BEAUFORT SEA GRANULAR RESOURCES WORKSHOP

February 13, 1992

PREVIEW VOLUME

Sponsored by:
INDIAN AND NORTHERN AFFAIRS CANADA

Prepared by:
EBA ENGINEERING CONSULTANTS LTD.

ø A-1

BEAUFORT SEA GRANULAR
RESOURCES WORKSHOP
February 13, 1992

PREVIEW VOLUME

Sponsored by:
Indian and Northern Affairs Canada

Prepared by:
EBA Engineering Consultants Ltd.

Table of Contents

Tables of Contents (Contd)

HERSCHEL ISLAND STUDY

For Presentation At:

BEAUFORT SEA GRANULAR RESOURCE
SEMINAR, FEB. 13, 1992

For Presentation By:

R. Quinn
Terra Surveys Limited
Sidney, B.C.

INTRODUCTION

In 1984 and 1985 a series of studies were undertaken to locate and delineate potential areas for the future development of offshore granular resources near Herschel Island, Yukon Territory. The work, carried out by M.J. O'Connor and Associates and EBA Engineering Consulting Inc., was authorized by the Department of Indian and Northern Affairs and the studies were carried out in collaboration with the Geological Survey of Canada. In addition, the major petroleum operators assisted in the program by providing access to propriety data for incorporation in the synthesis of the geophysical and geotechnical data.

Geological Setting of the Area

The study area, shown in Figure 1, lies on the Natsek Plain, an area for which little subsea information was available prior to the DIAND Herschel Island study. Exposures on the Yukon Coastal Plain reveal sediments which are thought to predate the early Wisconsin glaciation. It has been suggested that these sediments were deposited during the nonglacial interval immediately preceding the early Wisconsin.

Sections of the pre-Wisconsin sediments exposed on Herschel Island reveal complex marine, deltaic, fluvial, lacustrine and even terrestrial depositional environments. It is thought that the early Wisconsin glaciation occurred greater than 40,000 years ago and may have been responsible for a major ice-thrusting event at Herschel Island. The Mackenzie Trough probably influenced the movement of the early Wisconsin ice sheet forming a lobe of ice to the northwest. The lobe is thought to have thrust sediments from Herschel Basin to form Herschel Island (Mackay, 1959).

Herschel Basin is separated from the Mackenzie Trough to the east by a submarine ridge or sill which joins Collinson Head to Kay Point. This ridge is thought to be an intact remnant of the original pre-Wisconsin marine sequence which escaped removal by the ice-thrusting event.

METHODOLOGY

A three-phase approach was carried out to determine the geological conditions:

i) marine geophysics to provide information on the nature of the soil conditions in the Herschel area;
ii) marine geotechnical drilling to confirm the geological conditions interpreted from the seismic records and also to provide grain size distribution of the granular deposits.
iii) synthesis of this data along with existing other regional data available.

Geophysical Program

The field data acquisition phase included coverage of the Herschel area by two vessels, the NORWETA and the BANKSLAND. The geophysical equipment included precision survey echo sounder, side scan sonar, subbottom profiler, boomer, and airgun. Several hundred kilometres of data were collected over the study area between Collinson Head and Kay Point.

Geotechnical Program

The geotechnical field studies were carried out from the ARCTIC KIGGIAK by EBA Engineering Consultants Ltd. Bore hole locations were selected to determine the stratigraphy, both on Herschel Sill and Herschel Basin.

Four locations were investigated on the sill. At these locations, two boreholes were drilled and sampled to depths of 19.7 m and 5.7 m, while two probe holes were drilled to test the thickness of gravel at the other two locations. Surficial sediments at each of these locations were sampled using the grab dredge on the ARCTIC KIGGIAK.

The additional two boreholes drilled within Herschel Basin were intended to test the possibility that some of the anomalous bathymetry within the basin may be due to glacially related granular resource deposits.

SUBSEA FEATURES IN THE STUDY AREA AND THEIR GRANULAR RESOURCE POTENTIAL

Four distinct subsea regions were identified and are shown in Figure 2. These included: Herschel Basin, Herschel Sill, Yukon Coastal Shelf, and the Babbage River Paleochannel.

Herschel Basin

The deepest water depths were found in Herschel Basin where the bottom of the basin is enclosed by the 50 m isobath and with water depths up to 80 m. The east side of the basin has pingo like features that rise steeply to within 25 m of the sea surface. Geotechnical and geophysical studies showed that the floor of the basin consists of approximately 40 m of laminated silty clay overlying sand, stiff clay and gravel. Ice lensing observed in the surficial clay suggests that the basin was drained and the bottom sediments exposed for some period of time in the past. Although extensive sand and gravel layers were noted in the sub seabottom sediments, the extreme water depths and the presence of a thick surficial clay unit preclude the development of any granular resources in Herschel Basin.

Herschel Sill

The precise subsurface conditions which underlie the sill joining Collinson Head to Kay Point were difficult to resolve acoustically, but surface sampling, test dredging, and several geotechnical boreholes proved useful in determining the surficial geology. For the most part, the sill is comprised of the same terrain units which may be found near Collinson Head and Kay Point. The eroded remnants of these mainly stiff, fine grained sediments are locally covered by modern sand and gravel shoals up to 7 m or more in thickness along the crest. South of Collinson Head, the bore holes and probe holes drilled on the crest of the sill showed granular thickness of up to about 3.5 m (see Figure 3.) The granular material was made up of sand and gravel containing subrounded to subangular particles. The coarse grained deposits are underlain by a stiff silty clay sequence.

Maximum water depths along the crest reach 17 m, but most of the sill is much shallower (4 - 12 m). In addition to ice scours, the presence of ripple marks along the crest of the sill as well as in other areas of the study such as the coastal shelf, provided indirect evidence regarding the nature of the seafloor and distribution of surficial granular resources. On the west side of the shoal north of Kay point well developed ripple trains were evident. The ripple marks were also helpful in delineating both the nature of the surficial sediments and the lateral limits of individual soil types. In Figure 4 the boundary between the sandy and clayey soils at the seabed are clearly defined.

Discontinuous ice-bonding is common in the fine grained soils which constitute the regional sill sediments, but is not expected to occur in the modern sand and gravel shoals. Almost 17,000,000 m^3 of granular material suitable for engineering purposes are already known to be located in these shoals. The present information suggests that an additional 70,000,000 m^3 are probably available at the seabed, and another 40,000,000 m^3 of material may also be located, if it can be proven that the glaciofluvial features noted near Kay Point also extend offshore, see Figure 5. Unfortunately, much of the granular resources on the sill are located in relatively shallow water depths, where conventional hopper trailer suction dredges may not be appropriate. Nevertheless, it is presumed that other technologies could be used for development if warranted by future granular resource requirements.

Yukon Coastal Shelf

The narrow coastal shelf which borders the north and west side of Herschel Basin was, like the Herschel Sill, difficult to map using high resolution seismic techniques, because the water depths are shallow (less than 14 m) and the shelf is underlain by firm to stiff or dense materials which form part of the morainal, lacustrine, or glaciofluvial sequences found along the coastline. Recent soft sediments appear to be absent in most areas, except near the basinward edge of the shelf. Geotechnical drilling conducted by Gulf Canada has verified that silty to gravelly sands may be found in certain areas near Stokes Point, but shallow ice-bonding was also present near the coastline. The most prospective area for future granular resource development appears to be located between Roland Bay and Catton Point, but no groundtruth information is currently available in this area. Most of the present 9,750,000 m^3 of reserves on the shelf have been located by geotechnical boreholes. It is estimated that a total of 40,850,000 m^3 of sand and gravel may eventually be found on the shelf and along the coastline, if substantial additional drilling is conducted in the most prospective areas.

Babbage River Paleochannel

The drowned Babbage River Paleochannel does not appear to be generally prospective for development of seabed granular resources, especially in the deeper areas near Herschel Basin. The paleochannel may, however, contain some sand and gravel in the shallow waters near the Spring River, or at greater depths below the seabed than were mapped during the present study. Total volume of these deposits is presently estimated to be only 3,500,000 m^3.

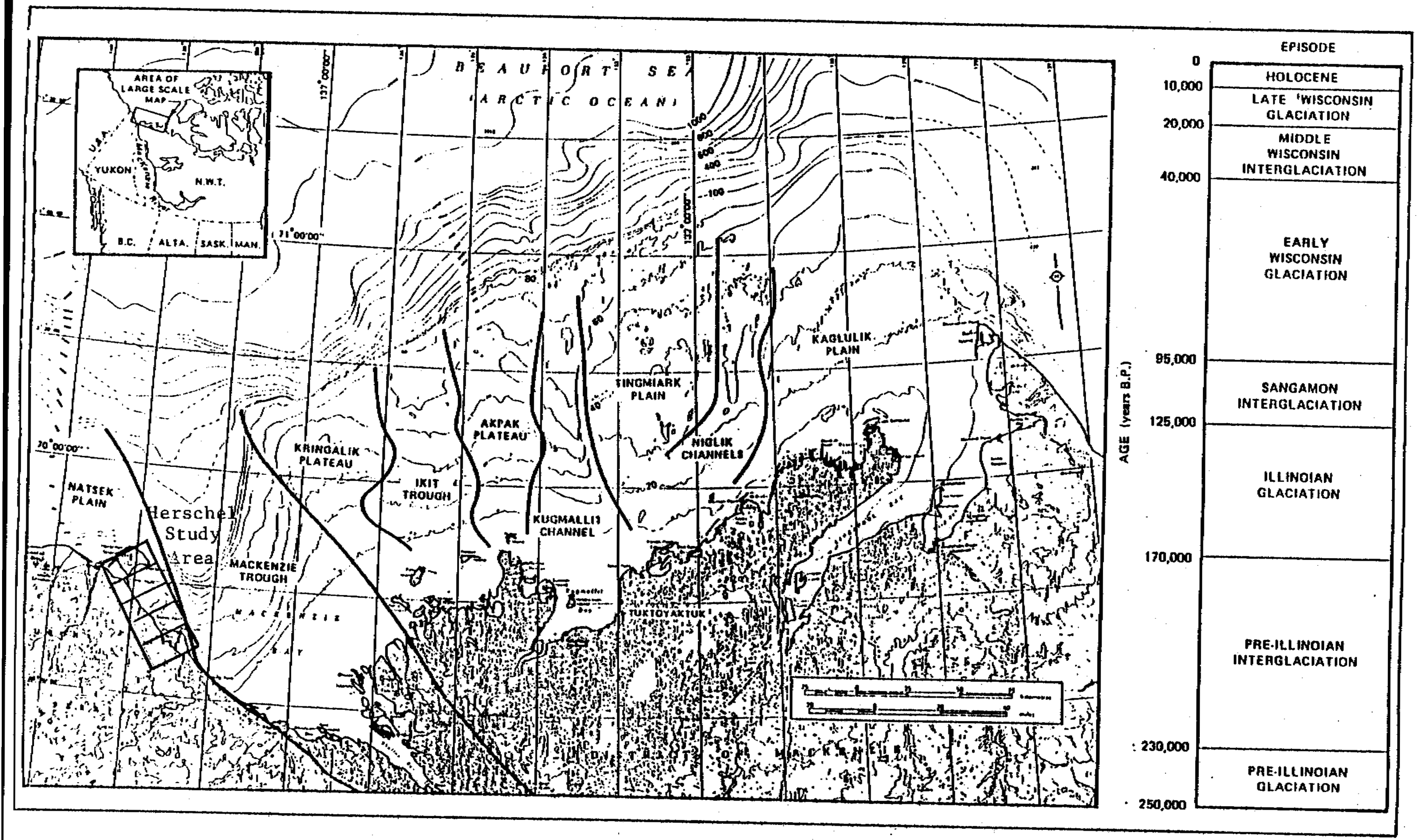
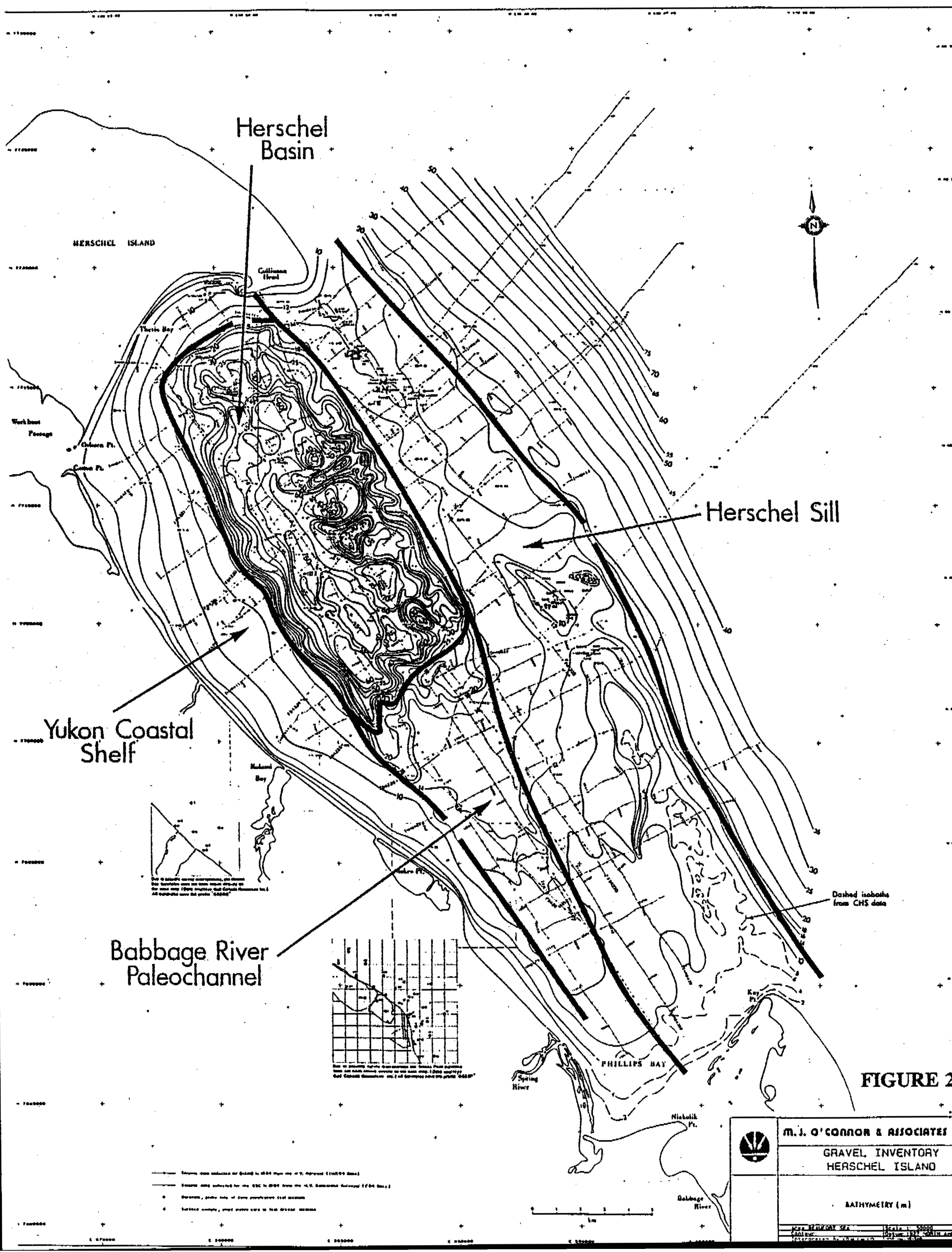


Figure 1. Herschel Island Study Area and Physiographic Regions of the Beaufort Sea with Geologic Time Scale.



Herschel
Basin
HERSCHEL ISLAND
Herschel Sill
Yukon Coastal
Shelf
Babbage River
Paleochannel
Dashed isobaths
from CHS data
PHILLIPS BAY
Spring
River
Babbage
River
M. J. O'CONNOR & ASSOCIATES
GRAVEL INVENTORY
HERSCHEL ISLAND
BATHYMETRY (m)

FIGURE 2

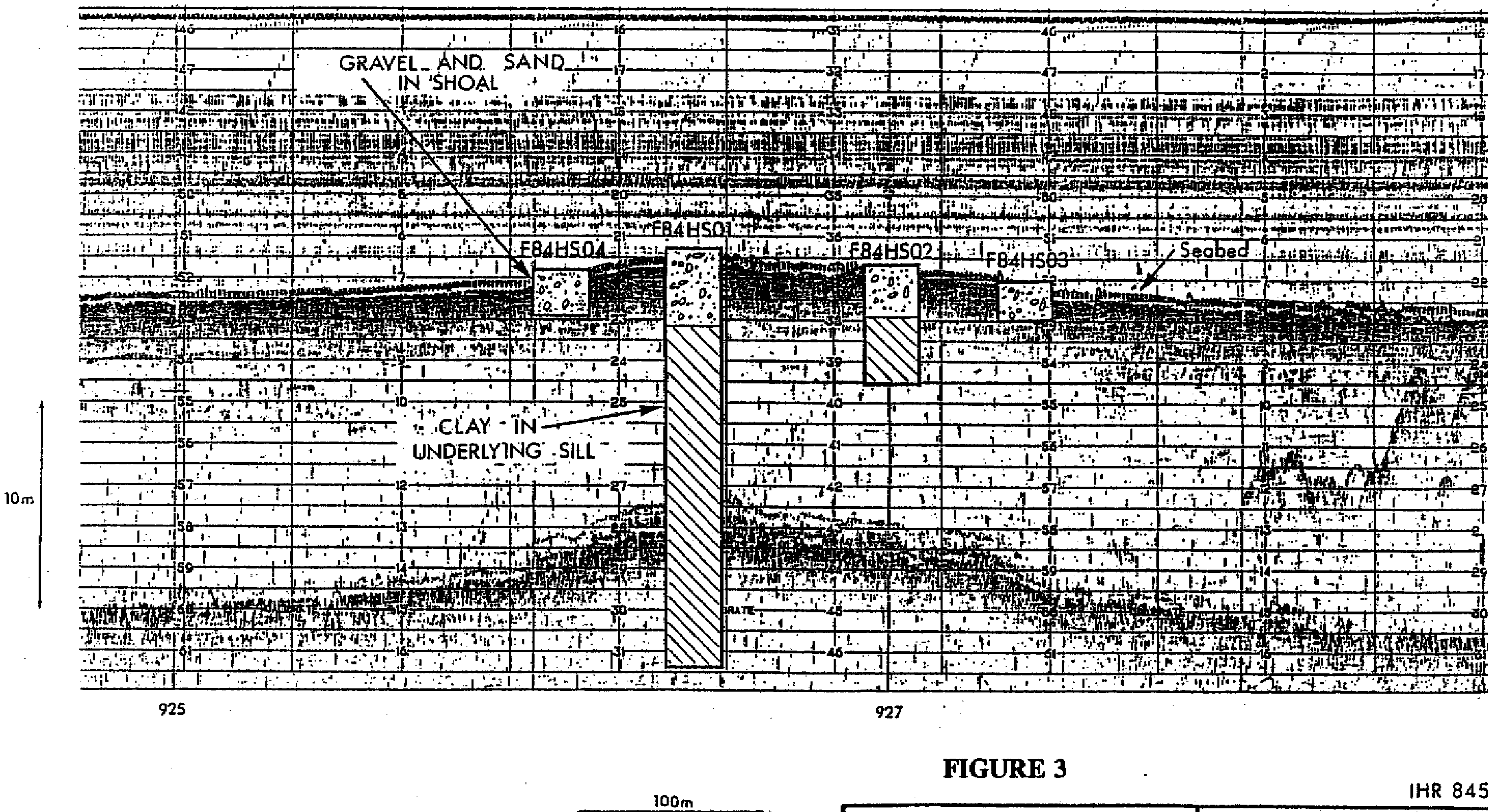


FIGURE 3

IHR 845

Stratigraphy of the Shoal South of Collinson Head	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 110-260	DATE: 85/07/22
	DRAWN BY: MG	

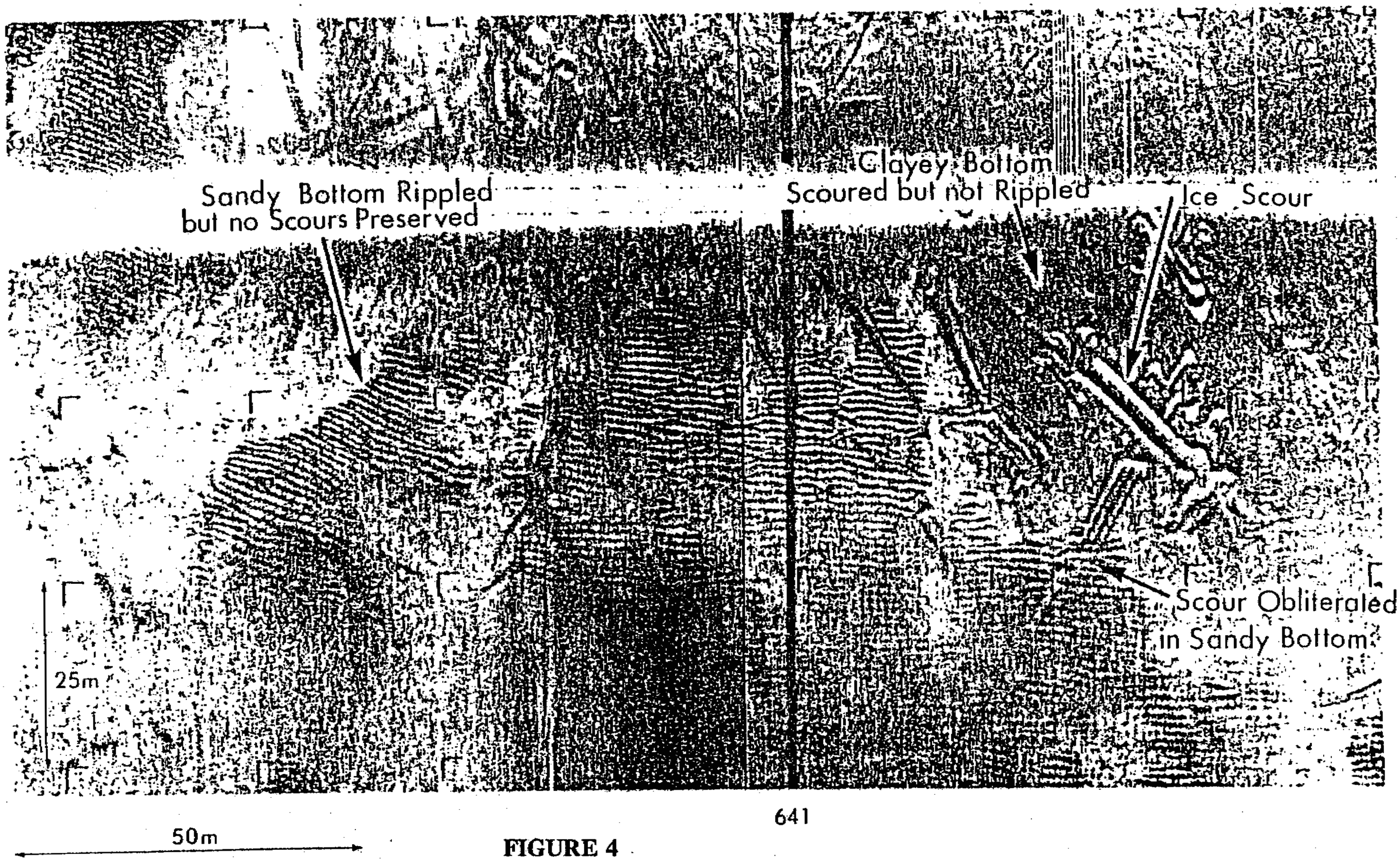
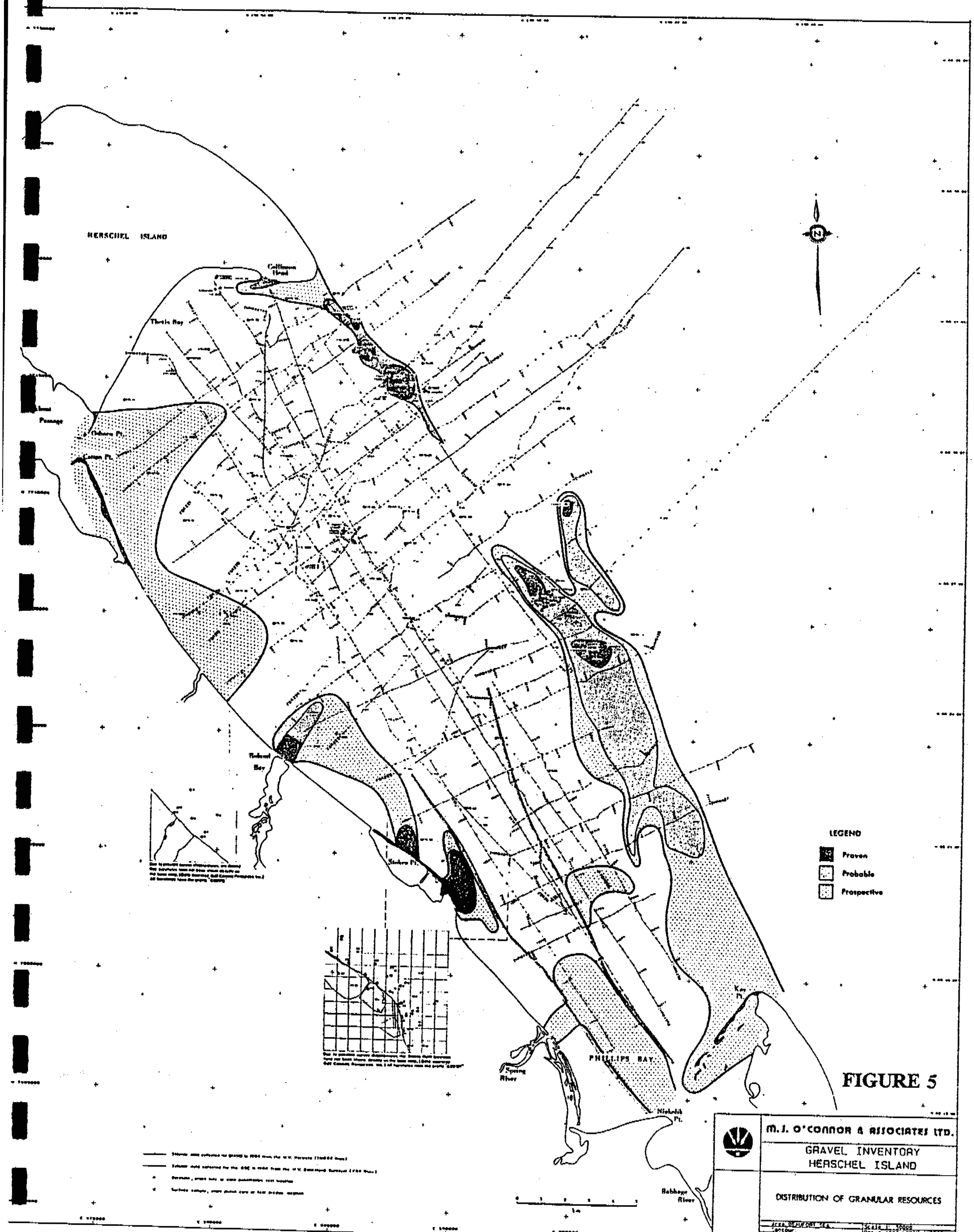


FIGURE 4

Ripple Marks Delineate Seabed Soil Type	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/07/22
	DRAWN BY: MG	



HERSCHEL ISLAND
Collinson Head
Thetis Bay
Osborn Pt.
Catton Pt.
Ptarmigan Bay
Stokes Pt.
PHILLIPS BAY
Spring River
Kay Pt.
Nicholik Pt.
Babbage River
LEGEND
Proven
Probable
Prospective
M. J. O'CONNOR & ASSOCIATES LTD.
GRAVEL INVENTORY
HERSCHEL ISLAND
DISTRIBUTION OF GRANULAR RESOURCES

FIGURE 5

OVERVIEW OF GRANULAR RESOURCE POTENTIAL FOR THE WESTERN BEAUFORT (YUKON) CONTINENTAL SHELF

Part or the Northern Oil and Gas
Action Program (NOGAP - Project A4-20)

Completed for:
Indian and Northern Affairs Canada
Natural Resources and Economic Development
Under D.S.S. Contract - OST85-00374

Completed by:
Earth & Ocean Research Ltd.
Dartmouth, Nova Scotia
June 1986

Original Report Author:

Lauchlin Meagher

Presented by:

John F. Lewis

Lewis Geophysical Consulting
376 Prospect Bay Rd.
Box 93, Site 15, RR#4
Armdale, Nova Scotia

February, 1992

Phone 902-852-3442 Fax 902-852-4788

ABSTRACT

An investigation of the potential granular resource base of the western Beaufort (Yukon) continental shelf has been completed covering approximately an area of 5000 square kilometres. The region extends from the northern Yukon coast to the shelf edge in approximately 80 m of water and is bounded by the Mackenzie Trough on the east and the Alaska/Yukon border (141° W longitude) on the west. A limited data base of 240 grab samples, 18 piston cores and two geotechnical boreholes was available for the region and the interpretation has been based on these samples and a data set of 2770 km of high resolution seismics and selected echo sounder data from a 14055 km data base.

Since ground truthing data was very limited, no "proven" granular deposits have been identified. Based on the seismics and seabed physiography of the region 19 localized "probable" and "prospective" granular resource zones have been identified. These have been localized into a "Coastal Zone" where coarse aggregate deposits are an extensions of onshore deposits (probable resource), a "Middle Shelf Zone" dominated by lag deposits localized on shoals (prospective) and an "Outer Shelf Zone" where a combination of possible outcropping coarser materials and concentrations of ice rafted materials are the likely sources of coarse materials (probable and prospective).

Beyond the 10 m contour 556-842 million cubic metres of Probable resource have been estimated and inshore of this contour an additional 444 to 740 million cubic metres are identified. Prospective resources are estimated to be an additional 328 million cubic metres primarily from the stamuki shoal features in the Middle Shelf zone. A 20th prospect is defined as the entire larger Outer Shelf Zone which constitutes an area of 1400 square km. This entire region is considered as prospective but of an unknown (probably less than 1 m) thickness and therefore has not been incorporated into these resource volume estimates.

Lack of borehole and grab sample quantitative grain size analysis for the available samples limits estimates of the resource quality to very general statements. With this constraint the alluvial fan materials and the materials on the eastern edge of the Middle Shelf are expected to be of high quality of mixes sand and gravel while the remainder of the deposits will likely be gravel and sand rich but prone to high percentages of fine undesireable materials.

INTRODUCTION

During 1986 an interpretation and integration of the previously collected bathymetric, geophysical and geological data from the western Beaufort Shelf was undertaken by Earth & Ocean Research Ltd for the Department of Indian and Northern Affairs. The investigation was to provide an overview of the granular resource base of this area to assist in planning of future exploration studies to delineate granular materials for use in the onshore or offshore construction by industry or government.

Figure 1 shows the location of the study area consisting of the Western Beaufort (Yukon) Shelf or Natsek Plain (O'Connor 1982 physiographic province) extending from the shoreline to the shelf edge at approximately the 80 m water depth contour. The region is bounded on the west by the Yukon/Alaska border at longitude 141° W and on the east by the Mackenzie Trough and the eastern edge of Herschel Island at approximately longitude 139° W. The region constitutes approximately 5000 km^2.

DATA BASES

Prior to 1984/85 there was little data available for the western Beaufort Shelf region. CHS bathymetric chart 7601 indicated a few widely spaced sounding lines with non systematic coverage. A total of 53 grab samples and 4 piston cores had been taken by the GSC within the boundaries. Grain sizes and broad distribution mapping of the surficial sediments had been presented in Pelletier (1975), Vilks et.al., (1979) and Pelletier (1985). A single geotechnical borehole, Natsek 4, was drilled in 1978, and textural descriptions and test results were presented by McClelland Engineers Ltd. (1979).

A significant increase in the data base occurred in 1984 when a combined hydrographic and geophysical survey was conducted from the M.V. Banksland by the CHS and the GSC. This survey yielded 14055 Km. of heave compensated echo sounder data, 820 Km. of 10 in^3 airgun, 50 Khz. sidescan and 3.5 Khz profiler data, 14 piston cores to a maximum 1.5 meter penetration, and 187 Shipek grab samples which have only been visually described (no quantitative grain size analysis). The results of the hydrographic survey are presented in McGladrey (1984) and resulted in the preparation of CHS field sheet WA10167. A preliminary interpretation of the geophysical and geological data is presented in Meagher (1985).

In 1985 an additional 1950 Km. of 10 in^3 airgun, 3.5 Khz profiler and EG&G boomer data were collected from the C.S.S. Tully by Geomarine Associates. No sediment samples were collected during this program. Approximately half of these 1985 data lines were collected from within the area of the present study, the remainder covers an area to the north and east. The field operations are reported in Fehr(1986).

Also during the 1985 field season, a geotechnical borehole (GSC-1), was drilled from the M.V. Broderick on the outer shelf (EBA Engineering Consultants Ltd. 1986). This borehole, located at 70°08'23.91"N, 140°28'17.86"W, was drilled to a sub-seafloor depth of 52.6 meters. Additionally a number of boreholes were drilled for industry, on the Alaskan shelf. Five of these are located near the site and reference is made to field notes of these borings.

In total the limited direct samples data base consisted of 240 grab samples, 18 piston cores and two geotechnical boreholes shown in Figure 2. The high resolution geophysical data set shown in Figure 3 totalled 2770 km of high resolution seismics which was supplemented by selected echo sounder data from a 14055 km data base (not plotted here).

At the time of writing of this study EOR was also working on a Quaternary geological synthesis of the seismostratigraphy of the area (Lewis and Meagher, 1991) and Mr Jim Shearer was analyzing the sidescan sonar data for ice scour and other seabed transport information (Shearer, 198_). Challenger Survey was also developing a 3-D presentation of the bathymetric information for the region (Challenger Surveys, 198_) and McGregor Geosciences Ltd had prepared a hazards report over the Edlok wellsite. Data from these studies, though preliminary at the time of writing of this report, have been incorporated were relevant to the discussions here.

SITE DESCRIPTIONS

The Western Beaufort (Yukon) Shelf had been designated the Natsek Plain by O'Connor (1982) and was noted to be primarily a fine grained sedimentary sequence that did not correlate with the general geological model for the eastern Beaufort Shelf (O'Connor, 1980). Lewis and Meagher (1991) developed a comprehensive seismo stratigraphic description of the area that indicates the Upper Tertiary and Quaternary section within the region.

BATHYMETRY AND PHYSIOGRAPHY

Figure 4 is a detailed bathymetric contour map of the Yukon Shelf developed by a physiographic features oriented re-contouring of the 1984 hydrographic survey data presented on CHS field sheet WA 10167. The shelf has a regional slope of 1:833 to the north. The surface slopes northward in the coastal and mid shelf regions and trends increasingly toward the northeast as the shelf edge is approached. The transition from shelf to slope is abrupt and occurs approximately at the 80 m water depth contour. The shelf edge is noticeably regular with no prominences or incisions, possibly the result of planation by glacier ice restricted to the trough during the Wisconsin Glaciation.

The major physiographic sub-regions of the Yukon Shelf have been defined in this program and are outlined in Figure 5 and given informal names. Two ridges dominate the shelf morphology. The Inshore Ridge extends from due west of Herschel Island for a distance of approximately 60 km. It is approximately enclosed by the 24 m water depth contour and is about 4 km wide. The Offshore Ridge is a larger feature and occupies the outer north facing shelf from the 50 m contour to the shelf edge. This ridge extends west onto the Alaskan shelf and within the study area the ridge is 66 km long and 14-18 km wide. The axis of the ridge is situated near the southern flank were an minimum water depth of 37 m is noted. A narrow linear spur ridge extends from its northeast corner in a northeast direction to the shelf break.

Topographically the Outer Ridge is irregular with numerous linear and sinuous superimposed shoals of one to several metres in local relief. These shoals form a second ridge complex named the "Natsek Ridge" which is sub-parallel to the main ridge and displays a branching pattern suggestive of dendritic drainage controlled formation. This pattern is most apparent on the 3-D representations constructed by Challenger Surveys and depicts four or five tributary ridges that coalesce with the trunk ridge at their eastern ends. These ridges die out in a westerly direction and do not extend beyond the Alaska-Yukon Boundary.

There are numerous smaller shoal features observed on the shelf though they are predominantly concentrated immediately north of the Inner Ridge. There are noticeably fewer shoals in the mid shelf region though those present are thought to be relict stamuki shoals developed as the seas encroached across the coastal plain. A few shoals near the edge of the Mackenzie trough just south of the Outer Ridge exhibit significantly higher relief and slope which may represent limited exposure of coarser, more resistant materials lying between Units L and M. Alternately these shoals could possibly be morainal deposits.

The Outer Trough separates the two ridges. It is broad and flat bottomed with small mounds of 2 to 5 m elevation scattered over its floor. The bottom of this trough descends to the east at a low gradient where it is truncated as a sort of hanging valley into the Mackenzie Trough. Maximum depths in the Outer Trough are 58 m. The Inshore Trough is a smaller feature enclosed by the 24 m contour with a maximum depth of 27 m. It is 36 km long and 6 km wide at its maximum. The Inshore Ridge has been interpreted as a series of stamuki shoals constructed by sour action of the winter ice pack as it rotates against the shore fast ice. Subsurface evidence suggests that the stamuki shoal has developed on an older shoal feature.

SURFICIAL COVER

The surficial sedimentary cover on the Yukon Shelf represents a conflicting interpretational situation. From the subsurface seismo-stratigraphy and borehole data that is available, all of the strata from just beyond the nearshore zones to the offshore portions of the shelf consists of fine grained materials with very low concentrations of sands or gravels indicated. From the surficial grab sample information the indications suggest that the inner shelf is predominantly a silty-clay facies while the samples and sidescan data for the offshore region indicate these regions to be a sand-gravel dominant facies. Based on this discrepancy it is concluded that the coarser offshore facies is a thin lag deposit which is too thin to resolve with the high resolution seismics and has been transported into the area by ice rafting.

Figure 6 is a map of the bottom sediment distribution of the Yukon shelf that was presented by Pelletier (1985) based on the pre 1984 sample data base (approximately 50 samples). This map was compiled using an analyzed data set and could not be modified using the qualitative descriptions of the samples collected during the 1984 surveys.

Jim Shearer (pers. com.) has interpreted high gravel concentrations from the sidescan data to be restricted to a narrow zone that runs the length of the Mackenzie Trough shelf edge. These data also indicate extensive areas that are dominated by sand ripples and meggaripples. The sand ripples are observed within the eastern and central Outer Trough while the megaripples occur in a narrow linear zone sandwiched between the eastern edge of the gravel zone and the Mackenzie Trough Shelf edge. The distribution of these zones has been outlined on the Granular Resource map of Figure 10 as it was not felt that the qualitative descriptions could be used to modify the Pelletier maps though this information is considered important to the granular resource assessments.

SUB-SURFACE GEOLOGY

The sedimentary section beneath the shelf region thickens to seaward and rests unconformably and paraconformably of a region-wide Miocene erosion surface. The sub surface sedimentary strata form a predominantly fine grained clastic wedge laid down under shelf, coastal, subaerial and glacial environments. These strata correlate with the Upper Iperk Sequence on the eastern Canadian Beaufort Shelf and the Gubik formation on the Alaskan Beaufort Shelf. The surficial cover over the greater part of the shelf consists of a stiff to soft, grey clayey silt to silty clay with various admixtures of gravel. High concentrations of gravel and sand occur seaward of the river mouths and in a broad apron that follows the shelf edge. The gravels at the river mouths are offshore extensions of, or reworked components of alluvial fans onshore. The offshore gravel concentrations contain significant proportions of exotic clast lithologies and indicate at least a partial provenance from the Canadian Arctic Islands. These lithologies suggest an ice rafted, drop stone origin for these materials.

The present seafloor of the shelf area is erosional in character and represents the latest shelf wide unconformity surface as evidenced by truncation of the subsurface strata at this surface. With the possible exception of the near shore zone (Unit Q within the Inshore Trough areas), there is no indication that present day sedimentation is occurring on the shelf. Erosion and sediment redistribution by current and wave action, and ice keel scouring is evident and may have removed a significant amount of the sedimentary section. Age determinations based on the limited boreholes available suggest that the exposed sediments on the seabed are of Mid to Late Pleistocene in age (50,000 to 80,000 b.p.).

The seismo stratigraphic sequence underlying the Yukon Shelf is interrupted by numerous unconformity surfaces, several of which display channel development and record a history of a least six to ten regressive and transgressive episodes since the Miocene that have alternately subaerially exposed and drowned the shelf. At least two of the unconformity surfaces form apparent buried shoreline topographies near the present day shelf edge suggesting subaerial exposure affected the entire shelf at various times (Horizons 12 and 15). The net effect of these cycles has been a progradation of the shelf edge toward the north. Figure 7 shows a north south transect line across the shelf indicating the seismo-stratigraphic sequences associated with this shelf development. A total of 11 seismo-stratigraphic units are identified on the shelf and 8 are exposed on the seabed. This sequence of subsurface sedimentary units have been identified and designated with alpha codes which range from Unit G (below Horizon 7) at the base (Miocene pre unconformity materials) to Unit P (above horizon 15) which represents the youngest mappable (with the present data set) sediments preserve at the shelf edge (possibly as much as 50,000 years old). Figure 8 outlines the relationship of the various stratigraphic units within the Western Beaufort (Yukon) Shelf sequence and provides a tentative age correlation of the respective units compared to the age dating from the GSC-1 borehole and projected correlation to work completed on the Alaskan Beaufort shelf and North Slope regions. Unit Q represents a localized, ponded, overlying unit that is restricted to the Inshore Trough region and cannot be stratigraphically position within the general sequence because of its isolated extent. This unit is observed to disconformably lie on top of the contemporaneous units R and L in this nearshore region. Figure 9 is a map of the exposure of these units as they intersect the seabed. There is likely a very thin surficial veneer over these exposures which was below the resolution capabilities of the seismic systems employed in the mapping process and represents the, apparently, unrelated surficial lag materials mapped in the surficial sediment distribution map of Figures 6 and 10.

DEPOSITIONAL SUMMARY AND PROVENANCE

The subsurface sediments on the Yukon Shelf represent a predominantly fine grained clastic wedge sequence characteristic of continental shelf outbuilding. These materials were predominantly deposited under marine and nearshore marine conditions with a fine grained source of supply from the south or possibly alongshore from the east or west. As has been outline above these materials are presently being eroded at the seabed and the limited borehole evidence indicate a very sparse content of coarser materials. As a result these sediments are not believed to represent a source for lag borrow materials.

The sediments presently residing on and very near the seabed of the Yukon Shelf indicate that the relation between locale, bathymetry, stratigraphy and sample texture is not straightforward and that distribution is controlled by several independent mechanisms.

The presemt day predominant source of new sediments to the Yukon Shelf is the coastal retreat ongoing along the Yukon Coastline. The coastline west of Komakuk Beach and extending almost to Clarence Lagoon is dominated by fine grained lacustrine sediments. Coastal erosion is documented along this coastline (Rampton, 1982) and similar regions on the Alaskan North Slope record average rates of retreat that are approximately 5.4 m/year and locally reaches 18 m/year

(Reimnitz et.al., 1985). These new sediments are not observed to be collecting in any significant deposits however on the shelf and it is presumed that the fines are virtually all being swept of the shelf to be deposited in the Mackenzie Trough and over the northern shelf edge.

The gravels and sands of the Coastal Zone are relict and were deposited as alluvial fans at a time of lower sea level. They are presently being reworked into marine landforms of baymouth bars, islands and spits, and they are also being transported offshore a minimal distance where they form a thin veneer on top of the fine grained lacustrine or lagoonal materials which occupy the Inshore Trough.

The coarse grained materials found on the Middle Shelf are generally, though not always located on shoals and the majority of shoals in this region are composed of fine grained materials. The sands and gravels in this region are unevenly distributed and generally occur in a bimodal distribution with mud. Since there appears to be no subsurface source for these materials it presumed that these materials have been transported to the middle shelf regions from the alluvial sands by ice rafting with subsequent concentration through winnowing on the tops of the shoals.

This mechanism is invoked on a larger scale for the gravels on the Outer Shelf where the surficial veneer of coarse materials is ubiquitous. The coincidence and restriction of this resource to the Outer Shelf along with the exotic lithologies, suggesting an Arctic Island source, imply that these material were most likely transported to the shelf from offshore, possibly at a time of lower sea level when access by ice was restricted to the 40 to 50 m isobath.

GRANULAR RESOURCE MODEL AND EVALUATIONS

DISTRIBUTION

Figure 10 presents the interpreted distribution of potential granular resources for the Yukon Shelf area. The description of potential aggregate concentration is subdivided into three geographic zones: a Coastal Zone where coarse aggregates are drowned extensions of onshore deposits, a Middle Shelf Zone dominated by lag deposits localized on shoals and an Outer Shelf Zone where a combination of outcrops of coarse material and concentrations of ice rafted detritus are the likely sources of coarse materials.

Using these distinctions 20 prospects have been mapped over the entire shelf with prospects 1 to 4 being representative of the Coastal Zone, 4 through 15 being in the Middle Shelf Zone and 16 through 19 being in the Outer Shelf Zone. Prospect 20 constitutes the entire Outer Shelf Zone though has not been incorporated into the following volume estimates because there is currently virtually no evidence available for a thickness estimate of the coarser materials in this region.

The selection and identification these prospects has been defined, at least initially, based on the sample descriptions. Within the Coastal Zone the areal extent of the prospects has been extended using the bathymetric data and very limited seismic coverage available in the region. In the Middle Shelf Zone the bathymetry contours and field profiles were used to both map and evaluate prospects supplemented by microprofiler records when available in order to attempt to establish a probable depth of the resource. While the entire Outer Shelf Zone is identified as "prospective", specific areas have been designated prospects based on likely topography (prominent shoals), seismics or topography plus samples in order to narrow the search areas to some degree. This is done while recognizing that an unique relationship between shoal areas and coarse materials is not established from this study for the Outer Shelf area.

RESOURCE PROSPECT GRANULAR VOLUME ESTIMATES

There are no "proven" resources defined within the region. Given the conflicting nature of the cores, boreholes and seismics against the available grab sample data, it is obvious that the grab samples cannot be taken as representative of the substrate to any depth greater than a few centimetres.

