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D.G. Roberts [1]
C.J. Uruski [2]
D.G. Masson [1]
R.G. Rothwell [1]

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Wormley, Godalming,
Surrey GU8 5UB
(042-879-4141)

(Director: Dr. A. S. Laughton)

Bidston Observatory,
Birkenhead,
Merseyside L43 7RA
(051-653-8633)
(Assistant Director: Dr. D. E. Cartwright)

Crossway,
Taunton,
Somerset TA1 2DW
(0823-86211)
(Assistant Director: M. J. Tucker)

Geological Investigations of the East Greenland Continental Margin - Preliminary Report

D.G. Roberts [1]
C.J. Uruski [2]
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R.G. Rothwell [1]

1. Institute of Oceanographic Sciences, Wormley, Surrey

2. Department of Geological Sciences, University of Durham, Durham

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1. INTRODUCTION

Prior to the episode of rifting and sea-floor spreading which separated Greenland from the Rockall Plateau and Northwest Europe, these three continental masses formed part of the Laurasian super-continent. The East Greenland continental margin is of interest because of its former contiguity with the western Rockall Plateau, and particularly in view of the substantial Mesozoic section exposed onshore in the Jamieson Land Basin, north of Scoresby Sund.

Onshore, Birkelund and Perch-Nielsen (1976) have documented the Mesozoic and Tertiary succession, while Surlyk (1977a, b; 1978a, b) has discussed aspects of Jurassic sedimentation and tectonics, and Henderson (1976) the petroleum geology. However, the offshore area has remained largely unexplored, not least because of the difficulties of operating in an environment only ice-free for relatively short periods each summer. Offshore seismic studies have previously been reported by Featherstone et al. (1977) and Hinz and Schluter (1979), while Larsen (1975) has described preliminary aeromagnetic results.

2. IOS GEOPHYSICAL INVESTIGATIONS

The IOS programme of field investigations on the East Greenland margin was initiated in late summer 1979. The geological objective of the field programme was to comprehensively study the structure of the continental slope between Scoresby Sund and Cape Farewell, including the Denmark Strait. Aspects of the study of particular importance included a comparison of the East Greenland margin with its former conjugate, now represented by the western margin of the Rockall Plateau, with special emphasis on the distribution of the suite of dipping reflectors observed on both margins. A study of the offshore extension of the Mesozoic Jamieson Land Basin south of Scoresby Sund was also planned, and the sedimentological regime imposed by the southwards flow of water through the Denmark Strait was to be examined using GLORIA and seismic reflection techniques.

To execute the field programme, the R.V. Starella was chartered from J.W. Marr and Co. Ltd. and fitted out with IBM 1130 data logger and processing system, satellite and LORAN-C navaids, precision echo-sounder, gravimeter, magnetometer, 6-channel seismic reflection profiling system, and the GLORIA-Mk II long-range side-scan sonar system. Departure of the cruise, originally scheduled for September 1st, was delayed for 20 days due to a major failure of the ships gearbox and propulsion motors. The delay necessitated a reappraisal of the programme, and a reduction of the 4 to 5 weeks originally planned for the East Greenland Survey.

R.V. Starella arrived in the Denmark Strait area on September 28th. In view of severe weather forecasts for the south-east Greenland margin, effort was concentrated on examining the area between the Denmark Strait and Scoresby Sund, and a number of traverses across the margin were completed before bad weather and icing forced a return to the south. Further traverses across the margin were made until damage to Gloria enforced an entry into the sheltered waters of Dryafjord to effect repairs. The repairs completed, improved weather conditions allowed the remaining time (5 days) off East Greenland to be spent between the Denmark Strait and Cape Farewell. To optimise on this time, ships tracks were chosen to infill gaps in the seismic reflection coverage previously obtained by Durham University, and to provide ties between seismic lines crossing the slope. A complete narrative of the cruise can be found in IOS Internal Document No. 73.

3. SCOPE OF THIS REPORT

The purpose of this report is to present preliminary free-air gravity and magnetic anomaly maps (figures 2, 3) as well as a summary of the seismic stratigraphy of the East Greenland margin. These maps have been compiled from the Starella cruise data and from data previously obtained by Durham University. Additional data now being acquired from other sources will be used to update these maps. In addition, a preliminary map of isochrons to basement is presented (figure 4), but this part of the project is less advanced and will be further developed when the seismic data held by Durham University has been reprocessed.

4. SUMMARY OF THE ONSHORE GEOLOGY OF EAST GREENLAND (FIGURE 6)

4.1 Crystalline Basement

The crystalline basement of East Greenland can be subdivided into three major units: Archaen (>2500 m.y.), Proterozoic (2500-1000 m.y.) and Caledonian (520-375 m.y.) (Bridgewater et al., 1978). The Archaen basement consists of deformed and metamorphosed granitic and granodioritic rocks of amphibolite or granulite grade. The Proterozoic complexes consist of supracrustals and intensely reworked and sheared Archaen rocks, with a trend perpendicular to the present coast. North of Scoresby Sund, the basement is composed of lower Palaeozoic and older rocks which were extensively deformed during the Caledonian orogeny.

4.2 Devonian and Carboniferous

Following the Caledonian orogeny, Devonian and Upper Carboniferous continental clastics were deposited in intra-montane basins, with thicknesses locally exceeding 12 km. Such rocks are only known onshore north of Scoresby Sund.

4.3 Permian

Early Permian conglomerates and arkoses are found in a narrow zone in the Jamieson Land Basin. Deposition is thought to have taken place contemporaneously with the formation of half-grabens related to a major NNE-SSW fault (Haller, 1970). A major transgression took place in the Late Permian, and reefs, evaporites and sandy limestones of this age are known (Birkelund and Perch-Nielsen, 1976).

