GRAVITY AND BATHYMETRY ALONG SEISMIC REFRACTION LINES, CANADIAN ICE ISLAND, N.W.T., 1986

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GRAVITY AND BATHYMETRY ALONG SEISMIC REFRACTION LINES, CANADIAN ICE ISLAND, N.W.T., April 18-May 2, 1986

L.W. Sobczak and J.R. Weber

INTRODUCTION

A combined gravity - bathymetry survey along seismic refraction lines was carried out from the Canadian Ice Island base camp, similar to the one conducted in 1985. The refraction experiment, radio communications, navigation, program administration and scheduling of aircraft hours were described by the Refraction Team (1986). In 1986, only part of the refraction lines could be covered with the 30 alloted helicopter hours. In 1985, 77 gravity observations and 61 water depths were made using about 29 hours of Bell 206 helicopter time (Sobczak and Schmidt, 1985). In 1986, 63 gravity and sounding measurements were made using about 28 hours of Bell 206L helicopter time. This helicopter was used whenever it became available from the seismic refraction program (The Refraction Team 1986). The locations of the 1985 and 1986 surveys are shown by crosses and stars, respectively (Fig. 1). Previous observations are shown by dots. In 1986, there were 111 stations planned and an extra 12 were added at the end of the survey. Observations were taken at shot points and recording sites which were usually about 5 km apart.

Two gravity meters (G75 and G498) were used to make control ties from Resolute Bay to the Ice Island. On the Ice Island, G75 was placed in an insulated box and was used as a base monitor during the survey. After the completion of the survey, this meter was left on the Ice Island to be used as a reference gravimeter for the continuous recording gravimeter (S56) which is in operation during the summer months when the Ice Island is drifting. G498 was used as a mobile unit in the undamped mode and was returned to Ottawa at the end of the survey.

The Edo 9040 echo sounder did not function properly during traverses. This resulted in a loss of about five helicopter hours. Water depths were obtained with a new seismic sounder (Weber and Sobczak, 1986, copy enclosed).

This report discusses the gravity - bathymetry field survey and results.

Transportation and Navigation

This year a 206L extended jet ranger helicopter proved to be an improvement over the smaller jet ranger used last year. It is more spacious and allowed easier access and better distribution of equipment.

Again, as last year (Sobczak and Schmidt, 1985), Syledis navigation was used with five transmitters at LOKK, HUBBARD, BJARENSON, MEIGHEN and ICE ISLAND (Fig. 1). About every four days one of the transmitters required servicing. This year, a remote Syledis display in the cockpit was available which facilitated navigation of the helicopter. Jack Davison and Morley Wright, technicians from DFO at BIO installed and maintained the Syledis system as discussed by the Refraction Team (1986). Also, as a backup, Omega navigation with geographical coordinate display was available.

During the last traverse to shot point S (Fig. 1), Syledis limits were experienced. S was less than 200 km away from the farthest transmitter LOKK (Fig. 1). There, a ceiling of 300 feet with icing conditions was experienced and the Syledis receiver in the helicopter would lose lock with the transmitters when below an elevation of 400 feet. Under considerable difficulty the pilot managed to locate two sites and then decided to return to the Ice Island because of the icing conditions and inability to lock onto the transmitters below 300 feet. On the return to the Ice Island, Omega was used for navigation.

During the course of the survey the shot points and recording sites were reoccupied as the ice was stationary. The accuracy of the positions is believed to be within 1-5 m (J. Davison, personal communication, 1985). The transmitter positions were established by global positioning system (T.I. 4100) to an absolute accuracy of better than 40 m (J. Popelar, personal communication, 1986).

Gravity Measurements

Both gravimeters operated very well. Gravimeter G75, used as a base monitor, drifted 0.35 dial divisions in 10 days while the mobile gravimeter G498 drifted 0.55 dial divisions in the same time. This drift is much less than the 1.5 dial divisions that it experienced last year in the same time period. G498 was used in the undamped mode with gravimeter oscillations usually of about 3 eyepiece divisions. Observations were taken in three to five minutes to an accuracy of about 0.1 mGal.

Only one control station (No. 9211-86) was required on the Ice Island as the ice was stationary during the survey. Sixty-three detail stations (Nos. 10001-86 to 10063-86) were established along seismic spreads from J to K to L and Ice Island to P to R. (Fig.1). Due to a lack of helicopter time and a loss of about 5 hours with echo sounders, spreads L to M to N, R to S to T and T to B were not completed.