Table 1 summarizes the prospects within the Western Beaufort (Yukon Shelf) study region indicating the areas of each resource prospect with an estimated thickness for each along with the probable or prospective reserve best estimated volume calculations. A confidence factor is included for each prospect based on a review of the sample, bathymetric and seismic evidence available on each site combined with an interpretive assessment of these data. A detailed discussion of each prospect region is include in the original report though will not be repeated here.

Prospects 1 to 4 and 18 have been evaluated as "probable" resource areas with an estimated potential total reserve of 556 to 841 million cubic metres of gravel and sand mixture. The remaining prospects are considered "prospective" resource areas with a total estimated volume of 329 million cubic meters. The region inshore of the 10 m isobath extending to the shoreline has been designated as a probable reserve with a potential volume of 444-740 million cubic metres. This region has been separated out from the others because unusual dredging techniques would be required within this nearshore region and it may or may not represent an economically recoverable resource for the region.

CONCLUSIONS

From a study of the sample, bathymetric, and geophysical data available on the Yukon Shelf the following conclusions can be drawn:

-There are no proven deposits of coarse material within the study due primarily to a lack of borehole control

-Probable areas include four drowned alluvial fan deposits adjacent the coastline and a grouping of shoals of possibly resistant substrate or morainal material situated on the east central edge of the shelf.

-The total volume of material identified as probable resource from the 10 meter isobath to the shelf edge is 557 to 842 million cubic meters.

-An additional 444 to 740 million cubic meters of probable resource is calculated for the area lying between the 10 meter isobath and the shoreline.

-Prospective areas include a number of shoals on the Middle Shelf and virtually the entire

Outer Shelf from the 40-50 meter isobath to the shelf edge.

-This latter area is not satisfactorily resolved from the data at hand and it is possible that the coarse grained deposit may be a surficial veneer of only a few centimetres thickness over most of the area.

-The prospective areas, exclusive of the general area of the Outer Shelf represents a total resource volume of 329 million cubic meters.

-The Outer Shelf zone has an area of 1400 million square meters but no thickness is attributed to the deposit at this time.

-The quality of the granular material requires more extensive analyses of the grab samples. From the data at hand it appears that the quality in terms of grain size and sorting will be highest on the drowned alluvial fan deposits and the possible moraine deposit on the east central shelf edge, and elsewhere will be deteriorated by high admixtures of fine grained material.

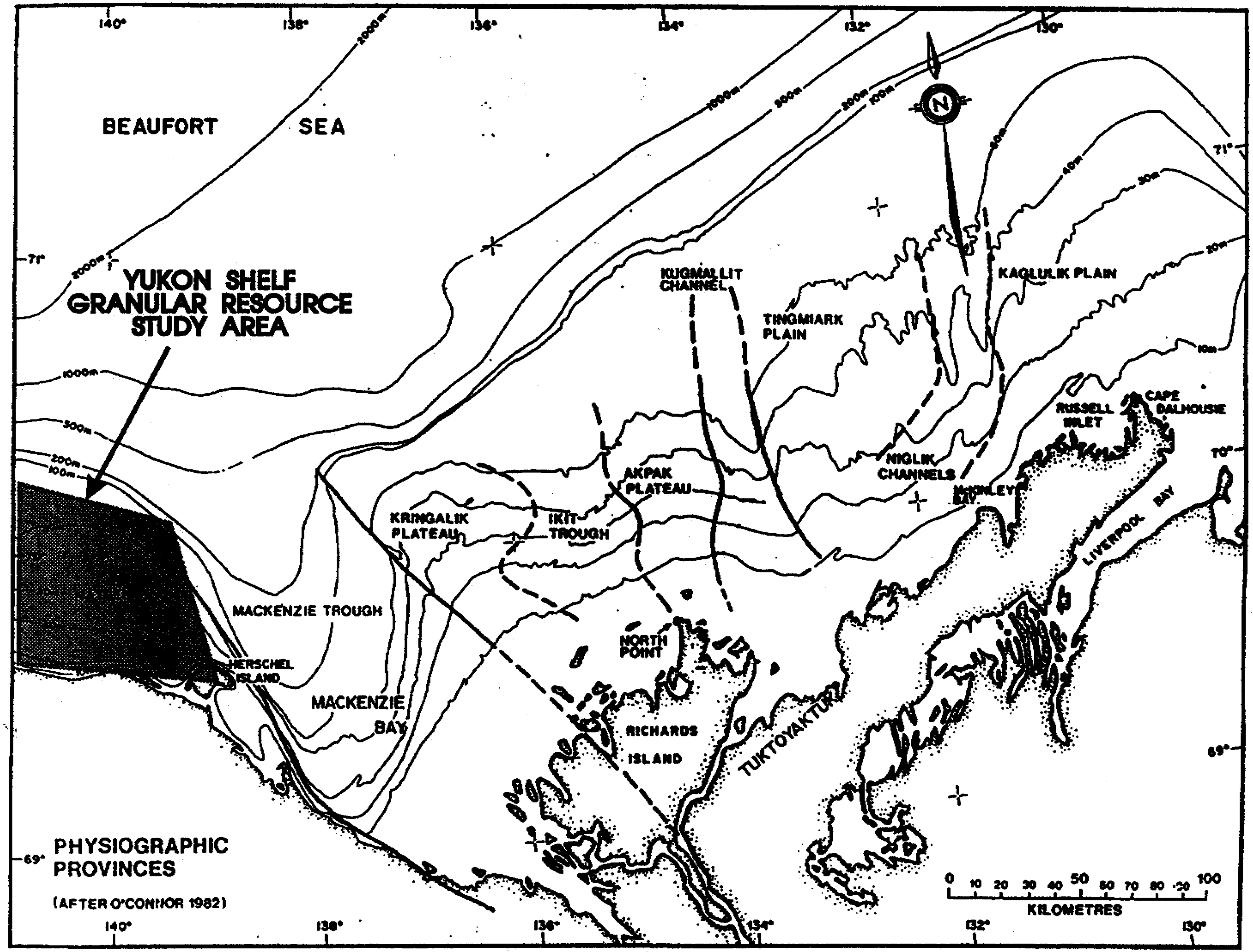
TABLE 1

SUMMARY OF GRANULAR RESOURCE POTENTIAL ON THE WESTERN BEAUFORT (YUKON) CONTINENTAL SHELF

ZONE	PROSPECT	AREA $m^2 \times 10^6$	AV. THICK m	PROBABLE $m^3 \times 10^6$	PROSPECTIVE $m^3 \times 10^6$	CONFIDENCE LEVEL
BEACH (volume not included in total)						
	1B (0-10m)	73.99	6-10	444-740		HIGH
COASTAL						
	1 (10-20m)	71.35	6-10	428-713.5		HIGH
	1A	74.65	-			MODERATE
	2	2.4	2.5	6.0		HIGH
	3	2.9	2.0	5.8		HIGH
	4	25.1	2.0	50.2		HIGH
MIDDLE SHELF						
	5	13.0	2.0		26.0	MODERATE
	6	1.8	1.5		2.7	MODERATE
	7	--	--			LOW
	8	6.5	--			LOW
	9	2.9	2.0		5.8	LOW
	10	1.1	2.0		2.2	LOW
	11	3.4	1.0		3.4	LOW
	12	4.0	0.5		2.0	LOW
	13	1.0	0.5		0.5	LOW
	14	11.0	0.8		8.8	LOW
	15	2.7	0.7		1.9	LOW
OUTER SHELF						
	16	3.0	2.0		6.0	MODERATE
	17	--	--		--	LOW
	18	16.7	4.0	66.0		HIGH
	19	31.7	8.5		269.5	MODERATE
TOTALS		**275.2**		**556.0-841.5**	**328.8**	

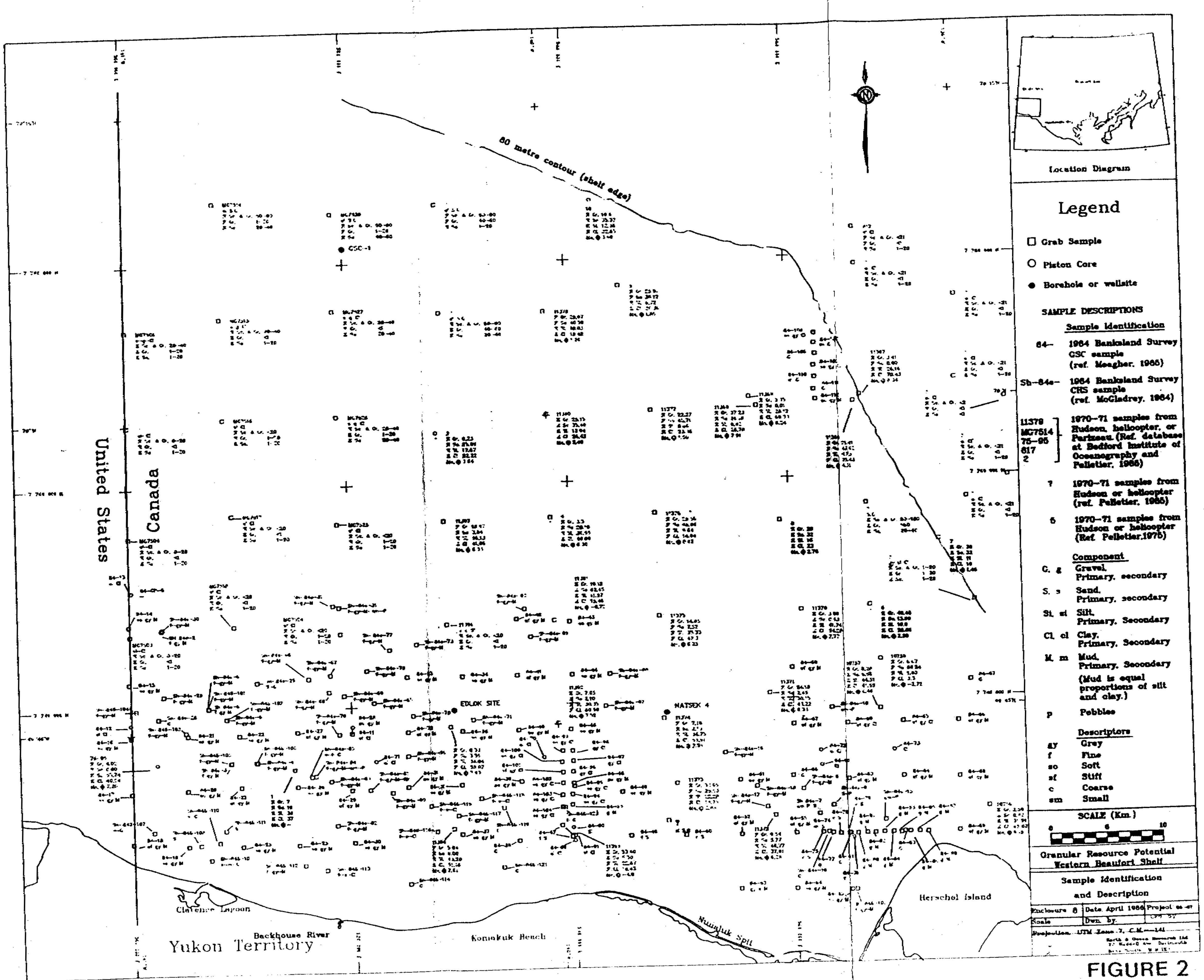
Note: The entire Outer Shelf (Prospect 20) is not included in the above summation pending additional information on the nature and thickness of the coarse grained veneer. It is however considered "prospective" and includes an area of 1400 million square metres.

LIST OF FIGURES - ISSERK BORROW SITE



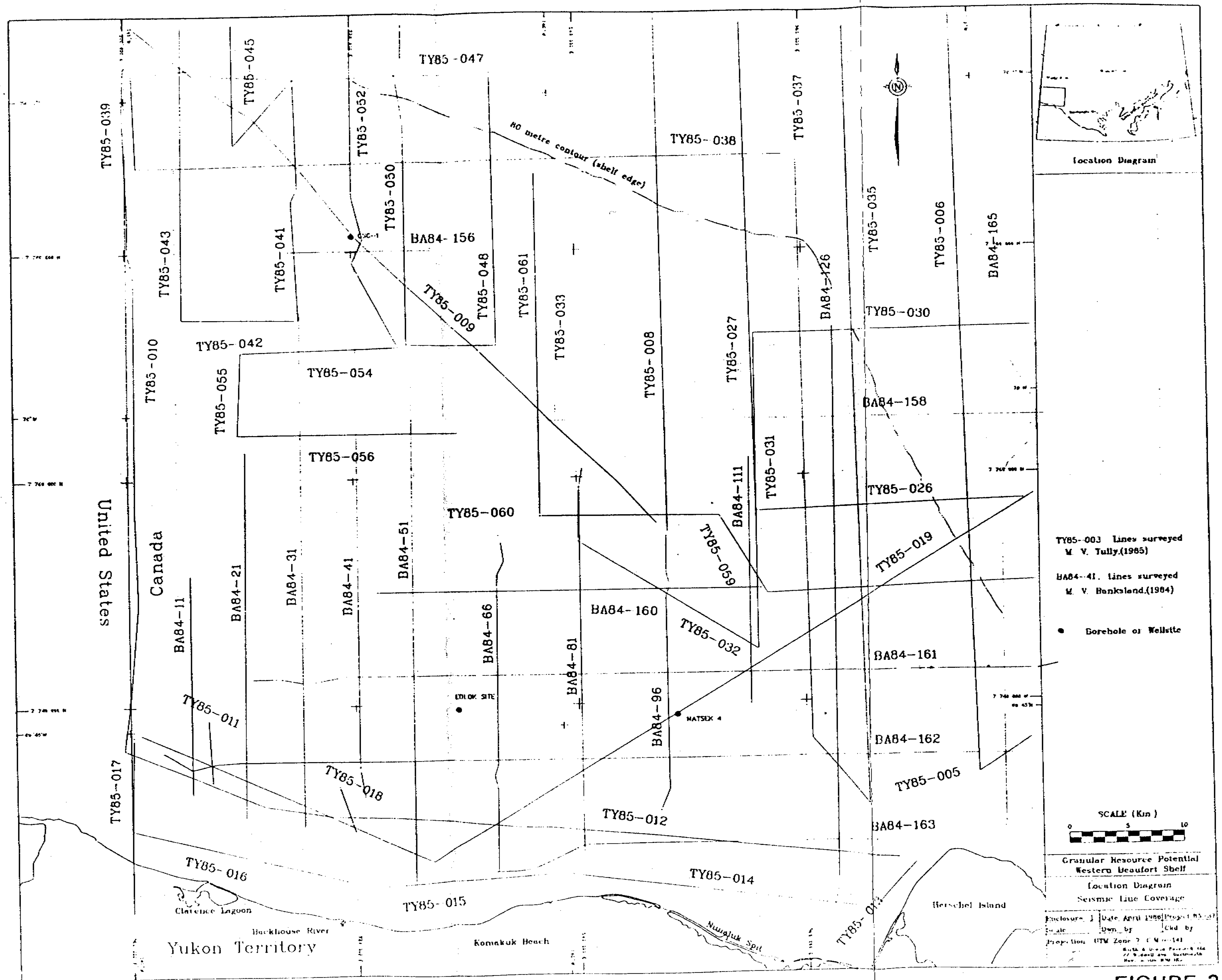
LOCATION DIAGRAM

FIGURE 1



80 metre contour (shelf edge)
United States
Canada
Yukon Territory
Clarence Lagoon
Backhouse River
Komakuk Beach
Nunaluk Spit
Herschel Island
EDLOK SITE
NATSEK 4
Location Diagram
Legend
Grab Sample
Piston Core
Borehole or wellsite
SAMPLE DESCRIPTIONS
Sample Identification
64– 1964 Banksland Survey GSC sample (ref. Meagher, 1985)
Sh-84e– 1964 Banksland Survey CHS sample (ref. McGladrey, 1964)
11379 MC7514 75–95 617 2 1970–71 samples from Hudson, helicopter, or Parizeau. (Ref. database at Bedford Institute of Oceanography and Pelletier, 1985)
7 1970–71 samples from Hudson or helicopter (ref. Pelletier, 1985)
6 1970–71 samples from Hudson or helicopter (Ref. Pelletier,1975)
Component
G, g Gravel, Primary, secondary
S, s Sand, Primary, secondary
Si, si Silt, Primary, Secondary
Cl, cl Clay, Primary, Secondary
M, m Mud, Primary, Secondary (Mud is equal proportions of silt and clay.)
P Pebbles
Descriptors
gy Grey
f Fine
so Soft
sf Stiff
c Coarse
sm Small
SCALE (Km.)
0 5 10
Granular Resource Potential Western Beaufort Shelf
Sample Identification and Description
Enclosure 8
Date April 1986
Scale
Dwn. by
Projection UTM Zone 7, C.M. -141

FIGURE 2



Location Diagram
80 metre contour (shelf edge)
United States
Canada
Yukon Territory
Clarence Lagoon
Backhouse River
Komakuk Beach
Nunaluk Spit
Herschel Island
KOLOK SITE
NATSEK 4
TY85-039
TY85-045
TY85-052
TY85-047
TY85-050
TY85-038
TY85-037
TY85-043
TY85-041
BA84-156
TY85-048
TY85-061
TY85-033
TY85-009
TY85-008
TY85-027
BA84-126
TY85-035
TY85-006
BA84-165
TY85-030
TY85-010
TY85-042
TY85-054
TY85-055
BA84-158
TY85-056
TY85-060
BA84-111
TY85-031
TY85-026
TY85-059
TY85-019
BA84-51
BA84-41
BA84-31
BA84-21
BA84-11
BA84-66
BA84-160
TY85-032
BA84-81
BA84-161
BA84-96
TY85-011
BA84-162
TY85-017
TY85-018
TY85-005
TY85-012
BA84-163
TY85-016
TY85-015
TY85-014
TY85-013
TY85-003 Lines surveyed M. V. Tully.(1985)
BA84-41. lines surveyed M. V. Banksland.(1984)
Borehole or Wellsite
SCALE (Km)
0
5
10
Granular Resource Potential
Western Beaufort Shelf
Location Diagram
Seismic Line Coverage
Enclosure 1
Date April 1986
Scale
Dwn by
Chd by
Projection UTM Zone 7

FIGURE 3

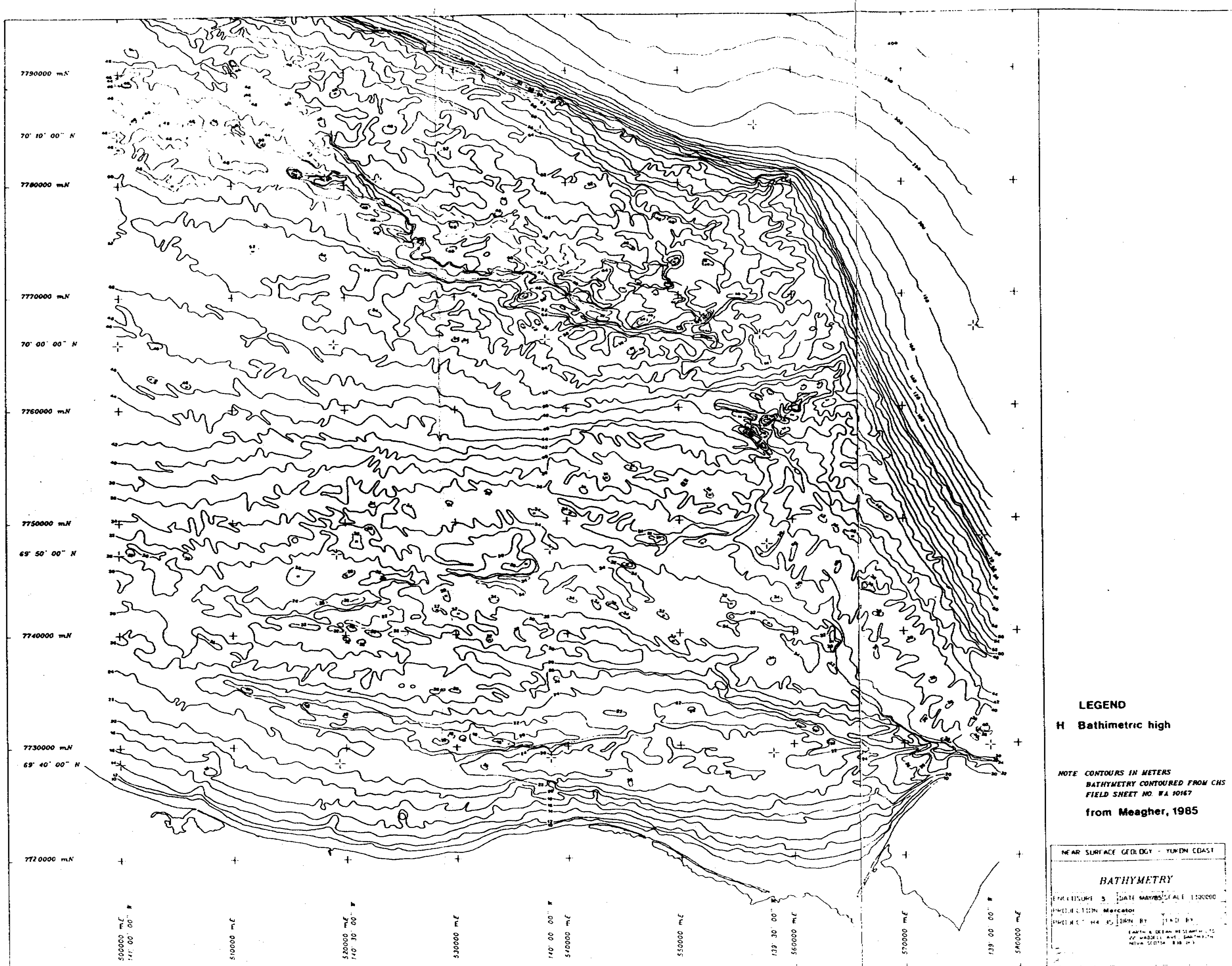
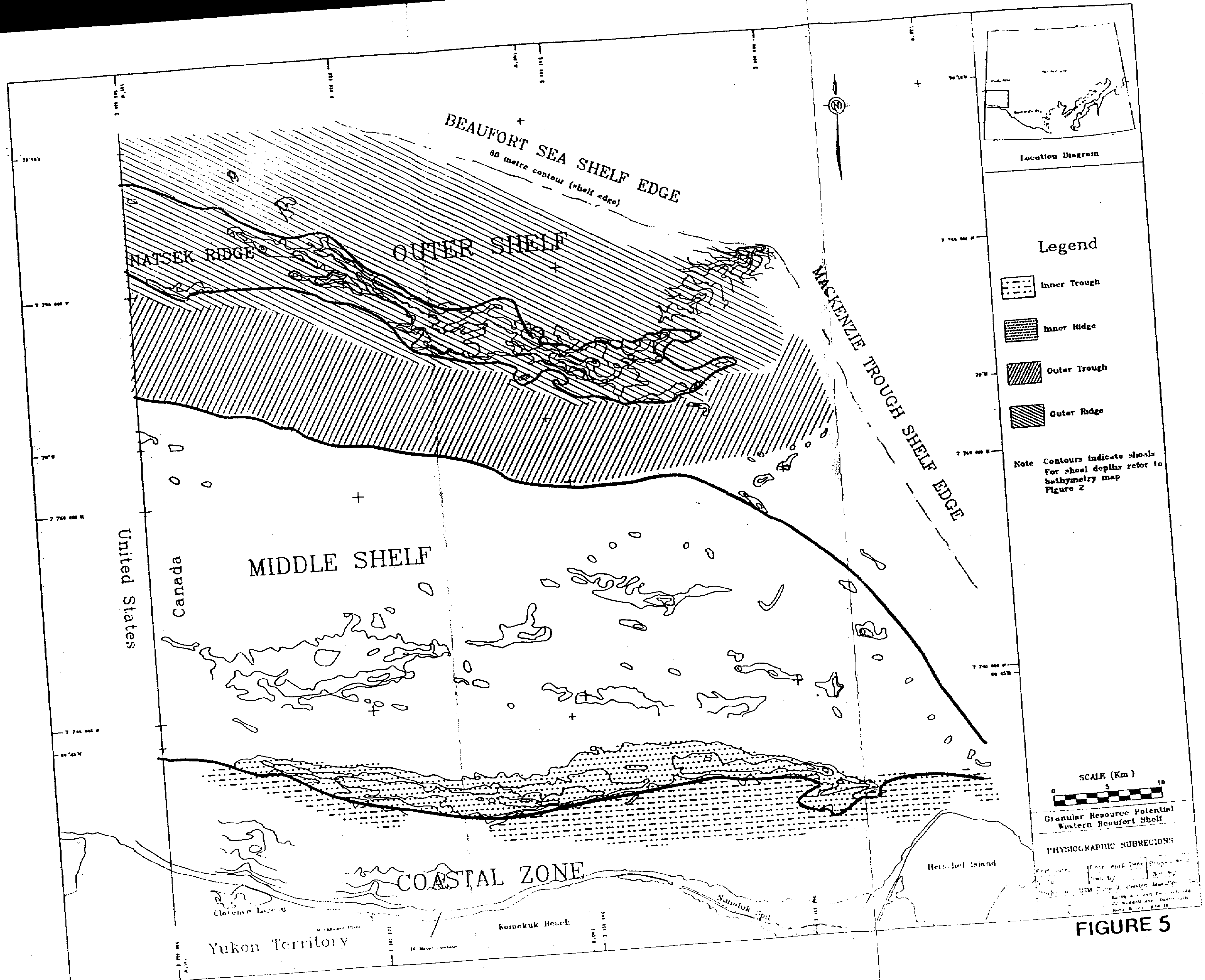
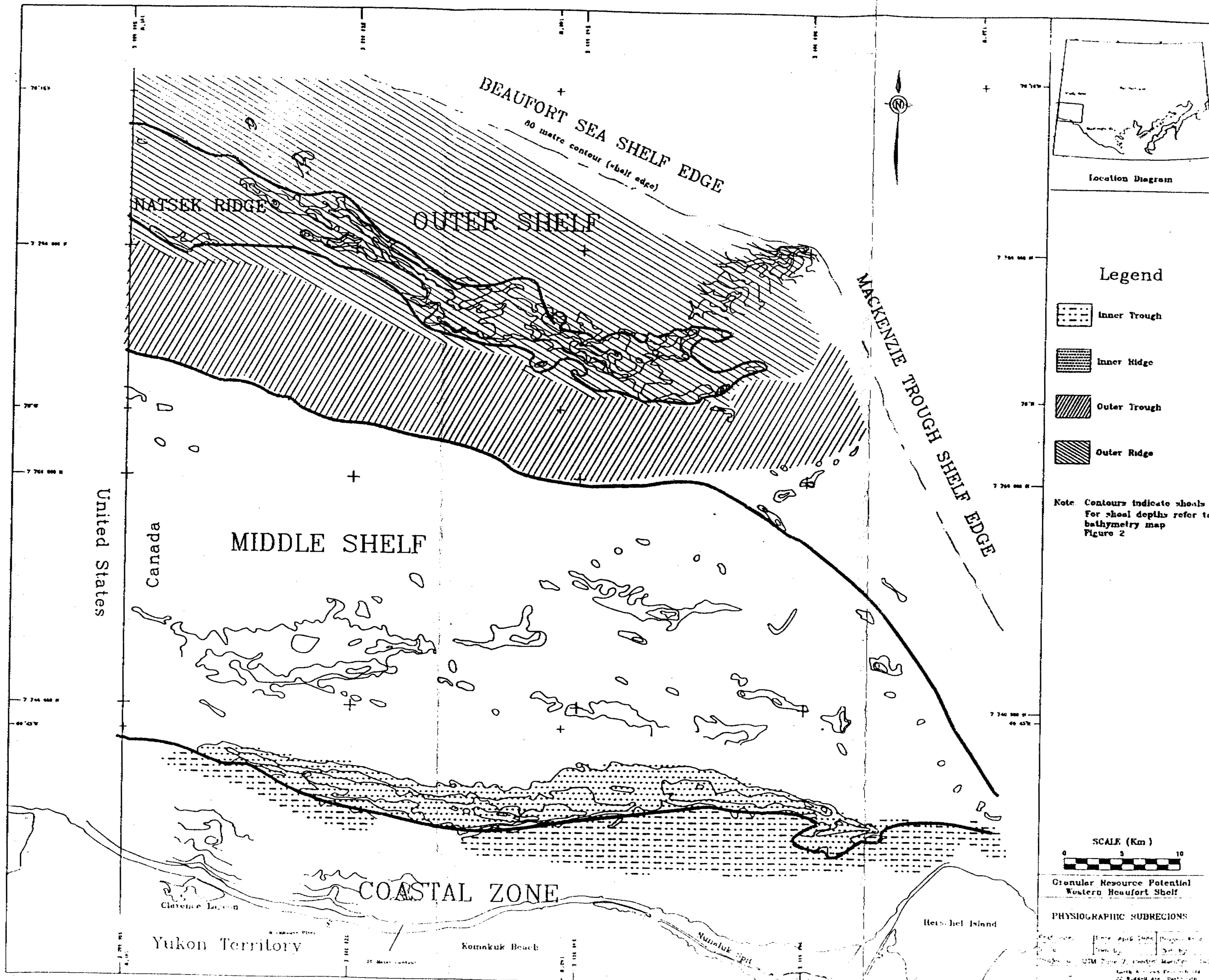

7790000 mN
70° 10' 00" N
7780000 mN
7770000 mN
70° 00' 00" N
7760000 mN
7750000 mN
69° 50' 00" N
7740000 mN
7730000 mN
69° 40' 00" N
7720000 mN
500000 mE 141° 00' 00" W
510000 mE
520000 mE 140° 30' 00" W
530000 mE
140° 00' 00" W 540000 mE
550000 mE
139° 30' 00" W 560000 mE
570000 mE
139° 00' 00" W 580000 mE
LEGEND
H Bathimetric high
NOTE CONTOURS IN METERS
BATHYMETRY CONTOURED FROM CHS
FIELD SHEET NO. WA 10167
from Meagher, 1985
NEAR SURFACE GEOLOGY - YUKON COAST
BATHYMETRY
ENCLOSURE 3
DATE MAY/85
SCALE 1:100000
PROJECTION Mercator
EARTH & OCEAN RESEARCH LTD.

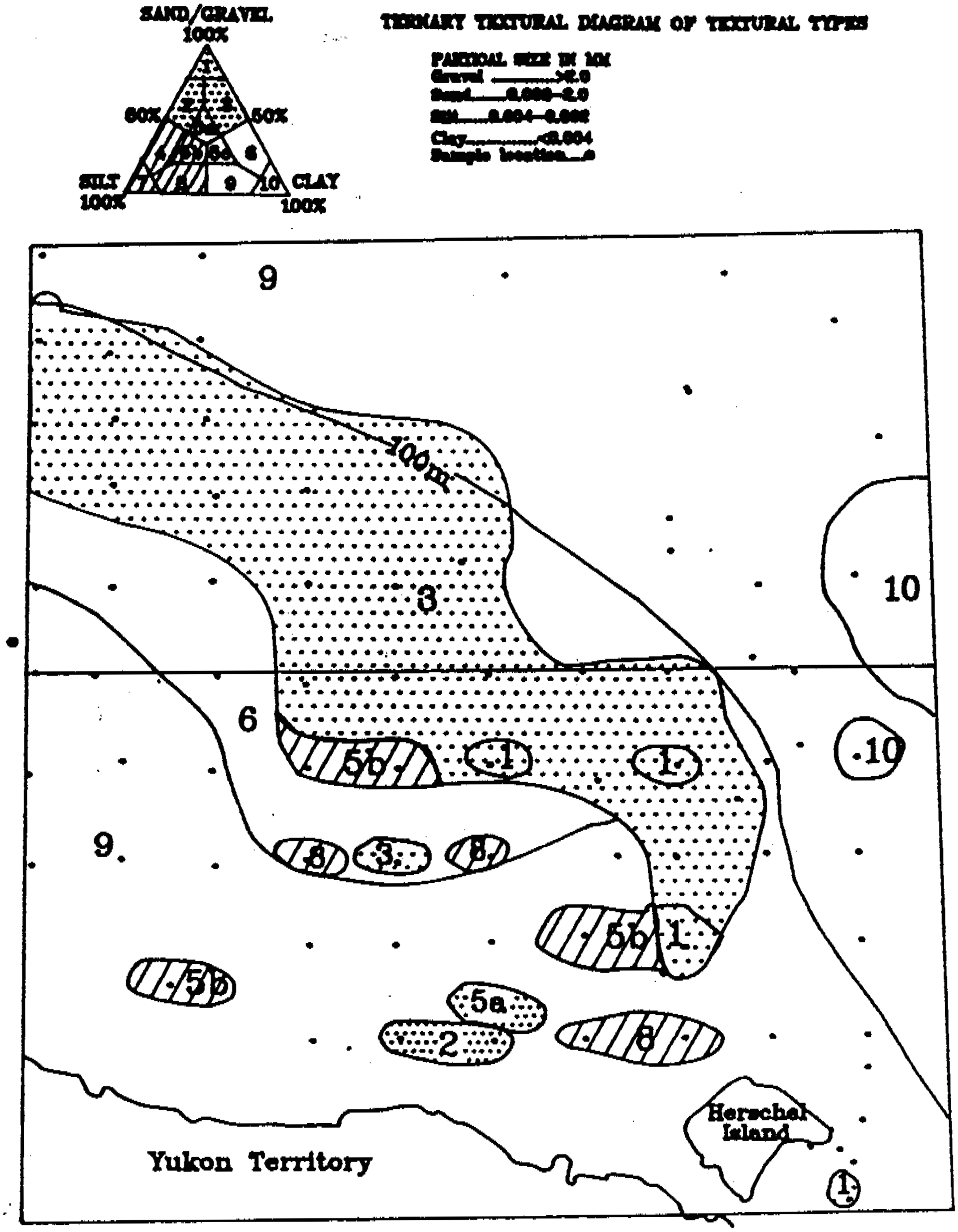
FIGURE: 4


BEAUFORT SEA SHELF EDGE
60 metre contour (shelf edge)
OUTER SHELF
NATSEK RIDGE
MACKENZIE TROUGH SHELF EDGE
MIDDLE SHELF
United States
Canada
COASTAL ZONE
Clarence Lagoon
Komakuk Beach
Nunaluk Spit
Herschel Island
Yukon Territory
Location Diagram
Legend
Inner Trough
Inner Ridge
Outer Trough
Outer Ridge
Note Contours indicate shoals
For shoal depths refer to
bathymetry map
Figure 2
SCALE (Km)
0
5
10
Granular Resource Potential
Western Beaufort Shelf
PHYSIOGRAPHIC SUBREGIONS
FIGURE 5



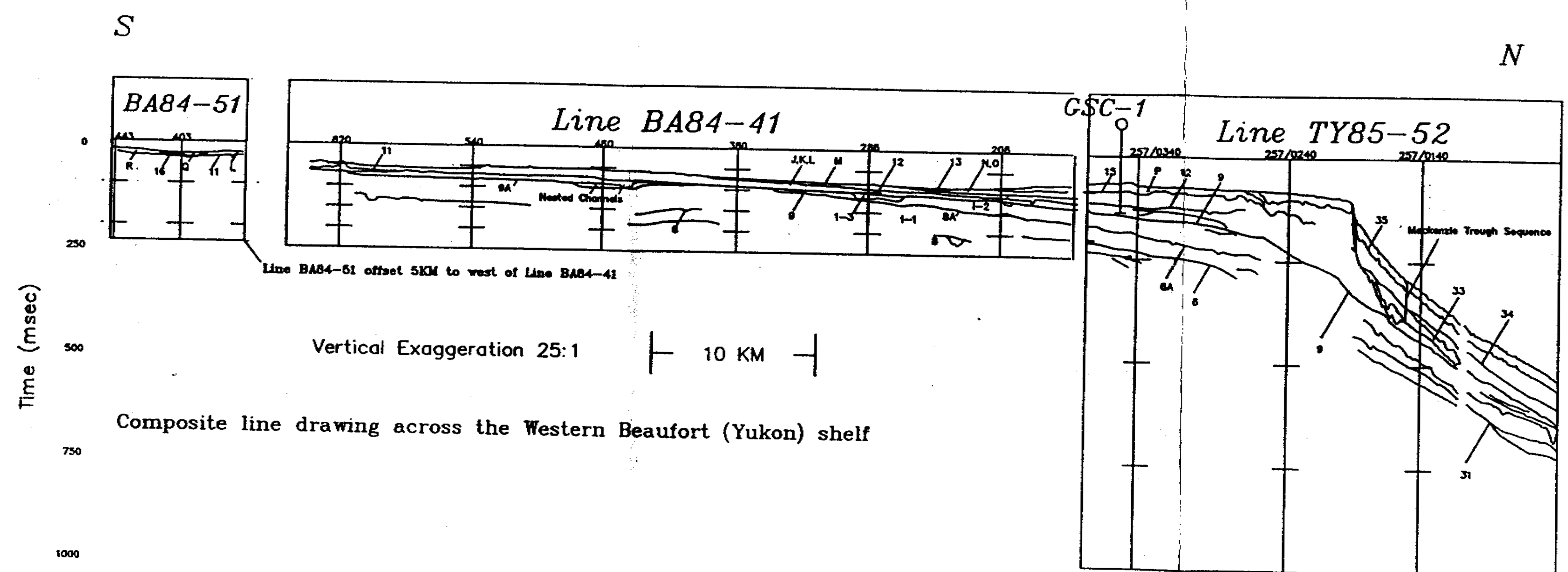
BEAUFORT SEA SHELF EDGE
80 metre contour (shelf edge)
NATSEK RIDGE
OUTER SHELF
MACKENZIE TROUGH SHELF EDGE
MIDDLE SHELF
United States
Canada
COASTAL ZONE
Clarence Lagoon
Yukon Territory
Komakuk Beach
Herschel Island
Location Diagram
Legend
Inner Trough
Inner Ridge
Outer Trough
Outer Ridge
Note: Contours indicate shoals. For shoal depths refer to bathymetry map Figure 2
SCALE (Km)
0
5
10
Granular Resource Potential
Western Beaufort Shelf
PHYSIOGRAPHIC SUBREGIONS

FIGURE 5



Distribution of bottom sediment types
(After Pelletier, 1985)

FIGURE 6



Composite line drawing across the Western Beaufort (Yukon) shelf

FIGURE 7

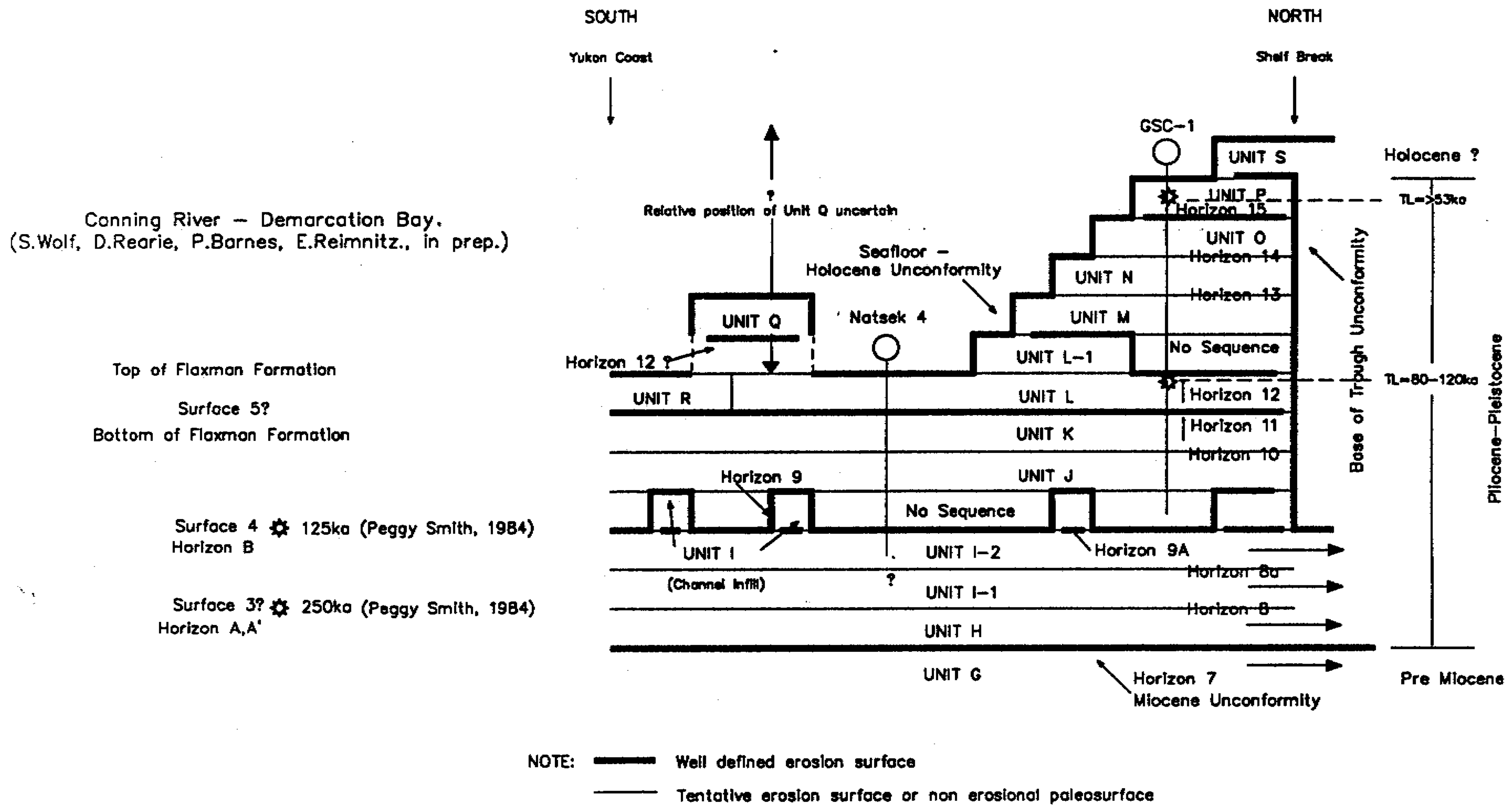
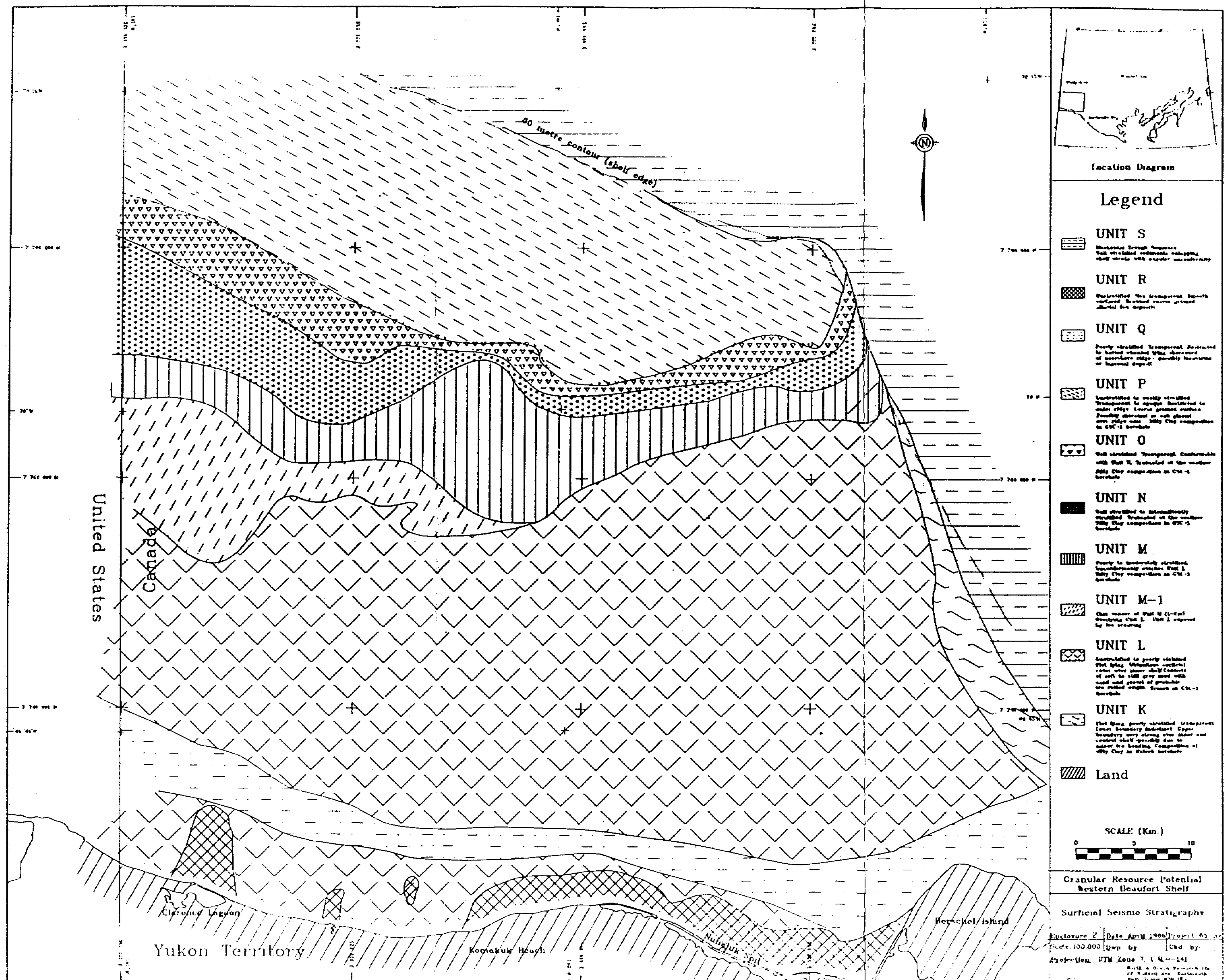
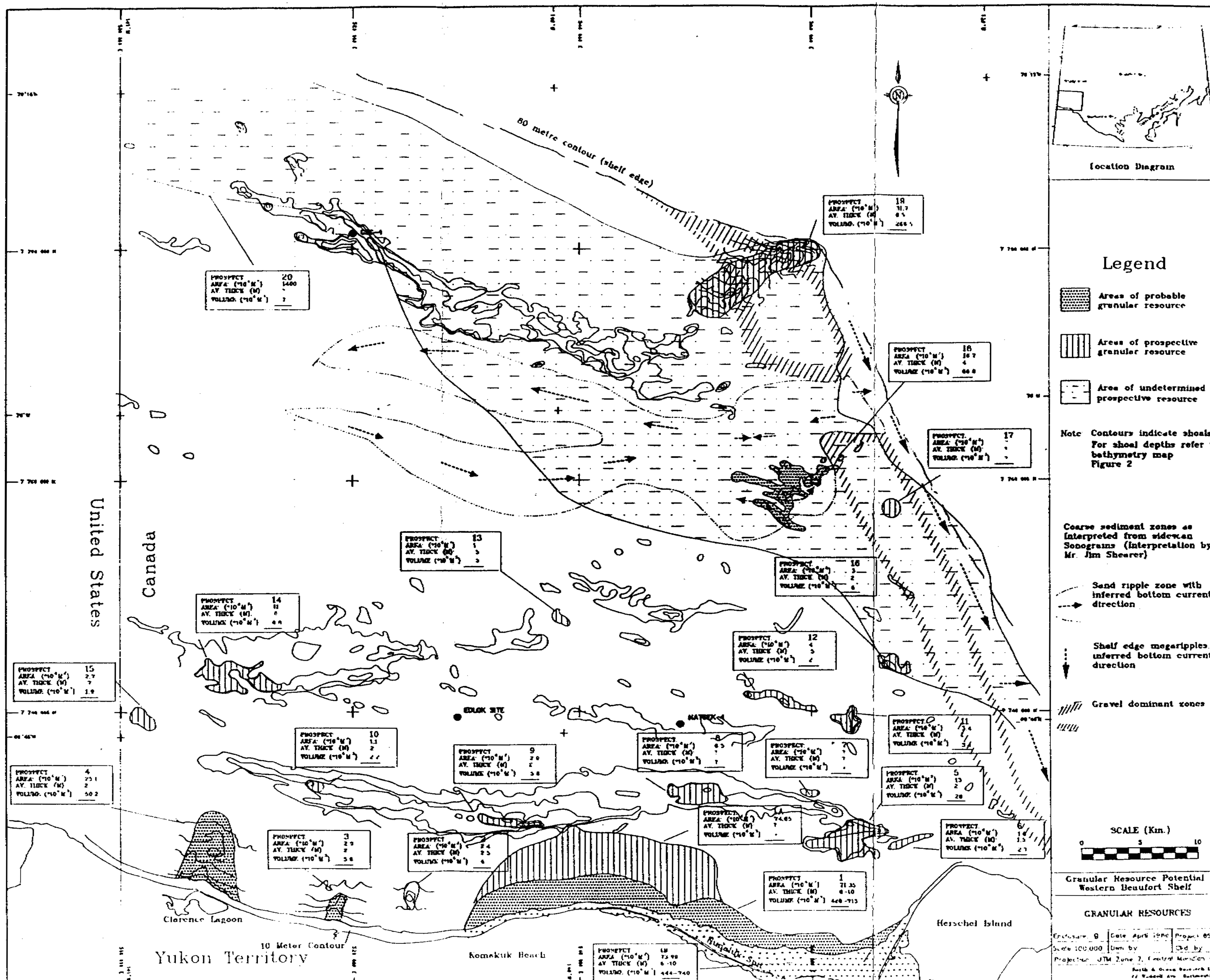


FIGURE 8 SEISMO-STRATIGRAPHIC RELATIONSHIPS AND AGES - WESTERN BEAUFORT (YUKON) SHELF



60 metre contour (shelf edge)
United States
Canada
Yukon Territory
Clarence Lagoon
Komakuk Beach
Nunaluk Spit
Herschel Island
Location Diagram
Legend
UNIT S
UNIT R
UNIT Q
UNIT P
UNIT O
UNIT N
UNIT M
UNIT M-1
UNIT L
UNIT K
Land
SCALE (Km.)
0
5
10
Granular Resource Potential
Western Beaufort Shelf
Surficial Seismo Stratigraphy

FIGURE 9



Location Diagram
Legend
Areas of probable granular resource
Areas of prospective granular resource
Area of undetermined prospective resource
Note Contours indicate shoals For shoal depths refer to bathymetry map Figure 2
Coarse sediment zones as interpreted from sidescan Sonograms (Interpretation by Mr. Jim Shearer)
Sand ripple zone with inferred bottom current direction
Shelf edge megaripples inferred bottom current direction
Gravel dominant zones
SCALE (Km.)
0
5
10
Granular Resource Potential
Western Beaufort Shelf
GRANULAR RESOURCES
80 metre contour (shelf edge)
United States
Canada
Yukon Territory
10 Meter Contour
Clarence Lagoon
Komakuk Beach
Herschel Island
EDLOK SITE

FIGURE 10

A STUDY OF GRANULAR RESOURCES
IN THE ISSIGAK DEPOSIT
FOR THE

BEAUFORT SEA GRANULAR RESOURCES WORKSHOP

February, 1992

Prepared by:
EBA Engineering Consultants Ltd.
0306-34786

INTRODUCTION

The Issigak site is unique in many ways. It is one of the few deposits with any significant portion of gravel in the Beaufort-Mackenzie region and is the only source of granular materials located between Herschel Island and the Akpak Plateau. For reference, Figure 1 shows the location of the deposit and the major physiographic zones nearby.