4.4 Mesozoic

Major Mesozoic tectonic events are known from the early and late Triassic, Rhaetic, Pliensbachian, Bajocian, Bathonian, Late Oxfordian, Kimmeridgian, mid-Volgian-Valangian, Aptian-Albian and Turonian. The Late Jurassic to Early Cretaceous phases were particularly important, and resulted in the formation of a series of westward tilted blocks, suggestive of a rift axis further to the east. This major phase of Mesozoic tectonism is also known from off Norway, but its relationship to the later opening of the Norwegian Sea is not fully understood. It may represent the northward continuation of the rift system that ultimately became the Rockall Trough; alternatively, it could also relate to the development of the Viking Graben in the North Sea.

4.5 Tertiary

Pre-volcanic exposures of Tertiary sediments are restricted to small pockets protected from erosion by the overlying basalts. These sediments exhibit a westerly pinchout and are of both shallow marine and terrestial facies.

In the Jamieson Land Basin, the thin Tertiary section is composed of conglomerates and fluviolacustrine sandstones of westerly derivation. In southeast Greenland, a thin early Tertiary succession of marine sediments, partly contemporaneous with the early volcanics, is present at Cap Gustav Holm. In the Kangerdlugssuaq area, thin lower Albian to Danian sediments exhibit an upward transition from marine to near continental facies, and are unconformably overlain by submarine lavas and tuffs.

The succeeding lavas are almost exclusively sub-aerial, and reach an estimated thickness of 6-7 km near Kangerdlugssuaq, although thinner to the north and south. Eruption took place within a few million years during the Late Palaeocene, immediately preceding the initiation of spreading between East Greenland and Rockall (Soper et al., 1976). Towards the end of the igneous episode, a coast parallel dyke swarm, which can be traced offshore as far south as 63°N, was intruded into the lava pile. The dykes are reversely magnetised, and were probably intruded during the reversed polarity interval prior to anomaly 24 time. Following the dyke intrusion, strong oceanward tilting of fault blocks took place along a coastal monoclinal flexure, possibly accompanied by some minor faulting. Later tectonic activity was confined to an Oligocene-Miocene phase of normal faulting with uplift of 1.5 to 2 km in the coastal area, probably in response to the initiation of spreading on the Kolbeinsey Ridge, north of Iceland. Post-basalt calcareous sandstones and mudstones of Eocene and Oligocene age, possibly separated by a small hiatus, are known from Kap Dalton and Savoia Halvo. A number of syenitic intrusions which post-date the basalts also occur.

5. CONTINENTAL MARGIN GEOLOGY

5.1 Bathymetry

The bathymetry of the continental shelf and slope off East Greenland is shown in figure 1, together with the track coverage on which the other figures have been based. The width of the continental shelf varies considerably along the margin, being wide in the area of the

Denmark Strait but narrowing both northward and southwards. In the latter area, it is cut by a number of deep glacially excavated troughs which appear to be genetically related to the major fjords.

The continental slope varies considerably in its physiographic expression along the margin. North of the Denmark Strait it is narrow and steep, but its gradient decreases southward towards the Strait. South of Scoresby Sund its trend is NE-SW but it becomes more northerly towards the Denmark Strait. To the east, the Denmark Strait is flanked by the insular shelf and slope of Iceland. Immediately south of the Strait, the slope trends E-W, but southwards it turns to a NE or NNE trend which is maintained to the southern tip of Greenland. On this part of the margin, the slope has a steep upper part and a gentle lower slope. The few canyons present appear to be related to the glacially excavated troughs on the shelf.

5.2 Free-air gravity anomalies (figure 2)

The free-air gravity anomaly map in general closely reflects the topography of the margin. North of the Denmark Strait, a belt of positive anomalies corresponds to the well-known edge effect close to the shelf edge, but these edge effect anomalies do not continue south of 69 °N and the outer part of the shelf in the vicinity of the Denmark Strait is characterised by lower gravity anomalies. South of the Denmark Strait, the belt of positive edge effect anomalies is again prominent and nearly continuous, only being broken near 63 °N. These anomalies parallel the edge of the slope except near 66 °N, where there is some suggestion of a change in trend towards the north.

South of the Denmark Strait, the slope is also generally characterised by positive anomalies, with only rare negative anomalies. The absence of significant negative anomalies, coupled with the general lack of gravity lineations on the slope is puzzling since the lower slope in this area is underlain by the apparently thick sediment succession containing dipping reflectors (figure 6), which occupies a linear basin between 60° and 66°N and over which one would expect a linear negative anomaly. Further gravity modelling exercises are required to investigate this problem. One feature of possible significance is the relative increase in negative anomalies over the slope north of 63°N, compared with the region further south. This change coincides with the break in the edge effect anomaly mentioned earlier, and may possibly relate to the deep-seated boundary between Proterozoic and Archaen basement in the underlying continental basement.

5.3 Magnetic Anomalies (figure 3)

Two major magnetic anomaly provinces can be delineated in the study area. The continental shelf is characterised by short wavelength high amplitude anomalies that relate to Precambrian basement and/or Tertiary intrusive and extrusive rocks at shallow depth. Between 63° and 65°N the complex anomaly pattern over the inner shelf may be associated with the southerly prolongation of the East Greenland dyke swarm (Larsen, 1978). It should be noted that the contours in the broad shelf area west of the Denmark Strait are based on very sparse data, and the mapped anomaly pattern cannot be considered accurate.

Beyond the shelf edge, the most obvious feature is the suite of linear NE-SW trending positive and negative anomalies. These represent the oldest oceanic lineations identified off East Greenland, and are identical to those observed west of Rockall. The oldest anomaly in the region is anomaly 24.

Immediately to the west of anomaly 24 the linear anomaly pattern is no longer apparent, and the anomalies are typically lower in amplitude. This change is particularly clear on the original magnetic profiles, although less obvious on the magnetic anomaly map. It is inferred to correspond to the transition from oceanic to continental crust, and coincides with the outer edge of the mapped extent of the suite of dipping reflectors underlying the lower slope. There is not, however, any obvious coincident change in the gravity anomaly pattern which might also be associated with the continent-ocean boundary.