Gravity measurements were reduced to free-air and Bouguer anomalies by a method described by Tanner and Buck (1964) using the International Gravity Standarization Net (1971) and the Geodetic Reference System (1967).

Water Depth Measurements

Generally, the performance of the echo sounding equipment was unsatisfactory during traverse although the equipment appeared to work in the test mode. On the first traverse off the Ice Island ambiguous return echos were received and the depths did not correspond with the seismic depths obtained in 1985. Morley Wright checked out the echo sounders. He was able to produce a clear return signal from a metal plate across a building from a distance of about 20 feet. Then the equipment was taken by skidoo off the Ice Island where there was about 0.5 m of new smooth ice. After about 15 minutes of tuning the two sounders, a clear echo at 228 m was produced by both sounders. However, on returning to the camp, sounding through the 44 m thick Ice Island ice could not be obtained. Based on the clear sounding obtained off the Ice Island it was decided to use the echo sounder on traverse. However, the sounder failed again and the helicopter had to return to camp to fetch the seismic sounder. Seismic soundings at the stations where the echo sounder failed later showed the depths to be 550 and 611 m, respectively.

Two-way travel times were converted to water depths using Matthews' velocity-depth relationship (Matthews, 1939). This relationship was checked for the Arctic Ocean by Sobczak et al. (1973) and found to be adequate for sounding purposes.

RESULTS

(i) Field Progress

Locations, water depths, free-air anomalies, and Bouguer anomalies reduced at a density of 2.67 Mg/m^3 for the 1986 and earlier surveys are shown in Charts 1 to 3, respectively, at a scale of 1:1,000,000. Locations of gravity and water depth measurements (dots prior to 1985, crosses for 1985 and stars for 1986), seismic refraction shot points (lettered) and Syledis transmitters within the area bounded by latitude 78°N to 83°N and longitude 85°W to 115°W are shown in Figure 1. Figures 2 - 4 show bathymetry, free-air and Bouguer anomalies at page-size scale. In 1986 four out of nine seismic refraction spreads were completed (J to K to L and O to P to R). The gravity - bathymetry coverage along the remaining seismic spreads L to M to N, R to S to T and T to B lies in part within the 1963 survey area and the remainder will likely be covered in 1987 in a joint hydrographic-gravity program of the Departments of Fisheries and Oceans and Energy, Mines and Resources.

(ii) Water depths

Water depths are shown in Chart 1 and Figure 2. Twenty-six additional water depths, taken from the Arctic Geophysical Review (Sobczak and Sweeney, 1978), have been added to the unmapped area northwest of Nansen Sound and the area of the refraction lines. Two trans-shelf channels, perpendicular to the coastline, strike northwest from within the mouth of Nansen Sound and seaward of the mouth of Sverdrup Channel. These two channels, although still poorly mapped, are unique as they are the only ones to cut the shelf break of the Canadian Arctic Margin and will be referred to in this discussion as Nansen Channel and Sverdrup Channel, respectively. These channels are flanked by prominent plateaus which are about 250 to 400 m higher than the channel floors. During the winter months of 1985 and 1986 the Canadian Ice Island was stationary over the plateaus to the northeast and southwest of Nansen Channel respectively, and these will be referred to as the Canadian Ice Island Plateau East and the Canadian Ice Island Plateau West. The one southwest of Sverdrup Channel and northwest of Meighen Island will be referred to as the Meighen Plateau as it appears to be the seaward extension of Meighen Island.

Nansen Channel differs substantially from Sverdrup Channel. It is deeper, more V-shaped with deep pockets right into the mouth of Nansen Sound (maximum depth of 733 m) whereas Sverdrup Channel along the two intersecting seismic refraction lines is broader, flat bottomed and appears to be more filled in. The 300 m contour of the Sverdrup Channel meanders along the southern refraction line whereas in Nansen Channel it is located on the steep channel sides extending landwards into Nansen Sound. This eastern portion of Peary Channel curves around the western sides of Meighen and Axel Heiberg islands with a maximum sounding depth of 708 m just south of Meighen Island.