In late 1986 through March 1987, EBA Engineering Consultants Ltd. compiled and interpreted available data for the Issigak deposit (EBA, 1987). This work was conducted under funding provided by NOGAP Sub-project A4-6, through Indian and Northern Affairs Canada. The primary purposes of the study were to interpret the geology of the deposit, and to quantify the remaining reserves. Those tasks were relatively easy. The hard work was in finding the data, much of which was missing, and resolving inconsistencies between overlapping data sets.

HISTORY OF SITE EVALUATION

The first site work on shallow sediments in this area was done in late winter 1974. More work was done in winter 1975. Both programs were conducted through the ice at about the limit of conventional land based equipment. Although we encountered minor gravel and other geologically unique sediments during those programs, we didn't "discover" the Issigak borrow deposit. The credit for the discovery should go to Dome Petroleum which began gravel exploration in the area in the summer of 1980. They were searching for construction materials for work at the Tarsuit N-44 site.

Between 1974 and summer 1986, there were 26 various programs or operations at Issigak. Included in that were nine geotechnical sampling programs, six seismic mapping programs, eight dredging operations, and three bathymetric mapping exercises. Prior to 1986, almost 3.5 million cu.m. of granular material were reported to have been removed from Issigak during four of the dredging operations. In addition, there were four other dredging programs for which the quantity of material removed could not be determined.

DATA RELIABILITY

The problem with too much data is that it has to be compared to look for inconsistencies. At Issigak, there were 199 boreholes, several bathymetric surveys and bathymetric data collected during seismic programs. The correlation between various data sets was found to be very poor. This has serious implications for many other sites because of the scale of inaccuracies implied. For example:

a) The difference between water depth interpreted from borehole soundings and bathymetric surveys was greater than 1.0 m for 25 percent of boreholes. That is a big error for a site in only about 9.0 m of water.

b) The difference between various sets of bathymetric mapping was not much better. Datum differences of 0.5 to 1.0 m are common between data sets.

c) Where two boreholes were located nearby, the differences in subsurface interpretation was frequently enough to imply that one of them must be wrong. For nine pairs of holes with an average distance apart of 27 m (max. 40 m), the average difference in granular material thickness was greater than 0.4 m (max. 0.8 m) and the average difference in water depth was 0.4 m (max. 0.8 m). These are significant differences for a deposit with an average thickness of less than 1.5 m.

PHYSICAL DESCRIPTION

The Issigak deposit is almost 11 km long and up to 1500 m wide. In section, the deposit is a thin veneer which averages less than 1.5 m thick. Issigak appears as a low ridge or series of small knobs on most bathymetric maps because of the overall flatness of the coastal sediments. Figure 2 shows the maximum section through the ridge. Drawings with high vertical exaggeration serve to create the impression of a ridge. Figure 3 shows the ridge at a vertical exaggeration of only 10x. This is a much better section to picture when considering the morphology of the deposit.

Detailed bathymetry, compiled in Figure 4, shows four or five pods of higher relief. The relative importance of initial deposition and subsequent erosion in producing this relief is difficult to establish. These areas of high relief, however, are generally related to the thickness of granular resources. They are also related to the distribution of boreholes, because most were located on areas of higher relief. Figure 5 shows the distribution of boreholes.

Our understanding of the thickness of the deposit is somewhat skewed because the boreholes have been concentrated in areas of highest relief. Based on 162 boreholes which were mostly in the thicker parts of the deposit, the average thickness of the Issigak granular resources is 1.44 m. Overall the average thickness is less.

STRATIGRAPHIC CHARACTERISTICS

There are enough boreholes in the deposit to develop a reasonably complex facies model of it. Table 1 shows the strata sequence that has been interpreted. It was not practical to try and indicate the thickness of these 12 units and subunits for such a relatively thin deposit. In fact, the total strata sequence never appears in any borehole, but each unit appears in more than one borehole. Figure 6 shows what might be a typical section, if there is one.

Cobbles and boulders are easily missed by boreholes unless they are in a relatively high concentration. From dredging quality control work, there are reports that some dredge hopper loads contained up to 10 percent cobbles and boulders. Cobbles up to 130 mm were common and boulders up to 500 mm were observed. Figure 5 indicates the frequency of boreholes encountering cobbles in the deposit and Figure 7 indicates the distribution of coarse material on the seabed.

The relative distribution of sand and gravel within the deposit also was investigated. Based on gradation data provided by the borehole logs an interpretation of the sand to gravel ratio was made for each borehole. By averaging the ratios so derived for eight subdivision of the deposit shown on Figure 8, a trend to a decrease in the gravel fraction (ie. to finer material) from southwest to northeast was identified. The frequency for cobbles, indicated on Figure 5, seems to be greatest in the southwest but relatively uniform along the north arm of the deposit.

QUANTITY DETERMINATION

It is not possible to determine the quantity of granular material that was originally in the Issigak deposit. As indicated previously, in excess of 3.5 million cubic metres of material had been removed prior to 1986. For at least four other dredging programs, the quantity of material removed was unknown.

Bathymetric data collected for Esso in 1984 and 176 boreholes obtained for Esso in 1983 (EBA, 1983) provide the basis for understanding the quantity of granular material on site, although 1.5 million m^3 of granular resources were removed between those two times.

It was concluded that at the end of 1986, reserves of granular material on site were as follows.

a)	Proven Reserves	3.3 million cubic metres
b)	Probable Reserves	5.1 million cubic metres
c)	Prospective Reserves	5.8 million cubic metres

GEOLOGIC AGE

The Issigak deposit was interpreted in this NOGAP study to be of early Holocene age. That means the deposits are non-glacial and likely non-marine. The basis of this interpretation is the correlation of regional unconformities on several regional seismic lines by Guy Fortin (1986) and some biostratiographic work done by Elliot Burden (1986).

Burden's work on samples from the Tarsiut N-44 site identified three unconformities. The earliest lies below non-marine sediments that Hill (1985) dated at 27,000 years. The second occurs above non-marine sediments which have an age of about 14600 and overlie prograding late-Wisconsinian deltaic sediments. Above the second unconformity are early Holocene shallow deltaic sediments which were dated between 9500 and 6800 years. The third unconformity lies between those and pro-deltaic (marine) late-Holocene sediments that are less than 6800 years old. This unconformity (U/C3) is the trace of the last marine transgression.

The process by which the three unconformities at Tarsiut N-44 can be traced to Issigak is a little complex. The first correlation was one of stratigraphic similarity between Tarsiut A-25 and N-44. These two site are a little less than 6 km apart. Table 2 shows this correlation. At Tarsiut A-25, Unconformity U/C2 is about 16 m below seabed (bsb).

The next step in the correlation was Fortin's interpretation of a seismic line extending southward from Tarsiut A-25 and passing about 12 km west of Issigak. Figure 9 shows that section. The relatively unvarying depth of Unconformities U/C1 and U/C2 suggest that Wisconsinian sediments are deeply buried at Issigak. Unconformity U/C2 was interpreted to be 10 to 15 m bsb near Issigak.

The third correlation, shown on Figure 10, traces Unconformities U/C2 and U/C3 from Esso's Omat and Kaubvik sites past Issigak at a distance of about 2300 m to the north and further west to a point about 11 km west of Issigak. Unconformity U/C2 is about 10 m below seabed and U/C3 is about 4 m bsb where they pass Issigak.

The fourth tie-in to this correlation is based on stratigraphic correlation of a series of boreholes between Esso's Kadluk O-07 site and Issigak. This profile, which location is shown on Figure 11, crosses the Omat seismic line and ties the regional seismic data to Issigak.

The stratigraphic features that have been correlated along this section are interesting. There is a zone which begins at the depth of Unconformity U/C2 on the Omat line and can be seen in five of the boreholes between Issigak and the Omat line. It has the features of partially desiccated terrain such as blocky texture and salt encrusted fissures. Overlying that is a silty clay strata containing occasional fine pebbles (drop stones?). This horizon appears to correlate with evidence of unconformable strata changes at 8 to 9 m bsb under the Issigak deposit and at about 8 m bsb inshore of Issigak. Figure 12, shows the interpreted section.

Late Holocene (recent marine) sediments appear to pinch out between the Kadluk site and Issigak. In some boreholes the dropstone clay strata is exposed on the seabed and in others it underlies a thin strata of recent sediments. This interpretation, based mostly on borehole data, could be confirmed with seismic records which could not be found for the study.

In conclusion, it appears that the Issigak deposits pre-date the last marine transgression, which Hill (1985) suggests would be about 2500 years ago. Furthermore they are situated on top of approximately 6 m of early Holocene deltaic sediments which correlate to those Burden dated at between 9500 and 6800 years.

SEDIMENT GEOLOGY

The surface on which the early Holocene deltaic sediments were deposited may have been well above seabed. It is likely that shell fragments, finely laminated clays, and interbedded sands with organic rich strata must be fluvial or lacustrine in origin. Furthermore, it would take a relatively large fluvial channel to move over 9 million m^3 of sand and gravel with cobbles and boulders up to 500 mm. Therefore it is puzzling that such a channel has not been identified on any seismic section or in any borehole.

It also is difficult to conceive of a source for the granular material that is far upslope of the present deposit. The fluvial erosion of a barrier island, like Pelly Island, has been suggested as a possible source for coarse material; however, there is no evidence, as yet, of a rise to the seabed of Unconformity U/C1 and the older, coarser sediments. The question of source area and details of the transport system have not been resolved, as yet.

REFERENCES

Burden, Elliot (1986). 'Mid and Late-Wisconsin Through Holocene Biostratigraphic Zonation of Beaufort Sea Shelf Sediments from Herschel Island to the MacKenzie Shelf'. A draft report submitted to GSC.

EBA Engineering Consultants Ltd. (1983a). '1983 Offshore Geotechnical Site Investigation, Issigak Borrow Site.' Report to ESSO, (EBA Job Number 101-3868).

EBA Engineering Consultants Ltd. (1987). 'Synthesis and Interpretation of Bathymetric, Geophysical and Geotechnical Data from Issigak Borrow Block.' Report to Indian and Northern Affairs Canada (EBA Job. No. 0301-34241).

Fortin, G. (1986). 'A Preliminary report on the Issigak Deposit'. An interim project report submitted to EBA Engineering Consultants Ltd.

Hill, P.R., Mudie, P.J., Moran, K. and Blasco, S.M. (1985). 'A Sealevel Curve for the Canadian Beaufort Shelf'. Canadian Journal of Earth Sciences Vol. 22, No. 10, pp. 1383-1393.

Table 1: Stratigraphy of the Issigak Deposit

Unit Name	General Description
1A Overburden Clay	- soft silty Clay of Holocene age - thin, irregular veneer, generally absent over main prospect
1B Interbedded Clay & Gravel	- stratified sediments of Holocene? Clay & Gravel washed landward of main prospect
2A Upper Sand	- clean to silty Sand, thin but widespread on flanks of main prospect
2B Main Gravel	- ranges from Gravel-Sand ($2B_1$) to gravelly Sand ($2B_2$), coarser on top and may contain cobbles
2C Underlying Sand	- Stratified clean, uniformly graded Sand ($2C_1$) over silty fine Sand ($2C_2$), may contain shell fragments and organic-rich zones.
2D Clay Interbed	- silty clay up to 1.2 m thick occurring in at least three areas of main prospect
2E Lower Gravel & Sand	- found below Unit 2D, commonly a Gravel strata ($2E_1$) overlying a Sand strata ($2E_2$), - $2E_1$ is very similar to 2B - $2E_2$ is very similar to $2C_2$
3 Underlying Clay	- below all granular sediments are: 3A - interbedded laminae of Clay & Sand 3B - organic-rich Silt or Clay 3C - silty clay

TABLE 2

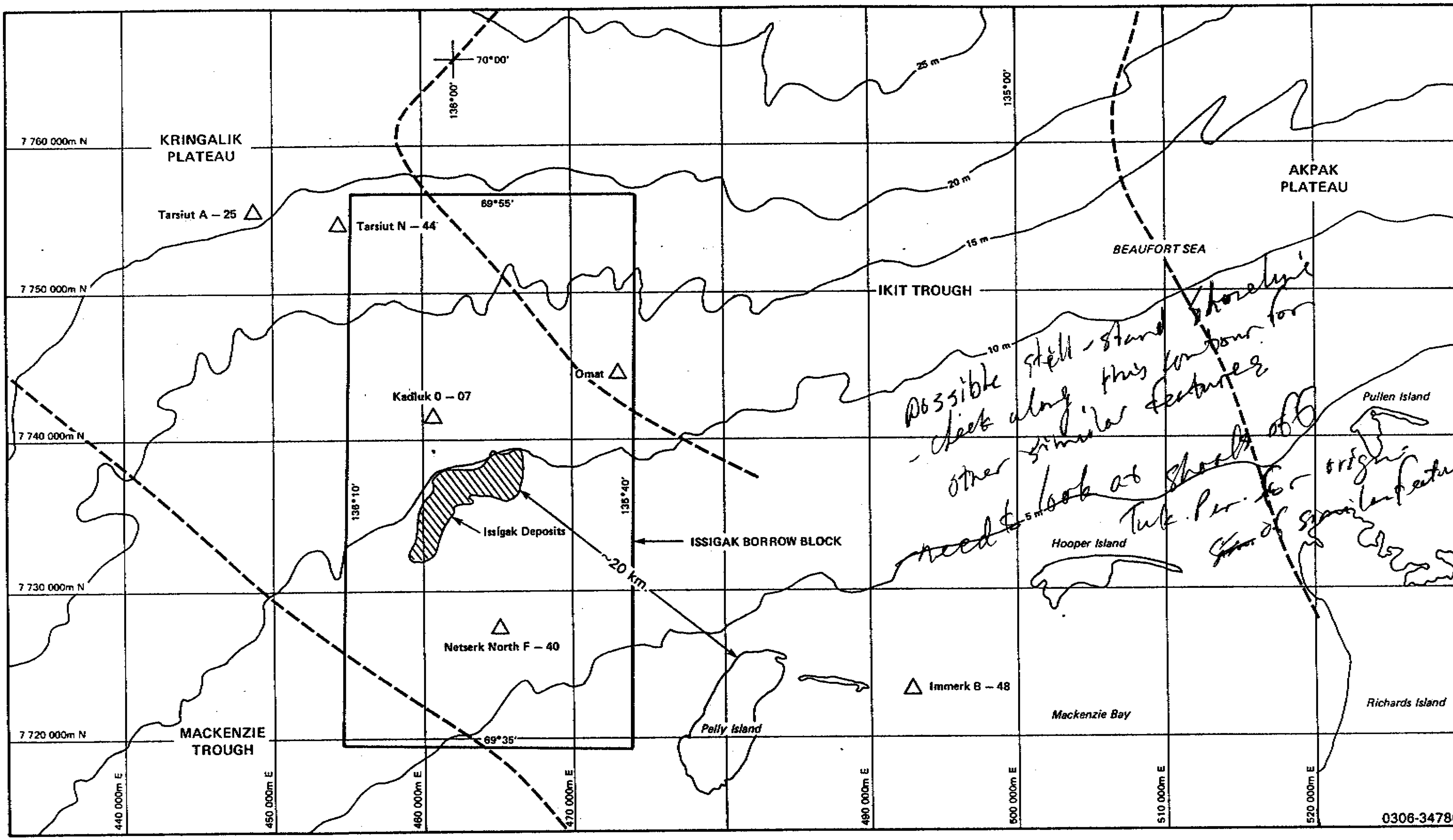
REGIONAL STRATIGRAPHIC COMPARISON

TARSIUT A-25 (from McClelland, 1978)		TARSIUT N-44 (by P. Hill in Burden 1986)		BURDEN'S (1986) TARSIUT N-44 INTERPRETATION			KADLUK H-08 (FROM HARDY, 1983)		KADLUK 0-07 (FROM HARDY, 1983)	
7 756 500 m N 448 200 m E 24 500 m SE 23 m		7 755 000 m N 454 000 m E 18 800 m SSE 23 m		UTM CO-ORDINATES DISTANCE TO ISSIGAK DEPOSITS (m) WATER DEPTH (m)			7 742 360 m N 461 300 m E 5 200 m SSE 14 m		7 741 500 m N 400 600 m E 4 400 m SSE 14 m	
DEPTH (m) (bsb)	DESCRIPTION	DEPTH (m) (bsb)	DESCRIPTION	UNIT	DEPOSITIONAL ENVIRONMENT	INTERPRETED AGE	DEPTH (m) (bsb)	DESCRIPTION	DEPTH (m) (bsb)	DESCRIPTION
0 - 3	Olive grey soft to firm clay with shell fragments.	0 - 6	Grey bioturbated clay with shell fragments.	A	Prodelta Becoming Marine	Present	0 - 3	Soft silty clay.	0-2.5	Soft silty clay, trace of gravel.
					Unconformity (U/C_3)	< 6 800 7 500				
3 -16	Dark grey silty clay with silt partings to lenses stiff to very stiff	6 -15	Dark grey bioturbated silty clay with silt lenses and dessicated horizons.	B	Delta		3 -13	Stiff silty clay.	2.5-13	Stiff silty clay, laminated, some sand layers near top, trace of gravel.
					Unconformity (U/C_2)	9 500 14 600				
16-22	Dark grey silty fine sand with some gravel.	15-21	Laminated/lenticular graded silty clay (top) to graded sand and clay (bottom).	C	Becoming Non-Marine	17 000	13-26	Compact silt.	13-17	Silt sandy to trace of sand.
22-34	Olive grey silty clay with silt partings grading down to clayey silt with clay partings.	21-36	Laminated dark grey silty clay. (gradational transition)	D	Prograding Delta				17-34	Interbedded silty clay and clayey to sandy silt

TABLE 2 (continued)

REGIONAL STRATIGRAPHIC COMPARISON

TARSIUT A-25 (from McClelland, 1978)	TARSIUT N-44 (by P. Hill in Burden 1986)	BURDEN'S (1986) TARSIUT N-44 INTERPRETATION	KADLUK H-08 (FROM HARDY, 1983)	KADLUK O-07 (FROM HARDY, 1983)
34-60 Olive grey clay with silty partings and silty layers.	(gradational transition) 36-56 Laminated silty clay.	E Prograding Delta	26-70 Very stiff silty clay	34-61 Very stiff laminated silty clay with occasional silt pockets.
	56-66 Homogeneous, bioturbated silty clay with forams.	F 18 000		
60-86 Olive grey clay with organic and sandy pockets and some shell fragments. 86-94 Olive grey clayey silt with some wood fragments. 94-121 Grey clay with silt lenses and partings some wood fragments 121-122 Silty fine sand. End of Borehole	66-129 Thick bedded, laminated clay with some sand beds and organic debris.	Prodelta to Marine G Marine Transgression	70-76 Dense fine sand. 76-100 Stiff clay. 100-113 Stiff silty clay. 113-131 Stiff silty clay. End of Borehole	61-93 Dense fine sand, occasional shell fragments and thin silt and clay layers. End of Borehole
	129 Dated Peat Horizon 130-166 Laminated silt and clay. End of Borehole	Non-Marine 27,000 H Rapidly Prograding Delta		



EBA Engineering Consultants Ltd.

FIGURE 1 PHYSIOGRAPHIC REGIONS (after O'Conner, 1982)

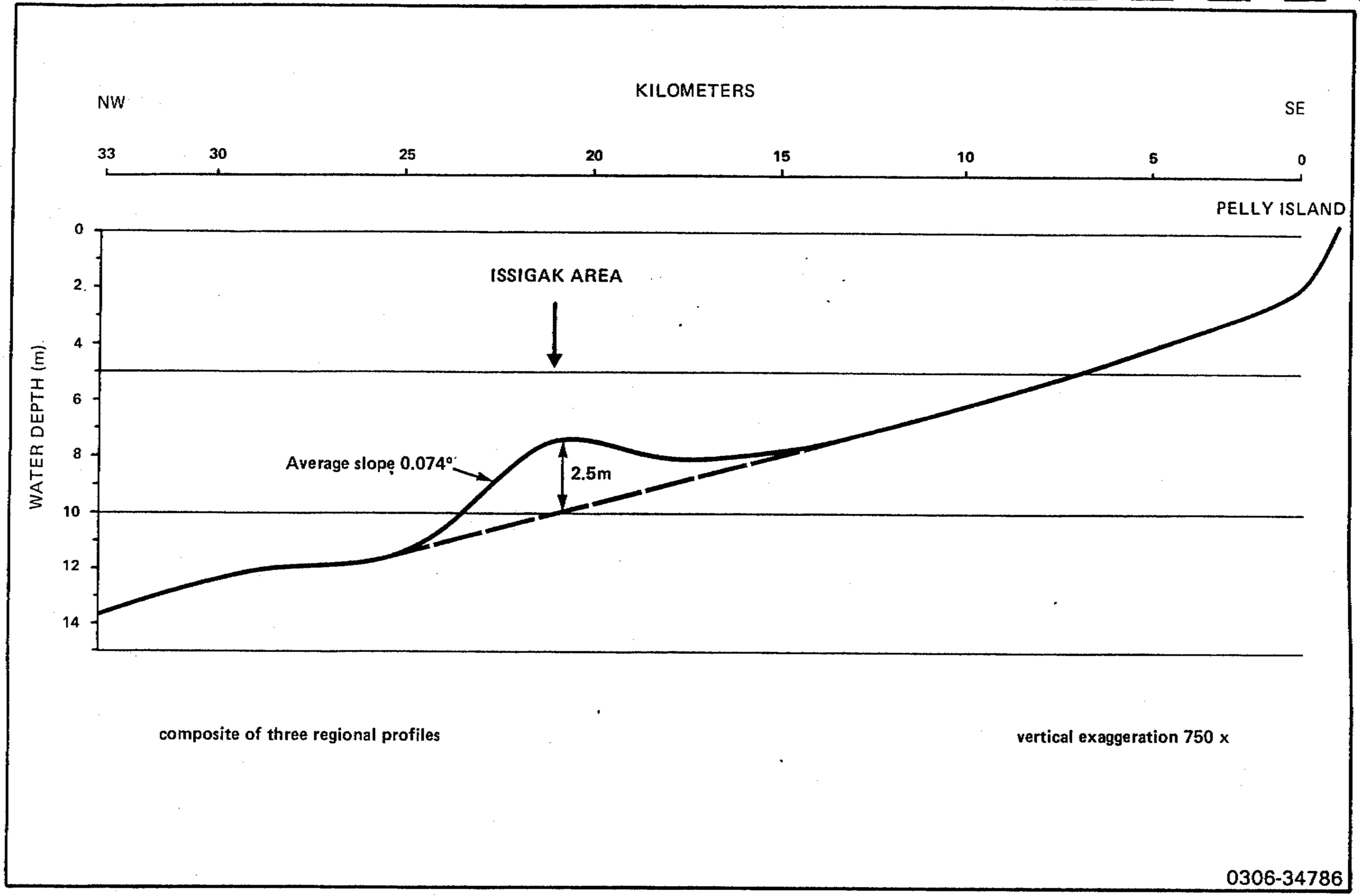
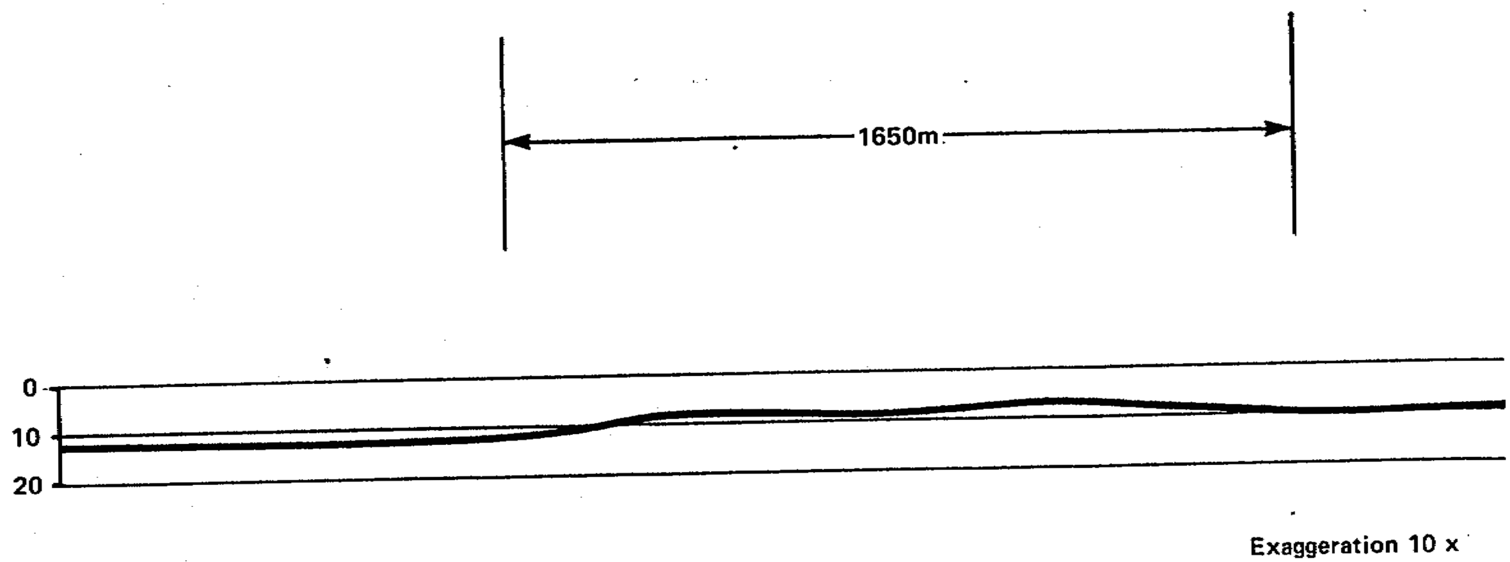
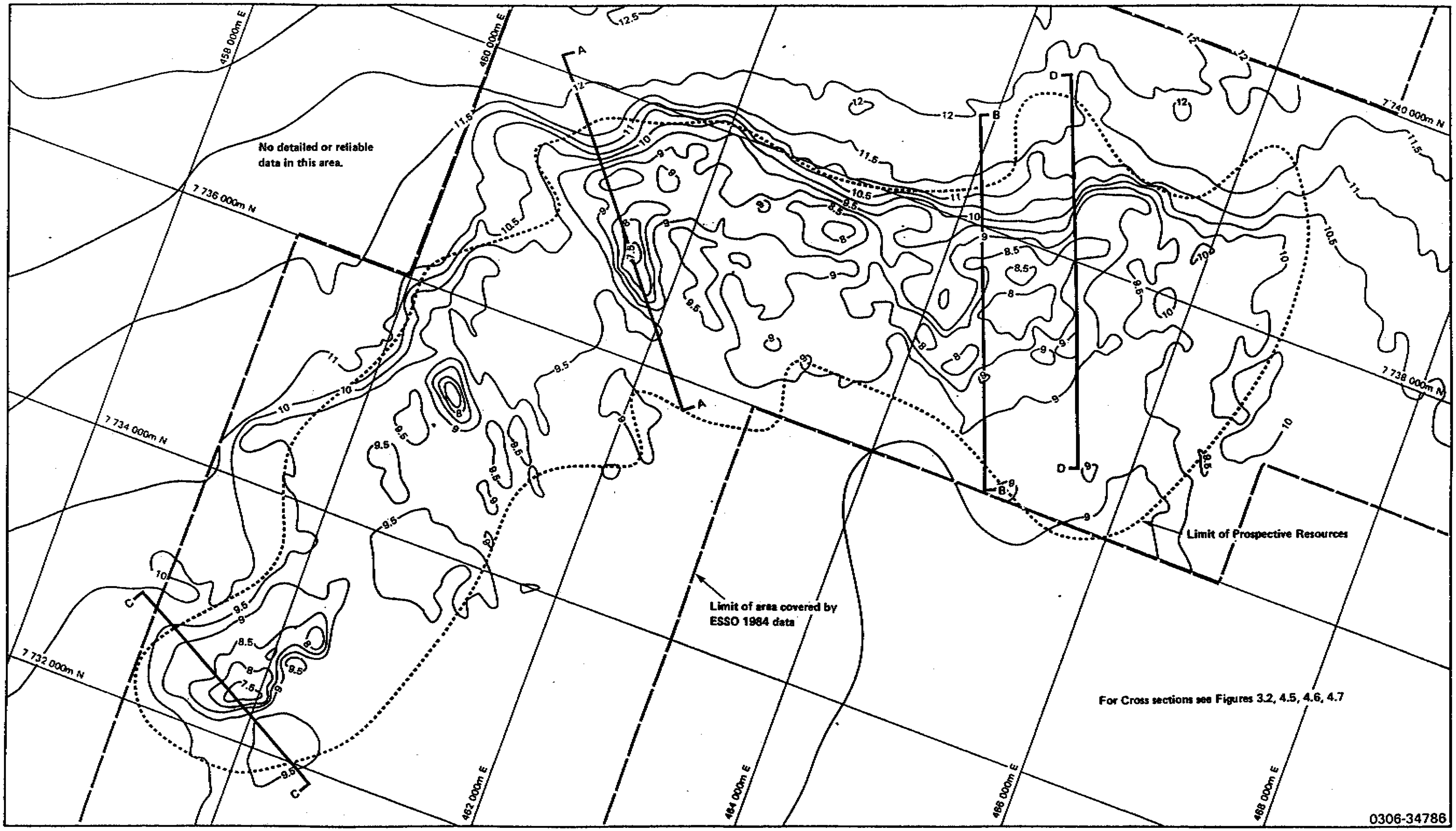


FIGURE 2 COMPOSITE REGIONAL BATHYMETRIC PROFILE FROM PELLY ISLAND THROUGH THE ISSIGAK AREA



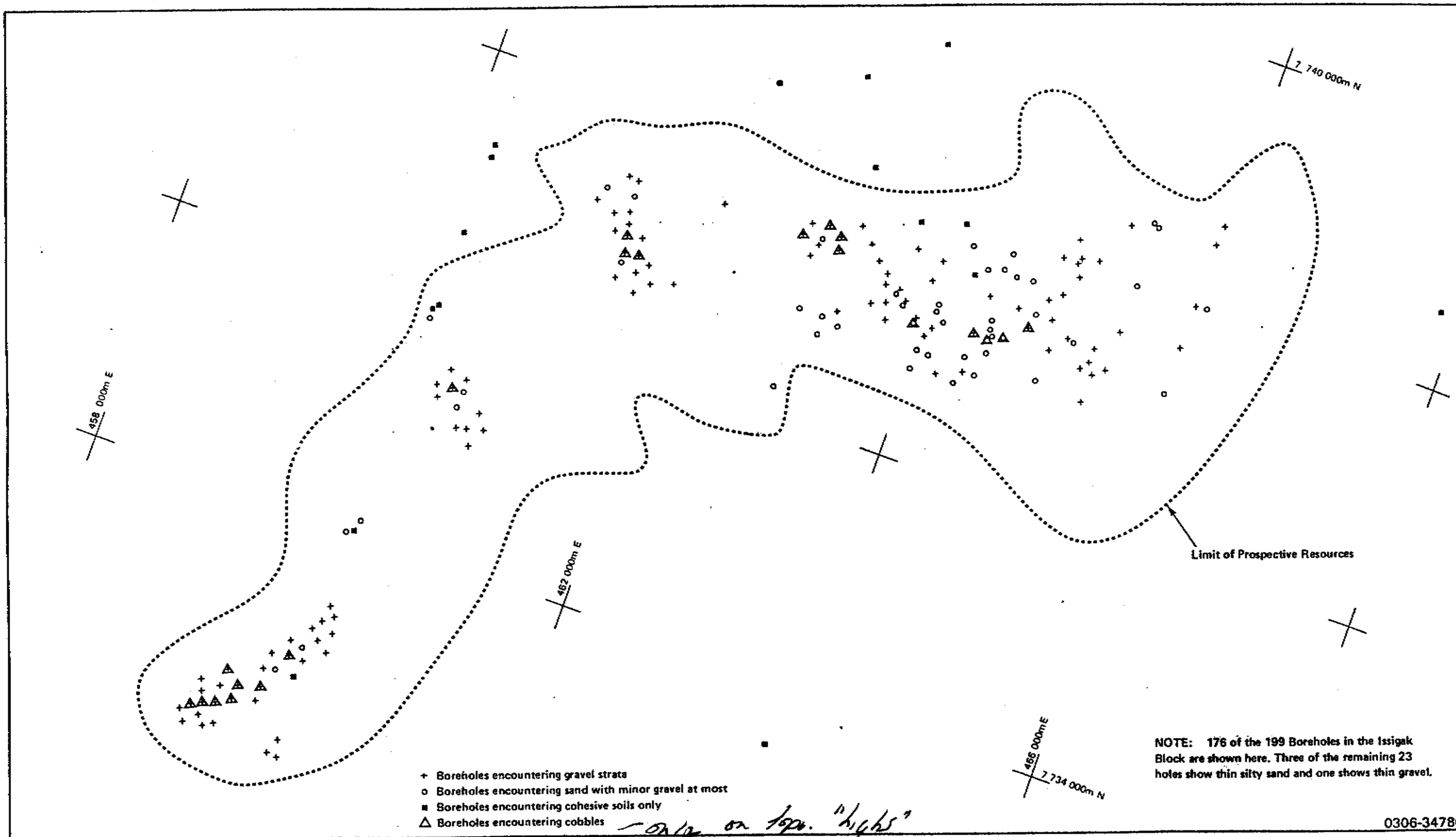
0306-34786

FIGURE 3 SECTION A–A THROUGH ISSIGAK DEPOSIT



EBA Engineering Consultants Ltd.

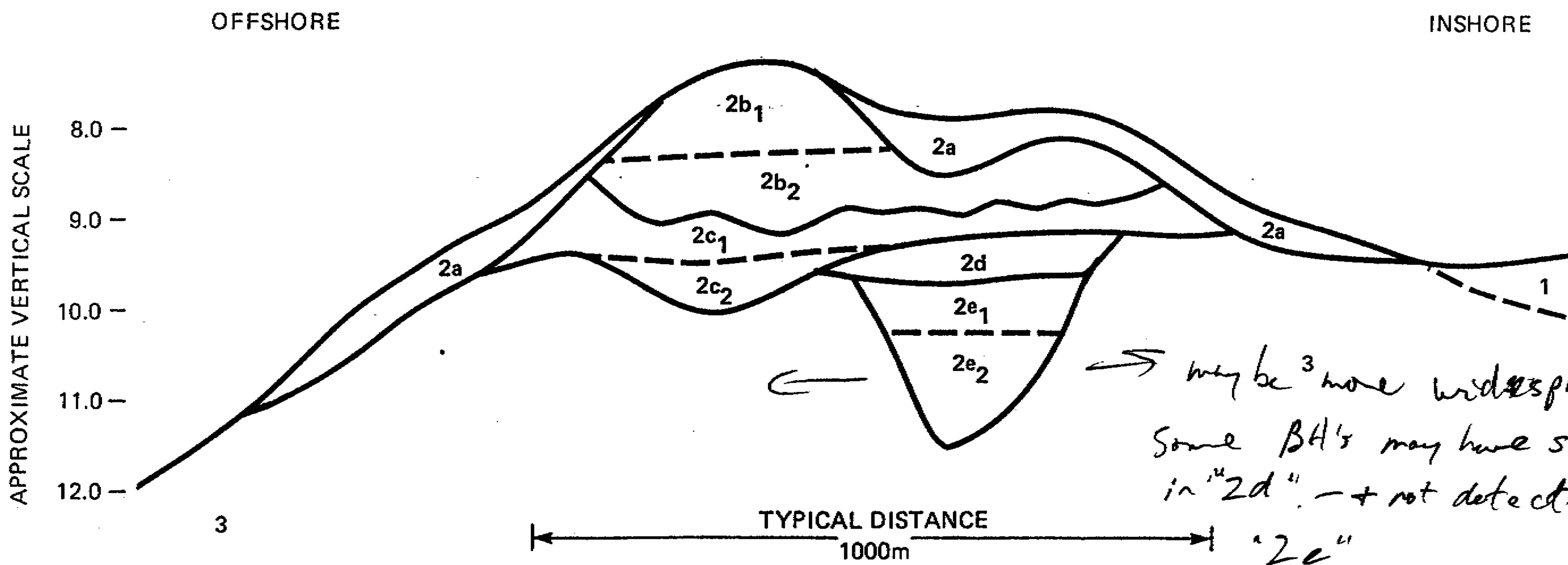
FIGURE 4
DETAILED BATHYMETRIC CONTOURS FOR THE ISSIGAK DEPOSIT



— only on topo. "highs"

EBA Engineering Consultants Ltd.

