

043 Design of an Iceberg Scour
Repetitive Mapping
Network for the
Canadian East Coast

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DESIGN OF AN ICEBERG SCOUR REPETITIVE MAPPING NETWORK
FOR THE CANADIAN EAST COAST

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SUMMARY

This report provides recommendations for the establishment of a repetitive seabed mapping network for the purpose of monitoring the recurrence rates of iceberg-seabed interactions on the eastern Canadian continental shelf. The selection of control areas and corridors making up the network is based on a detailed analysis of predicted grounding densities, generated by a computer model developed at the Atlantic Geoscience Centre, combined with available information on existing iceberg scours, observed and interpreted groundings and scours, seabed geologic conditions, and existing geophysical data. The recommended network includes one control mosaic on Makkovik Bank, two control corridors (long, narrow swaths) on Hamilton Bank, and four possible control corridors on Grand Bank. This network covers a variety of water depths and surficial geologic conditions over a broad geographic range, thus ensuring that the results will be applicable to many other areas on the shelf. The size and orientation of each control area or corridor, the geophysical instruments to be used, the survey techniques, and the recommended intervals between surveys have all been specified and are designed to ensure optimum probability of successful, complete, and reproducible data collection. Past experience with repetitive mapping has shown that changes in the above parameters from one survey to the next reduces the chances of documenting new iceberg scour features. Besides providing quantitative data on the recurrence rates of iceberg impacts, the repetitive mapping program will also provide useful information concerning the rate of obliteration of existing iceberg scour features and sediment mobility within the control areas and corridors.

RÉSUMÉ

Ce rapport contient des recommandations concernant l'établissement d'un réseau cartographique systématique répété qui permette le suivi des interactions iceberg-fond marin sur la plateforme continentale Est du Canada.

La sélection des zones et des corridors composant ce réseau est établie à partir d'un modèle informatisé développé au Centre Géoscience Atlantique (CGA) et de données existantes sur les traces marines, les zones d'échouage et les conditions géologiques et géophysiques. Le réseau proposé comprend une zone de contrôle sur le banc Makkovik, deux corridors (longs et étroits) sur le banc d'Hamilton et quatre corridors de contrôle sur le Grand Banc. Ce réseau couvre une variété de profondeurs et de conditions géologiques étendue, assurant ainsi la possibilité d'extrapoler les résultats à d'autres régions. La taille et l'orientation de chaque zone, les instruments géophysiques à utiliser, les techniques de cartographie et l'intervalle recommandé entre deux passages font l'objet de spécifications précises de manière à assurer une collecte de données complète et fiable. Des expériences passées ont prouvé que les changements de paramètres d'un passage à l'autre réduisent les chances de documenter adéquatement les nouvelles traces. En plus d'apporter des données nouvelles sur la fréquence d'impact des icebergs, ce programme fournira également des informations concernant le rythme auquel les traces disparaissent et permettra de contrôler la mobilité des sédiments dans les zones étudiées.

1.0 INTRODUCTION

Production of offshore hydrocarbon reserves on the continental shelf east and north of Newfoundland will require installation of subsea facilities including gathering lines, well-head structures, and, possibly, pipelines. Of concern in the design and protection of these facilities is the process of scouring of the seabed by drifting icebergs. Quantitative data concerning the recurrence rates of iceberg-seabed interactions for a given area are particularly important. A reliable method for determining iceberg scour recurrence rates is repetitive seabed mapping using echo sounder, sidescan sonar, and high resolution subbottom profiler systems to provide data on the number and character of new scour events over a given period. This method, which has been used successfully for sea ice scours in the Beaufort Sea area (Lewis 1978; Hnatiuk and Wright 1983; Shearer et al. 1986), involves establishment of a network of control areas or corridors on the seabed which may be accurately resurveyed on a periodic basis. Detailed and accurate remapping of the selected areas and corridors not only provides absolute recurrence rates but also yields information concerning the character of the new scours or pits (depth, width, and orientation versus water depth, seabed slope, and surficial material) and allows for qualitative estimates of the rate of degradation of existing scours. These data may then be used to verify and refine theoretical models of scour recurrence rates (Lewis 1978; d'Apollonia and Lewis 1986). Information on the statistical distribution of new, undegraded scours, as provided by a remapping program, is essential for the prediction of the incidence of future deep scours (Gaskill et al. 1985).

This report provides recommendations for the establishment of a repetitive mapping network for the Canadian eastern offshore region, including the location and size of control areas and corridors, the interval between surveys, the survey equipment, and survey techniques with grid orientation. The proposed network and techniques are designed to optimize the successful collection of complete and reproducible data.

2.0 METHODOLOGY

The selection of control areas or corridors in areas where there is a high probability of seabed scouring by icebergs is of paramount importance to the success of any iceberg scour repetitive mapping program. To this end a numerical model developed at the Atlantic Geoscience Centre to forecast the spatial distribution of iceberg grounding events (d'Apollonia and Lewis 1986) has been used in the design of the iceberg scour repetitive mapping network recommended here. Though this model is in the early stages of assessment and was uncalibrated at the time of its application in this study, the output is considered useful in illustrating the anticipated nature of the regional distribution of groundings based on iceberg arrival data. This model simulates mean long-term iceberg grounding¹ events given information on iceberg flux, draught distribution, and bathymetry, assuming net unidirectional iceberg drift. The model is run for a predetermined regional grid with cells of 5 x 5 nautical miles (9.3 x 9.3 km). For each model cell, the mean number of iceberg groundings is calculated as the product of the mean iceberg flux and the proportion of icebergs that interact with the bathymetry. The total mean flux through each row of cells comes from independent iceberg observation (see Section 3.4). The range in water depths, plus an allowance for scouring depth and iceberg draught changes because of tilt and roll, is applied to the given iceberg draught distribution to determine the proportion of icebergs that ground in each cell. The model also includes an option to simulate decline of the iceberg population and decrease in iceberg draught

1 "Grounding" is used to denote any iceberg-seabed interaction.

resulting from iceberg break-up and ablation processes. Model results are used to generate contoured plots of the predicted number of groundings per unit area (usually per square kilometre) for a given period (10 to 1,000 years). The reader is referred to d'Apollonia and Lewis (1986) for a more complete discussion of the assumptions and limitations of the model.

In this study the model was applied to the Labrador Shelf and northern Grand Bank regions only. The Baffin Island and Lancaster Sound regions farther north are well suited to iceberg repetitive mapping programs but are more difficult and costly to survey accurately and are far removed from the areas of current exploration.

Given the areas of potentially high recurrence rates for groundings predicted by the model and supported by existing scour density and inferred grounding data, three other criteria were considered prior to choosing the location of the survey network:

- a) Regional and local surficial geology. It is well known that the character of the top few metres of the seabed controls, to a certain degree, the nature of a given scour as well as the subsequent preservation of that scour. For instance, scours formed in soft, muddy, cohesive sediments, such as those in the Beaufort Sea, are usually well defined and relatively resistant to degradation (Lewis 1978), whereas those formed in loose, friable, sediments, such as sands on the eastern Canadian offshore banks, are poorly defined and may be rapidly eroded (Lewis and Barrie 1981; Josenhans and Barrie 1982). In order to understand the longevity of scours in different sediment types, the repetitive

mapping network was chosen to cover a variety of surficial geologic conditions. These selections will ensure that the findings may be extrapolated to as many areas with similar seabed conditions as possible.

- b) Existing seabed survey data. To optimize cost effectiveness and efficiency, existing regional, site-specific, and sidescan mosaic data were considered when selecting the locations of the control areas and corridors. In addition, the original survey equipment and techniques used to collect existing data were considered when choosing equipment for the new repetitive mapping network in order to ensure that new and previous records will be comparable.

- c) Potential development sites. Those areas in which active exploration and development planning are continuing represent areas of needed information and therefore are prime locations for control areas and corridors. In such areas which fail to satisfy the criteria discussed above, for example the Hibernia study area where predicted grounding rates are very low and seabed conditions are poor for scour preservation, an attempt was made to choose an area with similar bathymetric and geologic conditions but higher predicted grounding rates. The data may then be extrapolated to the area of interest. This approach recognizes that, whereas the absolute number of scours in the two areas will not be the same, the character of new scours should be comparable for a given size of iceberg.

3.0 DATA COLLECTION AND MODEL INPUT

The project identified two study regions: the Labrador Shelf and northern Grand Bank. Each region was divided into a grid with cells of 5 x 5 nautical miles (9.3 x 9.3 km) and, for each cell, the inputs included cell centre co-ordinates, minimum and maximum water depth, and relative iceberg density. In addition, available regional data concerning current speed and direction, iceberg flux, and draught distribution were incorporated.

3.1 BATHYMETRY

Bathymetric data for the Labrador Shelf were compiled from existing 1:250,000 charts contained in the Geological Survey of Canada Open File Report No. 1081 (1984). Bathymetric data for northern Grand Bank were compiled from 1:250,000 scale Natural Resources Charts (Canadian Hydrographic Service Reference Nos. 15060, 15070, 14968, 14978, 14966, 14976). Cells were identified by a row and column number, and minimum and maximum water depths for each cell were noted.

3.2 ICEBERG DENSITY DISTRIBUTION

Data on the relative seasonal density distribution of icebergs traversing the Labrador Shelf area have been compiled by Gustajtis and Buckley (1978) using International Ice Patrol (IIP) data collected from 1963 to 1977 inclusive. These data are presented on four colour charts (spring, summer, fall, and winter) published by the Centre for Cold Ocean Resources Engineering (C-CORE) at a scale of

1:2,000,000. A 1:2,000,000 plot of the model grid was overlain on these charts and the iceberg density at the centroid of each 5 x 5 nautical mile cell was digitized for all four seasons.

The number of icebergs in each grid cell on northern Grand Bank was counted using 11 years of IIP data from 1968 to 1978. Calculations were made of the icebergs in each cell as a fraction of the total number of sightings of bergs in 5-nautical-mile segments of latitude. The results approximate the relative average iceberg density in each cell for the period 1968 to 1978, expressed as a fraction of the total number of icebergs sighted in each respective zone of cell latitudes. Incomplete coverage in this region required that a larger cell size (15 x 15 nautical miles, or nine 5 x 5-nautical-mile cells) be used. The densities were assigned to the centroids of these larger areas and the data were then smoothed.

3.3 ICEBERG DRAUGHT DISTRIBUTION

The most comprehensive iceberg draught data set for the east coast Canadian offshore is that compiled by Petro-Canada Exploration Inc. on the Labrador Shelf (Hotzel and Miller 1983). This data set, which includes a total of 258 draught measurements, was made available to ESRF for use in the Atlantic Geoscience Centre (AGC) grounding model. In addition, 214 iceberg draught measurements made between latitudes 49° and 75°N during 1972 to 1979 are reported by El-Tahan and El-Tahan (1982) and El-Tahan et al. (1985).

For the Grand Bank region, two different draught distributions were applied during successive model runs. A

theoretical draught distribution developed by Hotzel and Miller (1983) was modified slightly by extrapolating the tail of the distribution from 90 m to 245 m (d'Apollonia and Lewis 1986) and adopted for use in the AGC grounding model as the "baseline" distribution for this region. Additionally, a recent draught distribution released by Mobil Oil Canada, Ltd. (1985) based on measurements of 113 icebergs in the region was used.

3.4 ICEBERG FLUX

Several published observations and estimates of the mean total annual iceberg population crossing a given degree of latitude now exist (Murray 1969; Anderson 1971; Ebbesmeyer et al. 1980; Lewis and Benedict 1981). For the purpose of this study, mean populations of 2,800 icebergs per year crossing latitude 61°N , 2,300 icebergs per year crossing latitude 56°N , and 400 icebergs per year crossing latitude 48°N were chosen (Ebbesmeyer et al. 1980). The mean annual iceberg flux passing through each cell was calculated as the product of the fractional relative iceberg density in each cell (see Section 3.2) and the total annual iceberg flux across the cell latitude. An optional distribution of the total flux was available where regional mean currents were known. In this option the cross-latitude flux was apportioned by the ratio of the product of mean southward current speed and average iceberg density in each cell to the sum of products of current speeds and iceberg densities for the whole segment of latitudes to which the total flux applies.

3.5 CIRCULATION

Generalized regional circulation patterns (current speeds and direction) were used in the AGC grounding model to calculate the mean relative annual iceberg flux through individual cells given the observed relative density. Model runs for northern Grand Bank were made assuming the following mean southerly iceberg drift speeds: 0.1 m/s in water depths of <110 m; 0.3 m/s in water depths of 110 to 150 m; 0.5 m/s in water depths of >150 m based on estimates given by Petrie and Anderson (1983).

For the Labrador Shelf, local current measurements compiled by Oceans Limited for another ESRF study (Woodworth-Lynas et al. 1985) being carried out by C-CORE have been made available for future calibration of the estimated regional circulation.

4.0 MODEL OUTPUT AND ASSESSMENT

In this section the patterns of predicted groundings generated by the AGC model for the Labrador and northern Grand Bank regions are described and assessed against existing iceberg scour densities, documented iceberg groundings, surficial geology, and existing seabed surveys and mosaic data.

4.1 LABRADOR SHELF

4.1.1 Output from Model

A map of predicted groundings covering the Labrador Shelf between latitudes 53° and 61°N at a scale of 1:1,000,000 (see Chart 1) was generated with the following inputs:

Period - 100 yr

Iceberg density - average annual density from
Gustajtis and Buckley (1978)

Draught distribution - Petro-Canada data set

Iceberg flux - 2,800 bergs/yr at 61°N, 2,300 bergs/yr at
56°N

Currents - uniform (see Section 3.5)

In addition, a map covering Makkovik Bank at a scale of 1:250,000 (see Chart 2) was generated as follows:

Period - 100 yr

Iceberg density - average annual density from
Gustajtis and Buckley (1978)

Draught distribution - Petro-Canada data set

Iceberg flux - 2,300 bergs/yr crossing 56°N
Currents - uniform (see Section 3.5)

This map allowed detailed comparisons with existing geologic and bathymetric data.

In general, the number of predicted groundings on the Labrador Shelf is strongly controlled by bathymetry, with the highest number of predicted groundings occurring in the areas of shallowest water on the top of the banks. On initial runs, the model also predicted high grounding densities in inshore areas west of northern Saglek Bank and at the southern end of Cartwright Saddle. This prediction is because the model is sensitive to the rough seabed topography found in the inshore zone which causes excessive modelled groundings.¹ These anomolous grounding areas were not used in the study.