The linear oceanic anomalies can be followed north to 64°N, to the point where the continental slope changes trend to E-W. At this point both the outer limit of the suite of dipping reflectors and the inferred position of the continent-ocean boundary are displaced eastward, and anomalies 22 to 24 are absent in the area immediately to the north. The missing anomalies can be located on the opposite side of the ocean basin north of Hatton Bank, and their absence off Greenland suggests a jump in the position of the spreading axis during the early phases of spreading between Greenland and Rockall. Anomalies 20 and 21 intersect the continental slope west of the Denmark Strait. This may indicate that the outer shelf in this area is underlain by oceanic crust; alternatively, the E-W trending slope in the area may represent another fracture zone indicating a further displacement in the former position of the spreading axis. Quantitative modelling is clearly required to test these ideas.

North of the Denmark Strait, the magnetic anomaly pattern has been mapped from aeromagnetic surveys flown by the U.S. Naval Oceanographic Office. Here, the oldest anomaly adjacent to the continent-ocean boundary is anomaly 5/6, in contrast to the much older anomaly 24 to the south (figure 6). The two parts of the margin thus formed at different times, with the transition between the two spreading regimes occurring in the vicinity of the Denmark Strait.

5.4 SEISMIC STRATIGRAPHY

In this section, a summary of the seismic stratigraphy based on a preliminary assessment of the available seismic data and previously published results (Featherstone et al., 1978; Hinz and Schluter, 1979) is presented. A more detailed analyses must await the reprocessing of the Durham data.

The region can be divided into two geological provinces, with the division occurring in the Denmark Straits area. North of the Strait, the shelf is underlain by some 3 km of sediments which prograde seawards (figure 5A). Oceanic basement identified under the lower slope is Miocene (anomaly 5/6) in age. Landward, the Miocene prograding section rests on faulted Eocene-Oligocene sediments which in turn are underlain by Palaeocene to lower Eocene basalts. Peacock (pers. comm. 1979) has noted some evidence for Mesozoic sediments beneath the inner shelf east of Scoresby Sund, but their extent remains an unknown and requires further study.

South of the Denmark Strait, a very different seismic stratigraphy is observed (figure 5B). Beneath the slope and shelf, a prominent unconformity separates a lower section characterised by many strong oceanward dipping reflectors from an upper oceanward prograding section. The degree of progradation is variable, and a first look suggests that the variation may be related to the sedimentary regime imposed by a deep-water current flowing out of the Denmark Strait and southwards along the slope. A prominent unconformity within the upper sequence may correspond to the R4 event (Eocene-Oligocene) observed on Rockall Plateau (Roberts, 1975).

The suite of dipping reflectors are observed over a broad belt which averages some 70 km in width, but which is widest off southeast Greenland and narrows northwards to disappear beneath the slope west of the Denmark Strait (figure 6). This part of the section occurs only to the west of the continent-ocean boundary and bears great similarity in seismic character and structural position to the comparable section observed in the Edoras Basin in the western Rockall Plateau. In this latter area they are pre-Late Palaeocene in age. Landward, the suite of dipping reflectors appears to truncate against a major fault which lies near the shelf edge. It should be noted that the isochrons to 'basement' (figure 4) define the top of this unit, and not true basement, in the area where it occurs.

REGIONAL TECTONIC HISTORY

The margin off East Greenland is divisible into two areas with radically different tectonic histories. North of the Denmark Strait, Late Jurassic-Early Cretaceous rifting may have heralded the separation of Europe from the Rockall Plateau/Greenland with sea-floor spreading in the Rockall Trough. Along the entire margin voluminous Early Tertiary igneous activity immediately proceeded the **initiation** of major spreading between Greenland and Rockall/Europe at anomaly 24 time. Since then the spreading axis between Greenland and Rockall has remained essentially fixed. However, farther north in the Norwegian Sea, the Aegir ridge spreading axis became extinct in Oligocene time, and a new spreading axis, the Kolbeinsey Ridge, was initiated to the west. This jump hived off the original continental slope north of the Denmark Strait to form the Jan Mayen ridge. The new slope is thus Miocene and younger in age in contrast to the Eocene age to the south. The change in spreading geometry is documented by Oligocene/Miocene tectonism on the Greenland coast.

FIGURE CAPTIONS

Figure 1 Bathymetry of East Greenland continental margin. Tracks shown are those used in the compilation of figures 2-4.

Figure 2 Free-air gravity anomaly over the East Greenland margin. Contour interval 10 mgals.

Figure 3 Magnetic anomaly pattern over the East Greenland margin. Contour interval 200 γ.

Figure 4 Preliminary map of isochrons on basement based on IOS and Durham University data. Contour interval 0.5 secs two-way travel time. Note that the unconformity defining the top of the suite of dipping reflectors is taken as 'basement' in the areas where it occurs.

Figure 5A Schematic cross-section through the continental margin of East Greenland between 68° and 70°N, showing the assumed deep structure. (Modified after Larsen, in press).

5B Schematic cross-section through the continental margin of East Greenland between 61° and 65°N, showing the assumed deep structure. (Modified after Larsen, in press).

Figure 6 Summary of the offshore and onshore geology of the East Greenland area.