FIGURE 5 LOCATION OF BOREHOLES IN THE BORROW PIT AREA



may be 3 more widespread
Some BH's may have stopped in "2d" - + not detected "2e"
- may be worthwhile investigating this in future

UNIT	DESCRIPTION	UNIT	DESCRIPTION
1	Silty Clay	$2c_2$	Silty Sand
2a	Clean Sand	2d	Silty Clay
$2b_1$	Sandy Gravel to Sand & Gravel	$2e_1$	Sandy Gravel
$2b_2$	Gravelly Sand	$2e_2$	Silty Sand
$2c_1$	Clean Sand	3	Silty Clay

0306-34786

FIGURE 6 **GENERALIZED STRATIGRAPHY OF THE ISSIGAK DEPOSIT**

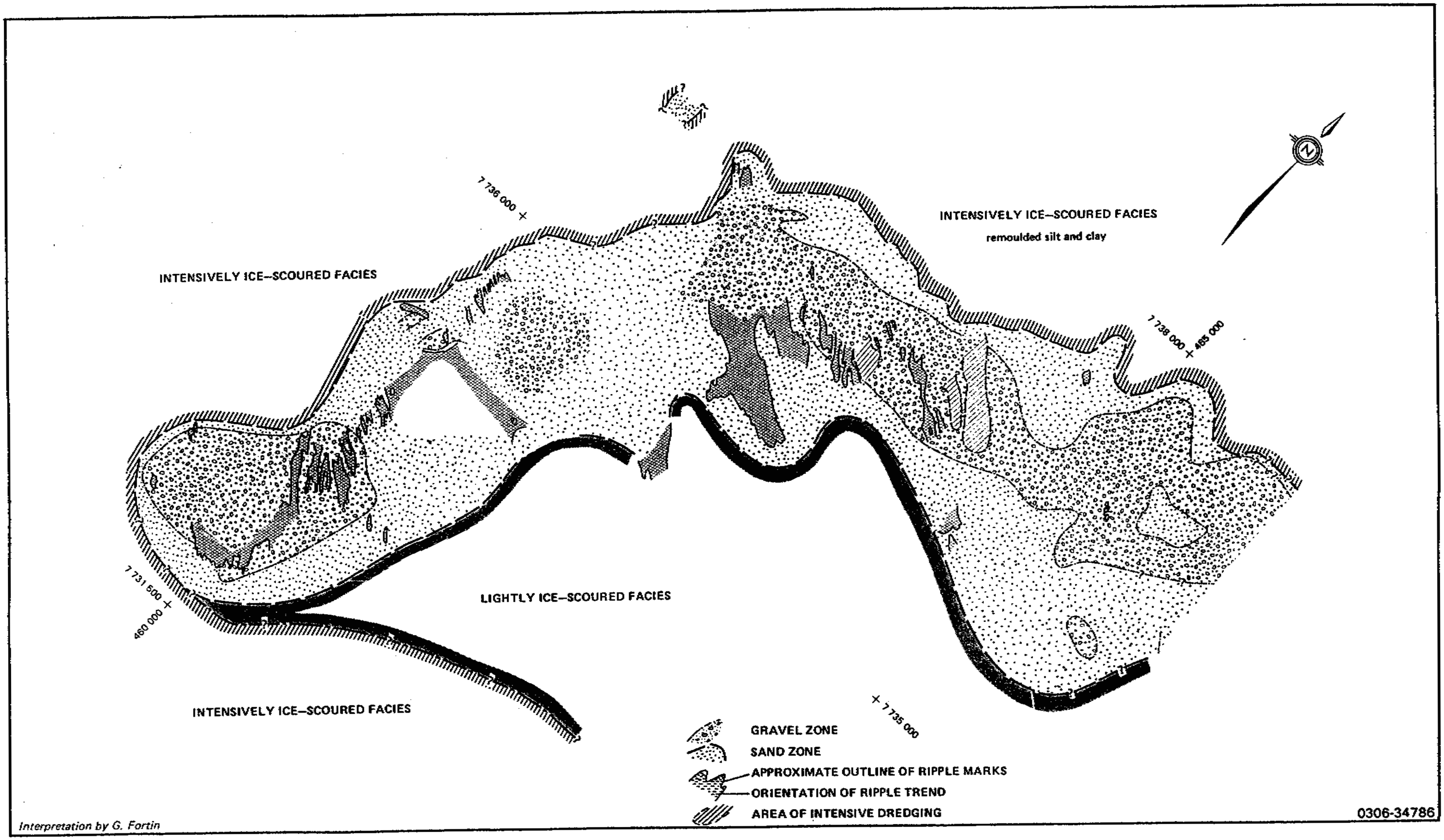
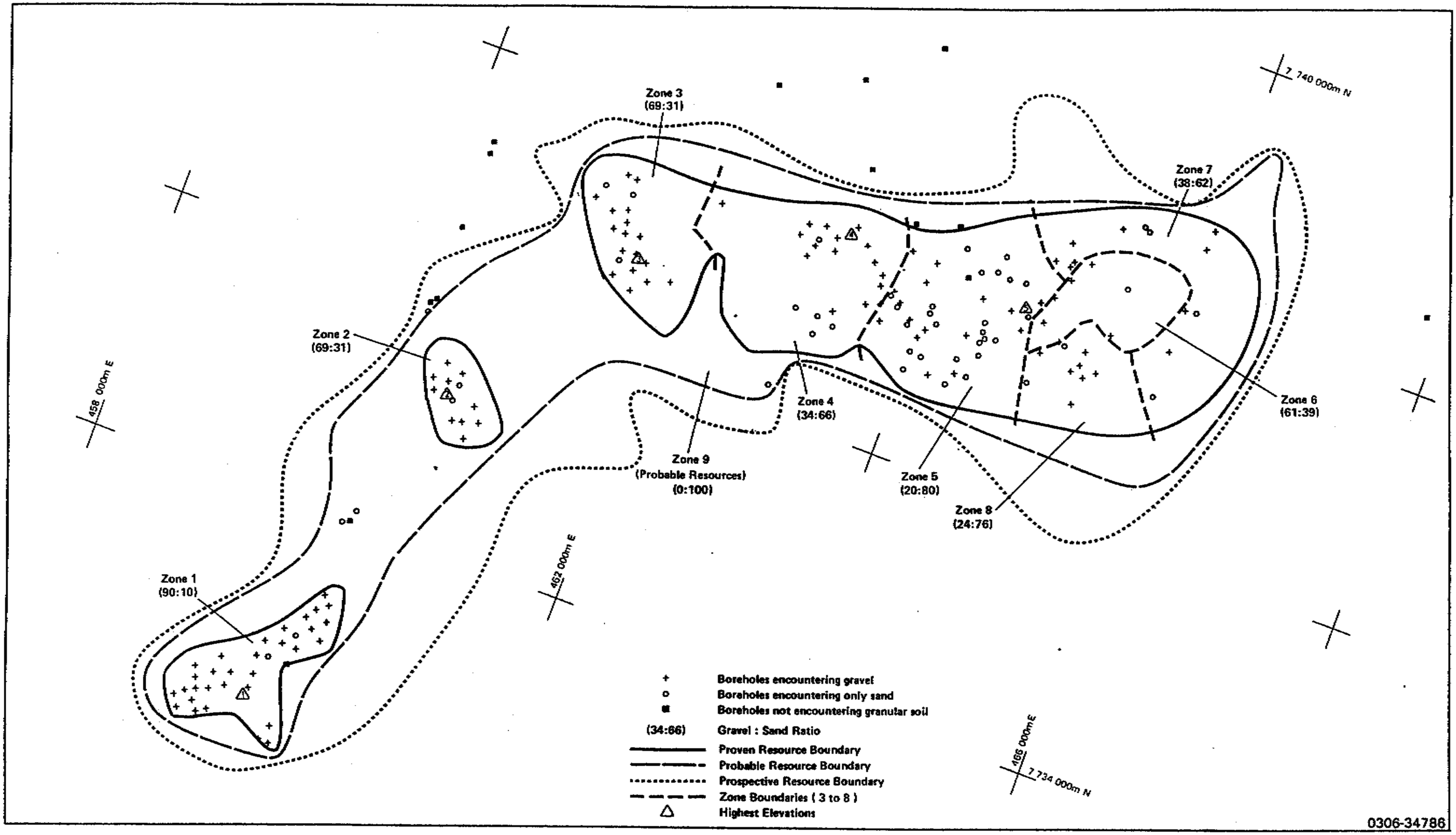
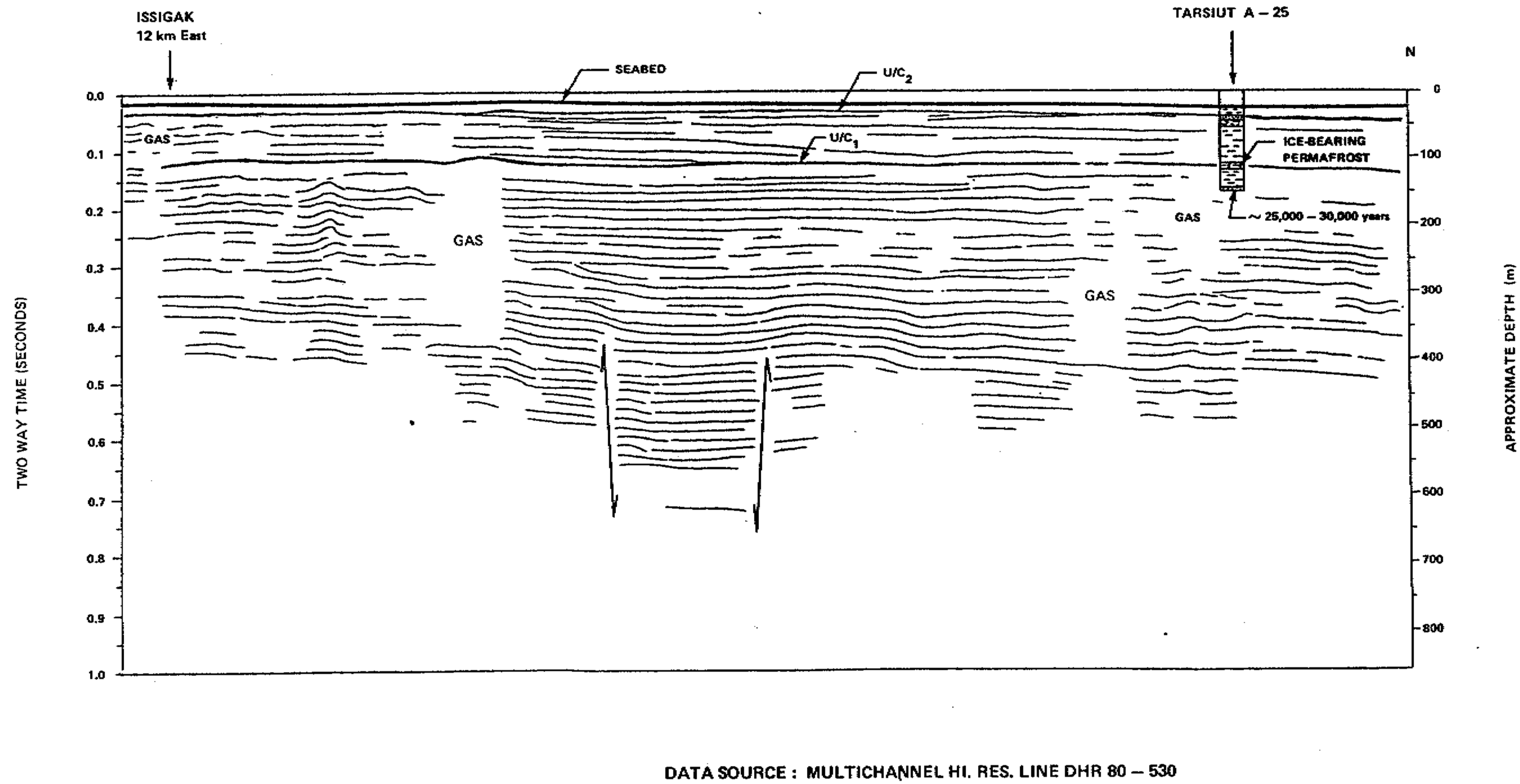


FIGURE 7 SIDESCAN INTERPRETATION OF SEABED CONDITIONS



EBA Engineering Consultants Ltd.

FIGURE 8 RESOURCE & ZONE BOUNDARIES

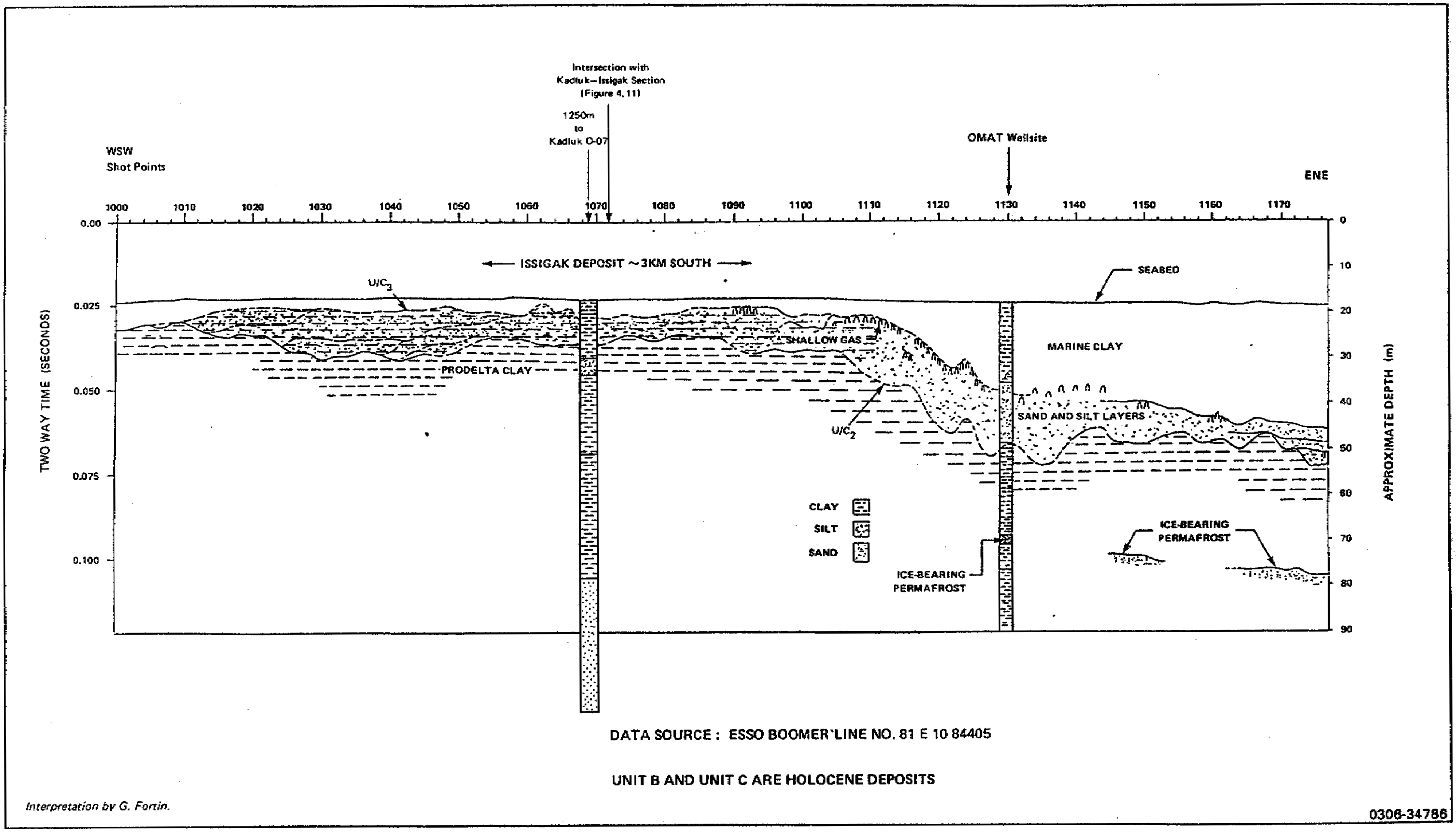


Interpretation by G. Fortin.

0306-34786

EBA Engineering Consultants Ltd.

FIGURE 9 SHALLOW STRATIGRAPHY FROM TARSIUT A–25 TO ISSIGAK AREA



EBA Engineering Consultants Ltd.

FIGURE 10 SURFICIAL GEOLOGY FROM OMAT WELLSITE TO AN AREA NEAR THE ISSIGAK DEPOSIT

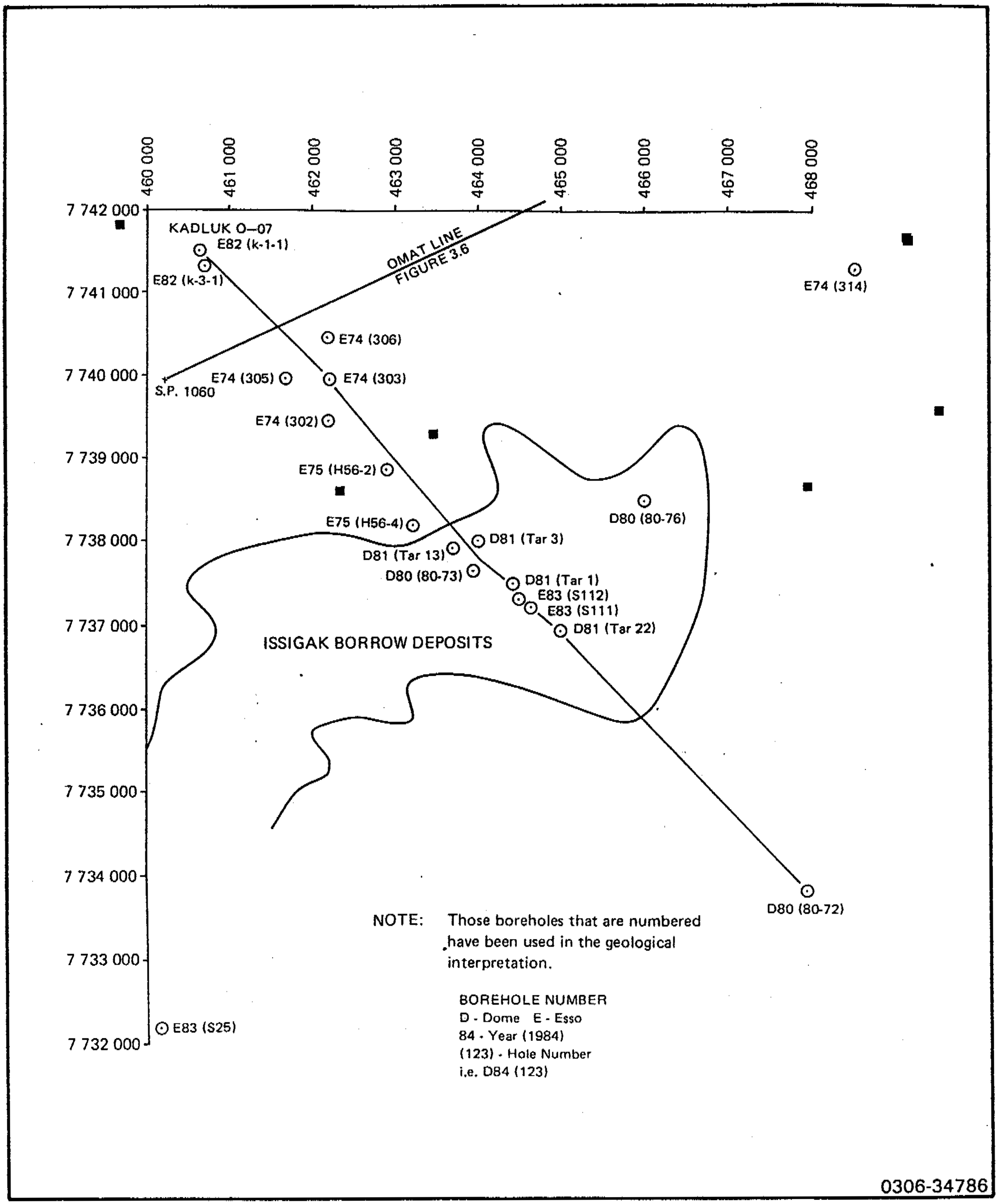


FIGURE 11 INTERPRETATION OF THE KADLUK–ISSIGAK REGIONAL STRATIGRAPHY

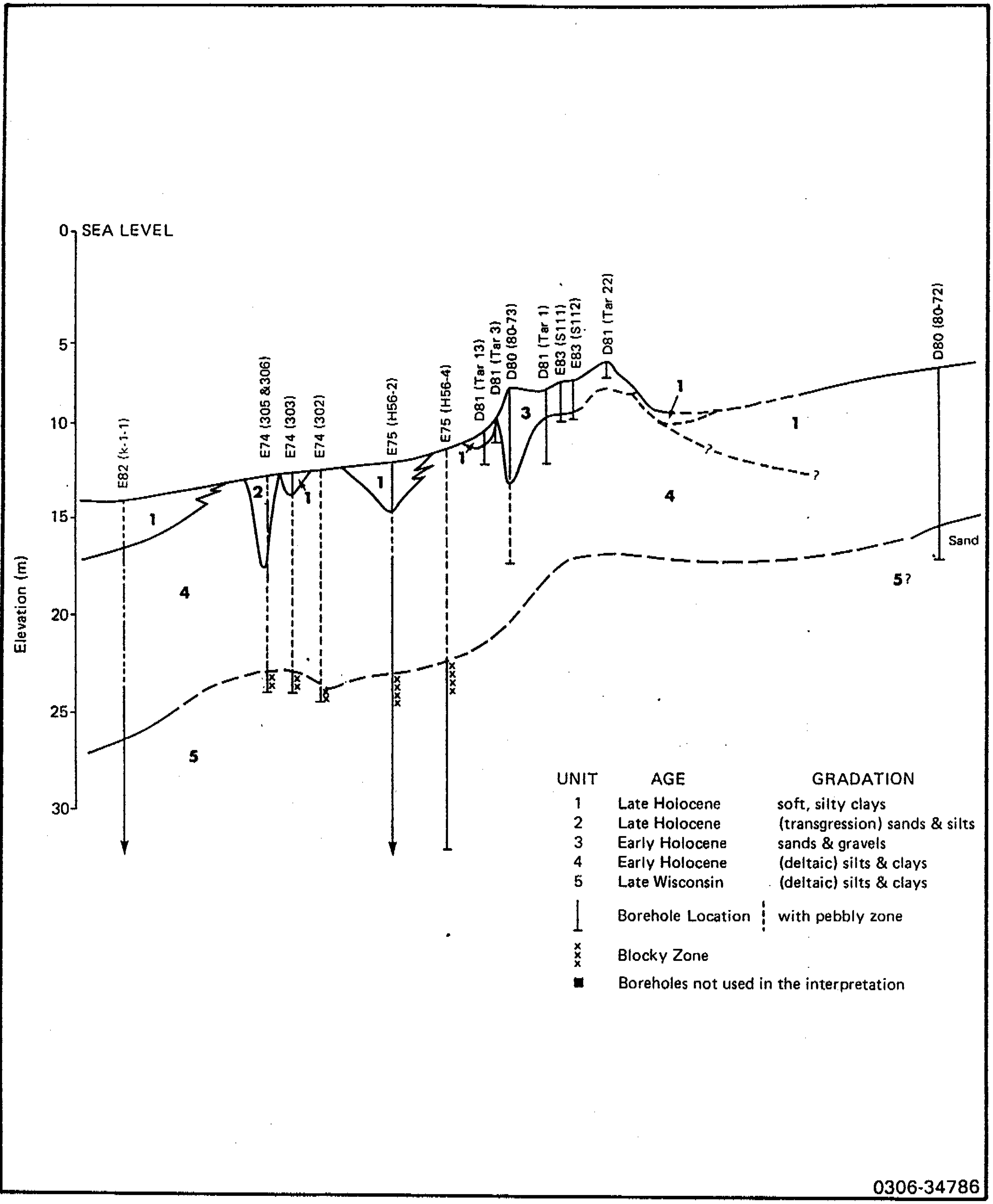


FIGURE 12 INTERPRETATION OF THE KADLUK–ISSIGAK REGIONAL STRATIGRAPHY

REAL-TIME INTERPRETATION OF MARINE RESISTIVITY

W.J. SCOTT

C-CORE
Centre for Cold Ocean Resources Engineering
Memorial University of Newfoundland

ABSTRACT

This paper describes the development of a real-time interpretation capability for the MICRO-WIP marine resistivity system. The program was carried out in 1987 by Hardy BBT Ltd. for Indian and Northern Affairs Canada. Scientific Authority for the project was Mr. R.J. Gowan of INAC. W.J. Scott of Hardy BBT was the project leader.

Prior to this program, waveforms of transmitted current and received voltage had been digitised and recorded on tape during survey. Processing after the survey was required to calculate apparent resistivity and chargeability values. In this program the MICRO-WIP was rebuilt around a data acquisition system (DAS) and a controlling computer. While the DAS stacked and averaged the incoming signals, the computer inverted the previous data set in terms of a layered model.

The system was tested first on a network of resistors designed to simulate conditions observed on a previous survey in the Beaufort Sea. Once the system was proven on the simulator, field trials were undertaken in Okanagan Lake in British Columbia. There the ratios of water resistivity to bottom and sub-bottom resistivities were comparable to those observed in the Beaufort. In the trial the transmitter current was reduced from normal in the ratio of water resistivities in Okanagan Lake and in the Beaufort Sea. The system was shown to have low noise levels. The field results showed reasonable values for data inverted in real time in terms of a multi-layer model.

INTRODUCTION

This paper describes the development of a real-time interpretation capability for the MICRO-WIP marine resistivity system. The program was carried out in 1987 by Hardy BBT Ltd. for Indian and Northern Affairs Canada. Scientific Authority for the project was Mr. R.J. Gowan of INAC. W.J. Scott of Hardy BBT was the project leader.

The detection of sub-bottom permafrost and granular deposits is very important for the design and construction of offshore facilities in the Beaufort Sea. Granular deposits will supply valuable borrow material for construction of islands while the presence of permafrost will influence the choice of routes and construction of pipelines.

In 1980, Hardy Associates (1978) Ltd. (now Hardy BBT Ltd.) began the development of the marine resistivity system known as MICRO-WIP, (MICROprocessor controlled Waterborne Induced Polarization). In various stages of development, this system was used for fresh water work in mineral exploration and for salt-water searches for granular materials. Initial results of a survey offshore Alaska were described by Scott et al., 1983. At that time, design of the system was relatively established and only minor changes were made from then until the commencement of the program described in this paper. The system was used in the Canadian southern Beaufort Sea in 1985 in a successful program to map granular materials for island construction (Scott and Maxwell, 1989). In this survey, it was felt that a major limitation to the 1985 system was the lack of a real-time resistivity interpretation capability.

In 1977 with INAC funding, the existing marine resistivity system hardware and computer software were redesigned to incorporate real-time interpretation of the resistivity data. The system was assembled and bench tested prior to carrying out a field trial. Descriptions of the equipment design, bench tests and field trial results are presented in this report. Since the 1987 INAC program the MICRO-WIP has been transferred to a PC-based system, which is also briefly described in this paper.

BACKGROUND

The use of electrical resistivity measurements has long been accepted on land as a means of mapping the distribution of granular resources and permafrost (Scott et al., 1979). In general, electrical resistivity of soils is a function of grain size, with sands and gravels having a higher resistivities than silts and clays. This relationship holds even when the pore water in the materials is saline. Furthermore, frozen materials have much higher electrical resistivities than the same materials in an unfrozen state.

Figure 1a, after Scott and Maxwell (1989), shows values of electrical resistivity for some typical soils on land as a function of temperature. From this figure, it is clear that freezing the soil generates a drastic increase in its resistivity. Figure 1b shows the range of resistivity values for typical soils on land. The higher the resistivities observed in soils, the more coarse-grained those soils are likely to be, provided that temperature and moisture content conditions are similar. A similar relationship prevails for seabed materials, although the actual resistivity values are smaller. Results of the 1991 survey, as yet unpublished, indicate that increasing gas content in a soil increases resistivity as well.

Resistivity Measurements

Measurement of resistivity on land or water involves injection of electrical current through two electrodes and measurement of the resulting potentials between other electrodes. A quantity known as apparent resistivity is calculated from these measurements in the following manner:

$$\rho a = (V/I) * f(G),$$

where ρa is apparent resistivity,
I is the injected current,
V is the observed voltage, and
f(G) is a function of the geometry of the electrodes .

If V is in volts, I is in amperes, and the distances in f(G) are in metres, then the units of ρ are ohm-metres (Ω-m).

If the ground under the electrode array is homogeneous to a depth much greater than the size of the array, then the measured apparent resistivity would be equal to the true resistivity of the earth. Such a uniform case rarely occurs in nature, the apparent resistivity usually represents some function of the distribution of values in the earth within the range of the measurement.

The general procedure in making electrical resistivity measurements involves varying the size of the array and thus, the volume of ground affected by the measurement, and observing changes in apparent resistivity as a function of this variation. The resulting set of observations is called a sounding.

The array most commonly used in marine resistivity is the multi-dipole array. For this array, an increase in depth of penetration is normally accomplished by increasing the spacing between transmitter and receiver dipoles, while keeping the dipole size constant. The expansion of array sizes is carried out in terms of the dipole multiple n. The smallest array is with $n = 1$. In this case, the distance between the nearest transmitter and nearest receiver electrode is one dipole length. Increased penetration is achieved by increasing the number of dipole lengths separating transmitter and receiver dipoles. In practical field situations, the largest separation normally achievable is limited by signal strength to $n = 6$. Thus a multi-dipole sounding consists of six apparent resistivities calculated for $n = 1$ to 6.

Interpretation of Resistivity Measurements

Once a set of apparent resistivity values has been measured, interpreting the results of electrical surveys to identify granular materials or permafrost is a two-part process. The first part is obtaining a model which fits the observations; the second part is making the correlation between the model parameters and the type of soil to be expected.

Resistivity models are described by layer thicknesses and resistivities. In the case of a multi-dipole sounding, the apparent resistivities for n = 1 to 6 can be used to develop simple models involving the water and two sub-bottom layers lying on a half-space. The resistivity and thickness of the water can be determined by independent means. Sub-bottom materials can be modelled in terms of two layers lying on a half space. In areas where granular materials are expected to be close to the bottom, variation of resistivity in these upper two layers would be indicative of variation of grain size in the near sub-bottom.

The parameters of the model are obtained from the measured apparent resistivities by an inversion process. A first estimate is made of the model resistivities and thicknesses, and the apparent resistivities which would be observed for this model are calculated. These resistivities are compared with those observed in the field and adjustments are made in the model parameters in the direction which minimizes the disagreement between observed and calculated apparent resistivities. Normally, several cycles of calculation and adjustment will bring the calculated and observed apparent resistivities into reasonable agreement, provided that a good initial model is used.

It should be understood that it is frequently possible to obtain more than one model which will satisfactorily match the observed apparent resistivities. Thus, it is important that the starting model be reasonably close to the situation which is being investigated. External control such as drill hole information, sub-bottom profile information, and geological inference can thus be used to help sharpen the precision of the geophysical interpretation.

Measurement Techniques for the MICRO-WIP

Marine resistivity measurements with the MICRO-WIP system are made by means of a streamer towed behind a survey vessel. This arrangement is shown schematically in Figure 2. The multi-dipole array is incorporated into the streamer. The two electrodes nearest the survey vessel are used to transmit electrical current into the water and sub-bottom materials. The other seven electrodes on the streamer are used to measure the resulting voltage distribution as a function of distance fro the source, and consequently, as a function of penetration into the sub-bottom. These seven electrodes allow the calculation of the six values of apparent resistivities as discussed above. Experience in the Beaufort Sea in 1985, indicates that a current of 15 amperes is adequate to give reliable signal levels for measurements of this sort with a dipole length of 25 metres and separations of n = 1 to 6.

1985 MICRO-WIP Survey, Southern Beaufort Sea

During the summer of 1985, the system was operated in the Beaufort Sea to map resistivities in support of evaluation of granular resources (Scott and Maxwell, 1989). This survey was carried out prior to the dredging of material to build an artificial island. Despite very bad ice conditions which allowed only very limited access to the survey area, some 40 kilometres of survey data were obtained during a two day period. After completion of the survey, however, a ten day period elapsed before the first preliminary interpretation was provided to the client. A further period of a month ensued before presentation of the detailed interpretation.

Fortunately for the future of MICRO-WIP, other geotechnical information had already indicated the presence of granular material, and the borrow pit was successfully established shortly after the preliminary interpretation was supplied. The final interpretation showed that the borrow pit was indeed in the optimum location.

From the 1985 survey several things emerged. The first was the need for real-time processing in order to avoid delay in providing interpretation. The second was an understanding of the general range of resistivities to be expected in the sub-bottom materials. These resistivities correlated reasonably well with those initially determined by Scott (1975), in resistivity soundings carried out through the sea ice in the same general area. The 1985 survey further provided some observed values of apparent resistivity as a function of dipole spacing which could be used in simulated trials with modified equipment.

It was in light of this experience that the 1987 INAC development program was undertaken. The objective of this program was to develop the capability to carry out interpretation in real-time, in order that reconnaissance surveys could be performed shortly before dredging, with interpretations produced shortly thereafter.

SYSTEM DESIGN AND TESTING

To provide real-time interpretations, two functions had to be developed within the system. The first of these was the averaging of the digitized waveforms and calculation of apparent resistivity values. The second was to invert the apparent resistivity values in terms of a 3-layer model. Within the time constraints of real-time processing, it did not appear possible to perform both functions in a single computer. It was therefore decided to carry out the first function within a data acquisition system (DAS), and the second in the computer which controlled the DAS.

A Hewlett Packard HP 3852 data acquisition and control system was selected. The system could be configured for a variety of applications. It had built-in intelligence, an internal clock and a programmable pacer which could be used as timing control for remote devices. A controller was built to turn the transmitter on and off in synchronization with the timing supplied by the pacer signal in the HP 3852. A Hewlett-Packard 9816 computer was selected to drive the DAS, and to run the inversions.

To test the system in the laboratory, a resistance network was devised to simulate a streamer in the sea. With this network and a very low-powered transmitter, bench tests were conducted to refine the performance of the real-time inversion routines.

Finally, the entire system was installed on a suitable vessel for a field trial on Okanagan Lake, British Columbia. There the real-time resistivity interpretation capability of this system was demonstrated during the field trial.

Two computer programs were developed to run the system. Both of these have now been superseded by the PC-based programming, and thus will not be described in detail here. The first program downloaded a set of instructions to the DAS to set up the system pacer, scan the amplifier channels, stack the voltages, and check the gains. The main program initialized the plotter, started the DAS, read data from the DAS, ran the inversion, and plotted the real-time resistivity section.

In the 1991 system, the DAS has been replaced by a set of data acquisition boards installed in the PC, which stack the incoming signals, and store the results directly in memory. The PC then uses these values to calculate the apparent resistivity and chargeability values. At present the system does not have the real-time inversion implemented, but the programming is structured to include inversion, and the routines developed in 1987 will be incorporated in the near future.

Choice of Electrode Array

The 1985 survey was performed with an array of 25-metre dipoles and n=1 to 6. This array was initially designed for mineral exploration, where arrays with constant dipole size are common. The combination of water depth, water resistivity and sub-bottom conditions in the 1985 Beaufort Sea survey area was such that the 25-metre array gave good definition of the surface layers and at the same time, adequate penetration to map relic permafrost at depth.

Subsequent computer modelling supported by an Industrial Research Assistance Program (IRAP) Grant suggested that better resolution of deep features and better definition of near-surface resistivities could be obtained with an array in which the receiver dipole size increased logarithmically with distance from the transmitter dipole. As part of the IRAP program, such a streamer was built. The spacings of this streamer are given in Table 1.

Because the 1985 data were taken with constant dipole lengths, the simulator network was established for this configuration, but the data acquisition system and inversion routines were configured to handle either constant-spacing arrays or logarithmic-spacing arrays.

TABLE 1: LOGARITHMIC STREAMER

DISTANCE (metres)	IDENTIFICATION	ELECTRODE
0	Start of Cable	
25		C1
	Current Dipole	
50		C2
60		P1
	Potential Channel 1	
70		P2
	Potential Channel 2	
85.75		P3
	Potential Channel 3	
107.75		P4
	Potential Channel 4	
141.25		P5
	Potential Channel 5	
189.25		P6
	Potential Channel 6	
260.50		P7

SIMULATION OF BEAUFORT SEA MEASUREMENTS

Within the time and cost constraints of the 1987 INAC program, it was impossible to collect real data from the Beaufort Sea with the modified system. It was, however, possible to predict, from forward modelling programs already in existence, the apparent resistivities that would be observed with the new system over given geologic conditions, and to choose a network of resistors that would provide the appropriate signal levels.

The interpretation carried out on the data from the 1985 survey showed that the resistivity of the seawater in the southern Beaufort Sea was typically about 2.0 Ω-m. (Interpretations of data from the 1991 survey, over a wider area, show variations of seawater resistivity from 1 to 8 Ω-m.) In electrical terms, the sub-bottom materials in the 1985 survey area could be represented by three layers. The uppermost layer appeared to have resistivities ranging from 1.6 to 2.6 ohm-metres. From the limited drilling carried out to a establish the borrow pit, it appears that this range of resistivities spanned materials from clayey silts to coarse sands with occasional pebbles. Within the survey area, none of this material appeared to be frozen.

The bottom-most layer interpreted in the 1985 survey had resistivities which ranged from a low of 10 ohm-metres to a high of greater than 500 ohm-metres. The variation of resistivity generally reflected the depth to the top of the layer, with the highest resistivities occurring where the layer was shallowest. A single drill hole intersected permafrost at the interpreted depth to the top of this layer within the borrow area. From the high interpreted resistivities and from the fortuitous intersection in the borehole, it was concluded that the high resistivity parts of this layer represent the ice-bonded material, and that the ice content generally correlated with the interpreted resistivity values.

An unexpected outcome of the interpretation procedure was that between the uppermost layer, (1.6 to 2.6 ohm-metres) and the deepest (permafrost) layer, there appeared to be a layer of significantly lower resistivity (0.5 to 1.5 ohm-metres). This layer has no apparent direct geological correlation. However, work in the Alaska Beaufort Sea, (Sellmann, P.V., 1985 pers.comm.) suggests that there is a pronounced increase in salinity of pore waters immediately above the degrading permafrost. Such an increased salinity would result in lowered resistivities and would provide a reasonable explanation for the observations from the 1985 survey.

Table 2 summarizes the likely set of conditions which would be encountered in looking for granular materials in the southern Beaufort Sea. While this is a reasonably comprehensive set of geologic conditions, the innate perversity of nature is such that it is not possible to predict all configurations which are likely to be encountered. Furthermore, it should be realized that even with the logarithmic array, the maximum number of layers that can be resolved is three layers lying on a half-space. Forward calculations can be carried for all of the models in Table 2 and a set of observed of apparent resistivities can be derived. However, in cases with more than three layers, the inversion will not necessarily lead back to the starting model. This is an intrinsic limitation of resistivity methods and must be recognized if application of marine resistivity is contemplated.

This problem, known as the problem of equivalence, can be resolved to some extent if acoustically determined boundaries coincide with some of the electrically defined boundaries. For example, it is obviously possible to define the bottom of the water (top of seabed) with a depth sounder, and thus to remove the influence of the water from any model by calculation. In the case of Group 5, (Table 2), the top of the granular material under the silts and clay should constitute an acoustic reflector unless the fines are gas-saturated. In such a case, fixing the thickness of the fine-grained layer from the sub-bottom profiler record will aid in resolving such equivalences.

TABLE 2: TYPICAL SUB-BOTTOM GEOLOGICAL CONFIGURATIONS*

MODEL NO.	LAYER MATERIAL (ρ (Ω-m), t(m))
1A	Granular (2.2,20) / Saline (1,20) / Permafrost (100,∞)
1B	Granular (2.2,10) / Saline (1,10) / Permafrost (500,∞)
1C	Granular (2.2,20) / Saline (1,20) / Unfrozen (10,∞)
2A	Fines (1.6,20) / Saline (1,20) / Permafrost (100,∞)
2B	Fines (1.6,10) / Saline (1,10) / Permafrost (500,∞)
2C	Fines (1.6,20) / Saline (1,20) / Unfrozen (10,∞)
3A	Permafrost (20,2) / Granular (2.2,20) / Saline (1,20) / Permafrost (100,∞)
3B	Permafrost (20,2) / Granular (2.2,10) / Saline (1,10) / Permafrost (500,∞)
3C	Permafrost (20,2) / Granular (2.2,20) / Saline (1,20) / Unfrozen (10,∞)
4A	Permafrost (15,2) / Fines (1.6,20) / Saline (1,20) / Permafrost (100,∞)
4B	Permafrost (15,2) / Fines (1.6,10) / Saline (1,10) / Permafrost (500,∞)
4C	Permafrost (15,2) / Fines (1.6,20) / Saline (1,20) / Unfrozen (10,∞)
5A	Fines (1.6,5) / Granular (2.2,20) / Saline (1,20) / Permafrost (100,∞)
5B	Fines (1.6,20) / Granular (2.2,10) / Saline (1,20) / Permafrost (100,∞)

*TOP LAYER IS ALWAYS WATER (2 Ω-m, 8 m THICK)

Table 2 shows 14 likely geologic configurations, of which only 1A, 1B and 2A, the three most representative of conditions encountered in the 1985 survey were built into the physical simulator.

In order to provide a realistic transition from one of the three models to another, it was necessary to prepare a series of intermediate models so that the variation in measurement could proceed incrementally as would be the case in a field survey. Five or six intermediate steps were chosen between the three models.

A single simulator network requires fourteen resistors. The three models, with the necessary transition resistor arrays as well, represented an array of one hundred and fifty-four resistors. Physical simulation of larger numbers of models becomes extremely difficult without a large investment in switching and resistor arrays.

The simulator starts with model 1B (Table 2). Rotation of the selector switch moves through the transition resistors, arrives at model 2B and then through more transitions to model 1A. Thus with the MICRO-WIP receiver connected to the output of the simulator, it was possible, by rotating the selector switch, to simulate a survey starting in granular material on ice-bonded permafrost, passing into an area of silts and clays on ice-bonded permafrost, and then on into an area of granular material on low-resistivity permafrost. Turning the switch in the opposite direction would run the simulated survey in the other sense.

Figure 4 shows parts of the survey results for a "two-way run" through the simulator. The apparent resistivities are referred to by their fiducial numbers, shown along the top of the section. Model 1B is represented by the interpreted resistivities at Fiducials 2 and 108. Model 2B is represented by Fiducials 26 and 78, and Model 1A by Fiducial 52.

It is reassuring to note that there is good agreement between the two interpretations for model 1B,(Fiducials 2 and 108) and for model 2B (Fiducials 26 and 78). Hence the inversion has indeed led back to essentially the original model in each case. The interpreted resistivity of the upper layer repeats within about one and half percent and surprisingly, the resistivity of the deepest layer repeats exactly. The most poorly determined layer is the conductive (saline) middle layer, whose resistivity is interpreted to only within about seven percent.

Note that the resistivities presented on the simulated data set did not match exactly the model resistivities presented on Table 2. This occurred because the current supplied by the simulation network was incorrect by approximately ten percent. Since it is a constant difference, it does not affect the conclusions reached for the simulated trial.

In general, resistivity interpretations provide resistivities to a precision of only a few percent. However, the experience in the Beaufort Sea was that with slowly varying apparent resistivities, the repeatability of estimates of resistivity for near surface materials was within two to five percent. The variation in interpreted resistivity values as a function of grain size was in the order of forty percent, and thus well beyond the likely error of interpretation.

FIELD TRIALS IN OKANAGAN LAKE

Once the system had been proven on the simulator network, it was then taken into the field for an operational trial. Okanagan Lake was chosen because it was the nearest body of water to Calgary which was of sufficient size and which was likely to be navigable during the winter time. The field trials were carried out in mid-February, 1987.

Okanagan Lake is a long lake which runs approximately north-south through the central part of British Columbia. The lake is typically 5 km wide and extends over one hundred kilometres from Penticton in the south to Vernon in the north. The test area was situated at Kelowna, B.C. Figure 5 is a location map that shows the approximate area of the lake in which the trials were carried out.

In the deeper parts of Okanagan Lake, the water depth is up to 300 m. The depth sounder operated with the MICRO-WIP system has a useable water depth of 120 m. This depth was exceeded several times during the trials. In the neighbourhood of Kelowna, there are significant areas where water depths ranged from 4 to 8 m and the bottom was relatively smooth. It was felt that the deeper water would allow an assessment of the noise level of the system in a uniform medium and the shallow areas would represent operating conditions which are similar those expected in the Beaufort Sea.

In Okanagan Lake, water resistivities are approximately 30 times greater than those of the Beaufort Sea. By the same token however, sub-bottom resistivities are also 30 times higher; the contrast between water and bottom is therefore reasonably similar to that to be expected in the Beaufort Sea.

Very little is known about the unconsolidated deposits in Okanagan Lake. However, Nasmith (1981), describes the surficial geology of sediments in the neighbourhood of the lake. From Nasmith's description, it appears that the sediments underlying the shallow portions of the test area are deltaic deposits derived from the mixed fine and coarse sediments lying above Kelowna. The shallower areas are predominantly fine grained silts and clays while granular areas are exposed on the slopes on the edges of the shallows.

Rocks exposed on shore in the neighbourhood of this survey showed intense shearing. The rocks under the lake are probably even more strongly sheared, and water-saturated as well. They would therefore be expected to have resistivities of a few hundred ohm-metres. It is reasonable to assume that the bedrock resistivities would be in the same ratio to the shallow sub-bottom resistivities as would permafrost resistivities in the southern Beaufort Sea to the overlying sediments.

While the geology of Okanagan Lake is obviously different from that to be expected in the Beaufort Sea, resistivity contrasts from water to sub-bottom sediments to deeper sub-bottom materials should be in the same general proportions as those in the Beaufort Sea. Because resistivity interpretations deal primarily with contrasts between resistivities of layers rather than with absolute values, it is reasonable to use this area as a test site for assessing the performance of a system designed for the Beaufort Sea.

The major difference would be that in the Beaufort Sea, to obtain readings at the same level of confidence, much higher transmitter currents would be required. It is probable that currents would have to be approximately 30 times higher to compensate for the approximately 30 times lower general resistivities. The survey on Okanagan Lake was carried out with 0.5 amperes while measurements in 1985 in the Beaufort Sea used 15 amperes. Thus it appears that the ratio of currents used in the two settings is approximately in proportion to the ratio of the resistivities to be observed.

The primary purpose of the field trials was to establish that the modified data processing system could provide inversion of resistivity data in real-time. The field survey was thus broken into two parts. The first was to establish the noise levels in the system and demonstrate that these are low enough not to interfere with the measurements. The second was to demonstrate that the inversion technique provided answers within the real-time constraints of operating the survey.

Because of budgetary limits, a minimum set of equipment was deployed for the survey. The minimum equipment included the MICRO-WIP and an analogue-recording depth sounder with a digital output. The depth sounder was deployed in order to provide water-depth information as part of the input to the inversion process.

The budget constraints prevented the use of the sub-bottom profiler and magnetometer which normally would be part of this survey system in the field. Furthermore, because no exact geological control was available, it appeared unnecessary to employ the precise navigation system which normally would be part of the survey.

The MICRO-WIP system performed extremely well on trials with only minor modifications necessary to provide smooth functioning. The Huntec Lopo transmitter used in this survey produces an extremely noisy wave form, which was filtered to remove high-frequency components. The filtered wave form was essentially the same in character and frequency content as that which is normally obtained from the high-powered system used in the Beaufort Sea.

In this survey, for the first time, the raw data consisted of the six apparent resistivities associated with the six dipoles, normally stored on disk. Figure 6a shows a plot of the pseudosections of apparent resistivity and chargeability derived in the field and plotted in real-time. The beginning of the line is in deep water. This represents essentially the noise level of the system in a homogeneous medium. The end of the line is in water depths of 4 to 8 metres. These resistivities, and chargeabilities in mineral surveys, constitute the raw data which is recorded with the system in its present configuration. Figure 6b shows the results of real-time inversion of the raw data on a different line, in terms of a layered model.

It should be emphasized that without control, it is difficult to come to an absolute determination of the accuracy of the interpretations. However, the resistivity values and thicknesses determined for the sediments appear to consistent with those derived from the on- shore geological model. Resistivities range from sixty to several hundred ohm-metres and the resistivity of near surface materials appears somewhat higher in areas where granular material would be expected.

DISCUSSION AND RECOMMENDATIONS FOR FUTURE WORK

The development program described in this paper resulted in a system which operated on a variety of surveys, in freshwater lakes mainly in Ontario and Quebec. The major limitation of the system was that the operator was required constantly to adjust the gain settings to avoid saturation and maintain adequate signal levels. The DAS used in the system was not capable of sufficient calculations to monitor and adjust the gains. Accordingly in 1991 it was decided to transfer the system to an IBM-PC compatible computer, and to incorporate automatic gain control. This work was completed just in time for a survey in August 1991, funded by Atlantic Geoscience Centre, EMR, through NOGAP.

Unfortunately, the real-time inversion programming had not been transferred by the time of the survey, although it is expected to be ready by the summer of 1992. The survey included side-scan sonar, and two sub-bottom profilers as well as the MICRO-WIP resistivity system. The results are now being compiled.

There is a relationship between lateral resolution and survey speed. One inversion is carried out for every thirty-two seconds worth of data. At a survey speed of one kilometre per hour, each sounding represents a lateral translation of approximately nine metres. At a survey speed of one knot, each reading represents a distance of approximately sixteen metres and at a survey speed of three knots, each sounding represents a distance of fifty metres. Thus, the choice of survey speed depends upon the lateral resolution that is required in near surface features. As vessel speed increases, so does the noise level, and a practical upper limit for resistivity surveying appears to be about three knots.

Lateral resolution also depends on the array size. The volume of measurement which is represented by each of the apparent resistivities depends upon the spacing between the transmitter and receiver pair which are used for the calculation. Thus the volume involved in measurement of shallow resistivities is quite small, and a movement of fifty metres may involve significant lateral variation. However, for permafrost at depths of fifty to one hundred metres, separation between the transmitter and the farthest spaced dipole is of the order of two hundred metres and thus a lateral translation of fifty metres does not imply a major replacement of the volume of measurement by new material. The desired depth and resolution of the target therefore will have some influence on the selected speed, as it appears feasible to make reliable resistivity measurements at the speeds of up to three knots.

There is some evidence (Olhoeft, 1975) that frozen clays give rise to small induced polarization (IP) effects. The IP effect may be a useful indicator to distinguish between frozen granular materials and frozen clays, . The IP effect is more noise-sensitive than the resistivity. A survey in which IP affects are measured would probably have to be conducted at a significantly lower speed than one conducted solely for resistivity measurements. It appears that with the 1987 system, realistic measurements of IP affects can only be made at survey speeds of one knot or less. Much of the present development work is concentrated on improving this noise performance. .

Present research is concentrating on electrode design and on improvement of averaging processes in the programming. With improved electrodes, it is felt that reduced noise levels would allow higher survey speeds even when measuring IP effects as well.