Highest predicted grounding densities occur on Makkovik and Harrison Banks (35 to 40/km² in 100 yr). On Saglek and Nain Banks the predicted groundings are much lower (16 to 20/km² in 100 yr) but occur over larger areas of the seabed. Predicted grounding rates are lowest on Hamilton Bank (maximum 10/km² in 100 yr) and occur mostly along the shallow western margin of the bank.

4.1.2 Iceberg Scour Density

A regional map containing information concerning iceberg scour density on the Labrador Shelf (see Chart 3), compiled from existing regional survey data, has been used to assess the areas of high rates of iceberg grounding predicted by the AGC model. Chart 3 was produced as part of an ongoing

1 S. d'Apollonia, AGC, personal communication, 1985.

ESRF program (Regional Ice Scour Data Base Update Studies) and also contains information on scour orientation, depth, and width as well as qualitative assessments of scour character (King and Gillespie 1986). Measurements from the region (Hotzel and Miller 1983; El-Tahan and El-Tahan 1982; El-Tahan et al. 1985) indicate maximum iceberg draughts of 220 m, suggesting that modern iceberg-seabed interactions do not occur or are infrequent below these depths. Supporting this conclusion, regional sidescan data show a marked change from well-defined to subdued, degraded-looking scours in water deeper than about 220 to 230 m. For this reason, scours below 220 m on the ESRF map are assumed to be relict.

Thus all modern scouring is restricted to bank areas and to the shallow inshore zone. For the Labrador bank areas, the contoured predicted grounding data closely mimic bathymetry contours, with the highest number of groundings occurring in the shallowest water. Actual scour densities, defined by regional sidescan coverage (see Chart 3), are highest on the banks although local variations do occur, probably as a result of (a) bathymetric sheltering; (b) local current variations which deflect icebergs; (c) unfavourable geologic conditions, such as exist on southern Hamilton Bank where bedrock is close to the surface; or (d) rapid degradation of scours by currents and other agents.

Measured scour densities are highest on Saglek Bank and generally decrease southward. This distribution pattern is at variance from the model results, which show that the highest predicted number of groundings occurs on Makkovik and Harrison Banks farther south. This discrepancy most likely reflects the effect of varying surficial geologic and

oceanographic conditions on the different bank areas (see Section 4.1.4).

4.1.3 Iceberg Grounding Occurrences

Woodworth-Lynas et al. (1985) have used radar-tracking data in combination with measured draught data and detailed bathymetric data to identify grounded (stationary) and scouring icebergs on Saglek and Makkovik Banks, for the period 1973 to 1981 inclusive. Figures 1 and 2 illustrate the position of icebergs interpreted as grounded and the path of icebergs interpreted to be scouring. The criteria used to identify grounded and scouring icebergs and the seasonally limited observation periods are believed to produce a minimum estimate in the published results. Nevertheless, these data are useful as a calibration of the density of groundings predicted by the AGC model.

For Saglek Bank, iceberg trajectory observations exist for a total of six drilling seasons (August to October) covering an area of about 14,000 km². During these periods, 604 icebergs were observed and 26 (or 4.3%) were interpreted as grounded or scouring. This number is equivalent to 46 groundings per annum assuming the average monthly flux across latitude 59°N published by Anderson (1971), or roughly 0.33 groundings/km² for a 100-year period. The AGC model predicts an average of 7.0 groundings/km² for the same period. Even when the inherent insensitivity of the model used by Woodworth-Lynas et al. (1985), particularly its inability to detect scouring icebergs which did not first ground and icebergs grounded for periods of less than 12 hours, is taken into account, the numbers predicted by the AGC model still appear to be high. Part of this discrepancy arises because the flux across latitude 59°N used in the model run (2,355 icebergs/yr) is more than double that

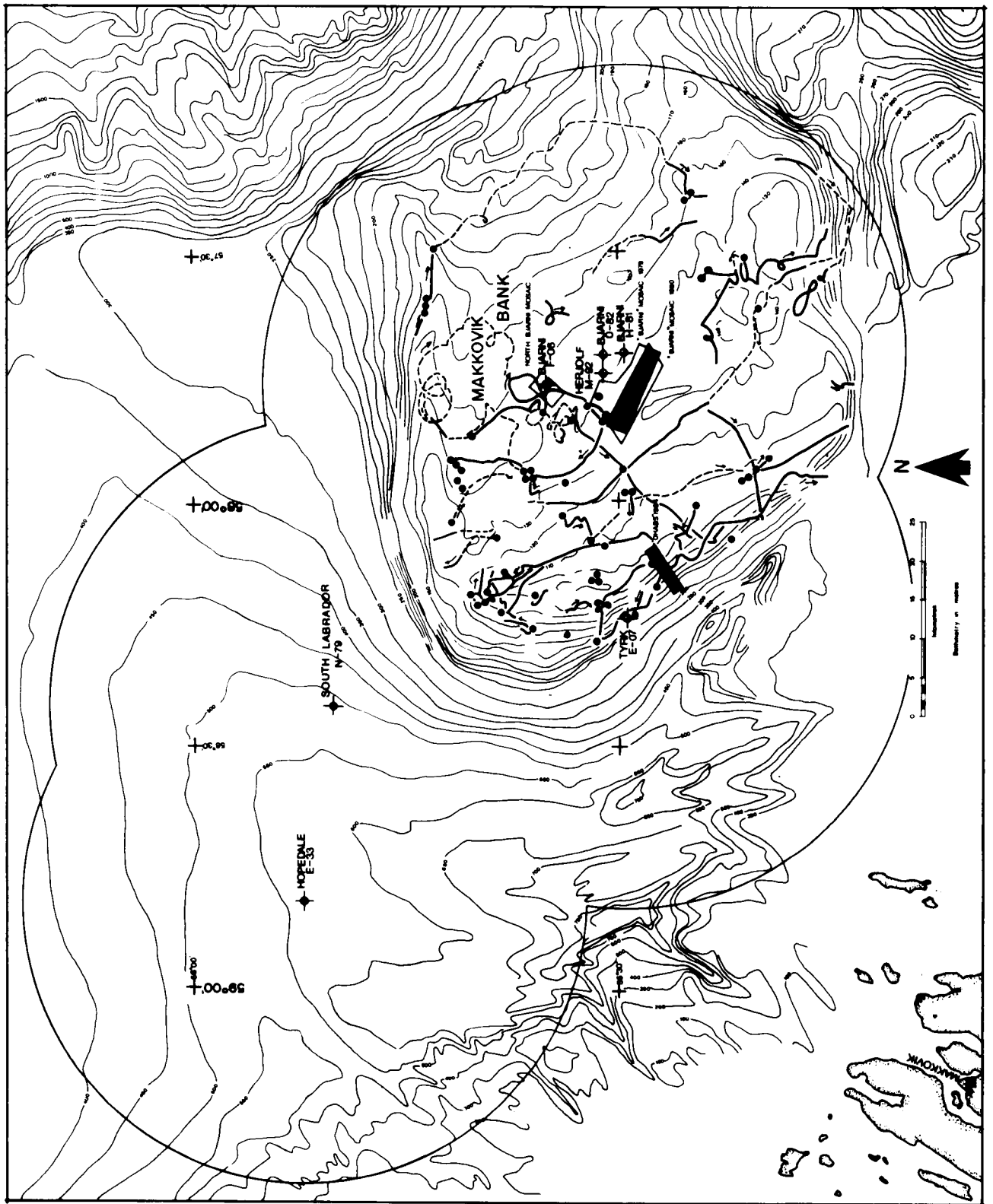


Figure 1: Interpreted iceberg groundings (dots) and scour tracks (solid lines) on Makkovik Bank, Labrador. Dotted lines represent free-floating paths of icebergs which grounded or scoured more than once (after Woodworth-Lynas et al. 1985).

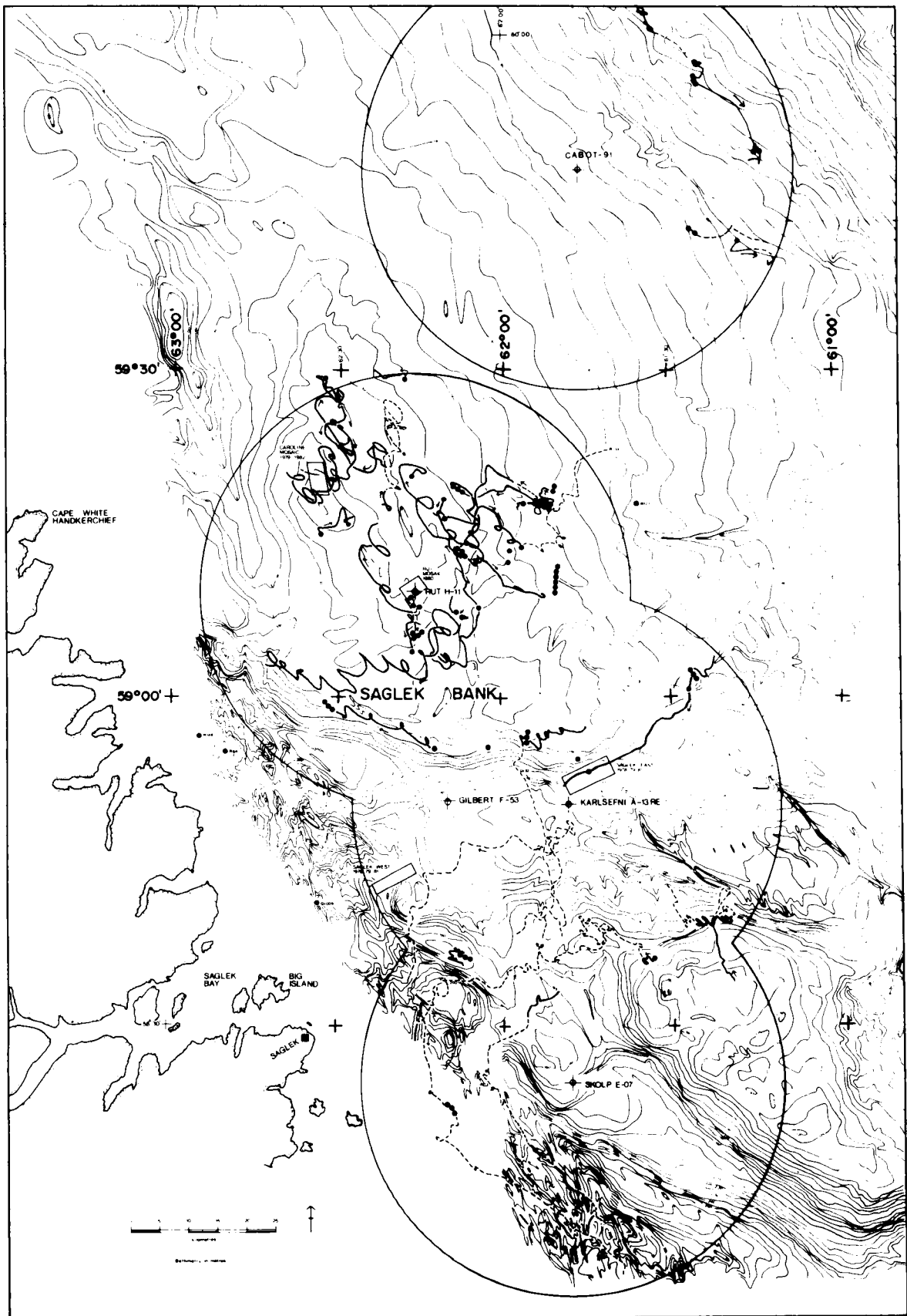


Figure 2: Interpreted iceberg groundings (dots) and scour tracks (solid lines) on Saglek Bank, Labrador. Dotted lines represent free-floating paths of icebergs which grounded or scoured more than once (after Woodworth-Lynas et al. 1985).

published by Anderson (1971) of 1,100 icebergs/yr. If this difference is taken into account the number of groundings predicted by the model is still about ten times that predicted by Woodworth-Lynas et al. (1985).

On Makkovik Bank, drill-rig radar observations exist for an area of about 10,500 km² over a total of seven drilling seasons. During these periods 30 icebergs were interpreted as grounded or scouring (Woodworth-Lynas et al. 1985). This number is equivalent to 430 groundings every 100 yr or an average of 0.05 groundings/km² in 100 yr. A similar study (El Tahan et al. 1985) inferred 52 groundings on Makkovik Bank out of 951 iceberg trajectories. The AGC model predicts average values of 7.6 groundings/km² in 100 yr over the same area which represents many times the number of groundings interpreted by Woodworth-Lynas et al. (1985). However, if the data of Woodworth-Lynas et al. (1985) are normalized to a yearly rate by using the monthly flux data published by Anderson (1971), the grounding rate is increased to 0.31 groundings/km² in 100 yr. Thus the model predicts 24.5 times the number of groundings observed, which may be reduced to a factor of 10 times if differences in assumed flux rates are taken into account. Refinements of the criteria used to identify scouring bergs could potentially increase groundings by 20 to 40%¹ indicating that the predicted grounding rates of the AGC model would still be high.

It should be emphasized here that, although the AGC model predicts numbers of groundings over an extended period (i.e., absolute scouring frequency), it is more realistic to view the results as an indication of the relative spatial

1. A. Simms, C-Core, personal communication, 1985.

distribution of grounding intensity. Aside from errors or inaccuracies of input data, discrepancies between inferred grounding rates and modelled grounding rates could mean that some of the model assumptions are invalid or, as already mentioned, the grounding rates inferred from radar observations may well be underestimated. It is possible that the actual scouring rate is bounded by the two estimates, which emphasizes the need for more direct information such as would be provided by a repetitive mapping program.

4.1.4 Surficial Geology

The surficial geology of the Labrador Shelf has been interpreted and compiled by Josenhans et al. (1986) from regional survey data. Chart 4 shows the surficial geology at a scale of 1:1,000,000. The area surrounding Makkovik Bank is illustrated in more detail on Chart 5. A complete discussion of the surficial geology of the Labrador Shelf is given by Josenhans et al. (1986). The predicted groundings maps were compared with the surficial geology to determine which areas best combine high rates of scouring with bottom conditions most suitable for recording and preserving scours.

The best sediments for recording and preserving scours are cohesive, muddy silts and sands (Units 4, 5A, and 5C on Chart 4). These types of sediments occur for the most part in off-shelf areas below the depth of modern scouring. However, muddy silts and sands do occur on Saglek Bank, particularly in Karlsefni Trough.

