed by the Hudsonian orogeny in Canada, and by the Nagssugtoqidian orogeny in West Greenland during the period from 2000 to 1600 my. Identification of correlatable Lower Proterozoic units has been made on the basis of their unconformable relation to the Archean basement. Particularly good sedimentary sequences are found on the western margin of the Labrador trough where the effects of the Hudsonian orogeny are minimal. A similar sedimentary succession overlies the Archean in the area just to the north of Ivigtut, and it is possible that many of the metasedimentary sequences of northern Baffin Island were deposited in Aphebian times.

A major structural and thermal event began around 2000 my and lasted until about 1500 my. It affected all of Baffin Island, most of Labrador and much of Western Greenland. The grouping of ages on Baffin Island and in central West Greenland around

1800-1600 my suggests that the rocks have recorded the age of uplift at the end of the Hudsonian. The rocks of the Labrador trough and those of the Ketilidian fold belt in southern Greenland give ages ranging from 1650-1500 my, indicating a later thermal event than that which affected the rocks to the north. In most of the rest of Labrador, K-Ar ages from 1650-1200 my have given rise to the Elsonian as an independent orogenic term (Stockwell, 1964). In Labrador, large layered anorthosite intrusions marked the end of the Hudsonian and Ketilidian orogenies. Similar post-tectonic intrusions in southern Greenland are typically granitic.

Bridgwater (1967) notes that the next stage of development in both Canada and Greenland, was widespread cratogenic magmatism and sedimentation, immediately preceding Grenville metamorphism. Volcanic activity in the Gardar reached its peak around 1250 my and it was in this time period that many large alkaline igneous bodies were emplaced. In Greenland it appears as if intrusion of these rocks was largely controlled by E-W trending wrench faults, and the possibility arises that the developing Grenville fold belt to the south was responsible for these stresses. Grabens developed from these fault zones and they appear to have been the centers of deposition for continental molasse-type sandstones. A similar sequence of continental sediments in northern Baffin Island and Bylot Island occurs in presumed southeast trending grabens of similar age (Trettin, 1969). Coincidentally, E-W faults relating to the anorthosites of the Nain (Wheeler, 1960) occur in Canada at approximately the position they might be expected to occupy as continuations of Gardar faults. These fault zones appear in many cases to represent reactivation of earlier Archean structures. Activity on these faults continued up until the time of the Grenville event (955 my) with K-Ar ages of 900-1000 my being found in the proximity of the fault zones in southern Greenland. Significantly, this is the first evidence that Grenville activity reached Greenland (Bridgwater et al., 1971)

In addition some of these zones appear to have been active more recently, perhaps simultaneously with the development of a spreading center in the Labrador Sea. A similar Precambrian fault zone in the Disko Bay area to the north may have been reactivated during the rifting of Davis Strait and Baffin Bay (Chapter 3).

Upper Proterozoic-Lower Palaeozoic

An important swarm of post-Grenville diabase dikes trending sub-parallel to the coast occurs throughout most of Baffin Island. Crustal tensions indicated by these dikes are exhibited by northwest trending faults, which give rise to a series of grabens. Fahrig et al. (1971) argue, on the basis of geologic and palaeomagnetic evidence, that sediments in these grabens were not deposited during the Helikian as Trettin (1969) previously suggested, but are actually Hadrynian (675 my) in age. This is proposed as proof of a late Precambrian rift zone in the Davis Strait and that both the Strait and Baffin Bay may contain Palaeozoic strata. Diabase dikes near to Davis Strait, in addition to possessing magnetisations obtained during this Precambrian rifting, have obtained a secondary magnetisation possibly associated with a period of mild reheating during a proposed Tertiary opening of Davis Strait and Baffin Bay. Thus northeast-southwest tensions may have occurred several times.

Poulsen (1966) has noted a very small occurrence of Lower Palaeozoic sediments (possibly Ordovician in age) in the Sukkertoppen district of West Greenland.

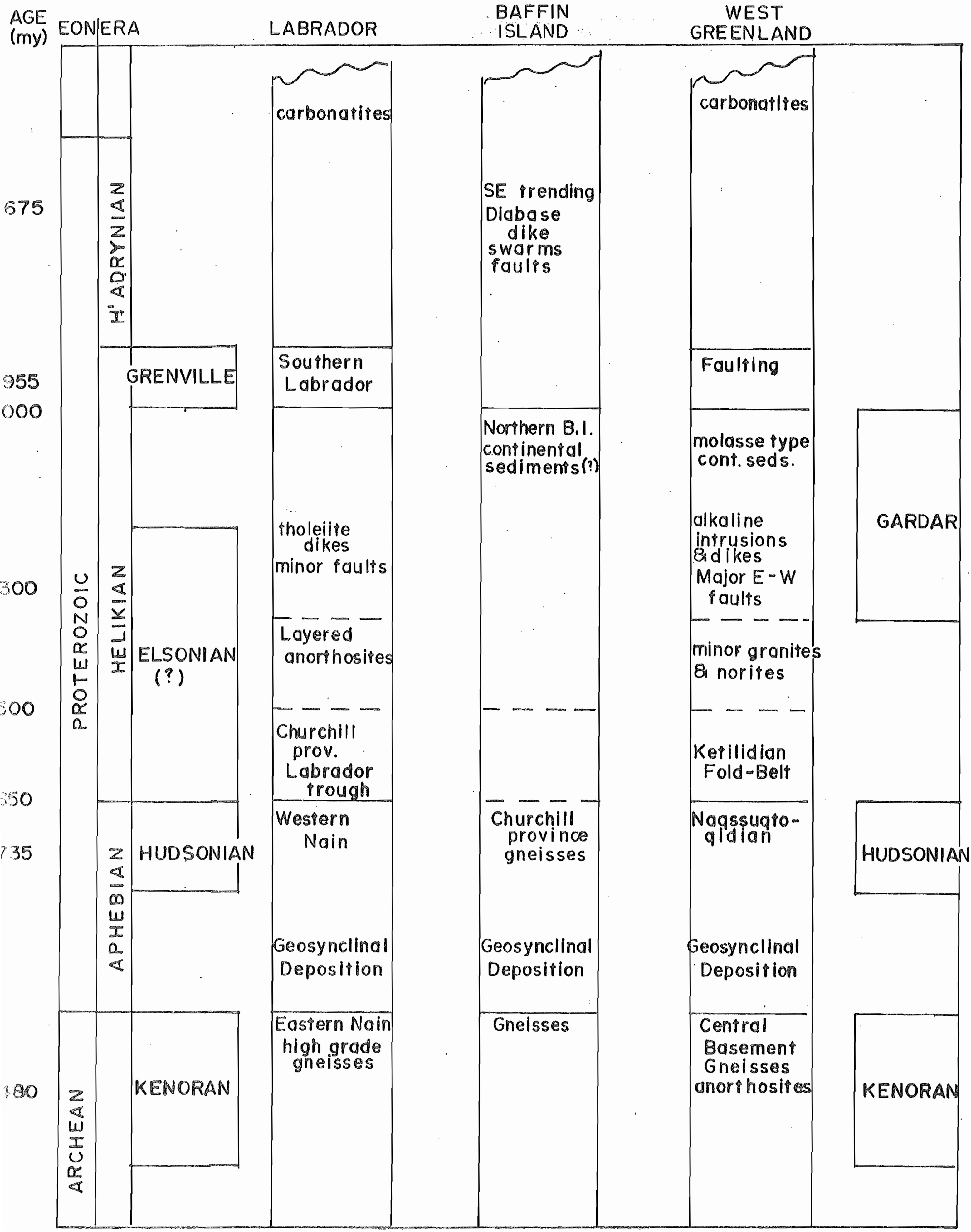
The locality is situated between two parallel faults which strike 060°. It is possible that this faulting took place at the same time as the northwest trending faults were formed on Baffin Island. Doig (1970) has noted a possible correspondence between Lower Palaeozoic carbonatites of the St. Lawrence graben system and alkaline rocks in Labrador and West Greenland. The ages of these carbonatites (560-600 my) may indicate a period of widespread magmatism after the proposed Hadrynian rift, much like a similar magmatic episode which occurred after the Hudsonian.

Jurassic

In south-west Greenland it is not true that all the rocks are of Precambrian and Lower Palaeozoic age, for a swarm of dikes trending parallel to the coast intersects the numerous Gardar dikes and faults of 1150 my. K-Ar ages on these dikes show a Jurassic age (138-164 my) and their occurrence suggests they may have been intruded during the initiation of rifting in the Labrador Sea (Watt, 1969). Similar Jurassic dikes are found in Newfoundland.

Figure 2

Stratigraphic and Structural Divisions in the Precambrian of Labrador, Baffin Island and West Greenland



AGE (my)
EON
ERA
LABRADOR
BAFFIN ISLAND
WEST GREENLAND
675
955
000
300
500
550
735
180
PROTEROZOIC
ARCHEAN
H'ADRYNIAN
HELIKIAN
APHEBIAN
GRENVILLE
ELSONIAN (?)
HUDSONIAN
KENORAN
carbonatites
Southern Labrador
tholeiite dikes minor faults
Layered anorthosites
Churchill prov. Labrador trough
Western Nain
Geosynclinal Deposition
Eastern Nain high grade gneisses
SE trending Diabase dike swarms faults
Northern B.I. continental sediments(?)
Churchill province gneisses
Geosynclinal Deposition
Gneisses
carbonatites
Faulting
molasse type cont. seds.
alkaline intrusions & dikes Major E-W faults
minor granites & norites
Ketilidian Fold-Belt
Naqssugto-qidian
Geosynclinal Deposition
Central Basement Gneisses anorthosites
GARDAR
HUDSONIAN
KENORAN

FIG. 2

The similarities in stratigraphy and tectonics suggest that the lands bordering the Labrador Sea, Baffin Bay and Davis Strait were once part of a single Precambrian shield (Fig. 2). If they were in fact joined during the Precambrian, their present geographical locations suggest, as was originally speculated, that they have drifted apart.

The next section will be concerned with a review of previous literature on the mechanisms which may have been responsible for this separation. Most of the speculation arises from the extensive work which has been done in the Labrador Sea (Laughton, 1971; Le Pichon et al., in press; Godby et al., 1966). However, recent studies of the nature of the crust, sediments and structures in Baffin Bay are presented so that satisfactory suggestions on the spreading history of this lesser known area may be given in Chapter 5.

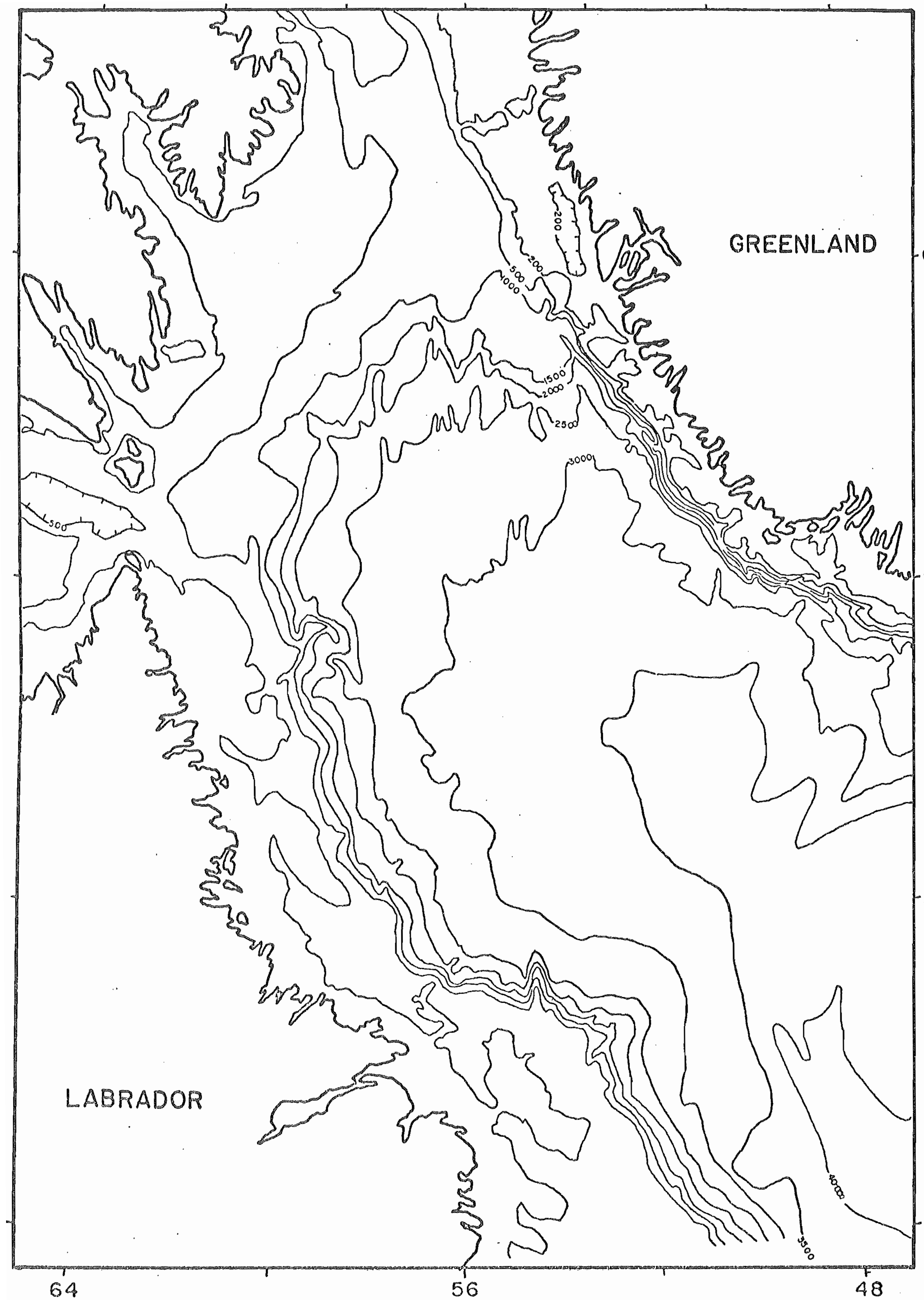
2.3 Geological and Geophysical Observations in the Labrador Sea

The Labrador Sea extends northwest from about 52°N 43°W to the Davis Strait sill to form a major basin between Labrador and Greenland (Fig. 3). The

Figure 3

Bathymetry of the Labrador Sea

(contours in metres)



GREENLAND
LABRADOR
200
500
1000
1500
2000
2500
3000
3500
4000
64
60
56
52
64
56
48

basin has a maximum depth of 3500 metres, but the bottom rises to depths of about 200 metres in Davis Strait. The sides of the basin differ markedly. Along the Greenland slope, the basin rises steeply to form a very narrow continental shelf while the Labrador side is composed of a well-defined slope and a wide continental shelf. In the region of Davis Strait (and into Baffin Bay) the opposite is true. The wider shelf prevails on the Greenland side and a very narrow shelf occurs on the Baffin Island side.

Ewing and Ewing (1959) were the first to suggest that the crust of the Labrador Sea was oceanic, their conclusions being based on a single seismic refraction profile near the extreme eastern margin. Their work showed that at least 1 km. of sediment was underlain by up to 5.5 km. of oceanic crust. Drake (1963) used a continuous seismic profiling technique to demonstrate the existence of a rough acoustic basement buried beneath unconsolidated sediments near the center of the sea. A compilation of earthquake epicenters by Sykes (1965) showed a cluster around 61°N and an overall high seismicity for the Arctic, though still only about 10% that of an active oceanic ridge.

These preliminary studies suggested that any proposed median ridge in the Labrador Sea had to be much older than the present active ridge systems, due to the thick sediment cover and low "residual" seismic activity.

Hood and Godby (1964) began compiling aeromagnetic information over the Labrador Sea. Later work published in Godby et al. (1966) and Hood et al. (1967) suggested that a pattern of linear magnetic anomalies on their eastern zone could be correlated with Drake's buried ridge in the central portion. A quiet central anomaly, compared with the large axial anomalies of active ridges, was attributed to the age of the ridge, with its deeply buried magnetic sources and its present inactivity. The western magnetic zone showed similar lineations, though somewhat more confused. This zone terminates abruptly at about 59°N 58°W and Hood et al. (1967) attribute this to either a fracture zone or increased burial of magnetic basement. Johnson et al., (1969) substantiated the previous aeromagnetic evidence with the aid of both magnetic and reflection transverses and apparently were able to trace the buried ridge to the sill of Davis Strait. At 64°N the basement high nearly reaches the surface but the rugged relief of the more southerly profiles is replaced by a flat-topped mass. The trends in the magnetics do not appear to continue into Davis Strait. They suggest that the terminus of the western magnetic zone at 60^{O}N may bear evidence of a fracture zone striking 050^{O} which would offset the basement high at 61^{O} 30'N, where the eastern portion of the magnetic anomalies appears to change to a more N-S direction. The quiet central anomaly was attributed to the generation of oceanic crust while spreading rates declined to zero.

For the southern Labrador Sea, Mayhew (1969), assuming the axis of symmetry of magnetic anomalies represents the old spreading center, applied the extended time scale of Heirtzler et al. (1968) to correlated profiles. A correspondence was found between the oldest part of the Heirtzler model, and the pattern in the Labrador Sea, which suggested that the youngest anomaly corresponded to anomaly 27 (65 my BP) and anomalies over the flanks extended to event 32 (75 my BP). Le Pichon et al. (in press) have considered another approach to the problem of continental drift, and have studied the geometry of the opening of the Labrador Sea on the basis of movements along transform faults (Fig. 4). The Farewell fault abruptly terminates in the central

Figure 4

Geological and Geophysical Features Associated with the opening of the Labrador Sea

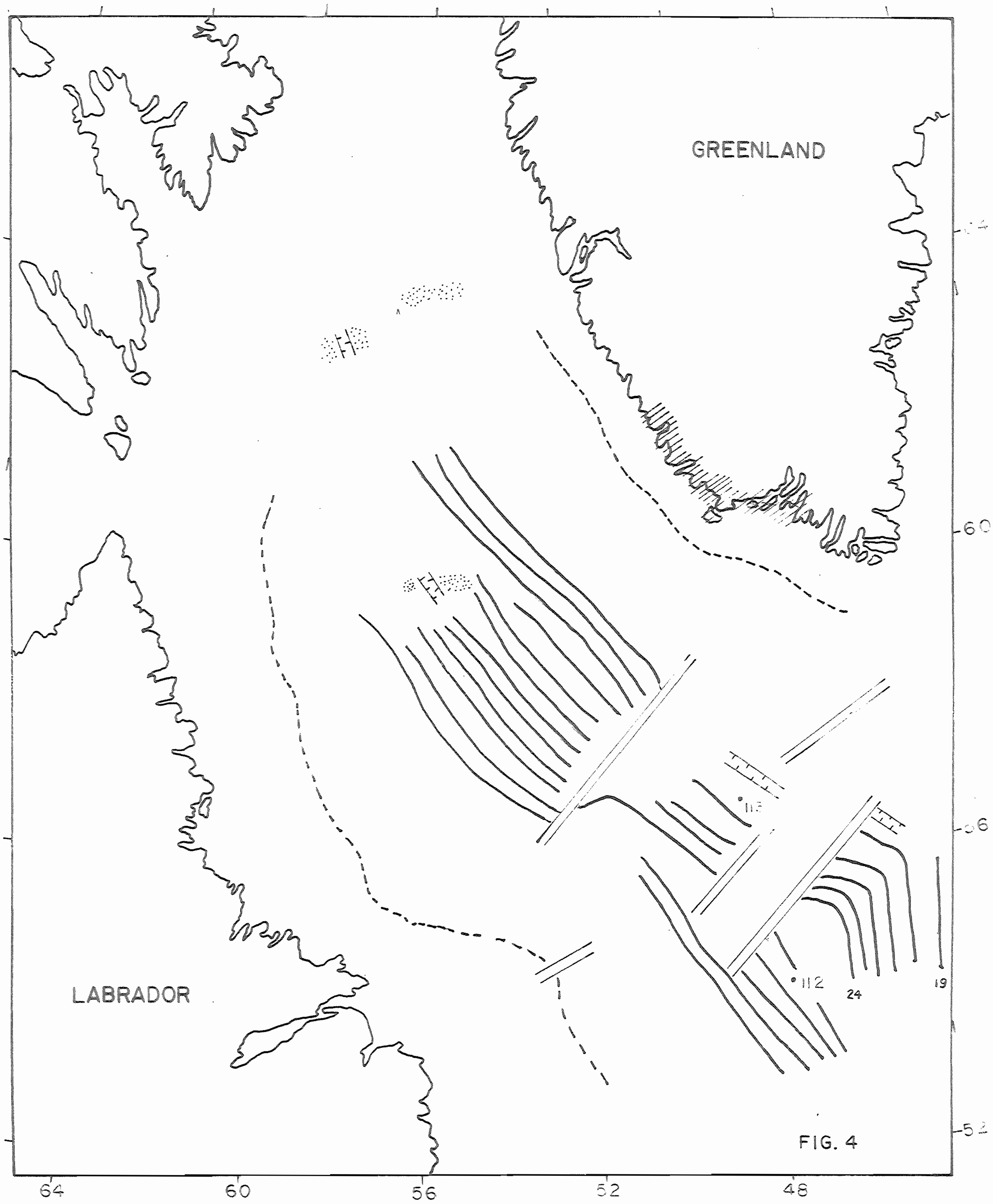


FIG. 4

- - - - - edge of continental shelf

transform fault

median valley

Zone of Jurassic dikes

basement high

magnetic trends

19 anomaly number

• 112 Joides drill hole

portion of the sea and does not appear to continue to the Labrador coast. However a buried fault extending northwest from the Labrador shelf near 55^{o}N may represent the extension of the Farewell transform fault. Their present disposition can be accounted for by two separate phases of opening. The first phase of opening took place as a simple rotation about a pole defined by these two fault segments. The time period involved is taken to be 80-60 my and is based on the age of separation of Rockall Bank and Greenland (anomalies 32-24). Their second phase is a simple strike slip motion along an assumed fault joining the ends of the two previously mentioned faults. The attitude of this fault is parallel to the attitude of a known portion of the Gibbs fracture zone at 52^{o}N. The age of this phase is estimated to be between 60-49 my and is based on a comparison with anomalies 24-20 given in Vogt et al. (1970) for the Mohns ridge, an extinct axis of spreading in the Norwegian Sea. The suggested strike-slip motion could be taken up by motion along Nares Strait and a fault which would truncate the western magnetic zone and extend through Davis Strait. The ridge first observed by Johnson et al. near 64^{o}N is interpreted as a part of this north-south transform fault. Spreading apparently took place at the rate of about 1 cm/yr.

Vogt et al. (1970) present an account of possible sea floor spreading from the Alpha Rise in the Arctic Ocean north of Ellesmere Island, based on magnetic profile symmetry and lineations. Observations suggest the cessation of spreading in the Tertiary. Hall (1971) reports that seismic profiles across this feature show buried topography similar to the mid-Atlantic ridge and the presence of several transform faults. It is possible that this ridge and the Labrador Sea ridge were connected by way of Nares Strait, Baffin Bay and Davis Strait.

The JOIDES deep-sea drilling project (Leg 12) has recently drilled two locations in the Labrador Sea (Fig. 4). Site 112 was chosen to determine the age of a prominent reflector which had been correlated with a similar distinct reflector near Rockall Bank off Great Britain. A reinterpretation of previous magnetic surveys (Laughton, in press) demonstrated that this site lay on the axis of a very old spreading center which has importance in the first phase of opening of the Labrador Sea and the North Atlantic. The cores from this hole showed that the reflector was mid-Oligocene in age. The oldest sediments found were Palaocene (56 my) and though the base of the hole was in basalt, it was on a topographic high and may not represent true basement. For this reason the probable age of the basement was int rpreted to be 65 my. After spreading from this axis ceased, spreading from a new axis began to the north, the same spreading axis reported in all the previous work. Site 113 was chosen near a basement high close to the axis of spreading, but the oldest cored sediments were no older than Miocene, before drilling was stopped. Based on the stratigraphy, linear anomaly patterns and transform faults, Laughton finds three major divisions in the tectonic history of the sea. Initial rifting began at 82 my on the axis through site 112 and continued until 60 my. During this time period Greenland moved as part of the European block relative to Labrador on the North American plate. Around 60 my the old spreading center shifted to the north and a triple point was formed, with relative motion of the Greenland, North American and European plates. Spreading on the Labrador ridge ceased around 47 my when the locus of spreading shifted entirely to the mid-Atlantic ridge. Since that time the Greenland and North American plates have been moving as one. Laughton reports evidence for very minor renewed activity in the Oligocene (35 my) and the present earthquake distribution in the Labrador Sea suggests that very small movements may be taking place at present, though heat flow values are normal for oceanic regions (Pye and Hyndman, in press).

The hypothesis first presented by Mayhew (1969) has been revised by Le Pichon et al. (in press) and Laughton (in press), the latter two now only differing in minor ways. The main features of this latest work concerning the opening of the Labrador Sea are:

1) activity associated with the mid-Labrador Sea ridge could have begun as early as Jurassic with uplift and tensions at the margins of the proto-Atlantic.
2) 82-60 my Rotational phase of opening.
   A two plate motion with separation of North American and European plates.
3) 60-47 my Translational phase.
   A triple point forms with relative motion of Greenland, North American and European plates.
4) 47 my to present.
   Spreading entirely from the mid-Atlantic and Reykjanes ridges.

Significantly, no structures have been positively identified as those arising from sea floor spreading in Baffin Bay and Davis Strait. However, the results of recent studies (Barrett et al., 1971; Park et al., 1971; and C. Keen et al., 1971) conducted in these two areas may provide the necessary information regarding the timing, geometry and mechanisms of opening.

2.4 Geophysical Studies in Baffin Bay

Although a large volume of geophysical data had been collected prior to 1970 in Baffin Bay, it consisted for the most part, of widely spaced magnetic profiles collected on many different cruises. It has only been in the past year that a concentrated geophysical effort has been made. In the summer of 1970 three Canadian research vessels were in the Bay conducting refraction and reflection seismic profiles, as well as magnetic and gravity surveys, with the express purpose of identifying geological phenomena which could be associated with continental drift.

The central portion of Baffin Bay is approximately 2300 metres deep, and is bounded to the east and west by fairly steep continental slopes. The shelf on the Greenland side is very much wider than the shelf on the Baffin Island side and has an average width of 200km. The northern slope is much less well defined; the average gradient being about 1:200 from 500 to 1500 metres. To the south, the basin is bounded by the Davis Strait sill (Fig. 5).

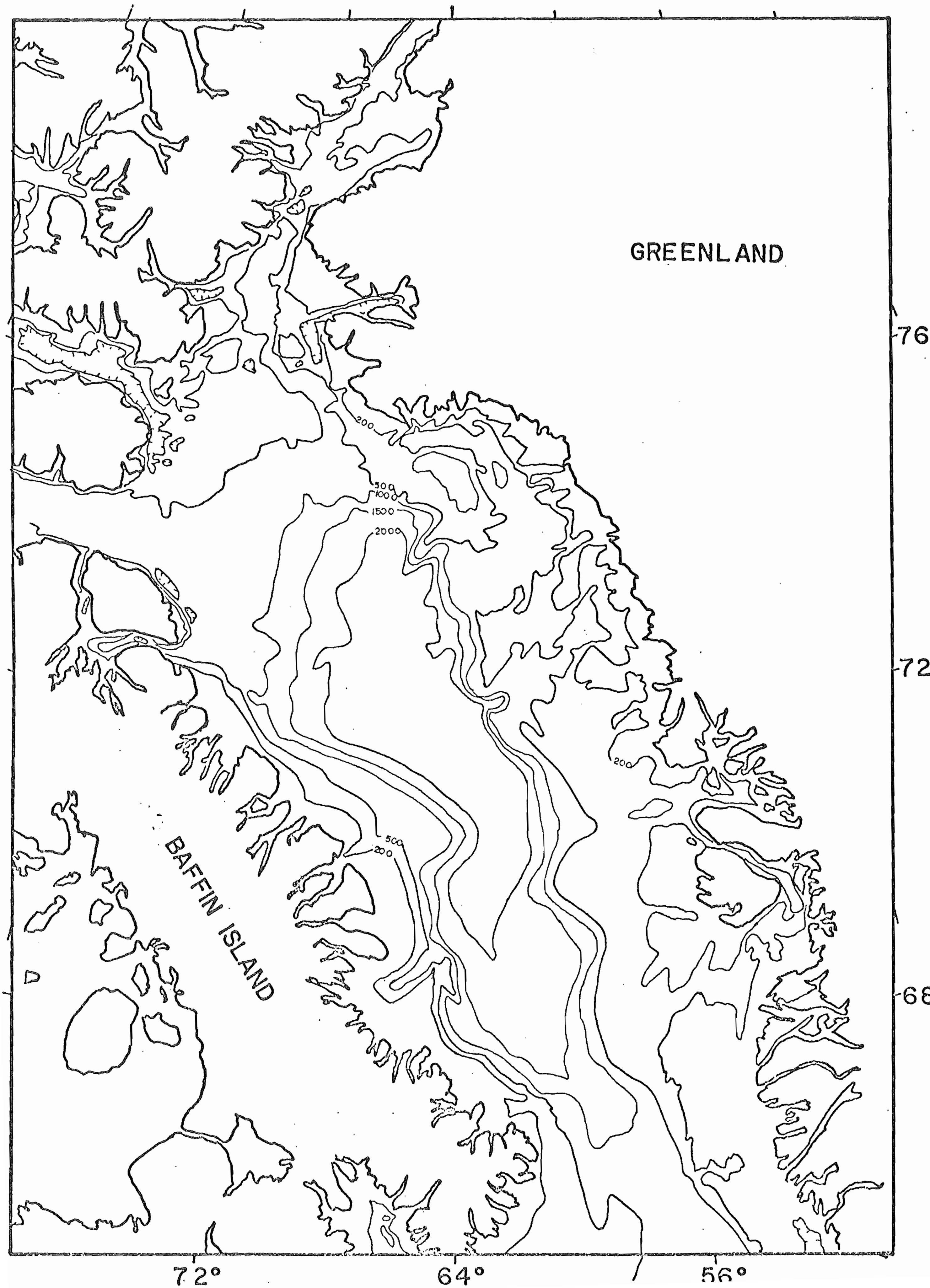
Early work in the area was initiated by Manchester (1964). Isolated magnetic profiles across the central basin showed that the magnetic anomalies were of very low amplitude and the wide separation made correlations between profiles impossible. However, the shelves on both sides of the Bay were characterised by anomalies of much larger amplitude and shorter wavelength. In addition, several anomalies were discovered which could be related to faults of presumed Tertiary age in the Cape York district. Henderson (pers. comm.) suggests that Tertiary age volcanics may exist in the same area.

An important result of Manchester's work was the observation of intensely sharp positive and negative anomalies in Davis Strait. This led to the speculation that these anomalies were associated with the Tertiary volcanics which occur on either side of the Strait, and the large negative anomalies found in the eastern portion could be associated with reversely

Figure 5

General Bathymetry of Baffin Bay

(contours in metres)


GREENLAND
BAFFIN ISLAND
76°
72°
68°
72°
64°
56°
200
500
1000
1500
2000
200
500
200

magnetised layers in these basalts.

Barrett (1966) investigated the magnetic pattern in Lancaster Sound and has demonstrated the existence of a fault on the north side. The structure appears to be that of a half-rift, with the northern side downthrown approximately 8 km. Johnson (1971) on the basis of seismic reflection records has found a major fault on the south side and has suggested that the feature is more likely a graben. Basement depth determinations by Gregory et al. (1961) suggest a prominent fault on the north side of Devon Island and a seismic profiler track from west to east in Jones Sound shows the presence of slightly westward dipping Palaeozoic sediments in the eastern end of the Sound (Manchester, 1964).

Geophysical surveys conducted from CSS DAWSON and CSS HUDSON constitute the basis for the remaining portion of this review.

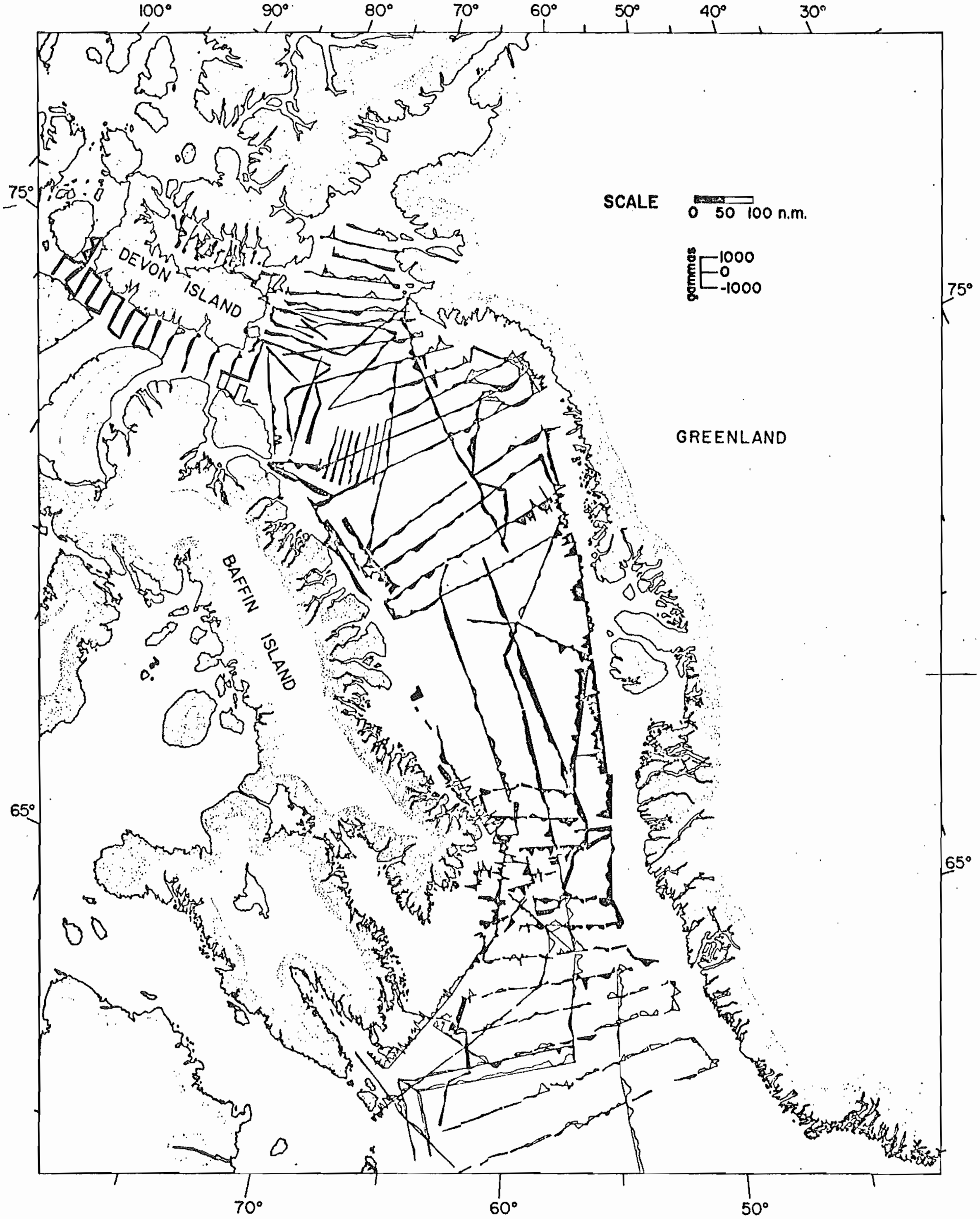
A reflection profile in the central part of Baffin Bay from Bylot Island to near Svartenhuk peninsula shows 3 seconds of water, 2 seconds of flat lying sediments, and a rough reflector at 5 seconds. Towards the Baffin Island shelf, acoustic crystalline basement rises beneath the sediment cover and is associated with large gravity and magnetic anomalies. The basement rise marks the contact of disturbed and undisturbed sediments. A two dimensional model to satisfy the gravity suggests that normal faulting has taken place at the transition between continental and oceanic crust (C. Keen, pers. comm.). It appears as if the eastern margin of the Bay is also fault-bounded (Keen et al., 1970), the basement surface of the West Greenland shelf dipping down to the west, to abut against a basement beneath part of the West Greenland continental slope. The sediments of the Baffin Island side, near the mouth of Lancaster Sound typically prograde toward the center of the Bay.

Reflection records over the trough separating a rough inner shelf from Cape York Bank, show approximately 150 metres of transparent overlying sediments which have been folded and normally faulted. The thickness of these sediments is demonstrated by the presence of a large -50mgal. gravity anomaly to the south and a persistent NW-SE trending large negative magnetic anomaly shown on Fig. 6. Hood and Bower (1970) interpret this magnetic anomaly on the basis of model studies and finds that it could be caused by the burial of magnetic basement by up to 6 km. of

Figure 6

Residual Magnetic Profiles in the Northern Labrador Sea, Davis Strait and Baffin Bay to 1970

(from Keen et. al., 1970)


100°
90°
80°
70°
60°
50°
40°
30°
75°
75°
65°
65°
70°
60°
50°
SCALE
0 50 100 n.m.
gammas
1000
0
-1000
DEVON ISLAND
BAFFIN ISLAND
GREENLAND

sediments. Johnson (1971) has interpreted the seismic reflection records and proposes that this feature is a graben.

A refraction line in the center of the Bay (Barrett et al., 1971) agrees well with the reflection records and is the first concrete evidence that the crust of Baffin Bay is oceanic.

On the basis of recent gravity profiles, C. Keen et al. (1971) interpret a 400 km wide strip of oceanic crust. This width of oceanic crust generation could be compared with a similar width produced by the now extinct Mohns ridge at the same time period (Vogt et al., 1970).

Fig. 7 illustrates the distribution of earthquake epicenters in the northern Baffin Bay region. Two facts should be noted:

1) their confinement to the northern part of Baffin Bay;
2) the significant cluster near 73^{o}N 71^{o}W.

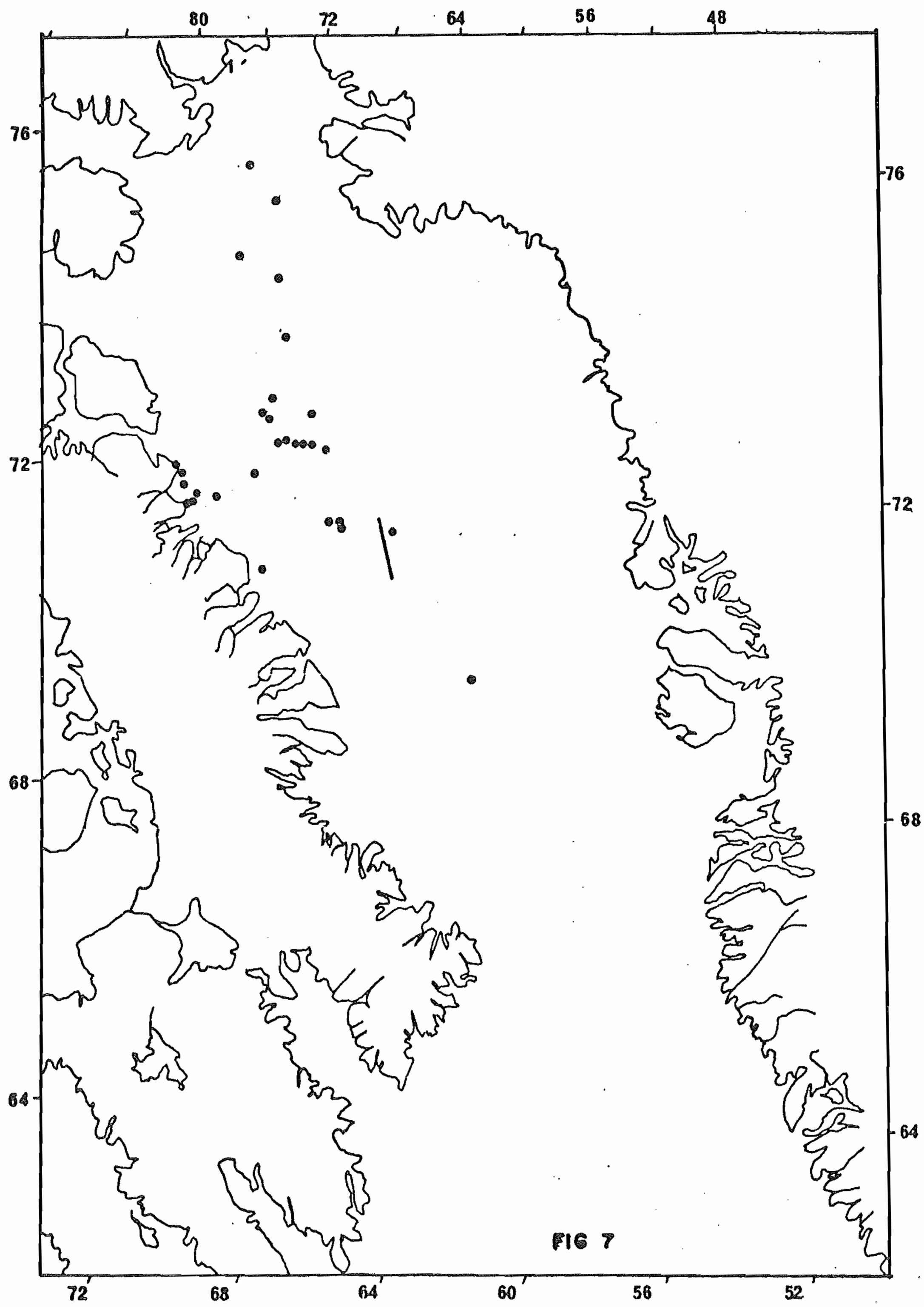
Seismic investigations of structures in this area of concentration, (Johnson, 1971) shows that the thick pile of sediments has not been disturbed in any way by earthquake activity. In addition, the heat flow

Figure 7

Earthquake Epicenters in

Baffin Bay

Refraction Line of Barrett et.al., 1971



Earthquake Epicenters

Refraction Line

(Barrett et al, 1971)

is normal (Pye, 1971). The distribution of epicenters still remains a problem. Magnetic profiles in this same region could not be contoured because of their low amplitude, and the high diurnal magnetic activity, but have shown linear trends which:

1) do not parallel the bathymetric contours, and
2) agree well with a pole of rotation in Lancaster Sound (Le Pichon et.al., in press)

and are the first evidence that linear magnetic anomalies associated with sea floor spreading may occur in Baffin Bay.