The marine resistivity system provides information which is a valuable supplement to but not a replacement of normal acoustic surveys. The results of the 1991 survey indicate that gaseous sediments are easily penetrated by electrical measurements, and structure which is lost in acoustic profiles can be followed with electrical measurements. Incorporation of depths from seismic surveys in post-survey interpretations improves the reliability of the electrical models, and thus of the final interpretation.

There is some evidence in the 1991 survey data that gaseous sediments have elevated resistivity values. The presence of gas in pores of a soil should also give rise to increased IP effects. It is possible that gas contents can be estimated from combined acoustic and electrical surveys.

In its present form the MICRO-WIP is clearly a useful tool for the mapping of grain-size variations in near-bottom sediments in the Beaufort Sea. If geophysical mapping of granular deposits in the Beaufort Sea is to be undertaken, then consideration should be given to the use of the MICRO-WIP system.

REFERENCES

Dyck, A.V., Scott, W.J., and Lobach, J., 1983, Waterborne Resistivity/Induced Polarization Survey of Collins Bay, Wollaston Lake, in Uranium Exploration in Athabasca Basin, Sask. Canada, ed. E.M. Cameron., Geol. Surv. Can., Paper 82-11, p. 281-289.

Lobach, J.L. and Scott, W.J., 1980, A system for resistivity surveying in water: *in* Scott, W.J. and Brown, R.J.E., eds., Nat. Res. Counc. Can., Tech. Mem. 128, p.35-45.

Nasmith, H., 1981, Late Glacial History and Surficial Deposits of the Okanagan Valley, British Columbia. B.C. Min. Energy, Mines and Resources, Bull. 46.

Olhoeft, G.R., 1975, The Electrical Properties of Permafrost, Unpublished Ph.D. Thesis, University of Toronto, 172 p.

Scott, W.J., 1975, Preliminary Experiments in Marine Resistivity Near Tuktoyaktuk, District of Mackenzie. Geol. Surv. Can., Paper 75-1, Part A, p. 141-145.

Scott, W.J., Sellmann, P.V., and Hunter, J.A., 1979, Geophysics in the Study of Permafrost: Review Paper, Proc. Third Int. Conf. on Permafrost, 2, National Research Council of Canada, p. 93-115.

Scott, W.J., Laing, J.S., and Botha, W.J., 1983, Waterborne Resistivity /Induced Polarization Survey in Prudhoe Bay. Proc. Fifteenth Offshore Tech. Conf., Houston, May 1983, p. 227-230.

Scott, W.J. and Maxwell, F.K., 1989, Marine resistivity survey for granular materials, Beaufort Sea: J. Can. Soc. Expl. Geoph. 4, 4, p. 104-114.

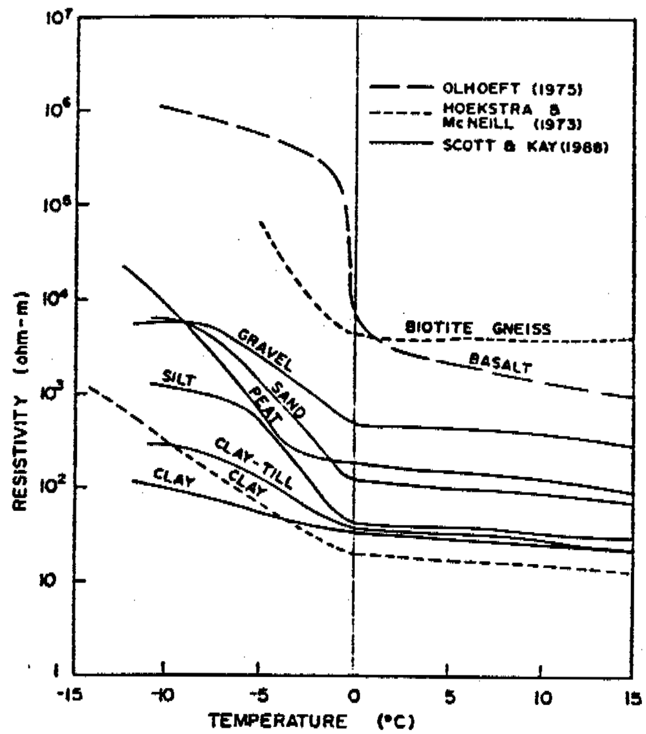


Figure 1: a) Resistivity as a function of temperature.

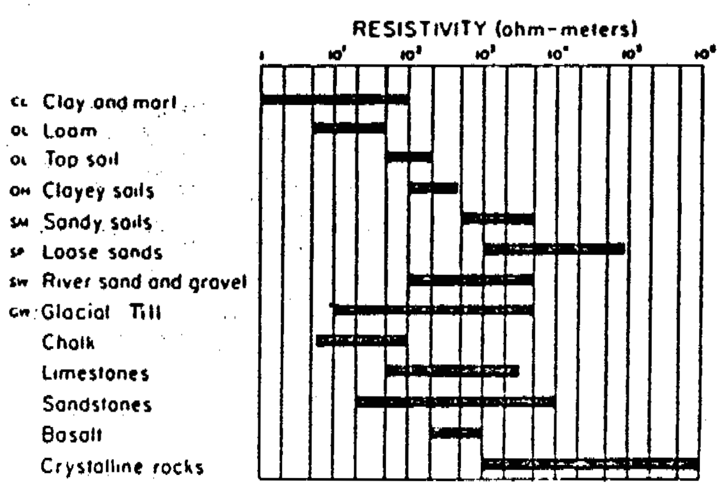


Figure 1: b) Resistivity ranges for typical soils. (Scott and Maxwell, 1989)

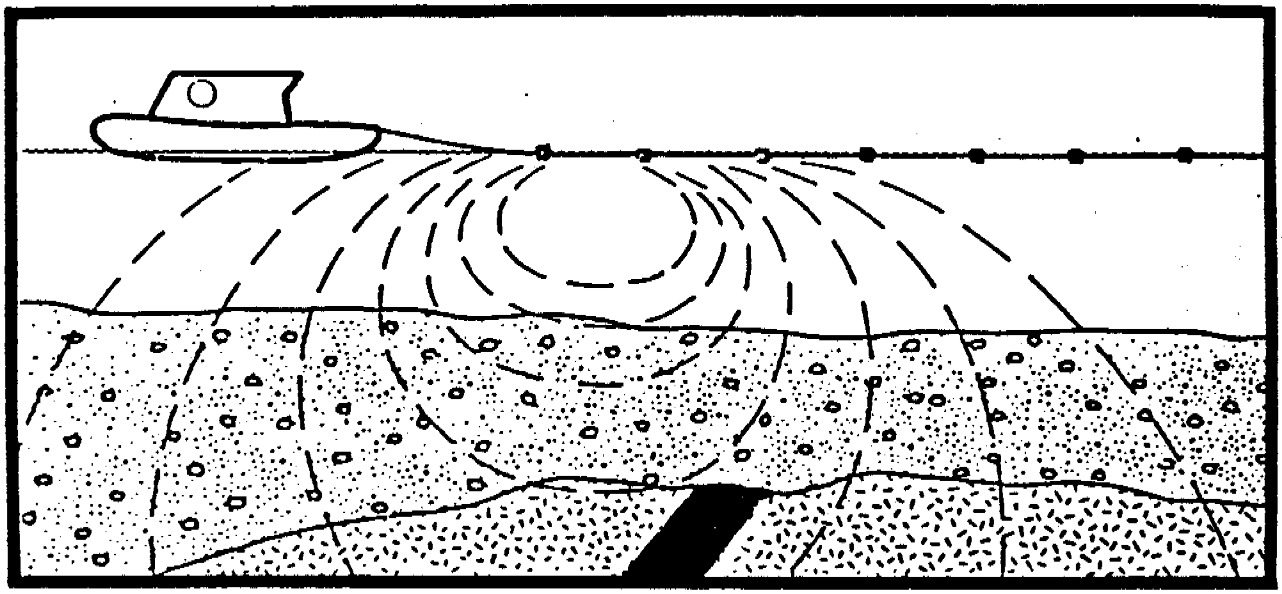


Figure 2: Schematic layout of MICRO-WIP marine resistivity system.

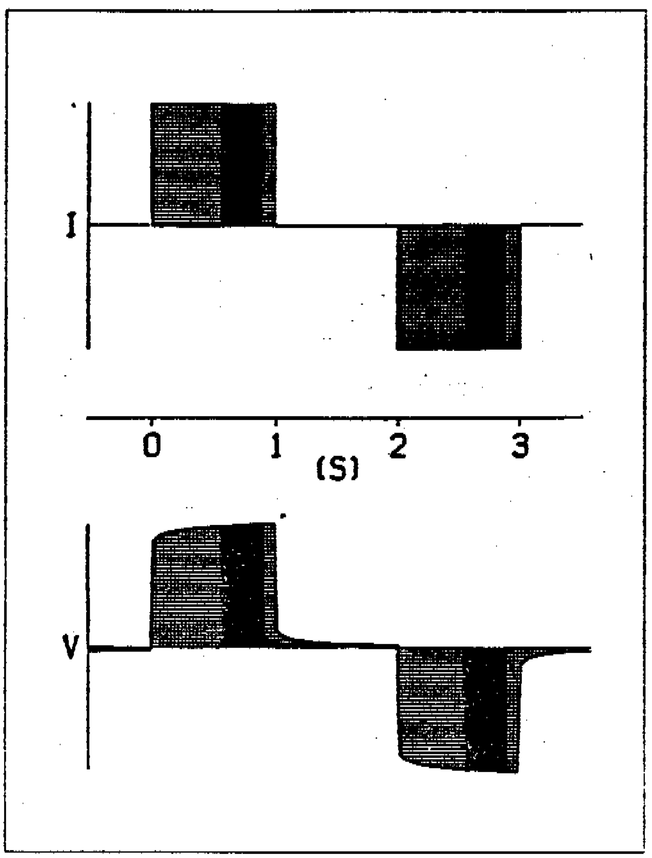


Figure 3: Waveforms of current and voltage, showing measurement windows. (Scott and Maxwell, 1989)

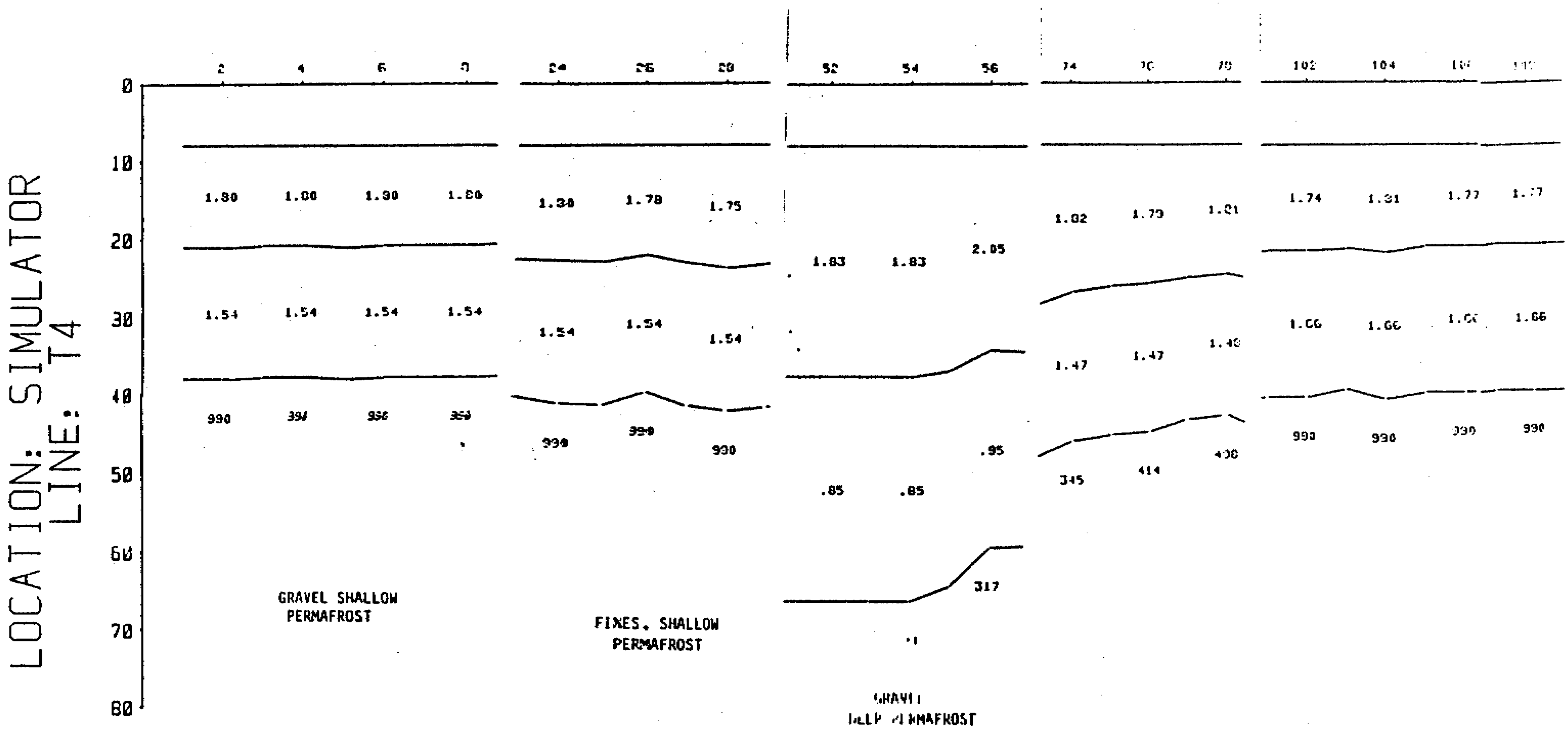


Figure 4: Parts of real-time inversion results from simulator run.

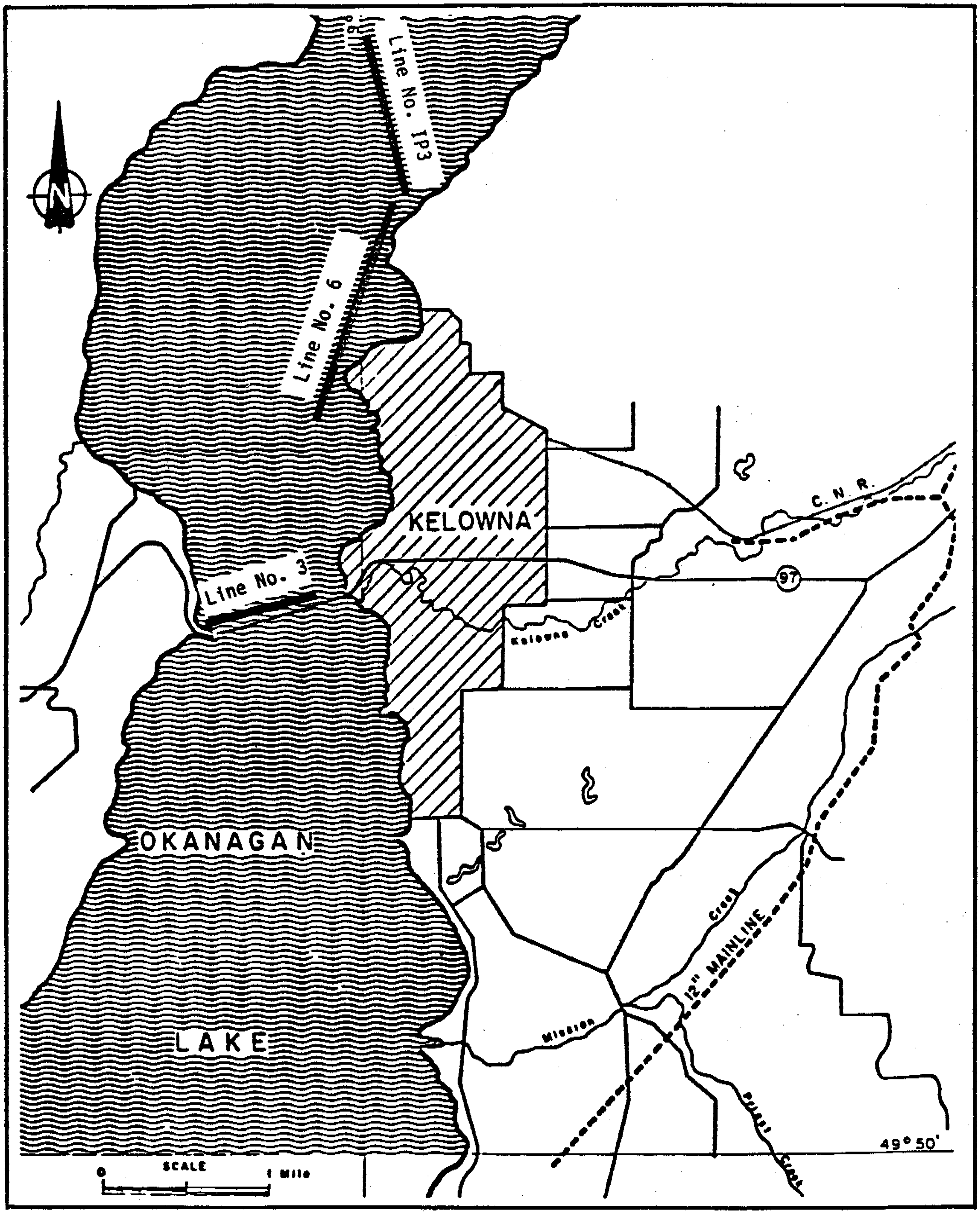


Figure 5: Okanagan Lake, showing survey lines for field trial.

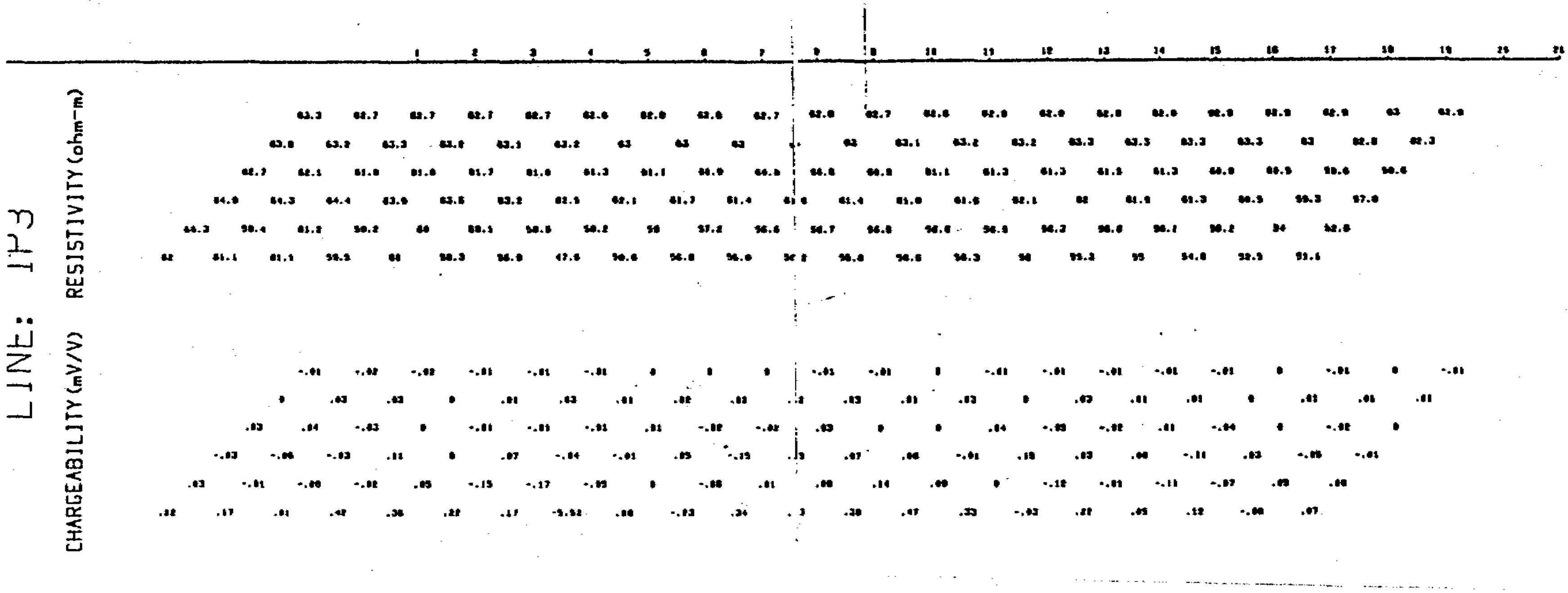


Figure 6: a) Pseudosection plotted in real time for line IP3.

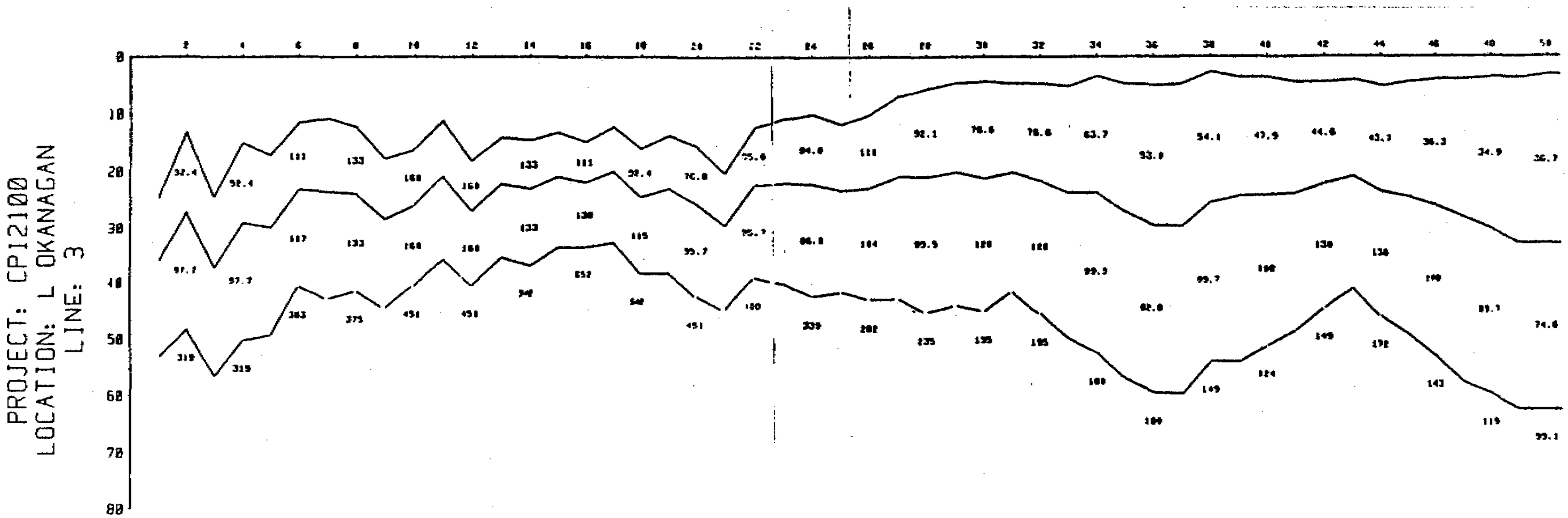


Figure 6: b) Part of Line 3 in Okanagan Lake, with result of real-time inversion of resistivity data.

POTENTIAL SITES FOR GRANULAR RESOURCES OFF THE SOUTHWEST COAST OF BANKS ISLAND, N.W.T.

Guy R. Fortin
H.R. Seismic Interpretation Services Inc.
4165 des Berges Street
Cap-Rouge (Qc)
G1Y 1L6

INTRODUCTION

Despite long sailing distances from present hydrocarbon exploration sites in the central Baufort Sea, the narrow shelf bordering the southwestern coast of Banks Island has been identified by the department of Indian and Northern Affairs Canada (INAC) as a prospective area for gravel deposits. Although O'Connor (1983) indicated that more than 50 000 000 m^3 of gravel may exist at suitable depth for dredging between Cape Lambton and Sachs Harbour (Fig. 1), the granular resources in this area remain largely unexplored. Between 1981 and 1983, three separate geophysical programs have been carried out by the industry to investigate the surficial geology for gravel deposits off the island coast. The results of two site specific surveys conducted in 1981 and 1982 at the mouth of the Masik and Rufus rivers have been reported to Dome Petroleum by Fortin (1982 and 1984; Fig.1). A detailed evaluation of the regional survey completed in 1983 was prepared by Fortin (1987) on behalf of INAC (A4 NOGAP project; subproject A4-16). The regional survey includes six lines totalling 130 km of seismic data (echo sounder, side scan sonar, subbottom profiler, boomer and air gun systems) recorded in water depths oscillating between 10 and 25 m. The present paper summarizes the findings of the 1983 regional survey. This information was presented with more details in Fortin (1987) who constructed three synoptic plates showing both onshore and offshore geology (Plates I, II and III; Fig. 1).

ONSHORE GEOLOGY (Vincent, 1983)

The surficial geology of the coast is dominated by morainal deposits that include three distinct glacial till sheets: the Bernard, the Sachs and the

Carpenter tills (Table 1 and Fig. 2). The Bernard Till (Unit 2; Fig. 2) covers extensive areas of the western region of Banks Island and is present north of Sachs Harbour. This deposit is relatively thin (1-10 m) and comprises a fine-grained matrix. The distribution of the Sachs Till (Unit 12; Fig. 2) has been particularly well established in the Sachs Harbour and Masik River areas. The Sachs Till is thin (1-2 m) and includes a sandy matrix with a high fraction of sediments coarser than 2 mm. The Carpenter Till (Unit 15; Fig. 2) extends along the coast between Masik River to the south and Middle Lake to the north. The Carpenter Till is characterized by a sandy and rocky matrix, as well as a significant proportion of gravel and rock fragments. Of particular interest is the "young" morphology of the Carpenter Till which consists of crests of till and ice contact deposits oriented parallel to the coast and separated by kettles. The main till properties are summarized in Table 1. In the nearshore area, deposits of borrow materials may originate from erosion and reworking of these three till units, as well as from undifferentiated Quaternary deposits (Unit 1; Fig. 2) that include stratified sand and gravel deposited by glacial meltwater at the mouth of the Masik River.

TABLE 1. TILL PROPERTIES

TILL UNITS	N	GRAIN SIZE (%)				CHARACTERISTICS
		>2mm	sand	silt	clay	
Bernard Till (Unit 2, Fig. 2)	34	28.7	45.0	33.0	22.0	Blackish colour & fine matrix. Fraction >2mm : high proportion of sedimentary rocks (carbonates, sandstones and chert), small proportion of igneous rocks (diabase & gabbros).
Sachs Till (Unit 12, Fig. 2)	3	50.7	61.4	21.8	16.8	Ligh colour, sandy matrix & high fraction > 2mm. Fraction > 2mm : mainly sedimentary rocks (carbonates & sandstones), higher proportion of gabbros than other tills.
Carpenter Till (Unit 15, Fig. 2)	1	38.6	46.5	32.2	21.3	Sandy & rocky matrix. Fraction > 2mm : high proportion of gravel & diabase rock fragments. Granitic rocks within the till.

Note: - N : Number of samples.

DISCUSSION ON OFFSHORE BORROW PROSPECTS

The procedure used to predict the occurrence of aggregate deposits near the seabed is mainly based on qualitative interpretations of seismic data as only six sediment samples were taken along the survey lines. For this reason, the geological inferences propose herein may not be exact at specific sites since only a detailed seabed sampling program can confirm the presence and extent of borrow deposits.

Given the limitations inherent to the dredging techniques used at the present time and in the foreseeable future, eleven target areas have been identified as borrow prospects (Fig. 2 and Table 2). Several of the promising sites (high or fair priority) appear to coincide with offshore extensions of the Sachs Till or Bernard Till and their associated morainic system (Sites B, C, E, J and K). These relatively old deposits may have been reworked at several times in the past which would have resulted in pockets of well sorted materials lying on a flat seafloor (Fig. 3). Another high priority site (Site A) may include glaciofluvial sand and gravel deposited at the mouth of the Masik River. Although gravel resources are likely associated with the offshore extension of the Carpenter Till, this type of deposits (Site D) has a low potential as a result of its high seabed relief, its young appearance (little reworking), and the presence of numerous erratics (Fig. 4).

Recommendations for follow-up studies (Table 2) are made on a site specific basis in order to improve our understanding of the geological setting of each individual borrow prospect and to determine the extent and quality of the granular deposits. In addition, the portion of the shelf between Middle Lake and Mary Sachs Creek is designated for future regional investigations.

CONCLUSION

Based on the available acoustical data and a very limited amount of bottom samples, one may conclude that the potential for gravel deposits is important between the mouth of the Masik River and Duck Hawk Bluff (Fig. 2). However, the very uneven seafloor relief in certain areas (Carpenter Till) and the complexity of stratigraphic conditions encountered in several places present challenging environmental obstacles to the safe and efficient dredging of these granular resources. In addition, development of these patchy deposits will require accurate horizontal control systems aboard the dredges. The potential for gravel in the surveyed area off Cape Kellett Spit appears to be low because of both the presence of a fine- to medium-grained (silt and fine sand) surficial layer covering this area and the absence of source deposits (till units) for very coarse materials.

With respect to the complex geology, great diversity of source deposits, poor seismic coverage and near absence of ground-truth information, there is an obvious need for both additional high-resolution seismic reflection and refraction data. These surveys will serve to position bottom sediment samples and shallow boreholes at critical locations in order to determine the quality and exact thickness of the granular deposits.

REFERENCES

FORTIN, G. R. (1982). Marine Bottom and Subbottom Survey, Banks Island Borrow Site, Beaufort Sea. Report submitted to Dome Petroleum Ltd by Geoterrex Ltd, Project No. 93-15.

__________ (1984). Marine Bottom and Subbottom Survey, Banks Island Gravel Search. Report submitted to Dome Petroleum Ltd by Geoterrex Ltd, Project No. 93-28.

__________ (1987). Interpretation and Synthesis of High Resolution Reflection Seismic Data from Banks Island Borrow Area. Report submitted to Dept. of Indian Affairs and Northern Development by H.R. Seismic Interpretation Services Inc, Project NOGAP A4; subproject A4-16.

O'CONNOR, M.J. (1983). Regional Inventory of Offshore Gravel Prospects, Canadian Beaufort Sea. Report submitted to Dept. of Indian Affairs and Northern Development by M.J. O'Connor & Associates.

VINCENT, J.-S. (1983). La Géologie Quaternaire et la Géomorphologie de l'Ile Banks, Arctique Canadien. Commission Géologique du Canada, Mémoire 405, 118 pp.

TABLE 2. SUMMARY TABLE OF OFFSHORE BORROW PROSPECTS

SITE	PRIORITY	PROGNOSTIC	CONSTRAINTS TO FUTURE DEVELOPMENT	RECOMMENDED FUTURE STUDIES[1]				
				Sample	Geo.	Mosaic	Photo	Drill
"A"	HIGH	Large volume of well sorted materials (fluvioglacial deposits?).Reworked sand with some gravel.	Shallow gas might cause difficulties during drilling of deep holes.	(1)	(2)	---	---	(3)
"B"	HIGH	Fair volume of patchy materials (sand & gravel). Till (Sachs?) outcrops. Erratics.	Number of erratics (cobbles & boulders) near seabed may increase toward the Sachs Till outcrops.	(1)	(2)	(3)	(4)	(5)
"C"	FAIR	Small volume of thin patches of reworked materials (sand & gravel) atop a till (Sachs?) surface. Frequent erratics.	Frequent outcrops of a old till surface (poor sorting, high compaction, possibly ice-bearing). Numerous erratics visible on sonograph. Proximity of the coast.	(1)	(2)	(3)	(4)	(5)
"D"	LOW	Reworked materials originating from a young till sheet (Carpenter Till?). Westward fining facies change.	Irregular seafloor. Erratics may be common.Till outcrop (poor sorting,high compaction, possibly ice-bearing). Proximity to the coast.	(1)	(2)	(3)	(4)	(5)
"E"	FAIR	Patches of reworked sand with some fine gravel. Frequent outcrops of a fine-grained till (Sachs or Bernard Till?).	Frequent outcrops of a till surface (poor sorting, high compaction, possibly ice-bearing). Patchy nature of good granular materials. Possible presence of erratics. Proximity to the coast.	(1)	(2)	(3)	---	(4)
"G"	LOW	Thin veneer of reworked sand with some gravel. Fining facies change away from the source deposit (fine-grained till?).	Occurrence of till outcrops that may include fine-grained units, highly compacted and ice-bearing sediments.	(1)	(2)	(3)	---	(4)
"H"	LOW	Thin veneer of reworked sand with some gravel originating from an old till unit (Sachs or Bernard Till?)	Occurrence of till outcrops that may include fine-grained units, highly compacted soils and ice-bearing sediments. Marginal volume of borrow.	(1)	(2)	(3)	---	(4)
"I"	LOW	Lag deposit? Submerged coastal feature?	Geologic origin not well established. Marginal potential?	(1)	(2)	---	---	(3)

"J"	FAIR	Thin veneer of reworked sand with some gravel originating from an old till unit (Sachs or Bernard Till?).	Frequent outcrops of a fine-grained till (Sachs or Bernard Till?) that may include a variety of lithologies, highly compacted soils and ice-bearing sediments.	(1)	(2)	(3)	---	(4)
"K"	HIGH	Large volume of reworked sand and gravel originating from a frontal moraine (Sachs Till?).	No serious constraints.	(1)	(2)	---	---	(3)

NOTES: [1] The recommended future studies should not be conducted simultaneously, but in the order shown. One should proceed with the next step only if the results of the previous step(s) dictate additional works.

SAMPLE: Seabed sampling (grab samplers and corers).
GEO.: Detailed geophysical program including: precision bathymetry, side scan sonar, subbottom profiler, Uniboom and deep-tow refraction data.
MOSAIC: Preparation of a seafloor mosaic from side scanning imagery.
PHOTO: Seabed photographs and/or video, diving.
DRILL: Shallow geotechnical drilling.

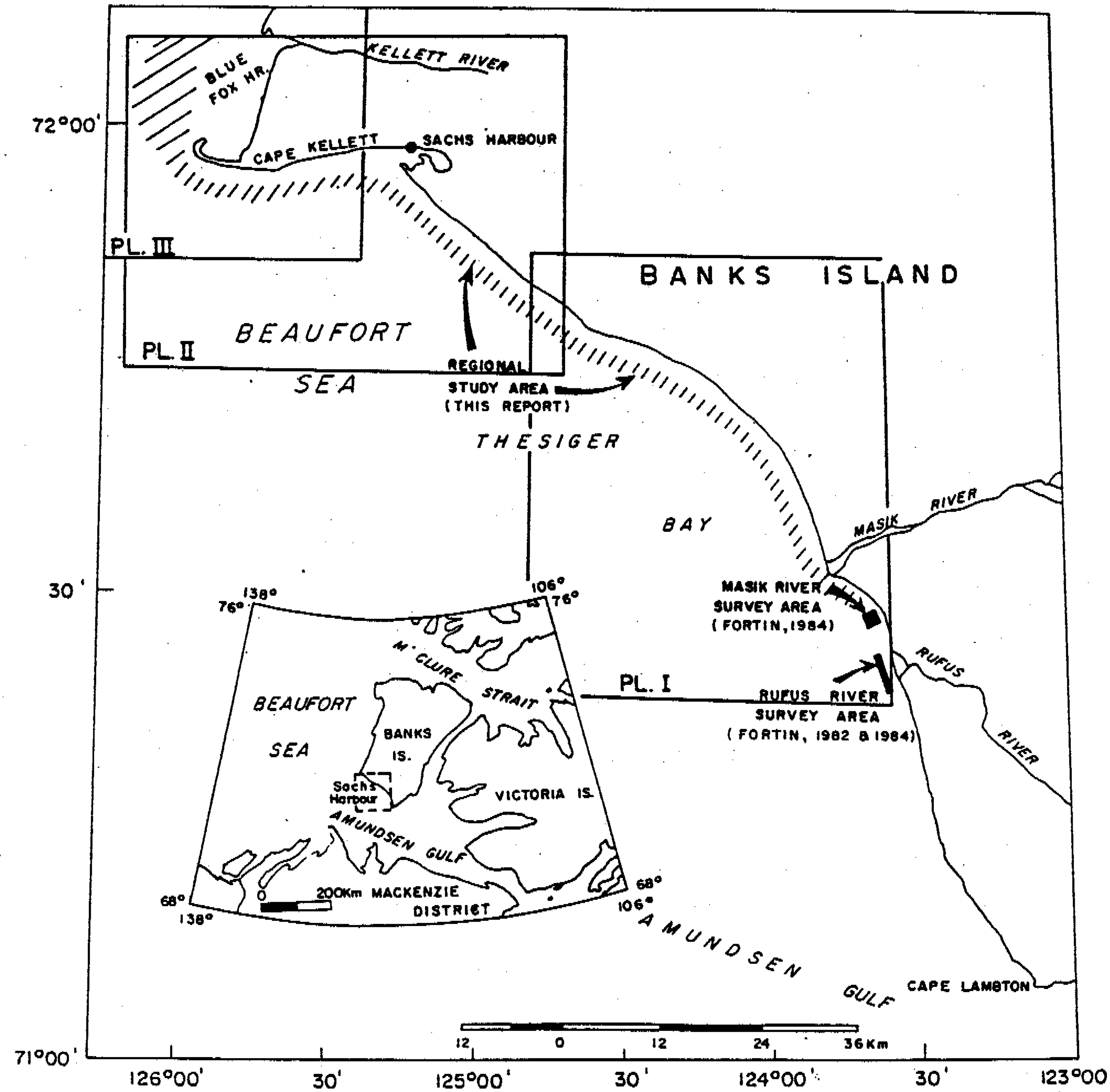


FIG. 1 LOCATION MAP

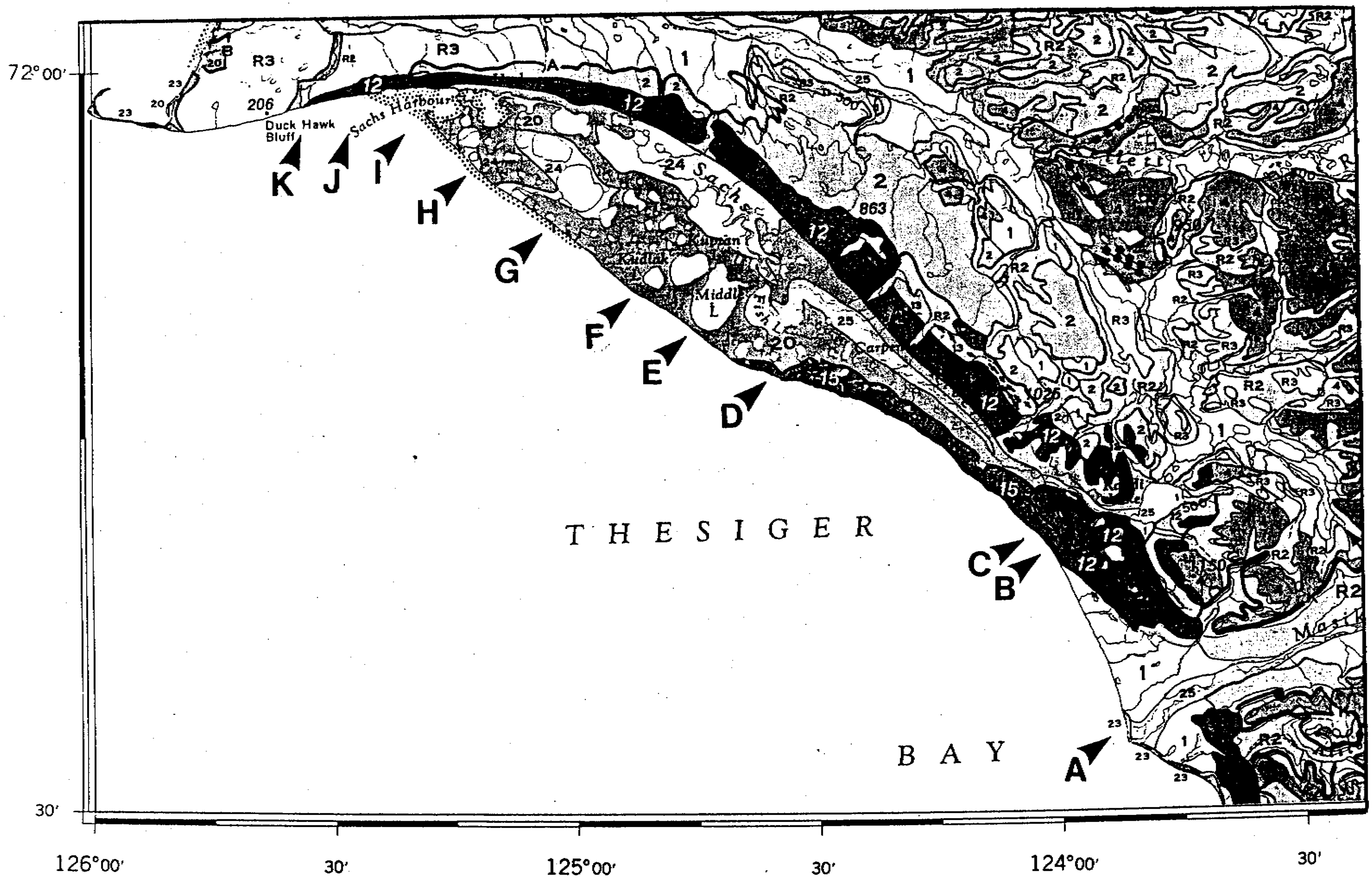


Figure 2. Onshore geology (Vincent, 1983) and approximate location of offshore borrow prospects (Fortin, 1987).

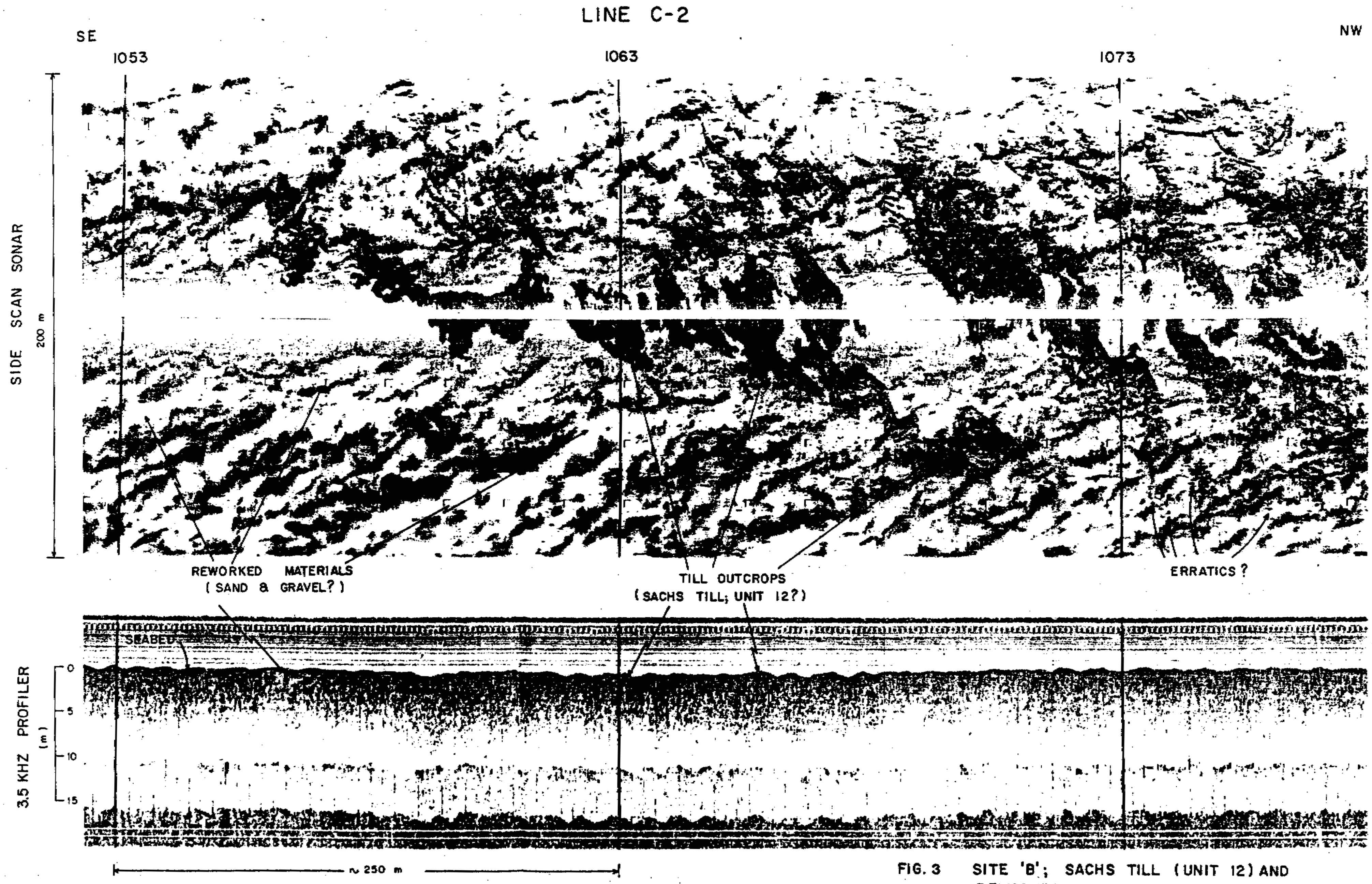


FIG. 3 SITE 'B'; SACHS TILL (UNIT 12) AND REWORKED MATERIALS.