Bank-top areas on the Labrador Shelf usually consist of overconsolidated glacial tills, gravel lags, and mobile sands which are not ideal for recording and preserving scours but which do provide a variety of environments in

which to study scours. On southern and central Hamilton Bank, Tertiary bedrock occurs close to, or at, the seabed. This setting is similar to the geology of the Hibernia area of Grand Bank. Thus, these two areas have similar geological and environmental settings.¹

4.1.5 Existing Survey Data

Chart 6 illustrates track lines for existing Atlantic Geoscience Centre (AGC) surveys, the location of seabed mosaics compiled by C-CORE, and the position of exploratory wells on the Labrador Shelf.

Regional sidescan sonar and subbottom profiler survey coverage exists in all areas with high rates of predicted groundings. The best data coverage comes from Saglek and Makkovik Banks. Most of the track data on Hamilton Bank from AGC cruise 73-027 is of poor quality and this bank is the least understood area on the Labrador Shelf. Limited subsequent data collected by AGC (83-030) is of good quality. For the most part, regional sidescan sonar data were collected using the BIO 70-kHz system with a 1.5-km swath width (Jollymore 1974). Differences in resolution make this system's data incompatible with the 100-kHz, 400-m swath-width data required for a high-quality repetitive mapping network. However, remapping the AGC lines with 70-kHz sidescan sonar should produce comparable data though not of as high resolution as 100-kHz data. The 70-kHz data provide a good regional picture into which the repetitive mapping network may be fitted. Subbottom profiler data collected by BIO using the Huntec DeepTow Seismic (DTS) system will be compatible with data collected during the repetitive mapping program but generally will be of poorer

1 H. Josenhans, AGC, personal communication, 1985.

quality as a result of higher survey speeds. A fundamental problem in using existing AGC data in the repetitive mapping network is the lower navigational standards used when conducting regional surveys which may make it difficult to accurately relocate the same area of the seabed for repetitive surveys.

Sidescan sonar mosaics of the seabed have been compiled by C-CORE for small areas of every bank on the Labrador Shelf (see Chart 6). Data quality varies from poor to good. The best mosaics occur on Saglek Bank (Saglek East and West) and on Makkovik Bank (North Bjarni). Both the Saglek West and North Bjarni mosaics have been surveyed more than once, however, the failure to cover 100% of the previous survey area or to survey with the same equipment and in the same orientation in successive years has resulted in a lack of success in identifying new scours or other seabed changes (Woodworth-Lynas and Barrie 1985). In addition, the location and orientation of the mosaics has not been optimal within the framework of local scouring conditions.

4.2 NORTHERN GRAND BANK

4.2.1 Output from Model

Model results for northern Grand Bank (46° - 48° N, $47^{\circ}15'$ - 52° W) were generated with the following inputs:

Period: 1,000 yr

Iceberg density: IIP data compiled by Fenco (Nfld.)
Ltd.;

Draught distribution: "Baseline" and Mobil Oil
Canada, Ltd. (1985) (see
Section 3.3)

Two maps (Figures 3 and 4) were produced by running the model using the two different draught distribution data sets.

Figure 3 illustrates the predicted groundings assuming the "baseline" draught distribution. The map is contoured in number of groundings/km² in 1,000 yr. Maximum values of 24 groundings/km² are predicted. A high number of predicted groundings occurs just north of Downing Basin in 100 to 140 m of water. This area has rough seabed topography, and there is some possibility that the number of predicted groundings may be overestimated in this area because the model is sensitive to bottom roughness.

Figure 4 illustrates predicted groundings when the draught distribution information from Mobil Oil Canada, Ltd. is applied to the model. The pattern of groundings is similar to that predicted using the "baseline" draught distribution. A high concentration of predicted groundings again occurs north of Downing Basin and the same cautions apply as were stated previously. A band of higher numbers of predicted groundings follows the northeast margin of the bank in water depths of 100 to 150 m. For both model runs, predicted groundings in the Hibernia study area are very low.

4.2.2 Iceberg Scour Density

Chart 7 illustrates existing iceberg scour densities compiled from regional sidescan sonar and subbottom profiler records collected by the Atlantic Geoscience Centre. These data were compiled originally as part of the ESRF Regional Ice Scour Data Base Update Studies (Geonautics Limited in prep.).

Figure 3

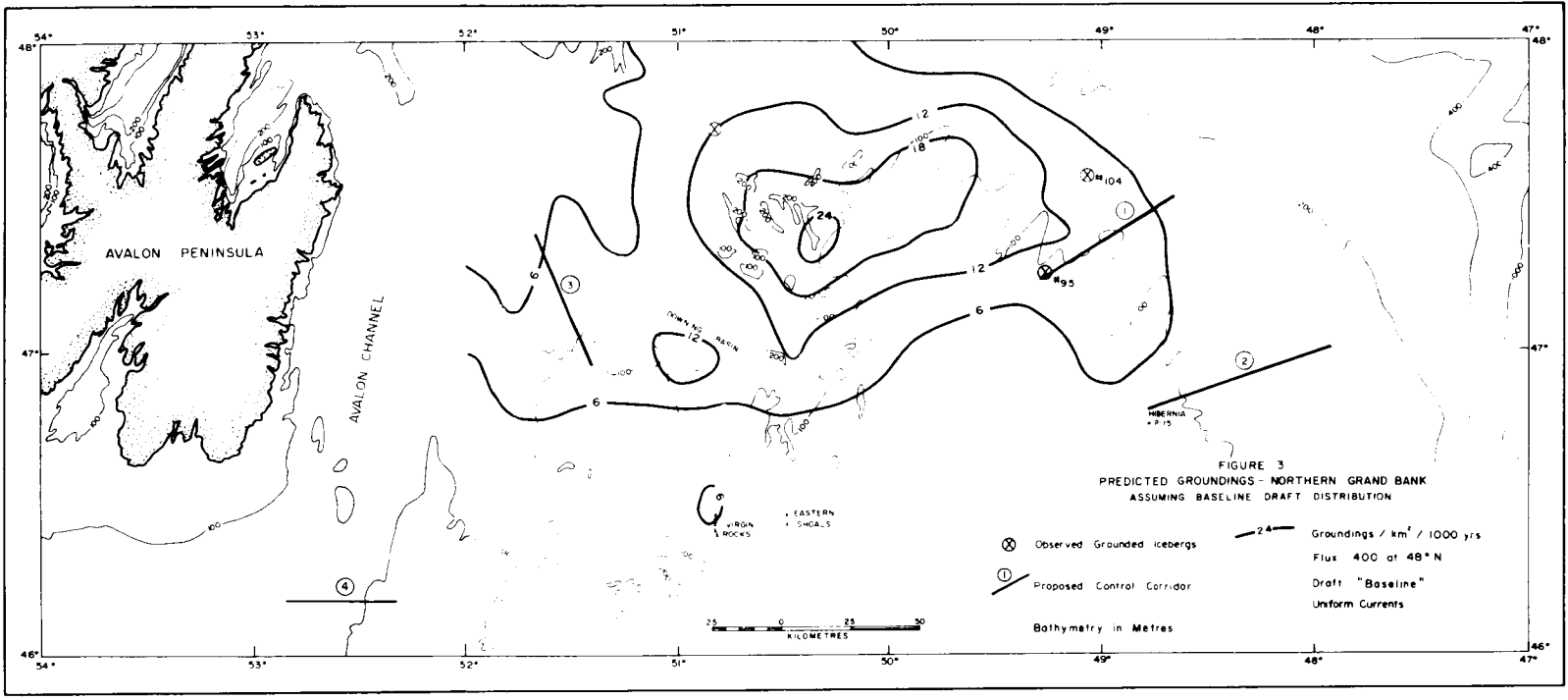
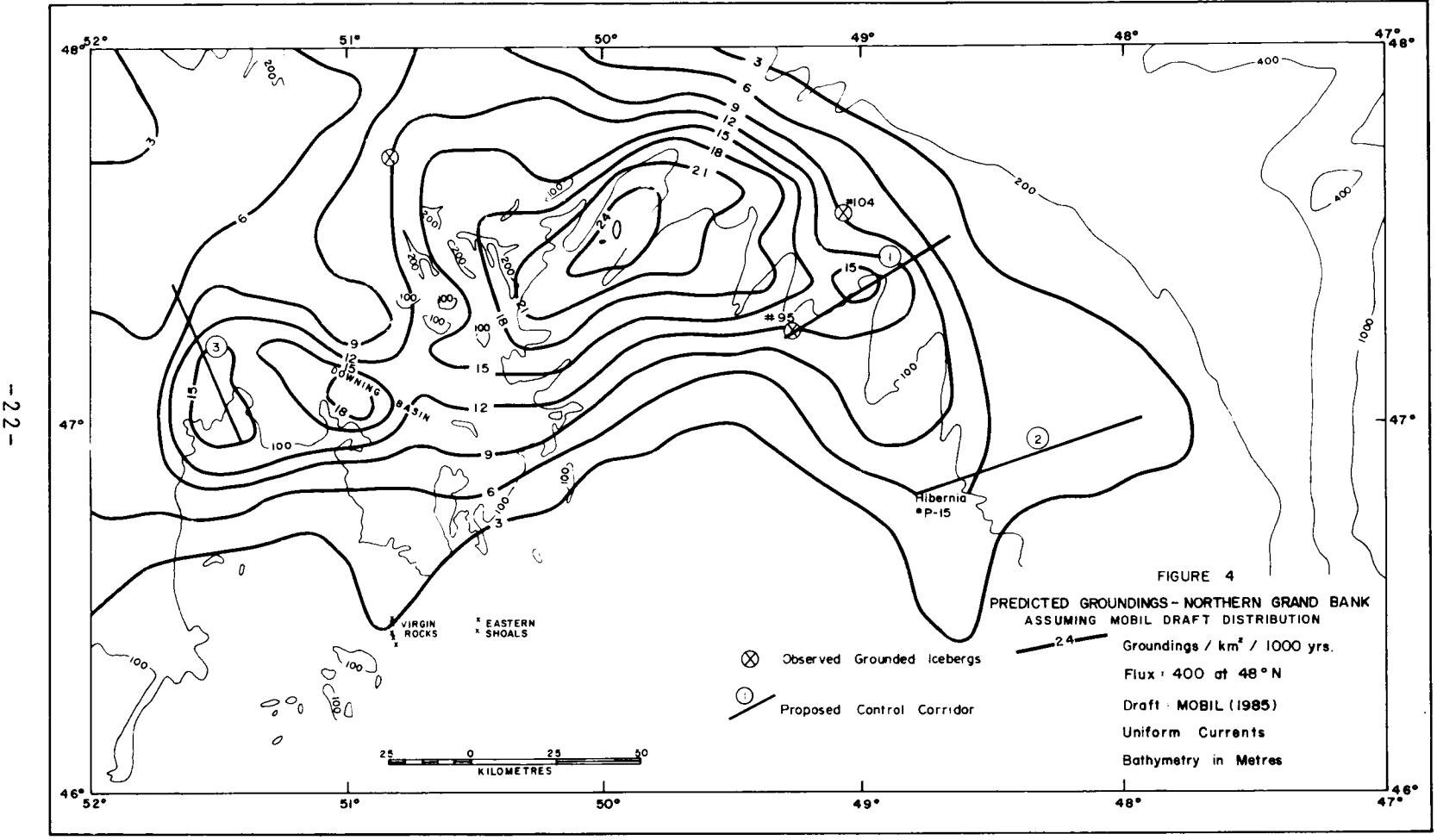


Figure 4



Densities of observed scours are greatest along the northern margin of Grand Bank and in the Avalon Channel area. In water depths greater than 110 m, two scour populations are present, including an older, reworked network which is overlain by younger scours. Above 110 m depths, only Holocene-age (i.e., younger than 10,000 yr) scours exist. Based on the observed density of these scours, the number of inferred modern groundings is greatest on the flanks of Grand Bank in water depths of 140 to 160 m (Lewis and Barrie 1981). A narrow zone of short, irregular scours and pits is generally found at the break in slope at the edge of the bank whereas, on the top of the bank, scours are sparse and irregular in shape. Scour depths are generally less than 1 m deep on the top of the bank and increase in depth with increasing water depth (Geonautics Limited in prep).

4.2.3 Iceberg Grounding Occurrences

A compilation of iceberg groundings, based on drill-rig or surface-based radar observations such as that produced for the Labrador Shelf by Woodworth-Lynas et al. (1985) and by El Tahan et al. (1985) does not exist for Grand Bank. A few groundings have been reported by scientists conducting regional surveys (e.g., a grounded two-million tonne iceberg was reported at 47°45'N, 50°50.5'W by Dr. S. Smith aboard the C.S.S. DAWSON, BIO 85-008 cruise). Surveys of two grounded icebergs (see Mosaic A on Chart 8) have been carried out by Geonautics Limited for Mobil Oil Canada, Ltd.

There is no way to gauge the accuracy of the grounding rates predicted by the AGC model because independent data on iceberg groundings were not available at the time of writing to calibrate or verify the model. However, it should be kept in mind that, for the Labrador Shelf, the model as used

here predicts numbers of groundings which are, in absolute terms, many times higher than those inferred (see Section 4.1.3) and the same trend is expected to apply to the northern Grand Bank region.

4.2.4 Surficial Geology

No regional geologic compilation of the surficial geology of Grand Bank exists at present. However, a reasonable understanding of the geologic conditions is possible through regional data collected by Fader and King (1981) and through detailed compilations of small areas of the Bank (e.g., Barrie et al. 1984; Fader et al. 1985).

In water depths of less than 110 m, a relatively thin (average 1 to 2 m, maximum 5 m) cover of clean, compact, fine- to medium-grained sands and coarse, subrounded gravels overlying a semiconsolidated Tertiary surface is found across northern Grand Bank. The surficial sediments were reworked during a late Wisconsinan-early Holocene transgression and the distribution of facies appears to be controlled by bathymetry. In the Hibernia study area, Barrie et al. (1984) have divided the surficial sediments into five units on the basis of texture and bedforms. North and east of the Hibernia study area, in water depths greater than 110 m, continuous sand with scattered pebbles and an increased mud component overlies an irregular Tertiary, or younger, surface. The sand cover thickens with increasing water depth. To the west, the surficial cover thickens into Downing Basin where a maximum of 50 m of muddy glaciomarine sediment and till overlies Cambro-Silurian bedrock (Fader and King 1981). In Avalon Channel, a relatively thin cover of glacial till (1 to 5 m) and isolated pockets of glaciomarine sediment overly bedrock of Cambrian to Silurian age.