Recent geophysical surveying in Baffin has outlined a 400 km wide strip of oceanic crust and a deep sediment filled graben in Melville Bay. These two areas will assume a particular significance in Chapter 5.

Chapter 3 Geological Setting

3.1 Introduction

The purpose of this chapter is to provide a geological basis for the data presented in Chapter 4. Secondly, in keeping with the overall theme of the investigation of continental drift between Canada and Greenland, particularly in Davis Strait and Baffin Bay, the geological similarities between the rocks of central West Greenland and central East Baffin Island are demonstrated. In addition, an interpretation of the structural development of the West Greenland basin is presented to aid in:

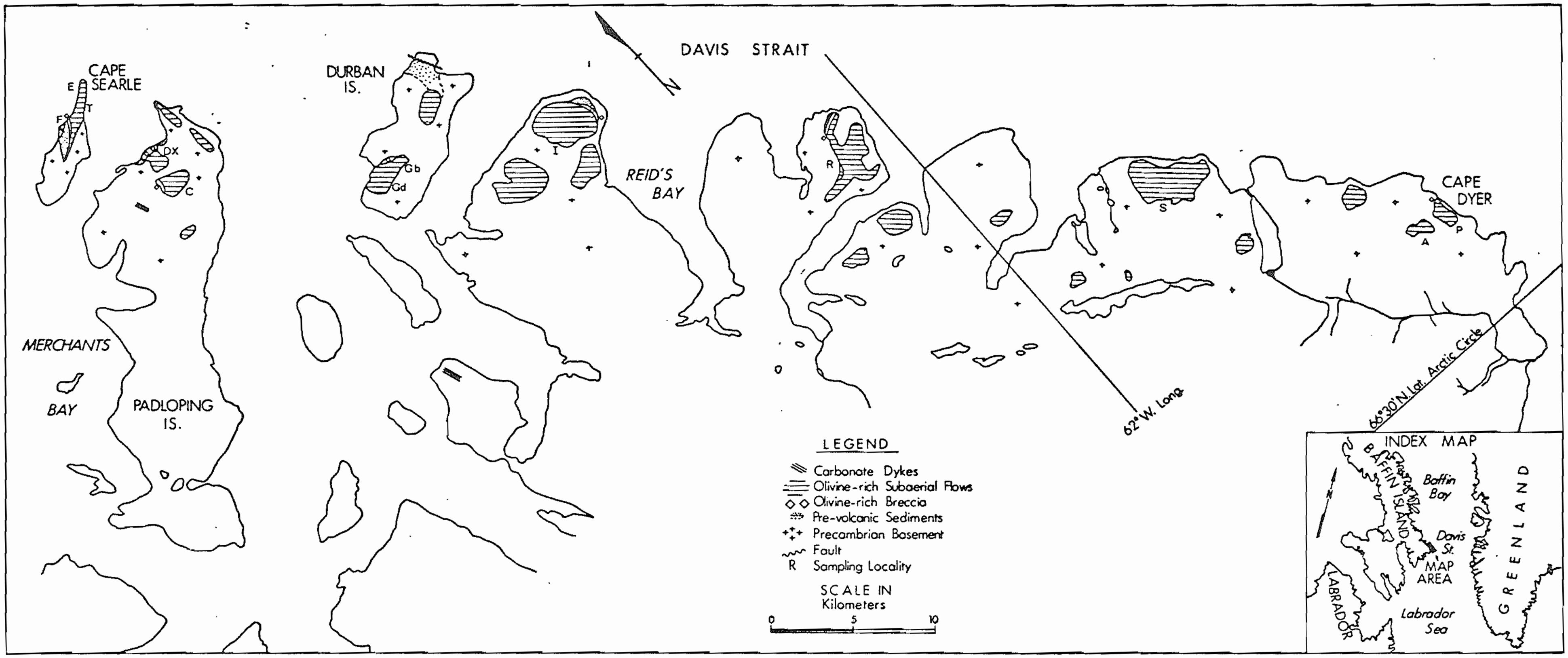
1) magnetic and seismic interpretation;
2) relating these structures to other known structures in Baffin Bay;
3) a brief assessment of the offshore hydrocarbon potential.

The Baffin Island coast of Davis Strait and Baffin Bay is composed mainly of acid rocks; granites, gneisses and quartzo-feldspathic paragneisses all of which have undergone the effects of the Hudsonian orogeny. In the Davis Strait area, flat-lying Tertiary extrusives overlie the irregular erosion

Figure 8

Map of outcrops of Tertiary basalts Sediments between Cape Dyer and Cape Searle, Baffin Island, N.W.T.

(from Clarke and Upton, 1971)


DAVIS STRAIT
CAPE SEARLE
DURBAN IS.
REID'S BAY
CAPE DYER
MERCHANTS BAY
PADLOPING IS.
62° W. Long.
66°30'N Lat. Arctic Circle
LEGEND
Carbonate Dykes
Olivine-rich Subaerial Flows
Olivine-rich Breccia
Pre-volcanic Sediments
Precambrian Basement
Fault
R Sampling Locality
SCALE IN Kilometers
0 5 10
INDEX MAP
BAFFIN ISLAND
Baffin Bay
Davis St.
MAP AREA
GREENLAND
LABRADOR
Labrador Sea

surface of the Precambrian, though in some cases minor terrestrial sediments intervene. The basalts occur in a string of 20 major separate outcrops from Cape Dyer to Cape Searle (Fig. 8). The outcrops are all found within 10 km. of the coast and none is larger than 10-15 km^2, most being considerably less.

On the West Greenland coast, basalts are exposed on land from Disko Island to the northern part of Svartenhuk peninsula. As on Baffin Island they rest directly on the Precambrian basement of similar age (Hudsonian) but sediments of both terrestrial and marine origin intervene locally.

3.2 The Precambrian of Baffin Island

With the exception of widely distributed Helikian strata in northern and northwestern Baffin Island, the Precambrian of Baffin Island consists of heterogeneous, complexly folded granitic gneisses with interbanded limestones, graphitic schists, quartzites and mafic schists. K-Ar ages from 1690-1750 my are the result of the metamorphism of the earliest Archean basement and overlying Lower Proterozoic sediments. Metamorphism took place during the Hudsonian orogeny and the rocks are thus classed as part of the

Churchill province together with the rocks of the Western Nain. Also associated with this orogeny are very large syn-tectonic granite bodies, the largest one on the island occupying an area of 60,000 km^2 (Bridgwater et al., in press).

North of Cape Dyer in the coastal area near Clyde, granitic gneisses with biotite and less commonly hornblende, are associated with widespread lenses, bands and patches of amphibolite thought to be derived from dikes and sills. Throughout this area near horizontal foliation prevails though recumbent folds have been detected locally (Kranck, 1955). The gneisses inland from Clyde contain a belt of crystalline limestones with metamorphic derivatives and a belt of quartzites with lesser carbonates and meta-argillites. To the west of Cape Dyer and within parts of the Piling group (Jackson, 1969) metamorphosed Lower Proterozoic sediments are found mantling central gneissic domes. As stated in Chapter 2, an important swarm of diabase dikes, dated at 675 my, occurs throughout most of the Island. The dikes are apparently associated with a late Precambrian rift zone. Crustal tensions suggested by these dikes are shown by a large number of NW trending faults, which form a series of grabens. North of

Cape Dyer the Hudsonian gneisses are folded in the same northwest direction, subparallel to the coast.

To the south of Cape Dyer however the predominant regional strike is to the northeast (Blackadar, 1961).

In the region of the volcanics, gneisses and migmatites are the two varieties of rocks in abundance, and their mineralogy (quartz-biotite-two feldspars) suggests that recrystallisation took place under amphibolite conditions. Locally however, granulite facies metamorphism occurs. In the Merchants Bay area (Fig.8) metamorphosed ultrabasic material occurs as boudinaged biotite amphibolite and pyroxenite layers (Clarke and Upton, 1971).

3.3 Cretaceous-Tertiary Sediments of the Cape Dyer Region

The sediments in most cases intervene between Precambrian rocks and overlying Tertiary volcanics. They consist of unconsolidated quartz sands, impure sandstones, shale and fluviatile conglomerates, all apparently terrestrial in origin. The current cross-bedding, abundant plant fossils and lack of marine fossils attests to the non-marine origin of these sediments. The fossils, which have been ascribed to the Palaeocene (Clarke, 1968) agree with the K-Ar age of 58±2 my for the overlying volcanics. A very rough examination by Clarke led to the correlation of these fossils with those found in lower Paleocene sediments on Nugssuaq peninsula (West Greenland) and described by Koch (1963).

Sediment-volcanic exposures are of two main types:

1) where the sediments are overlain by breccias, tuffaceous layers occur within the sediments within a few metres from the contact;
2) when the sediments are overlain by subaerial basalts, sedimentary bands are found within the first few flows.

3.4 Tertiary Volcanics, Baffin Island

The isolated outcrops of basalt are everywhere found in the depressions of the irregular erosion surface of the basement rock. The flows which range from normally 1-10 m up to 35 m in thickness are in most cases horizontal (Clarke and Upton, 1971). The lava succession normally thins rapidly to the west. Any deviation from the horizontal is due to the slumping of the unconsolidated sediments below. As mentioned before, breccia is often the lowest member of the sequence and its rapid accumulation appears to halt any further sedimentation. The composition of the flows ranges from picrites to olivine-rich basalts. Pleistocene glaciation apparently did not extend this far east as evidenced by the lack of striations and glacial erratics on the outcrops (Ives, 1963).

Two differing colours, orange and black, distinguish the two types of breccia. The difference is attributed to the greater degree of hydration of the glass and the oxidation of the iron in the more finely divided orange breccia. Clarke (1968) notes that "the type and degree of alteration in these breccias, their water contents and stratification combined with the prolific amounts of basaltic glass all suggest a sub-aqueous origin for these initial extrusives". One of the most noticeable features of these breccias is the giant cross-bedding which they display and is evidence for the provenance of the breccias if not for the whole sequence. In addition, if the tops of these breccias were all close to sea level at their time of deposition their position now involves a structural uplift of 400-500 metres.

The overlying picrites and olivine rich flows weather to a light grey colour and diminishing olivine content results in a darker and more cohesive rock. The average thickness of the flows is less than 5 metres. A description of the mineralogy and texture is given by Clarke (1968). Clarke and Upton (1971) found that the occurrence of flows was a local phenomenon since no correlation of flows from outcrop to outcrop could be made. The small areal extent and relative thinness of the flows provides evidence for the fact that the volcanic activity in this province was short-lived compared to other Tertiary tholeiitic provinces of the North Atlantic region.

Dikes, mineralogically identical to the flows, and cutting both the sediments and volcanics occur only at Cape Searle and Padloping Island (Fig. 8). However, their number (20), average size (2 m.), and lack of thermal metamorphism of the sediments in the region of the dikes preclude the possibility that they are the sole source for all the volcanic material, even in this restricted locality. It seems more likely that they have been the source for local, smaller flows.

In the light of this research, the most important conclusion is the hypothesis that the source area for the volcanics is to the northeast and offshore in Davis Strait. The following facts support this conclusion:

1) there are no central volcanic conduits in the area;
2) the small number of dikes, their size, and failure to occur inland from the basalt flows;
3) the southwest dip of the giant cross-bedding;
4) successive flows progressively overlap southwest onto the Precambrian.

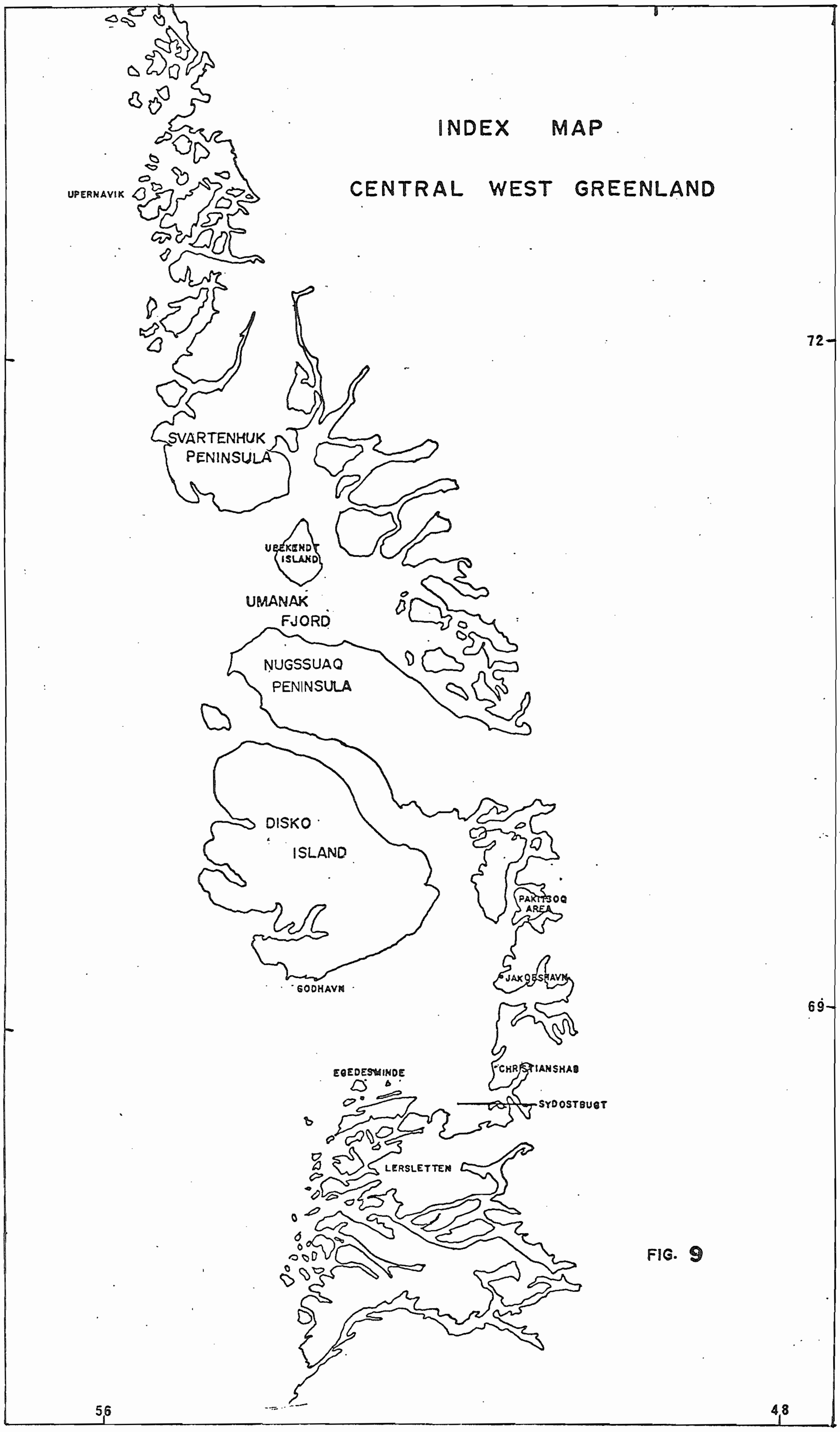
3.5 Precambrian of Central West Greenland

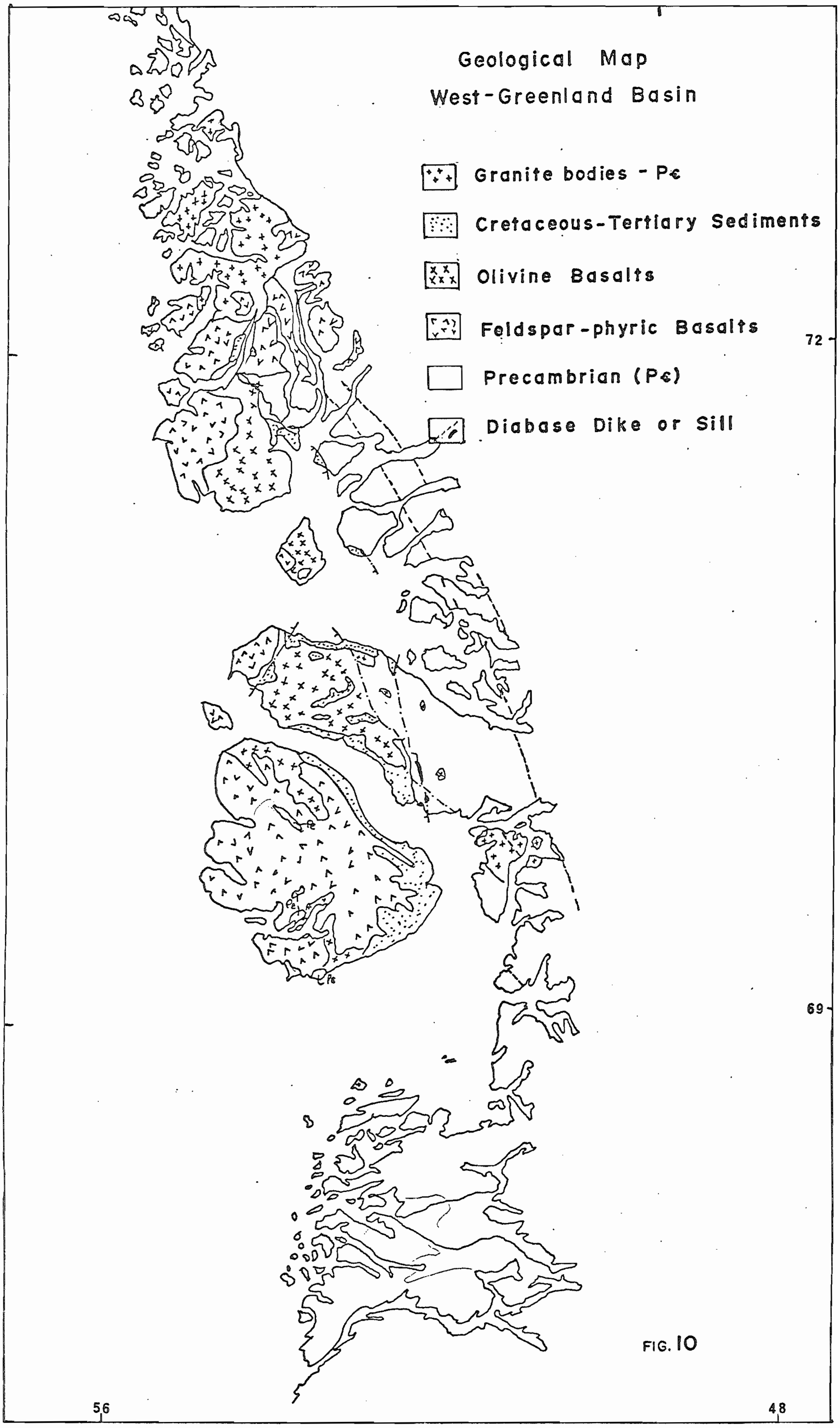
The Precambrian geology of West Greenland from Cape York to Upernavik is poorly known. The Greenland ice cap in many places extends right to the shores of Baffin Bay and little bedrock is exposed. However, from Upernavik south to Agto, re-mapping by the GGU for the publication of 1:500,000 maps, has produced detailed structural and geological analyses, mostly contained in reports by Henderson (1969), Escher and Burri (1968), and Henderson and Pulvertaft (1967). K-Ar ages in this region, (Larsen and Moller, 1968) show that the rocks have all been affected by an orogeny which formed the Nagssugtoqidian fold belt at the same time as the Hudsonian occurred on Baffin Island.

i) The Egedesminde-Christianshaab Area

The area to the south and southeast of Disko Island has been described by Henderson (1969). As shown by Figure 10 the rocks are all Precambrian and crystalline and form a part of the Nagssugtoqidian fold belt as defined by Ramberg (1949). Reactivation of the older basement from 1690-1750 my, has produced metamorphism ranging from amphibolite to granulite facies.

The two limits of metamorphism allowed Ramberg to recognise two main complexes within this area. The Isortoq complex (granulite facies) occupies the southernmost section and the Egedesminde complex (epidote-amphibolite facies) occurs over the remaining portion. Within this latter complex the dominant rock type is a quartzo-felspathic gneiss of granodiortic composition. However local structural and textural differences are widespread. North of Christianshaab and southeast of Egedesminde compositional banding is predominant and consists of varying amounts of biotite and hornblende. Broad zones of


INDEX MAP
CENTRAL WEST GREENLAND
UPERNAVIK
72
SVARTENHUK
PENINSULA
UBEKENDT
ISLAND
UMANAK
FJORD
NUGSSUAQ
PENINSULA
DISKO
ISLAND
PAKITSOQ
AREA
GODHAVN
JAKOBSHAVN
69
CHRISTIANSHAB
EGEDESMINDE
SYDOSTBUGT
LERSLETTEN
56
48
FIG. 9



Geological Map
West-Greenland Basin
Granite bodies - P€
Cretaceous-Tertiary Sediments
Olivine Basalts
Feldspar-phyric Basalts
Precambrian (P€)
Diabase Dike or Sill
72
69
56
48

FIG. 10

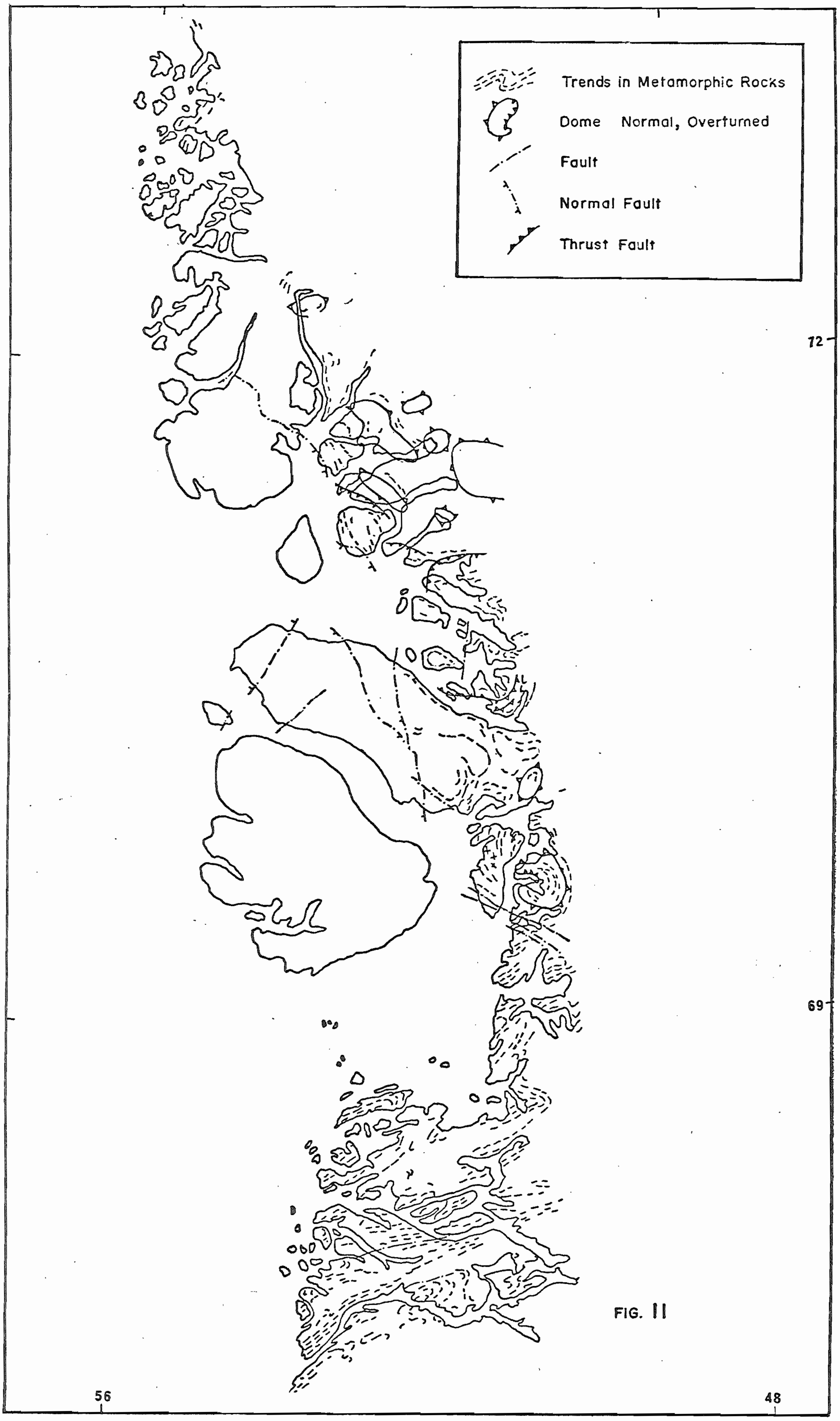

Trends in Metamorphic Rocks
Dome Normal, Overturned
Fault
Normal Fault
Thrust Fault
72
69
56
48

FIG. 11

amphibolite up to 0.25 km in width and persisting for tens of kilometres are common. In several places, the gneiss shows weak banding and is locally homogeneous. Intercalated mica schist and pelitic gniesses are found around Sydostbugt in the quartzo-felspathic gneiss. The schists and pelitic gneisses frequently contain pegmatite ranging in size from very small lenses to sheets of considerable lateral extent and thicknesses of a metre or more. The mixture of these igneous and metamorphic bands is due to metamorphic segregation and the resulting rock is migmatitic. Large granite bodies occur on the island of Manitoq, northeast of Egedesminde, in the western part of Lersletten, and an extensive and concordant sheet occurs in western Sydostbugt.

In the archipelago of southern Disko Bugt there is a meta-sedimentary series of mica schists and quartzites of low metamorphic grade and a metavolcanic series of greenstones. The almost complete absence of quartzites in the complex directly to the south, led Ellitsgaard-Rasmussen (1954), to conclude that these rocks were of a different origin and occupy a part of the suprastructure of the old fold belt as opposed to the gneisses of the infrastructure.

In addition, diabase (dolerite) dikes of possible Tertiary age are shown to occur on the map (Fig. 10). Textures in some of these dikes suggest that they crystallised under special conditions perhaps in the presence of water.

Henderson, (1969) has recognised several phases of deformation. The main phase is represented by upright and steeply inclined folds trending northeast to east (Fig. 11). The units which give use to this dominant tectonic fabric are the compositional bands in the gneisses and the discrete bands of mica schist and amphibolite. A supposed later deformation has produced a minor northwest trend as shown by the circular eye fold in Lersletten south of Egedesminde, but Escher and Burri (1968), in the area to the north, recognise these as most likely the earliest phase of deformation.

Only a few major undifferentiated faults are found in the area with their dominant strike being NNE.

ii) Disko Island

In a zone approximately 20 km wide and 80 km long, in the western part of Disko Island, small inliers of Precambrian gneiss with amphibolite banding are found. They appear to form a continuation of the series described for the southern Disko Bugt archipelago. The axis of this structural high stretches from Anarssuit Island north of Egedesminde to Stordal in northern Disko (Fig. 11).

iii) Jakobshavn-Southern Nugssuaq Area

The crystalline rocks of this area have been mapped in detail by Escher and Burri (1967). The area around Jakobshavn is dominated by the Jakobshavn gneiss, light coloured, granodioritic and composed mainly of quartz, biotite and oligoclase. Within this gneiss, Escher and Burri recognised two different formations:

1) the lower or Satut formation characterised by thick siliceous gneiss horizons and the almost complete absence of amphibolites, and
2) the upper or Klokkerhuk formation composed of light grey granodioritic gneiss with abundant amphibolite layers.

The Anap Nuna group of supracrustal rocks overlies conformably the Jakobshavn gneiss and forms a curved synclinal belt in the northwestern part of the mapped area. The lower part of this group is composed essentially of quartzites and mica schists and the upper formation is composed of semi-pelites. A large zoned granite (the Ata granite) occurs in the north central section near the core of the synclinal belt.

Two main tectonic styles are developed in the area (Fig. 11):

1) a southern complex characterised by an ENE orientation of fold axes, and
2) a northern complex with fold axes curved around the central gneissic dome.

Significantly, the transition between these two areas is marked by the presence of several important northwest trending faults in the area of Pakitsoq. The highly deformed style of the northern complex appears to continue as far north as Upernavik and emphasizes the importance of this fault zone as a major break in the Precambrian metamorphic development.

The southern complex is dominated by the same trends which occur in the Egedesminde area.

The central gneiss dome, the supracrustal belt and the Ata granite are the three main structural units to the north of the Pakitsoq fault zone. The central dome has a diameter of 25 km and lithologically belongs to the Klokkerhuk formation. Amphibolite bands are very common. The western part of this dome is overturned with a very shallow dip to the east while the eastern section has a normal east-sloping domal dip. The western section with the overturned flank is a nappe-like feature with an overlap locally of at least 12 km.

As in the Egedesminde complex the rocks belonging to the Jakobshavn gneiss have a mineralogy characteristic of amphibolite facies metamorphism. The lowermost portion of the supracrustal belt exhibits amphibolite facies mineralogy while the upper group has a mineralogy indicative of greenschist facies conditions.

Diabase dikes and sills, relating to the formation of the volcanic sequence on Disko Island, are also found. The largest of these occurs just west of the inland ice and stretches to the north for some 400 km. The directions of these dikes and sills vary from WNW near Jakobshavn to NNW farther north and their orientation may be of significance in the interpretation of the faulting, relating to the development of the Cretaceous-Tertiary basin to the west.

iv) The Umanak Fjord Region

In the Umanak region, similar lithologies to those occurring in the Jakobshavn area have been mapped. Henderson and Pulvertaft (1967) have identified:

1) a lower predominantly gneissic group, the Umanak gneiss;
2) an upper supracrustal or metasedimentary Karrat group, subdivided into two formations:
    i) a lower unit of quartzites and various schists,
    ii) an upper uniform metagreywacke group of at least 5 km thickness.

The Umanak gneiss, further divided into three formations, is a light coloured, biotite to hornblende-biotite gneiss of granodioritic composition. Banding in this gneiss is variable, local homogeneity common and numerous amphibolite bands are found.

The gneisses are presumably remobilised Archean basement on which Lower Proterozoic sediments represented by the supracrustals were deposited. Two different formations have been recognised in this metasedimentary group.

Structures in the area are similar to those found in the northern complex of the Jakobshavn area but with more abundant and smaller scale folds and domes. Overfolds and nappes are dominant in the south and southwest but the central and northern regions are dominated by eight major domal features. The domes appear to have been the first to develop with subsequent deformations producing, first the overfolds and later the nappes. Multiple deformations have masked a dominant regional strike.

The mineralogy of the Umanak gneiss indicates characteristic amphibolite facies metamorphism. The lower Karrat group displays the same conditions while the upper group has been affected by greenschist facies conditions. Correlations between the formations shown in the Umanak area and those in the Jakobshavn region are shown in Figure 12 , while a regional comparison between all the afore-mentioned areas on the basis of composition, structure and metamorphism is shown in Figure 13 .

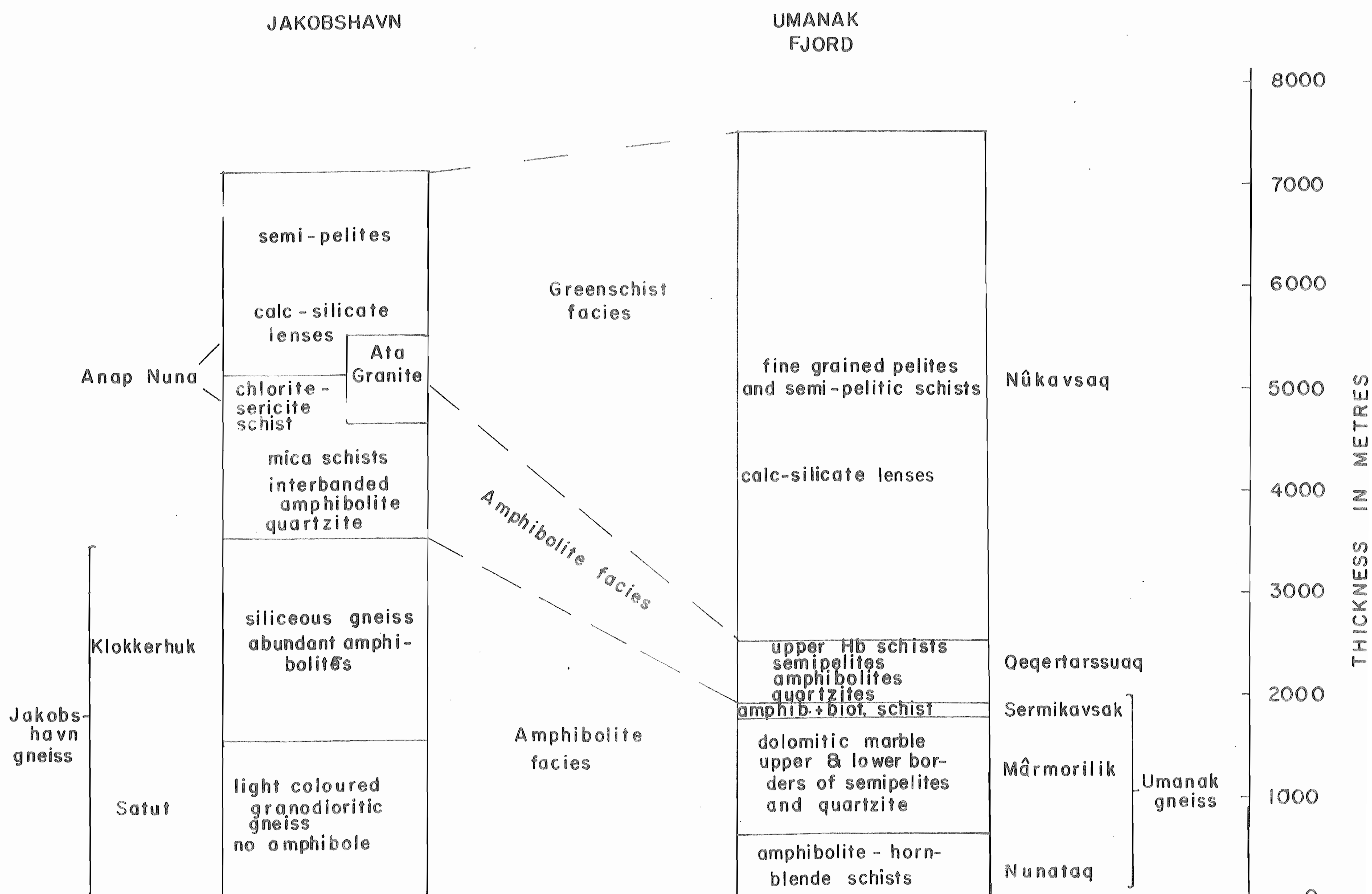

JAKOBSHAVN
UMANAK FJORD
8000
7000
6000
5000
4000
3000
2000
1000
0
THICKNESS IN METRES
semi-pelites
calc-silicate lenses
Ata Granite
Anap Nuna
chlorite-sericite schist
mica schists
interbanded amphibolite quartzite
Klokkerhuk
siliceous gneiss abundant amphibolites
Jakobshavn gneiss
Satut
light coloured granodioritic gneiss no amphibole
Greenschist facies
Amphibolite facies
Amphibolite facies
fine grained pelites and semi-pelitic schists
Nûkavsaq
calc-silicate lenses
upper Hb schists semipelites amphibolites quartzites
Qeqertarssuaq
amphib.+biot. schist
Sermikavsak
dolomitic marble upper & lower borders of semipelites and quartzite
Mârmorilik
Umanak gneiss
amphibolite-hornblende schists
Nunataq

FIG. 12

Figure 13

	Isortoq	Egedesminde	Jakobshavn South	Jakobshavn North	Umanak
Composition	quartz-dioutic gneiss	granodioritic gneiss lenses of amphi- bolite layers of mica schists and semi- pelites replacement granites	Jakobshavn gneiss 1) Satut forma- tion, light colored grano- dioritic gneiss 2) Klokkerhuk- siliceous gneiss abundant amphibolite	1) supracrustal metasediments 2) central Klok- kerhuk forma- tion	Karrat metasedi- ments Umanak gneiss
Structural Trends	NE to ENE trends dominant F2 folds	steeply inclined NE to E-W trend- ing isoclinal folds F2 deformation	ENE orientation of fold axes Major F2 deforma- tion earlier F1	central dome with overturned west flank-nappe-like 2 large synclines curve around	domes in north overfolds and nappes in south

	Isortoq	Egedesminde	Jakobshavn South	Jakobshavn North	Umanak
Structural Trends		earlier minor F1 phase strong gneissic banding NNE striking undifferentiated faults	deformation NW to NNE	central dome strong F3 deformation N to NW trends WNW to NW trending faults	
Dikes		Tertiary diabase dikes	2 major Tertiary dikes striking NNW		
Metamorphism	granulite facies	epidote-amphibolite facies	amphibolite facies	green-schist to amphibolite facies	green-schist to amphibolite

	Isortoq	Egedesminde	Jakobshavn		Umanak
			South	North	
Age		1690 to 1750 my	1740±30 my 1750±50 my	1720 my	1720 my

3.6 The Cretaceous-Tertiary Basin of West Greenland

Cretaceous-Tertiary rocks in West Greenland occupy the area between Svartenhuk peninsula in the north and the Gronne Islands in the south (Fig. 10). Sediments of both terrestrial and marine origin were laid down between Lower Cretaceous and the lowermost Palaeocene (Danian). In this latter period, volcanism of the type that affected other large areas in the North Atlantic region, occurred in the area. The lowest members of the sequence are some tuff bands and some subaqueous volcanic breccias which are overlain by a very thick pile of subaerial lavas.

i) Sediments

The Disko Island and southern Nugssuaq sedimentary sequences are comprised almost entirely of limnic and fluviatile deposits with occasional marine sediments. The remaining areas from southern Nugssuaq to northern Svartenhuk experienced marine sedimentation throughout the entire Senonian. The southernmost limit of the basin is the Gronne Islands where a small outcrop of thinly bedded dolomite occurs beneath a diabase sill.

The entire basin appears to have been fault-bounded since the commencement of sedimentation (Rosenkrantz and Pulvertaft, 1969). Both on Nugssuaq and Svartenhuk peninsulas, basalts overlap the faults and lie directly on Precambrian rocks to the east, so that it is most likely that sediments were never deposited to the east.

Rosenkrantz and Pulvertaft (1969) have given a review of the biostratigraphy in the sedimentary sequence, and have noted a prominent change in faunal affinities at the end of the Senonian. From Late Turonian to Late Maestrichtian the area was covered by a body of water which had a direct connection via the Canadian Archipelago with the large Cretaceous sea which covered most of central North America. Affinities of the fauna with European fauna did not exist. However the fauna of the Lower Danian have very strong affinities with the fauna of northwestern Europe suggesting, at the very least, an extension of the proto-Atlantic into this region.