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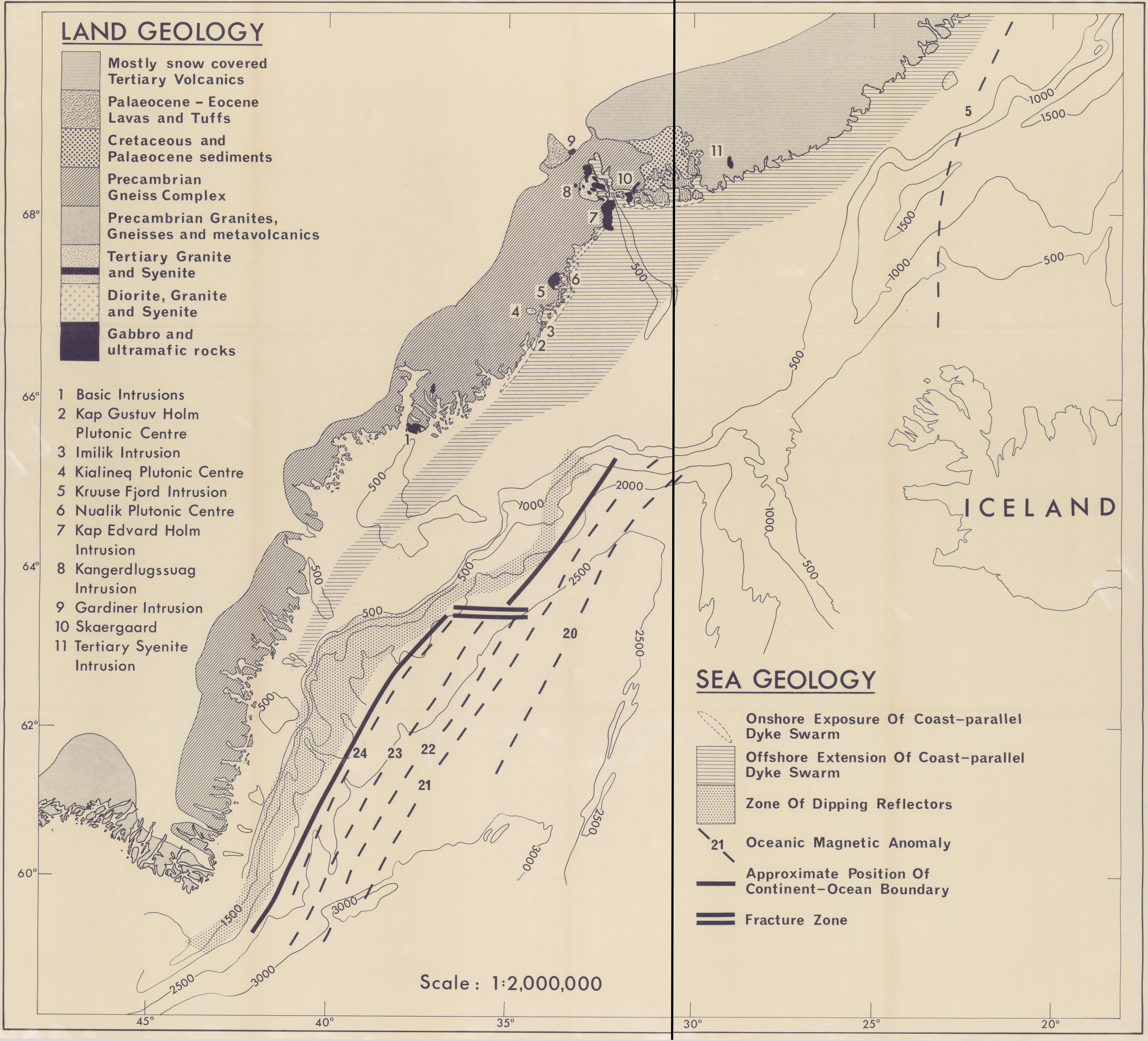