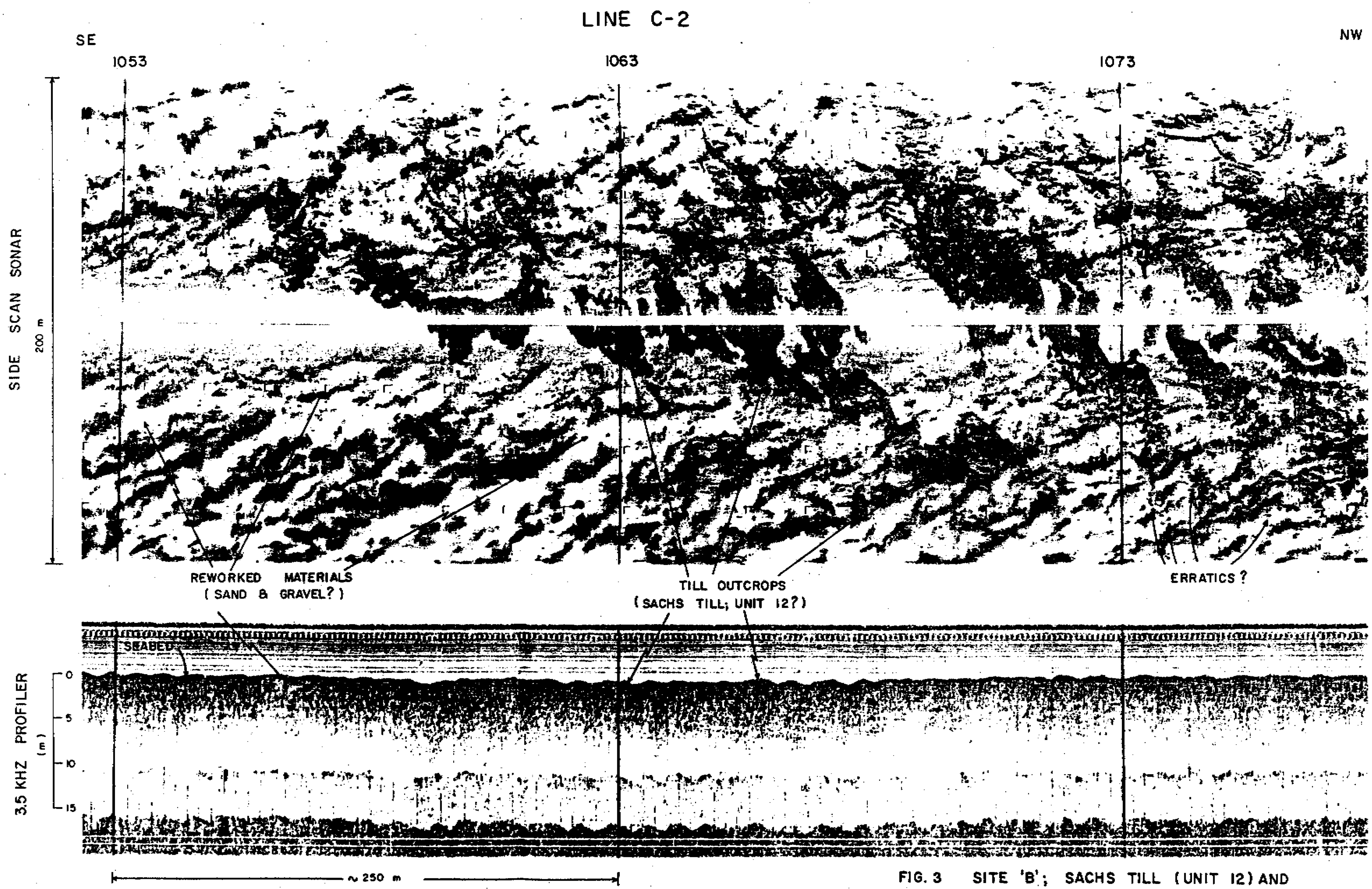


FIG. 3 SITE 'B'; SACHS TILL (UNIT 12) AND REWORKED MATERIALS.

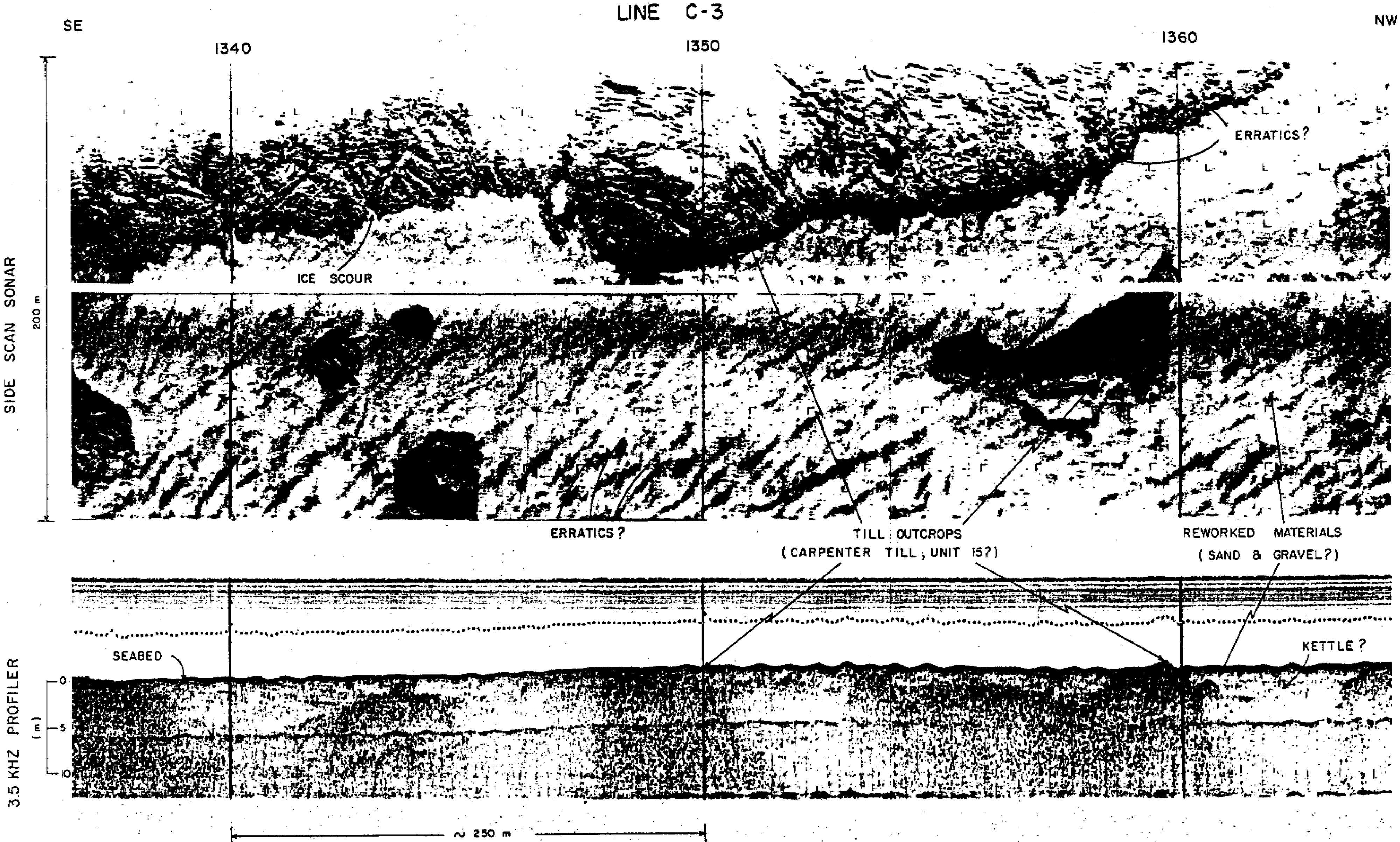


FIG.4 CARPENTER TILL (UNIT 15) AND REWORKED MATERIALS.

NORTHERN GRANULAR RESOURCES MAPPING INFORMATION SYSTEM

John Peters

Earth & Ocean Research Limited
Dartmouth, Nova Scotia

1.0 INTRODUCTION

Indian and Northern Affairs Canada has over the past four years compiled an extensive inventory of information pertaining to granular resources in the Arctic.

Funded under the NOGAP programme, the project has evolved from a digital inventory of high resolution marine seismic track line data, to digital renditions of interpreted geological maps, borehole locations, borrow sites and the encapsulation of all of this data into a user-friendly data management and desktop mapping system called **inFOcus**.

This paper describes the development of the inventory, its contents, and the way that the data can be used to assess and plan activities through the simple and powerful interface provided by the **inFOcus** software.

2.0 PROJECT HISTORY

The Arctic Granular Resources Inventory started in 1988 with the compilation and conversion into digital form of industry and government regional and site survey track lines. A large body of hard copy shot point maps, and some digital shot point data, were digitized and converted into the format for INAC's mapping system.

It was clear that effective use of the inventory would require its organization within a geographic information system (GIS). However, it was recognized that GIS is not an appropriate technology for inventory applications, especially considering the high capital, training and maintenance costs that are associated with this technology. In 1990, EOR proposed the assembly of the inventory within **inFOcus**, a simple, inexpensive data management and mapping system well suited to interrogating and visually overlaying diverse geo-referenced data sets.

All of the track data compiled to date, the Beaufort borehole database and a body of interpreted geological maps were imported into **inFOcus**.

The inventory was expanded in 1991 to include a graphical database of on-land borrow sites digitized from aerial photographs. Further work is currently in progress to update the seismic tracks, build on the borrow sites inventory, and to provide linkages to the ESE-BASE borehole management system that contains a comprehensive borehole geotechnical database.

3.0 THE INVENTORY

Below is a summary of the inventory as it has so far evolved.

3.1 High resolution marine seismic track lines

Over 1500 track lines spanning 29000 line-km have been digitized and imported into **inFOcus**. These comprise:

All government lines surveyed up to and including 1986 - 355 lines covering 14000 line-km.

All regional lines shot by ESSO, GULF and DOME to the end of 1986 - 581 lines covering 12000 line-km.

All site survey lines shot by GULF and DOME in the ISSERK and ERK-SAK borrow blocks. This consists of 9 out of a total of 19 surveys conducted by GULF in the region up to 1986; and 12 out of a total of 40 conducted by DOME. None of the site surveys conducted by ESSO have been digitized.

This is not a navigation database. The intent is to be able to assess coverage, especially in the context of other information such as borehole locations and the distribution of geological units, bathymetry, lease boundaries etc. In most cases, a sufficient number of shot points have been digitized to define way points and to correlate shot point ranges to a particular geographic area.

It is now realized that digitized track lines within site surveys is overkill, and that the outline of the survey area would be just as useful. The study catalogue compiled by McElhanney in 1988 provides coordinates of the study areas. This database has been imported into **inFOcus**, and outlines of survey areas can be plotted for all studies completed up to the end of 1986.

3.2 Boreholes, grabs and cores

All borehole sites compiled up to 1988, updated to 1990 and supplemented with vibracore and grab sites, are accessible within the **inFOcus** system. Summary attributes, such as hole id, owner, drill depth etc. are contained within each record, and can be accessed directly from the map of hole locations.

It is planned to import the full geotechnical database compiled by EBA, so that selections of holes for map display can be based on a broad range of geotechnical search criteria.

3.3 Geological maps

Geological maps associated with detailed studies of granular resources in the Isserk and Erksak borrow blocks have been imported into the **inFOcus** system. These include data control, bathymetry, isopachs of geological units and interpreted resource potential maps. These can be overlayed with one another or with seismic and borehole database information for further analysis.

In 1991, geological maps associated with additional studies in the Herschel and Banks Island regions were digitized and imported into the system.

3.4 Borrow sites

A major part of the 1991 inventory project was the contruction of a graphical database of on-land borrow sites. Source data for most of the entries were aerial photographs at approximately 1:36000 scale. Outlined deposits were digitized and linked to database records containing attribute information such as site id, resource type, geologic origin etc. Site plan inventories have been compiled into **inFOcus** for the following areas:

Mackenzie Valley
Alaska Highway corridor
Dempster Highway corridor
South Slave area
Inuvialuit Settlement area
Individual communities such as Fort Good Hope and Fort McPherson.

4.0 DATA MANAGEMENT AND RETRIEVAL

The Northern Granular Resources Mapping Information System provides a comprehensive inventory of deposit, borehole, seismic and geological information. These data can be displayed as maps and printed or plotted in various projections and at any scale.

The data are organized into "applications" focussing, for example, on seismic data or borrow sites or a particular geographic region. The data management subsystem provides the full capabilities of a relational database management system within a "point and click" non-technical user interface. The user is presented with menus of "English" descriptions of data sets or maps instead of file names, and can contruct using a mouse:

- complex queries without a knowledge of command syntax.
- reports based on hard-wired or custom formats
- maps consisting of multiple overlays such as bathymetry, isopachs, borehole locations and seismic coverage.

Several screens follow this text which show the data management interface and some example maps printed on a laser printer at low resolution. High quality figures can be produced on high resolution laser printers and plotters.

5.0 CURRENT ACTIVITIES

Planning is in progress to expand and refine the inventory. The following aspects are being considered:

- update of the high resolution marine seismic coverage
- expansion of the on-land borrow site inventory
- import of the Yukon Shelf regional geology study
- refinement of database structures and cross-linkages
- enhancement of the applications through improved data organization, customized queries and reports.
- development of procedures to report and update inventory statistics.

The aim in the present project is to provide a fully operational planning tool for granular resource management in the North. In support of this several new initiatives also should be considered for future work.

6.0 FUTURE INITIATIVES

Presently, the basemap for the inventory data is derived from the 1:2000000 scale CIA world data bank. For many applications, detailed cultural and topographic information will be vital. A first step would be to import the 1:250000 NTS series digital basemaps for all or specific regions of the North. All of the maps are available for import into **inFOcus**. An example of these maps is provided for the area covering western Yukon.

The offshore equivalent is regional bathymetry for the Beaufort Sea. Subsets of the region are available in digital form from Canadian Hydrographic Service. Howver, a uniform scale coverage at 1:1000000 scale, for example, would be of major benefit for many applications.

Any resource development and management plan must consider information related to jurisdiction, land ownership and control, environmental impact, and development infranon-technical user interface. The user is presented with menus of "English" descriptions of data sets or maps instead of file names, and can contruct using a mouse:

- complex queries without a knowledge of command syntax.
- reports based on hard-wired or custom formats
- maps consisting of multiple overlays such as bathymetry, isopachs, borehole locations and seismic coverage.

Several screens follow this text which show the data management interface and some example maps printed on a laser printer at low resolution. High quality figures can be produced on high resolution laser printers and plotters.

5.0 CURRENT ACTIVITIES

Planning is in progress to expand and refine the inventory. The following aspects are being considered:

- update of the high resolution marine seismic coverage
- expansion of the on-land borrow site inventory
- import of the Yukon Shelf regional geology study
- refinement of database structures and cross-linkages
- enhancement of the applications through improved data organization, customized queries and reports.
- development of procedures to report and update inventory statistics.

The aim in the present project is to provide a fully operational planning tool for granular resource management in the North. In support of this several new initiatives also should be considered for future work.

6.0 FUTURE INITIATIVES

Presently, the basemap for the inventory data is derived from the 1:2000000 scale CIA world data bank. For many applications, detailed cultural and topographic information will be vital. A first step would be to import the 1:250000 NTS series digital basemaps for all or specific regions of the North. All of the maps are available for import into **inFOcus**. An example of these maps is provided for the area covering western Yukon.

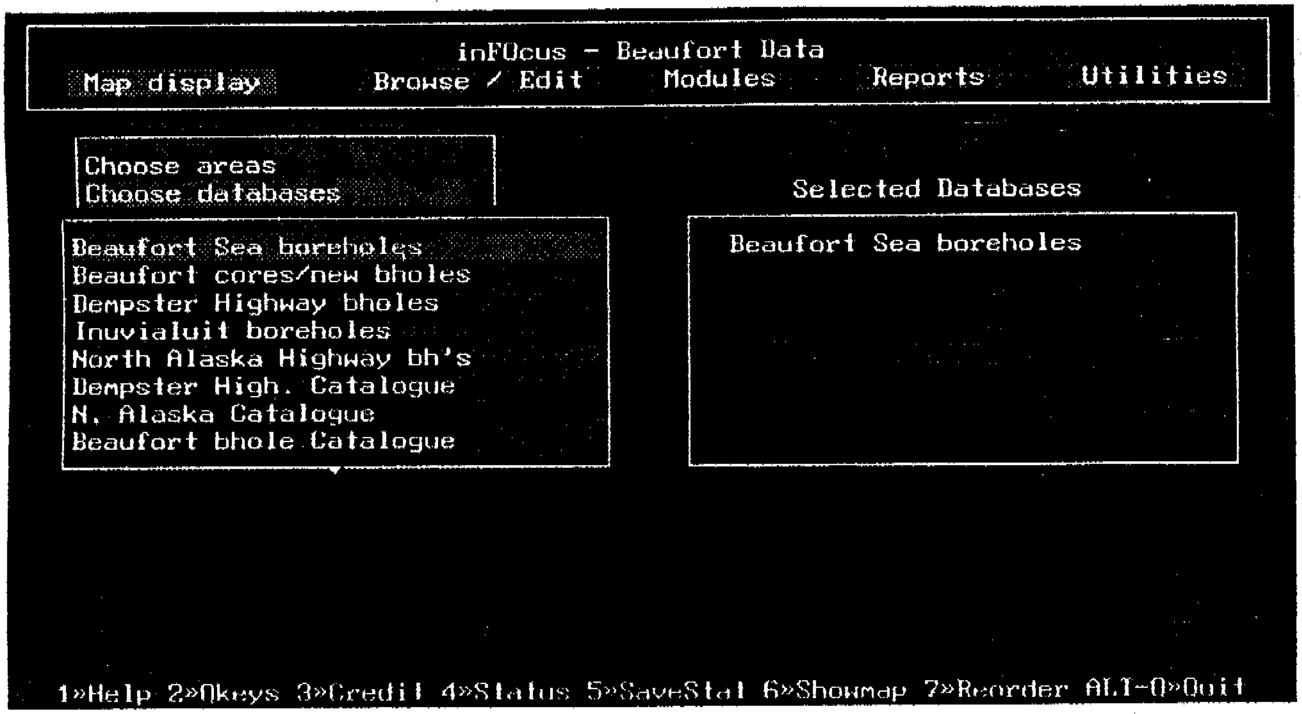
The offshore equivalent is regional bathymetry for the Beaufort Sea. Subsets of the region are available in digital form from Canadian Hydrographic Service. Howver, a uniform scale coverage at 1:1000000 scale, for example, would be of major benefit for many applications.

Any resource development and management plan must consider information related to jurisdiction, land ownership and control, environmental impact, and development infrastructure. The Northern Granular Resource Mapping Information System lends itself to integration with these types of data. **inFOcus** applications have developed elsewhere that integrate geological, fishery, environmental, cultural and land use data that are used together to target resource conflicts and environmental sensitivities. Examples are:

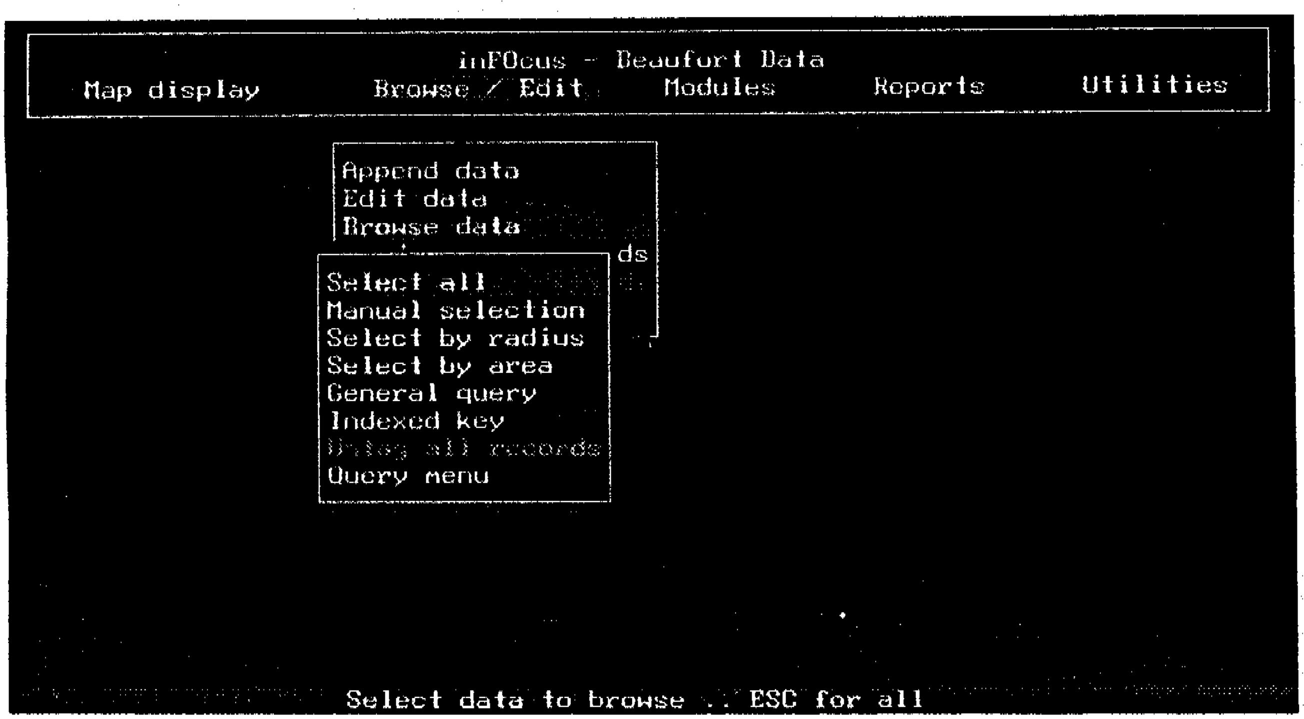
IRMIS (Integrated Resource Management Information System) for offshore Prince Edward Island
IRMIS for coastal zone Nova Scotia
NATLUS - the national protected lands database

New and existing land use and environmental databases should be imported into the system and routine procedures developed to address common planning issues in a timely fashion. One of the compelling advantages of the **inFOcus** approach is its low cost and high user accessability. Data can be delivered to all users easily.

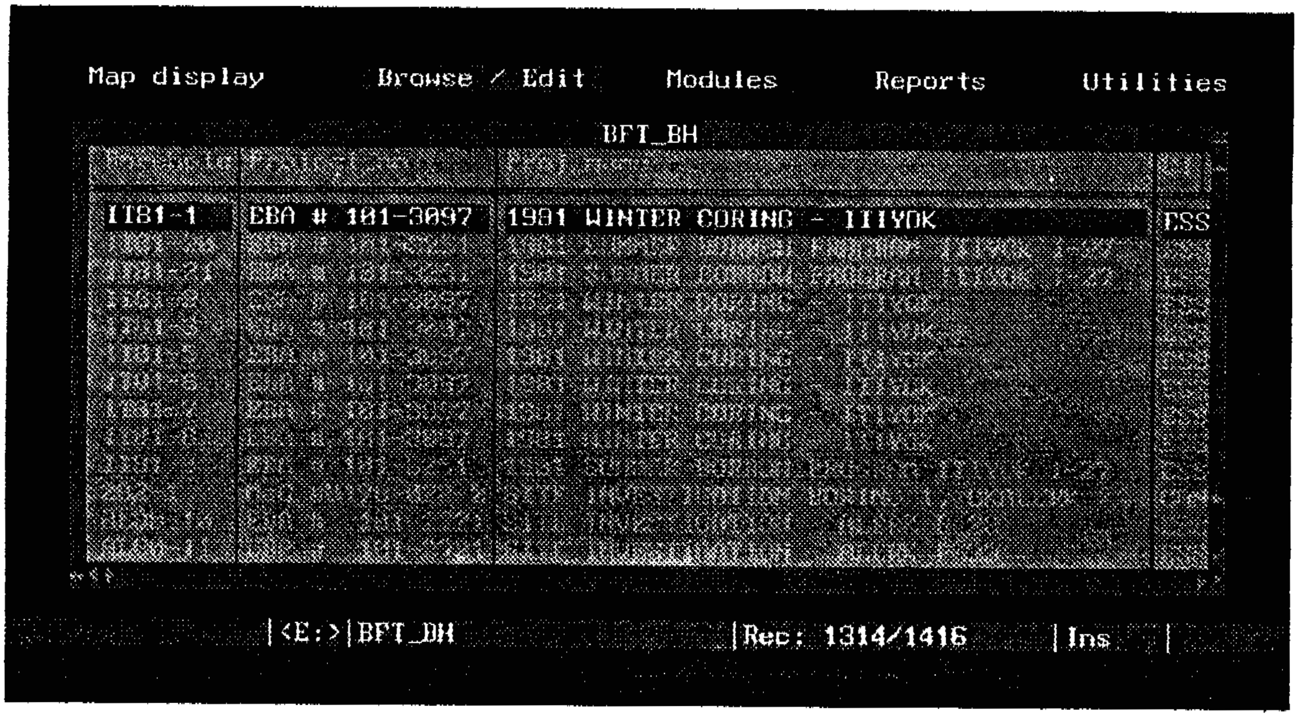
Effective planning and advocacy for resource development is dependant on the ability for all interested groups to share and comprehend the same data. One example is the promotion of the NATLUS application by the mining industry. On the one hand, it provides a tool for the industry to assess land access restrictions. On the other, it will provide native peoples and jurisdictions a clear picture of their rights and responsibilies. All parties will be able to argue their agendas based on the same information. This approach will become critical for all aspects of resource development in the North.



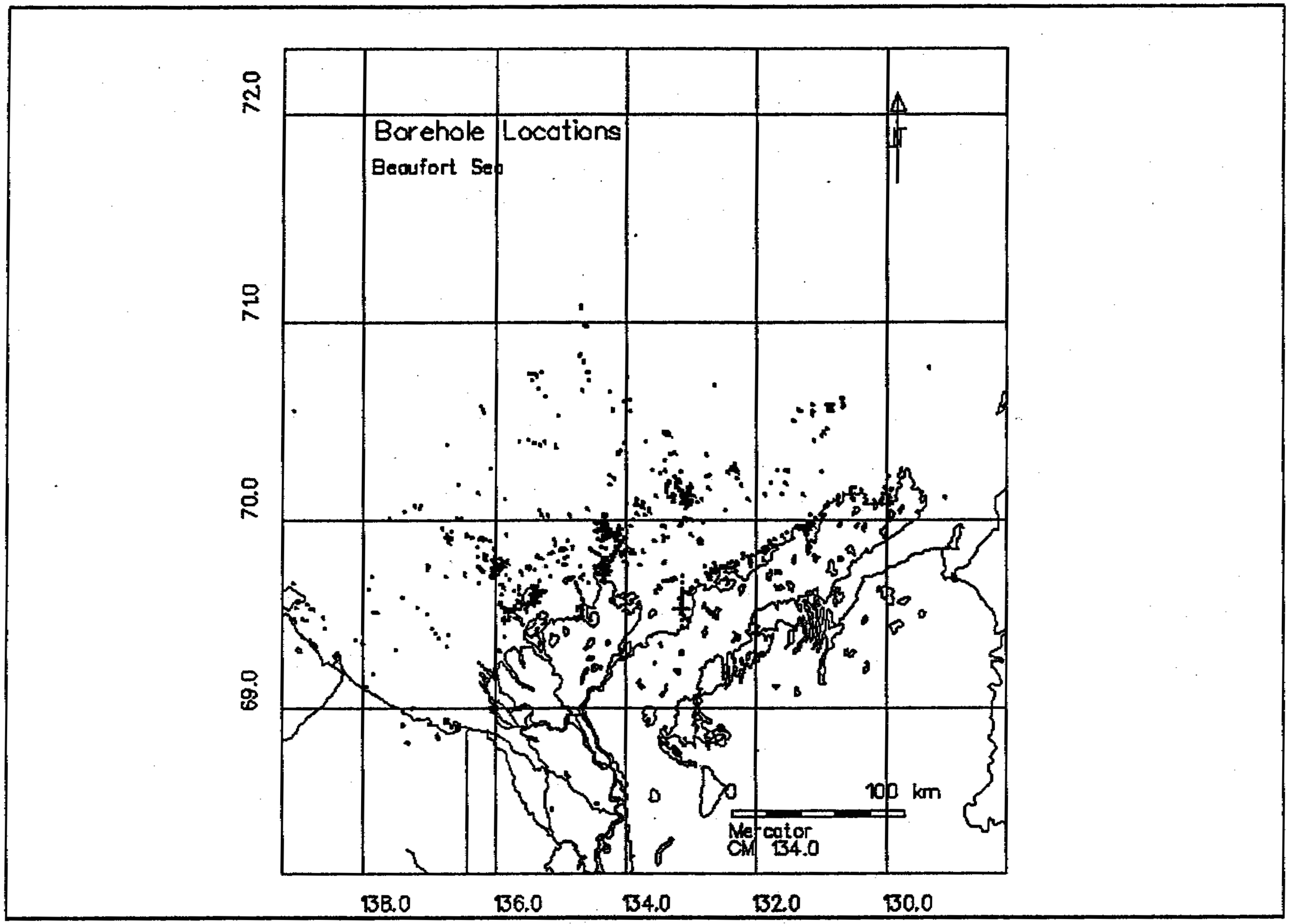
Databases menu in inFOcus. Databases are referred to by "English" aliases, thus insulating the end user from the need to remember cryptic filenames.



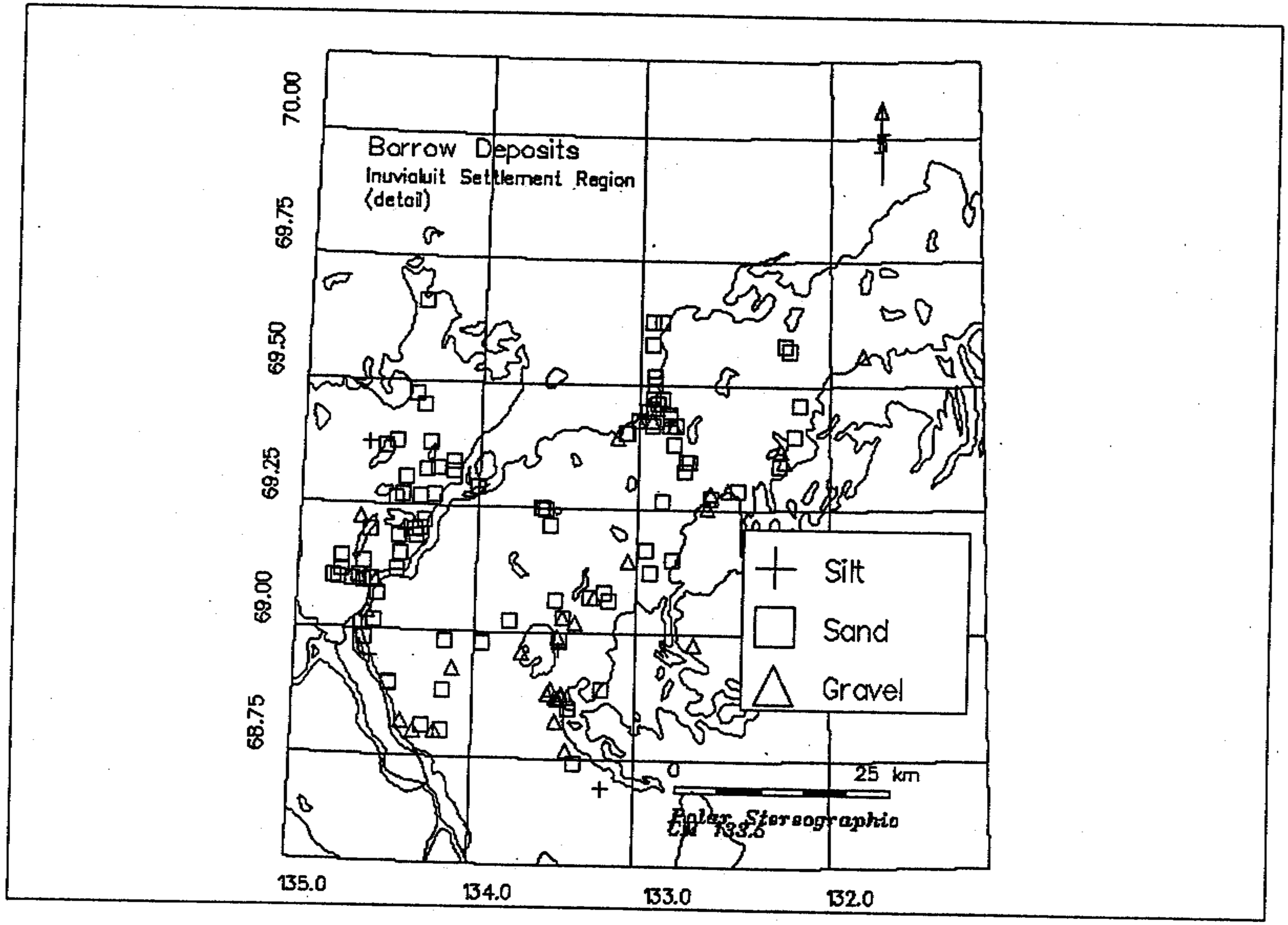
Databases can be searched in a variety of routine ways, in addition to general queries that are constructed through a mouse driven query interface.



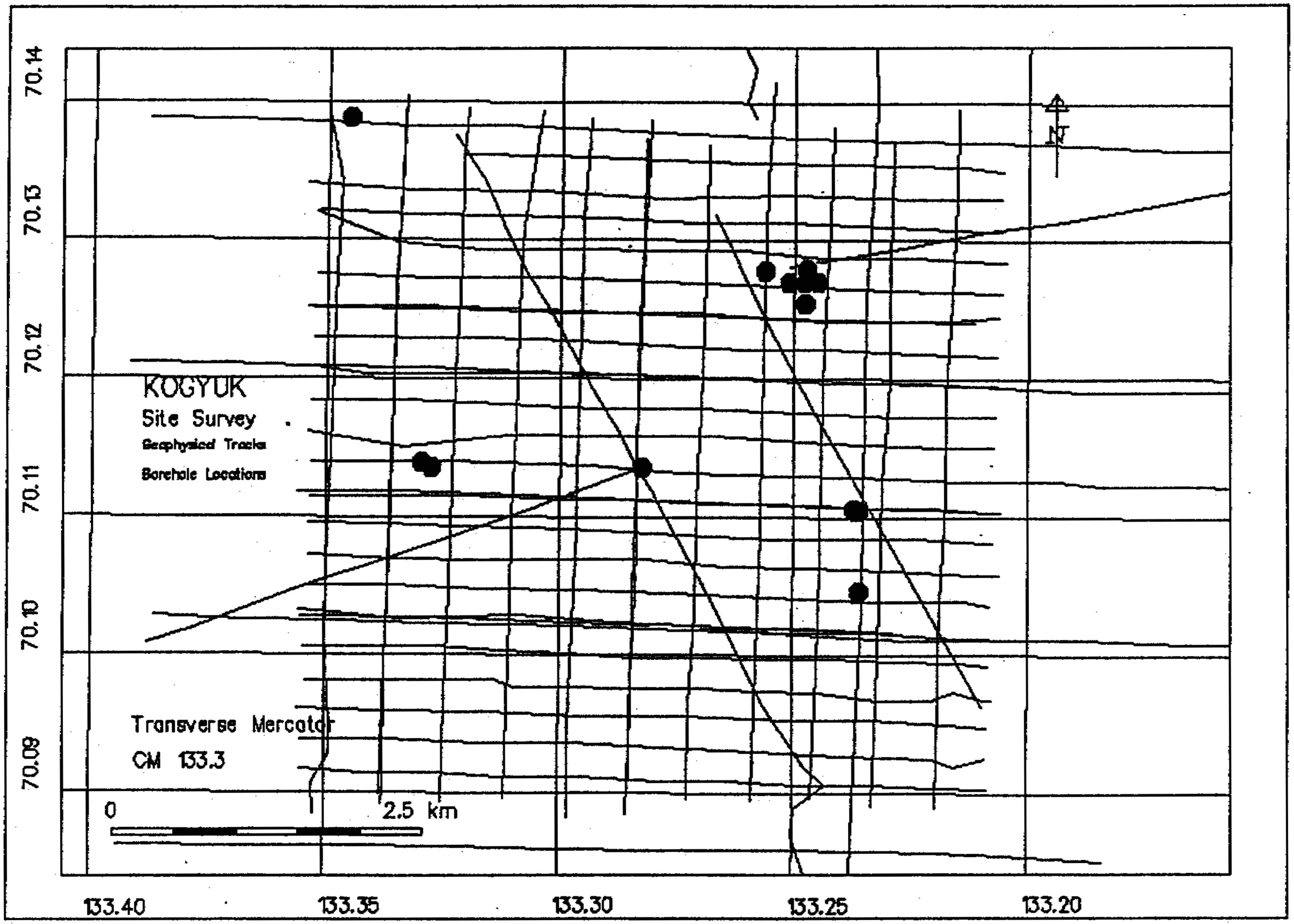
The results of queries can be browsed within a movable, sizeable browse window. Here the 1416 boreholes compiled to 1988 are shown.



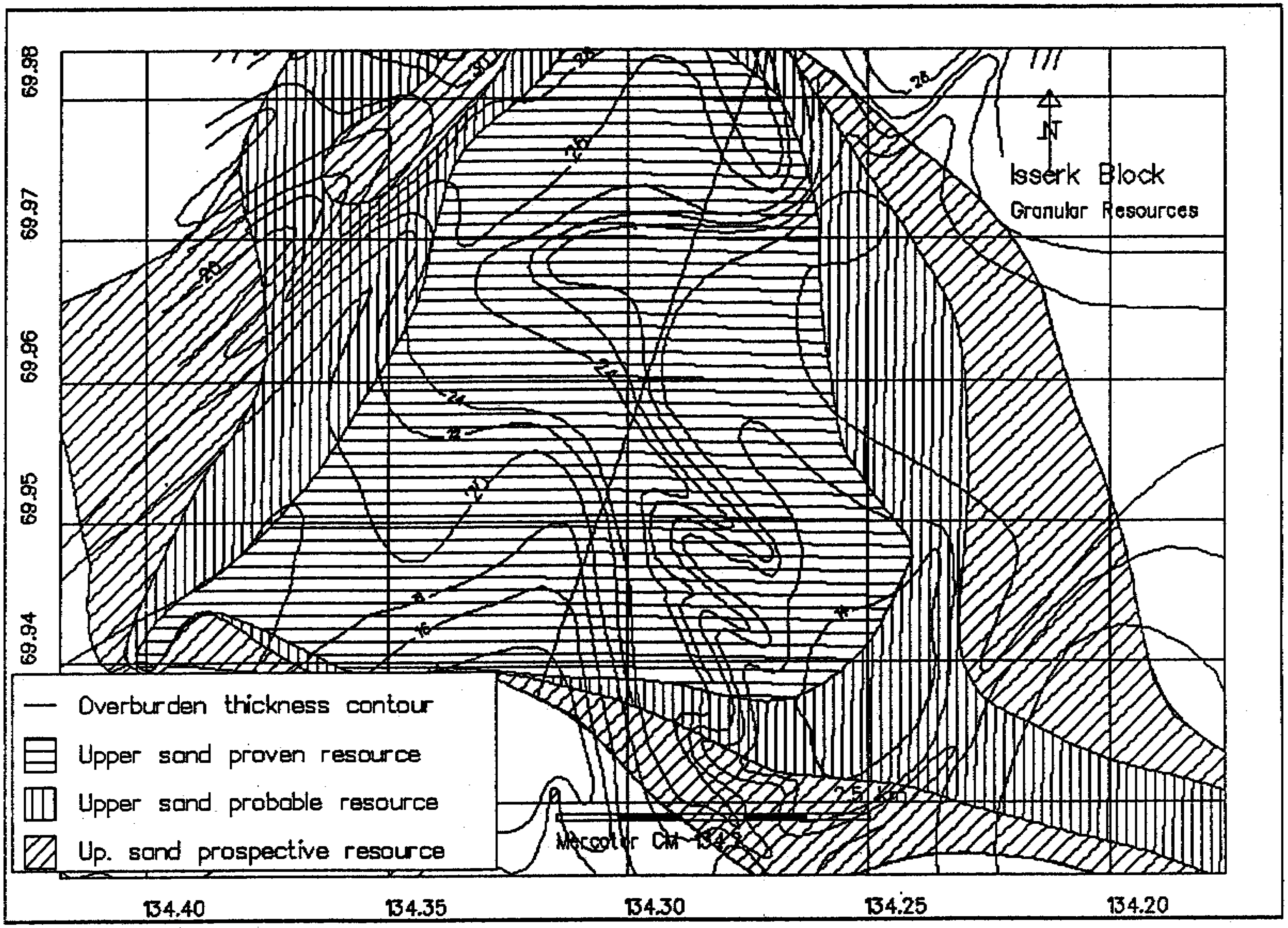
Borehole location points contain data base reference information such as the project number, date, client, location in UTM and Lat/Long, water depth and borehole termination depth.



Borrow deposit information is available for much of Canada's North West Arctic region. Individual sample points are backed-up with data base information regarding the source reference, year, location in UTM and Lat/Long, granular type and USC classification.



The Kogyuk Site Survey is one of several detailed geophysical and geotechnical site survey programs accessible within the existing data base.



The Isserk Block resource potential displayed with depth to deposit surface from mean sea level.

SYNTHESIS AND INTERPRETATION OF BATHYMETRIC, GEOPHYSICAL, GEOLOGICAL AND GEOTECHNICAL DATA: ISSERK BORROW BLOCK - SOUTH CENTRAL BEAUFORT SEA

Part or the Northern Oil and Gas
Action Program (NOGAP - Project A4-20)

Completed for:
Indian and Northern Affairs Canada
Natural Resources and Economic Development

Completed by:
Earth & Ocean Research Ltd.
Dartmouth, Nova Scotia
1988

Authors:

Lauchlin Meagher and John F. Lewis

Presented by:

John F. Lewis
Lewis Geophysical Consulting
376 Prospect Bay Rd.
Box 93, Site 15, RR#4
Armdale, Nova Scotia

Phone 902-852-3442 Fax 902-852-4788

INTRODUCTION

The Isserk Borrow Site study program was one component of a set of concurrent studies that were initially conducted by Earth & Ocean Research Ltd. through 1987/88. These studies consisted of a two volume borrow study conducted for DIAND of which volume 1 is the Isserk site area and volume 2 is the Erksak borrow site area which will be discussed in the next talk. The other study was a regional surficial geology program for the South Central Beaufort Sea region which was completed for Steve Blasco of AGC. Steve will be discussing these regional geology results in a paper presented at this meeting.

Figure 1 is a map of the Beaufort sea showing the South Central Beaufort geological study area and the two concurrent borrow block study areas. These borrow study reports were completed by EOR under DSS contract AO632-7-5011/C1ST for Mr Bob Gowan of DIAND as a part of NOGAP project A4-20.

This paper is specifically in reference to the western Isserk study region (Fig 1) which is a 20km X 20km area of 400 km^2 lying approximately 9 km north or Pullen island. The study region defined as to be within the following boundaries:

NW: ZONE 8; 520,000E; 7,770,000N (70°02'16"N; 134°28'30"W)
NE: ZONE 8; 535,000E; 7,770,000N (70°02'10"N; 134°04'53"N)
SW: ZONE 8; 520,000E; 7,750,000N (69°51'31"N; 134°28'47"W)
SE: ZONE 8; 535,000E; 7,750,000N (69°51'25"N; 134°05'22"W)

The specific purpose of this study has been to evaluate all (or as much as possible) of the geophysical and geotechnical data available within these regions with the primary mandate of attempting to quantize the locations and volumes of proven, probable and prospective granular resources that are present.

All three of the above referenced studies used a common data base set which was compiled and collated with the intent of using it over the three study programs mentioned above.

DATA BASES

The mandate of these studies was to evaluate all high resolution geophysical and geotechnical data that had been collected in this study area. This consisted of a massive amount of data though not all of these data could be found and accessed within a reasonable search effort for this study and a resulting more limited, though still significant, data set was actually used.

DIAND had initiated an earlier data compilation contract with McElhanney Services Ltd which was a library search of the industry geophysical reports to identify the industry geophysical data sets that were initially collected (McElhanney Services Ltd., 1988). A second program with EOR was conducted to compile and digitize the geophysical track data (Peters, 1988) and a third with EBA to identify and compile the geotechnical data bases within the regions (EBA, Isserk 1988a, Erksak, 1988b, and Central Beaufort, 1988c).

The initial tasks of this present study was to locate and copy as much as possible of the geophysical data sets for use within these evaluations. This was carried out over a month long period in Calgary with considerable appreciated help of the respective industry Beaufort operators. A number of the geophysical records couldn't be located and after a reasonable effort it was decided to go with the data that had been collected.

NAVIGATION/GEOPHYSICAL DATA BASE

The track navigation and geophysical Data compilations included the entire area of the South Central Beaufort Sea geological study area

Figure 2 shows the navigation track plots for only the industry operator survey lines that matched Geophysical records that could be located and accessed for these study programs. Figure 3 shows the compiled navigation track plots of the government survey lines that were available to the study and were selectively accessed as required. Figure 4 shows the more limited area of the Isserk borrow site and the geophysical records available for just this area.

In general the overall geophysical data set is of good but variable quality. The quality is however dependent on weather conditions at the time of collection. Unfortunately the Isserk geophysical data set is an exception to this statement and is of limited use in determining stratigraphy equivalency of textural units between boreholes. There are a number of reasons for this.

a) significant data sets collected in 1983, 1984 and 1985 could not be located during the data search

b) within the remaining data set the line density is too low over much or the region to accommodate the high variability in texture and elevation of units within and between boreholes. The seismic data commonly shows many small local depressions or channel like features in the top of Unit C (basal sands) that are 100 to 500 m in width over relatively short distances along any line. To confidently map these details a line spacing of 500 m or less is required which is not achieved in this data set. As a result, considerable interpretive licence has been required in the construction of contours of this surface and the detail of the borrow structures which will be discussed here.

c) The data quality of the remaining lines is again variable and 30 to 40% of these lines are of relatively poor quality which further restricts their usefulness

These limitations largely restrict the litho-stratigraphic correlation of the Isserk Borrow Block to a study of the borehole stratigraphy and to the extent the seismic data can contribute it has been incorporated into the geological model.

Appendix 1 and 2 of the text reports (Meagher and Lewis, 1988) describe the McElhanney data base which consisted of a compilation showing the surveys completed and line data originally collected and the results of the data search respectively which describes the listed/found and copied data used for this study. Appendix 2 data base gives the locations of the original data as of April 1988 and the copied data is currently resident at AGC in their data archives.

GEOTECHNICAL

The geotechnical data bases were compiled and inserted into ESEBase record form by EBA Engineering Ltd. for the entire south central Beaufort area. This data base project will be described more fully in a latter paper presented by Rita Olthof of EBA.

For illustration Figures 2 and 3 show the locations of all of the almost 400 boreholes within the south Central Beaufort area. Figure 4 showed the combined survey lines and the 99 borehole locations within the Isserk study area only.