Information related to the hydrocarbon potential of the sediments is contained in a report by Henderson (1969). On Nugssuaq peninsula, masses of bituminous shale have slipped down steep cliffs and frictional heat has ignited the combustible material. Mud volcanoes giving off methane gas occur in areas of Quaternary deposits, where they are believed to be underlain by Cretaceous-Tertiary sediments or by volcanics directly overlying these sediments. There is evidence for a direct relation of the volcanoes to the bituminous shales, as well as to the major fault zones of the basin. Henderson cites evidence of a direct marine connection between the Sverdrup basin and the West Greenland basin in the late Cretaceous-early Tertiary. Since a continuous sequence of sediments back to mid-Pennsylvanian times occurs in the Sverdrup basin the report suggests that, where the rocks of the West Greenland sedimentary sequence are not lying directly on the Precambrian, they may overlie Palaeozoic and/or Mesozoic sequences. However, at the present time, there is no evidence onshore to suggest this possibility.

ii) Volcanics

As was the case for the Baffin Island volcanic sequence, both the sediments and overlying volcanics are found to occur in depressions on the highly dissected Precambrian-Cretaceous basement surface. In contrast, however, the volume of lava produced in Greenland was much greater and the basalts outcrop continuously for a distance of 340 km from south to north. Basal subaqueous breccias overlain by subaerial basalts make up the general stratigraphic sequence but these West Greenland lavas show a higher degree of chemical evolution. The subaerial pile is divided into a lower olivine-rich basalt similar to that found on Baffin Island but the olivine content decreases upward and the highest sequence consists of olivine-poor basalts rich in feldspar phenocrysts. These basalts have evolved from the earlier picrites by fractionation along olivine control lines (Clarke, 1970).

Olivine-rich breccias up to 300 metres in thickness, resting on marine sediments of Upper Turonian to Coniacian in age, are the lowest members of the sequence on Svartenhuk. The breccias exhibit a giant cross-bedding suggesting a southwesterly source area. The typical sequence of volcanics above the breccias ranges from subaerial picrites through olivine-poor to feldspar-phyric basalts. The flows range in thickness from 3-5 metres. An important fault zone passing through Svartenhuk peninsula controls the distribution of the late Cretaceous-Tertiary sediments and the earlier volcanics. Later extrusives have spilled over this fault zone and extend as far as the ice-cap, resting directly on the Precambrian basement. In the northern part of Svartenhuk the feldspar-phyric basalts have erupted subaqueously and the cross-bedding developed indicates a provenance again to the southwest. In this same area a thin band of terrestrial sediments marks the contact between the lower picritic and upper feldspar-phyric basalts, suggesting that the basin, at least in this section, was subjected to repeated uplift and subsidence. Several small trachytic bodies occur and they may represent the most evolved silicate rocks in the area. Repetitive faulting makes the estimation of total thickness difficult but 4-8 km is one estimate (Clarke, pers. comm.).

The entire sequence is represented on Ubekendt Island, excluding the subaqueous breccias. It is the site of the only central intrusive complex in the entire basin; a gabbro-granophyre body in the southern portion of the island (Drever, 1958) as well as a host of minor intrusions not seen elsewhere in the basin. A volcanic vent penetrates the upper lavas in the west.

In eastern Nugssuaq, the latest episode of volcanic activity has spilled lavas over the Ikorfat fault zone (Fig. 10) where they are found directly on the Precambrian, whereas to the west they rest on sediments of approximately 1-2 km thickness (G. Henderson, pers. comm.). Two Lower Danian fossiliferous basaltic tuffs are the oldest volcanics, and these are covered in turn by picrite breccias and subaerial basalts. Repeated occurrences of breccias in the lower section suggests that subsidence has played a major role in this area. Giant cross-bedding is again displayed by the breccias and in one location, west of the Itivdle valley, shows two different directions. One direction demonstrates provenance to the west, while the other direction shows a provenance to the east, possibly the Ikorfat fault zone. Henderson (pers. comm.) notes a volcanic vent near the fault zone. Overlying these breccias are olivine-rich basalts showing a sharp transition to the upper feldspar-phyric variety.

On Disko Island, the volcanics to the east lie on the sediments while in the west the lavas rest directly on the Precambrian, on the axis of the structural high mentioned in Section 3.5. Dips in the eastern part of the island are shallow but increase to the northwest corner and onto Hareoen Island. The base of the volcanic sequence is again composed of breccias which are picritic in composition. The subaerial flows are composed of a lower olivine basalt formation with a gradual transition to the latest feldspar-phyric basalts in Northern Disko. To the south the transition is very sharp, from olivine-free breccias to subaerial flows. On the south coast the first feldspar-phyric eruptions were subaqueous. Flow thicknesses in this region are the same as those farther north and if the source of the volcanics lies to the northwest of Disko, then the volcanics may have once extended even farther south, perhaps overlying the Precambrian south of Egedesminde (Clarke and Pedersen, in press).

3.7 Structural Development of the West Greenland Basin

As was mentioned previously, the West Greenland basin has been fault-bounded since the commencement of sedimentation, though the latest flows have overlapped the fault zones.

On Nugssuaq, the Ikorfat fault zone, dipping 40^o WNW has been the locus of 900 m of downward displacement. Of this displacement 400 m is expressed in the Maestrichtian sediments but the remaining

500 m of displacement took place after the deposition of the basalts. Precambrian exposures are absent west of the main fault and nowhere is the base of the sediments exposed, so that it is possible, as previously inferred, that sediments older than Turonian may underlie the exposed sequence. Unconformities have been described from almost all levels in the sequence attesting to conditions of repeated instability.

Flat-lying flows are present throughout most of the area but gentle warping, the result of movement along fault zones and seaward tilting can be seen. The lavas in western Nugssuaq and southern Svartenhuk have shallow dips near the coasts with increased dips near the fault zones. The opposite is true in NW Disko and in Svartenhuk, with increased dips near the coast. On Nuggssuaq in addition to the main fault zone, antithetic faults striking N-S demonstrate the prominence of block-faulting. The Itivdle fault zone continues to the SW corner of Hareoen. On northwest Disko Island there is a zone of downwarping to the west with dips increasing up to 25^{o}. Associated with this zone are a series of en echelon faults striking N-S. Henderson (pers. comm.) feels that this zone of downwarping is the same zone that affects the basalts northwest of the

Itivdle valley on Nugssuaq, though no major fault has been observed on Disko. If this is the case, then a fault exists parallel to the south coast of Nugssuaq, which has a right lateral displacement of about 25 km. Included in this argument is the obvious fact that diabase dikes and sills are associated with the boundary fault zone throughout the basin, and as such are seen to occur near the NE trending Itivdle fault. However another set of dikes parallels the coast, almost at right angles to the Itivdle fault. The proposed Nugssuaq fault may join up with the prominent Pakitsoq fault zone north of Jakobshavn, suggesting that reactivation during the Tertiary may have taken place.

The structural features have importance in connection with oil and gas exploration both on land and offshore. If hydrocarbons are present then the widespread block faulting in northwestern Nugssuaq makes the presence of fault traps in the sediments a possibility. In western Disko and northwestern Nugssuaq the basalts dip toward the sea and if the sediments follow this regional dip, hydrocarbons could possibly migrate up dip from lower marine to upper non-marine sediments to be trapped at a fault contact by the impermeable basalts. Areas where the basalts are thinnest would be areas of prime interest since the amount of cover over potential producing horizons would be minimised.

Rosenkrantz and Pulvertaft (1969) state "the Cretaceous-Tertiary faulting in West Greenland occurred inside the continental margin, but it is of the type expected near the borders of continental masses that have moved apart". Similar faulting has occurred on the east Greenland coast in connection with sea floor spreading in the North Atlantic (Haller, 1969).

3.8 Comparative Geochemistry of the Basalts

Detailed geochemical work on both the Tertiary basalts of Baffin Island and those of Svartenhuk has been reported on by Clarke (1970). Significant correlations between these two provinces were made on the basis of their chemistry and phase relations (see also Chapter 3).

The Baffin Island basalts are particularly rich in olivine with the most evolved composition having an MgO content of 8%. The presence on Svartenhuk peninsula of late-stage feldspar-phyric basalts with even more evolved trachytes suggests a greater degree of olivine fractionation (an average of 14 feldspar-phyric basalts gave an average MgO content of 5.8%). Both suites are hypersthene-normative picrites. Variations in the oxides demonstrate olivine control during differentiation for both groups. The results of chemical analyses, trace element studies and phase relations led to the following conclusions:

1) if the level of K_2O is a reliable criterion of the evolutionary stage of a magma, then these rocks represent very primitive mantle derivatives

   K_2O for Baffin Island lavas .02-.17%

   K_2O for W Greenland lavas .06-.85%

   the Baffin Island group lies at the more basic end though overlap between the two occurs (Clarke, 1967).
2) continuous linear trends on the variation diagrams show successive differentiation products of one slowly evolving source.
3) the two suites display similar trace element characteristics but at the same time they are sufficiently different from other comagmatic provinces that they may belong to a single petrologic province characterised by low levels of incompatible elements.
4) the eruptions on Baffin Island began before those

on West Greenland but the geochemical overlap suggests an overlap in the time of volcanic activity (Clarke, 1970).

Finally, the close geochemical relationship and the large geographical separation today, suggests that the two areas were probably very close during the time of volcanic activity in the Tertiary, and that simultaneous generation of the two lava fields has taken place.

3.9 Summary

The geology, structure and geochemistry of the rocks of both east-central Baffin Island and central West Greenland has been given in some detail. The following observations provide important evidence in favor of continental drift in the Davis Strait region.

1) metamorphic grades in the basement rocks are amphibolite facies, though granulite facies appear locally.
2) the same north-south structural divisions pertain in both cases

    southern sections show predominant northeast regional strikes

    northern sections exhibit more complex

doming and folding

3) K-Ar ages reported for the Precambrian rocks fall in the same range 1665 my-1790 my representing the Hudsonian orogeny in Canada and the Nagssuaq-toqidian in Greenland.

4) in the northern regions Lower Proterozoic sediments (now metamorphosed) mantle central gneissic domes.

5) large syn-tectonic granite bodies occur in both areas.

6) terrestrial sediments with fossils of lower Paleocene age are found in both provinces, though marine sedimentation has also occurred in the West Greenland basin.

7) for West Greenland the change in faunal affinities at the end of the Senonian from Arctic to mixed European and Arctic in the Danian suggests improved access of the proto-Atlantic at the end of the Cretaceous.

8) attitudes in the giant cross-bedding of the subaqueous breccias suggests a common source area in the Davis Strait.

9) the sequence in both provinces has been from subaqueous breccias to hypersthene-normative picrites with the West Greenland lavas having evolved to

a greater degree (as evidenced by later feldspar-phyric basalts).

10) both suites of volcanics appear to be related to a single petrogenetic scheme.

11) normal faulting has occurred at the margin of the West Greenland province and has had a profound effect on the history of sediment deposition and on the structure of the basalts.

Chapter 4 Geological and Geophysical Results

4.1 Introduction

To this point, the following aspects have been examined in the form of a review:

1) evidence for continental drift and sea floor spreading in the Labrador Sea;
2) evidence for the simultaneous development of a spreading center in the Arctic ocean suggesting that the Alpha rise and the mid-Labrador Sea ridge were once joined by way of Nares Strait, Baffin Bay and Davis Strait;
3) the existence of oceanic crust and graben-like features in Baffin Bay which may be associated with the suggested rift;
4) an area where similar rocks have been shown to occur on both Baffin Island and Greenland; the Precambrian rocks and Cretaceous-Tertiary sediments and volcanics bordering the Davis Strait.

In selecting an area for more detailed investigation to gain some insight as to the structures associated with the proposed Baffin Bay rift zone the Davis Strait area would seem to be a logical choice.

First, the development of the large volume of Cretaceous-Tertiary rocks on Baffin Island and in West Greenland basin is intimately linked in time to the spreading history and tectonics of the Labrador Sea. Secondly, investigation of the regions off-shore from these sequences would be in shallow water. Potential field surveys could be used more effectively as tools for mapping geological units since the source of the disturbing fields would be much closer to the surface. The bathymetric charts in the area (Section 4.12) suggest that near to the shore the topography is rough and characterised by North-South troughs, so that dredging becomes an attractive proposition.

4.2 Previous Geophysical Work Relating to Davis Strait

Manchester (1964) was the first to notice the large number of negative anomalies, up to -1000 gammas and sharply peaked, which are present in the eastern half of Davis Strait. He concluded that these large negative anomalies may be due to reversed natural remanent magnetism of lavas, which could be the same as those which were known to occur on Disko Island. However, large positive anomalies with amplitudes greater than 400 gammas are found and could also originate from volcanically derived rocks, of normal polarity.

Magnetic data from subsequent cruises in the western portion of Davis Strait are shown on Figure 6 . Anomalies of similar amplitude to those of the eastern half are shown to occur on the western side. However all are of high frequency and appear to be continuous to the north and south along the coast. In this area the recognition of a typical magnetic signature which could be attributed directly to volcanics offshore from Cape Dyer becomes much more difficult. Large amplitude high frequency anomalies also appear to be associated with areas offshore from known Precambrian localities. In contrast to the Precambrian rocks on the Greenland side of the Davis Strait, a large number of basic dikes trending northwest and associated with the Hadrynian rift zone (Fahrig et al., 1971) intrude the Hudsonian gneisses throughout most of Baffin Island. High frequency magnetic anomalies associated with the intrusion of basic dikes into Precambrian rocks have been observed on the Labrador shelf (Manchester, 1964) and the situation for the Baffin Island shelf may be analogous. The magnetic anomalies offshore from Precambrian rocks on West Greenland show much longer wavelength, smaller amplitude characteristics but similar dike swarms do not exist. High frequency Precambrian anomalies however do occur on the Greenland shelf in Melville Bay, off southwest Greenland and have recently been described off southeast Greenland (Vogt, 1970).

A comparison of recently published aeromagnetic maps (GSC Geophysics Papers, 5434-5437, 5440-5442) and the outcrop map compiled by Clarke and Upton (1971) shows several interesting features. Each of the separate outcrops of Tertiary volcanics is delineated by anomalies ranging from about 200 gammas up to 1200 gammas above the regional. Intervening Precambrian areas show very little magnetic relief, however susceptibilities of basic rocks are known to be several orders of magnitude greater than those of Precambrian gneisses. The contact between the area of basalt outcrop and the Hudsonian gneisses inland is fairly well defined. The gneisses show anomalies only on the topographic highs but the amplitude of these anomalies is still much less than those given by volcanic outcrop. The highs are surrounded by areas of little or no magnetic anomalies. In contrast to the area of Tertiary outcrop on land, the magnetic pattern offshore from the volcanics is much more striking. The high frequency pattern is much more homogeneous unlike the patchy pattern associated with isolated outcrops. This may indicate that the province is much more continuous offshore. The trends are roughly northwest and in one place are transected by a northeast trending lineament. No corresponding linear feature has been noted on land.

The high frequency anomalies of Fig.6 give way rapidly to smaller amplitude longer wavelength anomalies to the west.

Johnson et al. (1969) in the northern Labrador Sea have shown that an acoustic basement related to the tectonic development of the area occurs near 64^{o}N, 56^{o}W. They suggest that this basement occurs at the junction of the old Labrador Sea ridge and the Tertiary volcanic province. The eastern magnetic zone of the Labrador Sea appears to terminate at this point. Both Johnson et al. and Le Pichon et.al. (in press) suggest that this basement high is a part of a transform fault which truncates the western magnetic zone and continues into Davis Strait.

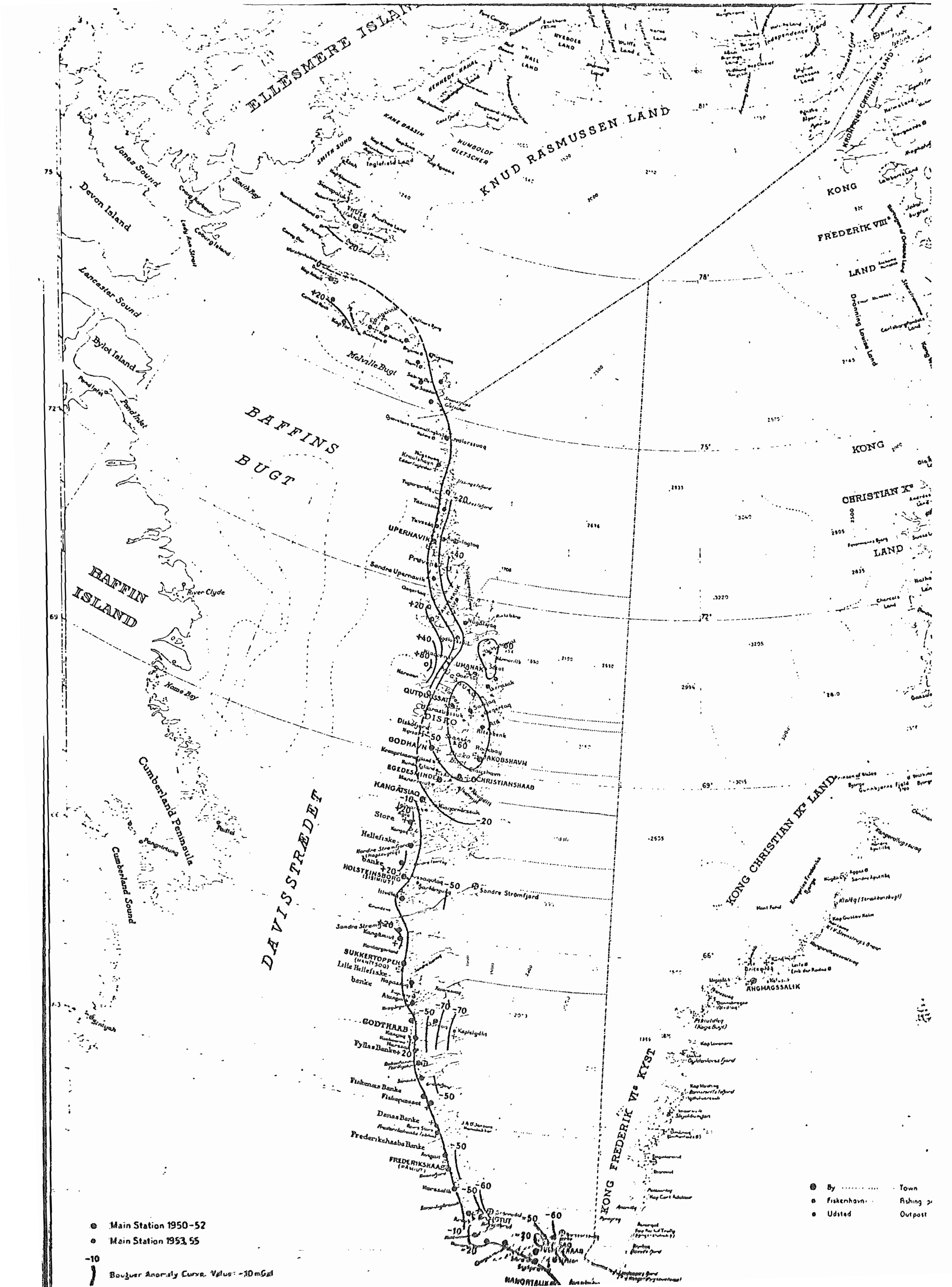
Gravity measurements on a limited coastal grid (16 stations in the Egedesminde to Svartenhuk area) were made by the Geodaetisk Institut Skrifter in

Figure 14

Bouguer Anomaly Map, 1953

Geodaetisk Institut Skrifter

Copenhagen, Denmark



ELLESMERE ISLAND
KANE BASSIN
SMITH SUND
HUMBOLDT GLETSCHER
KNUD RASMUSSEN LAND
Jones Sound
Devon Island
South Bay
Coburg Island
THULE
Lancaster Sound
Bylot Island
Pond Inlet
Melville Bugt
BAFFINS BUGT
KONG FREDERIK VIII's LAND
Dronning Louise Land
KRONPRINS CHRISTIANS LAND
Independence Fjord
KONG CHRISTIAN X's LAND
UPERNAVIK
Prøven
Søndre Upernavik
BAFFIN ISLAND
River Clyde
UMANAK
QUTDLISSAT
DISKO
GODHAVN
JAKOBSHAVN
CHRISTIANSHAAB
EGEDESMINDE
KANGÂTSIAQ
Store Hellefiske banke
HOLSTEINSBORG (SISIMIUT)
Søndre Strømfjord
Cumberland Peninsula
Cumberland Sound
DAVISSTRÆDET
SUKKERTOPPEN (MANITSOQ)
Lille Hellefiske banke
GODTHAAB
Fyllas Banke
Fiskenæs Banke
Danas Banke
Frederikshaabs Banke
FREDERIKSHAAB (PÂMIUT)
IVIGTUT
JULIANEHAAB
NANORTALIK
KONG CHRISTIAN IX's LAND
ANGMAGSSALIK
KONG FREDERIK VI's KYST
By .... Town
Fiskerhavn .... Fishing port
Udsted .... Outpost
Main Station 1950–52
Main Station 1953, 55
Bouguer Anomaly Curve. Value: −10 mGal

1953 (Fig. 14). The resulting contoured values of the Bouguer anomaly field show two interesting features:

1) a positive Bouguer anomaly in the extreme western end of Nugssuaq peninsula which may be associated with the change from continental to oceanic crust;
2) a negative anomaly in the Disko Bay area which may be associated with a thickening to normal continental crust thickness.

In addition L.W. Sobczak (pers. comm.) has compiled gravity measurements for four profiles across Baffin Bay. The general pattern of his data indicates:

1) a small narrow high extending N-S through the middle of the Bay with flanking and elongated negative belts, and
2) these are in turn flanked by large positive belts where free air anomalies are in excess of 80 mgal.

The eastern high is related to the high over the volcanic province and its continuation to the north may possibly define the edge of continental crust. The western high joins positive highs mapped over the southeastern end of Devon and Bylot Islands.

Aeromagnetic profiles (Henderson, pers. comm.)

have shown that the volcanic province of West Greenland does not continue under the ice cap to the east.

4.3 Magnetic Surveying Equipment, Data Reduction and Procedure

A proton-precession magnetometer, loaned by the Bedford Institute of Oceanography and described by Loncarevic (1968), was used to obtain profiles along the ships' track. The polarise-count time of the instrument was 6 seconds. Total magnetic field values were recorded on paper tape every 6 seconds, and day and time every minute, and on an analogue chart recorder accurate to the nearest 10 gammas. The detector was towed on a shielded two-conductor cable about 600 feet astern, where the ships' head effect would probably be less than 10 gammas (Bullard and Mason, 1961).

Soundings were made at all times, with the display on an Alpine recorder with a hull mounted Edo transducer providing the signal.

The LORAN coverage in the Baffin Bay-Davis Strait area is very poor so that Loran fixes in the survey area were supplemented by satellite navigation fixes. A Magnavox receiver with an Invac punch were used

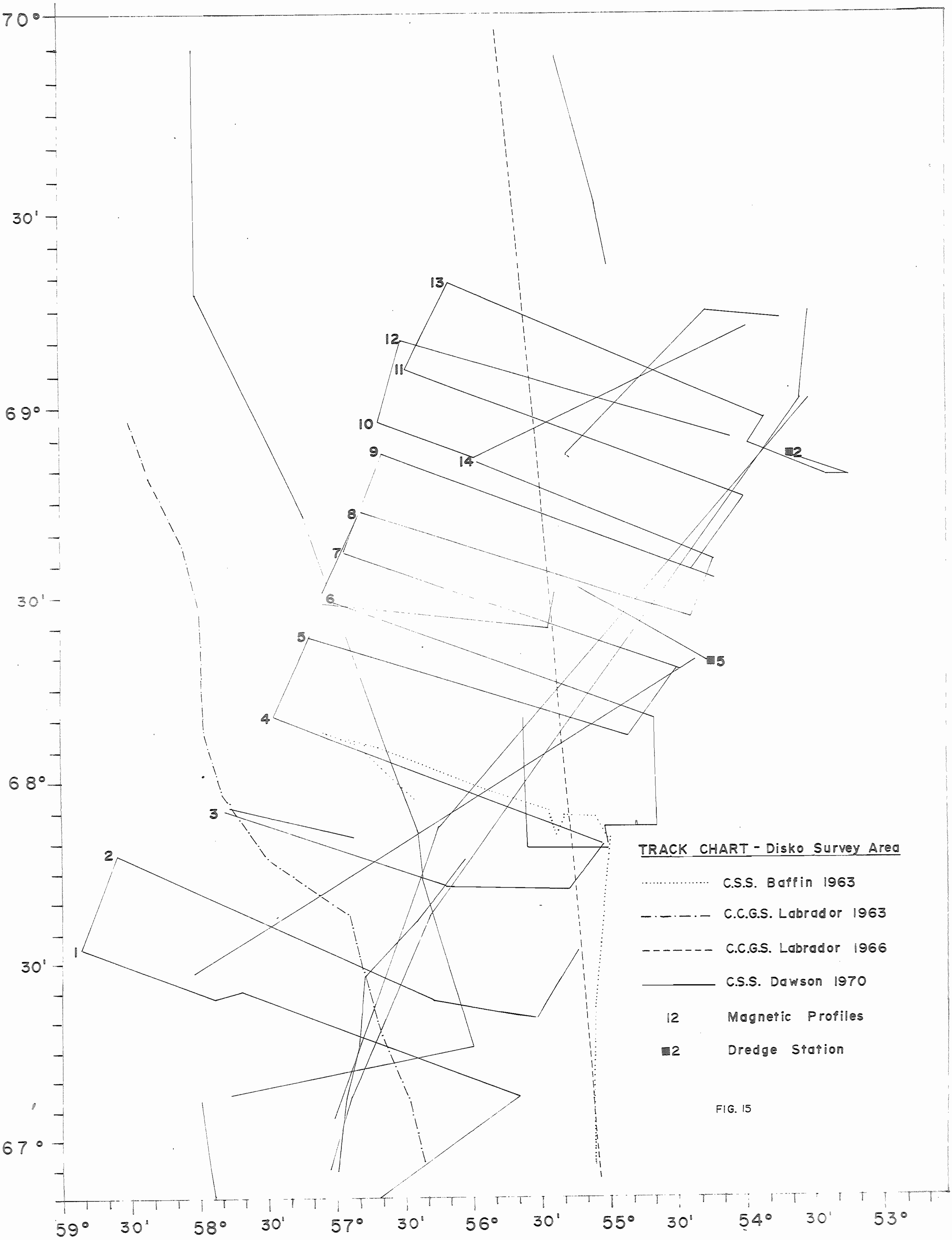

70°
30'
69°
30'
68°
30'
67°
59°
30'
58°
30'
57°
30'
56°
30'
55°
30'
54°
30'
53°
1
2
3
4
5
6
7
8
9
10
11
12
13
14
■2
■5
TRACK CHART - Disko Survey Area
C.S.S. Baffin 1963
C.C.G.S. Labrador 1963
C.C.G.S. Labrador 1966
C.S.S. Dawson 1970
12 Magnetic Profiles
■2 Dredge Station

FIG. 15

for this purpose. Computations of the fixes were performed on a PDP 8-L computer with two 4-K memory banks.

The tracks were plotted on 1:100 000 plotting sheets on board and visual examinations and comparison with gyrocompass headings and ships' speed showed that the satellite fixes were consistently better than LORAN fixes, though the latter were used in many cases as a guide. Most of the fixes when the ships' heading changed were dead reckoning from previous satellite fixes. The accuracy of the navigation appears to ±3 kilometres.

A regional correction was made to the magnetic data using the International Geomagnetic Reference Field (IAGA, 1968) which computes geomagnetic field values for any specified epoch and point in space in terms of spherical harmonic coefficients (up to $m = n = 8$).

The tracks, since the cruise, have been plotted on a more convenient 1:250 000 scale and Fig. 15 shows the tracks and location of areas where bathymetric, magnetic and seismic reflection information is available.

The survey was laid out over an area 95 km by 190 km southwest of Disko Island. Line spacing in the southern portion of the survey is about 15 km but is about 7 km in the more important northern portion.

The station magnetic records from Godhavn, Disko Island showed that the small scale fluctuations of the vertical field above the long wavelength diurnal field average 20 to 30 gammas over 20 minute time intervals. Large scale fluctuations up to 500γ have been omitted from Fig. 16.

Fig. 16 shows the reduced magnetic field profiles (based on two minute readings) with several lines omitted to avoid confusion. The magnetic anomalies in the northern 110 km are of very short wavelength and the line spacing needed to produce an adequate contour map would have had to be closer than the precision of the navigation. A detailed survey using a Dan marker buoy indicated that the upper limit of line spacing would have had to be .5 km.

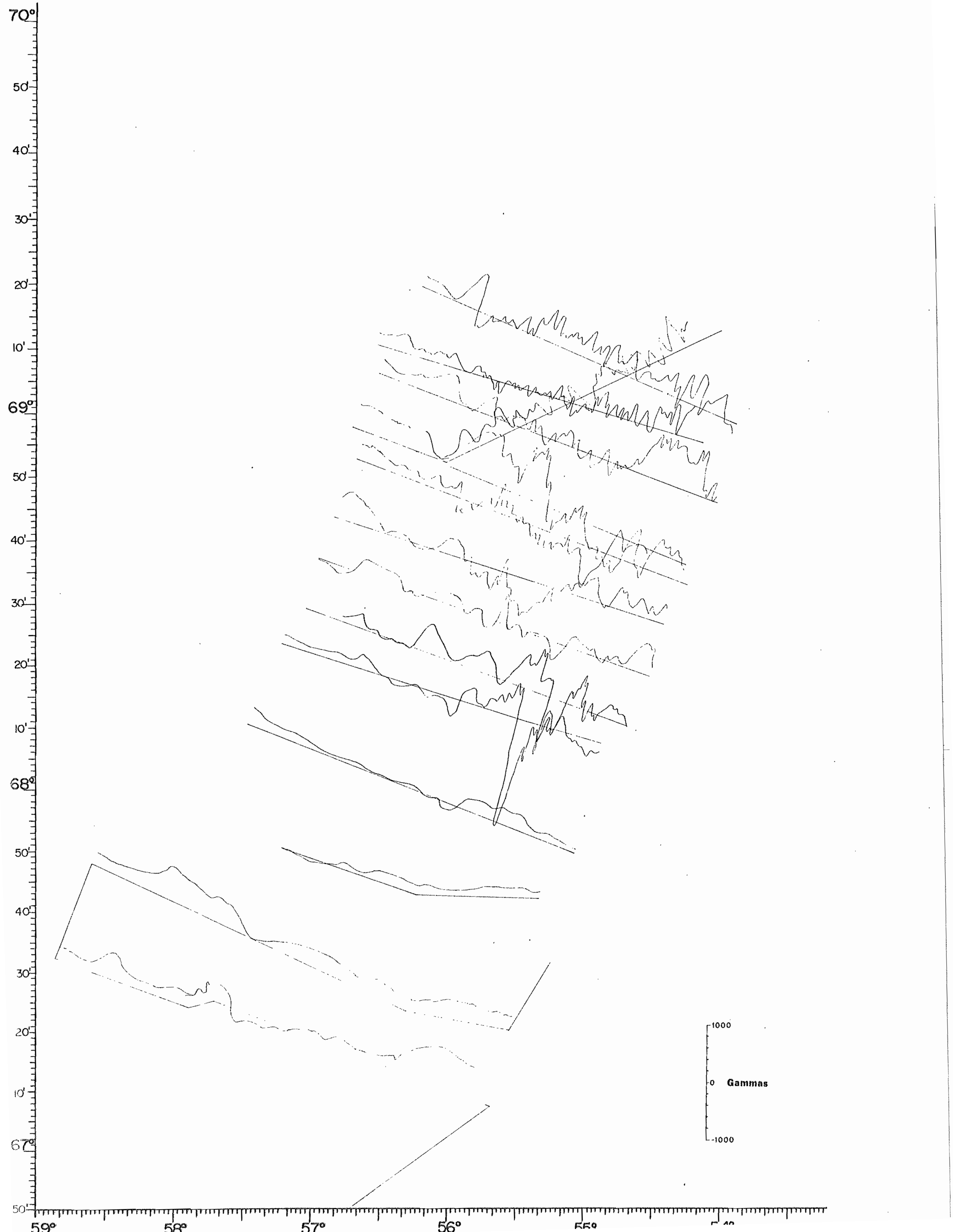
The dip of the Earth's field is about 82^{o} so that there would be very little displacement of the maxima and minima of the magnetic anomalies with respect to the causative bodies. The zero line of the profiles is also the ships' track and the north

Figure 16

Residual Magnetic Profiles

Disko Survey Area

C.S.S. Dawson, 1970


70°
50'
40'
30'
20'
10'
69°
50'
40'
30'
20'
10'
68°
50'
40'
30'
20'
10'
67°
50'
59°
58°
57°
56°
55°
1000
0 Gammas
-1000

side of the profiles indicates the side on which the positive ordinate of the residual magnetic intensity occurs.

4.4 Discussion of Magnetic Profiles

A preliminary examination of the magnetic profiles (and seismic profiles presented later) allowed us to postulate that:

1) the magnetically flat regions were caused by thick sediment to the south and west, but by Precambrian gneisses to the north and east nearer to the coast, and
2) the intense anomalies were due to the submerged extensions of the volcanics of the West Greenland province.

The difference between areas of Precambrian gneiss outcrop and areas where sediments are found can be seen in Fig. 17a, b. The portion of the profile thought to overlie sediments consists of long wavelength, low amplitude anomalies. This same phenomenon occurs over areas where gneisses are thought to occur, but with the long wavelength anomalies in many cases is a superimposed high frequency low amplitude component. Many small anomalies of 20 to 60 gammas occur over .25 to .50 kilometres. Some

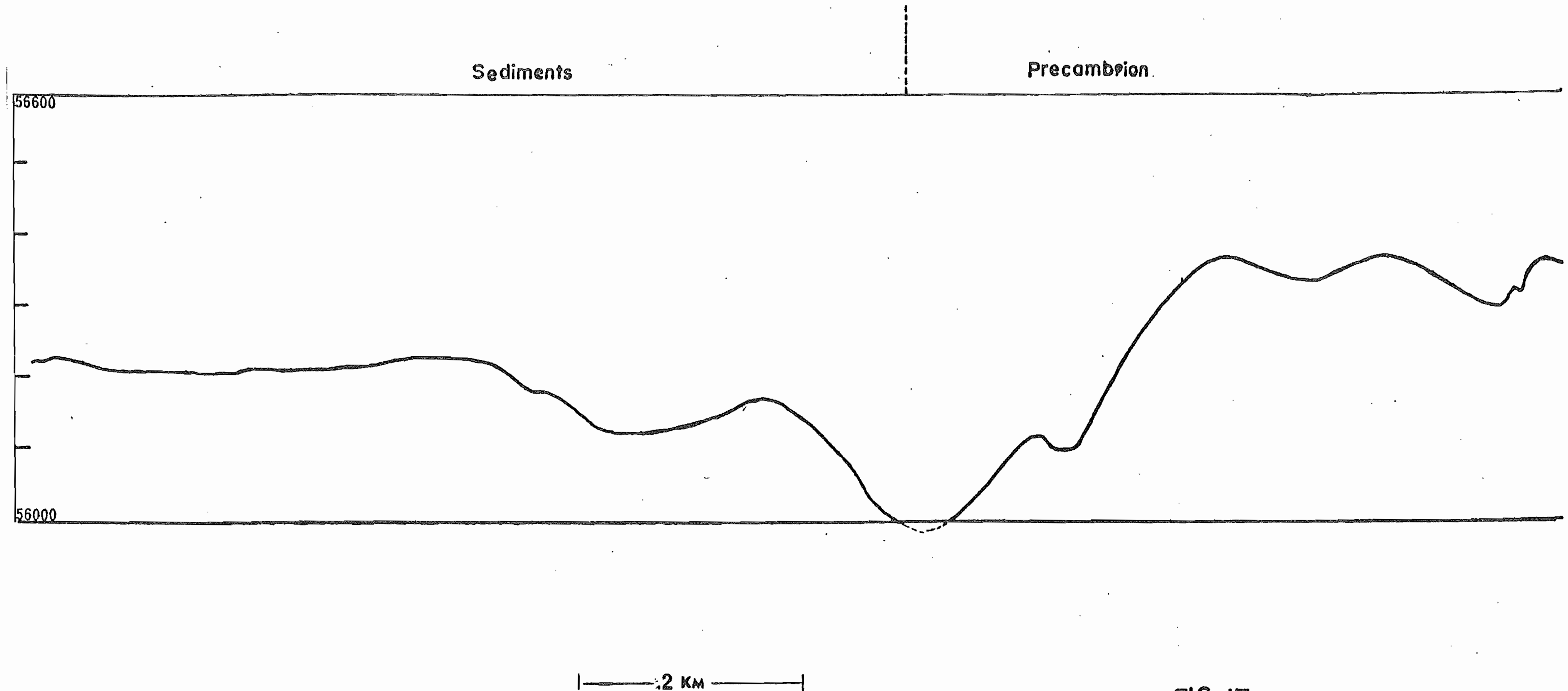


FIG. 17a

TOTAL FIELD MAGNETIC PROFILE 4

TOTAL FIELD MAGNETIC PROFILE 4

OVER PRECAMBRIAN GNEISS

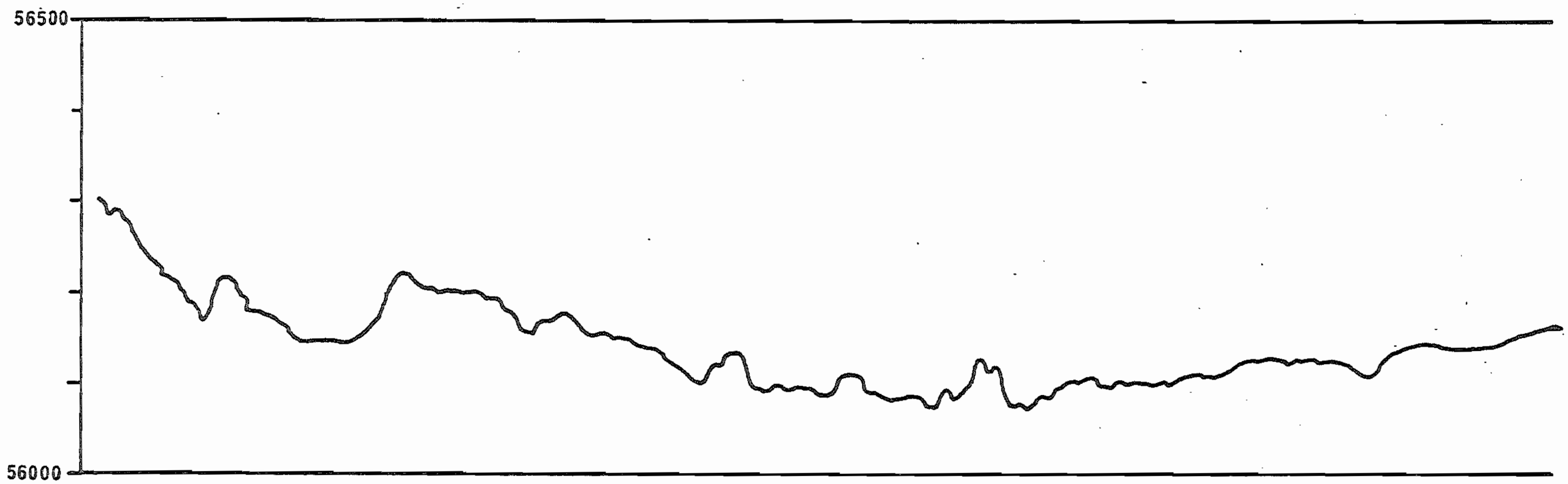


FIG. 17b

2 km.

explanation for this phenomenon may be reflected in the geology of the Precambrian rocks on land. Compositional banding is known to be a dominant feature of the gneisses of the Egedesminde area, depending on varying amounts of the mafic minerals, hornblende and biotite. Also important are the persistent amphibolite horizons, with widths of up to 0.25 km and extending for tens of kilometres. The regional strike of these formations is northeast. A magnetic survey over the Fiskenaesset complex (Sharma and Ghisler,1968) with its similar lithologies shows a very wide range of susceptibilities for the different compositional bands of the basement gneisses and for the amphibolite horizons. The remanent magnetisation is insignificant. As a magnetometer is towed over such a geological environment one might expect to encounter anomalies of differing size over small distances, corresponding to the compositional bands. Overall susceptibilities are still fairly low, compared to the susceptibilities of basaltic rocks (Section 4.10), so that the amplitudes would be relatively small.

On several occasions, magnetic profiles were run into Godhavn harbor on the south coast of Disko Island. Visual observation of the rocks of this coast showed that Precambrian gneisses outcrop directly at the entrance to the harbor. An examination of the geology of the area shows that Godhavn is situated on the axis of the Precambrian high which extends much farther to the north. Examples of this relationship between volcanics and Precambrian gneisses are shown in Figs. 18a,b. Other examples of the contact relation are shown in Fig.16 . One bathymetric profile over the gneisses was examined on a 200 fm. sweep. Bottom features show a very thin veneer of sediments draped over a very hummocky surface with wavelengths and amplitudes comparable to the magnetic anomalies. It is the type of terrain which could be expected in Precambrian areas which have undergone the effects of Pleist ocene glaciation.