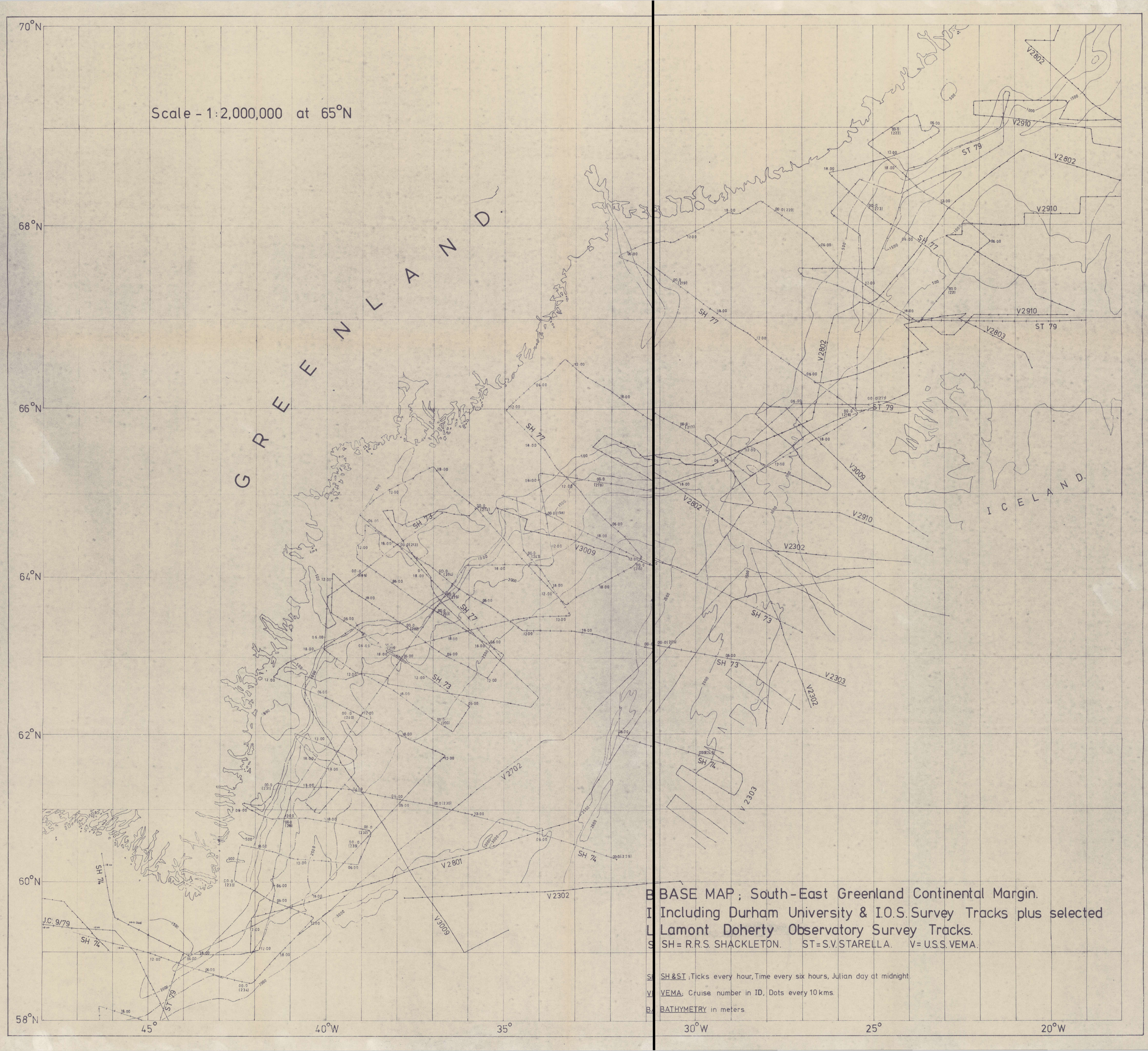
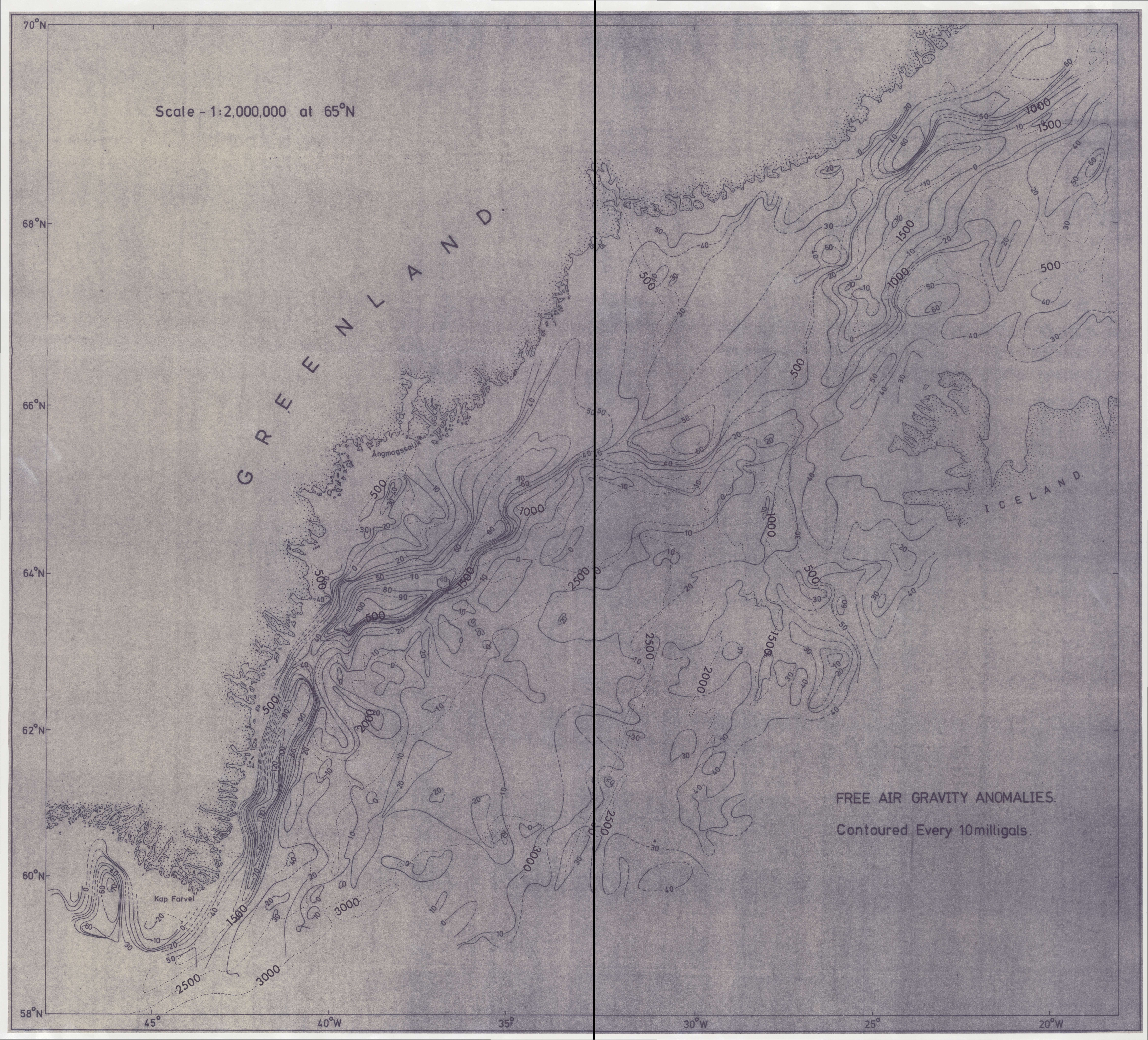