4.2.5 Existing Survey Data

Existing survey data from the area surrounding the Mobil Hibernia wellsites on northeastern Grand Bank represent the most extensive coverage anywhere on the Grand Banks of Newfoundland or Labrador Shelf (see Chart 8). In addition to regional coverage by AGC, the area has been surveyed by C-CORE (Barrie et al. 1984) and 27 site-specific surveys have been carried out by industry. Outside the Hibernia study area, existing data are restricted to widely spaced, regional coverage by AGC. Coverage is most complete on the northern part of Grand Bank and in Avalon Channel. Survey instruments on these cruises included the BIO 70-kHz sidescan sonar and a Hunttec (DTS) subbottom profiler.

5.0 SURVEY NETWORK SELECTION

5.1 SURVEY LOCATIONS

Based on an assessment of the iceberg groundings distribution predicted by the AGC model, as well as existing iceberg scour, iceberg draught, observed groundings, and surficial geology data, the following sites are recommended for inclusion in a repetitive seabed mapping network.

a) Makkovik Bank:

A combination of high rates of observed and predicted groundings, good bathymetric and geologic control, and varied geologic conditions make Makkovik Bank a favourable location for a repetitive mapping control area or corridor. In addition, three sidescan mosaics already exist for the area, and it is a promising location for future exploration and development.

b) Hamilton Bank:

Hamilton Bank is recommended as a site for a control area or corridor because it links geographically the Labrador Shelf and northern Grand Bank. Geologic conditions on the southern part of Hamilton Bank resemble those on much of Grand Bank. Predicted grounding rates are relatively low ($10/\text{km}^2$ in 100 yr) as compared to Makkovik Bank, but the chances of surveying new scours in successive years is greater than on Grand Bank. Good-quality regional data on central and southern Hamilton Bank are sparse. Additional data provided by the repetitive mapping program will do much to further the understanding of the region.

c) Grand Bank:

In spite of the low rates of predicted groundings on northeastern Grand Bank, a number of control areas and corridors are recommended for this area because data collected will be of considerable importance to those companies planning future exploration and development in the region. Long periods are expected between scouring events in this area, therefore a special effort to incorporate all existing regional and site-specific data into the repetitive mapping program will be necessary if results are to be obtained within a reasonable time frame.

Detailed repetitive mapping on Grand Bank will also provide semi-quantitative data concerning obliteration rates for existing scours. This information could be used to calibrate theoretical models concerning scour return rates which already exist for the region (Gaskill et al. 1985).

5.2 NETWORK SPECIFICATIONS

In this section recommendations on the number, location, size, and orientation of control areas or corridors in each of the areas identified in the previous subsection are given. In the case of control corridors, the choice of a four-line instead of a two-line survey corridor, such as has been used successfully in the Beaufort Sea, is suggested for two reasons. First, since a high-resolution, short-range sidescan system is recommended (see Section 5.3.3), a two-line survey would provide a very narrow area of seabed coverage, thereby increasing the chances of missing short scours or pits and reducing the ability to fully characterize individual scours. Second, navigational accuracies (see Section 5.3.1) and potential errors in

towfish positioning are such that as much as 10 percent of a two-line, 550-m-wide swath may be missed during resurvey.

5.2.1 Makkovik Bank

For Makkovik Bank, a single mosaic measuring 5.0 x 16.5 km located on the western margin of the bank is recommended (see Charts 2 and 6). Primary survey lines oriented N 115°E will provide data on a variety of geologic and bathymetric combinations in an area with a high number of observed (see Figure 1) and predicted groundings (see Chart 2) and should provide characterization of existing and future iceberg scours. The proposed line orientation should be checked during testing of the sidescan sonar equipment and any changes in line orientation deemed necessary to improve data quality should be made at that time. Assuming an operating sidescan sonar range of 200 m per channel, the recommended line spacing is 150 m. This spacing will provide greater than 100% overlap between survey lines and ensure maximum data quality for mosaicing. A survey speed of no more than four knots should be used to ensure best-quality data collection.

5.2.2 Hamilton Bank

Two control corridors are recommended for Hamilton Bank (see Chart 1). The northern corridor was chosen to provide data that will tie with Makkovik Bank because the geology in the two areas is similar.¹ This corridor crosses a ridge of relatively shallow water where the AGC model predicts the highest number of groundings in the area. The corridor is oriented N 40°E and will consist of four lines, each 20 km long. Assuming a sidescan operating range of 200 m per

1 H. Josenhans, AGC, personal communication, 1985.

channel, a line spacing of 150 m is suggested, which will yield an 850-m-wide swath of 100% seabed coverage.

The southern control corridor (see Chart 1) will be the same size and orientation as the northern corridor. This corridor was chosen because geologic conditions on the southern portion of Hamilton Bank are similar to those over much of Grand Bank (i.e., bedrock close to the surface). The predicted number of iceberg groundings in this area is low compared to elsewhere on the Labrador Shelf but is much higher than on Grand Bank.

As with the Makkovik Bank mosaic, survey speeds on the Hamilton Bank corridors should not exceed four knots.

5.2.3 Grand Bank

Because of the size of Grand Bank and the wide variations in geologic conditions and risk of iceberg grounding across the region, four separate control corridors are recommended (see Figure 3). These are listed below in decreasing order of perceived priority.

- (a) Corridor 1 lies to the northwest of the Hibernia study area in water depths of 100 to 160 m (see Figure 4). The corridor consists of four lines, each 55 km long and oriented N 060°E. Lines should be spaced 150 m apart assuming a sidescan operating range of 200 m per channel. The corridor crosses an area with a relatively high rate of predicted groundings and its southwest end crosses the scour No. 95 mosaic, site of a grounded iceberg documented by Geonautics Limited for Mobil Oil Canada, Ltd. in 1983. Another grounded iceberg (No. 104) was also documented just north of this locale during the same year (see Figure 4). Two separate

regional AGC cruises (80-010 and 83-033) run sub-parallel to the proposed corridor and the corridor also crosses the northern end of Mosaic No. 3 which is part of the Mobil 8000 Series. Good regional data control, existing mosaics, relatively high rates of predicted groundings, and a well-documented grounding event combine to make this a suitable location for a repetitive mapping study. In addition the area lies close enough to the location of present exploration activity to make the results useful to those operators. The corridor should cross a number of the different sedimentary facies delineated by Barrie et al. (1984) as well as the relict terrace at 100 to 110 m produced during the last low sea-level stand. This terrace separates areas of older and younger scours below 110 m from areas of younger scours above this depth (Lewis and Barrie 1981) and also has been found to be the location of concentrations of iceberg pits and short scours (Geonautics Limited in prep.). Extension of the recommended corridor onto the top of Grand Bank will ensure that the possible effects of bathymetric sheltering are documented.

- (b) Corridor 2 lies within the Hibernia region. Predicted grounding rates are negligible in this area, and there is no record of any groundings having occurred over the past decade. However, existing survey data coverage and geologic control for this area are superb and provide an excellent base on which to build a repetitive mapping program which will have the potential for providing data on iceberg scour return rates and also valuable information on obliteration rates of existing scours and sediment mobility within the area.

The proposed corridor consists of four lines, each 70 km long, oriented N 070°E. The proposed line spacing is 150 m, assuming a sidescan sonar range of 200 m per channel which will provide 100% coverage of the seabed. Closely spaced (2-km line spacing) sidescan sonar data, collected by C-CORE (Barrie et al. 1984) in the same area using a 100-kHz system, may be useful in extrapolating the findings of the repetitive mapping study to a larger area. The proposed corridor extends from 80 to 150 m water depth and crosses all five sedimentary units defined by Barrie et al. (1984). Again, extension of the corridor onto the bank top should provide useful data on the effects of bathymetric sheltering.

- (c) Corridor 3 is located on the east side of the Avalon Channel in an area where numerous iceberg scours are known to exist (see Chart 7). Predicted grounding rates in this area are of the same magnitude as for Corridor 2. The proposed corridor consists of four lines oriented N 023°W, each line being 50 km in length. The proposed orientation is roughly perpendicular to regional bathymetric contours. Some adjustment to the recommended orientation may be necessary to ensure optimum quality of data. Recommended line spacing is 150 m assuming a sidescan sonar operating range of 200 m, which will provide 100% coverage of a total 850-m-wide swath. Because Avalon Channel is known to be one of the main drift routes for icebergs (Dinsmore 1972), the potential for documenting new scours appears to be good. The close proximity of Corridor 3 to the port of St. John's, Newfoundland, makes it a convenient site to survey on a repetitive basis. However, any data on grounding recurrence rates obtained here would have

limited direct applicability to the main area of exploration farther east but would be of use in assessing the feasibility of a pipeline route through this area. Also the data could be incorporated into theoretical models of scouring in the region (Gaskill et al. 1985).

- (d) Corridor 4 is located on the southeast margin of Avalon Channel, south-southeast of Cape Race (see Figure 4). The proposed corridor consists of four lines, each 40 km in length, oriented N 090°W. This area was not modelled by AGC and regional data show that scours are rare except below 110 m water depths in Avalon Channel. However, data gained by repetitive mapping could be used to evaluate possible pipeline routes in this area and as a means of comparing scouring in southern Avalon Channel and northern Avalon Channel (Corridor 3).

As an alternative (or in addition) to Corridor 4, it may be advisable to survey a small, nearshore area along the east coast of the Avalon Peninsula, possibly near Bay Bulls. Data on scouring frequency, both by sea ice and icebergs in such areas, would be useful to companies interested in bringing production pipelines ashore.

5.3 EQUIPMENT SPECIFICATIONS AND OPERATING PARAMETERS

5.3.1 Navigation and Positioning

Accurate, reliable navigation is essential to the success of the repetitive mapping program. The ability to survey a straight line of a predetermined orientation at a constant speed, to monitor the position of the vessel at all times, and to resurvey in the same orientation in succeeding years are all essential. The inability to do this in the past has been a major reason for the failure of existing repetitive surveys on the east coast (Woodworth-Lynas and Barrie 1985). For this reason the onboard navigation and positioning equipment must be able to:

- provide accurate navigational information to guide the vessel along a given track;
- provide fix marks at regular intervals;
- record position fixes on magnetic tape and paper plots;
- provide an onboard track plot;
- provide fix location maps of the surveys when complete; and
- show location of known acoustic targets on the seabed.

Navigation ranges and accuracies differ for the two study regions. For Makkovik Bank, ranges of 100 to 150 km from shore stations are expected and accuracies of about 5 to 10 m are acceptable. To achieve these accuracies, a medium-range navigation system, such as Sercel Syledis, is recommended. For Hamilton Bank, ranges of 150 to 200 km are expected thus reducing position accuracies to 15 to 20 m when using a medium- or long-range system. For northeastern Grand Bank, ranges from possible shore stations will exceed 350 km and a long-range system, such as Cubic Western ARGO, will therefore be required. Acceptable positional

accuracies should be about 15 to 20 m. It is further noted that advances in Global Positioning System (GPS) navigation operating periods will facilitate the collection of accurate positional data on a continuous basis.

Standard calibration procedures must be carried out before and after surveying each control area or corridor. An acoustic target array deployed at each site (see Section 5.3.6) should be used to demonstrate the repeatability of the navigation system.

In the preceding discussion, positioning of the sidescan towfish has not been considered. Given sufficient funding, this capability would provide increased confidence in the absolute location of seabed features.

5.3.2 Echo Sounder

A narrow-beam, high-resolution, heave-compensated echo sounder capable of providing data of sufficient quality to allow accurate contour mapping of the seabed at 2-m intervals is recommended. Data should be corrected for the velocity of sound in water. The echo sounder should be properly calibrated (bar check) before and after each survey. The sounder should also be adjusted to account for transducer depth and the data should be reduced to lowest mean sea-level by correcting for tidal variations.

5.3.3 Sidescan Sonar

A narrow-beam, high-resolution, 100-kHz sidescan sonar system capable of providing both distortion-free (slant range and aspect ratio-corrected) field records is recommended for the repetitive mapping program. Range scales should not exceed 200 m. This type of system will allow accurate characterization of iceberg scours and is

detailed enough to detect smaller seabed features (megaripples, boulders, trawl marks) which may be used to qualitatively monitor local sediment mobility. Tow-fish height can be monitored through the use of an altimeter, in which case the on-board recorder must have three-channel capability.

In addition to the 100-kHz system, it may be advisable to carry a 70-kHz system and additional recorder on board during the repetitive mapping program. This system could be deployed along with the 100-kHz system to provide comparative data, especially where the survey route crosses or follows areas of existing 70-kHz AGC coverage.

On-site trials must be carried out at each survey location to adjust the instrument settings to obtain maximum coverage and ensure optimum characterization of both lithologic and topographic variations of the seabed. An inexpensive array of acoustic targets should be deployed at each site and these can be used to demonstrate the resolution of the sidescan system as well as to provide reference marks for future surveys (see Section 5.3.6). Data from the trial runs should be used to check that the intended orientation of the survey lines will provide optimum coverage of scours in the area.

In addition to coverage at the recommended areas or corridors, it is suggested that, if conditions permit, the sidescan sonar (and subbottom profiler) system be deployed while steaming between sites. This approach would be particularly beneficial in the Grand Bank region where any new scours are likely to be widely spaced. These data could be used for detecting new scours and also to provide tie lines between each repetitive mapping area or corridor.

5.3.4 Subbottom Profiler

A high-resolution subbottom profiler capable of up to 30-m penetration in gravelly till, with 30-cm interbed resolution, is recommended for the repetitive mapping program. The system should also include an integral medium-range (50-kHz), sidescan sonar. This dual capability will allow accurate correlation between the profiler and sidescan sonar data and will provide a basis for checking the relative position of the two tow-fish by correlating the 100-kHz sidescan data with the 50-kHz sonograms. If this is not done, it may be difficult to accurately correlate individual scour features observed on the profiler and sidescan records.

The subbottom profiler system must be fully heave-compensated and provide resolution of seabed relief of greater than 30 cm. It should also be capable of measuring the acoustic reflectivity of the seabed in two, separate time windows and of displaying these data as reflectivity profiles on the analogue records. The latter information is helpful for the discrimination of sediment types.

Trial runs of the subbottom profiler should be made prior to each survey to assess the motion compensation and acoustic reflectivity systems and to select power settings and fire rates which will ensure optimal data quality (penetration and spatial resolution) while minimizing potential interference with the other geophysical systems. Ideally the calibrations should be carried out in an area of known geology near the recommended survey areas and corridors. The integral (50-kHz), sidescan system should also be tuned at this time, bearing in mind that the tow-fish height to be used should provide optimal subbottom profiler data whereas the sidescan coverage and quality may suffer.