Examples of the type of anomalies associated with the basalts are shown on the profiles of the total magnetic field run into Godhavn harbor, and on profiles 5 and 6 on the residual map. These latter profiles showed very prominent negative magnetic anomalies up to 3000 gammas and coincidentally occur in the region where Manchester (1964) observed a similar phenomenon. The negative portion of the anomaly extends over about 7 km (based on inflection

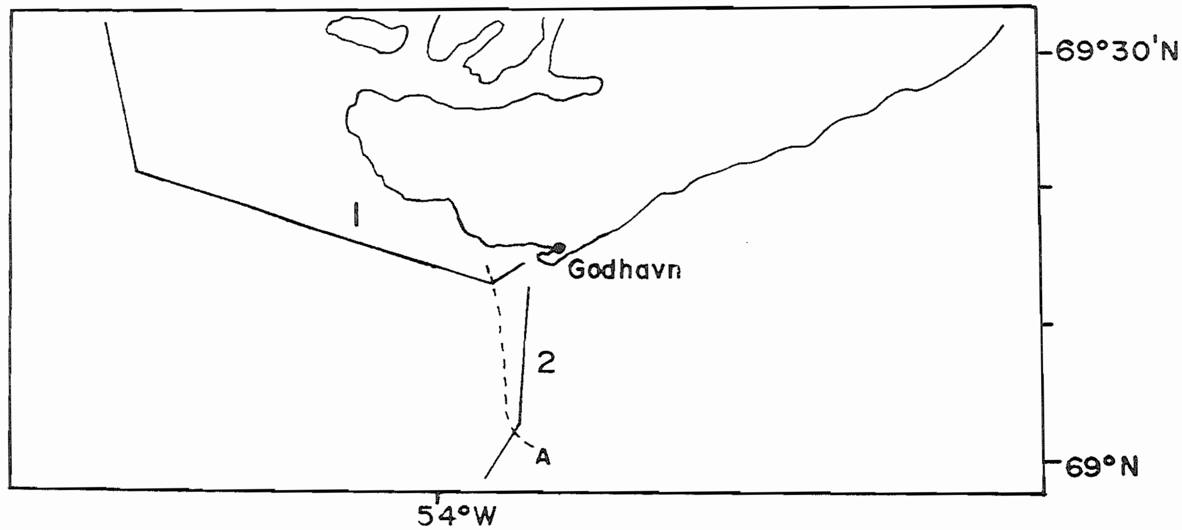

69°30'N
1
Godhavn
2
A
69°N
54°W

FIG. 18a

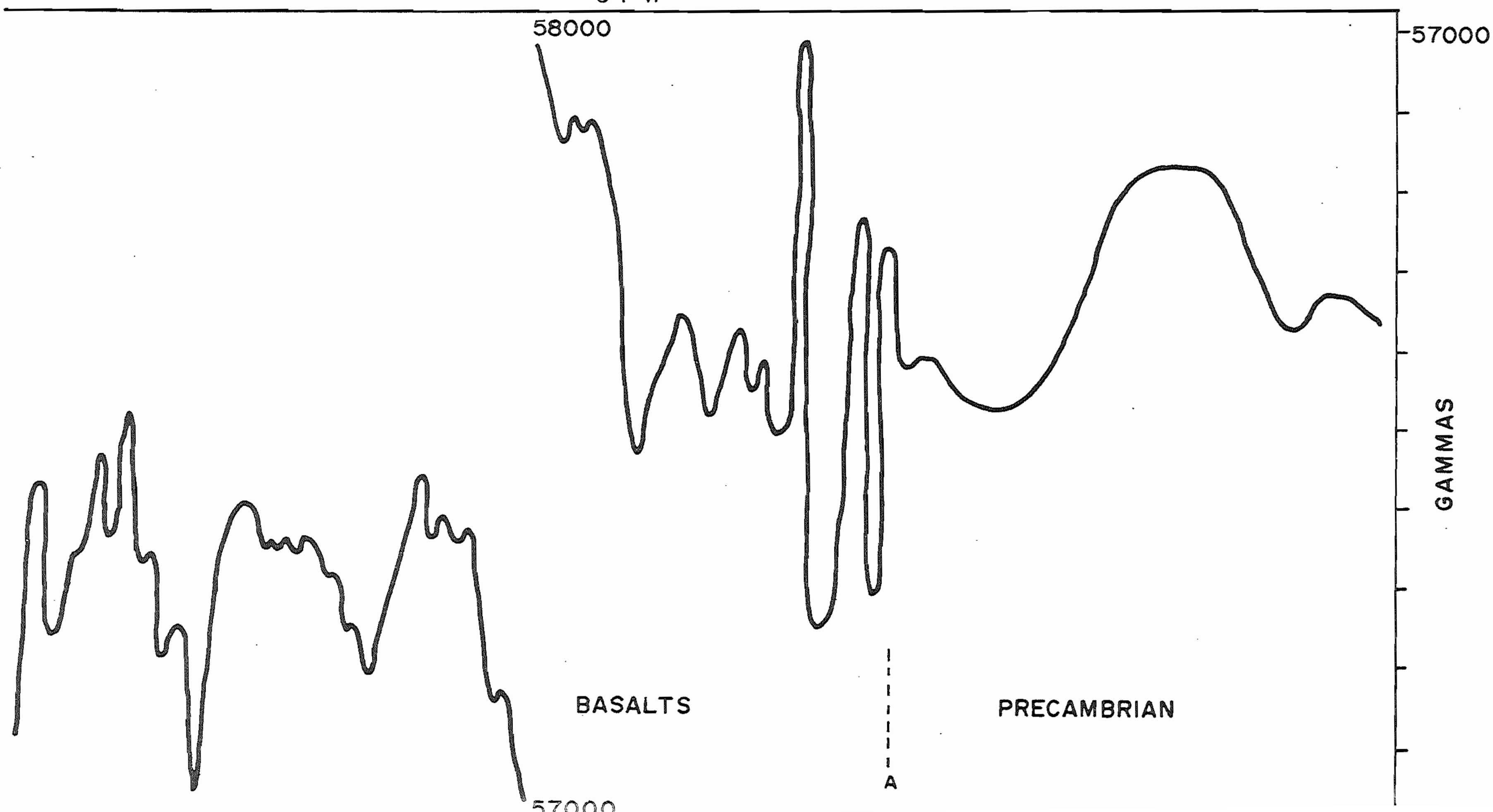
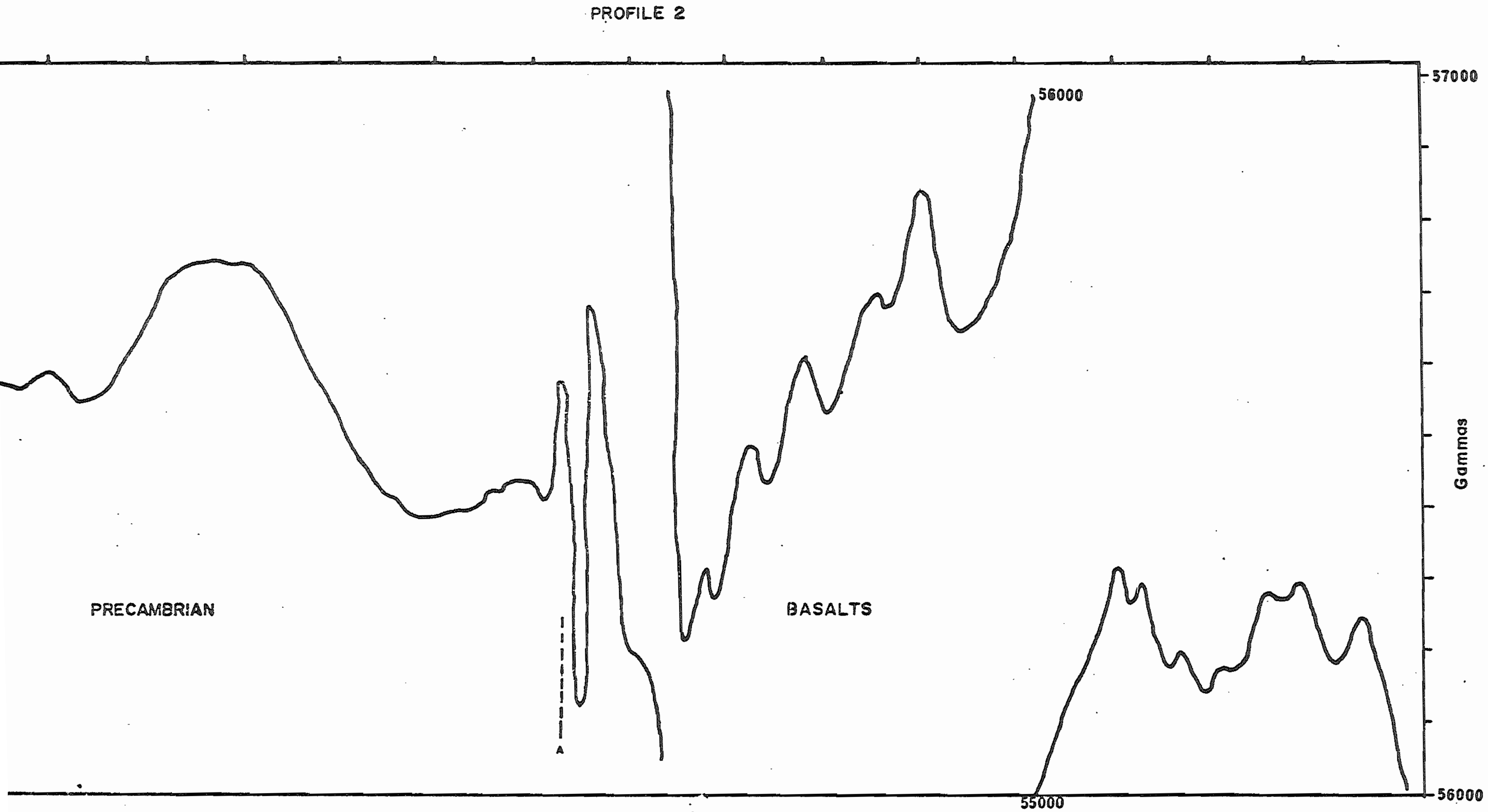

58000
57000
GAMMAS
BASALTS
PRECAMBRIAN
A
57000

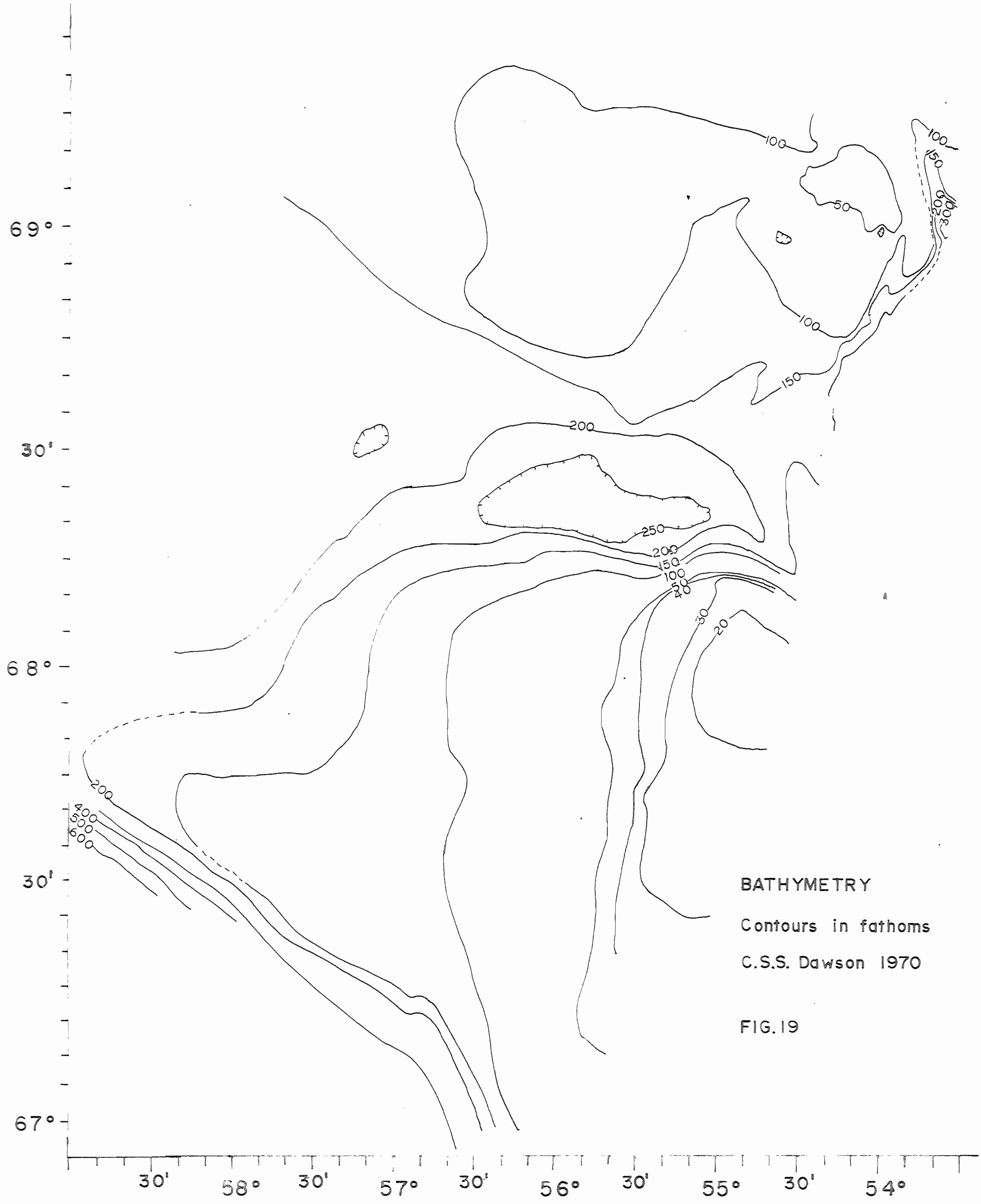
FIG. 18b



PROFILE 2
57000
56000
Gammas
PRECAMBRIAN
A
BASALTS
55000
56000

points). Flanking this central negative anomaly, to the west and east, are two large positive anomalies of 1000 and 600 gammas respectively. The extreme eastern end is interpreted to be Precambrian gneiss. On magnetic evidence only it is proposed that these anomalies could be the result of alternating blocks of normal and reversed polarity. The existence of many such geomagnetic events in the Tertiary (McElhinny, 1971) lends support for this hypothesis. The large widths of these zones from the magnetic records suggests that the particular normal or reversed event took place while many smaller flows were accumulating as a part of the volcanic pile. Then the positive and negative anomalies may represent the bulk magnetisation of a number of basalt flows. The very high frequency anomalies within any positive or negative zone could be the result of rapid variations in remanent magnetisation due to baked contacts between individual or several flows or perhaps hydrothermal effects (Ade-Hall et al., in press). The profiles farther to the north (9 to 14) do not show the alternating positive and negative features as strikingly as profiles 5 or 6. Perhaps the basalt flows in this region are flat lying so that each magnetic profile is crossing only the upper surface of a single flow. Profiles 9 and 10 both show strong wide negative anomalies near their western ends while profiles 10 and 11 show several strong positive anomalies. Associated with profiles 7 and 8 are morphologic features which could be classed as dip and scarp topography. Areas where these features are very evident include the central deep portion of the long northeast trending trough of Fig. 19 as well as up the northern slope of this trough. In one case there is a direct relation between one of these features and a prominent negative anomaly, and this topography may represent the surface expression of successive groups of dipping lava flows.

To the west of the area where basalt is thought to outcrop or is covered by a thin layer of sediments, most of the profiles show several moderately-sized positive anomalies. Topographically the bottom surface is undisturbed except for an occasional small gully or trough. These anomalies are presumed to reflect an increased depth to magnetic basement which is covered by more recent sediments. The nature of the "basement" underlying sediments in the southwest portion of the survey (profiles 1 to 4) is unknown. If the interpretation of the eastern



BATHYMETRY

Contours in fathoms

C.S.S. Dawson 1970

FIG. 19

anomalies is correct and is due to gneisses very close to the surface, then the anomalies in the western portion may reflect increased depth to this type of basement.

One of the most interesting features of the residual map is the degree of correlation shown between adjacent profiles. The trends vary between N-S and NNE and are slightly arcuate. The most persistent anomalies are those found in the area where sediments are presumed to overlie magnetic basement. One of these anomalies extends continuously for a distance of 100 km, though the line spacing makes this continuity very speculative. Other notable correlations are between profiles 5 and 6 where the very large negative trough on profile 5 can be correlated with the double negative trough on profile 6 and the related troughs on profiles 9 and 10.

The proximity of the widespread volcanic plateau of the West Greenland basin (described in Chapter 3) and the structures therein would seem to shed some light on this observation. The flows in the upper part of the feldspar-phyric sequence on Disko are up to 50 metres thick and of considerable lateral extent. The dips of these volcanics near the coasts in northwest Disko and Nugssaq range from 12 to 28 to the west and northwest.

If these dips were to continue into Davis Strait, one would expect to find shallow dipping lava flows in the offshore areas as well. The linear trends may reflect the remanent magnetisations of a large number of shallow dipping flows which have been subjected to either a normal or reversed geomagnetic field. The dip and scarp topography provides further evidence for this interpretation representing shallow dipping flows which have undergone block faulting and repetition much as the sequence on land.

4.5 Model Studies

Magnetic bathymetric and seismic profiles suggest that the offshore volcanic sequence has a structure similar to the flows on land and is composed of a series of shallow westward dipping flows. Calculations were made to test this hypothesis using a computer program described by Heirtzler et al. (1962).

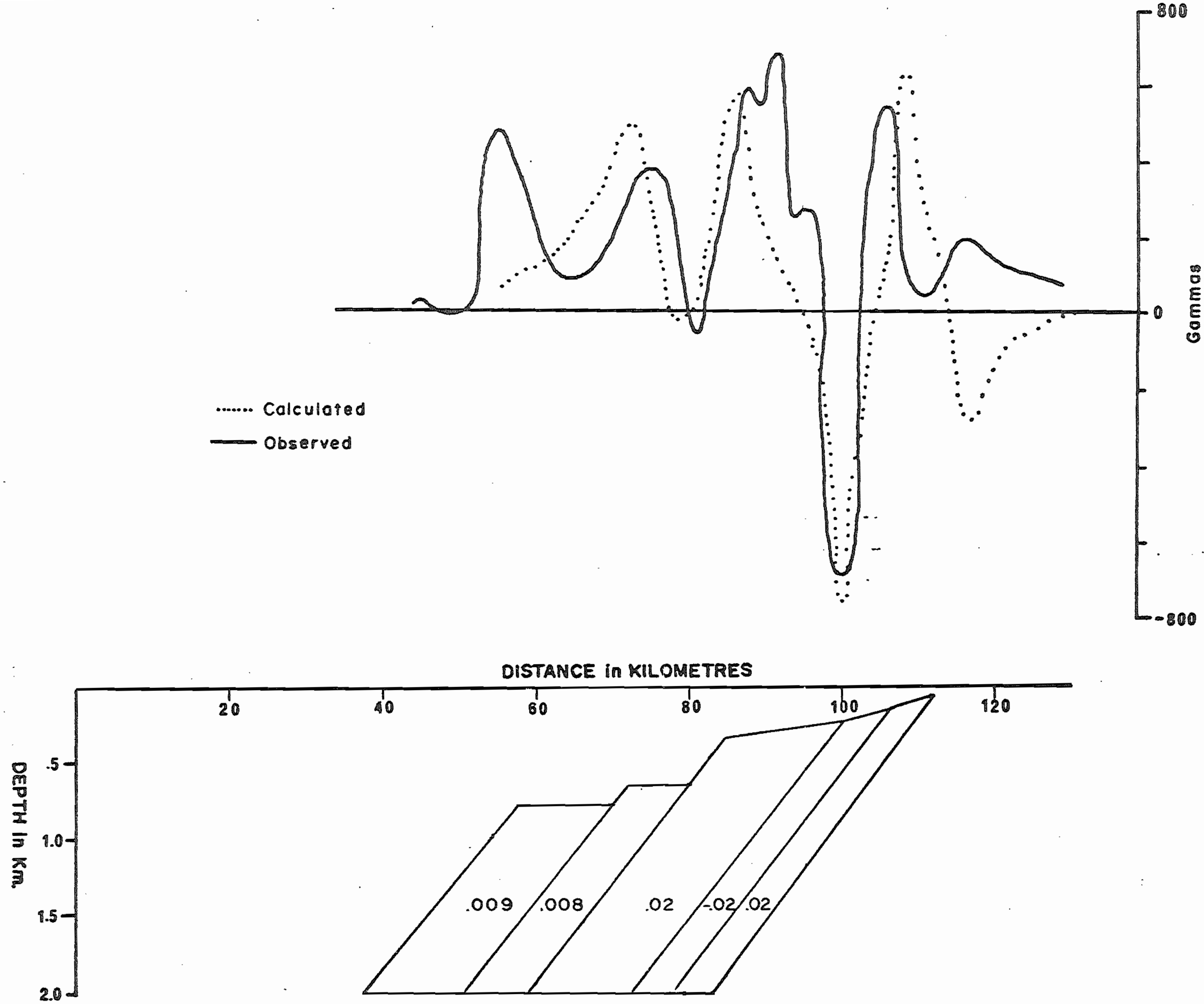
The dredged volcanics studied in Section 4. have been shown to possess a remanent magnetisation ranging from 2 to 20 times larger than the induced

Figure 20

Model Calculation

Dip of bodies is 15° and corresponds to the dip of the upper surface of the volcanics as deduced from the profiler records on Line 6.

Effective Susceptibilities are in emu/cc.


800
0
Gammas
-800
Calculated
Observed
DISTANCE in KILOMETRES
20
40
60
80
100
120
DEPTH in Km.
.5
1.0
1.5
2.0
.009
.008
.02
-.02
.02

magnetisation. For the purpose of the calculation the assumption was made that the anomalies were due to the natural remanent magnetisation of the Tertiary volcanics, and the direction of magnetisation was assumed to be parallel to the earth's field or the reciprocal of that direction, ie. dip 82°.

The range of effective susceptibilities for the analysed samples from the dredge hauls was .004 to .02 emu/cc and the effective susceptibilities in the calculation range from .008 to .02 emu/cc.

The model selected was composed of 5 dike-like bodies dipping 15° to the west. Body number 5 was assumed to have a reversed remanent magnetisation while the other 4 bodies were normal.

The results of the calculation are shown in Fig. 20 and though the overall correlation between observed and computed profiles is not perfect the form suggests that the assumed model is reasonable.

4.6 Seismic Reflection Profiles (Fig. 21)

Profiles 1, 1a and 2

These profiles were made in the southernmost portion of the survey area. Magnetic profiles with

SEISMIC REFLECTION PROFILES

DISKO SURVEY AREA

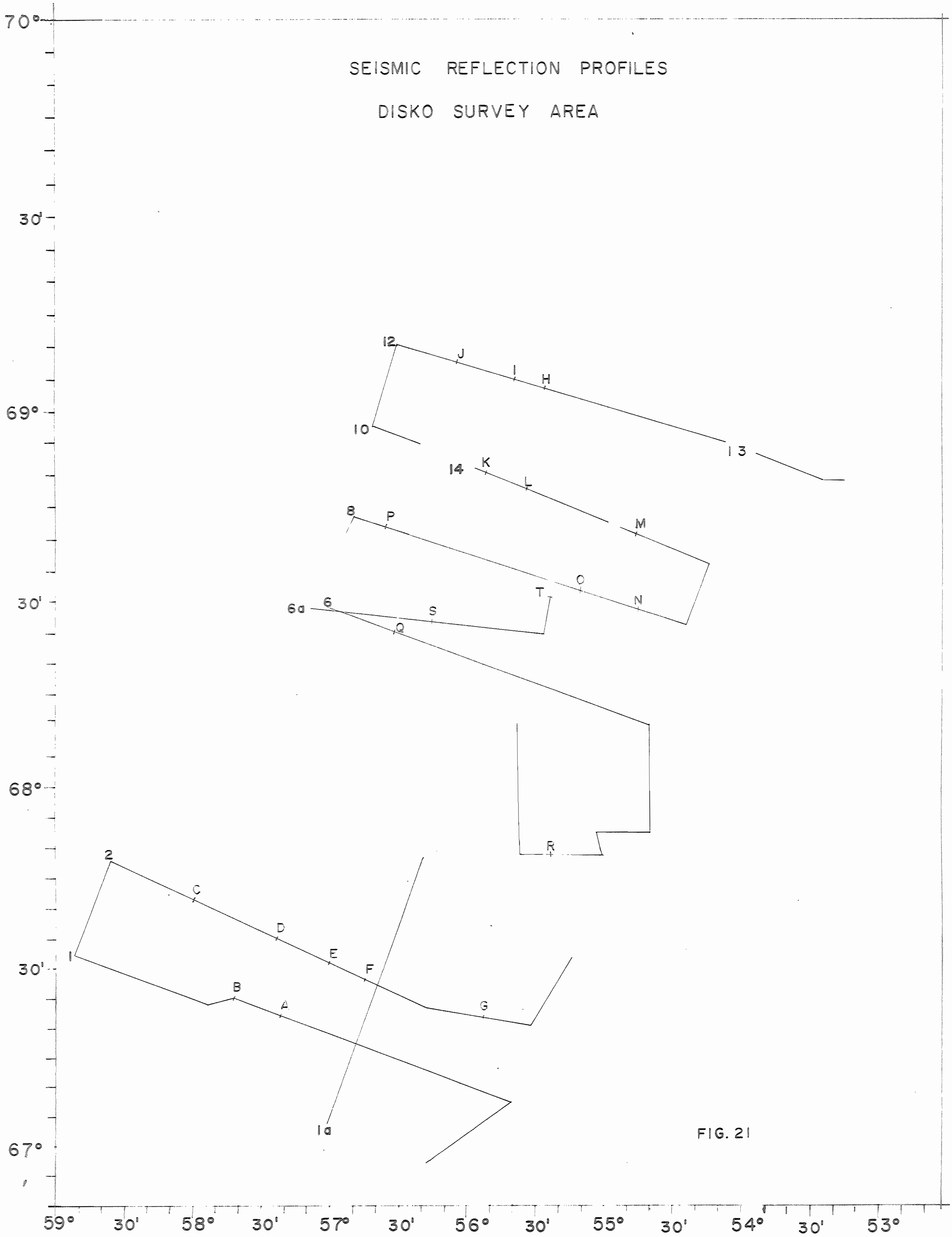


FIG. 21

long wavelength small amplitude anomalies suggested that sediments of unknown thickness were covering the source of the magnetic anomalies. The records in water shallower than 100 fm were difficult to interpret due to multiple reflections. However in the deeper water the magnetic interpretation was confirmed. The reflectors on profile 1 (Section A-B) show first a strong sub-bottom reflector, then relatively undisturbed sediments showing an apparent westward dip. The dip increases down the continental slope into much deeper water. Profile 2, 15 km farther north contrasts with profile 1. The sediments are more disturbed, showing small anticlines and synclines extending up the continental slope. At the top of the slope sedimentary interfaces dip very steeply towards the west and this same dip continues onto the shallower banks. At the 150 fm contour the westward dipping layers are replaced by horizontal beds which in several places are interrupted by normal faults (Fig. 23). At about the 100 fm contour (F in Fig.24,) the horizontal beds are draped onto an acoustic reflector which the magnetic profiles show to be Precambrian. The smooth surface of the sedimentary basin becomes more rugged at this point.

These profiles give the first concrete evidence for the existence of a sedimentary basin on the West Greenland shelf, possibly akin to the Atlantic Coastal Plain of eastern North America.

Profile 13

This profile was run into Disko Bay to cross the N-S trough where dredge station 2 was to be located. The bottom is extremely rough and no penetration of seismic energy was obtained except for thin layers of ponded sediments between high peaks. The magnetics had suggested that only Precambrian rocks and Tertiary basalts were present.

Profile 12

This profile shows a similar acoustic basement to that found in profile 13. The bottom topography is very rough up until I (Fig. 25) where the highly disturbed magnetics cease. Shallow dipping sedimentary reflectors at this point give way to more horizontally stratified sediments 15 km to the west.

Profiles 8 and 14

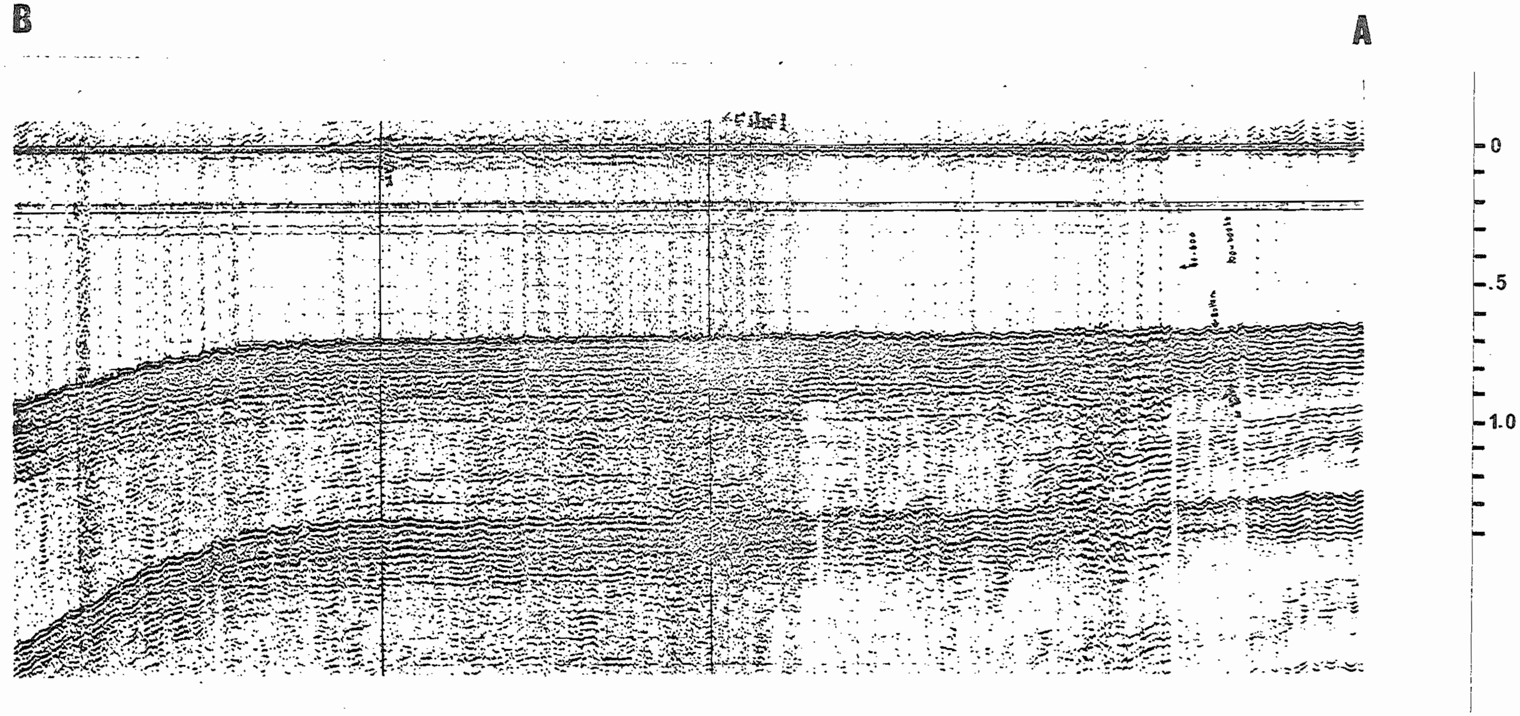
These two profiles show several important features which are reflected in the magnetics. Up to point L (Fig. 26) flat lying sedimentary layers can be seen. At point a very distinct sub-bottom reflector appears and is coincident with the commencement of highly disturbed magnetics. Where this reflector intersects the surface, the topography changes strikingly and dip and scarp features (the dip is to the west) are prominent. The topography and acoustic nature of the sub-bottom suggest that basalts are the source of the magnetic anomalies. Normal faults may possibly be reflected in the bottom topography. At O the disturbed topography gives way to a smoother surface and the profiler shows a thin cover of sediments over the basalts. The basalts become deeper towards the west and with increased sediment thickness the disturbed magnetics cease (Figs. 27 and 28)

Profile 6 (Figs. 29 and 30)

This profile is important because it traverses the three postulated geological formations interpreted from the magnetics and the bathymetry. The bathymetry shows that the profile straddles the prominent northeast trending glacial trough at about 68^{o} 30' N. From the northwest and extending to the southern slope of the trough are slightly disturbed sediments. Near the center of the trough a rough acoustic reflector appears at about 1.0 seconds and the sediments are draped over this basement. About halfway up the southwest slope the sediments give way to the acoustic reflector and all that remains of the basin is a thin veneer of sediments. Where the reflector comes closest to the surface the field becomes intensely disturbed. The attitude of the upper surface of the volcanics is suggestive of shallow dipping flows or groups of flows which progressively overlap to the southwest or they may exhibit repetitions of the same flows. Dips represented by the upper surface of the basalts are about 10° to 15° and are comparable to the dips found on Disko Island. The intensely disturbed field continues onto the broad bank. No penetration of seismic energy can be seen even after the magnetic field becomes much smoother. The original interpretation on the basis of magnetic evidence was that Precambrian gneisses exist to the southeast. Seismic evidence favors this conclusion. Reflections would not be expected from within steeply dipping Precambrian gneisses. The attitude of the contact is thus impossible to deduce but there is no indication of