Canadian Ice Island Plateau West protrudes furthest seaward, is the most prominent of the three plateaus, and has the narrowest crest. It appears to be more ridge-like with a narrow top. The crest plunges seaward from a depth of 144m along the southern seismic refraction line to possibly 700 m where it merges with the margin slope.

Canadian Ice Island Plateau East is elevated about 100 m above the general level of the shelf to the northeast off the northwestern coast of Ellesmere Island and plunges northwestwards to a depth of 700 m were it merges with the slope. At the 300 to 400 m depth contour the plateau is quite broad with gentle slopes to the northeast merging with the shelf and steeper ones to the southwest merging with the steep flanks of Nansen Channel.

The Meighen Plateau appears to be a northwestward, seaward extension of Meighen Island. It has steeper slopes to the southwest into Peary Channel and shallower ones to the northeast into Sverdrup Channel.

The bottom morphology for this largely unmapped region, where seismic refraction lines have been carried out in 1985 and 1986, appears to be quite complex. Detailed regional surveys will be required to fully map these features.

(iii) Free-air anomalies

Free-air anomalies and the gravity field in general, observed prior to 1985 within the area of this map (Fig. 3, Chart 2) have been discussed (Sobczak, 1963; Weber, 1963; Sobczak et al., 1963; Sobczak and Weber, 1970, 1973; Sobczak and Overton, 1984; Sweeney et al., 1984; Sweeney et al., in preparation). The discussion on free-air anomalies in this report (Fig. 3, Chart 2) is primarily restricted to those shown along the seismic refraction lines completed in 1985 and 1986.

Generally, higher gravity values are noted over the plateaus and lower ones over the channels but not in a one to one relationship. Differences between the gravity - bathymetry relationship indicates an anomalous behavior of the gravity field. The free-air gravity high over the Canadian Ice Island Plateau East (maximum value +35.6 mGal) is localized over the southeastern end of the plateau, trends parallel to the coastline, extends over the eastern flank of Nansen Channel and has a steep gravity gradient (3.22 mGal per km) to the west along seismic line E-H and a gradient of 3.72 mGal/km to the south where in both areas the ocean bottom is quite flat. To the east, an east-west low, centred on Phillips Inlet (minimum value -51.6 mGal), crosses the the seaward end of the Canadian Ice Island Plateau East and appears to merge with a northwestward trending belt of lows along Nansen Channel.

Gravity lows along Nansen Channel are normal in some places and anomalous in others. At the eastern end of Nansen Channel, a low (minimum value of -20.2 mGal) is localized over an area with deepest (maximum 733 m) water depths (normal). On the other hand, the low (minimum -20.4 mGal) northeast of Hubbard, although centred over Nansen Channel, does not overlie the deepest portion (maximum depth 566 m) but lies about 20 km to the west. This low trends northwards across the southeastern end of the Canadian Ice Island Plateau East and also extends seaward along Nansen Channel but disappears between D-E where Nansen Channel is quite prominent. Here this low appears to cross the seaward end of the Canadian Ice Island Plateau West and links with the low over Sverdrup Channel.

The gravity high over the Canadian Ice Island Plateau West is not centred over the crest but is shifted to the west about 16 km over the western flank of the plateau and trends more or less north- south along meridian 97°W crossing the plateau at an oblique angle of about 60°. The steepest gravity gradient (2.28 mGal/km) occurs at the south end of the high where water depths also increase abruptly to the southwest.

A very broad low overlies the seaward end of Sverdrup Channel and does not appear to go much further southeastward than the most southern refraction line.

A relative gravity high overlies the Meighen Plateau but it is not very prominent.

Within the area of the seismic refraction lines the bottom morphology is quite disturbed which to a large degree has a corresponding effect on the free-air anomalies making it difficult to determine what areas are gravitationally anomalous. However, Bouguer anomalies in areas of shallow water tend to overcome some of this difficulty.

(iv) Bouguer anomalies

Bouguer anomalies (Fig. 4, Chart 3) within the vicinity of the seismic refraction lines indicate a large (peak value 51.1 mGal) elliptical anomaly which overlies Canadian Ice Island Plateau East and West and whose strike is parallel to the coast. This anomaly, above the 30 mGal contour, may differ from the way it is shown as there are no gravity observations across Nansen Channel in the vicinity of the crestal area of this high. Above the 30 mGal contour this anomaly may form two separate anomalies. From the southern flank of this elliptical anomaly, a spur of positive values extends across Nansen Channel towards Hubbard. Also, on the southern side of the eastern end of this anomaly, a spur of positive anomalies crosses Cape Bourne and overlies the eastern end of Nansen Channel. Between these spurs lies a relative low (minimum value +0.9 mGal) which overlies and crosses Nansen Channel from the Hubbard area to the Canadian Ice Island Plateau East. No prominent high overlies Meighen Plateau.