5.3.5 Single-channel Seismic

A single-channel seismic system capable of 75-m penetration through over-consolidated sediment and bedrock with resolution on the order of 5 m is required for the repetitive mapping program. Data collected will be used to relate iceberg scour parameters to regional geology.

5.3.6 Acoustic Target Array

A bottom-mounted acoustic target array should be considered for deployment at each repetitive mapping area and corridor. The array should be designed to fulfil three requirements. First, it should provide reference points to be used in demonstrating the repeatability of the navigation system and for relocating the survey site in consecutive years. Second, it should be of sufficient size so that it may be detected by the 100-kHz sidescan sonar system. Last, it could provide a means of measuring changes in seabed conditions (sediment mobility) between survey periods by demonstrating sediment pile-up or erosion around the targets. Two to four acoustic targets are recommended for the Makkovik Bank mosaic, whereas targets should be deployed at the beginning and end of the corridors on Hamilton Bank and northeast Grand Bank.

In addition to acoustic target arrays, a list of the positions of well heads and other permanent bottom equipment on the seabed in the Makkovik, Hamilton, and Grand Bank study areas has been provided by the Canada-Newfoundland Offshore Petroleum Board and is included with this report (see Appendix A). Locating the well head or any other evidence of associated drilling activity on the sonograms may be useful when positioning the control corridor and in relocating the corridor for subsequent surveys. Also, the degree of burial of any equipment by sediment or evidence of

sediment erosion will provide information on sediment mobility within the area.

5.3.7 Sampling Equipment

Grab samples of surficial sediment at each proposed area and corridor are required to validate any textural variations observed on the acoustic records and as a means of relating sediment texture and bedforms to the hydrodynamic regime. Both vanVeen and Shipek samplers should be available. The vanVeen sampler is suitable for collecting samples in coarse, gravelly sediment whereas the Shipek sampler collects good samples of cohesive sediment and sand.

5.3.8 Seabed Photography

Collection of seabed photographs for each control area or corridor is recommended. The location of the photographs should be chosen following the initial geophysical survey to provide information on textural variations and any other features of interest on the seabed. The position of the seabed photographs must be recorded accurately and plotted on navigation charts. It would be advantageous to return to the same location in subsequent surveys to determine any changes in seabed character at each locale.

5.4 SURVEY INTERVALS

For any repetitive mapping program to be a success at least one new scour should be observed within any given control area or corridor. Recommended survey intervals for the repetitive mapping program are based on the number of new scours expected in each survey area (i.e. on observed groundings and/or modelled groundings in the control areas).

For Makkovik Bank, the recommended repetitive mapping control mosaic covers 82.5 km^2 . The average predicted number of groundings (AGC model) in the area is roughly $30/\text{km}^2$ in 100 yr, or, for the control mosaic, 24.75 groundings per year (see Chart 2). Five grounded or scouring icebergs in the same area over seven seasons are interpreted by Woodworth-Lynas et al. (1985) (see Figure 1). This number may be increased by as much as 600% if the data are normalized to a yearly observation period (see Section 4.1.3) meaning that roughly four icebergs per year may ground or scour in this area. Therefore, a yearly survey period is reasonable for the Makkovik Bank control area.

For the Hamilton Bank corridors, maximum grounding rates of $10/\text{km}^2$ in 100 yr have been predicted by the AGC model, which translates to 3.75 groundings per year per corridor (each of which covers 37.5km^2). The grounding rates predicted by the model may be high, therefore, a survey period of once every two years is recommended.

For Grand Bank, predicted grounding rates for Corridors 2 and 3 are $1.6/\text{km}^2$ in 1,000 yr or $0.07/42.5 \text{ km}^2/\text{yr}$. Therefore, based on model considerations, one grounding may be expected in one or the other of these corridors every 7.14 years. For Corridors 1 and 4, the chance of a grounding is even lower. Surveying once every 7 or 8 years is logistically impractical in light of development planning in the Hibernia area. For this reason, it is suggested that a survey period of once every two years for a minimum of two repetitions be adopted for each of the four areas. If results are required within a shorter time frame, it would be necessary to survey a larger area of the seabed. This could be accomplished either by establishing more corridors or by resurveying existing regional (AGC) lines. Although

these surveys may fail to record any new scours, they will provide valuable data on long-term sediment mobility in the control corridors.

It should be stressed that a certain degree of flexibility will be required when planning the resurvey period for a given control area or corridor. Ice conditions in the areas of interest should be monitored and any adjustments necessary to compensate for, or take advantage of, light, or severe, iceberg seasons will need to be made. Recent observations suggest that most iceberg scours may be generated early in the season when icebergs are locked in pack ice. Later in the season, when icebergs are free-floating and less stable, they are more likely to produce short, irregular scours or pits (ESRF Dynamics of Iceberg Grounding and Scouring report pending).

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APPENDIX A

UNRECOVERED BOTTOM EQUIPMENT AND DEBRIS, OFFSHORE NEWFOUNDLAND AND LABRADOR

The following is a list of unrecovered equipment or debris on the seabed which may be useful as reference points when establishing a repetitive mapping network. This list was provided by the Canada-Newfoundland Offshore Petroleum Board.

1. BP Columbia et al. Bonavista C-99
(49°08'05.19"N; 51°14'25.13"W)
Water Depth (WD): 329.3 m (1080')
Remaining: well head (no guideposts)
Approximate height: 4.3 m (14')

2. Amoco-Imperial Gannet 0-54
(45°03'54.6"N; 52°38'09.7"W)
Water Depth (WD): 100 m (328')
Remaining: template, guide structure, well head
housing, drill pipe fish
Approximate height: 7.7 m (25.3')

3. Eastcan et al. Gudrid H-55
(54°54'30"N' 55°52'32"W)
Water Depth (WD): 299.4 m (982')
Remaining: well head housing with protruding casing
Approximate height: 4.3 m (14')

4. Eastcan et al. Snorri J-90
(57°19'44.52"N; 59°57'44.37"W)
Water Depth (WD): 140.9 m (462')
Remaining: well head, guide structure (no protruding posts) and beacon
Approximate height: 4.6 m (15')

5. Total Eastcan et al. Skolp E-07
(58°26'24.71"N; 61°46'09.05"W)
Water Depth (WD): 166.5 m (546')
Remaining: top of guide base protruding from cement
Approximate height: 1-2 m (3-6.5')

6. Esso Voyager et al. Gabriel C-60
(47°19'08.84"N; 46°53'29.60"W)
Water Depth (WD): 1108.8 m (3637')
Remaining: guidelineless running assembly,
guidelineless landing structure, mud pan
Approximate height: 5 m (16.5')

7. Mobil et al. North Dana I-43
(47°12'43.60"N; 47°36'12.61"W)
Water Depth (WD): 221 m (725')
Remaining: temporary and permanent guide bases (no guideposts), well head housing mud
Approximate height: near zero

8. Mobil et al. Hibernia C-96
(46°45'10.19"N; 48°44'35.7"W)
Water Depth (WD): 81 m (266')
Remaining: no equipment on wellsite.
Note: On July 10, 1984, a Schlumberger explosives magazine was lost overboard and could not subsequently be located on the seabed. It is believed to be within a

few hundred meters of the wellsite. Contents are expected to have been neutralized by salt water, with the exception of 29" "Nobel" type detonators.

Approximate size of container: 1 m x 1.2 m x 0.75 m (3' x 4' x 2.5').

9. Esso Parex et al. Kyle L-11
(47°00'36.96"N; 47°02'49.34"W)
Water Depth (WD): 1118 m (3667')
Remaining: well head assembly and guidelineless running assembly
Approximate height: 4.1 m (13.5')
10. Petro-Canada et al. Terra Nova K-07 (SUSPENDED)
(46°26'43.57"N; 48°30'57.76"W)
Water Depth (WD): 92 m (302')
Remaining: no equipment protruding from sea floor;
sonar buoys located 2.4 m (8') above seabed
11. Petro-Canada et al. Terra Nova I-97 (SUSPENDED)
(46°26'42.68"N; 48°28'49.44"W)
Water Depth (WD): 96.5 m (317')
Remaining: corrosion cap, guidelineless running assembly, sonar buoys
Approximate height: 2 m (6.5') to top of GRA;
5 m (16') total to top of buoys
12. Husky/Bow Valley et al. North Ben Nevis M-61 (SUSPENDED)
(46°40'53.57"N; 48°25'18.60"W)
Water Depth (WD): 100 m (328')
Remaining: temporary and permanent guide bases,
guidelineless running assembly, corrosion cap
Approximate height: 3.5 m (11.5')

13. Ocean Ranger Debris wreckage on seabed.
46°01.6'N
47°57.4'W

In addition to the above, the following is a list of sites for which insufficient information exists to determine whether or not any equipment and/or debris remains on site.

1. PanAm Imperial et al. Grand Falls H-09
(45°28'19"N; 52°00'03"W)
W.D.: 78 m (256')
2. Tenneco et al. Leif E-38
(54°17'29.87"N; 55°05'52.17"W)
W.D.: 164.6 m (540')
3. Eastcan et al. Leif M-48
(54°17'45.92"N; 55°07'20.17"W)
W.D.: 165.2 m (542')
4. Eastcan et al. Bjarni H-81
(55°30'29.35"N; 57°42'05.52"W)
W.D.: 140.2 m (460')
5. Mobil Gulf et al. Bonniton H-32
(45°51'26.79"N; 48°10'31.76"W)
W.D.: 101.8 m (334')
6. Elf et al. Emerillion C-56
(45°15'04.79"N; 54°23'16.85"W)
W.D.: 119.8 m (393')

7. Amoco Imperial Skelly Phalarope P-62

(45°11'49.25"N; 51°24'14.40"W)

W.D.: 73.2 m (240')

8. Total Eastcan et al. Roberval K-92

(54°51'35.53"N; 55°44'35.76"W)

W.D.: 268.5 m (881')

Environmental Studies Revolving Funds

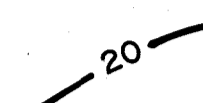


PROJECT DESIGN OF AN ICEBERG SCOUR REPETITIVE MAPPING NETWORK FOR THE CANADIAN EAST COAST

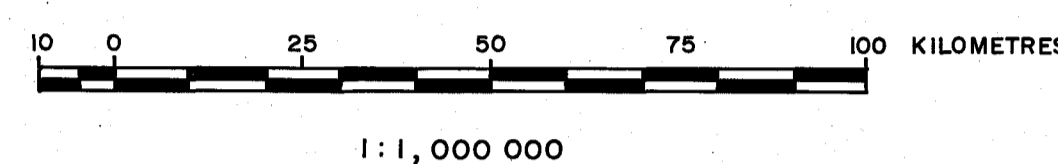
TITLE
PREDICTED ICEBERG GROUNDINGS
LABRADOR SHELF

SCALE 1:1 000 000 CHART 1 DATE JULY 1985

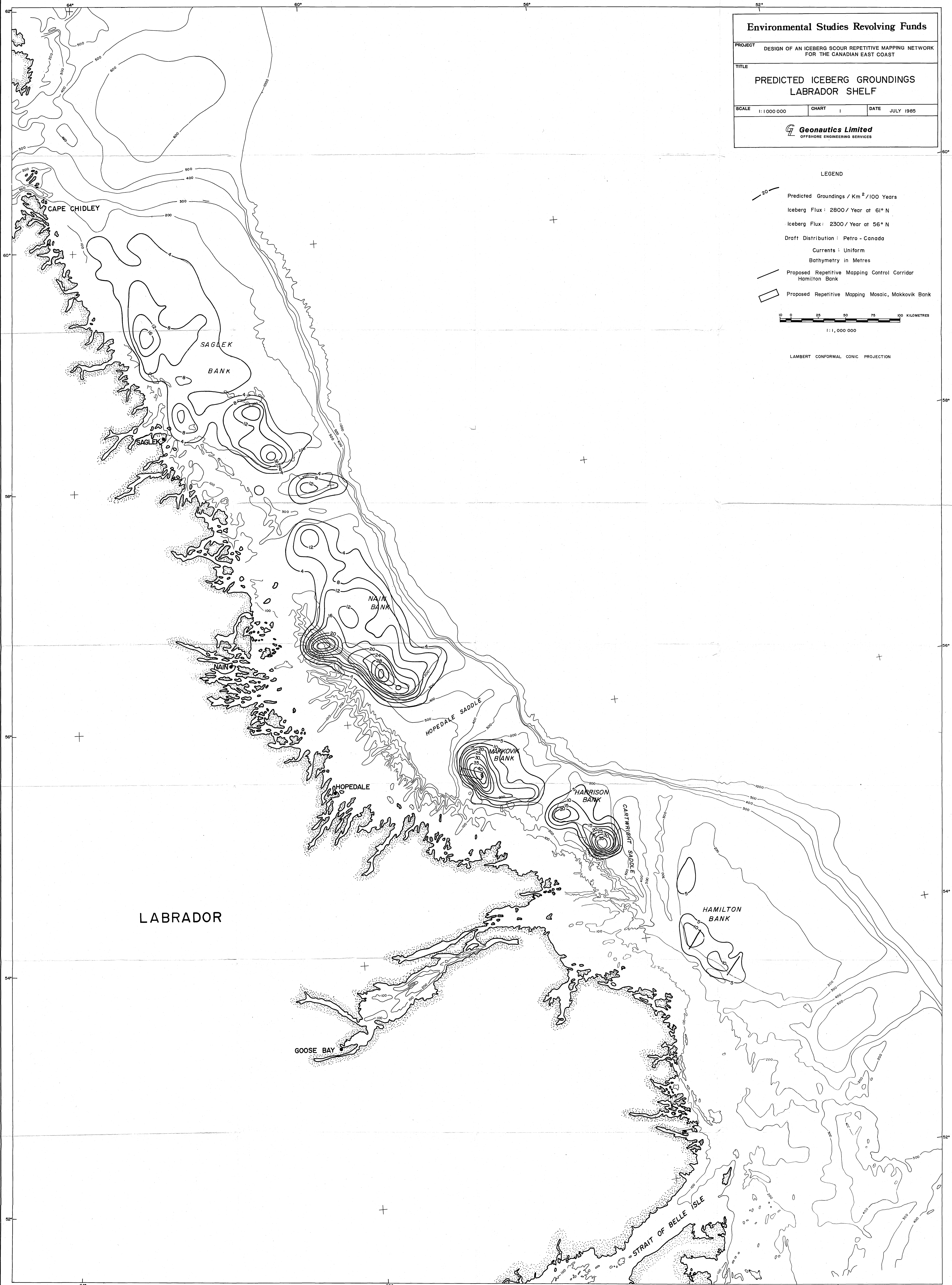
Geonautics Limited
OFFSHORE ENGINEERING SERVICES