Figures 22 to 31

Seismic Profiler Records with Horizontal Scale as Two-Way Travel Time in Seconds



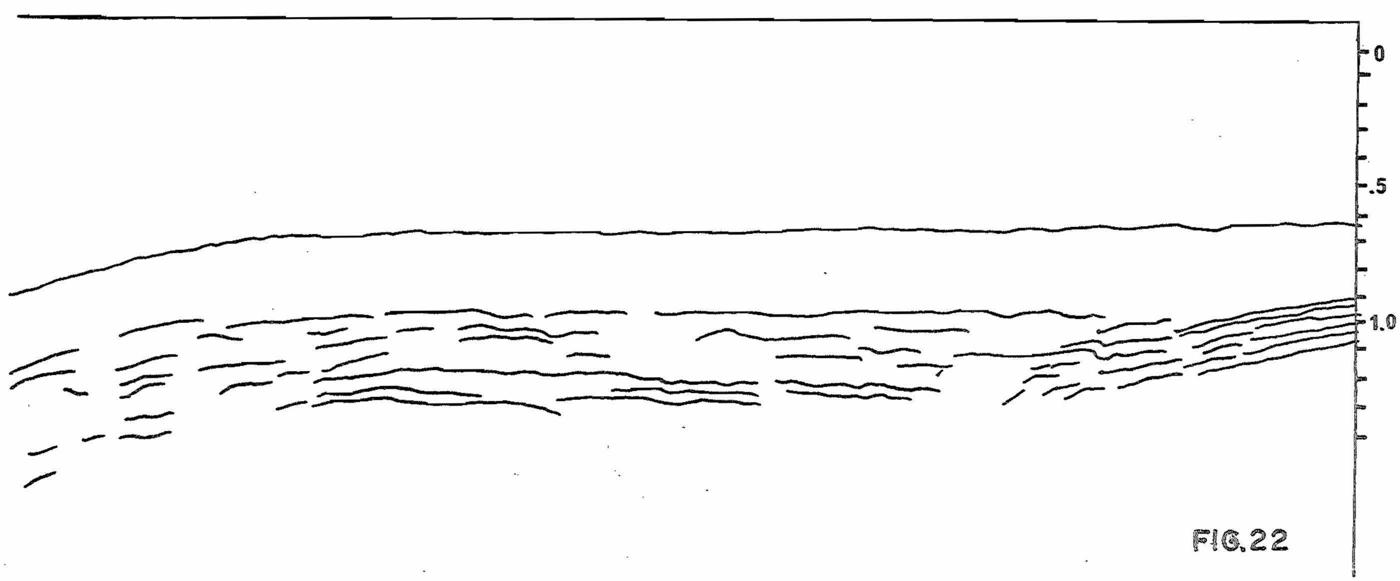


FIG.22

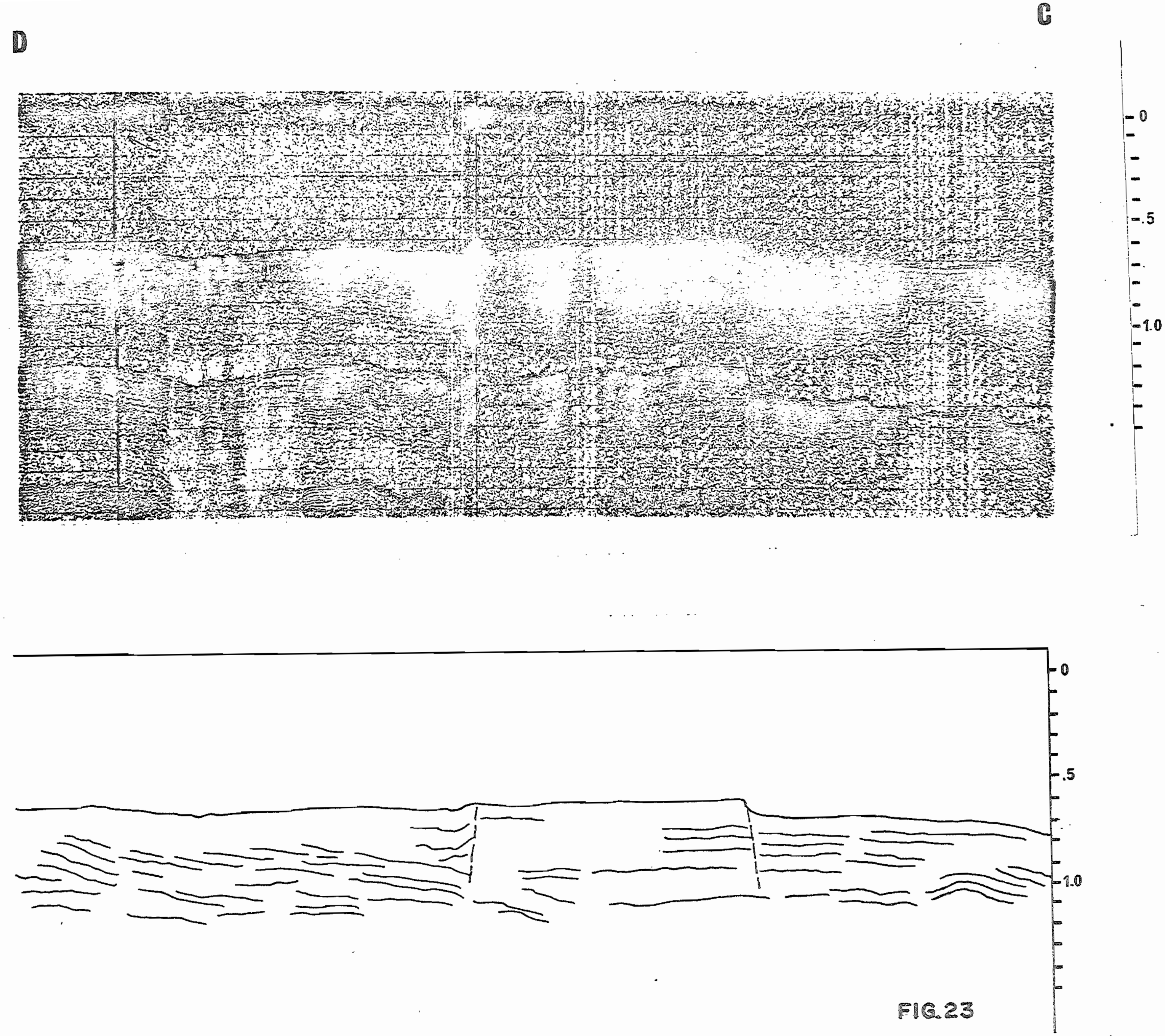


FIG. 23

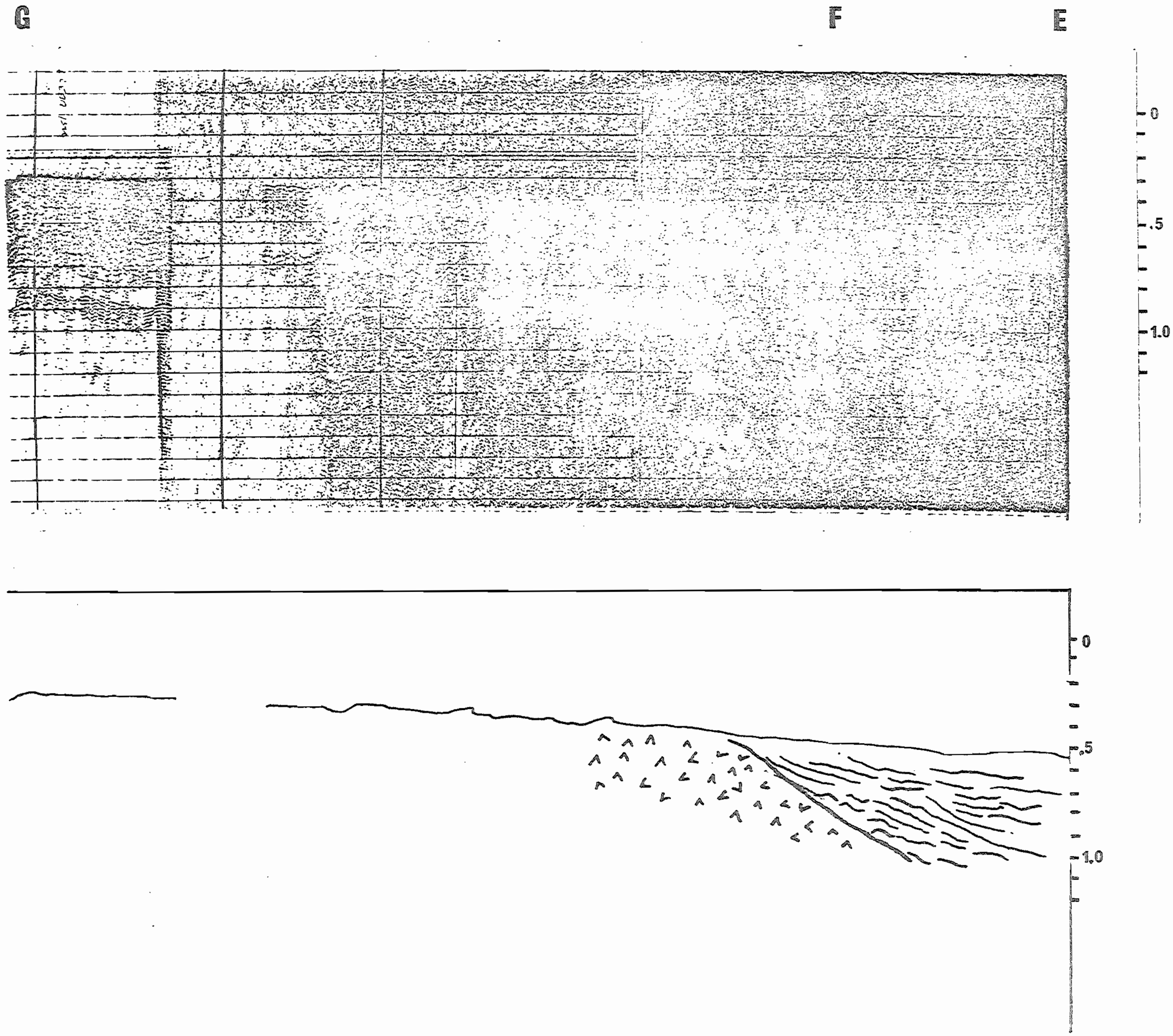


FIG. 24

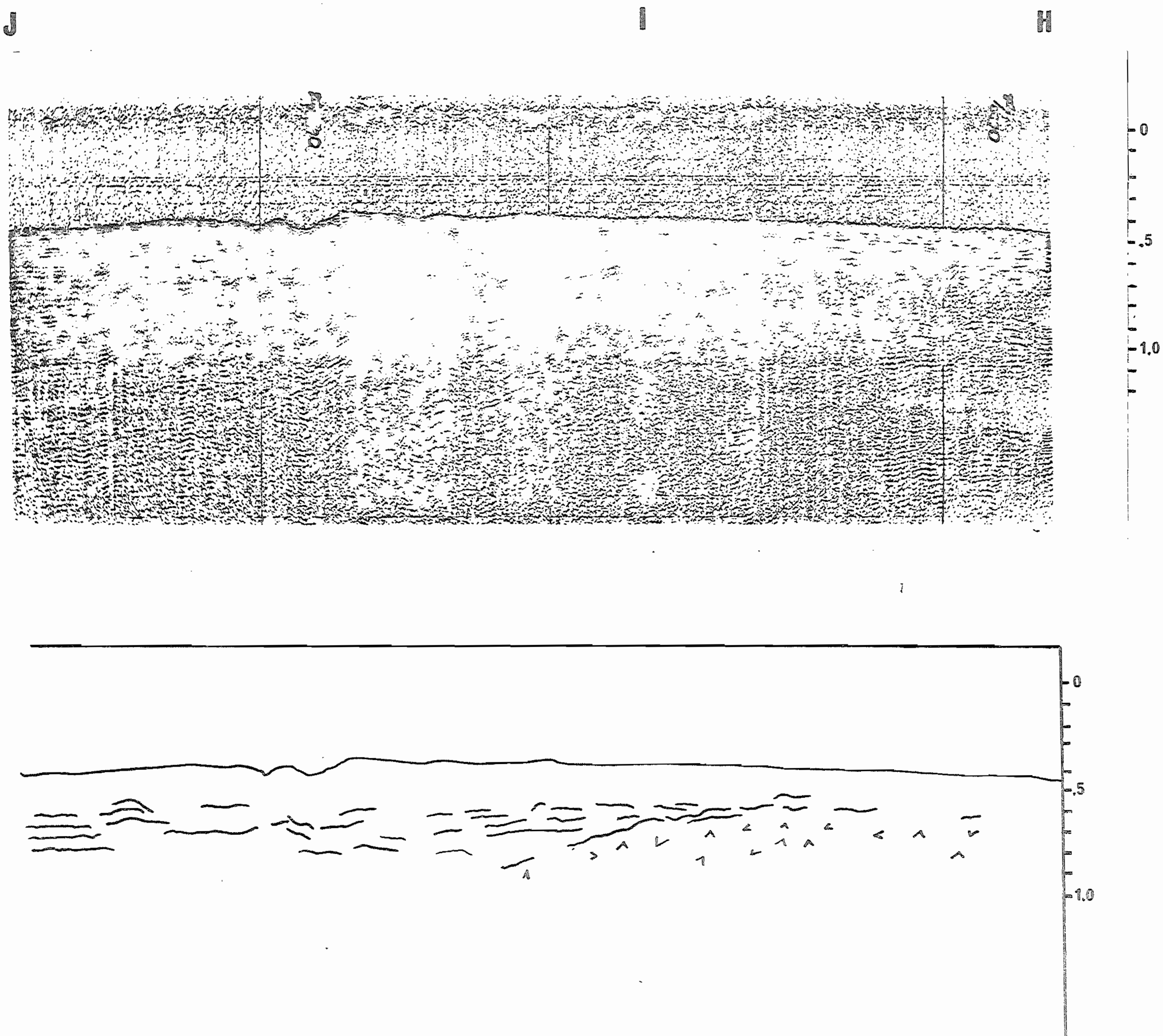


FIG. 25

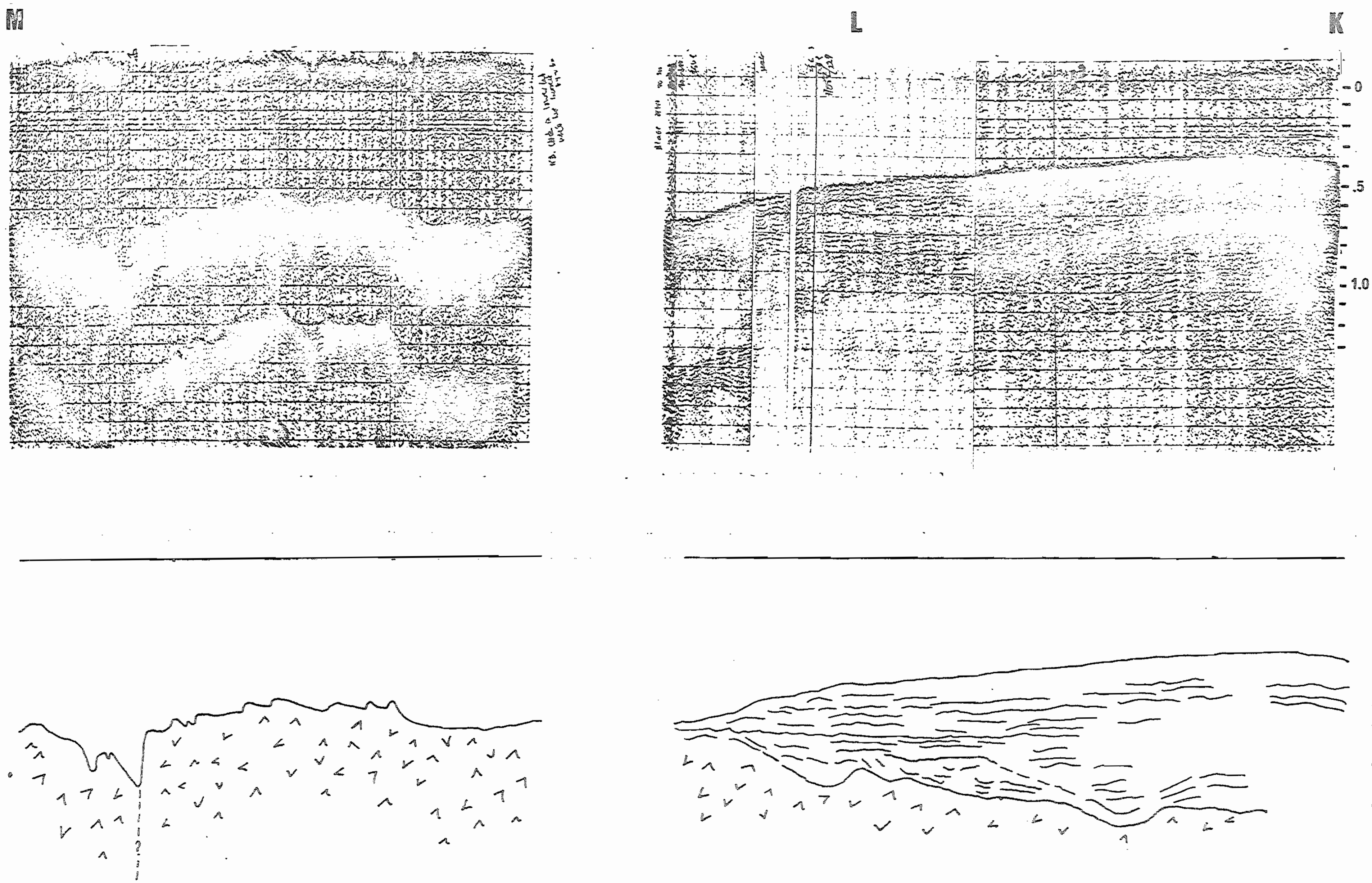


FIG. 26

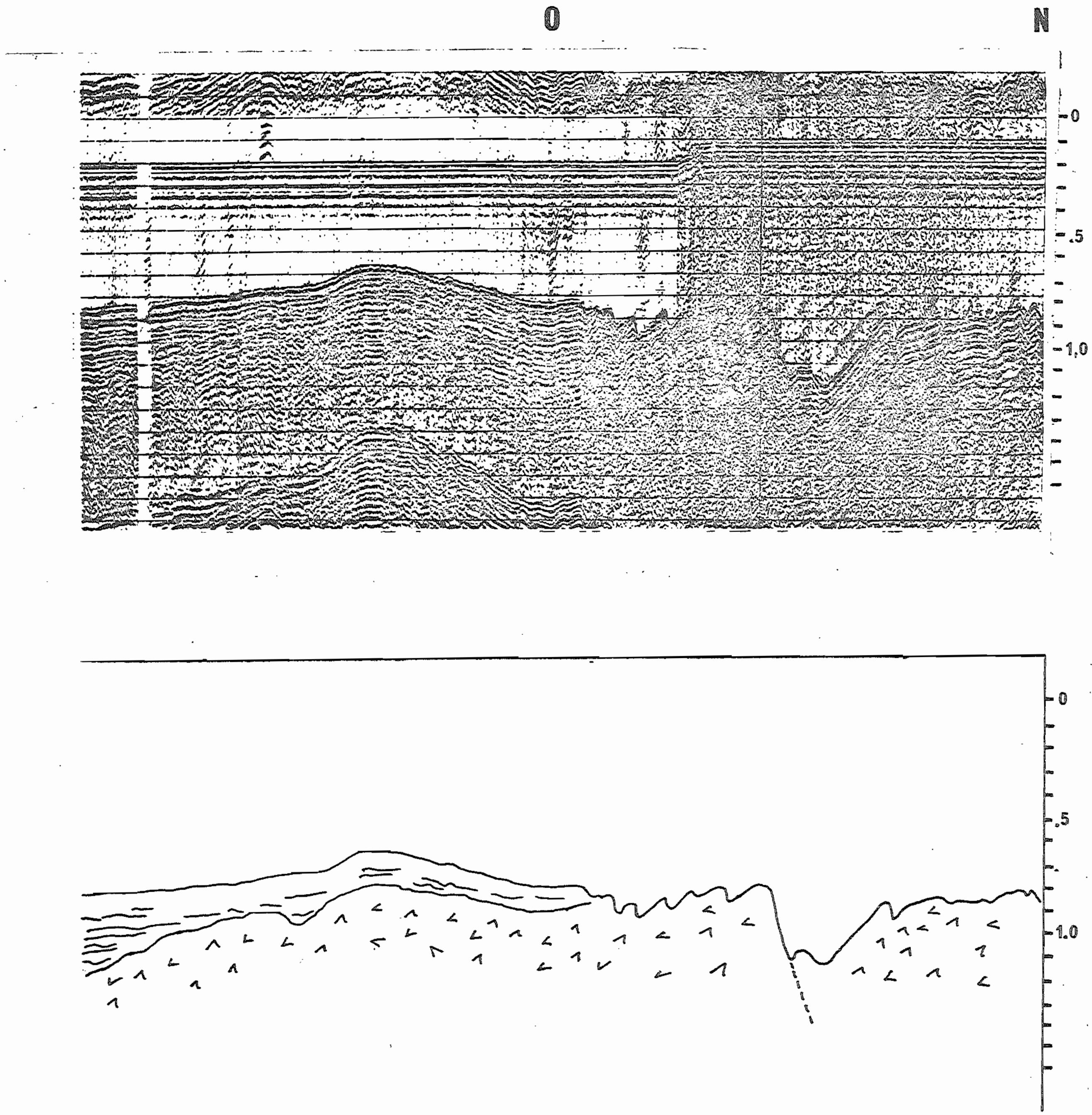


FIG. 27

P

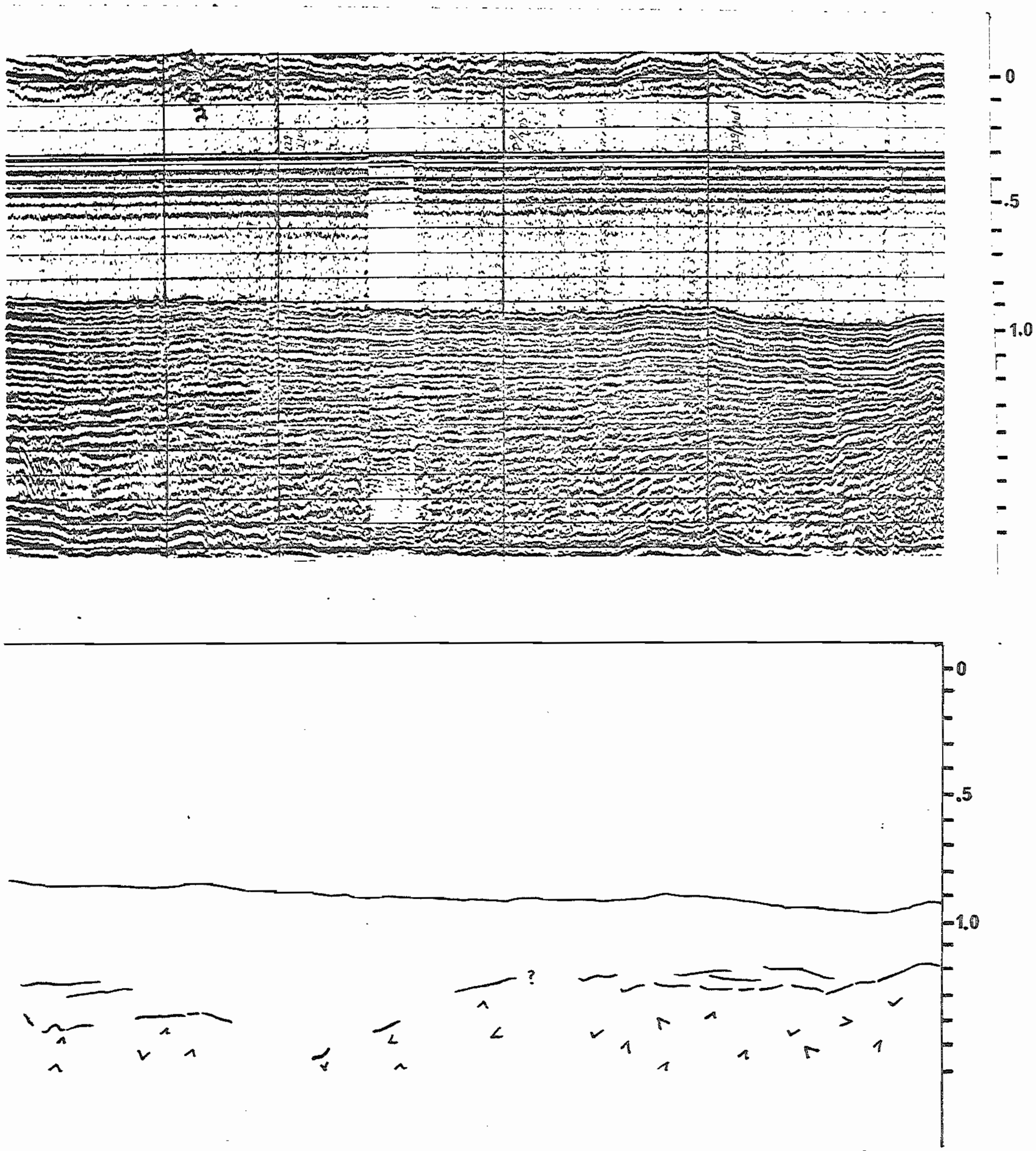


FIG. 28

Q

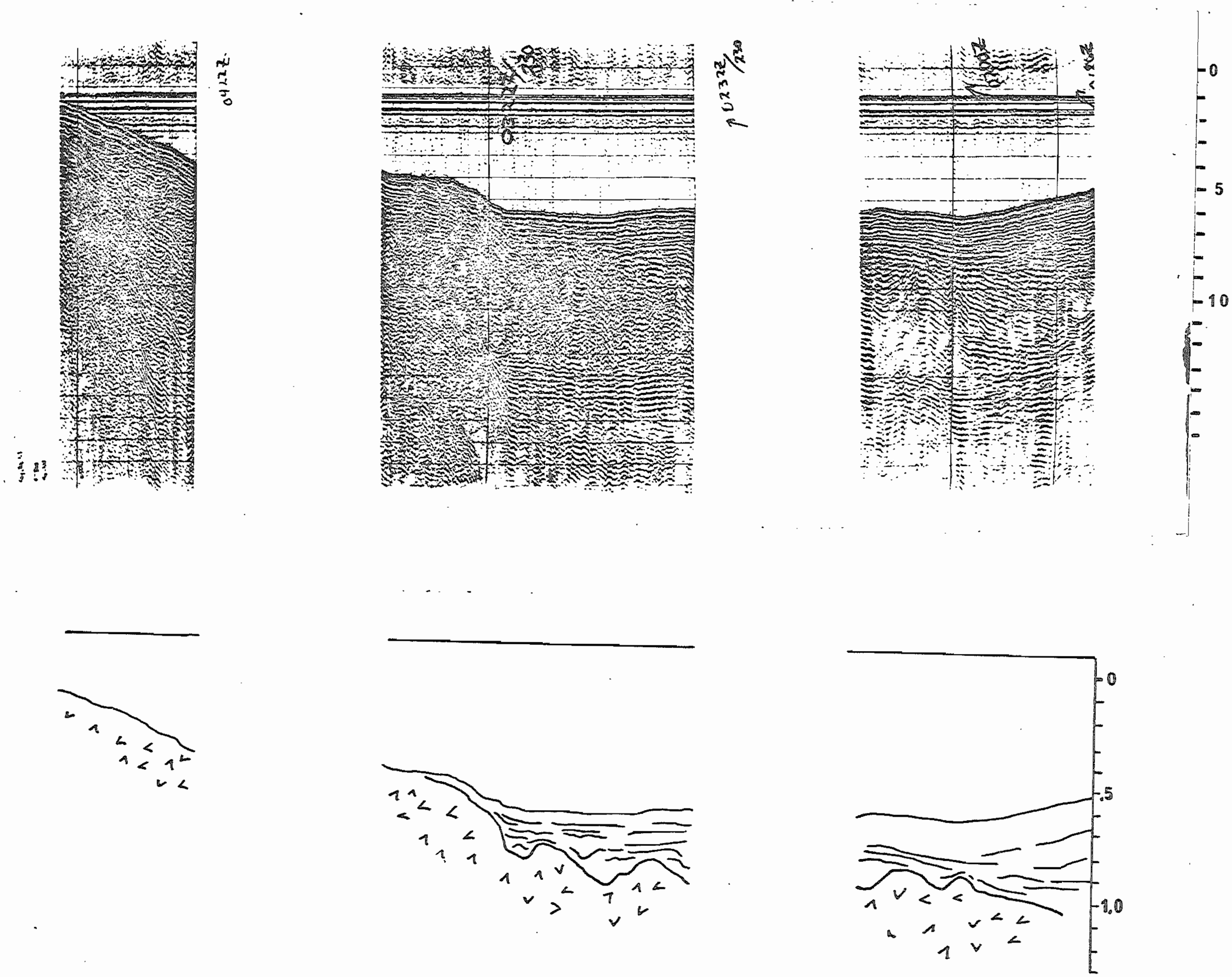


FIG. 29

R

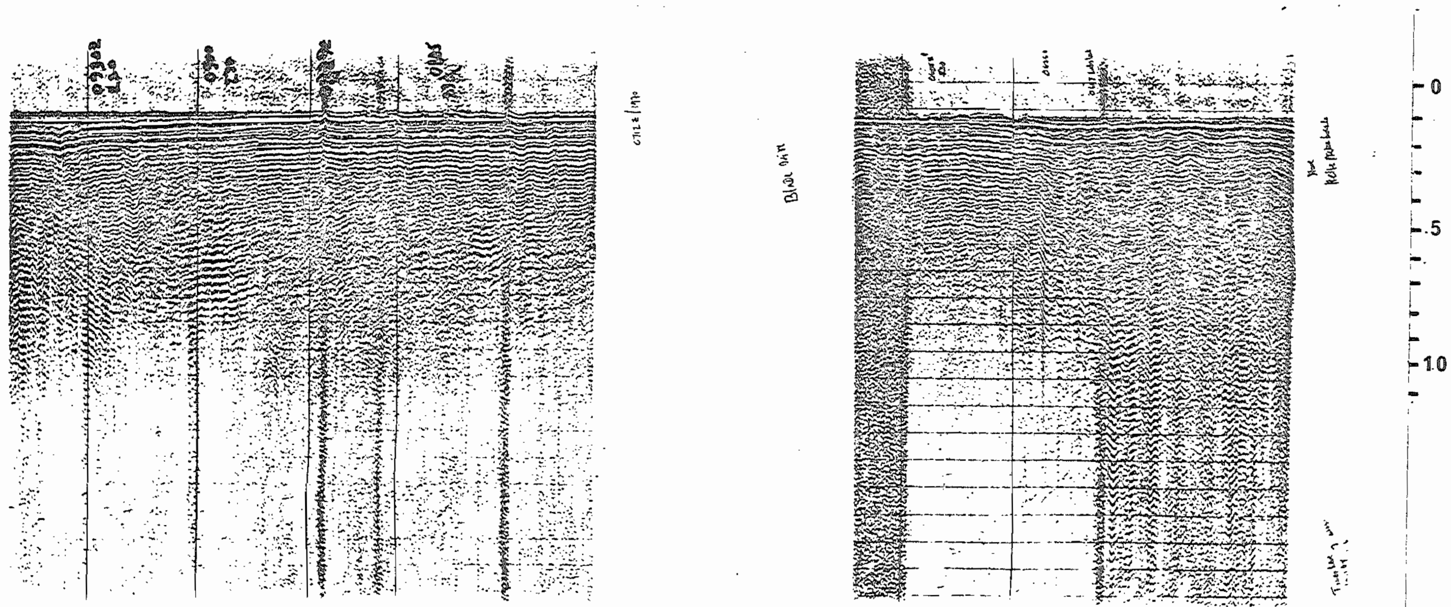
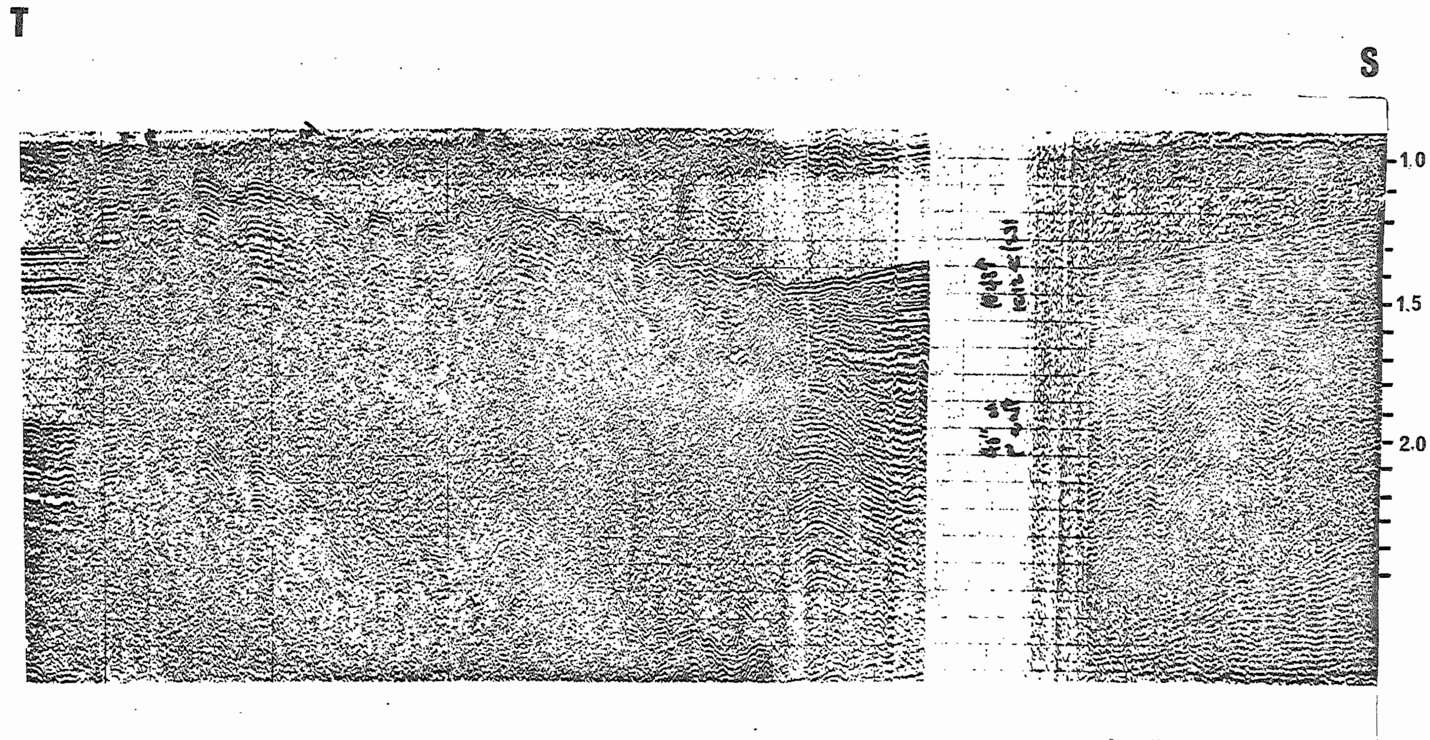


FIG. 30



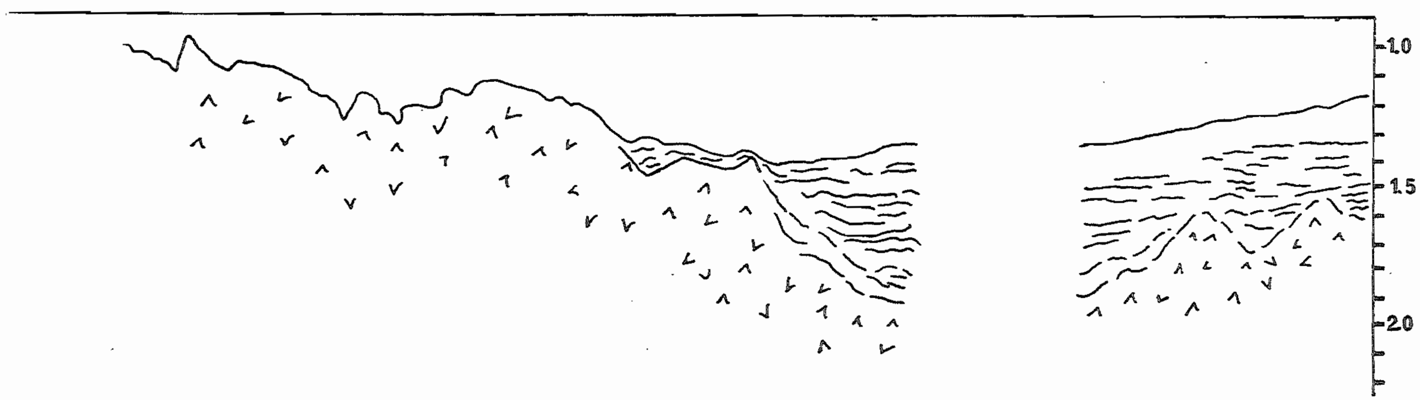


FIG. 31

a fault.

Profile 6a (Fig. 31)

This profile shows a very steep eastward dipping dip and scarp topography on the upper surface of an acoustic reflector buried under .5 seconds of relatively undisturbed sediments. The acoustic reflector reaches the surface at T where the dips appear to be to the west. The structure of the suggests a syncline or at least a gentle downwarping. Such structures are found on Disko and Nugssuaq in association with prominent faults.

Seismic reflection profiles have substantiated the interpretations made on the basis of the magnetics. Structures shown by the upper surface of exposed and buried basalts are similar to the structures exhibited by the volcanic sequence on land.

4.7 Quantitative Interpretation

Approximately 60 depth determinations were carried out on the original records to test the hypothesis that the volcanics do in fact deepen to the west beneath the coastal plain type sediments. The method used was Peters (1949) half-slope method which gives a maximum depth to basement. Depth determinations along lines with seismic control indicate that, in most cases, the values are at least .3 to .4 km too large.

Fig. 32 illustrates the location of the depth determinations and contours (in km) of depth to magnetic basement. The correspondence between these contours and the outcrop and extent of the basalts (Fig. 46) is very good, though the depth contours are shifted somewhat to the west.

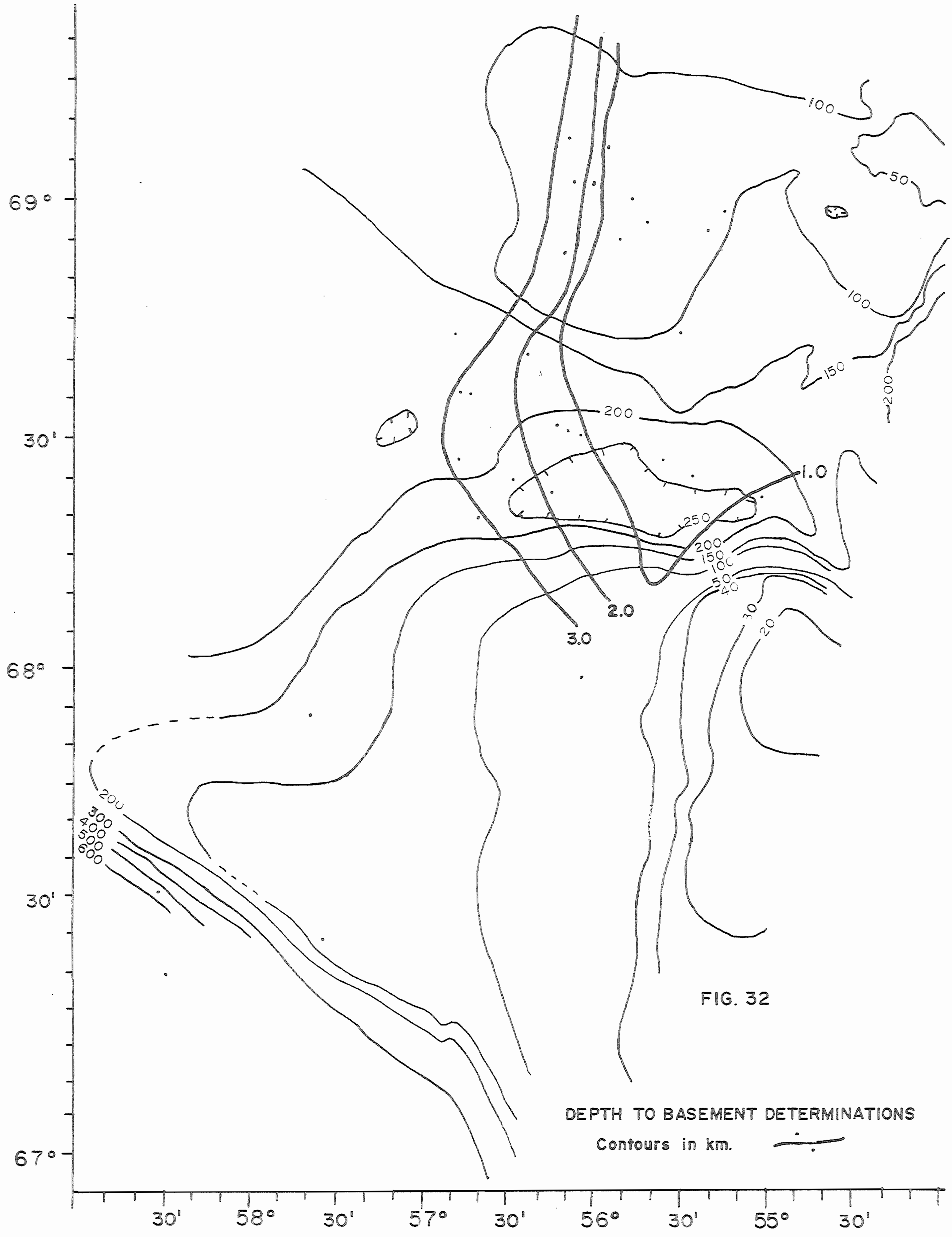
The depth to the top of the basalt layer (from sea level) is, in the area of outcrop, generally less than 1 km, in approximate agreement with the seismic depth profiles. To the west and southwest, the depth to basement increases to 3 km and the depth calculated on anomalies outside this zone show values ranging from 3.5 to over 6 km. To the south and southeast depths to basement are in the order of 1 to 2 km and are found in the area of Precambrian outcrop.

4.8 Northward Extension of the Volcanics

Since the latter part of the cruise was spent in undertaking extensive seismic reflection and magnetic surveys of the northwestern section of Baffin Bay and Lancaster Sound, several magnetic profiles to and from the survey area were made which provided useful information on the extent of the basalts offshore to the north (Fig.48). The tracks of the C.S.S. DAWSON plus magnetic profiles obtained by D.L. Barrett and K.S. Manchester and described by Keen et al. (1970) have allowed us to define the extent of the basalts many kilometres north of their known occurrence on land. A prominent longitudinal trough (Fig. 48) may denote the eastern margin of the basalts, an extension of the faulted margin of Cretaceous-Tertiary sedimentation. A portion of the track across the extension of the prominent Umanak fjord shows that anomalies characteristic of basalts do not occur and the possibility arises that they may have been eroded away. The topography north of the limit of basalts exhibits the same hummocky appearance as was evident for Precambrian terrain to the south.

4.9 Dredging

The dip and scarp topography of the acoustic basement with the associated large magnetic anomalies indicates that the volcanic sequence in the West



100
50
100
150
200
200
250
1.0
200
150
100
50
40
30
20
2.0
3.0
200
300
400
500
600
69°
30'
68°
30'
67°
30'
58°
30'
57°
30'
56°
30'
55°
30'
DEPTH TO BASEMENT DETERMINATIONS
Contours in km.

FIG. 32

Greenland basin may continue offshore for many tens of kilometres. In order to substantiate the geophysical interpretation, several dredge hauls were made in areas where the large magnetic anomalies were associated with steep sided troughs (Figs. 47,48)

The initial survey lines in the northeast portion of the survey area indicated that near shore and in the mouth of Disko Bay, the bottom topography was extremely irregular. However, the dominant feature was the long N-S trough indicated on the bathymetric profile which appeared to be a suitable area for dredging. The depth from trough to peak was about 350 fathoms. Magnetic profiles were extended to the east to define the eastern contact of basalts and Precambrian gneisses

The first profile in Disko Bay confirmed that the trough marked the eastern limit of basalt outcrop since the highly disturbed magnetic anomalies terminate about halfway down the western slope of this trough. Precambrian gneisses make up the outcrop to the east. It is significant to note that feldspar-phyric basalts of southern Disko Island rest directly on the Precambrian. Appropriately, a steep cliff on the western side of the trough was selected as the site of the dredge haul (Fig. 15, site 2). Dredge site 1, just to the east of site 2 produced only Precambrian gneisses.

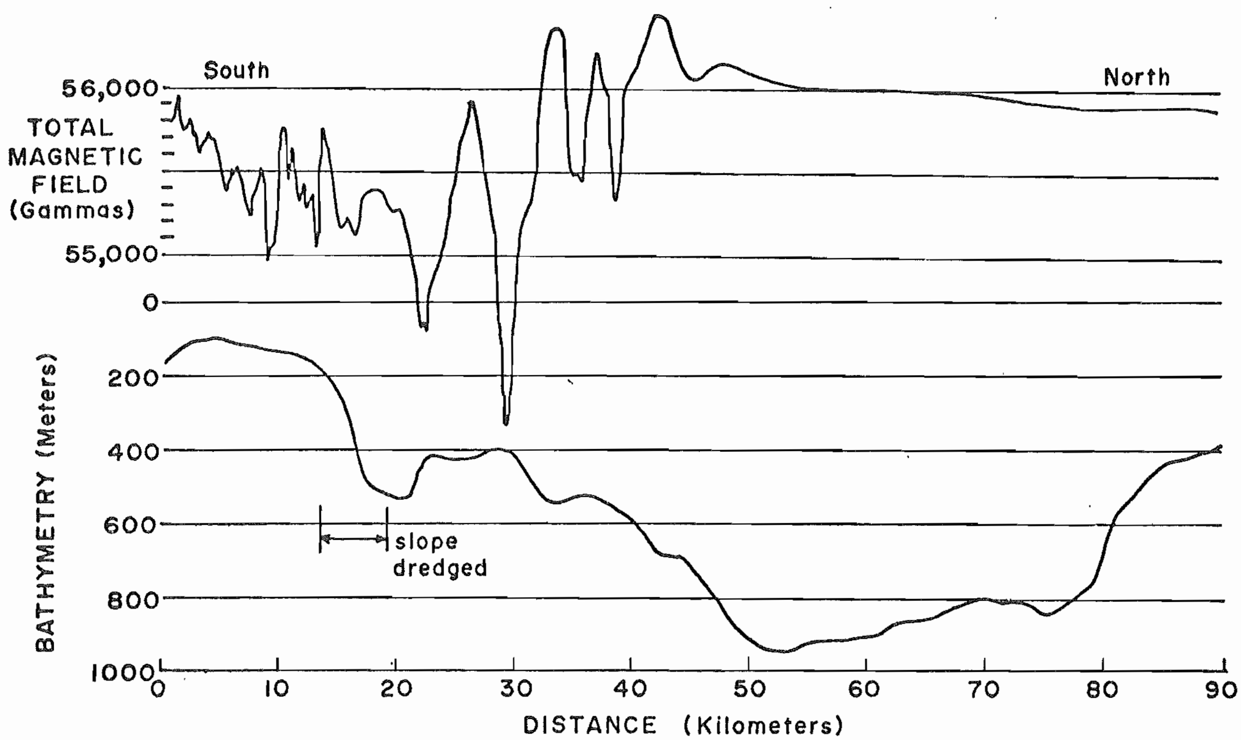
Site 5 was selected to the south again on the eastern side of the prominent longitudinal trough and the magnetic profile defined that this again formed the eastern margin of volcanics. One dredge station to the west of sites 2 and 5 produced only mud, confirming a sedimentary layer overlying the basalts. Another station in the same area resulted in the loss of the dredge.

The track northward from Godhavn into Melville Bay showed areas with anomaly patterns similar to those found off Disko Island. A dredge haul was made at 72° 57'N, 57° 30'W, from an east-west scarp with about 300 metres relief, to the west of the north-south trough which may mark the faulted eastern boundary of the basalts (Fig. 33). The anomalies characteristic of basalts terminate 30 km farther north.