To the east of the elliptical high lies an extensive low (minimum value -29.2 mGal) which curves around the northern flank of this high crossing the northern sides of the Canadian Ice Island Plateau East and West. Normally, gravity lows occur along or just seaward of the coastline, (Fig. 4, Chart 3). These lows usually reflect a seaward thickening of low density sediments.

The high, over the Canadian Ice Island plateaus, with accompanying landward trending spurs is anomalous to the shelf area. It has a steep gravity gradient (3.22 mGal/km) and probably indicates a shallow dense mafic rock complex maybe similar to the multi-layered intrusions drilled and modelled in the vicinity of northern Ellef Ringnes Island (Sobczak, 1963; Sobczak and Overton, 1984, Sweeney et al., 1984; Sobczak et al. 1986). In addition, the adjoining north-south trending high which crosses Cape Bourne and overlies the mouth of Nansen Sound may also be related to the exposed rocks of the Bourne Complex, south along the northwestern coast of Ellesmere Island and the Unnamed Formation exposed on the first peninsula southeast of Lokk (Thorsteinsson and Trettin, 1972). The Bourne Complex, a hybrid terrain, includes volcanic flows with abundant diabase intrusions of unknown age and the Unnamed Formation includes volcanic basalt flows also of unknown age. Mafic intrusions and flows are usually dense (greater than 3.00 Mg/m^3) and are generally distributed within low-density, sedimentary, host rocks which in turn, increase the bulk density of the host rocks. These probable zones of mafic rocks, as depicted by the gravity highs, lie at the northeastern extension of the Sverdrup Rim and northwestern edge of the Sverdrup Basin (Sobczak et al., 1986, Fig. 1).

Recommendations

During 1985 and 1986 the Edo echo sounders failed to operate. It is estimated that as a result, about 5 hrs. of 206 L helicopter time was wasted in 1986 alone, at a cost of about $4500, nearly equivalent to the cost of a seismic sounder (Weber and Sobczak, 1986). In the future, while operating over the Arctic Ocean, we are recommending only the use of a seismic sounder exclusively and the purchase of a second backup sounder.

The gravity-bathymetry survey requires nearly the full time use of a helicopter during the refraction survey in unmapped areas.

Some effort should be made to have the S56 gravity measurements taken in 1985 reduced and available within a reasonable length of time.

Statistics

Project Number:	86-904
Gravimeters:	G498, G75
Edo 9040 echo sounders did not function properly	
Seismic sounder:	Astro - Med Dash II recorder and TC-200 capture/playback module
Field books:	86-3A, 86-3B
Control Stations used:	9211-86
Detailed Stations used:	10,001-86 to 10,063-86
Observers:	L.W. Sobczak, J.R. Weber
Transportation:	Bell 206L helicopter, PDU
Pilot:	Marc Hutcheson
Engineer:	Jody McCrae
Navigation:	Syledis with filter 41

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Captions

Figure 1 Location of gravity and water depth measurements. Dots prior to 1985, crosses for 1985 and stars for 1986. The shot points in the refraction program are lettered.

Figure 2 Water depths in meters (contours at 100 m intervals).

Figure 3 Free-air anomalies (contours at 10 mGal intervals).

Figure 4 Bouguer anomalies (contours at 10 mGal intervals), $\rho = 2.67$ Mg/m^3.

Charts

Chart 1 Water depths in meters corrected using Matthews' 1939 velocity to water-depth relationship. Contours are at 100m intervals. Scale is 1:1,000,000. Projection is polar stereographic.

Chart 2 Free-air anomalies. Contours are at 10 mGal intervals. Scale is 1:1,000,000. Projection is polar stereographic.

Chart 3 Bouguer anomalies reduced at a density of 2.67 Mg/m^3 using the International Gravity Standardization Net 1971 and the Geodetic Reference System 1967. Contours are at 10 mGal intervals. Scale is 1:1,000,000. Projection is polar stereographic.