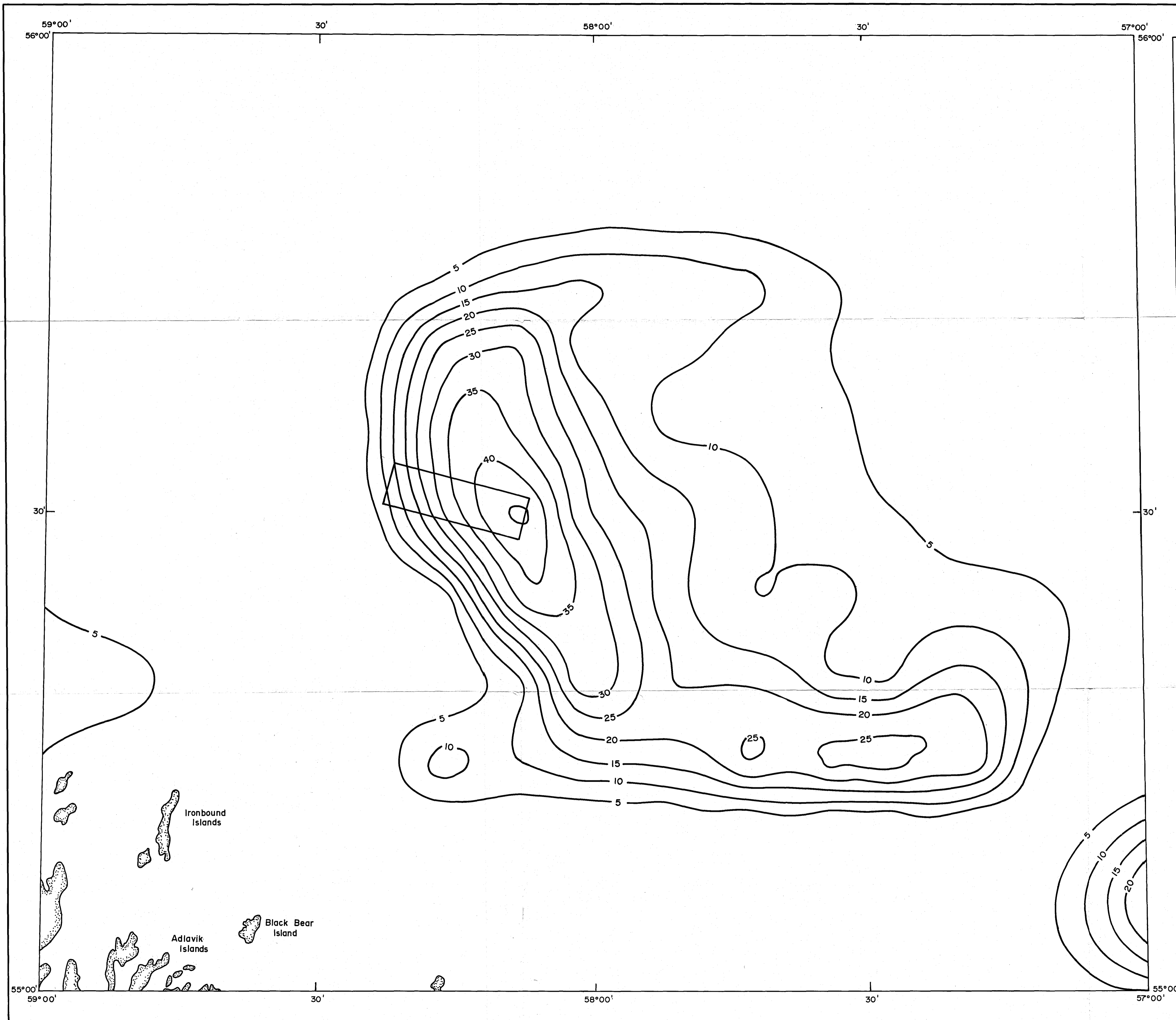
LEGEND

-  Predicted Groundings / Km² / 100 Years
- Iceberg Flux: 2800 / Year at 61° N
- Iceberg Flux: 2300 / Year at 56° N
- Draft Distribution: Petro - Canada
- Currents: Uniform
- Bathymetry in Metres
-  Proposed Repetitive Mapping Control Corridor
Hamilton Bank
-  Proposed Repetitive Mapping Mosaic, Makkovik Bank

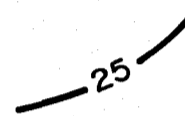



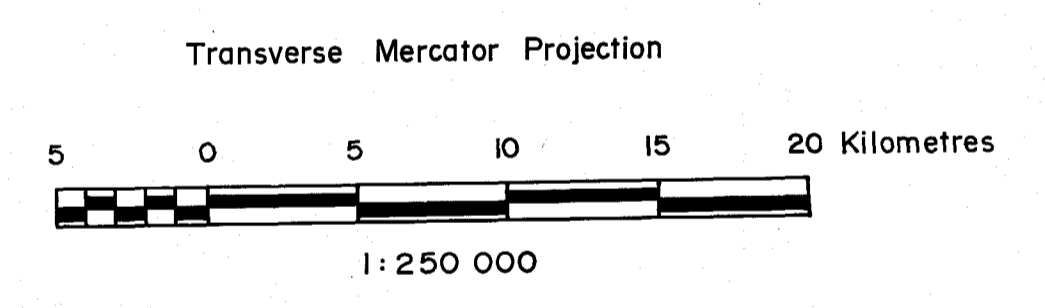
LAMBERT CONFORMAL CONIC PROJECTION





LEGEND

-  Predicted Groundings / Km² / 100 Years
- Iceberg Flux: 2300 Per Year at 56°N
- Draft Distribution: Petro-Canada
- Currents: Uniform
-  Repetitive Mapping Mosaic



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PROJECT DESIGN OF AN ICEBERG SCOUR REPETITIVE MAPPING NETWORK FOR THE CANADIAN EAST COAST

TITLE: PREDICTED ICEBERG GROUNDINGS
MAKKOVIK BANK
LABRADOR

SCALE: 1:250 000 CHART: 2 DATE: JULY 1985



Environmental Studies Revolving Funds

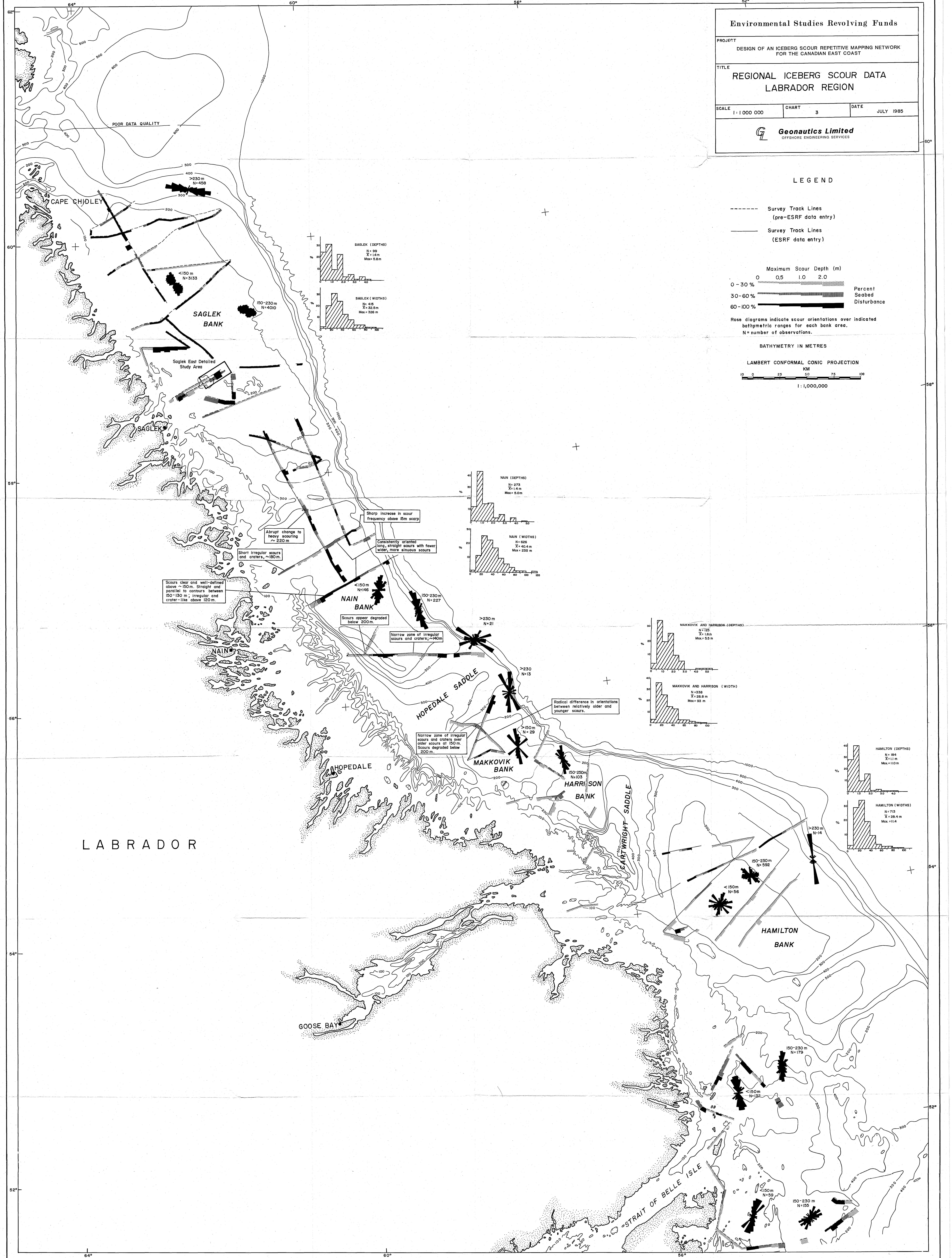
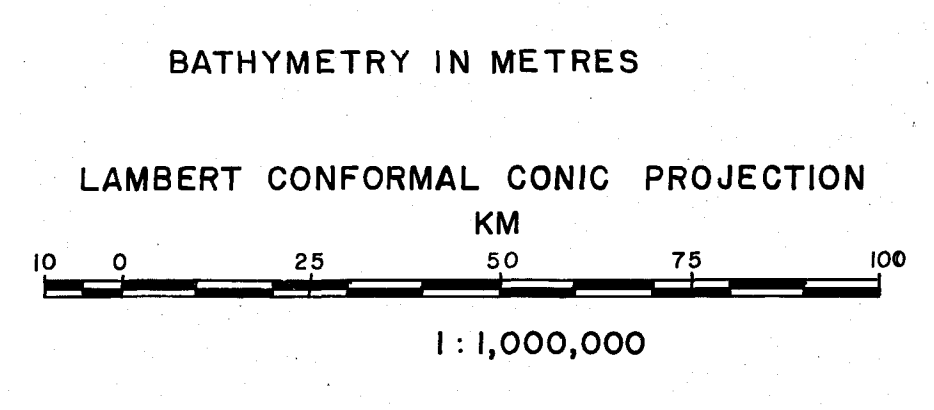
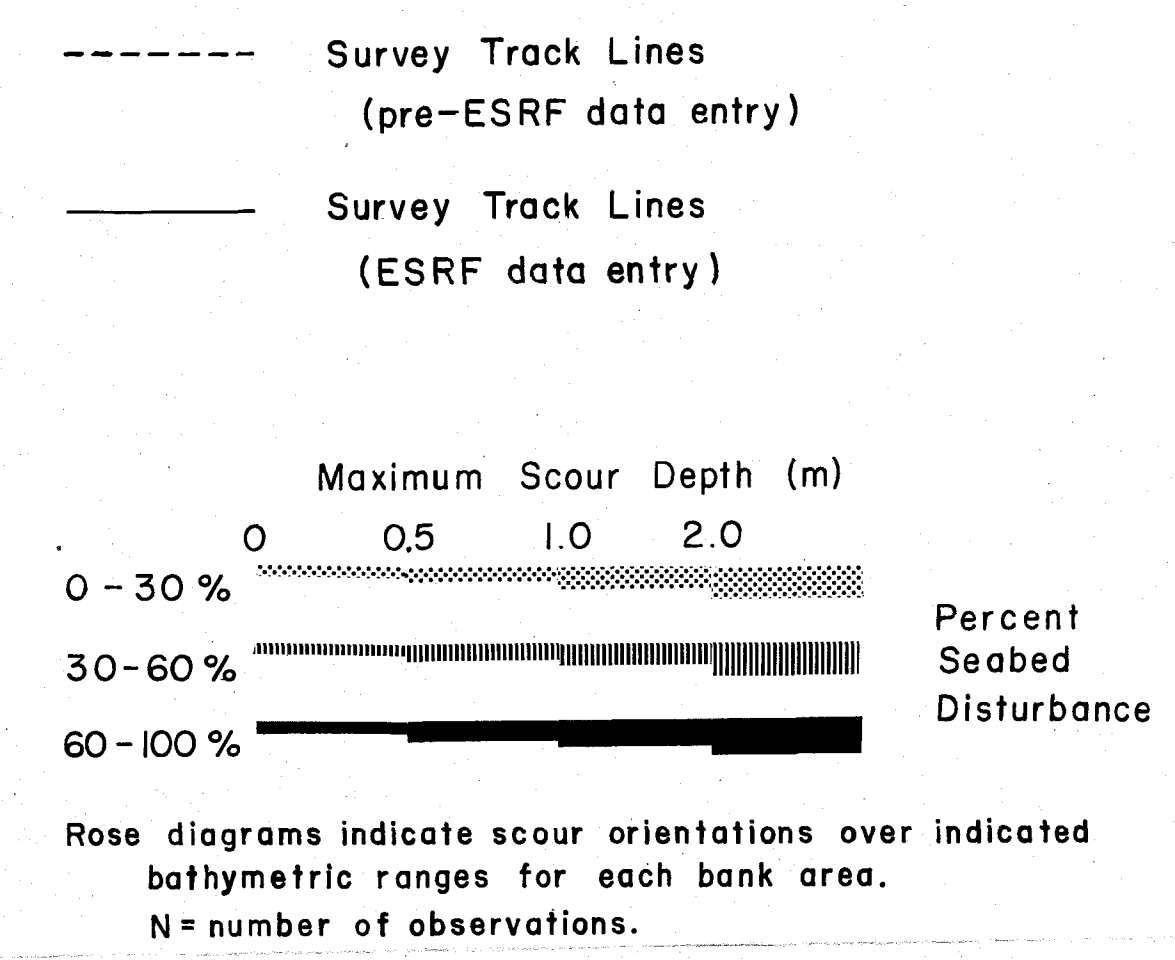
PROJECT: DESIGN OF AN ICEBERG SCOUR REPETITIVE MAPPING NETWORK FOR THE CANADIAN EAST COAST