Figure 33

Magnetic Profile over

Dredge Station 6


South
North
56,000
TOTAL
MAGNETIC
FIELD
(Gammas)
55,000
0
200
400
600
800
1000
BATHYMETRY (Meters)
slope
dredged
0
10
20
30
40
50
60
70
80
90
DISTANCE (Kilometers)

4.10 Magnetic Properties, Petrography and Opaque Mineralogy of Dredged Volcanics

Magnetic properties have been determined for 11 samples of basalt from the three dredge hauls previously described. In addition, polished sections from these samples were examined and the mineralogy of the silicates was determined for four of the 11 samples and 11 other samples.

The rocks selected for palaeomagnetic analysis were for the most part badly weathered. These were selected by J.M. Ade-Hall for an investigation into the effects of weathering of volcanic lavas and for this reason the results may not indicate the true properties found in much fresher samples.

Remanent magnetic intensities were determined on both a spinner and an astatic magnetometer. The apparent intensities for the astatic instrument tend to be slightly lower but the agreement is fairly good. The induced field results were obtained from the astatic magnetometer in a field of 0.55 oe, approximately equal to the field strength off Disko Island. In addition, magnetic properties of some Cape Dyer and Disko lavas determined by Kristjansson (pers. comm.) are given for a comparison between offshore and onshore characteristics. Also included is a table of previous measurements of the magnetic properties of submarine rocks (Watkins and Paster, 1971).

Petrography

Fifteen thin sections were examined with the aid of a polarising microscope and the results are listed in Appendix 1. Ten of the fifteen samples were basalts with plagioclase as the main phenocryst phase as well as smaller augite phenocrysts, and pseudomorphed olivines in some sections. The samples showed a range in size from fine to medium grained most being of the former type. The ground mass is typical for basalts with small plagioclase laths in sub-ophitic augites and possibly glass which has been altered to chlorite. The plagioclase phenocrysts show a small degree of zoning. One optically determined composition from a normal albite twinned grain gave An_{70}. Modal percents for this phenocryst range from 10 to 40%. In all of these sections plagioclase phenocrysts are associated with much smaller phenocrysts of augite which never make up more than 5%. Olivines are completely pseudomorphed to iddingsite (except in 5-03 where the central portion of one partially altered crystal gave a 2V around 90 indicating fresh forsteritic olivine) and have a very low modal percent. The olivine pseudomorphs are often clustered around the plagioclase phenocrysts giving a glomeroporphyritic texture to the rock. Opaques show several different relations depending on the grain size of the basalt. In the fine grained samples, the opaques are very fine grained and interstitial in the ground mass. In the coarser grained samples they appear as much larger grains with characteristic skeletal texture. They can make up to 5 modal percent.

A comparison of these descriptions with those given in Clarke (1968) suggests that these samples are probably feldspar-phyric basalts similar to those found in the upper part of the West Greenland volcanic sequence.

Two of the sections were highly vesicular showing an altered ground mass with plagioclase and much smaller augites as phenocryst phases. Zeolites (among them analcite was identified) fill the vesicles. The vesicles are rimmed by yellowish palagonite. The presence of vesicles identifies these as amygdaloidal basalts, but on the basis of their phenocrysts may still be classified as feldspar-phyric.

The last section, from a sample dredged at site 5, was fairly coarse grained, with no phenocrysts, 40% plagioclase laths, 50% augite crystals, pseudomorphed olivines <2%, and skeletal magnetites >5%. Such features are diagnostic of diabases and if this sample is local in origin, it may indicate that diabase dikes or sills are associated with the offshore faulted margin much as they appear on land.

There is no proof, except by inference, that these feldspar-phyric basalts were subaerially extruded. Out of the large number of samples of basalts dredged from the offshore province only two could be possibly classed as subaqueous. Both were remarkably weathered but appeared to be pillow breccias. If all the volcanics had been extruded in a subaqueous environment then more samples of this variety should have been collected.

It must be concluded on the basis of mineralogical evidence that these basalts from the offshore province are terrestrial in origin and are identical to many feldspar-phyric basalts found on land.

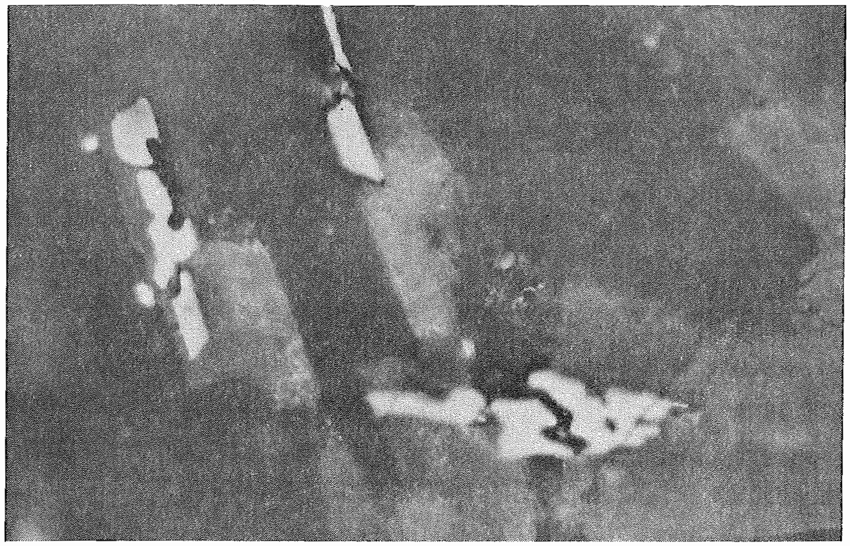
Opaque Mineralogy: and Magnetic Properties

Eleven polished sections were examined with the aid of a Reichert reflecting microscope and the results of which are listed in Appendix 2.

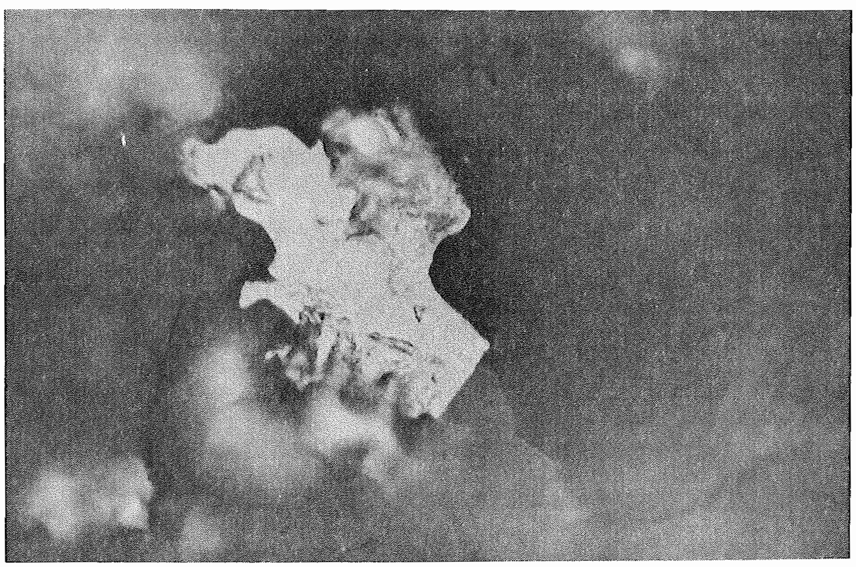
All of the samples except for 002 and 007 display features which appear to be similar to opaque mineralogies reported from submarine lavas (Ade-Hall, 1964). Most prevalent of the opaques are skeletal titanomagnetites ($(Fe,Ti)_3O_4$) ranging in size from 10μ to less than 1μ and tiny ubiquitous iron sulfides (Fig. 34). Occasionally primary laths of ilmenite can be seen. Such a mineralogy is indicative of a very low deuteric oxidation and identifies these samples as belonging to Class 1 on the deuteric oxidation scale of Wilson et al. (1968). This low deuteric oxidation state may attest to the low oxygen fugacities of the gas in the magma at least down to 500°C. The skeletal mode of occurrence of the single phase magnetites indicates rapid cooling of molten lava in which no large crystals had formed prior to solidification of the rock.

Sample 002 from site 6 however displays features of a highly altered mineralogy (Fig. 35). Large grains of greater than 75μ are prevalent and the mineralogy indicates a high deuteric oxidation state. Many grains show a complete replacement of titano-magnetite by pseudo-brookite ($Fe_2O_3 . TiO_2$), titano-hematite ($(Fe, Ti)_2O_3$) and rutile (TiO_2) (Class 6). Other grains show large islands of magnetite with exsolved needles of chrome-spinel, surrounded by ilmenitelamellae which have been completely altered to titanohematite and Fe-rutile (Class 5). A few grains of Class 3 oxidation state are also present. Such a mineralogy indicates that the opaques have undergone the entire range of deuteric oxidation. The initial sub-solidus oxidation of titanomagnetite is followed by aggregation into octahedrally directed exsolution-like texture of ilmenite in titano-magnetite, together with further stages of oxidation through Class 5 to a final form consisting of an aggregate of rutile, pseudobrookite and the titano-hematite. Laboratory studies on the stability field of pseudobrookite, suggests that this deuteric process can only take place in excess of $600^{o}C$ (Lindsley, 1965). In addition, a much slower rate of cooling is indicated by the relatively large grain size of the opaques.

Section 007 appears to have undergone the effects of some process other than deuteric oxidation.

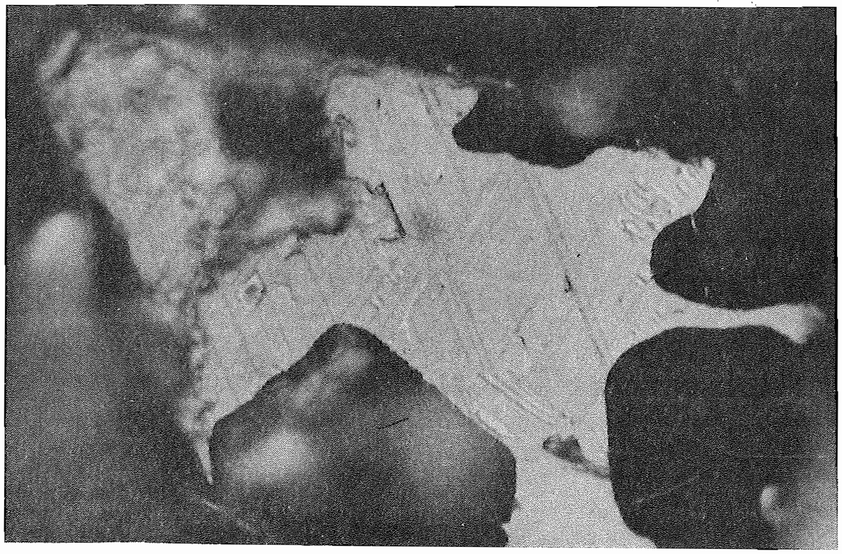


Class 1 Skeletal titanomagnetite

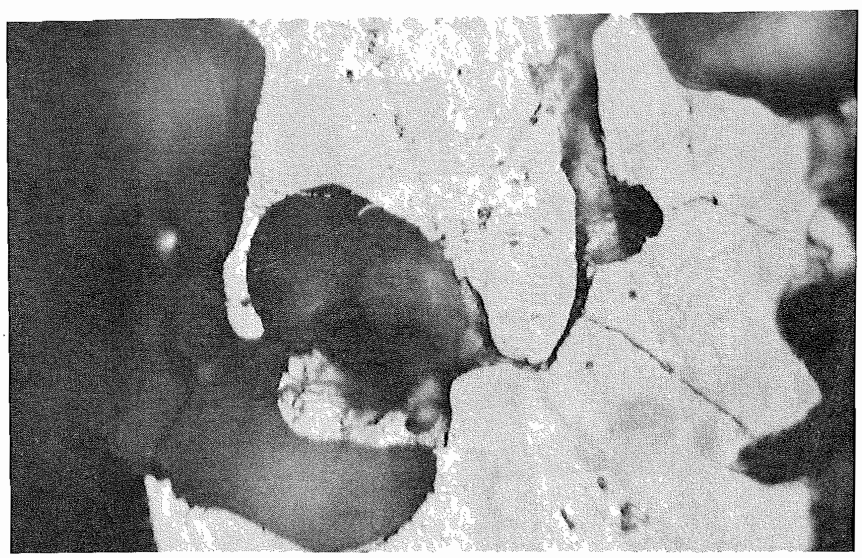


Class 1 Titanomagnetite with ferri-rutile granulation (poorly developed)

Figure 34

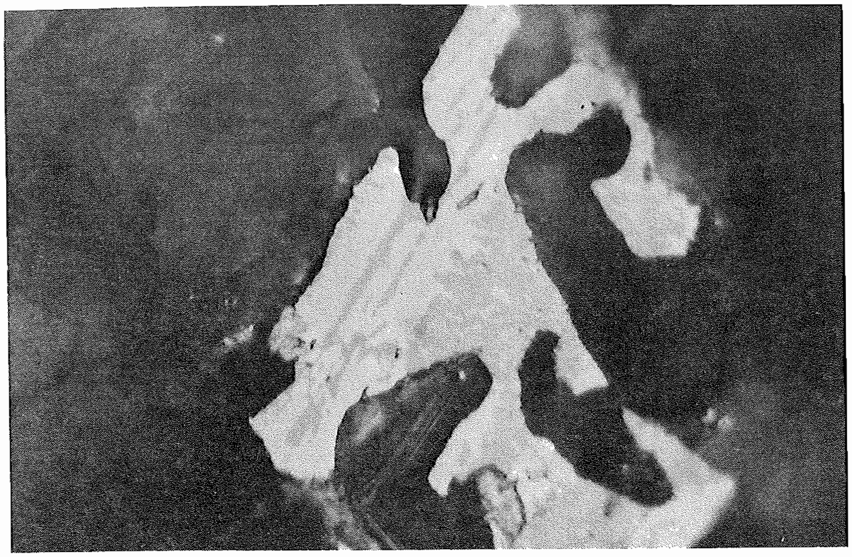


Class 3 Exsolved ilmenite lamellae



Class 6 White-titanohematite
Dark grey-ferri-rutile
Light grey-pseudobrookite

Figure 35



Class 6 White-titanohematite
Grey-pseudobrookite

Figure 36

This stems from the observation of patches of fine grained ferri-rutile granules exsolved from and resting in much larger titanomagnetite grains. Ade-Hall et al. (1968) report that such a granular assemblage is found in Iceland corresponding to the stratigraphically lowest zeolite assemblage zones which Walker (1960) has correlated with depth of burial. It is concluded that thermal alteration due to increased depth of burial is the prime cause of the granulation. Reheating to about 150°C has occurred in such cases (Ade-Hall et al., in press).

If the Davis Strait area was the site of high heat flow during the period of formation of the widespread volcanics a conservative estimate of the temperature gradient as 80°C/km would suggest that this sample may have been buried to a depth of 1 to 2 km. This estimate is not unreasonable considering the location of the dredge station (Section 4.9).

Though the dredged volcanics have been shown to be very much like the terrestial feldspar-phyric volcanics of the West Greenland province, their opaque mineralogy, with the exception of 002, resembles the mineralogy found in submarine lavas, for example at 45°N (Carmichael, 1970). The opaque mineralogy of the volcanics on land should be examined to test the ambiguity of this fact. Classes 5 and 6 grains in sample 002 were thought to be characteristic of continental lavas. However, magnetites from a hyaloclastic volcanic sediment from JOIDES, site 115 (between Reykjanes ridge and Rockall Bank) are also in a high oxidation state (P. Ryall, pers. comm.).

The typical Class 1 opaque mineralogy is associated in most cases with the fine grained varieties of the dredged samples. From this observation, it might be expected that these volcanics would show relatively strong remanent magnetisation and high Q ratios and that their remanence would determine the observed magnetic anomalies over the offshore province.

Table 1 reports the magnetic properties of the dredged samples. Table 2 reports the analyses performed on the Cape Dyer lavas and two remanence determinations on Disko volcanics.

The remanence values for the dredged samples average 4.3×10^{-3} $cgscm^{-3}$, though they cover a wide range from 10.9×10^{-6} to 13.2×10^{-3}. The values for both samples from Disko Island fall within this range. The two highest values correspond to sample 002 with the Class 6 mineralogy and one of the

Table 1

Dredge Station	Sample No.	Class and Description	NRM* Spinner $\times 10^{-3}$	NRM* Astatic $\times 10^{-3}$	Susceptibility $\times 10^{-3}$	Q
6	001	1	1.6×10^{-3}	weak	weak	-
6	002	feldspar-phyric basalt Class 5	11.0	12.0	1.8	6.7
6	003	feldspar-phyric basalt Class 1	3.7	4.1	1.05	3.9
5	004	1	1.7	2.0	weak	>>1
5	006	feldspar-phyric basalt 1	2.6	2.8	0.3	9.3
5	007	burial metamorphic effects 1	4.9	5.3	0.25	21.3
2	008	amygdaloidal feldspar-phyric basalt 1	13.2	13.6	0.7	19.4
2	009	1	5.4	5.5	1.85	2.91

Dredge Station	Sample No.	Class and Description	NRM* Spinner x 10^{-3}	Astatic x 10^{-3}	Susceptibility x 10^{-3}	Q
2	010	1	10.9×10^{-3}	weak	weak	-
2	011	1	5.3×10^{-2}	weak	weak	-
-	7		1.6×10^{-3}	weak	weak	-
		Mean	3.9		.99	10.6
		Standard Deviation	4.4		.65	7.2

* Units volume magnetisation c.g.s. emu.

Analyses by H.C. Palmer, Geophysics Laboratory
University of Western Ontario

Table 2

Sample No.	No. of Samples	Type	NRM* x 10^{-3}	Susceptibility* x 10^{-3}	Q
1	5		2.93	.43	6.8
4	5		2.33	.25	9.3
5	3	Baffin Island	1.87	.20	11.9
	3	olivine basalts	2.87		
6	6		3.00	.52	5.8
7	5		7.9	.95	8.3
2	5		5.12	1.33	3.9
		Mean	3.7	.6	7.7
		Standard Deviation	1.95	.4	1.5

* Units volume magnetisation c.g.s. emu.

Analyses by L. Kristjansson, Department of Geology
Memorial University

Table 3

Summary of Magnetic Properties

of Submarine Rocks

(from Watkins and Paster, 1971)

Reference	sample locality	rock type	N	$J \times 10^{-4}$ c.g.s.	$\chi \times 10^{-4}$ c.g.s.	Q	remarks
Matthews 1961	North Atlantic	basalt	41	44.0	5.0	20.0	—
Cox & Doell 1962	Northeast Pacific	basalt	23	5.4	3.0	40.0	—
Bullard & Mason 1963	Mendocino-Pacific	basalt	?	177.0	18.0	20.0	includes data from Ade-Hall (1964)
Ade-Hall 1964	Atlantic and Pacific	basalt	97	50.0	5.0	18.0	one third of samples 'decomposed'
Vogt & Ostenso 1966	M.A.R., 44° N	basalt	10	50.0	3.0	48.0	—
Opdyke & Hekinian 1967	M.A.R., 30° N	basalt	24	290.0	9.2	64.0	includes 'altered' samples
Luyendyk & Mason 1967	M.A.R., 22° N	basalt	8	63.0	18.0	12.0	—
Ozima *et al.* 1968	Pacific	basalt	9	35.7	2.7	24.8	—
Dymond *et al.* 1968	Cobb Sea Mount	basalt	1	4.5	0.8	10.4	—
DeBoer *et al.* 1970	Reykjanes Ridge	basalt	38	500.0	5.0	173.0	many samples from a few boulders
Carmichael 1970	M.A.R., 45° N	basalt	17	1680.0	—	110.1	—
Luyendyk & Melson 1967	M.A.R., 22° N	basalt breccia	9	7.4	4.9	3.41	much saponite present
Opdyke & Hekinian 1967	M.A.R., 30° N	spilitized basalt	4	0.04	0.55		—
Luyendyk & Melson 1967	M.A.R., 22° N	greenstone	3	0.06	0.53	0.2160	—
Carmichael 1970	M.A.R., 45° N	metabasalt and diabase	2	1.33	—	13.3	—
Opdyke & Hekinian 1967	M.A.R., 30° N	chloritized basalt	1	0.0016	1.84	0.0017	—
		Anorthosite gabbro	1	3.11	1.46	4.26	—
		olivine gabbro	1	5.40	3.35	3.22	—
		amphibolite	1	0.0032	0.81	0.0078	—
		serpentinite	1	23.2	38.5	1.2	—

N = number of specimens measured. J and χ values are sometimes e.m.u. g^{-1} and mass susceptibility, or e.m.u. cm^{-3} and volume susceptibility, respectively. $Q = J/\chi H$ where H = present ambient geomagnetic field intensity in oesteds. Refer to original reference for details of data averaging, which is sometimes per unit sample (several specimens) or per unit specimen. M.A.R. = Mid-Atlantic Ridge amygdaloidal feldspar-phyric basalts.

Susceptibilities range from a high of 1.8×10^{-3} $cgscm^{-3}$ to 0.3×10^{-3} with four samples possessing very weak susceptibilities (out of range of the measuring apparatus). A similar range is found for the susceptibilities in the Baffin Island series, but susceptibilities of Mid-Atlantic ridge volcanics are somewhat lower. Q values for submarine basalts show a wide range but many are comparable to the mean value for the dredged samples (Table 3).

In general the high Q ratios indicate that the natural remanent magnetisation in the basalts will be the prime source of the magnetic anomalies.

4.11 Geochemical Analyses of Dredged Volcanics

In his analyses of the geochemistry of the sub-aerial volcanics, Clarke (1970) concludes that the evolution of the feldspar-phyric basalts cannot have been controlled simply by olivine removal (as is true for the breccias, picrites and olivine basalts) since late-stage trends are usually widely divergent from olivine control lines. Evidence exists to show that low pressure fractionation has resulted in the production of these quartz-normative compositions.

Despite their high degree of evolution they can still be shown to have been derived from the same parental magma which produced the earlier members of the province.

Much of the argument stems from incompatible minor and trace element analyses. The "incompatibles" were defined by Ringwood (1966) as elements which are largely rejected from the structures of the major silicate phases to become concentrated in the residual liquids during crystal-liquid fractionation. These elements include among them: Ti, K, P, Zr, Rb, Sr, Ba, and Y. The characteristic signature of these elements in the Baffin Bay volcanics is their remarkably low abundances.

It has been argued that comparisons of analyses on the grounds of major element chemistry is too dependent on modal percent and type of phenocryst phase as well as the entire complex history of differentiation. However the incompatibles, though also affected by degree of partial melting of the mantle and type and of extent of subsequent fractionation, should increase in a nearly linear fashion during fractional crystallization.

Incompatible trace and minor element analyses

Table 4

Geochemical Analyses of the Davis Strait Volcanics*

Sample No.	TiO_2	K_2O	P_2O_5	Ba	Zr	Y	Sr	Rb	Cu	Ni	CaO	Zn
2-01	1.86	1.41	.13	50	110	30	350	22	210	100	6.9	90
2-05	1.66	.18	.19	50	75	32	205	<5	110	65	10.8	65
2-06	2.05	1.30	.12	50	125	30	330	25	190	95	7.0	105
2-10	2.02	1.12	.19	50	100	35	300	15	205	75	8.0	90
2-11	1.71	.15	.17	70	80	30	215	<5	195	75	10.9	70
2-12	1.72	.15	.20	70	85	32	210	<5	160	75	11.3	85
2-13	2.36	.22	.26	60	135	45	205	<5	210	65	10.6	95
5-03	2.10	.29	.23	105	115	40	190	5	250	70	10.7	70
5-10	2.07	.24	.24	100	135	35	230	<5	100	55	9.9	90
5-12	2.12	.25	.24	100	120	30	220	5	90	40	9.9	90
5-13	1.77	.15	.19	60	80	27	180	<5	120	125	9.5	75

Sample No.	TiO_2	K_2O	P_2O_5	Ba	Zr	Y	Sr	Rb	Cu	Ni	CaO	Zn
6-10	2.19	1.03	.39	40	100	40	270	7	200	50	8.9	85
6-11	2.53	.29	.39	130	160	55	195	<5	330	55	9.9	85
6-12	3.72	.27	.44	140	265	70	240	5	420	45	10.0	95
6-13	2.28	.21	.22	100	80	30	195	<5	150	70	11.3	65
6-14	1.56	.23	.20	40	150	50	200	5	250	60	10.0	100

* Analyses by G.R. Angell, Grant Institute of Geology, Edinburgh U.
X-ray fluorescence analysis, Philips 1212 automatic unit.

have been made on 16 of the dredged volcanic samples, (Table 3) some of which have been examined petrographically for their silicate and opaque mineralogy. To compare these analyses with those of the entire province and especially to the feldspar-phyric varieties, which they resemble mineralogically, simple variation diagrams between various elements given in Clarke (1968) have been reproduced (Figs. 37 to 40) and the new analyses added.

Figure 37 shows the relationship between the two incompatible major element oxides, TiO_2 and P_2O_5. These two elements, though chemically dissimilar, are largely rejected from the crystallizing phases. The definite overlapping trend for the subaerial volcanics with the Baffin Island series lying at the primitive end of a linear variation is very evident. The new analyses tend to cluster within the range of the feldspar-phyric volcanics but nearer the earlier compositions. However, one very high TiO_2 (6-12 with 3.72%) as well as several others from the northernmost dredge station appear to fall towards very highly evolved compositions.

The relation between Zr and TiO_2 is shown in Fig. 38. Taylor (1965) reports that when Ti minerals

Symbols common to Figures 37 to 40

- ● Baffin Island olivine basalts
- ▲ Svartenhuk basalts
- ■ Dredged basalts
- ○ Baffin Island intra-flow differentiates*
- △ Svartenhuk intra-flow differentiates*

* The trends of the tie-lines joining intra-flow differentiates and therefore representing the course of fractionation at 1 atmosphere lie parallel to the overall trend in the 2 suites.

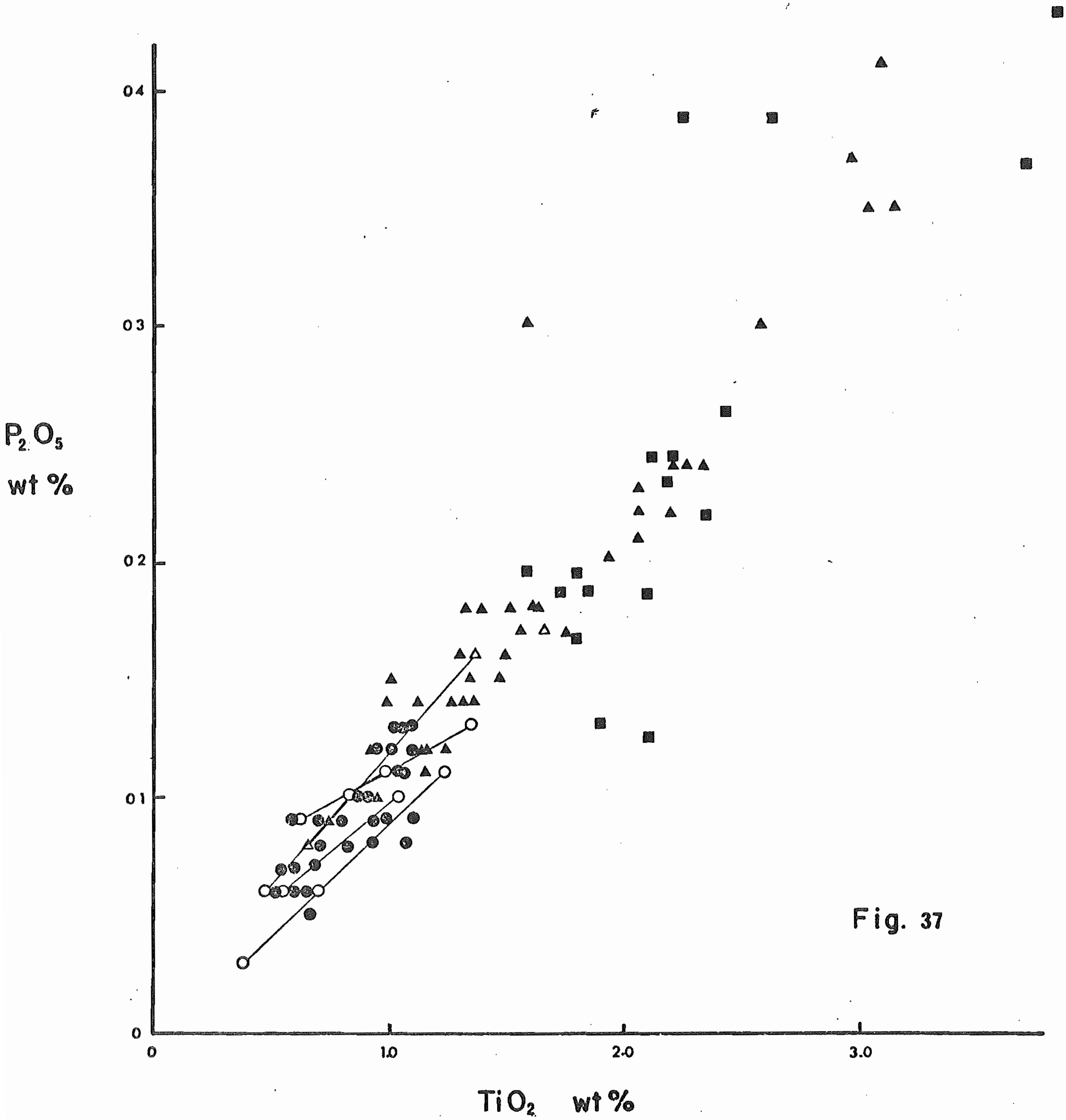


Fig. 37

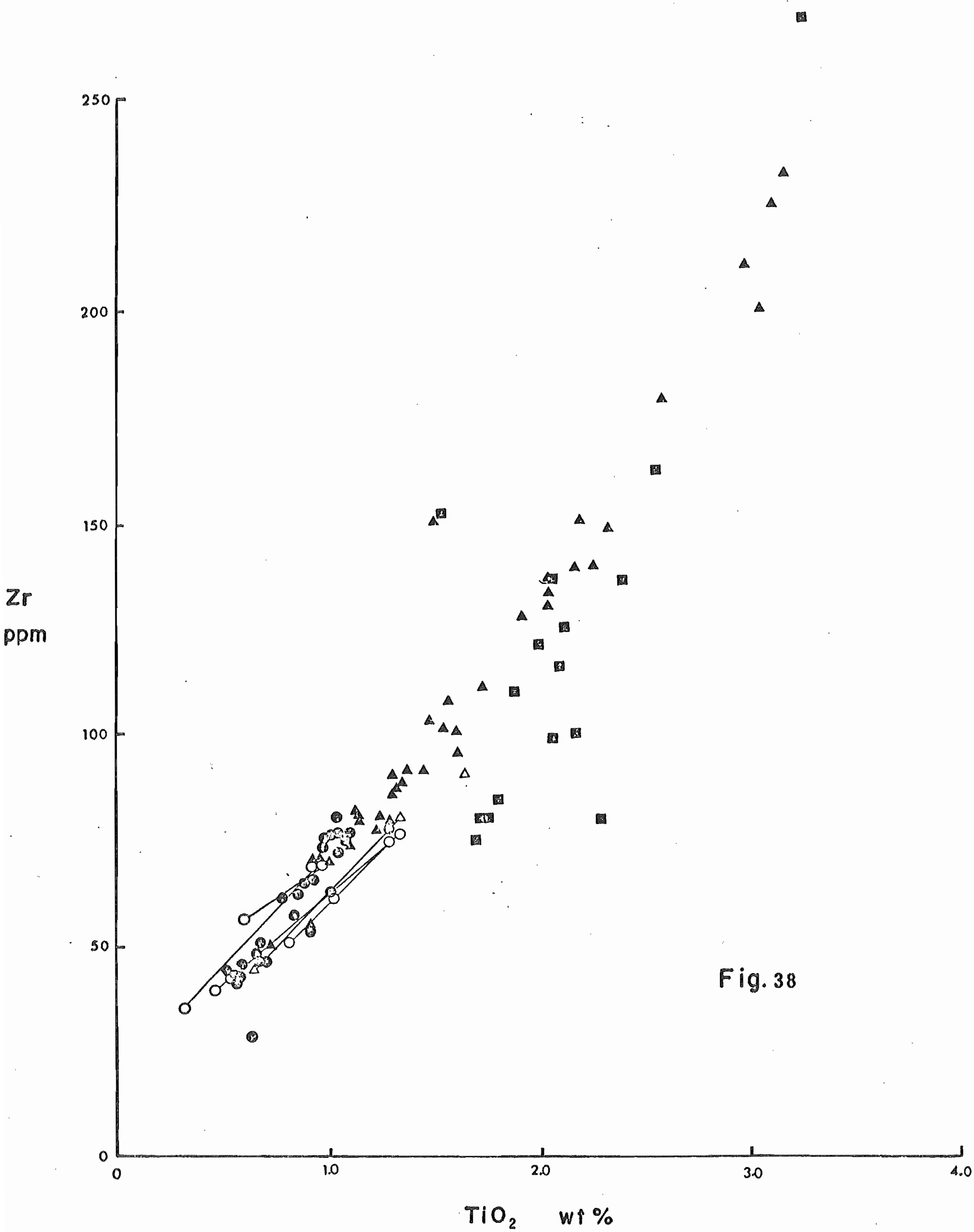


Fig. 38

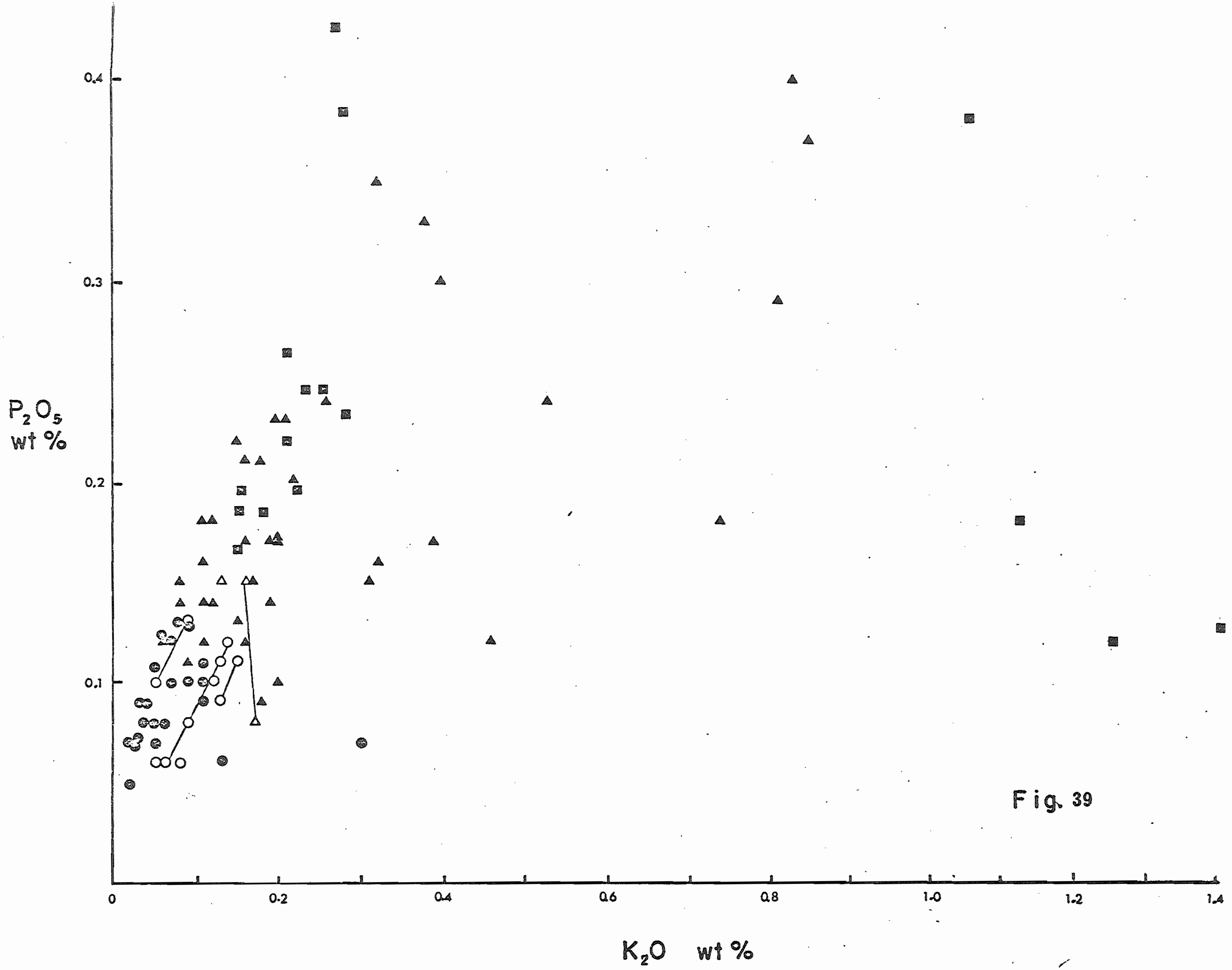


Fig. 39

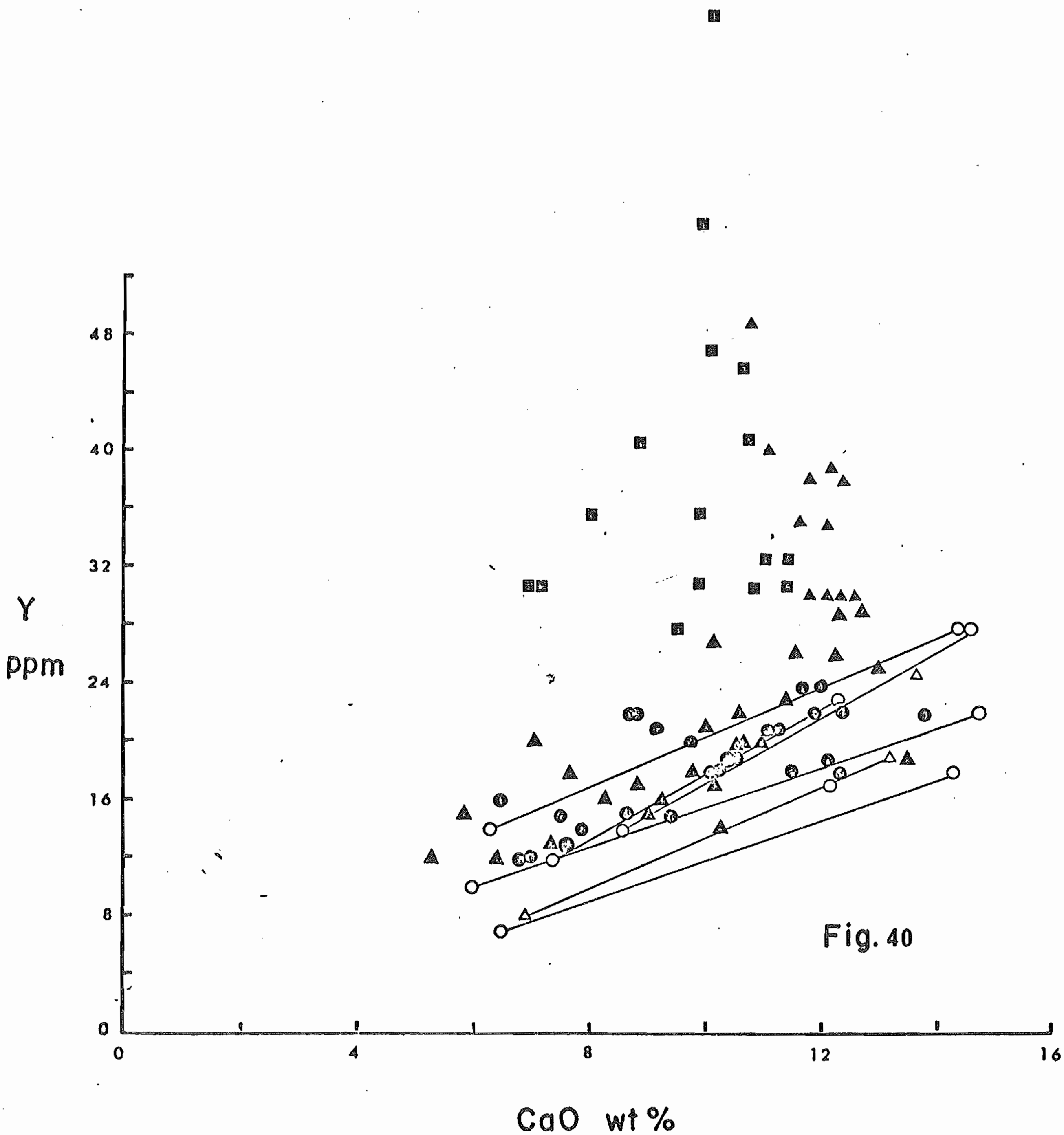


Fig. 40

are crystallizing, Zr may replace Ti, but otherwise both are incompatible and tend to remain in the residual liquid. The diagram again demonstrates a similar trend to Fig. 37 with most of the analyses clustering toward the less-evolved feldspar-phyric compositions.