The boreholes within the Isserk borrow block area tend to be clustered into four main groups within the region which were drilled for exploration island sites and a more regional area associated with previous work on the core area of the borrow prospect itself. Mr Neil MacLeod of EBA, via a subcontract to this study, assisted in developing a coding system for the sediments encountered within the boreholes which takes into account the sand and gravel quality and current dredging requirements and equipment restrictions of the Beaufort Sea Operators. The coding system has been used in the figures describing the borrow prospects and has been used for evaluation of the borrow potential of the respective sites when boreholes are available. This coding system is reproduced on the maps of the detailed borrow prospects discussed latter and for detailed discussions refer to Meagher and Lewis, (1988a and b).

SITE DESCRIPTIONS

PHYSIOGRAPHY .

The Isserk Borrow Block area lies on the Akpak Plateau (O'Connor, 1982) in 8 to 24 m of water (Figure 1). This region is a submerged upland physiographic region located in the south central Beaufort Sea. The Akpak Plateau is a trapezoidal shaped region of slightly convex seaward bathymetric contours trending almost northerly from the area of North Point on Richards Island virtually out to the shelf edge. It is bounded to the east by the Kugmallit Channel and to the west by the Ikit Trough. The area is characterized by an elevated regional unconformity surface defining the top of Unit C relative to the adjoining depression areas.

BATHYMETRY

Figure 5 is a contour map of the bathymetric contours over the Isserk site at a 1 metre contour interval. These contours are considerably smoothed as the contours were developed by a recontouring of the CHS worksheet which were surveyed in 1969 and 71. These worksheets were displayed at a 1:100,000 scale and line spacings were 800 to 1500 m. The region has been resurveyed in 1985/86 though the newer data was not available at the time of this study and it is anticipated that the these newer data which are more accurately positioned and of a higher line density will modify the shape and detail of the contours to some degree.

Overall the contours show a gently dipping plain dipping northward over the southern half and to the north-northeast over the northern half of the site. The seafloor is slightly raised along a north-south axis through the west-centre of the site and again along a northwest-southeast axis near the southeast corner. The ridges are separated from each other and are possible expressions of different geologic features.

Water depths over the site vary from a minimum of 8 m in the SE corner to a maximum of 24 m in the NE corner.

SURFICIAL COVER

The surficial cover over the Unit C sand material is displayed in Figure 6. The construction of this surficial cover map has been defined directly from borehole information and by inference from the seismic data. The map indicates two surficial clay units and a coarser zone of potential borrow materials.

The coarse material, occupies roughly the central and west central part of the block and extends toward the southeast to the southern border of the site. Sample data from the boreholes is available for the coarse material located in the central portion of the deposit. The coarse material is predominantly composed of poorly graded fine sands to silty sands. The sands are non cohesive, olive brown to dark brown. Occasional gravel clasts from 15 to 25 mm in diameter occur throughout the deposit. The gravel clasts, where described, are polished and sub-rounded. The gravel content increases in pockets located along the southwest edge of the coarse deposit where it is equally dominant with the sand. These deposits are noted as being "gap graded" with the gravels being fine textured and the sands being poorly sorted fine to medium textured.

There are no boreholes within the portion of the coarse zone that extends from the central deposit to the southeast and beyond the southern boundary to the south. Seismic evidence suggests that this zone is composed of a combination of two geologic units. The younger unit is an extension of the central deposit and it is inferred that the texture of this extension will be similar to that of the central zone, i.e., generally poorly sorted silty sands with some gravel. The unit is defined by the transition of the surface character on the microprofiler and boomer records from an irregular microrelief to a featureless microrelief. A slight doming of the seafloor is associated with this change in seismic signature.

The older unit extends from the south and is in contact with the younger in the south-central area. No borehole textural information is available for the deposit within the site although recent testing of the unit immediately to the south of the block reveals coarse sand and gravel at the seafloor (S.Blasco, pers comm.). The boundary of the deposit as outlined on the map, is defined as that area where Unit C rises to within two meters of the seafloor. The seismic data available are not of a sufficient resolution to measure the depth of the unit within this zone and there may be areas within this boundary that are very close to the seafloor. The microprofiler data do not show the smooth seafloor trace characteristic of sand size sediments at the seafloor across this zone and the deposit may be covered by a thin soft veneer.

The fine material surrounding the coarse deposit consists uniformly of inorganic clays with very occasional black organic streaks. They are generally low to medium plastic with a water content that varies from about 20% to 45%. The clays also vary from soft to very stiff. Trace amounts of sand in fine laminations are noted in several samples as well as trace amounts of silt, and shells.

While clay samples from throughout the area share this general variability, those of the Issungnak O-61 group of boreholes (IS78- series) at the northern boundary of the block are more consistently of high plasticity. Those of the Itoyuk I-27 (IT81- series), to the east, Isserk B-15 (B-15- series), to the south, and Issungnak South (S81-series) to the west are virtually all low plastic clays. This suggests that the Issungnak O-61 surficial clays are a different body than the clays to the south, a suggestion that is tentatively supported by the seismic data. A somewhat arbitrary boundary has been drawn across the northern end of the survey site to note this change in stratigraphic units.

SUB-SURFACE GEOLOGY

The sub-surface geology within the site can be described within the framework of O'Connor's stratigraphic model for the Beaufort shelf. Units A, B, and C are identified and facies within these units discerned. The near surface litho-stratigraphy and structure are complex and distinct changes in seismic character are observed vertically and horizontally along individual seismic profiles. Continuity in the seismic data is generally poor, and the ability to confidently follow seismic horizons from line to line is low. While varying in detail, the boreholes present a more consistent picture of the general stratigraphy.

Three borehole transects have been constructed; a north-south transect, an east-west transect, and a southwest-northeast transect. These are presented as Figures 7, 8 and 9. The orientations are approximate and the transects do not form straight lines as they are determined by the distribution of the boreholes. The geographic positions correlating to these transects has been shown on the seismic track plot and borehole map of Figure 4.

TOP OF C

The lowest regionally persistent horizon is a composite of a younger and an older erosion surface, the equivalents of U/C1 and U/CL. The character of each in the borrow block area is distinctive and they are distinguishable one from the other where data quality permits.

The older unconformity forms a highly incised, irregular surface. The surface has been removed by the subsequent erosion episode (U/C1) over the crest of the site and to the east as the Kugmallit Channel is approached. The seismic profiles indicate the irregular lower surface to descend to the east and west from a central high. The extreme irregularity of the horizon suggests an old subaerial erosion surface that has not been affected by the transgression.

The structure map presented in Figure 10 describes the shape of the upper surface of Unit C (U/CL unconformity). Where the younger erosion surface has excavated to the top of Unit C, it forms a smooth, featureless plain. The remnant areas that were not affected by this erosion episode display a highly dissected pattern. The surface descends to the north, east and west from an irregular crest that extends from the southeast edge of the site through approximately the site centre and beyond the site boundary to the northwest. The surface descends from a high of ten meters near the southern border, where it lies at or near the seafloor, to 34 meters at the northwest edge of the survey coverage. As the surface descends, there is progressively less planation by the later erosion episode, with the result that the map displays an increasingly more complex topography to the north.

DEPOSITIONAL SUMMARY

Predominantly fine to medium sand was deposited as Unit C through channel cut and fill processes in a locally variable but generally moderate to high energy fluvial or glacio-fluvial environment. Potentially coarser and more resistant material was deposited as a linear body that extended from the southeast corner of the site through the site centre. Subsequent to this deposition the surface of the unit was downcut under subaerial conditions to form a highly irregular topography of small channels and mounds (Figure 11a). The more resistant body was downcut to a lesser extent and formed the positive core for the plateau in this area. During this period, material was moved downslope via the gullies and also on the interfluves via dune formation. On the eastern flank of the plateau, leading down into the Kugmallit Channel, coarse material was aggraded into dune-like bedforms that indicate sediment movement to the east into the channel.

The sculpting of the highly incised topography was followed by a marine transgression that initiated the deposition of Unit B (Figure 11b). Preservation of much of the subaerially constructed topography on Unit C suggests that the initial transgression across this area was rapid. Predominantly fine material was deposited in the depressions on Unit C. As the sealevel rose, planation of the raised part of Unit C occurred and produced local lag gravel deposits that remained in contact with the source material. A distal sand facies spread out over the clays deposited on Unit C in the basinal areas. This was followed by a period of shallow marine deposition of fine material. A short second regression was followed by a slower transgressive rise in relative sealevel, during which time the raised portions of Unit C and the previously deposited Unit B strata were reduced by wave base planation to a smooth surface (Figure 11c and d). The elevated section of Unit C to the south and the previously reworked Unit B sands and gravels provided the source material for a thin coarse grained deposit centred over the crest of the site. Fine grained clays were deposited coevally away from the crest of Unit C.

With continued transgression, the wave base moved away to the south and the construction of the sand body ceased. The upper sand body was buried by marine clays in the deeper water area to the north. With continued shoreline retreat, this process may be ongoing. At present, however, most of the Isserk Block area is floored by old sediments laid down during the most recent transgression.

GRANULAR RESOURCE MODEL AND EVALUATIONS

The granular resources of the Isserk Borrow Block are located in two geologic deposits of different age, distribution, and depositional mode. The upper deposit represents a reworked deposit associated with Unit B, while the lower deposit consists the Unit C basal material. The distribution of the surficial prospect material is displayed as Figure 12 and the distribution of the lower prospect is shown in Figure 13. These maps incorporate divisions of the reserve into Proven, Probable and Prospective zones. Proven granular resources are defined as those resources whose occurrences, distributions, thickness and quality are supported by considerable ground-truthing information such as dredging and/or geotechnical drilling data. Probable reserves are defined as sands and gravels whose existence, extent and quality has been inferred on the basis of limited ground-truthing information and/or several types of indirect evidence, including sidescan sonar, shallow high resolution seismic, echo sounding and/or bathymetric and/or geological considerations. These estimates are based on an understanding of the proven reserves as determined from boreholes and a comparison with the seismically mapped prospective regions to provide an estimate of probable resource that may represent a viable planning figure for future utilization. Prospective Resources are defined as granular resource deposits whose existence and extent are speculated on the basis of limited indirect evidence, such as ripple marks on sidescan sonar records or general geological considerations.

Within the Isserk Borrow Block area measurements of overburden and resource thicknesses were made for each borehole. These analysis have revealed that there are two distinct bodies of sand flooring the Isserk block, with the lower sand being ubiquitous and the upper sand being of local extent.

Because of the applicability of this two resource model, the boreholes have been coded and are described in terms of a first encountered coarse unit and a second encountered coarse unit. This allowed spatial display of these data on the map sheets and subsequent contouring and definition of the two prospect areas. From observation it is apparent that where there is only one sand unit present and the borehole longer than about 10 meters, the sand unit present is the older of the two. The only instance where this may not apply is borehole IB80-84 near the centre of the Isserk block where the upper and lower sands may be in contact with each other.

UPPER SURFICIAL PROSPECT

The main body of the deposit is roughly triangular in shape and located in the west-central part of the block (Figure 12). A narrow, linear, "tail" extends from the southeast edge of the main deposit to near the southeast corner of the block area.

The spatial distribution of this deposit is defined on the basis of borehole control and the seafloor character of the boomer and profiler records. Coarse material on the seafloor, as identified in the boreholes, is associated with a distinct change in character on the seismic records.

While the map in Figure 12 displays the areal distribution of the deposit for the proven, probable and prospective zones, contours indicating the thickness of the deposit are only provided for the proven zone. The thicknesses are derived solely from the borehole logs as the base of the deposit was not observed on the geophysical data.

Twenty five boreholes have been drilled within the boundaries of this zone. Borehole penetration varies from 4.5 meters to 21.4 meters with 17 boreholes less than 10 meters long. The majority of the boreholes encounter sand at the seafloor and silty or clayey deposits at from 1.25 to 3 meters below seafloor. Two boreholes, IB80-84 and IB80-96 record sand from the seafloor to their depth of penetration. Borehole IB80-84 was drilled to a depth of 21.4 meters, and borehole IB80-96 to a depth of 9.1 meters. Three boreholes record a veneer of clay atop the surficial sands. The veneer varies from 0.2 meters to 0.6 meters. The boreholes, IB80-95, IB80-93, and IB78-5 are located in proximity to each other and the clay deposit may form a continuous veneer along the western side and northern tip of the zone.

The Proven resource is primarily based on the borehole information and occupies the central part of the deposit with the displayed boundaries defined by both borehole and seismic data. Within this zone there is a very high confidence that useable granular material occurs. Based on the borehole data, this zone has been further subdivided into zones dredgeable by hopper dredge only and by both hopper and stationary dredge methods. These subdivisions are shown by the heavy dash-dotted line subdivisions within the proven area. The position of these lines has been made using the Dredgeability assessments and the Development Concerns assessment of each of the boreholes and using a simple rule of equidistance between the boreholes within the proven reserve area. Based on these subdivisions two small regions associated with boreholes IB80-96 and IB80-84 are defined which are categorized as dredgeable with either hopper or stationary dredge. It is assumed that below the approximate 4 m level in each of these regions one would be mining the lower sand resource as opposed to the upper reworked Unit B materials.

The Probable resource boundaries are based on seismic and limited borehole information. This area is seen to rim the proven region with a tail defined which extends approximately 8 km off toward the southeast from the main body of the deposit. This tail region is defined exclusively with the seismic data.

The Prospective region is defined entirely on the seismic data set and is based on bottom character return along with faintly defined internal reflections seen within the data. It may represent an extension of reworked Unit B materials, however borehole information would be required to confirm this.

LOWER BASAL PROSPECT

The Lower Basal Prospect represents a region where the unconformity surface representing the top of Unit C comes to within 3 m of the seabed. The 3 m limit has been taken as the practical limit of overburden stripping when a Stationary Suction dredge is utilized. This region is located in the southeastern corner of the prospect area and is highly irregular in shape (Figure 13).

This region is defined almost entirely from mapping of the seismic data and is only confirmed by boreholes in the extreme northwestern tip of the area. Because of this lack of borehole confirmation the entire prospect is considered to be Prospective only at this time. Although some limited quality information is available, the boreholes indicate this lower unit to be highly variable in nature and considerable confirmation drilling will be necessary to confirm this region as a viable resource.

RESOURCE PROSPECT GRANULAR VOLUME ESTIMATES

Table 1 summarizes the estimates of proven, probable and prospective volume of granular resource for the two prospect areas defined in this report. The methods of volume calculation vary slightly for the two prospects in that the upper sand is assumed to represent a body which is exposed at the seafloor and no stripping is required, thus mining is limited to the thickness of the resource. In this case a minimum thickness of one metre is required and volumes are calculated based on the area between the contours times the average thickness assuming a linear proportion distribution between the contour lines (ie. area = 10 m^2, between the 2 and 3 m contours: therefore volume = 10 m^2 X 2.5 m = 25 m^3). For this upper material the total volume is taken as the sum of the volumes between all thickness contour lines. The total probable and total prospective resources incorporate the volumes of the higher probability materials.

Within the lower sand body volumes are calculated based on an assumed thickness of the resource material which reflects the assumed maximum depth of dredging capabilities. Since detailed evaluations of the depth of the resource are not possible at this time these values are taken as estimations only.

TABLE 1 GRANULAR RESOURCE VOLUME ESTIMATES - ISSERK BORROW BLOCK

Upper Sand Unit Exposed at the Seafloor

Unit Thickness (m)	Area (m^2 *10^6)	Volume (m^3 *10^6)
PROVEN RESOURCE		
> 1 < 2	4.483	6.73
> 2 < 3	4.964	12.41
> 3 < 4	5.534	19.37
> 4 < 5	2.896	13.03
> 5 < 6	1.185	6.52
TOTAL PROVEN RESOURCE:	**19.062**	**45.03**
PROBABLE RESOURCE		
Assume 1 meter minimum	18.006	18.01
TOTAL RESOURCE	**37.068**	**63.04**
PROSPECTIVE RESOURCE		
Assume 1 meter minimum	16.711	16.71
TOTAL RESOURCE	**53.779**	**79.75**

~~Sand~~ Sands with < 128 fines included / doesn't include D50 in selection criteria

Lower Sand Unit

PROSPECTIVE ONLY - Portion of Unit C covered by three meters of overburden or less

Unit Thickness (m)	Area (m^2 *10^6)	Volume (m^3 *10^6)
Assume 1 meter	40.840	40.84
Assume 5 meters	40.840	204.20
Assume 10 meters	40.840	408.00
Assume 20 meters	40.840	816.00

for Unit C - 30-50% of sand usable.

CONCLUSIONS

The Isserk Borrow Block of the south central Beaufort Sea covers an area of 400 square kilometres and contains significant amounts of proven, probable, and prospective granular resource materials. Through the integration of geophysical, geotechnical, and geological data collected over the past 15 years from both industry and government operators, two main deposits were identified. These deposits occur as fine to medium grained sand bodies that lie within a complex sequence of glacio-fluvial, fluvial, and transgressive marine type sediments that form a northwest - southeast trending ridge across the Akpak Plateau.

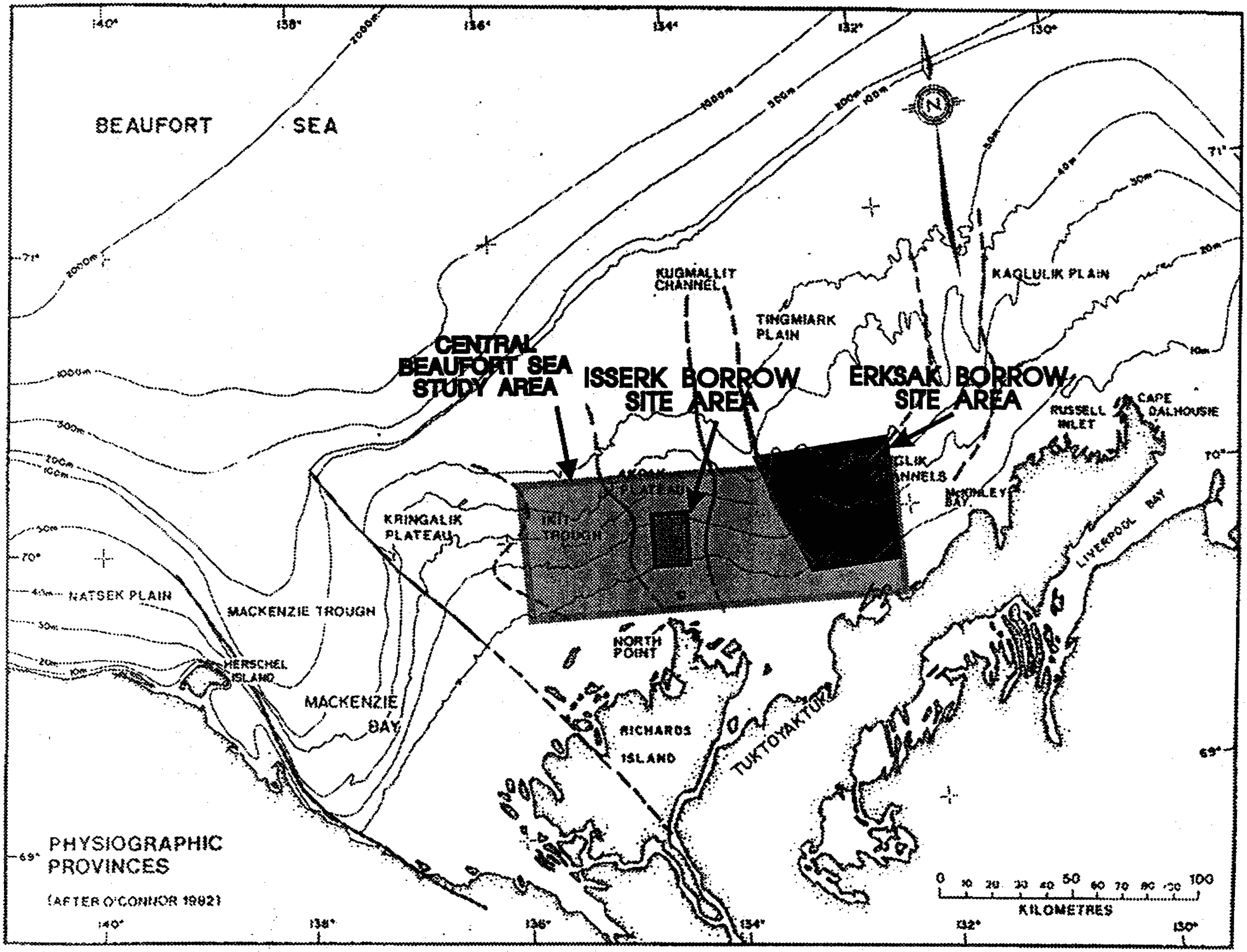
Some shallow permafrost - reasonably well bonded
- expect in Unit C -
- found in upper sand in few places

The first deposit (Upper Sand Unit) is a localized shallow sand body which lies in the central portion of the Isserk Borrow Block. Its triangular shape covers an area of approximately 53 million square metres. Borehole and seismic data indicate an estimated 19 million cubic metres of proven, 63 million cubic metres of probable, and up to 80 million cubic metres of prospective granular resource materials. The proven resource estimate is based primarily on borehole information and subdivided according to dredging and development concerns.

The second deposit (Lower Sand Unit) is a near surface exposure of Unit C which lies in the southeast quadrant of the study area. Its estimated 800 million cubic metres of prospective granular resources is based on limited seismic information only, and requires considerable future ground truthing. Of this 800 million it is likely that only 100 to 300 million might actually be recoverable when permafrost bonding and resource quality are fully considered and delineated.

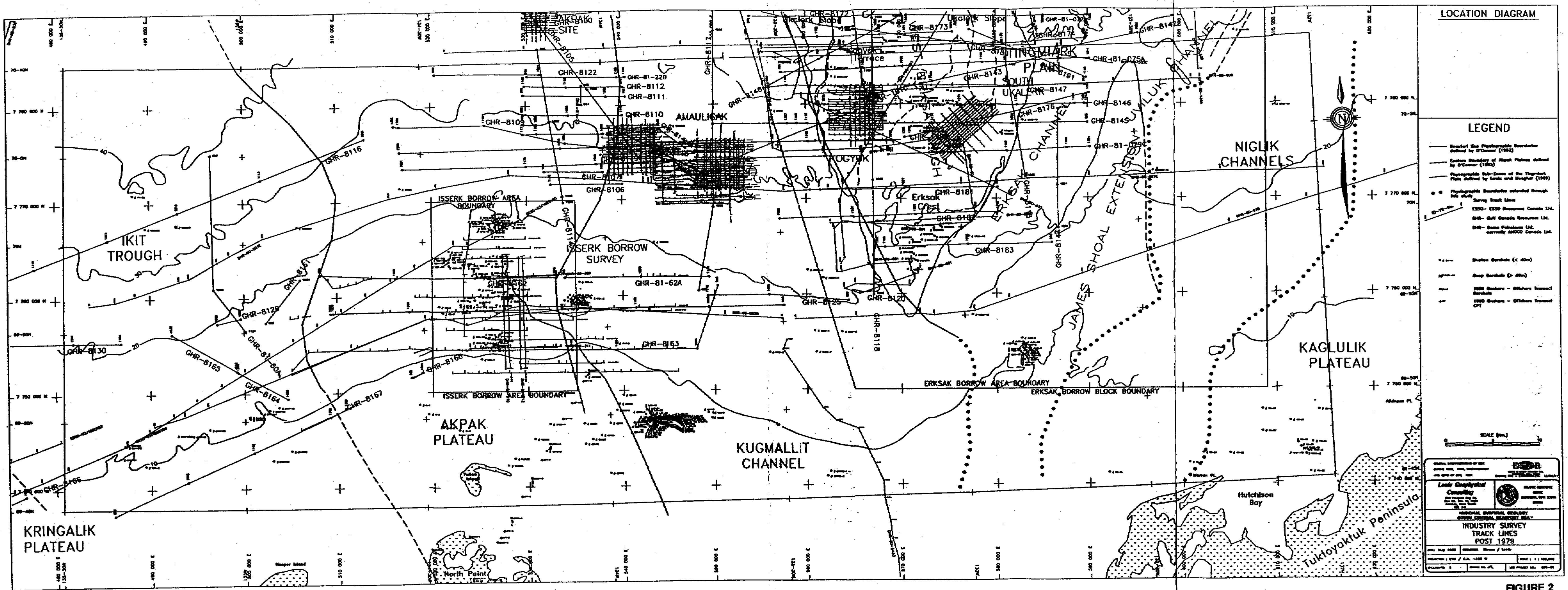
It is conceivable that the Lower Sand Unit extends beneath the Upper Sand Unit to the northwest, separated, however, by a clay layer of variable thickness. The actual extent and quality of this deposit can only be determined through further investigation.

LIST OF FIGURES - ISSERK BORROW SITE



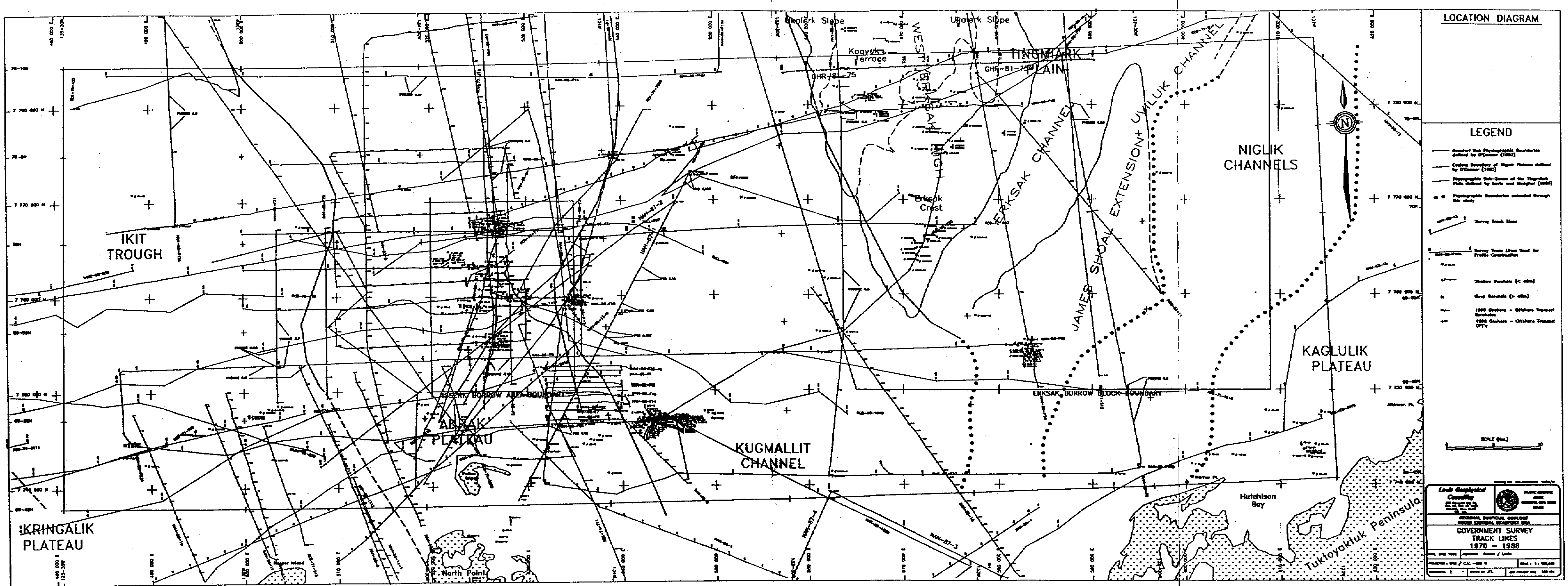
LOCATION DIAGRAM

FIGURE 1



LOCATION DIAGRAM
LEGEND
INDUSTRY SURVEY
TRACK LINES
POST 1979
NIGLIK
CHANNELS
KAGLULIK
PLATEAU
IKIT
TROUGH
AKPAK
PLATEAU
KUGMALLIT
CHANNEL
KRINGALIK
PLATEAU
ISSERK BORROW
SURVEY
ISSERK BORROW AREA BOUNDARY
AMAULIGAK
KOGYUK
Erksak
Crest
ERKSAK BORROW AREA BOUNDARY
ERKSAK BORROW BLOCK BOUNDARY
JAMES SHOAL EXTENSION
TINGMIARK
PLAIN
SOUTH
UKALERK
Hutchison
Bay
North Point
Tuktoyaktuk Peninsula
GHR-8116
GHR-8122
GHR-8112
GHR-8111
GHR-8110
GHR-8106
GHR-8126
GHR-8130
GHR-8165
GHR-8164
GHR-8167
GHR-8166
GHR-8163
GHR-81-62A
GHR-8125
GHR-8120
GHR-8118
GHR-8183
GHR-8146
GHR-8145
GHR-8147
GHR-8143

FIGURE 2



LOCATION DIAGRAM
LEGEND
IKIT
TROUGH
KRINGALIK
PLATEAU
AKPAK
PLATEAU
KUGMALLIT
CHANNEL
NIGLIK
CHANNELS
KAGLULIK
PLATEAU
ERKSAK CHANNEL
JAMES SHOAL EXTENSION+ UVILUK CHANNEL
TINGMIARK
PLAIN
Kogyuk
Terrace
Erksak
Crest
ERKSAK BORROW BLOCK BOUNDARY
Hutchison
Bay
Tuktoyaktuk Peninsula
North Point
GOVERNMENT SURVEY
TRACK LINES
1970 – 1988

FIGURE 3

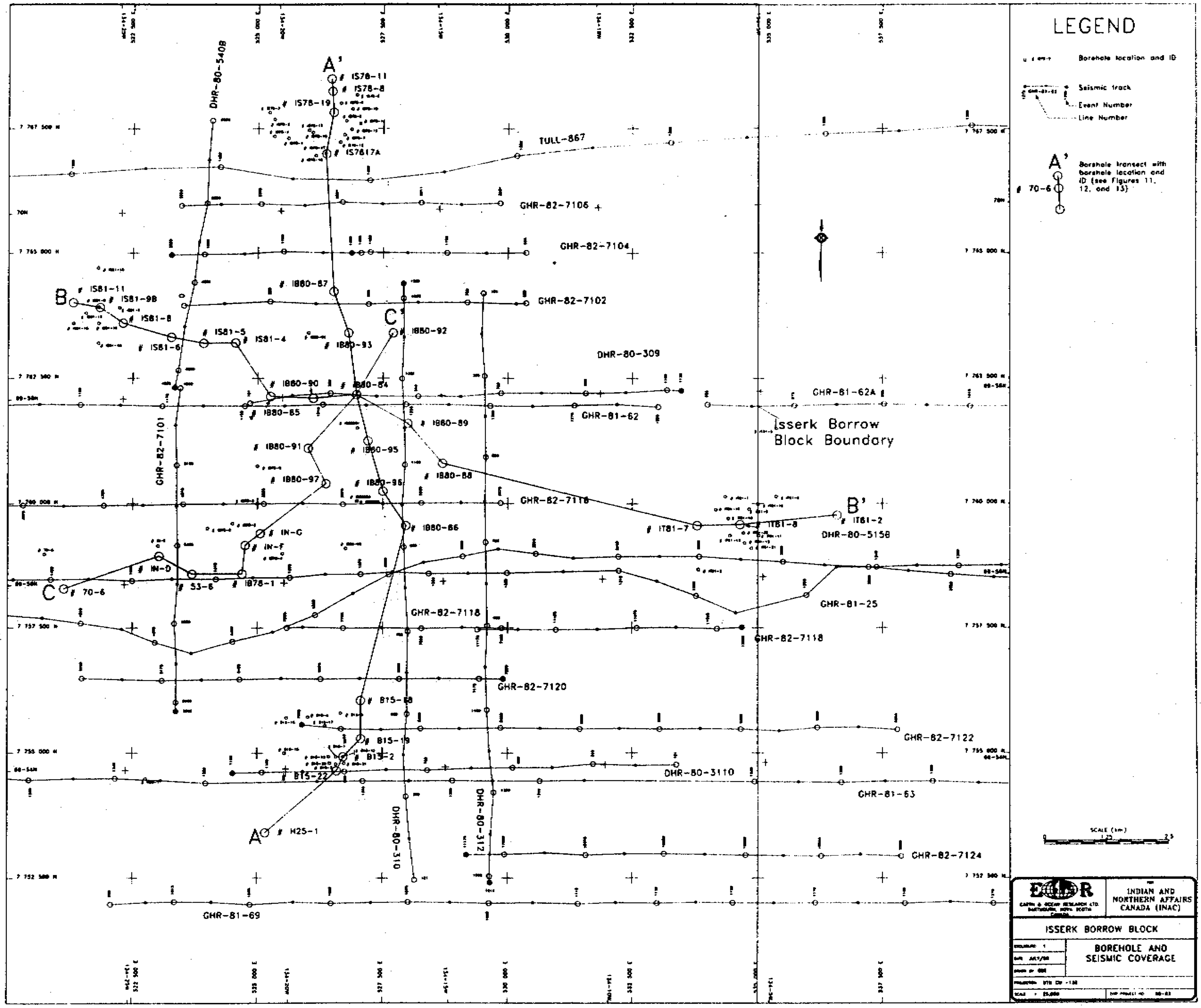
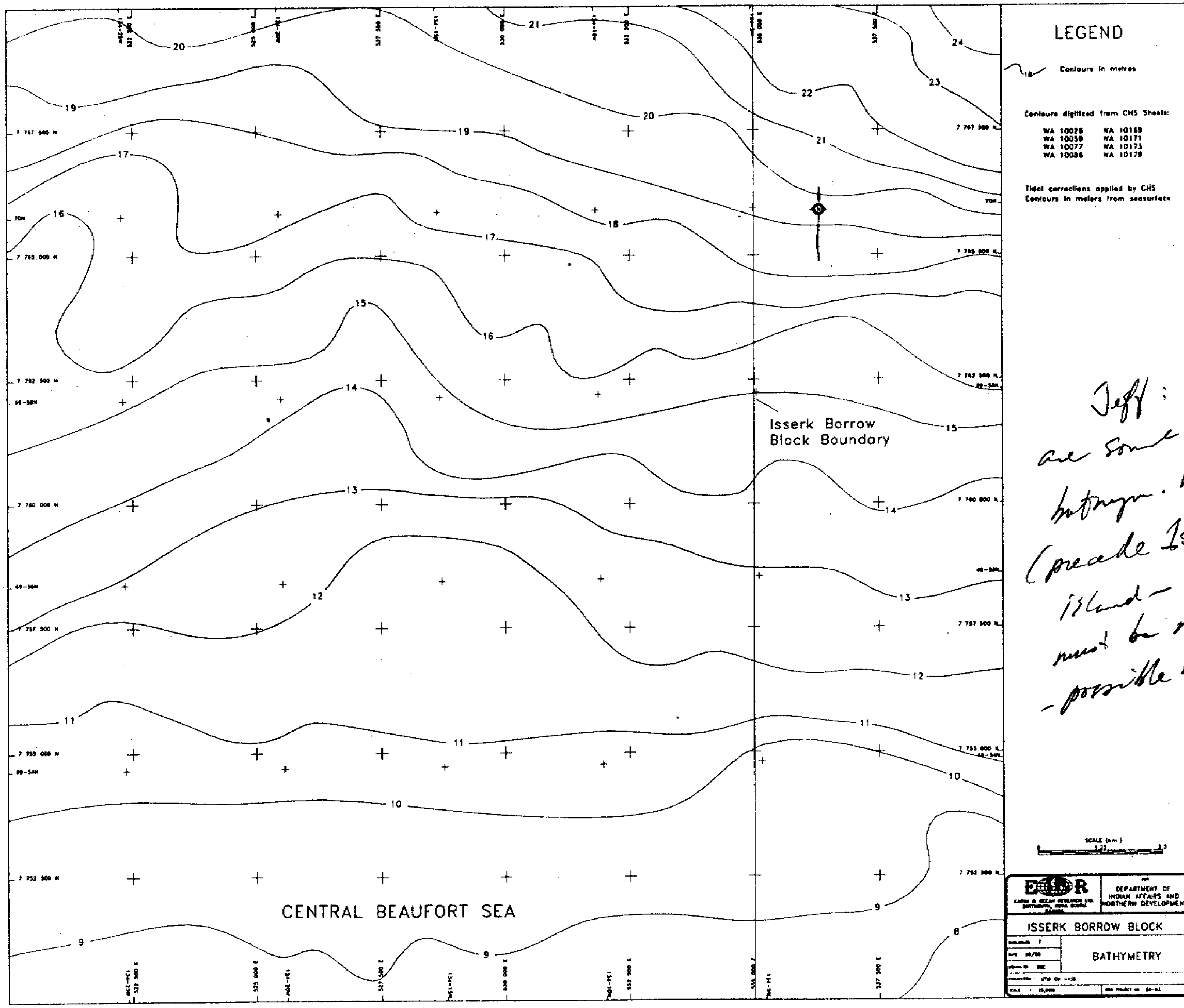
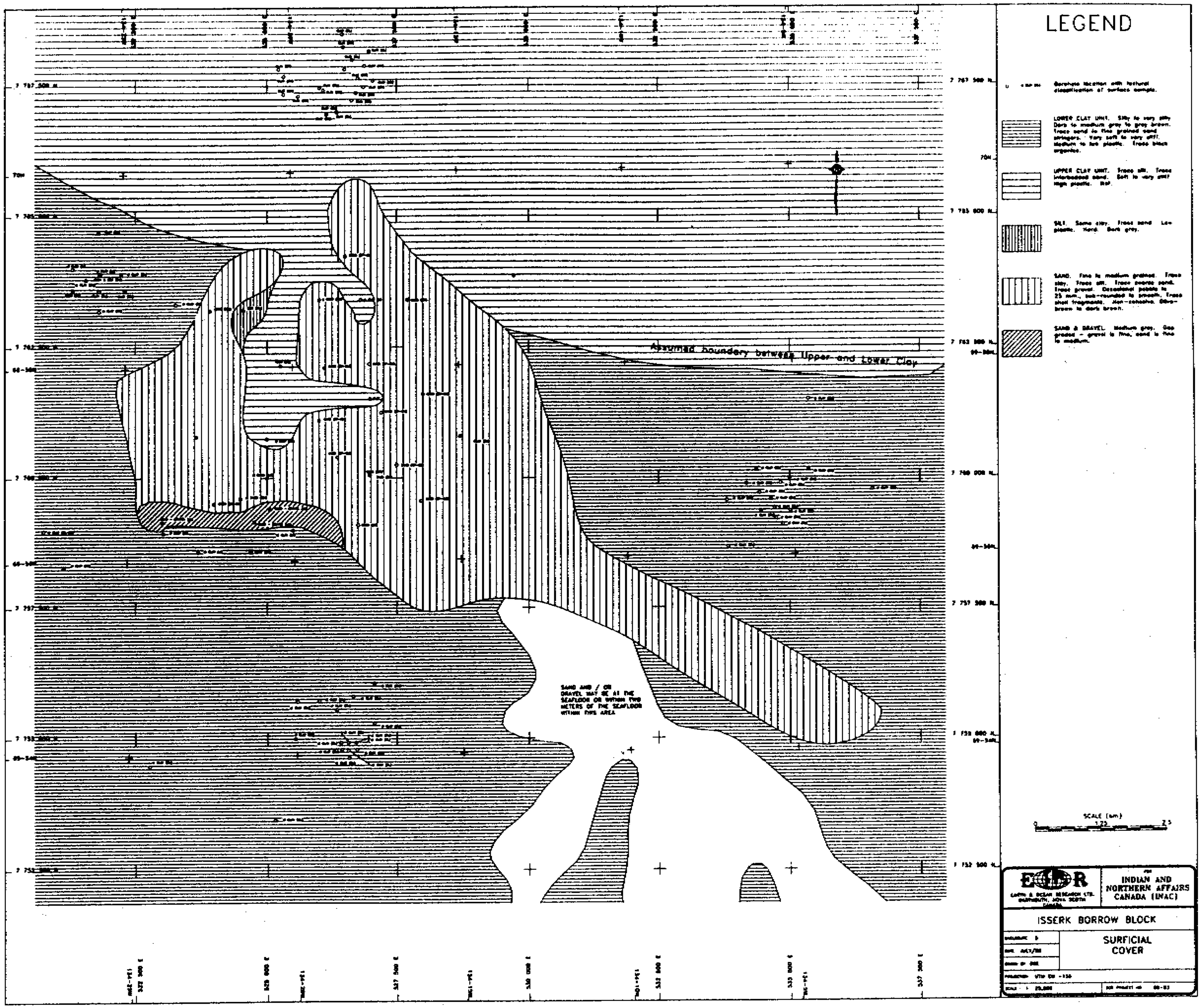

LEGEND
Borehole location and ID
Seismic track
Event Number
Line Number
Borehole transect with borehole location and ID (see Figures 11, 12, and 13)
ISSERK BORROW BLOCK
BOREHOLE AND SEISMIC COVERAGE
INDIAN AND NORTHERN AFFAIRS CANADA (INAC)
Isserk Borrow Block Boundary
TULL-867
GHR-82-7106
GHR-82-7104
GHR-82-7102
GHR-82-7101
GHR-82-7116
GHR-82-7118
GHR-82-7120
GHR-82-7122
GHR-82-7124
GHR-81-62A
GHR-81-62
GHR-81-25
GHR-81-63
GHR-81-69
DHR-80-540B
DHR-80-309
DHR-80-310
DHR-80-312
DHR-80-3110
DHR-80-5158

FIGURE 4



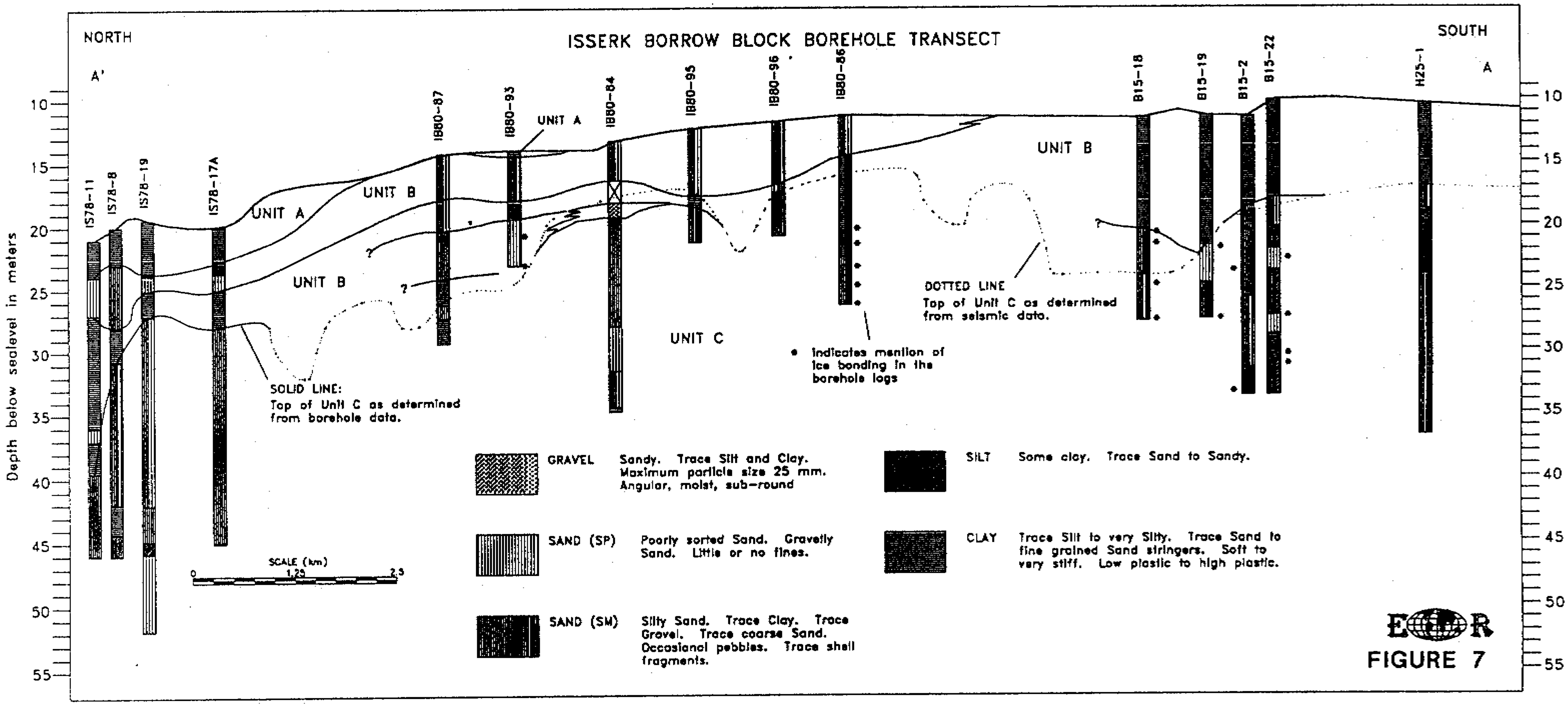
Jeff: are some bathym. highs (predate Isserk Island – must be natural ?? – possible origin ??

FIGURE 5



LEGEND
LOWER CLAY UNIT.
UPPER CLAY UNIT.
SILT.
SAND.
SAND & GRAVEL.
Assumed boundary between Upper and Lower Clay
SCALE (km)
0
1.25
2.5
INDIAN AND NORTHERN AFFAIRS CANADA (INAC)
ISSERK BORROW BLOCK
SURFICIAL COVER

FIGURE 6



NORTH
ISSERK BORROW BLOCK BOREHOLE TRANSECT
SOUTH
A'
A
IS78-11
IS78-8
IS78-19
IS78-17A
IB80-87
IB80-93
IB80-84
IB80-95
IB80-96
IB80-86
B15-18
B15-19
B15-2
B15-22
H25-1
UNIT A
UNIT B
UNIT C
Depth below sealevel in meters
SOLID LINE: Top of Unit C as determined from borehole data.
DOTTED LINE Top of Unit C as determined from seismic data.
Indicates mention of ice bonding in the borehole logs
SCALE (km)
GRAVEL Sandy. Trace Silt and Clay. Maximum particle size 25 mm. Angular, moist, sub-round
SAND (SP) Poorly sorted Sand. Gravelly Sand. Little or no fines.
SAND (SM) Silty Sand. Trace Clay. Trace Gravel. Trace coarse Sand. Occasional pebbles. Trace shell fragments.
SILT Some clay. Trace Sand to Sandy.
CLAY Trace Silt to very Silty. Trace Sand to fine grained Sand stringers. Soft to very stiff. Low plastic to high plastic.