TITLE: REGIONAL ICEBERG SCOUR DATA LABRADOR REGION

SCALE: 1:1,000,000 CHART: 3 DATE: JULY 1985

Geonautics Limited
OFFSHORE ENGINEERING SERVICES

LEGEND



Environmental Studies Revolving Funds

PROJECT
DESIGN OF AN ICEBERG SCOUR REPETITIVE MAPPING NETWORK
FOR THE CANADIAN EAST COAST

TITLE
SURFICIAL GEOLOGY
LABRADOR SHELF

SCALE 1:1 000 000 CHART 4 DATE JULY 1985

Geonautics Limited
OFFSHORE ENGINEERING SERVICES

LEGEND

UNIT 5 Post Glacial Marine Sediments (Holocene)

- 5A Pondered, Stratified Muds
- 5B Stratified Sands - derived from Winnowing
- 5C Stratified Sediments (texturally variable)

UNITS 3 & 4 Glacial Deposits (Pleistocene)

- 4 Pro and Subglacial Stratified Silts
- 3C Hudson Strait Till
- 3B Upper Glacial Till
- 3A Lower Glacial Till

UNIT 2 Bedrock (Tertiary)

Semi-consolidated Sandstones and Siltstones with some Limestones

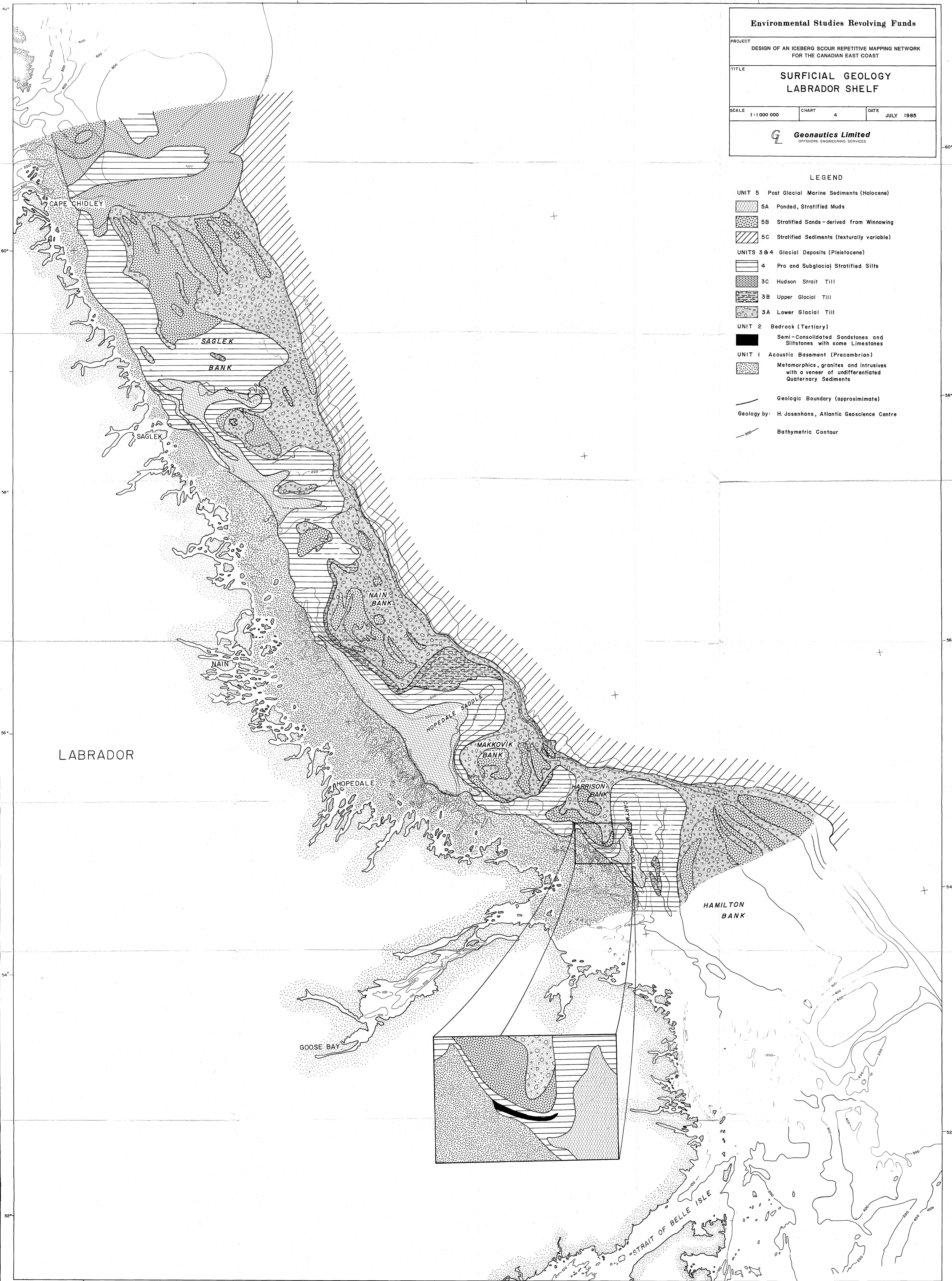
UNIT 1 Acoustic Basement (Precambrian)

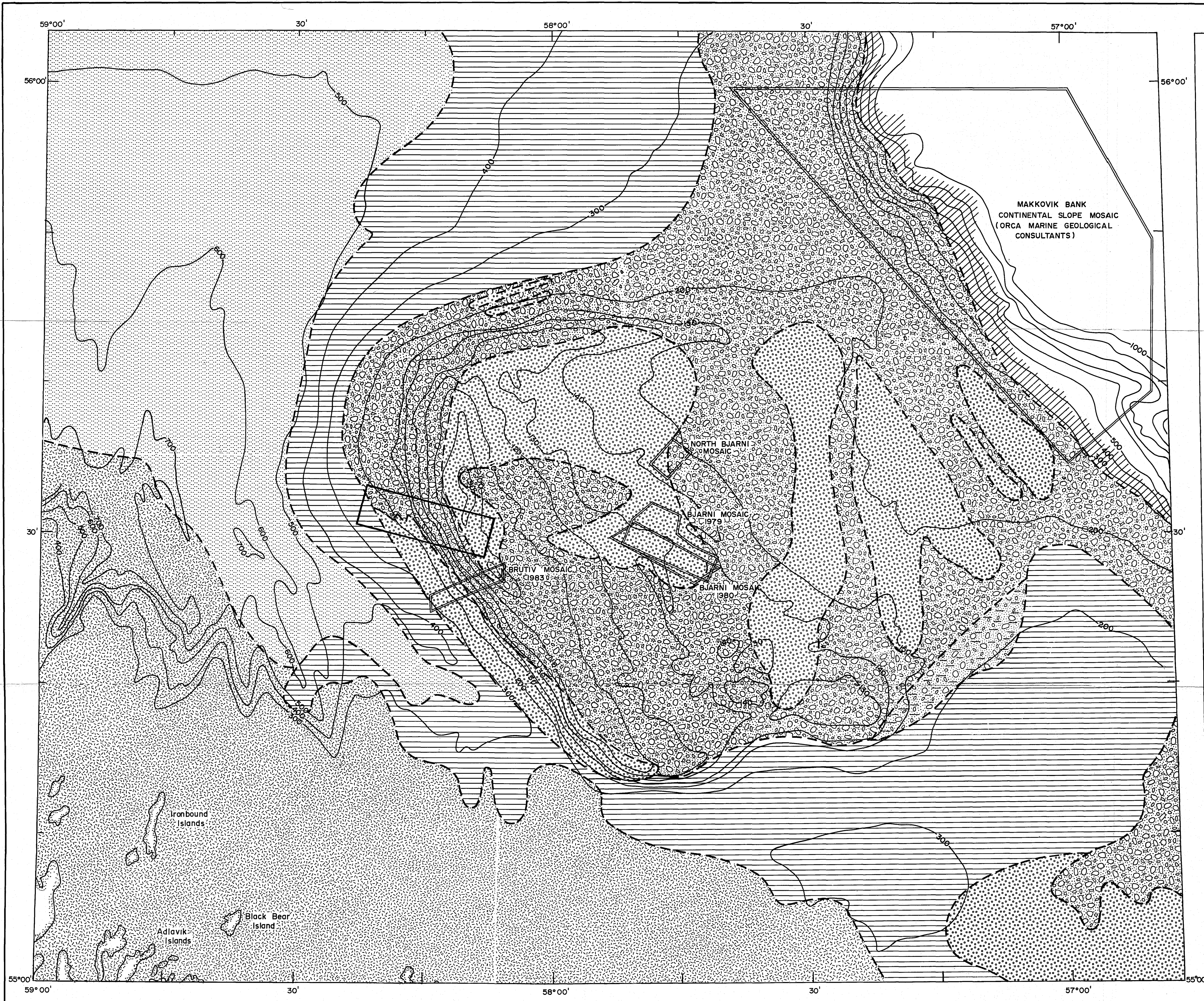
Metamorphics, granites and intrusives with a veneer of undifferentiated Quaternary Sediments

Geologic Boundary (approximate)

Geology by: H. Josenhans, Atlantic Geoscience Centre

Bathymetric Contour





MAKKOVIK BANK
CONTINENTAL SLOPE MOSAIC
(ORCA MARINE GEOLOGICAL
CONSULTANTS)

LEGEND

- Bathymetric Contour
 - Proposed Repetitive Mapping Mosaic
 - Existing Mosaics
 - Geologic Boundary (approximate)
 - UNIT 5 Post Glacial Marine Sediments (Holocene)
 - 5A Ponded, Stratified Muds
 - 5B Stratified Sands - derived from Winnowing
 - 5C Stratified Sediments (texturally variable)
 - UNITS 3 & 4 Glacial Deposits (Pleistocene)
 - 4 Pro and Subglacial Stratified Silts
 - 3B Upper Glacial Till
 - 3A Lower Glacial Till
 - UNIT 2 Bedrock (Tertiary)
 - Semi-Consolidated Sandstones and Siltstones with some Limestones
 - UNIT 1 Acoustic Basement (Precambrian)
 - Metamorphics, granites and intrusives with veneer of undifferentiated Quaternary sediments
- Geology by : H. Josenhans, Atlantic Geoscience Centre

Transverse Mercator Projection
CENTRAL MERIDIAN 57°W

1: 250 000

Environmental Studies Revolving Funds

PROJECT DESIGN OF AN ICEBERG SCOUR REPETITIVE MAPPING NETWORK FOR THE CANADIAN EAST COAST

TITLE: MAKKOVIK BANK SURFICIAL GEOLOGY

SCALE: 1: 250 000 CHART: 5 DATE: JULY 1985

Geonautics Limited
OFFSHORE ENGINEERING SERVICES

Environmental Studies Revolving Funds

PROJECT
DESIGN OF AN ICEBERG SCOUR REPETITIVE MAPPING NETWORK
FOR THE CANADIAN EAST COAST

TITLE
**EXISTING DATA COVERAGE
LABRADOR SHELF**

SCALE 1:1,000,000 CHART 6 DATE JULY 1985

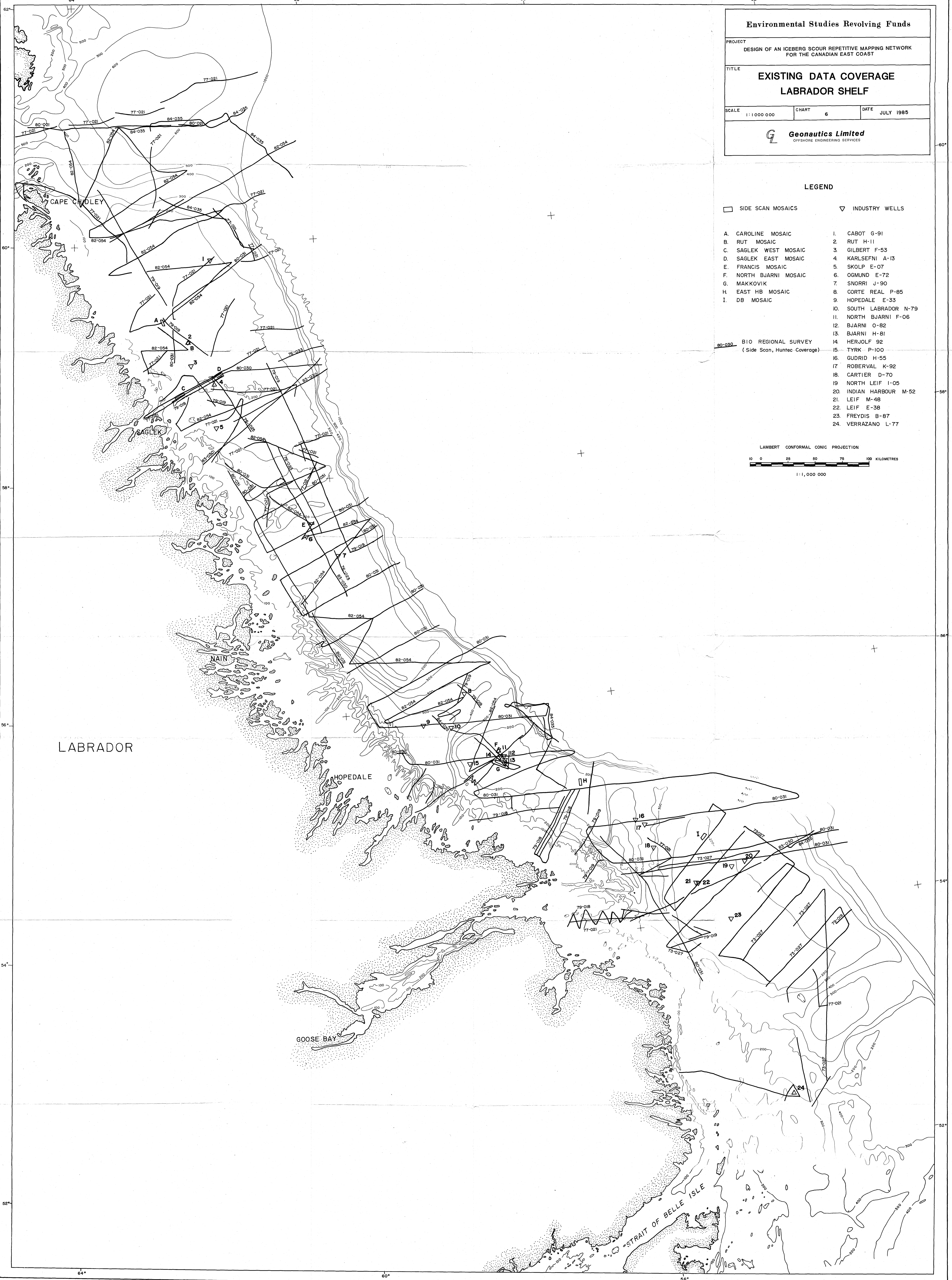
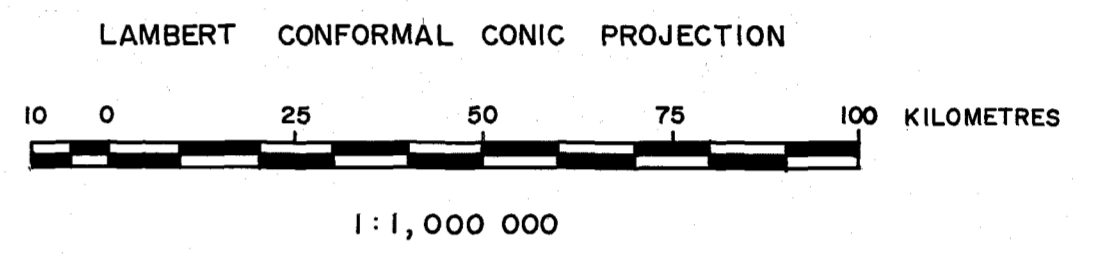