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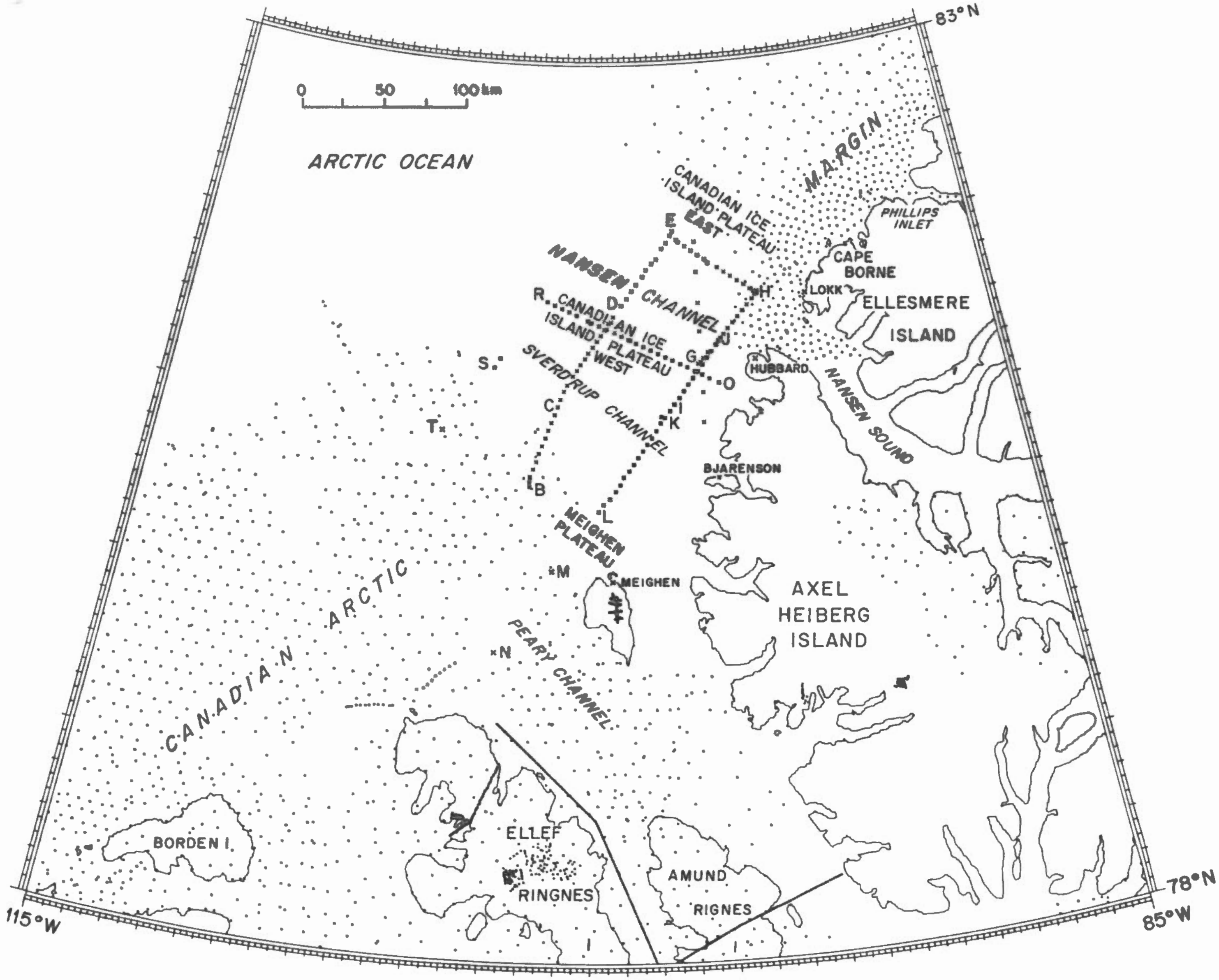

INTERNAL. CANADA ICE ISLAND . STATION POSITION
MAP PROJECTION IS POLAR STEREOGRAPHIC. SCALE IS 1/ 2500000
JUNE 19, 1986 AT TIF Y

----------- LEGEND FOR SYMBOLS -----------
• STATIC LAND OBSERVATION
• STATIC SEA/LAKE ICE OBSERVATION
• OBSERVATION WITH AN UNKNOWN DEPTH