K is classed as an incompatible due to its very large ionic radius and as such, is subsequently enriched in the liquid during early stages of fractional crystallation. The rather erratic behaviour of K_2O in the analyses is probably due to several factors:

1) reaction of the magma with sea water during extrusion, in the case of breccias;
2) small amounts of crustal contamination while the magma is en route to the surface (may be important at such low levels of K_2O in the magma);
3) weathering in the submarine environment (Hart, 1970).

It is possible that these factors may also have affected the other incompatibles though linear relations are apparent.

The recurring trends are again demonstrated (Fig. 39) except for the very high P_2O_5 levels in the samples from the northernmost dredge station.

Figure 40 shows the variation of Y with CaO. Yttrium normally occupies calcium sites when substituting for a major element. However, it is not taken preferentially over calcium in either plagioclase or augite. Therefore, increased fractionation should concentrate this element in the liquid phase. The Baffin Island and West Greenland suites show a strong overlap towards the more primitive end of the variation with slightly decreasing Y/CaO ratios. Rapidly increasing Y/CaO is demonstrated in the more evolved Svartenhuk basalts and in the new analyses. Very high Y values are found again for the northern dredge station.

In general, the feldspar-phyric basalts of the offshore province resemble the least evolved feldspar-phyric basalts of terrestrial origin. In addition, those varieties dredged from the faulted eastern margin south of Disko Island are found very near to the contact with Precambrian rocks so that it is likely that they represent volcanics of the lower section of the feldspar-phyric suite. In southern Disko the feldspar-phyric basalts rest directly on Precambrian basement. One implication is that even more evolved compositions may be found farther offshore. The gently seaward dipping and overlapping flows suggested on geophysical evidence support this implication. The position of the third dredge station is more to the centre of the defined area of extent of the volcanics and it would be expected that volcanics found in this area would be much higher in the stratigraphic succession.

The results of the incompatible minor and trace element analyses, compared to the analyses of the Baffin Bay volcanics (Clarke, 1970) are shown in Figs. 41 and 42.

The total of all the dredged samples implies that the group of samples as a whole occupies a position intermediate between the olivine basalts and the most evolved feldspar-phyric volcanics described by Clarke. The K_2O totals however may indicate the addition of potassium from sea water subsequent to crystallisation.

If the totals are recalculated on the basis of the implied stratigraphic positions of the offshore suite at the various dredge stations then two distinct series can be suggested. The average for 11 feldspar-phyric basalts dredged from near the base of the succession (sites 2 and 5) have lower TiO_2 and P_2O_5 but again fall toward the least evolved of the feldspar-phyric series. The totals for the 5 samples from the site 6, suggested to be at a higher

Comparison of Incompatible Minor Elements in Tholeiites

	TiO_2	K_2O	P_2O_5	
1	0.78	0.07	0.09 }	
2	1.25	0.2	0.15 }	Baffin Bay
3	2.29	0.39	0.26 }	
4	2.11	0.45	0.24 }	
5	1.95	.50	0.20 }	Davis Strait
6	2.46	.41	0.33 }	

1. Avg. 24 Baffin Island olivine basalts (Clarke, 1970)
2. Avg. 24 Svartenhuk olivine basalts (Clarke, 1970)
3. Avg. 15 Svartenhuk feldspar-phyric basalts (Clarke, 1970)
4. Avg. 16 offshore feldspar-phyric basalts
5. Avg. 11 feldspar-phyric basalts Stations 2 and 5
6. Avg. 5 feldspar-phyric basalts Station 6

Fig. 41

Comparison of Incompatible Trace Elements

	Ba	Sr	Y	Zr
1	49	126	17	55
2	69	215	19	82
3	143	285	33	156
4	76	233	38	119

1. Avg. 24 Baffin Island olivine basalts (Clarke, 1970)
2. Avg. 24 Svartenhuk olivine basalts (Clarke, 1970)
3. Avg. 15 Svartenhuk feldspar-phyric basalts (Clarke, 1970)
4. Avg. 16 Dredge samples - Davis Strait

Fig. 42

stratigraphical level, shows that they may represent the most evolved group that has been sampled. It might be speculated that even more highly differentiated rocks lie farther to the west.

Fig. 42 compares incompatible trace element totals and shows the same intermediate nature that was shown by the entire offshore suite except for apparently higher Yttrium values.

4.12 Bathymetry and Marginal Channels of the West Greenland Shelf

Soundings from the geophysical survey were plotted on the 1:250 000 track chart and the values contoured in fathoms. However, in order to obtain a more meaningful overall picture for the entire Davis Strait area values plotted on USHO Chart 5239 and 5237 were contoured and though the positional accuracy may be somewhat less than that for the survey, the agreement between contoured values is good (Figs. 19, 43 and 44).

The southern part of the map from 64°N to 67°N shows the continental shelf as it is typically developed for SW Greenland. Its width is approximately 75 km with a steep continental slope which drops off to the northern Labrador Sea. The sea itself slopes gently up to the Davis Strait sill. Development of a typical marginal channel is seen around 64^{o} 30'N, just to the north of the Godthaab deep, a classical example described by O. Holtedahl (1969). The marginal channel problem off southwest Greenland has been extensively studied by Grant (1970) for the more well-developed channels and transverse troughs on the Labrador shelf.

Marginal channels typically separate Precambrian crystalline rocks underlying a rough inner shelf and stratified sedimentary rocks on a smooth outer shelf. Their origin is attributed to several factors; glacial erosion at the front of an advancing ice sheet, normal faulting and post-glacial isostatic rebound.

Transverse troughs separating the outer banks also occur and are thought to be the routes by which the ice advanced to the continental slope.

O. Holtedahl has traced the marginal channels as far as 68^{o}N on the West Greenland shelf with the aid of detailed inshore bathymetry, and the general trend is noted on the bathymetric chart.

Key to Figures 43 and 44

Marginal Channels

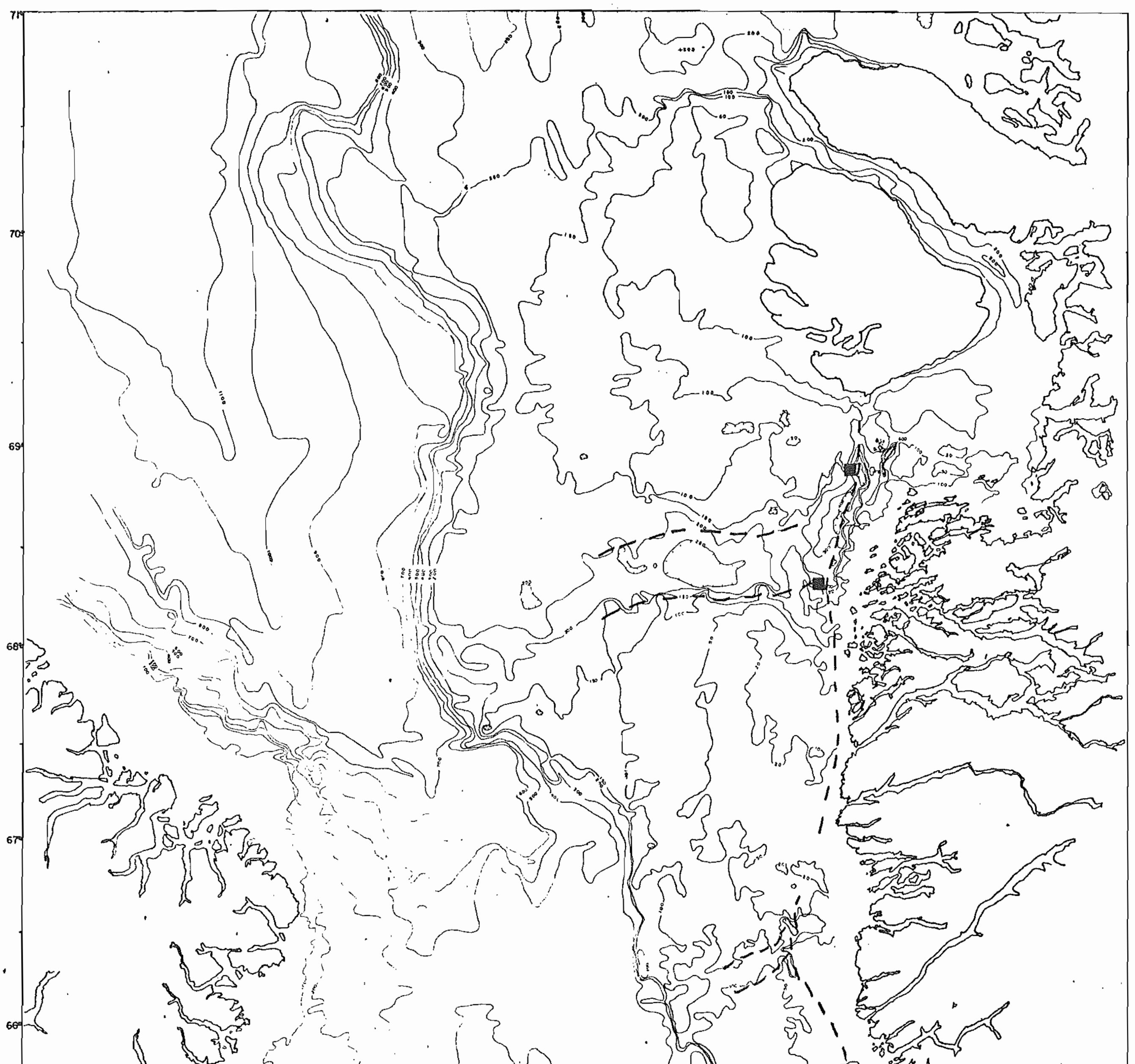
Transverse Troughs

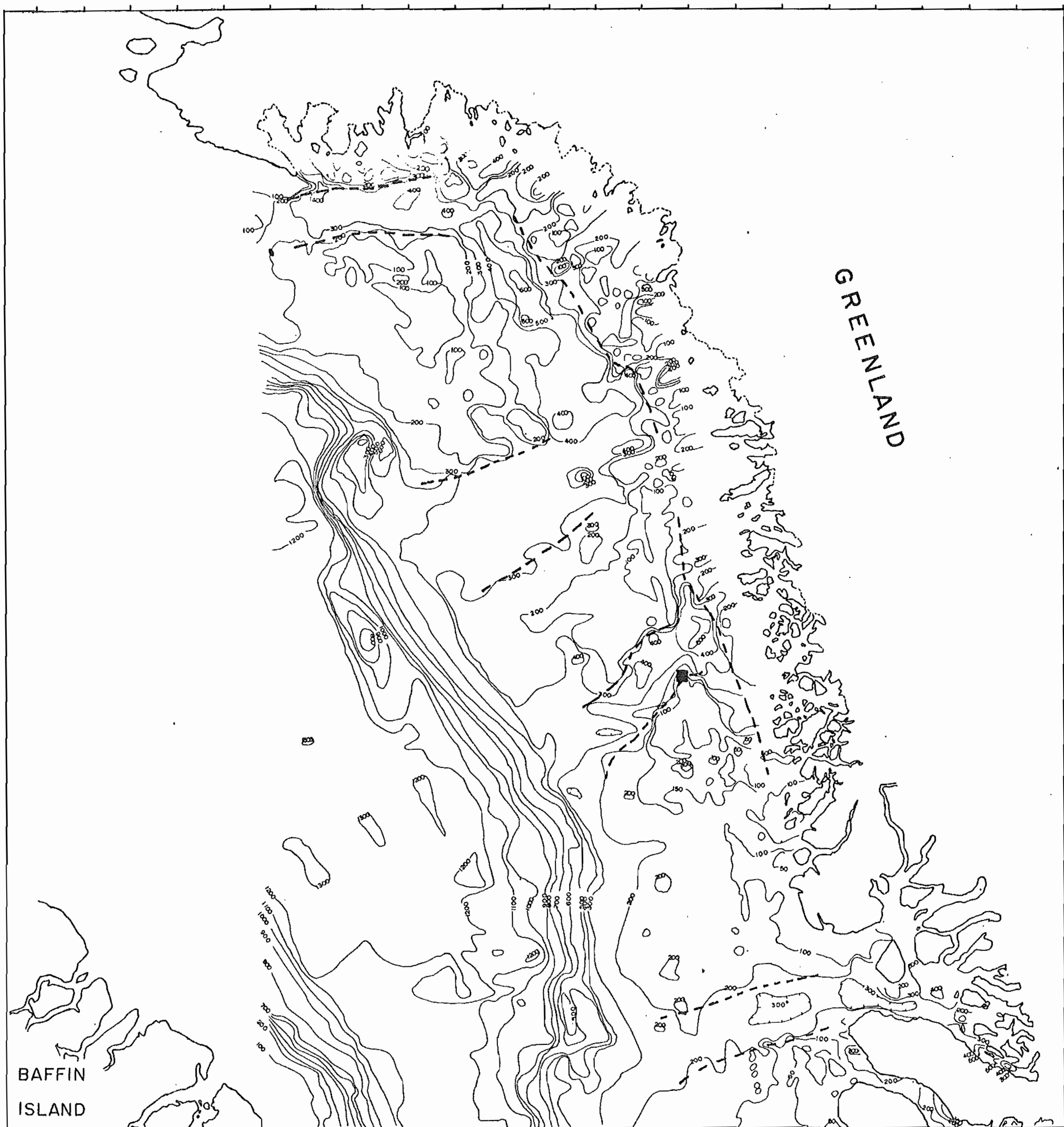
■ Dredge Station

(contours in fathoms)

Fig. 43 Contoured from U.S.H.O. 5239

Fig. 44 Contoured from U.S.H.O. 5237


71°
70°
69°
68°
67°
66°
65°
64°
65°
64°
63°
62°
61°
60°
59°
58°
57°
56°
55°
54°
53°
52°
51°
50°



GREENLAND
BAFFIN
ISLAND
76°
75°
74°
73°
72°
71°
70°
72°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°

Near $67^{o}N$ there is a pronounced widening of the shelf to approximately 300 km. This area has several interesting bathymetric features. The first of these is a northeast trending trough at $68^{o}N$ with depths in the central portion exceeding 250 fathoms. To the north of this trough and up to about $70^{o}N$ the shelf appears to be very smooth with widely spaced contours. Other prominent features are the two very deep longitudinal troughs northwest of Egedesminde which lie on either side of the N-S trending Precambrian structural high described in Chapter 3.

Wholesale continental glaciation has apparently not affected the Cretaceous-Tertiary rocks of Disko Island, but the existence of extensive Quaternary deposits to the southeast of Egedesminde suggest that the ice sheet skirted to the south of Disko Island. Glacial flow appears to have been NE to E-W as evidenced by the trends of the large number of long narrow fjords in the region. Large glaciers at the head of Disko Bay produce icebergs which move west and out onto the shelf. This prominent northeast trending trough then could be the result of glacial erosion. The smoother shelf area north of this trough appears to have been unaffected by this type of erosion so that, except for ice-rafted material it has been the site of relatively undisturbed sedimentation since the cessation of volcanic activity.

The two N-S troughs northwest of Egedesminde could be the result of several processes. From geophysical evidence presented earlier the southern portion of the most westerly trough lies at the contact between Precambrian gneisses and volcanics and as such may represent part of the major fault system associated with the Cretaceous-Tertiary basin. To the north this trough continues, to lie on the western side of the Precambrian high which outcrops as skerries at the mouth of Disko Bay. A shorter but correspondingly deep trough occurs just to the east of this high. It is possible that glaciers moving out of the Bay have scoured out deep troughs on either side of this high which presented an obstacle in their path.

The effect of relatively high unglaciated land on Disko Island may have been to produce a piedmont-type glacier which fanned out onto the shelf. The glaciers which affected the southwest Greenland shelf advanced over much thinner shelves into much deeper water.

To the north of Nugssuaq peninsula the Umanak fjord forms a northeast trending longitudinal trough and a smooth shelf area is found off Svartenhuk peninsula. North of Svartenhuk a longitudinal trough similar to the one south of Disko falls at the contact of Precambrian and volcanics and may again form the faulted eastern margin of the Cretaceous-Tertiary basin. North of the outcrop of volcanics established by magnetic mapping, marginal channels can be seen on the bathymetric chart. The Precambrian outcropping on land, the channel and the smooth outer banks in Melville Bay may bear evidence of the "true" marginal channels of Holtedahl and Grant. The faulted eastern margin of the basalt province and the marginal channels to the north appear continuous and the evidence points to a primary tectonic origin. Rift zones of Lower Paleozoic age produced similar trending faults on Baffin Island (Fahrig et al., 1971). As well, the development of the Labrador Sea rift zone and the proposed Baffin Bay rift zone are presumably related to normal tension faulting at the margins of these bodies of water. Normal faulting has played a prominent role in the development of the West Greenland basin.

The longitudinal troughs defining the eastern margins of the basalt province are expressions of normal faults and may be classified as marginal channels of tectonic origin. The continuity of the channels which extend north into Melville Bay and the tectonically formed marginal channels of the basalt province is significant.

4.13 Offshore Hydrocarbon Potential

As mentioned previously, the sedimentary facies of the Cretaceous-Tertiary basin have demonstrated a potential for both production and accumulation of hydrocarbons. Areas which would be of prime interest for offshore exploration are those in which the thickness of basalt cover over Cretaceous-Tertiary sediments is minimal, and the sediments are of considerable thickness. In addition, seaward dipping lavas which have been affected by block faulting, with subsequent repetition of the lava sequences, must be considered as favorable locations for stratigraphic traps.

The northwest coast of Nugssuaq, west of the Itivdle valley, fulfills these characteristics (Fig. 45). Precambrian rocks are not exposed west of the Itivdle fault nor is the base of the sediments seen.

Simplified Geological Map - Nugssuaq Peninsula

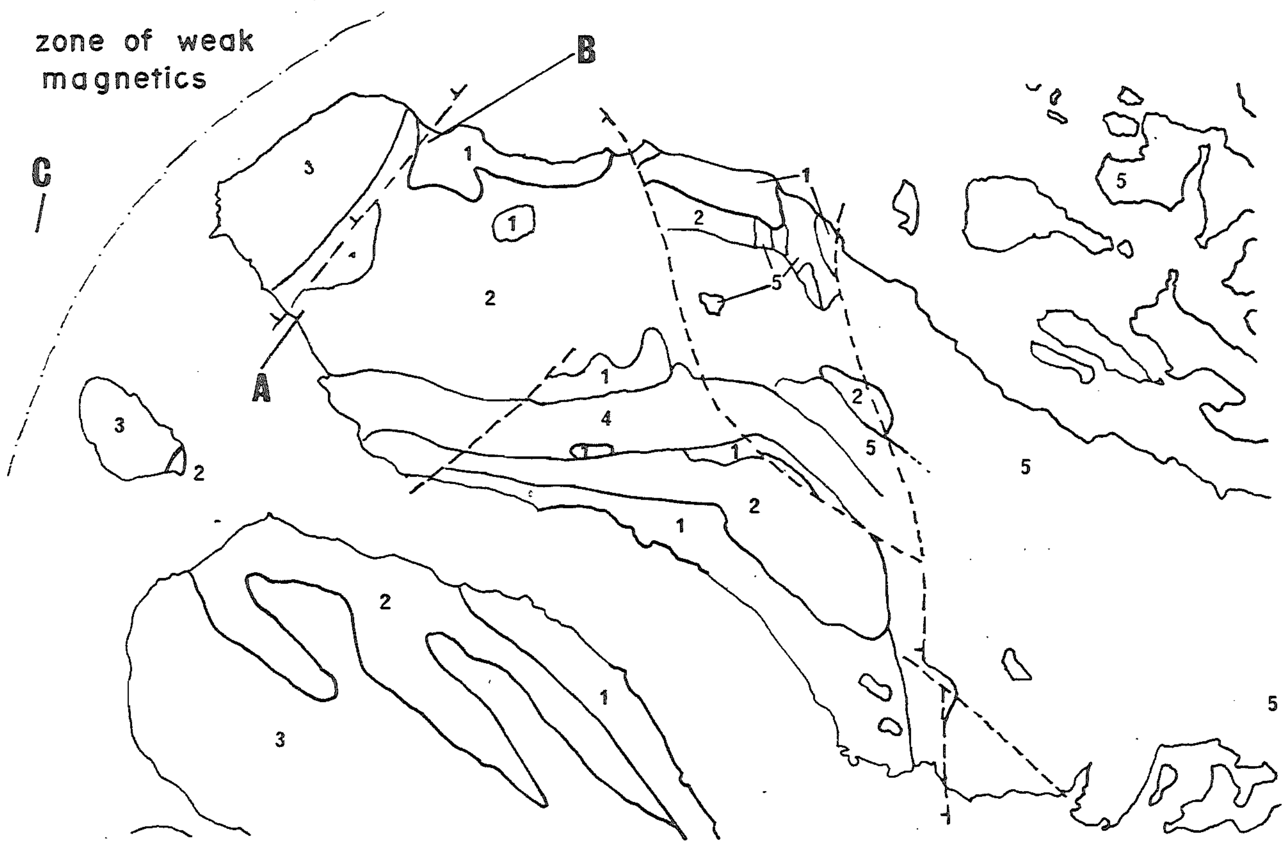


FIG. 45

1 Cretaceous - Tertiary Sediments
2 Olivine basalts
3 Feldspar-phyric basalts
4 Quaternary deposits
5 Precambrian

Sediment-Thickness Determinations

A	1.5 km	G. Henderson pers. comm.
B	2.2 km	G. Henderson pers. comm.
C	4 km	CSS Dawson 1970

Sediment thicknesses where the fault strikes the north and south coasts have been determined by gravity surveys (Henderson, pers. comm.) to be 1.5 km and 2.2 km respectively. Block faulting has been demonstrated (Chapter 2) in the geological descriptions, and finally, the dip of volcanics decreases from the Itivdle fault to the coast.

Magnetic profiling by C.S.S. DAWSON offshore to the west of the peninsula has delineated a zone of weak magnetic characteristics. The zone corresponds to the westward extension of the deep Umanak fjord and it is proposed that the basalts are either very thin or entirely absent. They may either have been eroded away or else their absence is a local phenomenon due to distance from a volcanic center.

A depth determination by the method of Vacquier et al. (1951), on an anomaly in this zone, has yielded a maximum depth (from both limbs) to an assumed Precambrian basement of approximately 4 km. The lack of other profiles in the area and the lack of knowledge of the strike of the underlying gneisses, decreases greatly the validity of this calculation. However an increased seaward thickness of sediments is possible if the Melville Bay graben, with its great thickness of sediments has extended this far south. In addition it was proposed in Chapter 2 that sediments of Mesozoic or even Palaeozoic age may underlie the Cretaceous-Tertiary sediments.

The evidence for the existence of a thick sedimentary sequence is indeed scanty, but could be proved or disproved by seismic, magnetic, and gravity profiling in the zone of weak anomalies defined by this survey. In addition, the correlation between sediments in this area and the sediments in the Melville Bay graben should be investigated.

4.14 Offshore Extent and Structure of the Davis Strait Volcanics

It was originally hoped that the volcanics which were thought to exist offshore from the West Greenland volcanics could be traced to join up with the volcanics of the Cape Dyer region. Such an hypothesis was first suggested by Clarke (1968). If this hypothesis is true then the ages of the two provinces are the same and hence an upper limit may be placed on the time of spreading in the Davis Strait. Such a limit could then be applied to the time of opening of the Labrador Sea.

The evidence presented in this survey does not support or disprove such a hypothesis. Seismic reflection profiles, magnetic profiles, magnetic models and depth determinations show however that the basalts dip to the west beneath a more recent sedimentary basin. One seismic profile shows either a syncline or at least a downwarping of the basalt upper surface to produce an apparent eastward dip to the volcanics. Such a feature may indicate proximity to a fault near the western edge of the province. Such structures have been observed on Disko Island and Nugssuaq. Evidence has been given that the volcanics appear to belong to the same volcanic sequence as the upper part of the lava series on Disko Island. The predominantly shallow westward dip of the volcanics appears to be preserved in the offshore sequence. The subaerial nature of the dredged samples indicates that subsidence has taken place at least relative to the sequence on land. This subsidence which is of the order of 1 km has caused the westward dip to both the onshore and offshore series as well as the prominent repetitive faulting which gives anomalous thicknesses to the series. Block faulting has been demonstrated for the subaerial volcanics onshore and the typical dip and scarp topography may be the reflection of such faults in the offshore sequence.

The West Greenland basin has been fault bounded since the commencement of sedimentation and up to 1 km of downthrow on the western block has been suggested for several locations (Rosenkrantz and Pulvertaft, 1969). Easterly extended magnetic profiles for the purpose of selecting dredge stations have demonstrated that the basalts do not extend any farther east than the large N-S longitudinal trough south of Disko Island. It has been proposed that the contact with Precambrian gneisses at least for the area 68^{o} 40'N to the southernmost limit follows this trough which may be an extension of the faulted eastern margin of Cretaceous-Tertiary sedimentation. The constant thickness of flows from north to south on Disko Island suggests that volcanics may have extended even south of Disko Bay to overlie the Precambrian gneisses in the Egedesminde area. On the south coast of Disko Island the feldspar-phyric basalts directly overlie the Precambrian and a similar contact relation exists for the offshore sequence. The southern and southwestern margins of the province follow no significant morphologic structures. No evidence has been found for the proposed Davis Strait transform fault suggested by Le Pichon et al. (1971). If such a structure exists it has been buried by more recent sediments whose upper surface has been shaped by more recent glaciation.

The bathymetric and magnetic profile northward from Disko Island shows a termination of magnetic anomalies characteristic of basalts at 73^{o} 15'N 57^{o}W. However a prominent longitudinal trough exists several kilometres to the east and it is proposed that, as was the case south of Disko Island, this trough marks the extension of the eastern faulted margin of the West Greenland basin. Profiles reported in Keen et al. (1970) have allowed for the extension of the volcanic province as far as 59^{o}W. The recognition of volcanics 100 km to the north of the most northerly occurrence of volcanics on land suggests that volcanics may have once overlain Precambrian granites and gneisses of the Upernavik region. The northern boundary is marked by an eastward trending bathymetric high.

In addition an absence of volcanics in the westward extension of Umanak Fjord has been noted. It is proposed that volcanics once outcropped in the area but have since been eroded away perhaps exposing underlying Cretaceous-Tertiary or older sediments up to 4 km in thickness overlying Precambrian gneisses. However G. Henderson (pers. comm.) has noted the possibility that the lack of volcanics may only be a local phenomenon and may not extend as far up Umanak Fjord as is shown by Fig. 48.

Bathymetric.seismic and magnetic profiles have allowed us to map the eastern contact of volcanics and Precambrian rocks and have suggested that the structural processes which affected the sequence on land have affected the offshore province.

The seismic profiles have shown the westernmost outcrop of volcanics but have also shown that they continue to the west beneath coastal-plain type sediments. Magnetic profiles showing a degree of correlation have shown the continuity of volcanic units over many kilometres even under the more recent sediments and reflect increased depth to volcanic basement.

The cumulative results of this survey are shown in Figs. 46, 47, 48.

Geological Map of the Central West Greenland Shelf

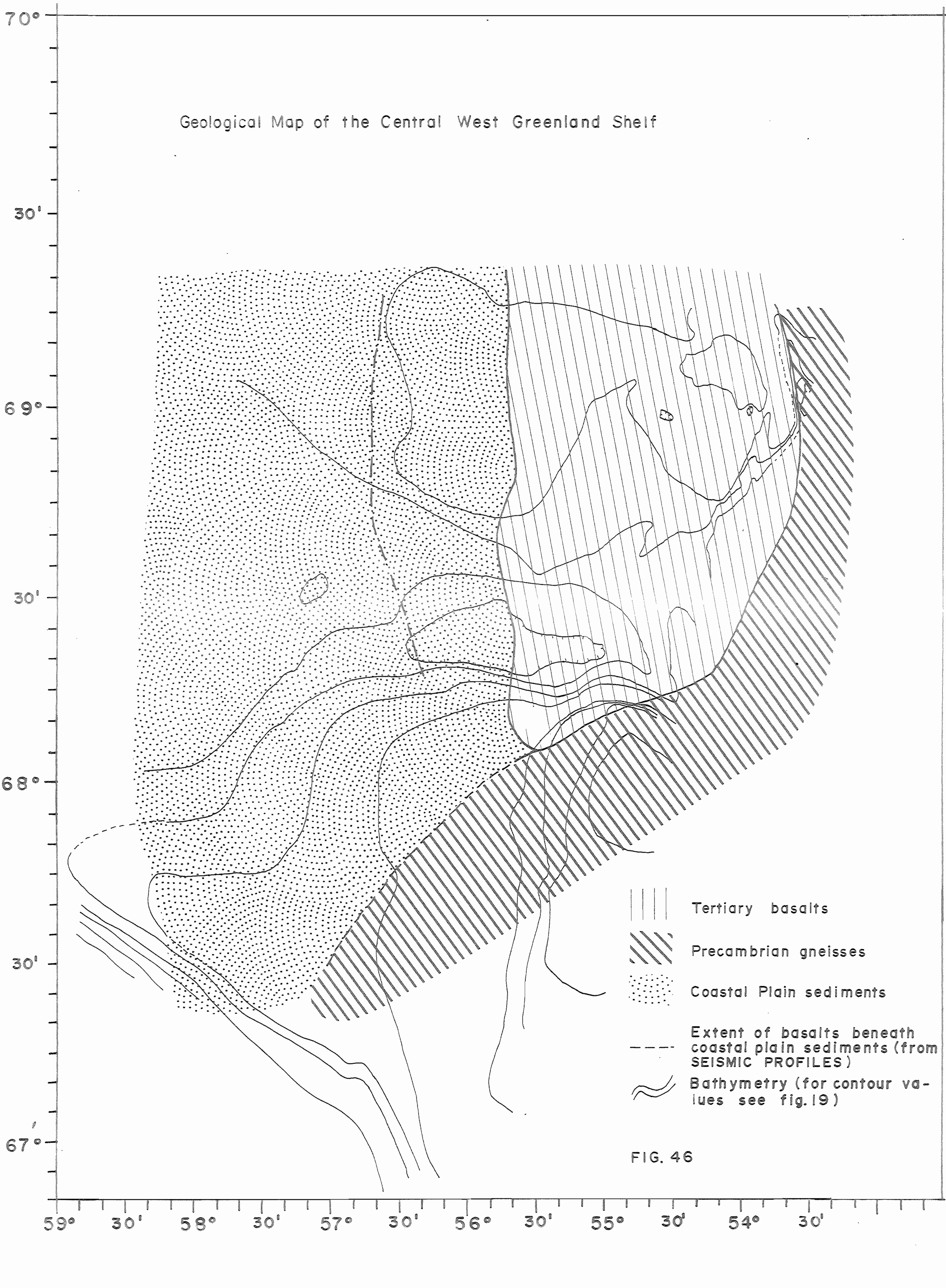


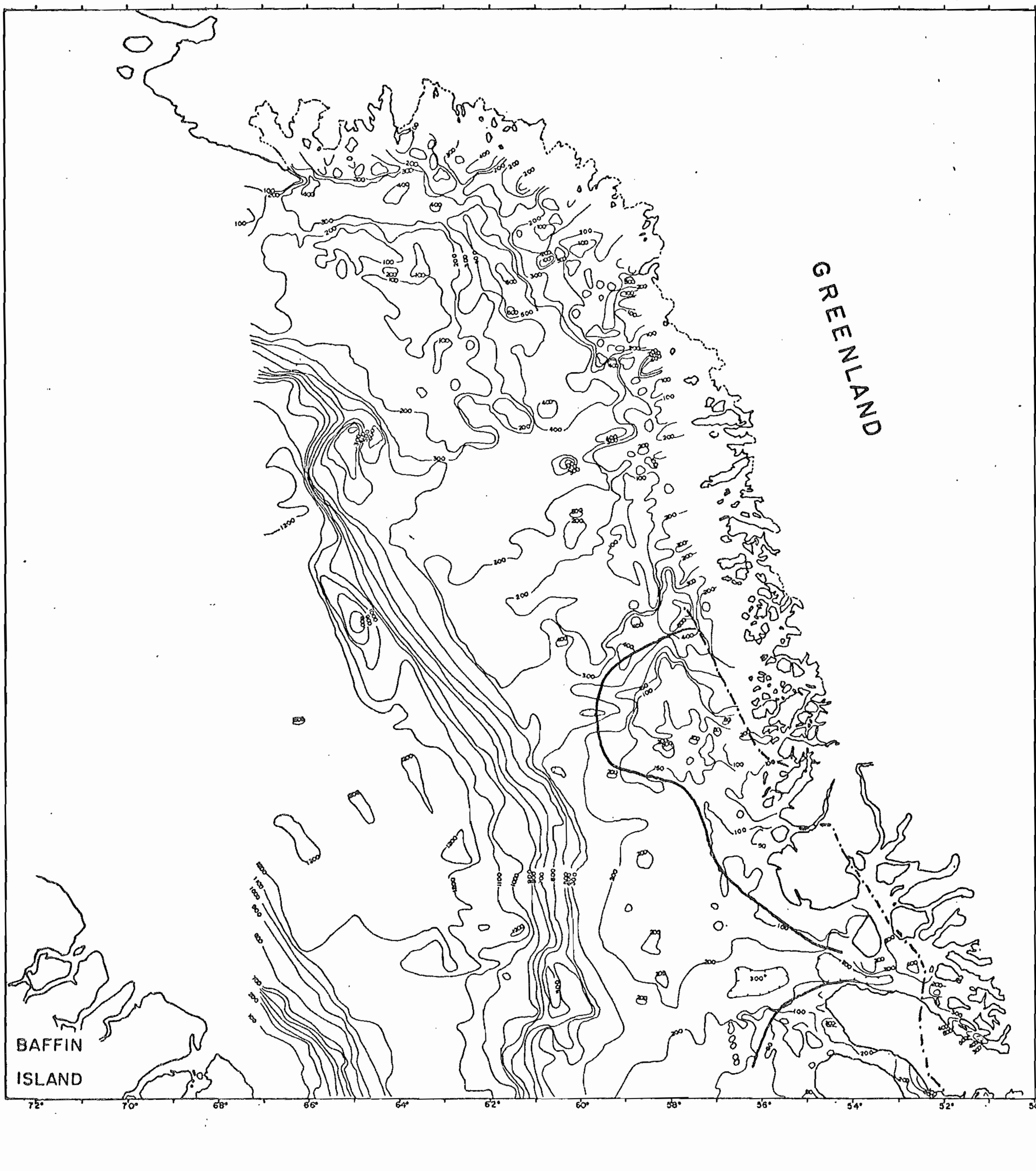
FIG. 46

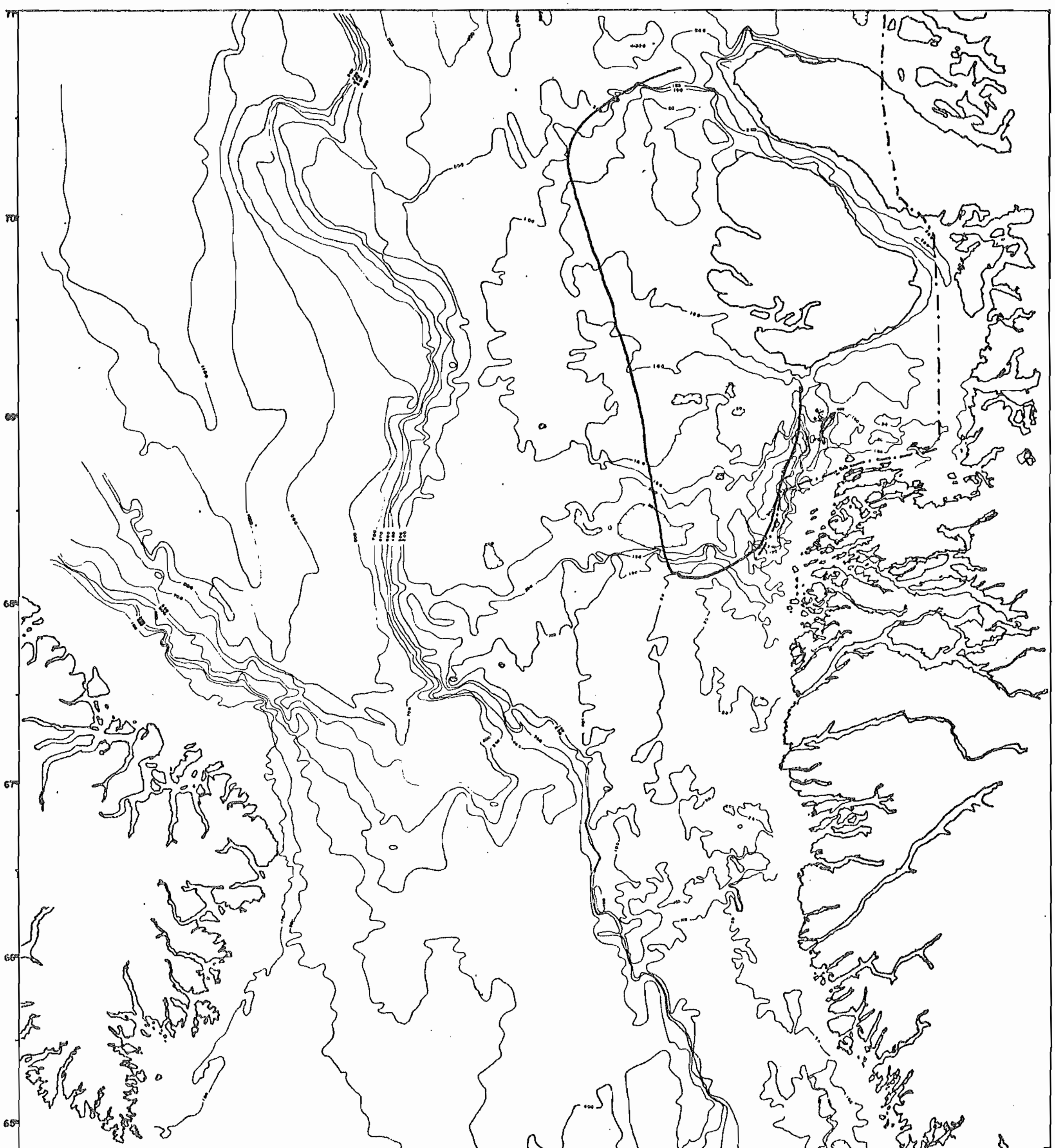
Figures 47 and 48

Offshore Extent of the West Greenland Volcanic Province

—·—·— Eastern Faulted Margin

(Bathymetry in fathoms)


GREENLAND
BAFFIN
ISLAND
72°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
76°
75°
74°
73°
72°
71°
70°


71°
70°
69°
68°
67°
66°
65°
64°
65°
64°
63°
62°
61°
60°
59°
58°
57°
56°
55°
54°
53°
52°
51°
50°

Chapter 5 Application to the Geological Development of the Baffin Bay Region

5.1 Summary

Geological studies and geophysical surveying in Davis Strait permit the following conclusions:

1) The volcanics of the West Greenland basin continue offshore for many tens of kilometres and 100 km. farther north than their most northerly occurrence on land.
2) The volcanics in the Disko survey area dip about 15 to the west, are overlain on their western margin by younger sediments, and overlie Precambrian gneisses on the south and east. The southwestern Precambrian contact is coincident with a N-S topographic depression which may be a seaward continuation of the faulted margin of Cretaceous-Tertiary sedimentation. A similar faulted margin may exist north of Upernavik in the form of a N-S longitudinal trough, which may join up with the faulted eastern margin of the Melville Bay graben. These boundary faults offshore are marginal channels of tectonic origin.
3) Chemical analyses of samples dredged from the

Disko survey area indicate that the offshore volcanics are similar to the least evolved feldspar-phyric volcanics on land. Samples from the northernmost dredge station exhibit more highly evolved characteristics than any previously reported analyses.

4) The region northwest of Nugssuaq Peninsula may be of interest from a petroleum standpoint, since the thickness of sediments overlying Precambrian gneisses may be up to 4 km.

The geological and geophysical reviews in Chapters 2 and 3 have provided a framework within which the results of this survey may be added to produce a new model for continental drift in the Davis Strait-Baffin Bay area.