LEGEND

□ SIDE SCAN MOSAICS ▽ INDUSTRY WELLS

- | | |
|------------------------|-------------------------|
| A. CAROLINE MOSAIC | 1. CABOT G-91 |
| B. RUT MOSAIC | 2. RUT H-11 |
| C. SAGLEK WEST MOSAIC | 3. GILBERT F-53 |
| D. SAGLEK EAST MOSAIC | 4. KARLSEFNI A-13 |
| E. FRANCIS MOSAIC | 5. SKOLP E-07 |
| F. NORTH BJARNI MOSAIC | 6. OGMUND E-72 |
| G. MAKKOVIK | 7. SNORRI J-90 |
| H. EAST HB MOSAIC | 8. CORTE REAL P-85 |
| I. DB MOSAIC | 9. HOPEDALE E-33 |
| | 10. SOUTH LABRADOR N-79 |
| | 11. NORTH BJARNI F-06 |
| | 12. BJARNI O-82 |
| | 13. BJARNI H-81 |
| | 14. HERJOLF 92 |
| | 15. TYRK P-100 |
| | 16. GUDRID H-55 |
| | 17. ROBERVAL K-92 |
| | 18. CARTIER D-70 |
| | 19. NORTH LEIF I-05 |
| | 20. INDIAN HARBOUR M-52 |
| | 21. LEIF M-48 |
| | 22. LEIF E-38 |
| | 23. FREYDIS B-87 |
| | 24. VERRAZANO L-77 |

80-030 BIO REGIONAL SURVEY
(Side Scan, Huntec Coverage)



LABRADOR

HOPEDALE

GOOSE BAY

STRAIT OF BELLE ISLE

Environmental Studies Revolving Funds

PROJECT
DESIGN OF AN ICEBERG SCOUR REPETITIVE MAPPING NETWORK
FOR THE CANADIAN EAST COAST

TITLE
**REGIONAL ICEBERG SCOUR DATA
GRAND BANKS REGION**

SCALE 1:1 000 000 CHAR# 7 DATE JULY 1985

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SHORE TECHNOLOGICAL SERVICES

LEGEND

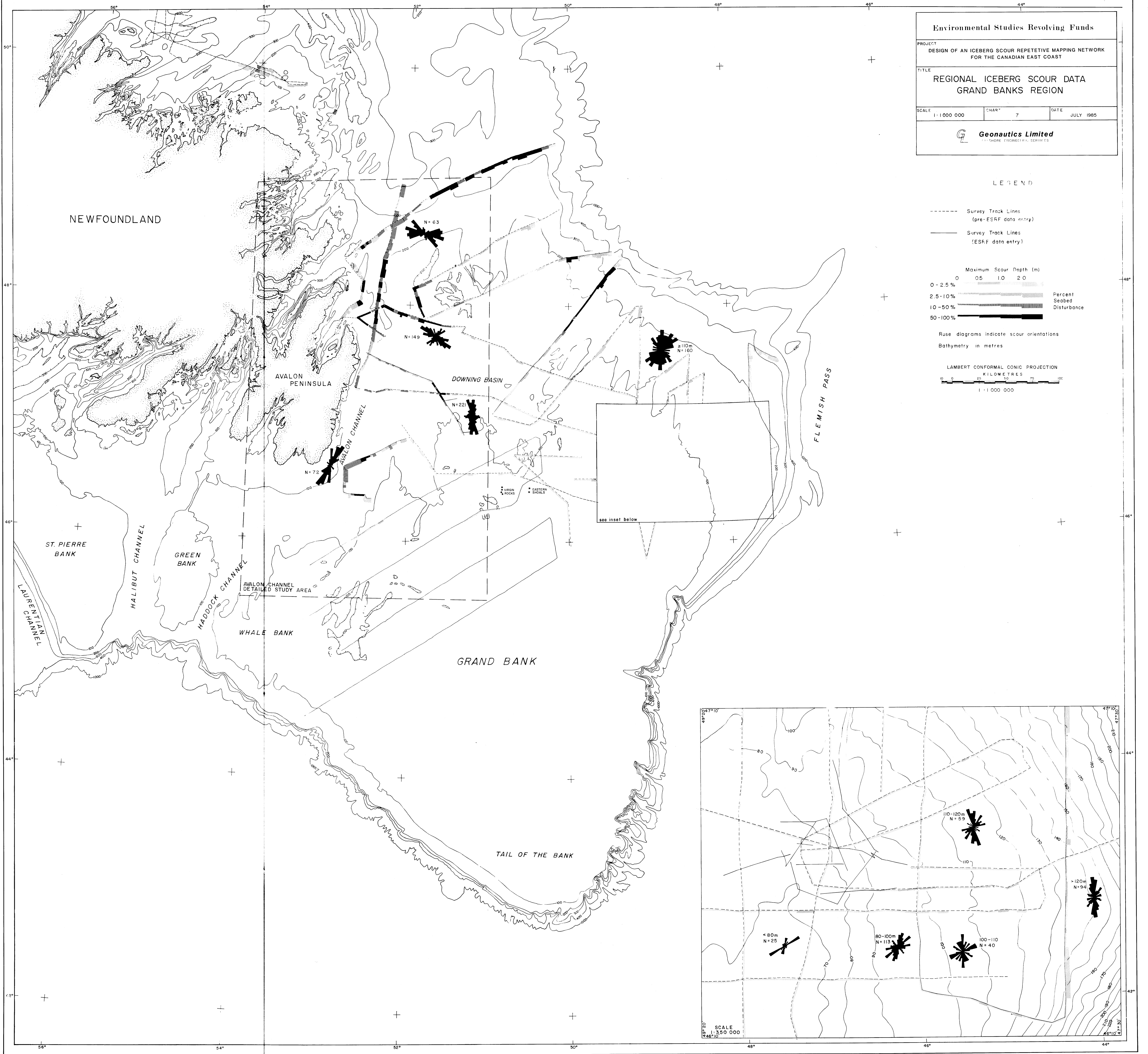
--- Survey Track Lines (pre-ESRF data entry)
— Survey Track Lines (ESRF data entry)

Maximum Scour Depth (m)
0 0.5 1.0 2.0

0-2.5% 2.5-10% 10-50% 50-100% Percent Seabed Disturbance

Rose diagrams indicate scour orientations
Bathymetry in metres

LAMBERT CONFORMAL CONIC PROJECTION
KILOMETRES
0 25 50 75 100
1:1 000 000



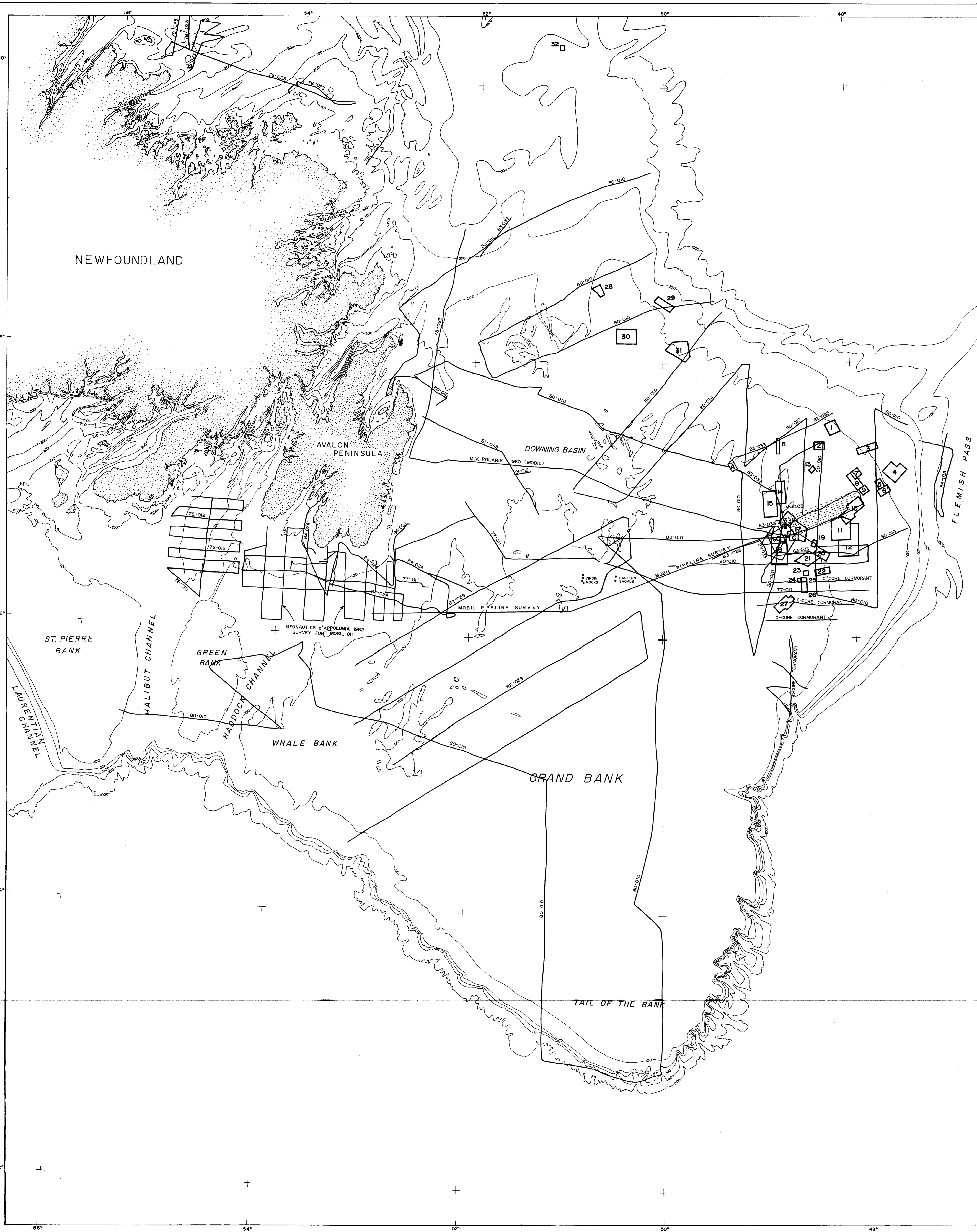
Environmental Studies Revolving Funds

PROJECT
DESIGN OF AN ICEBERG SCOUR REPETITIVE MAPPING NETWORK
FOR THE CANADIAN EAST COAST

TITLE
**EXISTING DATA COVERAGE
GRAND BANKS**

SCALE 1:1,000,000 CHART 8 DATE JULY 1985

Geonautics Limited
OFFSHORE ENGINEERING SERVICES



LEGEND

SIDE SCAN MOSAIC	INDUSTRY SITE SURVEYS
A. SCOUR #95 MOSAIC (1983)	1. BONANZA (1982)
B. MOSAIC 3 - 8000 SERIES (1980)	2. DOMINION (1983)
C. HIBERNIA EAST MOSAIC (1980)	3. RAGNAR (1981)
	4. DANA (1981)
	5. SOUTH PANTHER REV. (1984)
	6. SOUTH PANTHER (1984)
	7. WHITE BEAR (1984)
	8. TEMPEST NORTH (1980)
	9. SOUTH TEMPEST STEP-OUT (1984)
	10. TRAVE / WHITE ROSE (1979)
	11. WHITE ROSE FLANK (1981)
B.I.O. REGIONAL SURVEY (Side Scan, Hunttec Coverage)	12. ARCHER FLANK (1982)
21. INDUSTRY WELLSITE SURVEY AREA	13. CONQUEST (1984)
M.V. POLARIS 1980 (C-Core 4000 Series)	14. WEST FLYING FOAM (1981)
	15. MERCURY (1982)
	16. HIBERNIA (1979, 80, 81)
	17. MARA (1983)
	18. RANKIN (1981)
	19. NORTH BEN NEVIS REV. (1984)
	20. NORTH BEN NEVIS (1984)
	21. HEBRON (1981)
	22. VOYAGER (1983)
	23. TERRA NOVA (1981)
	24. BEOTHUK 1984
	25. BEOTHUK M-05 (1984)
	26. TERRA NOVA SOUTH (1981)
	27. PORT AU PORT (1981)
	28. TITUS (1983)
	29. CUMBERLAND (1981)
	30. LINNET (1982)
	31. SARONAC (1983)
	32. BAIE VERTE (1984)
	33. NAUTILUS (1981)

0 25 50 75 100
kilometres
1:1,000,000