FIG. 1

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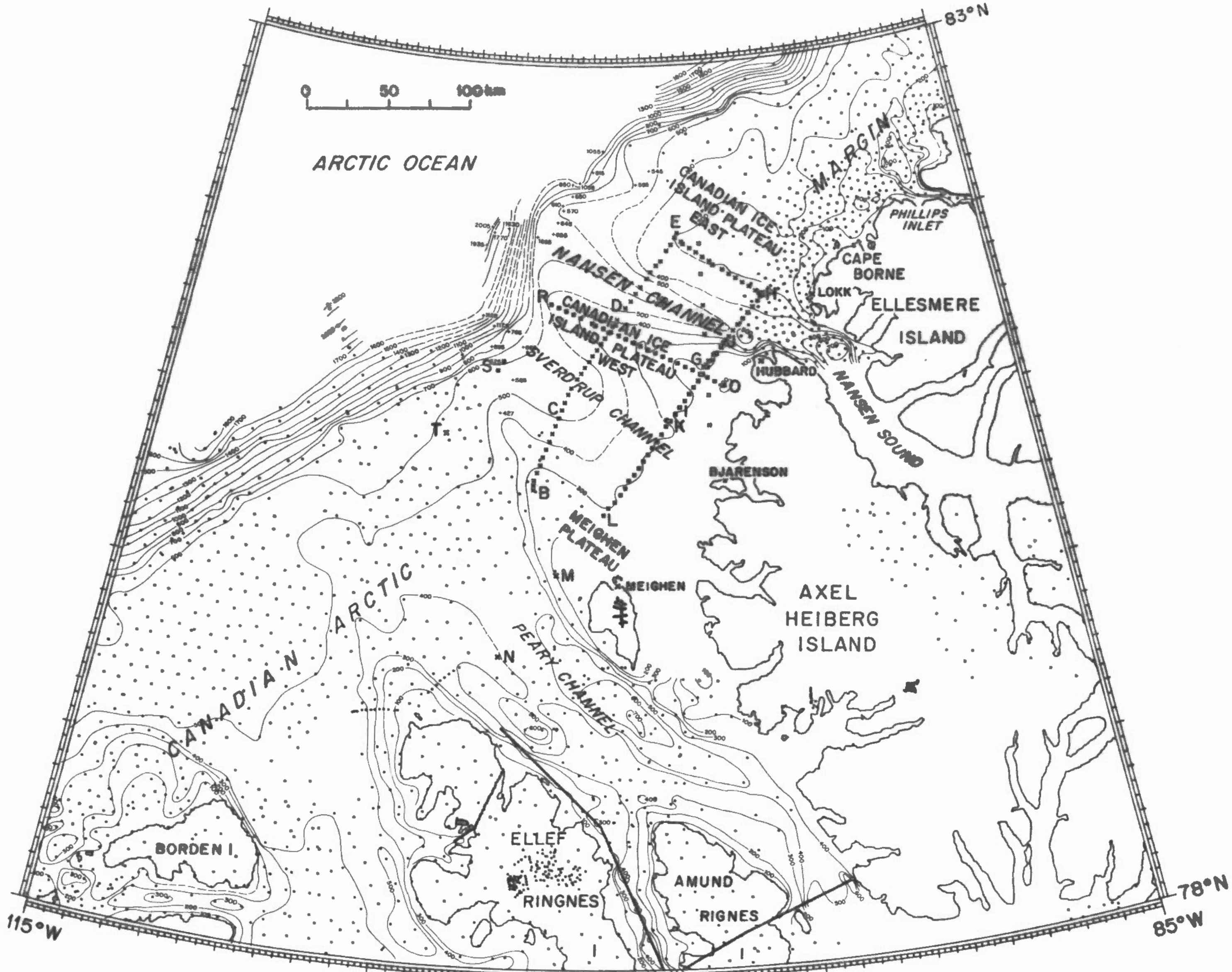

FIG. 2

INTERNAL. CANADA ICE ISLAND . STATION POSITION
MAP PROJECTION IS POLAR STEREOGRAPHIC. SC/ 1/ 2500000
JUNE 19, 1986 AT TIME 20.:

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* STATIC SEA/LAKE ICE OBSERVATION
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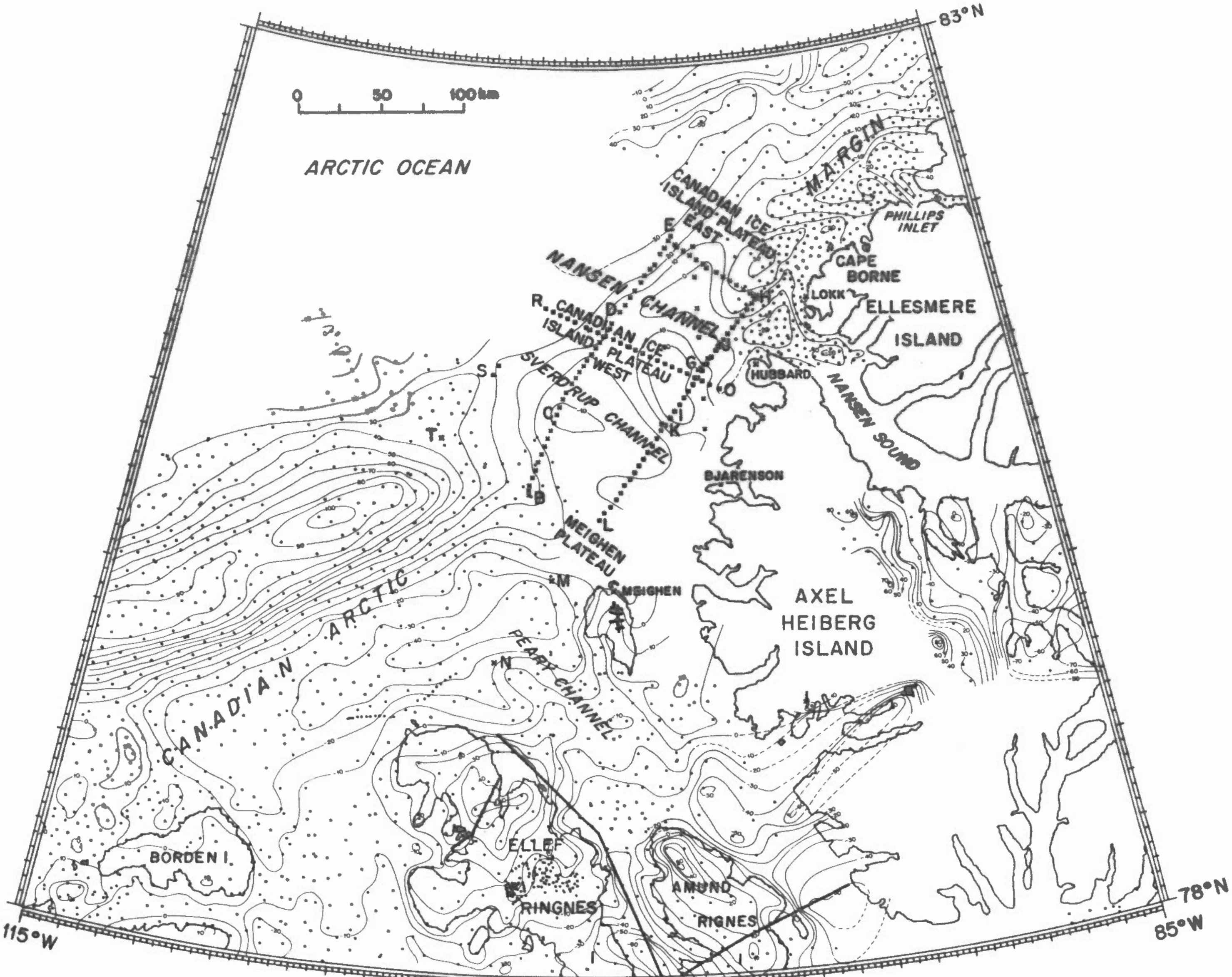

Fig. 3

INTERNAL. CANADA ICE ISLAND . STATION POSITION
MAP PROJECTION IS POLAR STEREOGRAP CALE IS 1/ 2000000
JUNE 19, 1988 AT 1 37

---------- LEGEND FOR SYMBOLS ----------
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• STATIC SEA/LAKE ICE OBSERVATION
OBSERVATION WITH AN UNKNOWN DEPTH