LAND GEOLOGY
Mostly snow covered Tertiary Volcanics
Palaeocene – Eocene Lavas and Tuffs
Cretaceous and Palaeocene sediments
Precambrian Gneiss Complex
Precambrian Granites, Gneisses and metavolcanics
Tertiary Granite and Syenite
Diorite, Granite and Syenite
Gabbro and ultramafic rocks
1 Basic Intrusions
2 Kap Gustuv Holm Plutonic Centre
3 Imilik Intrusion
4 Kialineq Plutonic Centre
5 Kruuse Fjord Intrusion
6 Nualik Plutonic Centre
7 Kap Edvard Holm Intrusion
8 Kangerdlugssuag Intrusion
9 Gardiner Intrusion
10 Skaergaard
11 Tertiary Syenite Intrusion
ICELAND
SEA GEOLOGY
Onshore Exposure Of Coast-parallel Dyke Swarm
Offshore Extension Of Coast-parallel Dyke Swarm
Zone Of Dipping Reflectors
Oceanic Magnetic Anomaly
Approximate Position Of Continent-Ocean Boundary
Fracture Zone
Scale: 1:2,000,000
68°
66°
64°
62°
60°
45°
40°
35°
30°
25°
20°


Scale - 1:2,000,000 at 65°N
GREENLAND
ICELAND
70°N
68°N
66°N
64°N
62°N
60°N
58°N
45°
40°W
35°
30°W
25°
20°W
BASE MAP; South-East Greenland Continental Margin.
Including Durham University & I.O.S. Survey Tracks plus selected
Lamont Doherty Observatory Survey Tracks.
SH = R.R.S. SHACKLETON. ST = S.V. STARELLA. V = U.S.S. VEMA.
SH & ST; Ticks every hour, Time every six hours, Julian day at midnight
VEMA; Cruise number in ID, Dots every 10 kms.
BATHYMETRY in meters


Scale - 1:2,000,000 at 65°N
GREENLAND
ICELAND
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FREE AIR GRAVITY ANOMALIES.
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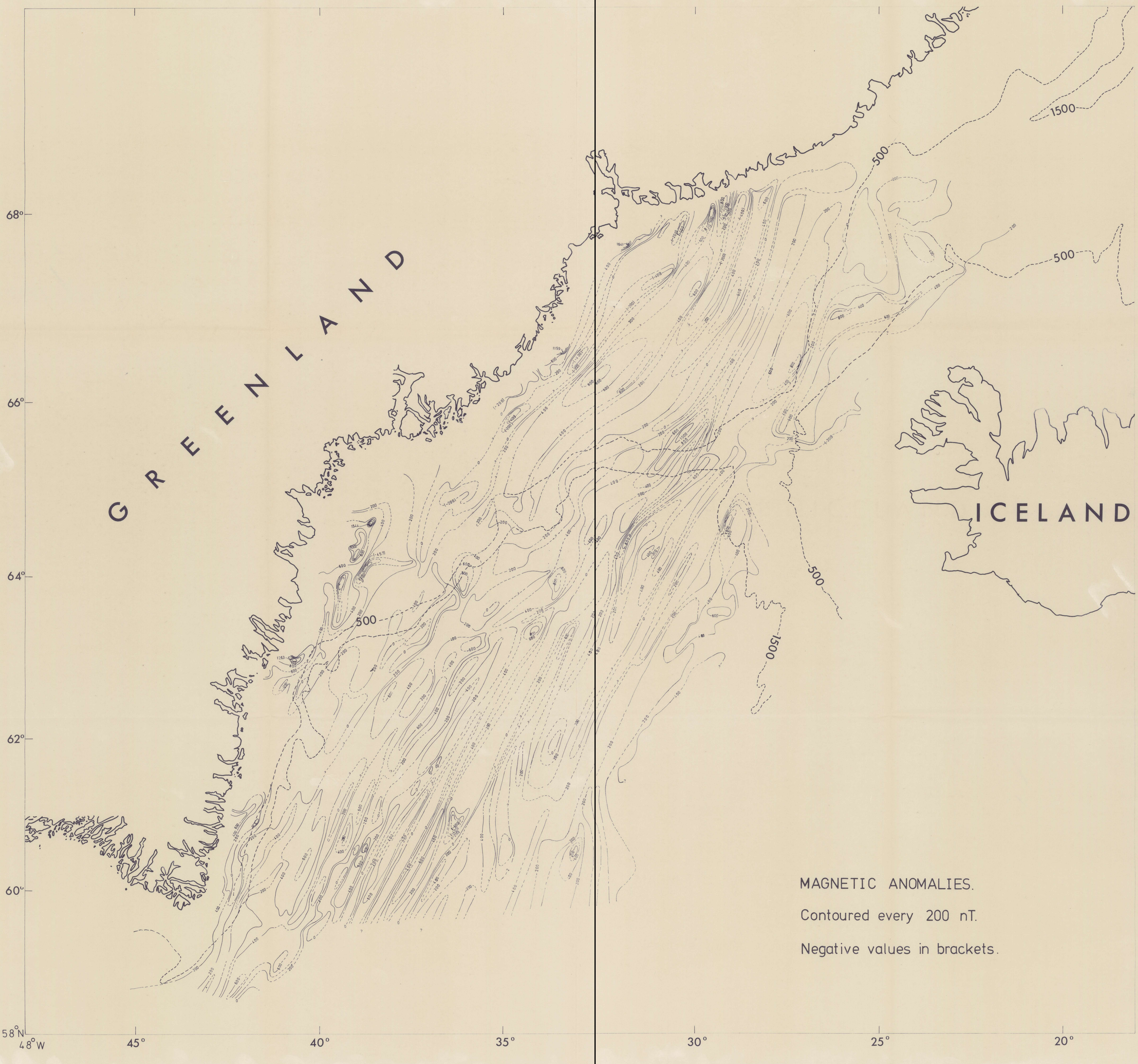
20°W