5.2 Geological Development of Baffin Bay Region

The tectonic regime in the Late Proterozoic appears to have had a profound effect on the features observed today in Baffin Bay. Fahrig et al. (1971) have recently suggested that a Hadrynian rift zone, with accompanying tensional features may have existed in Davis Strait in the very late Precambrian. Their conclusions stem from the observation on Baffin

Island of northwest trending diabase dike swarms, indicating crustal tension, and a sub-parallel northwest trending fault system which has resulted in the development of a series of grabens. Trettin (1969) previously suggested that in northwestern Baffin Island, one fault zone was a hinge line during Helikian sedimentation, and along this zone prior to Lower Palaeozoic sedimentation, the Hudsonian basement gneisses were elevated to the level of the Helikian strata. Fahrig et al. (1971) argue that the Helikian sedimentation may be Hadrynian in age so that formation of the dike swarms, faults, and grabens may be concordant and due to the same regional tension. The graben-like features of Frobisher Bay and Cumberland Sound (Manchester, 1964) follow the northwest trends. A half graben structure has recently been described by Grant and Manchester (1971) for Hudson Strait. Though they are cautious in classifying the bedrock as Palaeozoic or Proterozoic in origin, this half graben structure may also have been formed during the Hadrynian rift. Poulsen (1966) has noted the occurrence of Lower Palaeozoic sediments in a northwest trending fault-bounded area near Sukkertoppen, Southwest Greenland. This occurrence has important implications concerning the possible age of the sediments in the Melville Bay graben.

If we now shift our attention to the Baffin Bay region, the Melville Bay graben has a similar orientation and is composed of folded and normally faulted sediments (Johnson, 1971) up to 7 km in thickness (Hood and Bower, 1970).

The age of the oldest sediments in the Melville Bay graben has not been established. However, in Chapter 3 it was suggested that there may be sediments underlying the oldest marine sediments in the West Greenland Basin. The maximum thickness of these marine sediments is 2 km, considerably less than the thickness of sediments in the Melville Bay graben. One might infer that the Lower Palaeozoic sediments may possibly exist at the base of the Melville Bay graben. It is also interesting to note that the Melville Bay graben structure is reflected by faulting in the Thule-Dundas area of Northwest Greenland. The area has been described by Davies et al. (1963), who note numerous northwest trending normal faults, (one with a displacement of 2 km) which downfault younger Eocambrian rocks onto older Precambrian gneisses.

Though there is little evidence for faulting in the Precambrian of Disko Island, Henderson (1971) notes that the N-S trending structural high may be an old horst, and one may speculate that it may also have formed during the Hadrynian rift.

In addition to this major graben in Melville Bay, the present oceanic portion of Baffin Bay is bounded on the west and east by normal faults which may have first been active during the Hadrynian rift zone previously described. In this case, Palaeozoic sediments were also deposited in this proposed Baffin "graben", but are now disposed at the continental margins of Baffin Bay.

Evidence exists then, for a major tensional regime without sea floor spreading in the Upper Proterozoic-Lower Palaeozoic, which formed northwest trending dike swarms, faults, and grabens from Northern Baffin Island, and Baffin Bay as far south as Sukkertoppen, southwest Greenland. These features are illustrated on Fig. 49, a pre-drift reconstruction based on the elimination of the 400 km of oceanic crust in Baffin Bay, and matching of the top of the continental slopes off southwest Greenland and Labrador.

Figure 49

Structures formed during
the Hadrynian rift (675 my)

Diabase dikes

Faults

Grabens

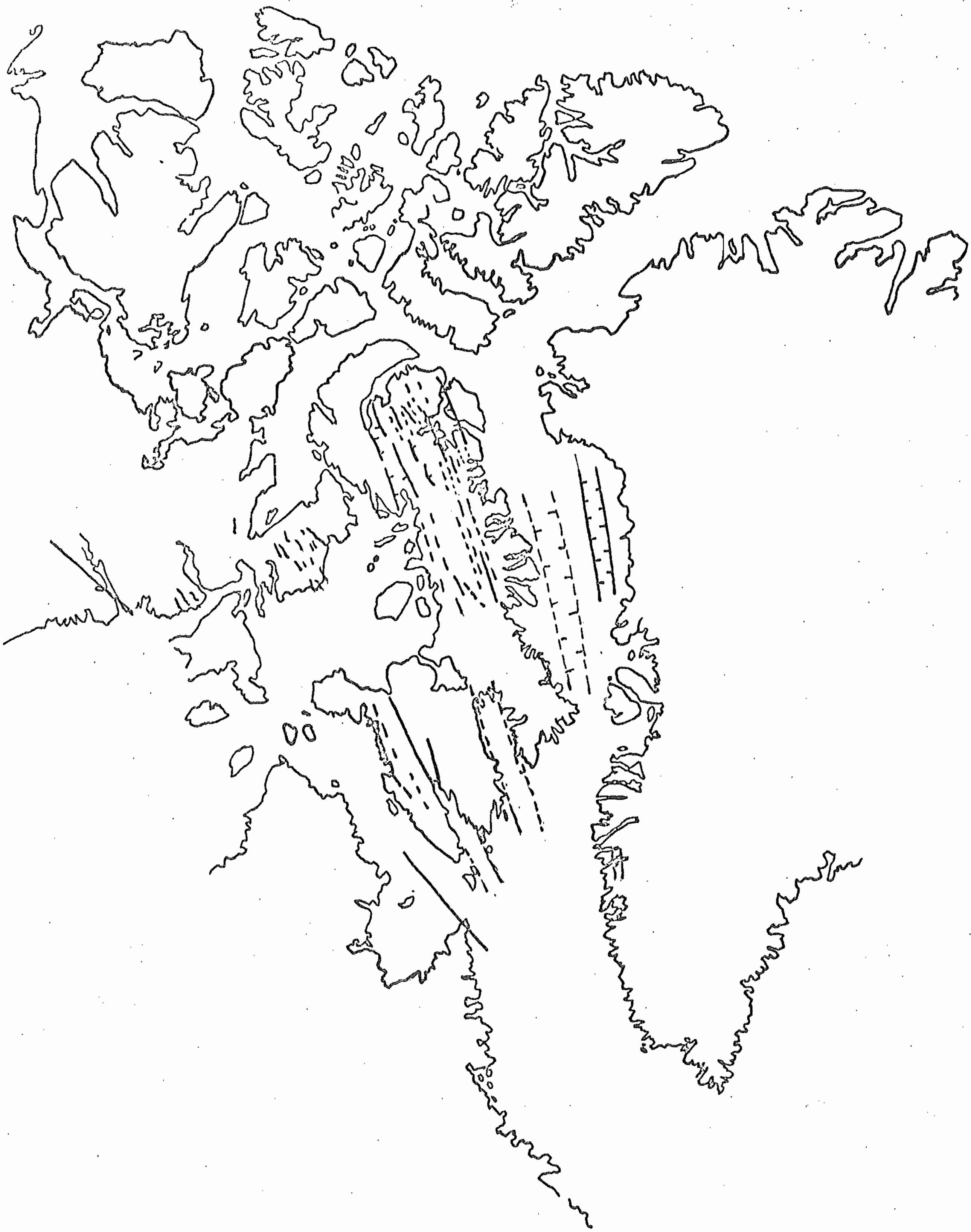


Figure 49

It is curious that no geological formations or structures directly surrounding Baffin Bay and the Labrador Sea can be found for the period from Lower Paleozoic at least until the Jurassic, but the great thickness of sediments in the Melville Bay graben may be indicative of a relatively undisturbed marine and/or non-marine sedimentary regime which continuously deposited sediments in the northwest trending Hadrynian features. Other evidence for this continuous sedimentary regime arises by comparison with other areas in the Arctic Archipelago. Lower Palaeozoic rocks have been identified in the northwest trending grabens of Baffin Island and an Ordovician sequence has been discovered in the fault-bounded area in Southwest Greenland (Poulsen, 1966). The Franklinian geosyncline was the site of uninterrupted deposition from Cambrian to Upper Devonian. Northwest of the Franklinian geosyncline, the Sverdrup Basin was the site of heavy sedimentation in a gradually subsiding depression from mid-Pennsylvanian until the early Tertiary (Thorsteinnson and Tozer, 1960). A marine connection between the Sverdrup basin and the West Greenland basin is suggested by Jeletzky (1971). However, there is no reason to disbelieve the suggestion that earlier seas did not reach into proto-Baffin Bay, north of the West Greenland basin. This latter area was apparently unique for it must have been initially at a higher elevation than regions north and south (see later) and deposition only commenced when it began to subside. Present day regions of Baffin Bay and Davis Strait thus appear to have been part of a stable cratonic block for some 500 my.

Renewed tensional activity in the Labrador Sea area was signalled by the swarm of Jurassic dikes intruded parallel to the coast, many along much older faults, in southwest Greenland (Watt, 1969). The tensional activity spread to the north to reactivate faults defining the Baffin Bay graben, and at least before sedimentation began in the West Greenland basin the boundary fault system was formed. It is likely that the area at the southern end of present day Baffin Bay was initially at a relatively higher elevation than the area between Labrador and southwest Greenland. Faunal evidence suggests that there was no link between the shallow seas which occupied Baffin Bay from the Cenomanian, and the proto-Atlantic, until the end of the Cretaceous. The initial movement in the West Greenland basin must have been a gentle subsidence in the early Cretaceous.

The first sediments to be deposited in the West Greenland basin,were non-marine, of Barremian-Aptian age (120-110 my) and are found on the north coast of Nugssuaq peninsula west of the Itivdle fault. Other younger fluvial and lacustrine deposits occur on the south coast of Nugssuaq, and include the entire sedimentary sequence on Disko Island. The sedimentary sequence on Baffin Island has been ascribed to the Paleocene (65-58 my) (Clarke and Upton, 1971). Deposition took place on the deeply dissected and weathered Precambrian surface and consisted of mainly arkosic sandstones derived from the Precambrian gneisses. Coarse conglomerates were formed in several places at the base of the boundary fault scarps. Pauses in the sedimentation allowed the accumulation of plant debris which gave rise to the coal layers in the non-marine strata of Baffin Island and West Greenland. Continued subsidence eventually allowed the influx of water from the north, and marine transgressions covered the northwestern part of the basin from the Late Turonian until the Paleocene. Limnic sedimentation continued at the margins of the sea. The shallow sea which covered this area (Rosenkrantz and Pulvertaft, 1969) was probably connected to the sea covering most of the Canadian Arctic Archipelago and possibly central North America. The fauna of this time period have affinities only with the fauna of these latter two areas and provide evidence that this sea, until at least late Cretaceous, was not connected to the shallow proto-Atlantic which existed between Labrador and Greenland to the south.

The dominant lithologic type of the marine Cretaceous (and also of the early Tertiary) is dark bituminous shale with pyritiferous, clay-ironstone concretions (Rosenkrantz and Pulvertaft, 1969) and occasional intercalated sandstones at the south-eastern margins of the sea. The organic rich nature of these marine sediments are indicative of the restricted nature of the water circulation in this shallow sea during Late Cretaceous and early Tertiary. A much similar situation existed for the now widening proto-Atlantic which must have extended up to the southern portion of Davis Strait (Schneider, 1969).

The presence of a restricted basin in between northern Baffin Island and West Greenland in the Late Cretaceous-Tertiary has important implications for petroleum exploration in Baffin Bay. It would be reasonable to suggest that similar organic-rich marine sediments were also deposited during the Cretaceous in the Melville Bay graben and in the still intact Baffin Bay graben. The change in West Greenland from the Senonian fauna of predominantly North American affinities to the overwhelmingly European Danian fauna suggests that an important event took place at the end of the Cretaceous which greatly improved the access by sea to the proto-Atlantic (Rosenkrantz and Pulvertaft, 1969).

In the late-Cretaceous and very early Tertiary a substantial elevation of the Davis Strait area took place and the marine deposits were deeply eroded. The uplift may have been due to a thermal expansion prior to volcanic activity. Fahrig et al. (1971) have noted the presence of a secondary magnetisation in Hadrynian age diabase dikes on Baffin Island near Davis Strait, which they suggest may have been acquired by mild reheating during the early Tertiary rifting of Baffin Bay.

During renewed subsidence in the Davis Strait region, in the early Paleocene, the first eruption of volcanic material in the form of subaqueous breccias occurred near the western side of the Baffin Bay graben. Marine sedimentation continued on the West Greenland side of the rift valley now, with occasional intercalated tuff layers probably derived from the activity on the Baffin Island side. Shortly after this initial volcanic activity, volcanism affected the northwestern portion of the West Greenland basin and both Baffin Island and Greenland experienced voluminous outpourings of breccias and later subaerial olivine basalts which displaced the shallow sea and halted further marine sedimentation in West Greenland (Clarke, 1968). The age of this activity can be determined from the age of the oldest marine sediments which Rosenkrantz and Pulvertaft have shown to be Danian.

Tensional stresses along the normal faults and subsidence continued throughout the early Tertiary. Finally, the continental crust was severed along one of the former sets of normal faults of the Baffin Bay rift valley to the southwest of the principal volcanic activity. New oceanic crust began to form and the source of the Baffin Island volcanics was carried away on the Greenland plate, as suggested by the geochemistry of the lavas. The igneous activity was apparently sufficient to fill the tension cracks produced by the drifting apart and the diabase dikes and sills were intruded along or near the boundary fault zone. The Tertiary diabase dikes to the east and south may have been intruded at this time. Volcanism continued in the east, and the West Greenland lava field was greatly extended by the eruption of the feldspar-phyric basalts (Clarke, 1968). Feldspar-phyric lavas fanned out to rest directly on the Precambrian basement on Disko Island, and to overlie Precambrian basement to the west. The lavas may also have once overlain the Precambrian gneisses of the Egedesminde area and overlapped the fault which now delimits the western extent of the recently mapped volcanics and Precambrian gneisses, southwest of Egedesminde. Later Pleistocene glaciation has removed all traces of volcanics on land, and they are not found east of the fault. The volcanic sequence in the north was preceded by a brief period of sedimentation before activity resumed. The feldspar-phyric lavas in the north flowed out to occupy the southern extension of the Melville Bay graben. The large volume of lava caused the volcanics to overlap the western margin of the graben but such an overlap did not occur at the eastern faulted margin. The same situation may exist in this area as was the case for the feldspar-phyric volcanics south of Disko Island. The volcanics may previously have existed to the east of the faulted margin but have since been eroded away. On Svartenhuk as on Nugssuaq these later volcanics have spilled over the fault zones.

On the basis of the present height of marine sedimentary rocks and pillow lavas on Nugssuaq and Svartenhuk a net uplift of approximately 1000 m has taken place since the Paleocene (Rosenkrantz and Pulvertaft, 1969). A post-volcanic uplift of 400-500 m has been noted for the Baffin Island volcanics (Clarke and Upton, 1971). Coastal plain sediments now cover the western margin of the offshore province. The great thickness of sediments now occupying central Baffin Bay (Johnson, 1971), the presence of oceanic crust and lack of a visible central ridge (on seismic evidence) suggests that subsidence may be continuing at present in Baffin Bay and Davis Strait.

The final process (exclusive of possible subsidence) to affect the West Greenland area, to produce the present day outcrop pattern was glaciation in the Pleistocene. The westward path of the glaciers or the ice sheet scoured out the volcanics in the westward extension of Umanak fjord, removed volcanics overlying Precambrian gneisses in the Egedesminde area and in the region north of Upernavik, and formed the NE-SW trending trough southwest of Disko Island.

Tilting and Warping of the Basalts

Rosenkrantz and Pulvertaft (1969) have determined that, wherever the eastern limit of the Cretaceous sedimentary basin is exposed, there is a fault, and that fault movements took place intermittently during the Cretaceous and early Tertiary. Sedimentation has generally kept pace with these fault movements. However, late stage faulting has affected the basalts causing areas of warping and tilting, while the Cretaceous-Tertiary strata have low angle dips throughout the area. Subsidence in the later stages of volcanic activity due to both depletion of the offshore magma sources and the weight of the lava pile has also contributed to these movements.

A gentle syncline trending north-northeast occurs in western Nugssuaq and Hareoen (Henderson, 1971), but the basalts are also down faulted and tilted west of the Itivdle fault. This down faulting has been accompanied by the development of a system of antithetic faults which has repeated many parts of the sequence. A northwest trending flexure occurs in northeastern Svartenhuk where dips are horizontal to the east of the boundary fault and change from 12^{o} W to shallow northeast dips near the coast. The axis of downwarping on Disko trends NE-SW across the northwest end of the Island.

Seismic profiling and the bathymetry in the southern part of the survey area shows that the offshore basalts are tilted 15^{o} to the west and have been affected by parallel and normal faulting. In the northern part of the survey area, lack of distinctive topography and magnetic profiling suggests that the basalt flows may be flat-lying (as on Southern Disko Island). The proposed eastern faulted contact may have acted as a hinge line to produce the structures in the southern end of the offshore province.

This new model for spreading in Baffin Bay-Davis Strait based mainly on geological observations in the Davis Strait area agrees fairly well with the two phases of opening suggested by Laughton (in press) and Le Pichon et al. (in press).

The first phase of opening (82-60 my) about a pole near Axel Heiberg Island was due to a splitting of the European plate from the North American plate by rotation. The second phase of opening (60-47 my) caused strong Tertiary compression of the Franklinian geosyncline and Sverdrup Basin (Christie, 1962; and Fortier et al., 1963), and further rotation of Ellesmere Island. Movement was essentially taken up by a strike-slip displacement along Nares Strait and produced the 400 km of oceanic crust in Baffin Bay.

However it is difficult to reconcile a rotation of Greenland away from North America during the 22 my of the first phase of opening without any production of volcanics in the Davis Strait area and no Cretaceous deformations in the Sverdrup basin. The volcanism which produced the Tertiary basalt province was entirely restricted to the second phase of opening. Thus the suggested age of the initial break, 82 my, is too old for the Baffin Bay region.

5.3 Comparison with Other Areas

It is sometimes useful to compare tectonic and structural histories of different areas which appear to have undergone a similar evolutionary process. Though there are many differences in geological development a structural parallelism exists between West Greenland and Southeast Greenland. The only visible difference is that a regular dike swarm appears to have been the feeder for the East Greenland sequence. However it is not unreasonable to suggest that dike swarms related to the offshore volcanic centers of the West Greenland basin may have also been the source for the volcanics in that province.

Haller (1969) has given an adequate description of the geological development of the areas north and south of Scoresby Sound and the comparison is striking. Faulting in a direction parallel to the coast began in Lower Palaeozoic and produced a series of grabens in which a thick sequence of sediments was deposited. The faulting persisted into the Mesozoic and is connected to the formation of the North Atlantic which may have begun as early as Jurassic. Towards the end of the Mesozoic a shallow sea existed on the East Greenland shelf. Near the end of the Mesozoic this shelf was gradually broken into a pattern of normally faulted blocks. To the south of Scoresby Sound, a thick succession of Paleocene basalts covers the Mesozoic sedimentary facies. Except for a few flows the entire sequence is subaerial. In the plateau the thickness of the volcanics reaches 7 km. The building of this plateau was apparently accompanied by a gentle subsidence so that the level of extrusion was never much above sea level. Part of the plateau became submerged near the end of the extrusive phase. Later a large portion of the plateau inland experienced epeirogenic uplift with a simultaneous sinking of the area to the southwest on the shelf.

Both areas, the West Greenland basin and the Scoresby Sound plateau volcanics appear to have undergone what might be described as developments due to tensional tectonics associated with the formation of an oceanic ridge.

Brock (1971) notes that rift-type faulting in the East African system has persisted since at least Permo-Triassic times and possibly much longer without any detectable spreading. In southwest Tanzania and neighbouring Malawi the floors of the rifts are Precambrian gneisses with or without a cover of Permo-Triassic, Cretaceous and Tertiary or recent sediments. A similar situation exists for the grabens of Baffin Island and Melville Bay where it appears as if continental rifting which began as early as Late Proterozoic has taken place without sea floor spreading. The Baffin Bay graben developed initially at the same time and in the same manner as the Baffin Island and Melville Bay features but became the site of sea floor spreading in the Tertiary.

5.4 Proposals for Further Work

Perhaps the main weakness of this study is the lack of documentation concerning the extent of the basalts to the west, where they disappear beneath the cover of coastal plain sediments. The model in this chapter implies that there is a fault or faults to the west and that oceanic crust exists in the deeper portions of Davis Strait. The former will be difficult to prove (though it is suggested by depth determinations) due to the acoustic nature of the basalts which may overlap the fault and the fact that the fault may be deeply buried under recent sediments. Two refraction lines, one on the shelf and one in deeper water west of Disko Island should demonstrate the change from continental to oceanic crust. In place of this sort of survey, seismic profiling in the deeper water of Davis Strait and several continuous magnetic profiles oriented NE-SW between Disko Island and Cape Dyer would be helpful. A geological and geophysical survey similar to the one described in this thesis should be undertaken to determine the offshore extent, structure and nature of the Baffin Island Tertiary basalts.

Another area of interest is the proposed sedimentary region northwest of Nugssuaq Peninsula. Seismic profiling would aid in, first, demonstrating the existence of sediments and, secondly, attempting to show a relation between these sediments and the sediments of the Melville Bay graben, at least in thickness. The presence of potential source rocks in the West Greenland basin and their offshore extension is obviously attractive to the petroleum industry. Both the scientific community and industry could benefit from profiles of at least a reconnaissance nature.

Finally, several geological problems should be investigated. Firstly, are the long diabase dikes in the Precambrian to the east of Disko Island, Tertiary in age or were they intruded in the Jurassic at the same time as the dikes of southwest Greenland? Secondly, what structural evidence is there in the gneisses to explain the obvious fact that the area of Davis Strait was initially at a higher elevation than areas to the north and south, before commencement of sedimentation in the West Greenland basin?

Marine geophysical investigations should also be made to prove the existence of the proposed Baffin Bay graben in the area of Davis Strait and north into Baffin Bay.

References

Ade-Hall, J.M., 1964. The magnetic properties of some submarine oceanic lavas. Geophys. J., 9, 85-92.

Ade-Hall, J.M., Palmer, H.C., and Hubbard, T.P., (in press). The magnetic and opaque petrological response of Basalts to regional Hydrothermal alteration. Geoph. J.R. Astr. Soc.

Barrett, D.L., 1966. Lancaster Sound Shipborne Magnetometer Survey. Can. J. Earth Sci., 3, 223-236.

Barrett, D.L., Keen, C.E., Manchester, K.S., and Ross, D.I., 1971. The Central Part of Baffin Bay is Oceanic. Nature, 229, 551-552.

Berthelsen, A., 1961. On the Chronology of the Precambrian of Western Greenland. Raasch, G.O. (edit.) Geology of the Arctic, Vol. 1, 329-338, University of Toronto Press.

Blackadar, R.G., and Fraser, J.A., 1960. Precambrian Geology of Arctic Canada. A summary account. Geol. Surv. Can. Paper 60-8.

Bridgwater, D., 1967. Feldspathic Inclusions in the Gardar Igneous rocks of south Greenland and their Relevance to the formation of major

Anorthosites in the Canadian Shield. Can. J. Earth Sci., 4, 995-1014.

Bridgwater, D., Escher, A., Jackson, G.D., Taylor, F.C., and Windley, B.F., (in press). The Development of the Precambrian Shield in West Greenland, Labrador and Baffin Island. Am. Assoc. Petrol. Geol. Symposium on Arctic Geology, San Francisco, 1971.

Brock, P.W.G., 1971. The Age of the East African Rift System and its Implications for Plate Tectonics. Abst. Geol. Assoc. Can. Meeting, Sudbury.

Bullard, E.C., and Mason, R.G., 1961. The magnetic field astern of a ship. Deep-Sea Research, 8, 20-27.

Christie, R.L., 1962. Northeastern Ellesmere Island, District of Franklin. Geol. Surv. Can. Prof. Paper, 62-10.

Clarke, D.B., 1965 (unpub.). A Petrographic and Field Study of the Tertiary Padloping Lavas of Baffin Island. M.A. Thesis, University of Toronto.

Clarke, D.B., 1968. The Basalts of Svartenhuk Peninsula. A Progress Report. Greenland Geological Survey. Rept. 15, 15-17.

Clarke, D.B., 1968 (unpub.). Tertiary Basalts of the Baffin Bay Area. Ph.D. Thesis, Edinburgh University.

Clarke, D.B., 1970. Tertiary Basalts of Baffin Bay: Possible Primary Magma from the Mantle. Contr. Mineral. and Petrol., 25, 203-224.

Clarke, D.B., and Upton, B.G.J., 1971. Tertiary Basalts of Baffin Island. Field Relations and Tectonic Setting. Can. J. Earth Sci., 8, No. 2, 248-258.

Clarke, D.B., and Pedersen, A.K., (in preparation). The Tertiary Volcanic Province of West Greenland in the Geology of Greenland.

Doig, R., 1970. An alkaline rock province linking Europe and North America. Can. J. Earth Sci., 7, No. 1, 22-28.

Drake, C.L., Campbell, N.J., Sander, G., and Nafe, J.E., 1963. A Mid-Labrador Sea Ridge. Nature 200, 1085-1086.

Drever, H.I., 1958. Geological Results of Four Expeditions to Ubekendt Ejland, West Greenland. Arctic, 11, 199-210.

Ellitsgaard-Rasmussen, K., 1954. On the Geology of a metamorphic complex in West Greenland. Medd. om Gronland, Bd 136, Nr 6.

Escher, A., and Burri, M., 1967. Stratigraphy and Structural Development of the Precambrian Rocks in the area north-east of Disko Bugt, West Greenland. Geol. Surv. Greenland. Report 13.

Ewing, J., and Ewing M., 1959. Seismic Refraction Measurements in the Atlantic Ocean Basins, the Mediterranean Sea, on the Mid-Atlantic Ridge and in the Norwegian Sea. Bull. Geol. Soc. Am., 70, 291-318.

Fahrig, W.F., Irving, E., and Jackson, G.D., 1971. Paleomagnetism of the Franklin Diabases. Can. J. Earth Sci., 8, No. 4, 1-13.

Fortier, Y.O., and others, 1963. Geology of the north-central part of the Arctic Archipelago, Northwest Territories (operation Franklin). Geol. Surv. Can. Mem. 320.

Godby, E.A., Baker, R.C., Bower, M.E., and Hood, P.J., 1966. Aeromagnetic Reconnaissance of the Labrador Sea. J. Geophys. Res., 71, 511-517.

Grant, A.C., 1970. Recent Crustal Movements on the Labrador Shelf. Can. J. Earth Sci., 7, No. 2, Part 2, 571-575.

Gregory, A.F., Bower, M.E., and Morley, L.W., 1961. Geological Interpretation of Aerial Magnetic and Radiometric Profiles, Arctic Archipelago, Northwest Territories. Geol. Surv. Can. Bull., 73, 148.

Hall, J.K., (in press). Geophysical Evidence for Ancient Sea-Floor Spreading from Alpha Cordillera and Mendeleyev Ridge. Am. Assoc. Petrol. Geol., Symposium on Arctic Geology, San Francisco, 1971.

Haller, J., 1969. Tectonics and Neotectonics in East Greenland - Review Bearing on the Drift Concept. Am. Assoc. Pet. Geol. Memoir 12, 852-858.

Hart, R., 1970. Chemical Exchange between Sea Water and Deep Ocean Basalts. Earth and Plan. Sci. Letters, 9, 269-276.

Heirtzler, J.R., Peter, G., Talwani, M., and Zurflush, E.G., 1962. Magnetic Anomalies caused by Two-Dimensional Structures: Their computation by Digital Computer and Their Interpretation. Lamont. Geol. Obs. Tech. Rept. No. 6.

Heirtzler, J.R., Dickson, G.O., Herron, E.M., Pitman, W.C., and Le Pichon, X., 1968. Marine Magnetic Anomalies, Geomagnetic Field Reversals and Motions of the Ocean Floor and Continents. J. Geophys. Res., 73, 2119-2136.

Henderson, G., and Pulvertaft, T.C.R., 1967. The

Stratigraphy and Structure of the Precambrian Rocks of the Umanak area, West Greenland. Geol. Surv. Greenland, Miscellaneous Paper No. 52.

Henderson, G., 1969. Oil and Gas Prospects in the Cretaceous-Tertiary basin of West Greenland. Geol. Surv. Greenland, Report 22.

Henderson, G., 1969. Precambrian Rocks of the Egedesminde-Christianshab Area. West Greenland. Geol. Surv. Greenland, Report 23.

Henderson, G., 1971. The Geological Setting of the West Greenland Basin. Geol. Surv. Canada Paper, (in press).

Hess, H.H., 1962. History of ocean basins in Petrologic Studies: a Volume in Honor of A.F. Buddington. A.E.J. Engel, H.L. James and B.F. Leonard Eds., Geol. Soc. Am., 599-620.

Holtedahl, O., 1970. On the Morphology of the West Greenland shelf with General Remarks on the "Marginal Channel" Problem. Marine Geology, 8, 155-172.

Hood, P.J., and Godby, E.A., 1964. Magnetic Anomalies over the Mid-Labrador Sea Ridge. Nature 202, 1099.

Hood, P.J., Sawatzky, P., Bower, M.E., 1967. Progress

Report on Low-Level Aeromagnetic Profiles over the Labrador Sea, Baffin Bay and across the North Atlantic Ocean. GSC Paper 66-58.

Hood, P.J., and Bower, M.E., (in press). Low-Level Aeromagnetic Surveys of the Continental Shelves bordering Baffin Bay and the Labrador Sea. Geol. Surv. Can. Paper 71-23.

IAGA Commission 2 Working Group 4, 1969. Analysis of the Geomagnetic Field - International Geomagnetic Reference Field 1965.0. J. Geophys. Res., 74, No. 17, 4407.

Ives, J.D., 1963. Field problems in determining the maximum extent of Pleistocene glaciation along the eastern Canadian Seaboard - a geographer's point of view. North Atlantic Biota and their History, Pergammon Press, London, 337-354.

Jackson, G.D., 1969. Reconnaissance of north central Baffin Island. Geol. Surv. Canada Paper 69-1, Part A, 171-176.

Jeletzky, J.A., 1971. Marine Cretaceous Biotic Provinces and Paleogeography of Western and Arctic Canada: illustrated by a detailed study of Ammonites. Geol. Surv. Canada, Paper 70-22.

Johnson, G.L., Closuit, A.W., and Pew, J.A., 1969. Geologic and Geophysical Observations in the

Northern Labrador Sea Arctic, 22, 56-68.

Johnson, J., 1971 (unpub.). A Contribution to the Structure of Northern Baffin Bay and Lancaster Sound. M.Sc. Thesis, Dalhousie University.

Jorgensen, O., 1967. K-Ar age determinations from West Greenland II. The Ivigtut Region. Greenland Geol. Surv. Report 15, 87-91.

Keen, M.J., Loncarevic, B.D., and Ewing, G.N., 1970. Continental Margin of Eastern Canada: Georges Bank to Kane Basin. The Sea, Vol. IV Part 2, 251-291. Wiley-Interscience.

Keen, C.E., Barrett, D.L., Manchester, K.S., and Ross, D.I., (in press). Geophysical Studies in Baffin Bay and some Tectonic Implications. Can. J. Earth Sci.

Koch, B.E., 1963. Fossil Plants from the Lower Paleocene. Medd. om Gronland 172, nr 5.

Kranck, E.H., 1939. Bedrock Geology of the Seaboard region of Newfoundland. Geol. Survey Newfoundland Bull. 19, 1-44.

Kranck, E.H., 1955. The bedrock geology of the Clyde Area in northeastern Baffin Island. Acta Geographica, 14, 226-248.

Larsen, O., and Moller, J., 1968. Potassium-Argon Age Studies in West Greenland. Can. J. Earth

Sci., 3, 683-692.

Laughton, A.S., 1971 (in press). The Southern Labrador Sea - A key to the Mesozoic and early Tertiary Evolution of the North Atlantic. Nature.

Le Pichon, X., 1968. Sea Floor Spreading and Continental Drift. J. Geophys. Res., 73, 3661-3697.

Le Pichon, X., Hyndman, R.D., and Pautot, G., 1971. A Geophysical Study of the Opening of the Labrador Sea. J. Geophys. Res. (in press).

Loncarevic, B.D., 1968 (unpub.). Preliminary Users Manual for Shipboard Magnetometer Watchkeepers. Bedford Institute Internal Note, 1968-7-1.

Manchester, K.S., 1964 (unpub.). Geophysical Investigations between Canada and Greenland. M.Sc. Thesis, Dalhousie University.

Mayh[illegible], [illegible].A., 1969 (unpub.). Marine Geophysical Measurements in the Labrador Sea. Relations to Precambrian Geology and Sea Floor Spreading. Ph.D. Thesis, Columbia University.

McElhinny, M.W., 1971. Geomagnetic Reversals during the Phanerozoic. Science, 172, 157-159.

Park, I., Clarke, D.B., Johnson, J., and Keen, M.J., 1971. Seaward Extension of the West Greenland

Tertiary volcanic Province. Earth and Plan. Sci. Letters, 10, 235-238.

Peters, L.J., 1949. The Direct Approach to Magnetic Interpretation and its practical application. Geophysics, 14, 290-320.

Poulsen, V., 1966. An occurrence of Lower Palaeozoic Rocks within Precambrian Terrain near Sukkertoppen. Geol. Surv. Greenland. Report 11.

Pye, G., 1971 (unpub.). Heat Flow Measurements in Baffin Bay and the Labrador Sea. M.Sc. Thesis, Dalhousie University.

Pye, G., and Hyndman, R.D., (in preparation). Heat Flow Measurements in the Labrador Sea and Baffin Bay.

Ramberg, H., 1949. On the petrogenesis of the gneiss complexes between Sukkertoppen and Christianshaab, West Greenland. Medd. dansk. geol. Foren., Bd 11, 312-327.

Rosenkrantz, A., and Pulvertaft, T.C.R., 1969. Cretaceous-Tertiary Stratigraphy and Tectonics in northern West Greenland. Am. Assoc. Petroleum Geol. Memoir 12.

Schneider, E.D., 1970. The Deep Sea - A Habitat For Petroleum. Undersea Technology, 10, 32.

Sharma, P.V., and Ghisler, M., 1969. On the applicability of magnetic prospecting for chromite in the Fiskenaesset region, West Greenland. Greenland Geol. Surv., Report 20.

Stockwell, C.H., 1964. Fourth report on Structural Provinces orogenics and time-classification of the rocks of the Canadian Precambrian Shield. Geol. Surv. Canada. Paper 64-17 (Part III).

Sykes, L.R., 1965. The Seismicity of the Arctic. Bull. Seismol. Soc. Am., 55, 519-536.

Taylor, F.B., 1910. The Bearing of the Tertiary Mountain Belt on the Origin of the Earth's Plan. Bull. Geol. Soc. Am., 21, 179-226.

Thorsteinnson, R., and Tozer, E.T., 1960. Summary Account of Structural History of the Canadian Arctic Archipelago since Precambrian Time. Geol. Surv. Canada, Paper 60-7.

Trettin, H.P., 1969. Lower Paleozoic Sediments of northwestern Baffin Island. District of Franklin. Geol. Surv. Can. Bull. 157.

Vacquier, V., Steenland, N.C., Henderson, R.G., and Zietz, I., 1951. The interpretation of aeromagnetic maps. Geol. Soc. Am. Memoir 47.

Vogt, P.R., 1970. Magnetized Basement Outcrops on the Southeast Greenland Continental Shelf. Nature, 226, 743-744.

Vogt, P.R., Ostenso, N.A., and Johnson, G.L., 1970. Magnetic and Bathymetric Data Bearing on Sea-Floor Spreading north of Iceland. J. Geophys. Res., 75, 903-920.

Vogt, P.R., and Ostenso, N.A., 1970. Magnetic and Gravity Profiles across the Alpha Cordillera and their Relation to Arctic Sea-Floor Spreading. J. Geophys. Res., 75, 4925-4938.

Watkins, N.D., and Paster, T.P., 1971. The magnetic properties of Igneous Rocks from the Ocean Floor. Phil. Trans. Roy. Soc. Lond. A., 268, 507-550.

Watt, W.S., 1969. The Coast Parallel Dike Swarm of Southwest Greenland in Relation to the Opening of the Labrador Sea. Can. J. Earth Sci., 6, No. 5, 1320-1321.

Wegener, A., 1924. The Origin of Continents and Oceans. Methuen, London.

Wegmann, C.E., 1938. Geological Investigations in Southern Greenland Part I. On the Structural Divisions of Southern Greenland. Medd. Gronland, Bd 113, Nr 248.

Wheeler, E.P., 1960. Anorthosite-adamellite complex of Nain, Labrador. Geol. Soc. Am. Bull., 71, 1755-1762.

Wilson, J.T., 1963. Continental Drift. Scientific American, 8, No. 4, 86-100.

Wilson, J.T., 1965. A New Class of Faults and Their Bearing on Continental Drift. Nature 207, 343-347.

Wilson, R.L., Haggerty, S.E., and Watkins, N.D., 1968. Variation of Palaeomagnetic Stability and other Parameters in a vertical traverse of a Single Icelandic Lava. Geophys. J. R. astr. Soc.

Appendix 1 Petrographic Descriptions

A. Dredge Station 2

2-01 Highly altered amygdaloidal basalt. Vesicles filled with zeolites and rimmed by yellowish palagonite. Altered ground mass with small plagioclase laths and less abundant augite.

2-05 Feldspar-phyric basalt. Fine grained ground mass with large plagioclase phenocrysts and small augites. Opaques (magnetite) are interstitial. Approx. mode: Plag 20%, Augite 5%, Mt 5%, Ground mass 70%.

2-10 Amygdaloidal basalt. Altered ground mass. Vesicles filled with white and green zeolites. Phenocrysts of plagioclase and augite phenocrysts. Magnetite very finely dispersed in ground mass.

B. Dredge Station 5

5-03 Coarse grained basalt (Diabase). Aggregates of plagioclase phenocrysts and subhedral augites. Pseudomorphed olivines cluster around plagioclase crystals. Large skeletal magnetites. Approx.

mode: Plag 40%, Aug 50%, Ol pseudomorphs 3%, Mt 5%.

5-10 Feldspar-phyric basalt. Fine grained ground mass. Several large plagioclase phenocrysts, occasional augites. Interstitial magnetites. Approx. mode: Plag 10%, Aug <2%, Ground mass 88%.

5-12 Feldspar-phyric basalt. Fine grained ground mass. Aggregates of small plagioclase phenocrysts. Occasional augites. Very fine grained magnetites. Approx. mode: Plag 15%, Aug <5%, Ground mass (+Mt) 80%.

5-13 Basalt. Fine grained ground mass with plagioclase laths, small augites, altered glass (chlorite) and medium sized magnetite grains. Very small augite phenocrysts. Approx. mode: Aug 1%, Mt 5%, Ground mass 94%.

C. Dredge Station 6

6-11 Coarse grained feldspar-phyric basalt. Ground mass coarse grained with large plagioclase phenocrysts (sometimes zoned) and small augites. Small skeletal magnetites. Approx. mode:

Plag 30%, Aug 5%, Mt 5%, Ground mass 60%.

6-12 Feldspar-phyric basalt. Fresh ground mass with aggregates of small aligned plagioclase phenocrysts and small augites. Fine grained magnetite. Approx. mode: Plag 15%, Aug 5%, Mt <3%, Ground mass 77%.

6-13 Feldspar-phyric basalt. Fine grained ground mass. Large plagioclase phenocrysts, occasional augites. Poikilitic magnetites enclosing feldspar laths and augites in ground mass. Possible altered glass. Approx. mode: Plag 20%, Aug 5%, Mt 5%, Ground mass 70%.

6-14 Feldspar-phyric basalt. Fine grained ground mass with small feldspar phenocrysts and very few augites. Olivine pseudomorphs. Interstitial magnetites. Approx. mode: Plag 15%, Aug 2%, Mt 2%, Ground mass 80%.

Sample No.	Deuteric Oxidation State	Description
001	1	Unaltered lath-shaped titanomagnetites. Interstitial to silicates. Grains 1μ wide to 10μ in length.
002	3,5,6	Highly altered. Large grains (75μ) show replacement of titanomagnetite by pseudo-brookite, titanohematite and rutile. Other grains show large magnetite patches surrounded by ilmenite lamellae which have been completely altered to titanohematite and Fe-rutile. Also large grains of magnetite with exsolved ilmenite lamellae. Few dispersed grains of hematite and Fe-sulfides.

Sample No.	Deuteric Oxidation State	Description
003	1	Lath-shaped skeletal titanomagnetites. No signs of deuteric alteration or burial effects.
004	1	No visible deuteric oxidation. Primary ilmenite laths-crystallised from liquid. Small skeletal titanomagnetites and very tiny (<1μ) sulfides.
005	1	Very tiny (<1μ) skeletal titanomagnetites.
006	1	Low deuteric oxidation. Grains of titanomagnetite ranging in size from 10 to 1. Very small Fe-sulfides and subliquidus ilmenite laths.
007	1+ Burial Metamorphism	Titanomagnetites show tiny exsolved ferri-rutile

Sample No.	Deuteric Oxidation State	Description
		granules but have retained low deuteric oxidation characteristics.
008	1	Skeletal titanomagnetites (3-10μ) and very tiny Fe-sulfides.
009	1	Breccia with zeolites filling vesicles. 5μ average size of skeletal titanomagnetites. Possible ferri-rutile granules.
010	1	Long laths of skeletal titanomagnetites. Low deuteric oxidation characteristics.
011	1	Poorly polished. Small titanomagnetites and Fe-sulfides.