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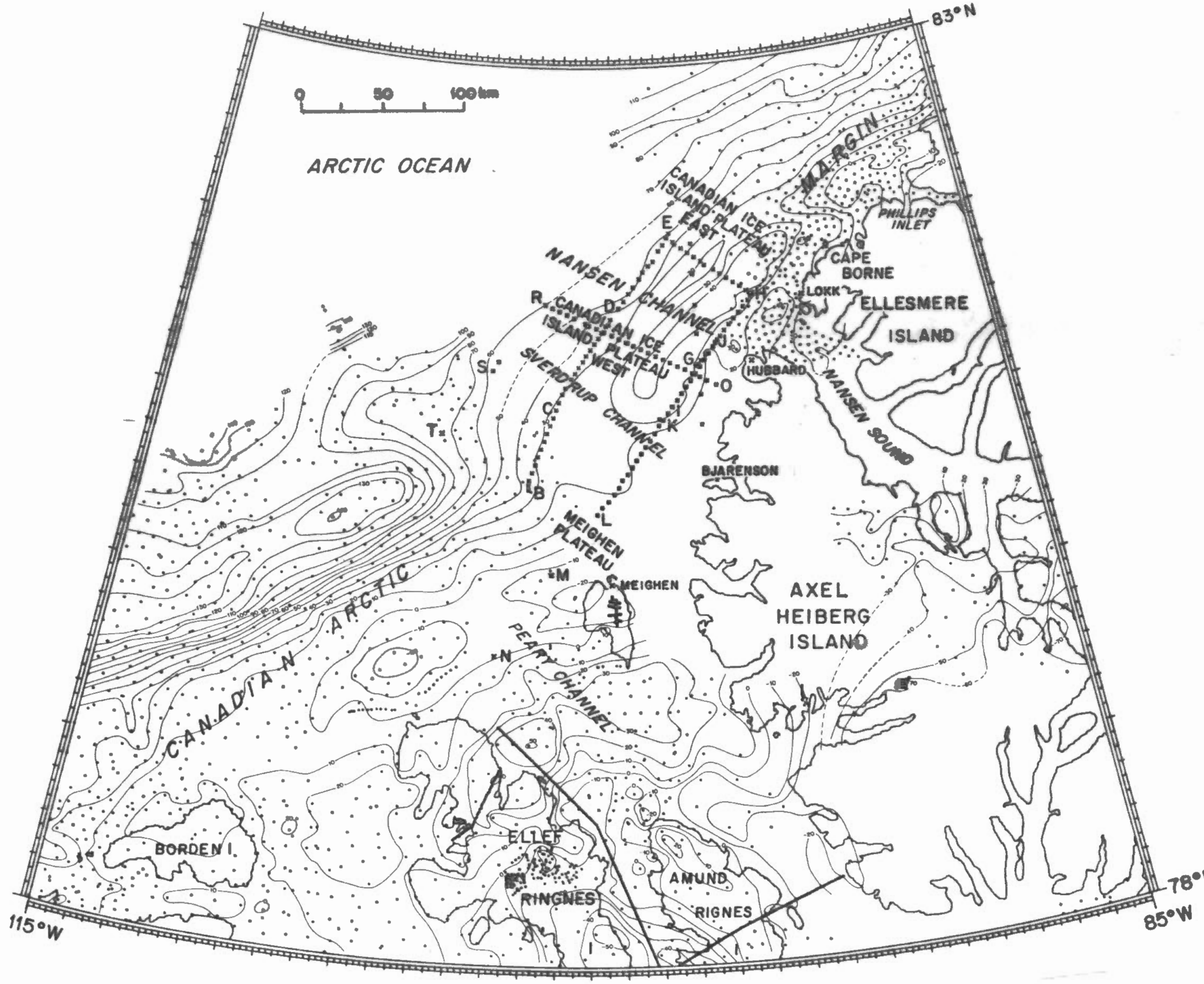

FIG. 4

INTERNAL. CANADA ICE ISLAND . STATION POSITION
MAP PROJECTION IS POL EOGRAPHIC. SCALE IS 1/ 2500000
JUNE) AT TIME 20.37

--------- LEGEND FOR SYMBOLS ---------
- STATIC LAND OBSERVATION
- STATIC SEA/LAKE ICE OBSERVATION
- OBSERVATION WITH AN UNKNOWN DEPTH