3.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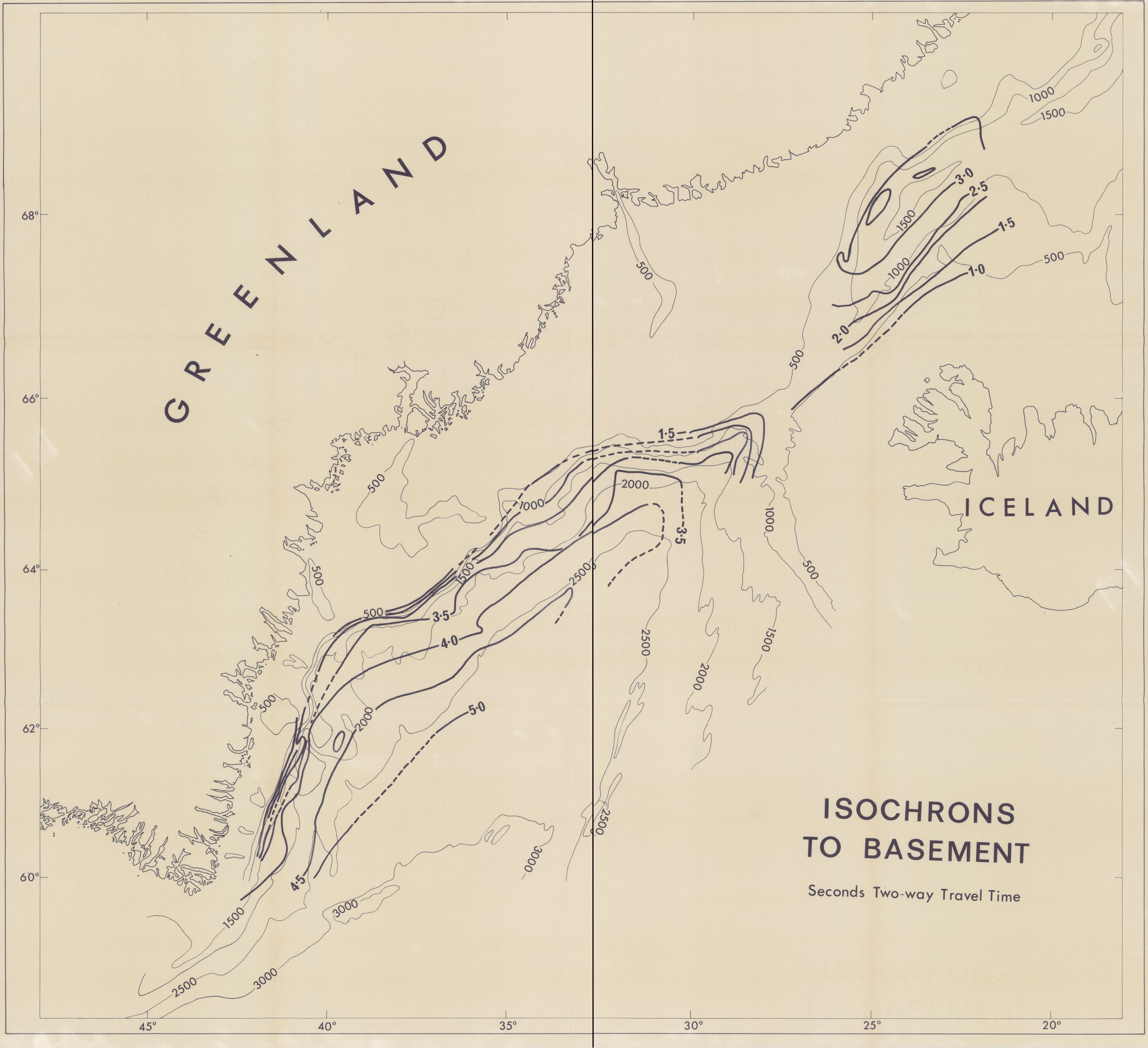
MAGNETIC ANOMALIES.
Contoured every 200 nT.
Negative values in brackets.


GREENLAND
ICELAND
ISOCHRONS
TO BASEMENT
Seconds Two-way Travel Time
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20°

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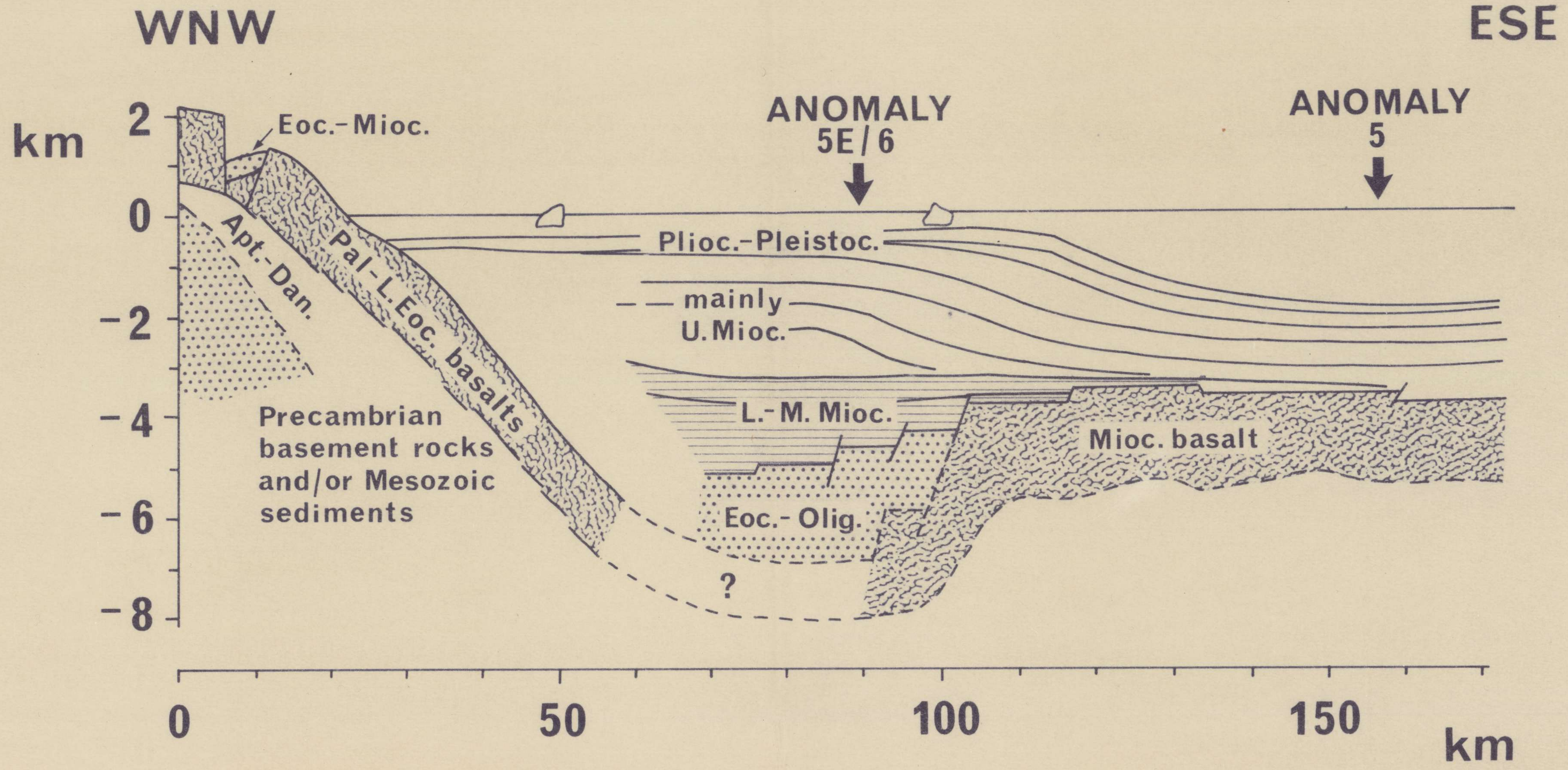
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Eoc.-Mioc.
Apt.-Dan.
Pal-L.Eoc. basalts
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Plioc.-Pleistoc.
mainly
U.Mioc.
L.-M. Mioc.
Mioc. basalt
Precambrian
basement rocks
and/or Mesozoic
sediments
Eoc.-Olig.
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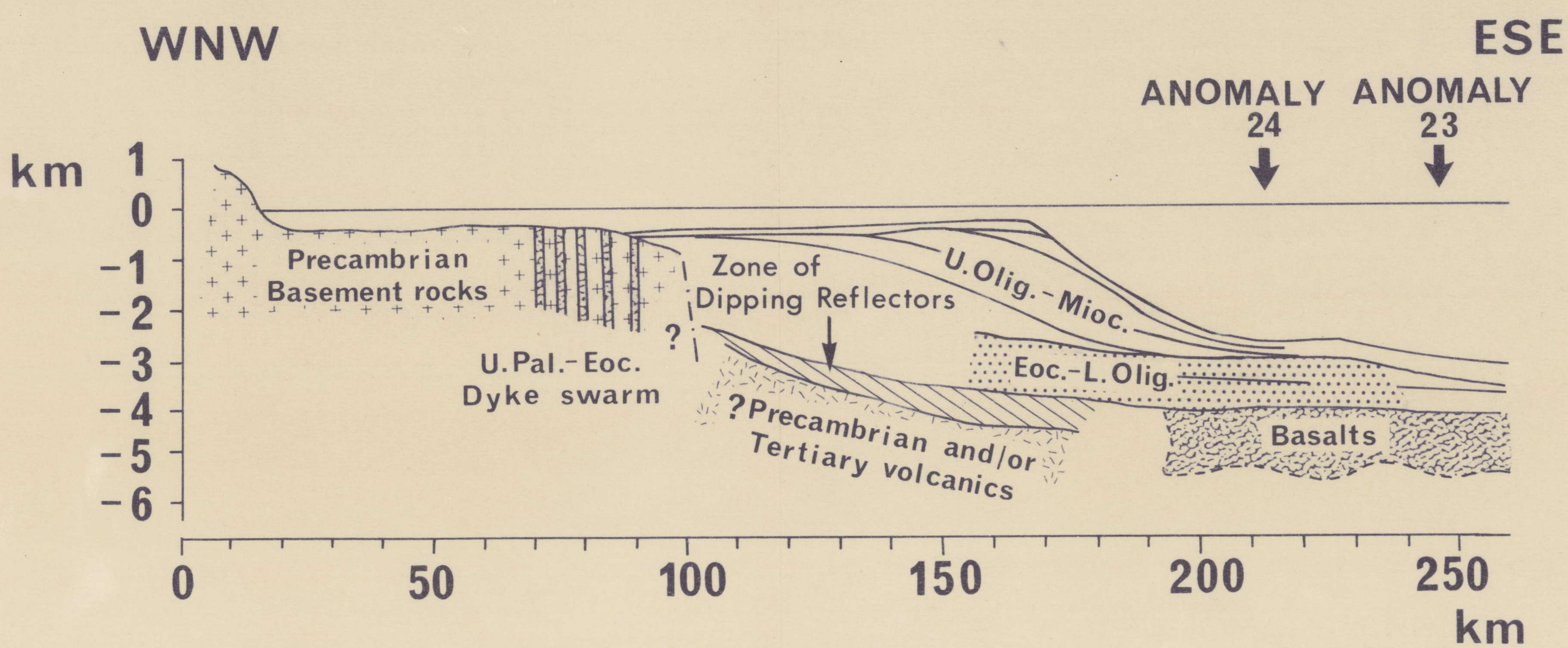
WNW
ESE
ANOMALY
24
ANOMALY
23
km
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0
-1
-2
-3
-4
-5
-6
Precambrian
Basement rocks
Zone of
Dipping Reflectors
U.Olig.-Mioc.
?
U.Pal.-Eoc.
Dyke swarm
Eoc.-L.Olig.
?Precambrian and/or
Tertiary volcanics
Basalts
0
50
100
150
200
250
km