FIGURE 7

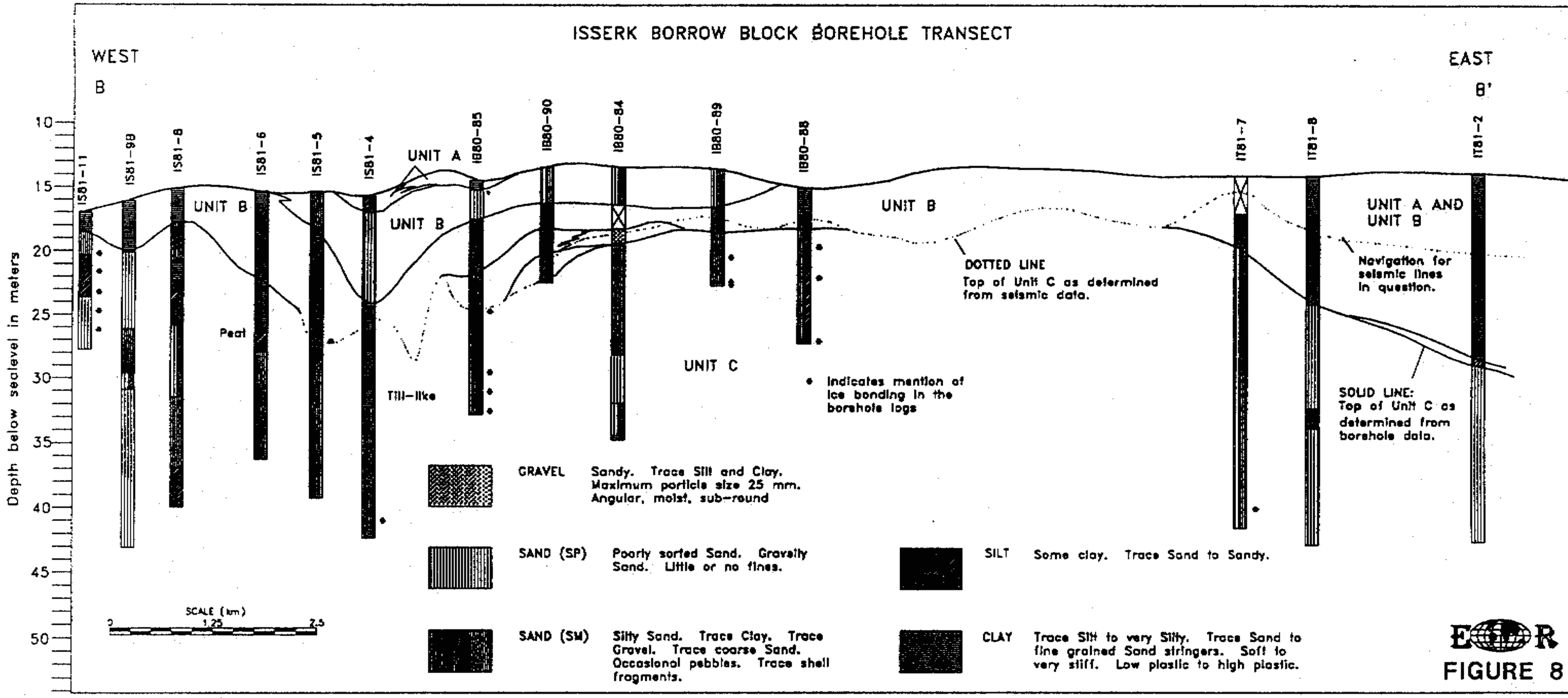

ISSERK BORROW BLOCK BOREHOLE TRANSECT
WEST
B
EAST
B'
Depth below sealevel in meters
IS81-11
IS81-9B
IS81-8
IS81-6
IS81-5
IS81-4
IB80-85
IB80-90
IB80-84
IB80-89
IB80-88
IT81-7
IT81-8
IT81-2
UNIT A
UNIT B
UNIT B
UNIT B
UNIT A AND UNIT B
UNIT C
Peat
Till-like
DOTTED LINE
Top of Unit C as determined from seismic data.
Navigation for seismic lines in question.
SOLID LINE:
Top of Unit C as determined from borehole data.
• Indicates mention of ice bonding in the borehole logs
GRAVEL
Sandy. Trace Silt and Clay. Maximum particle size 25 mm. Angular, moist, sub-round
SAND (SP)
Poorly sorted Sand. Gravelly Sand. Little or no fines.
SAND (SM)
Silty Sand. Trace Clay. Trace Gravel. Trace coarse Sand. Occasional pebbles. Trace shell fragments.
SILT
Some clay. Trace Sand to Sandy.
CLAY
Trace Silt to very Silty. Trace Sand to fine grained Sand stringers. Soft to very stiff. Low plastic to high plastic.
SCALE (km)
0
1.25
2.5
10
15
20
25
30
35
40
45
50
EMR

FIGURE 8

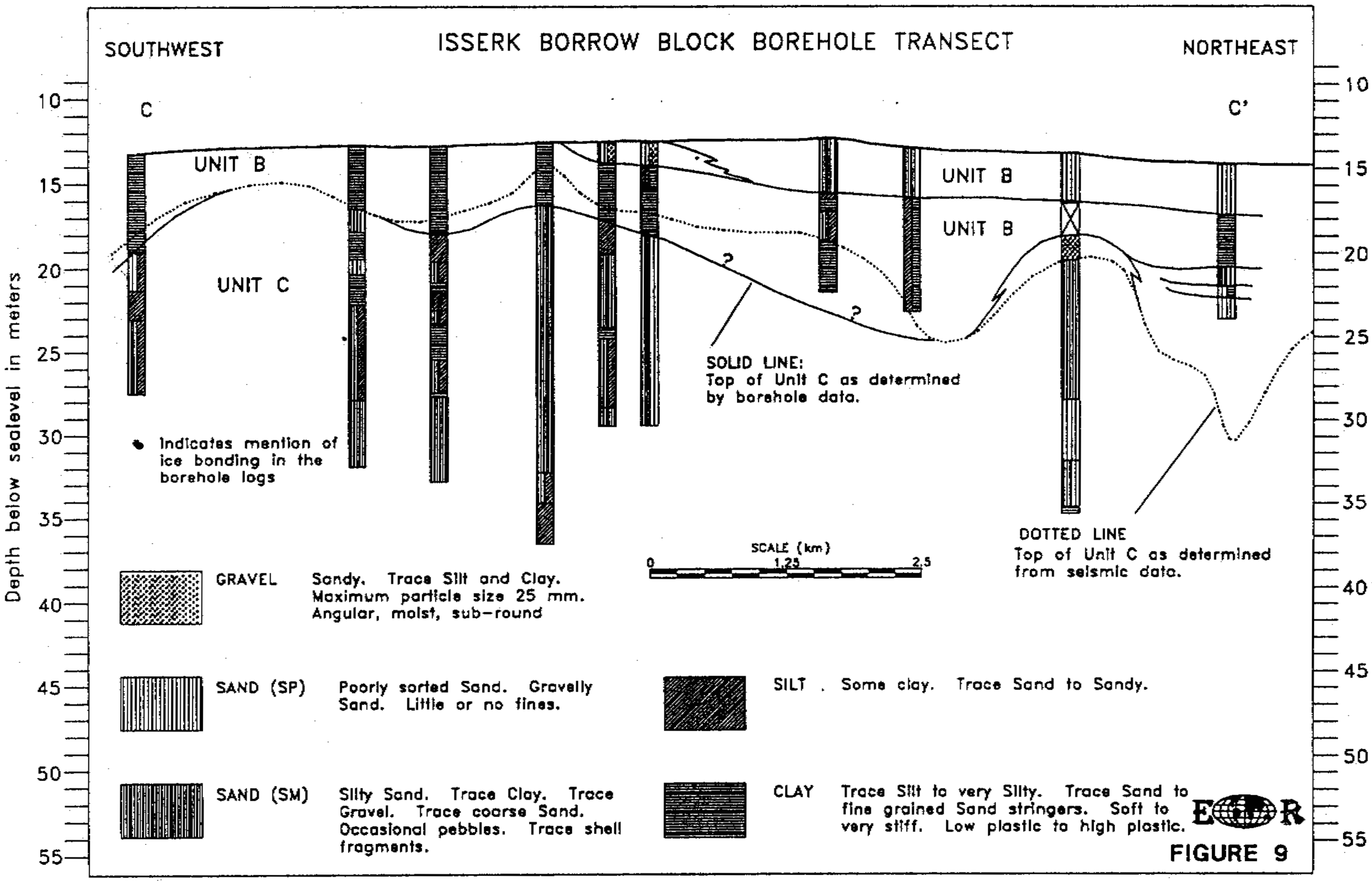

ISSERK BORROW BLOCK BOREHOLE TRANSECT
SOUTHWEST
NORTHEAST
C
C'
UNIT B
UNIT B
UNIT B
UNIT C
Depth below sealevel in meters
10
15
20
25
30
35
40
45
50
55
SOLID LINE:
Top of Unit C as determined by borehole data.
DOTTED LINE
Top of Unit C as determined from seismic data.
• Indicates mention of ice bonding in the borehole logs
SCALE (km)
0
1.25
2.5
GRAVEL
Sandy. Trace Silt and Clay. Maximum particle size 25 mm. Angular, moist, sub-round
SAND (SP)
Poorly sorted Sand. Gravelly Sand. Little or no fines.
SAND (SM)
Silty Sand. Trace Clay. Trace Gravel. Trace coarse Sand. Occasional pebbles. Trace shell fragments.
SILT
Some clay. Trace Sand to Sandy.
CLAY
Trace Silt to very Silty. Trace Sand to fine grained Sand stringers. Soft to very stiff. Low plastic to high plastic.
E R

FIGURE 9

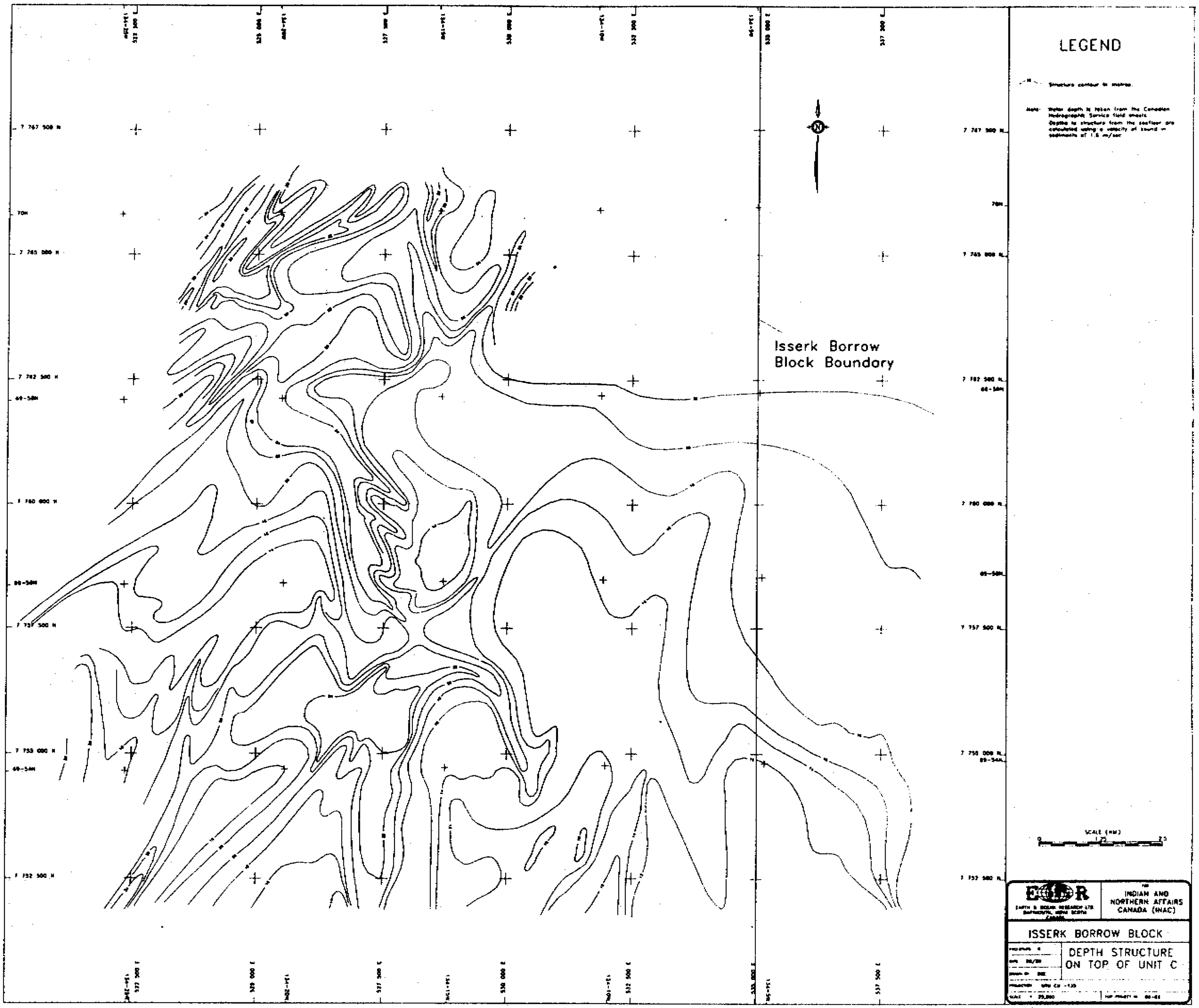

LEGEND
Isserk Borrow
Block Boundary
INDIAN AND
NORTHERN AFFAIRS
CANADA (INAC)
ISSERK BORROW BLOCK
DEPTH STRUCTURE
ON TOP OF UNIT C

FIGURE 10

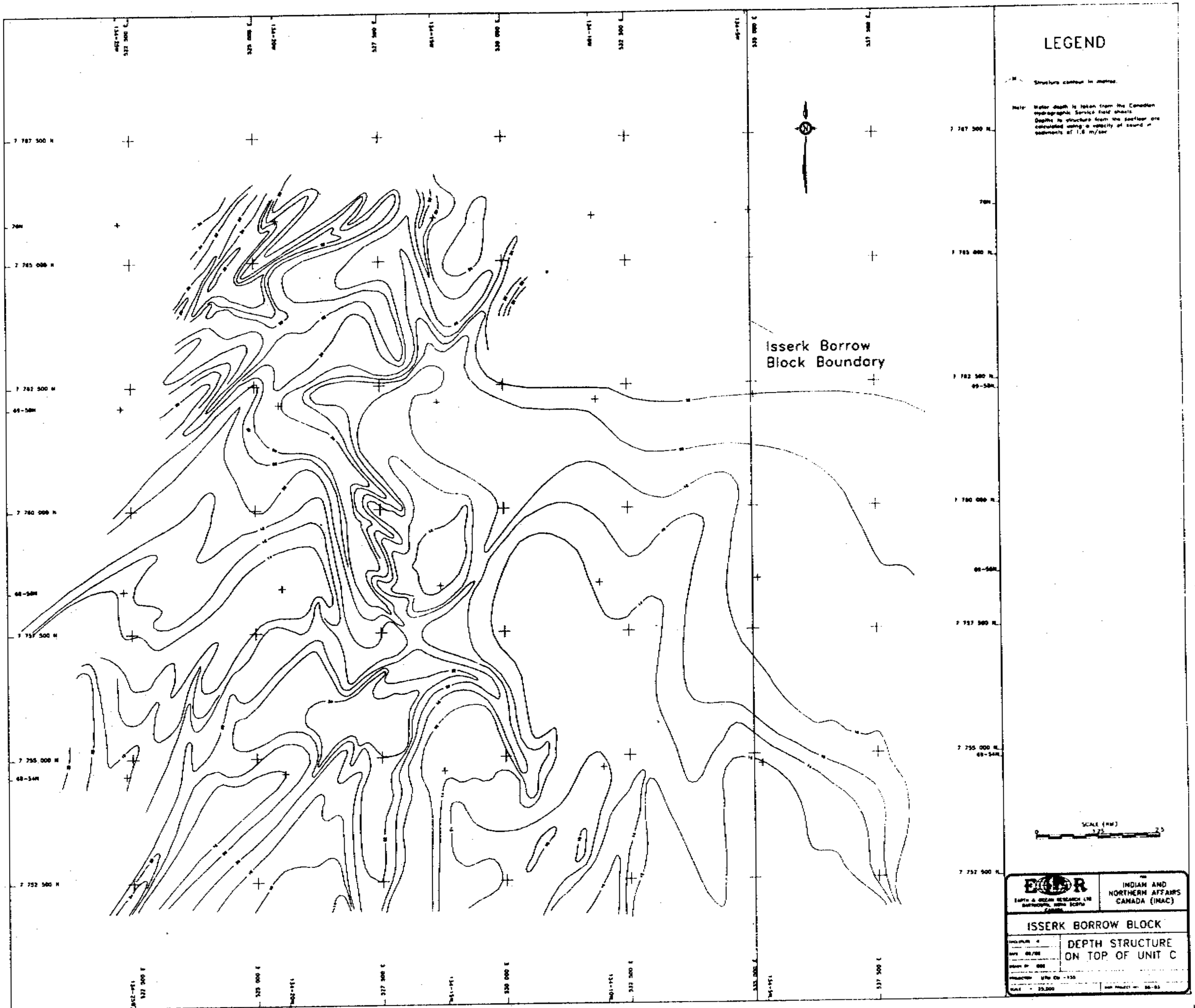

LEGEND
Structure contour in metres.
Isserk Borrow
Block Boundary
SCALE (KM)
INDIAN AND
NORTHERN AFFAIRS
CANADA (INAC)
ISSERK BORROW BLOCK
DEPTH STRUCTURE
ON TOP OF UNIT C

FIGURE 10

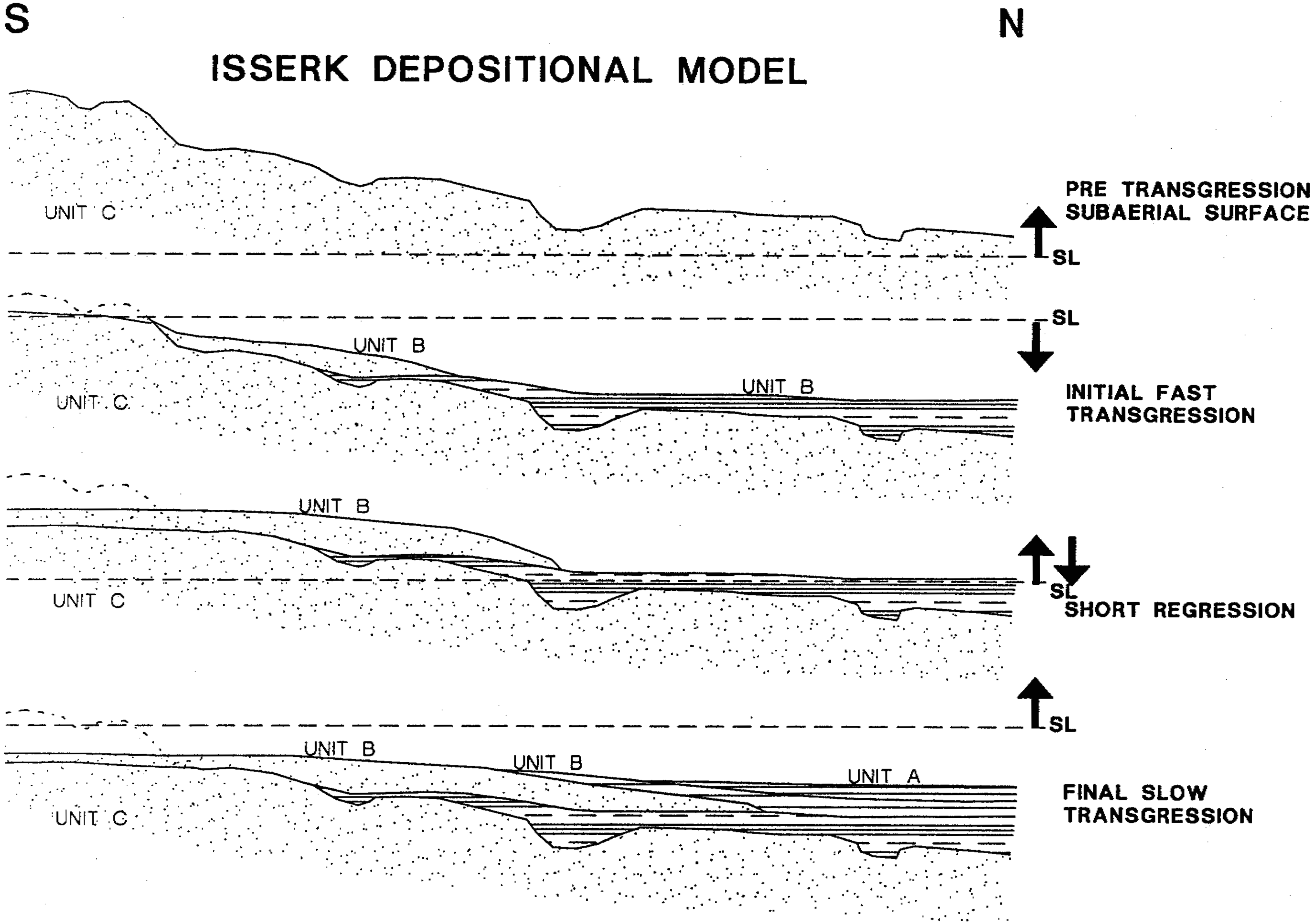

S
N
ISSERK DEPOSITIONAL MODEL
UNIT C
PRE TRANSGRESSION
SUBAERIAL SURFACE
SL
SL
UNIT B
UNIT B
UNIT C
INITIAL FAST
TRANSGRESSION
UNIT B
UNIT C
SL
SHORT REGRESSION
SL
UNIT B
UNIT B
UNIT A
UNIT C
FINAL SLOW
TRANSGRESSION

FIGURE 11

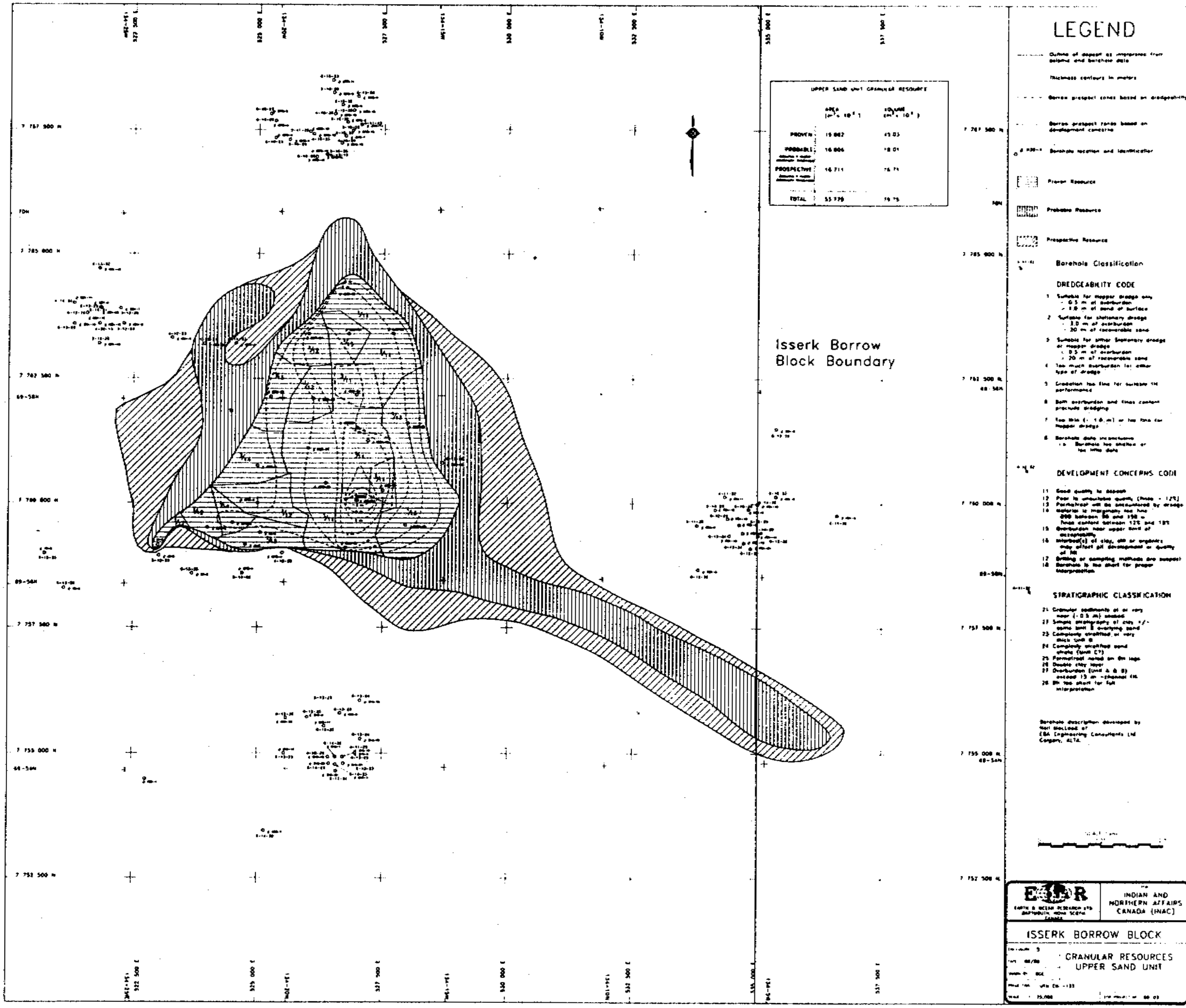
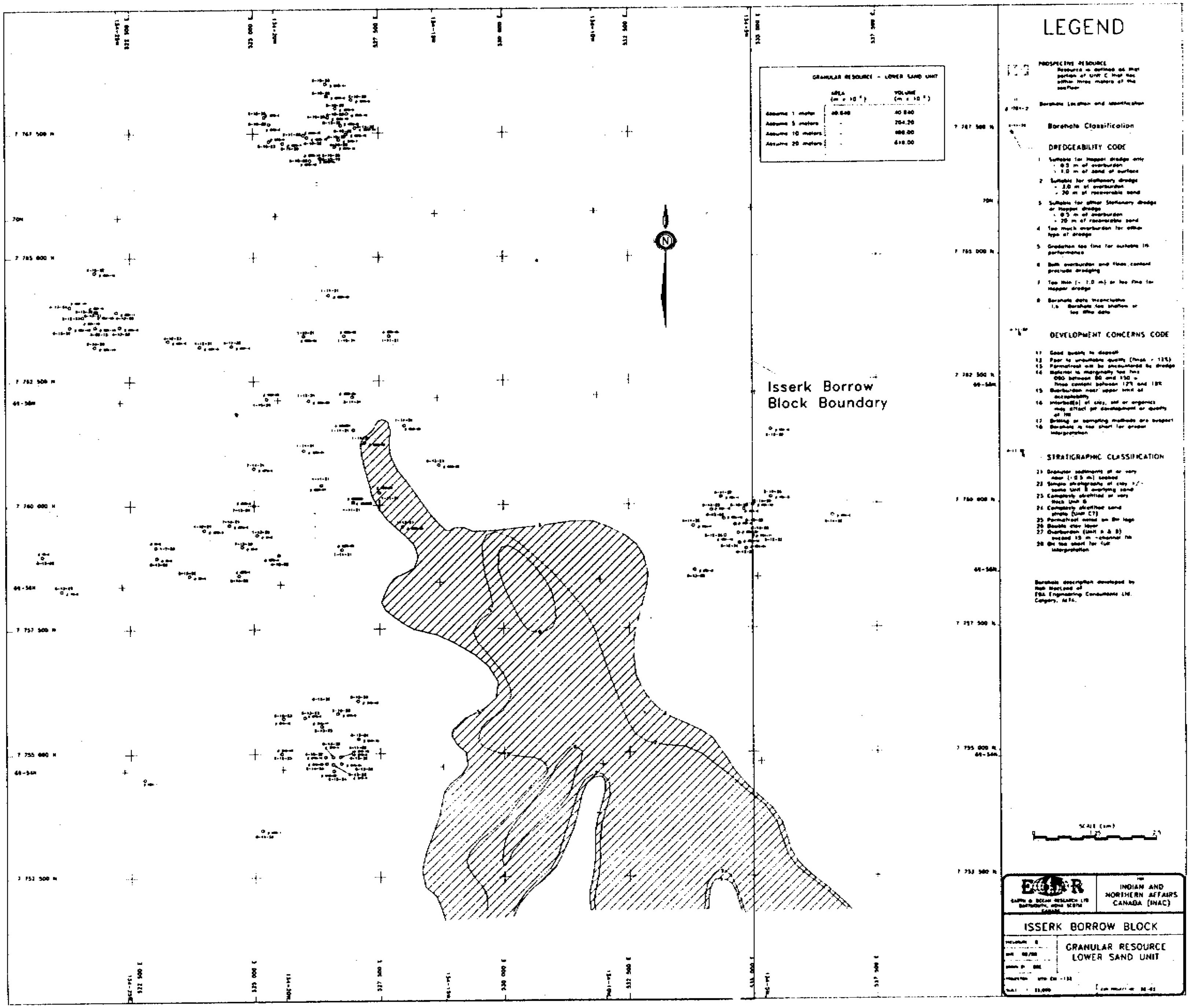

LEGEND
Borehole Classification
DREDGEABILITY CODE
DEVELOPMENT CONCERNS CODE
STRATIGRAPHIC CLASSIFICATION
PROVEN
PROBABLE
PROSPECTIVE
TOTAL
Isserk Borrow
Block Boundary
INDIAN AND
NORTHERN AFFAIRS
CANADA (INAC)
ISSERK BORROW BLOCK
GRANULAR RESOURCES
UPPER SAND UNIT

FIGURE 12



LEGEND
DREDGEABILITY CODE
DEVELOPMENT CONCERNS CODE
STRATIGRAPHIC CLASSIFICATION
Isserk Borrow
Block Boundary
INDIAN AND
NORTHERN AFFAIRS
CANADA (INAC)
ISSERK BORROW BLOCK
GRANULAR RESOURCE
LOWER SAND UNIT

FIGURE 13

SYNTHESIS AND INTERPRETATION OF BATHYMETRIC, GEOPHYSICAL, GEOLOGICAL AND GEOTECHNICAL DATA: ERKSAK BORROW BLOCK - SOUTH CENTRAL BEAUFORT SEA

Part or the Northern Oil and Gas
Action Program (NOGAP - Project A4-20)

Completed for:
Indian and Northern Affairs Canada
Natural Resources and Economic Development

Completed by:
Earth & Ocean Research Ltd.
Dartmouth, Nova Scotia
1988

Authors:

Lauchlin Meagher and John F. Lewis

Presented by:

John F. Lewis
Lewis Geophysical Consulting
376 Prospect Bay Rd.
Box 93, Site 15, RR#4
Armdale, Nova Scotia

Phone 902-852-3442 Fax 902-852-4788

ABSTRACT

The 2574 square km area of the Erksak Borrow Block area located in the southern region of the Central Beaufort Sea has been reviewed and assessed based on a comprehensive data base set of geophysical records and geotechnical boreholes. The borrow block lies primarily on the Tingmiark Plain region which is bounded by the Kugmallit Channel to the west and the Niglik Channels to the east. The detailed analysis of these data has allowed a subdivision of the Tingmiark Plain into the West Erksak High, the Erksak Channel, James Shoal Extension and the Uvilluk Channel. The West Erksak High has been further subdivided into subregions named the Erksak Crest, the Kogyuk Terrace and the Ukalerk Slope. The borrow region is primarily a drowned upland area of the Beaufort shelf of which the primary physiographic features were developed on the subaerially exposed surface of relatively coarser grained Unit C materials. These materials were deposited in a periglacial braided stream environment during the last low stand of sea level associated with the most recent glaciation. The region was inundated by the transgressing seas over the past 10,000 (offshore) to 3,000 (nearshore) years and as the regions were transgressed the sediments were reworked by the high energy environment of the nearshore breaker zone and continued wave base mobile zones until water depths increased significantly and these processes have basically ceased. The transgression and reworking processes has cut down the topographic high forming a transgression unconformity with the finer components winnowed out and transported to quiescent regions for re-deposition as Units A and B. The coarser materials were transported lesser distances, if at all and in some cases formed progradational wedges along the edges of the highs or were localized into sand ridges and sand bar features. Within some regions such as the Erksak Channel the distinction of transgressive formed features cannot be distinguished from pre transgression fluvial formed river bars or islands however.

The detailed analysis of this site has defined 33 prospective granular resource areas within the borrow block that potentially contain 18.9 billion cubic metres of resource material. Within these prospective regions a subset of 20 proven reserve regions are defined using the borehole and seismic coverage which indicate 720 million cubic metres of resources with a reasonably high probability of recoverability. With the available data resources and a comparison to the proven granular resources the prospective resource as been assessed a probable recovery volume of approximately 7.4 billion cubic metres though site specific borehole and acoustic confirmation studies would be required prior to any real resource utilization of these probable reserves.

INTRODUCTION

The Erksak Borrow Site study program was one component of a set of three concurrent studies that were initially conducted by Earth & Ocean Research Ltd. through 1987/88. These studies consisted of a two volume borrow study conducted for DIAND of which volume 1 is the Isserk borrow site area and volume 2 is the Erksak borrow site area. The third study was a regional surficial geology program for the South Central Beaufort Sea region which was completed for Steve Blasco of AGC. Steve will be discussing these regional geology results in a paper presented at this meeting.

Figure 1 is a map of the Beaufort sea showing the South Central Beaufort geological study area and the two concurrent borrow block study areas. These borrow study reports were completed by EOR under DSS contract AO632-7-5011/C1ST for Mr Bob Gowan of DIAND as a part of NOGAP project A4-20.

This paper is specifically in reference to the eastern Erksak study region (Fig 1) which is defined by:

ERKSAK BORROW BLOCK

NW: ZONE 8; 550,000; 7,800,000 (70°18'10" 133°40'15")
NE: ZONE 8; 609,000; 7,800,000 (70°17'04" 132°06'15")
SE: ZONE 8; 609,000; 7,750,000 (69°50'12" 132°09'57")
SW: ZONE 8; 565,000; 7,750,000 (69°51'04" 133°18'33")

These co-ordinates describe a quadrilateral that widens to the north. At its closest approach to land, the southern edge of the block lies approximately 9 km to the north of the Tuktoyaktuk Peninsula. The defined area encompasses approximately 2574 square kilometres of the Beaufort Shelf.

The specific purpose of this study has been to evaluate all (or as much as possible) of the geophysical and geotechnical data available within these regions with the primary mandate of attempting to quantize the locations and volumes of proven, probable and prospective granular resources that are present.

All three of the above referenced studies used a common data base set which was compiled and collated with the intent of using it over the three study programs mentioned above.

DATA BASES

The mandate of these studies was to evaluate all high resolution geophysical and geotechnical data that had been collected in this study area. This consisted of a massive amount of data though not all of these data could be found and accessed within a reasonable search effort for this study and a resulting more limited, though still significant, data set was actually used.

DIAND had initiated an earlier data compilation contract with McElhanney Services Ltd which was a library search of the industry geophysical reports to identify the industry geophysical data sets that were originally collected (McElhanney Services Ltd., 1988). A second program with EOR was conducted to compile and digitize the geophysical track data (Peters, 1988) and a third with EBA to identify and compile the geotechnical data bases within the regions (EBA, Isserk 1988a, Erksak, 1988b, and Central Beaufort, 1988c).

The initial tasks of this present study was to locate and copy as much as possible of the geophysical data sets for use within these evaluations. This was carried out over a month long period in Calgary with considerable appreciated help of the respective Beaufort Sea industry operators. A number of the geophysical records couldn't be located and after a reasonable effort it was decided to go with the data that had been collected.

NAVIGATION/GEOPHYSICAL DATA BASE

The track navigation and geophysical Data compilations included the entire area of the South Central Beaufort Sea geological study area. Figures 2 and 3 of the previous paper on the Isserk site outlined the entire navigation and geotechnical data bases available for the South Central Beaufort study area and will not be repeated hear.

Figure 2 in this paper shows the more limited area of the Erksak borrow site and the geophysical track lines and the location of the geotechnical boreholes available for just this area.

In general the overall geophysical data set is of good but variable quality. The quality is dependent on weather conditions at the time of collection. Difficult interpretation arises most commonly from real geologic conditions rather than poor collection technique. This is especially evident over the areas of main interest, the borrow sites. Records that display good resolution and are readily interpretable where they cross the channel areas to the east and west of the sites, become congested and the character difficult to determine over the coarser grained materials of the borrow sites.

Of the two main data sources, the boomer and the microprofiler, the microprofiler is the more suitable for the resolution of the nature of the surficial cover. The higher frequency envelope of this system makes the signal more susceptible to reflection and attenuation on coarser substrates and is therefore somewhat calibrated to discern sandy material from silty material. In the present application where the determination of coarse material at or very near the seafloor is critical, the profiler's lack of penetration ability in coarser sediments is of less importance than its ability to discriminate between sand and silt/clay. In comparing microprofiler data to borehole data it is observed that a strong correlation exists between signal attenuation and reflection character and sediment texture.

The boomer data is more valuable in establishing the seismo-stratigraphy of the study site. The reduced sensitivity to textural changes that limits the usefulness of the tool for discriminating coarse from fine material permits more consistent imaging to greater depths through coarse material. It is also noted that where boomer and borehole correlation is possible, a diagnostic seafloor return is also generated from this source over coarse substrates though it is less obvious than that of the microprofiler data.

Appendix 1 and 2 of the text reports (Meagher and Lewis, 1988a and b) describe the McElhanney data base which consisted of a compilation showing the surveys completed and line data originally collected and the results of the data search respectively which describes the listed/found and copied data used for this study. Appendix 2 data base gives the locations of the original data as of April 1988 and the copied data is currently resident at AGC in their data archives.

GEOTECHNICAL DATA BASE

The geotechnical data bases were compiled and inserted into ESEBase record form by EBA Engineering Ltd. for the entire south central Beaufort area. This data base project will be described more fully in a latter paper presented by Rita Olthof of EBA.

Initially 94 boreholes were identified within the Erksak Borrow Block (EBA, 1988b). While reviewing these data sets it was discovered that an additional 28 boreholes had been drilled within and just beyond the boundaries of the Erksak Borrow Block which proved useful in this study. These additional boreholes were reported within EBA's final (1988c) report.

The borehole coverage within the entire Erksak Borrow Block is sparse in relation to the overall size of the region. The boreholes tend to be clustered into 4 or 5 main groups which were drilled for exploration island sites and detailed dredging evaluations at specific locations. The coverage in these detailed regions is probably adequate for the detailed local assessment of borrow quality and quantity, however the detailed re-evaluation of these very limited areas has not been feasible within the context of this regional study.

Mr Neil MacLeod of EBA, via a subcontract to this study, assisted in developing a coding system for the sediments encountered within the boreholes which takes into account the sand and gravel quality and current dredging requirements and equipment restrictions of the Beaufort Sea Operators. The coding system has been used in the figures describing the borrow prospects and has been used for evaluation of the borrow potential of the respective sites when boreholes are available. This coding system is reproduced on the maps of the detailed borrow prospects discussed latter and for detailed discussions refer to Meagher and Lewis, (1988a and b).

SITE DESCRIPTIONS

Throughout this section, discussion and interpretation is restricted to the region of the Erksak Borrow Block. It is aimed primarily at the surficial physiography and shallow sedimentary section for the sole purpose of granular resource borrow evaluation. These restrictions encompass Units A, B and the top section of C which were initially defined in M.J. O'Connor's 1980 report. In order to facilitate the detailed discussion of this region the physiography of the area has been examined in detail and additional physiographic names beyond those presented by O'Connor (1982a) have been used to describe the bathymetric and shallow subsurface features within the area. These names are presented as informal names and are used primarily to aid the reader in following the detailed discussions within the original text report. Sedimentary Unit names referred to within this talk follow the O'Connor (1980) terminology conventions.

The interpretations have been directed specifically at the location and identification of coarser grained borrow materials and therefore does not follow the standard convention of most regional geologic descriptions. Thus sub surface maps generated are based on seismo-lithologic interpretations directed at delineating coarse materials and use ground-truth borehole evidence where possible. These maps are specifically <u>not</u> time stratigraphic interpretations which would be the norm for geological interpretation procedures.

BATHYMETRY

Figure 3 is a contour map of the bathymetric contours over the Erksak site at a 1 metre contour interval within regions where the CHS data was adequate and at a 2 m interval where the data was sparse. The high definition information (highly crenulated 1 m contours) has been developed by a careful re-contouring of Canadian Hydrographic Service (CHS) field sheet WA 10176 (water depth postings) which was resurveyed by CHS in 1986. The more smoothed contour area portions of the map have been constructed from the Natural Resource Series bathymetric map for the area. This latter bathymetric map was used to extend portions of the east and north zones of the site where the detailed newer field sheets were not available at the time of writing. The significant decrease in the crenulation of the contours, apparent on the produced map in these areas, is an artifact of this procedure and is not due to real changes in the seafloor microtopography.

The topography of the site is developed on a regional north-northwestward sloping plane. A minimum depth of 6 metres is recorded at the extreme southeast corner of the site and a maximum depth of 54 metres is noted at the extreme northwest corner. Superimposed on this plane are a number of distinct topographic features of varying scale that impart an irregularity to this surface. The larger topographic features are the physiographic regions: Tingmiark Plain, Kugmallit Channel, and Niglik Channels, outlined and described by O'Connor (1982a). Local variations in the bathymetry and the underlying paleosurface that influence and control the bathymetry permits the subdivision of the Tingmiark Plain into smaller component regions. These divisions and subdivisions are outlined on Figure 3. For ease of reference, the subdivisions are given informal names intended for use within the context of this report only.

The Tingmiark Plain has been subdivided into the West Erksak High, Erksak Channel, Uviluk High and Uviluk Channel. The West Erksak High is further divisible into the Erksak Crest, Kogyuk Terrace, and Ukalerk Slope. The southwest corner of the map area is occupied by the James Shoal Extension. The Kugmallit Channel and Niglik Channels are not subdivided.

SURFICIAL COVER

The distribution of the surficial sediment type exposed on the seabed within the Erksak Borrow Block is presented in Figure 4. The mapping of the surficial cover is based primarily on an examination of the seismic data, particularly the microprofiler records, validated wherever possible with visual descriptions of seabed samples. Where the seismically defined textural class boundary differs from that derived from the sample control, it is shown with a dashed line. Seismic data is used exclusively in the northwest and north where there are no boreholes and bathymetric field sheet coverage is not available.

Textural information from the tops of the 122 boreholes has been augmented by 164 seabed samples collected by the Canadian Hydrographic Service during the 1986 field season. CHS collected these seabed samples using a small grab sampler on a 5 km. grid over the area covered by Field Sheet WA 10176. Where shoal examinations were carried out, the seabed texture was determined using a smaller armed leadline sampling device. Size analysis are not routinely performed on grab samples by the CHS, and the samples are routinely discarded at sea after examination. The textures derived from the borehole logs are primarily based on visual description, though in some cases they are supported by lab testing. The surficial cover map is therefore restricted to broad textural classification.

The distribution of surficial sediments is topographically controlled. Sand and sand-dominant material is restricted to shoals although not all shoals are sandy. The Kugmallit Channel, and Erksak Channel are uniformly fine grained. With exceptions at the Amerk O-09 artificial island site and a sand sample taken from a small shoal located 4 km. to the northeast of the Amerk site. This shoal is anomalous in that it rises 6 metres to a water depth of 22 metres from an otherwise low relief plain and consists of sand where the surrounding area consists of soft clay. The feature has the appearance of an artificial island though the CHS field sheet records the location of artificial islands and this shoal is not noted as such.

Over the West Erksak High the sediment distribution is more varied, but still related to the local relief, with sand or muddy sand recorded over the ridges of the Erksak Crest and sandy mud or mud noted within the depressions. The outline of the distribution of sand at the seafloor as determined from the seismic data is displayed on the map with a dotted line. A comparison of this outline with the distribution mapped from the CHS samples shows that the fine cover is more extensive than the seismics alone would suggest. This is most likely the result of a veneer of fine material resting on the sand substrate. The thickness of this veneer would not exceed about 30 cm. or it would be visible on the microprofiler records.

Seismic and borehole data over the Uviluk High indicate that sand covers most of the surface with mud occupying two northwest-southeast trending depressions.

The southern shoreward portion of the area over the James Shoal Extension is generally covered by soft clay or mud. A sand sample is noted next to the Alerk P-23 artificial island and a second sand sample is recorded 3 km. to the east on the flank of the main shoal of the James Shoal Extension. The CHS sample grid did not sample the top of the main shoal but it is surmised that the sand sample is representative of the surficial cover of this feature.

The fine material surrounding the coarse deposits consist uniformly of inorganic clays with very occasional black organic streaks. They are generally low to medium plastic with a water content that varies from about 20% to 45% (Unit B type clays). The clays also vary from soft to very stiff. Trace amounts of sand in fine laminations are noted in several samples as well as trace amounts of silt, and shells.

SUB-SURFACE GEOLOGY

The sub-surface geology within the site can be described within the framework of O'Connor's stratigraphic model for the Beaufort shelf (Units A, B and C). However, the design of this program has been aimed specifically at "Borrow Materials" and as was noted at the Isserk Site a very complex relationship can exist with regards to Units B and C as far as coarser grained sands materials distribution is concerned. As there is no reason to assume a different geological scenario for the Erksak site and since this much larger region does not have the density of borehole control that was available at Isserk a tact of defining the distribution of the top of potential borrow material (sands) was taken as opposed to attempting to map the most recent regional unconformity (top of C). This concept worked well with the microprofiler and boomer data sets as in many instances the actual top of the unconformity surface could not be acoustically mapped beneath sandbars and shoals composed of the reworked Unit B materials. No attempt to differentiate upper and lower sand prospects on the maps of this study has been made as the added complexity would not have been viable on such a large and complex area. This distinction has to be left to more detailed site specific borrow target studies.

With this mandate in mind the seismic and borehole data sets were combined to produce a depth structure map of the Top of Prospective Sands within the site area (Figure 5). This surface is not a time stratigraphic horizon but is a composite of, in many cases, overlapping reflecting horizons of laterally discontinuous higher amplitude reflections interpreted to be the top of shallow sands or prospective borrow materials within the area. While these horizons are not time synchronous, when taken together, they form a morphological pattern that suggests a depositional system acting over a short period of time which is likely associated with a high energy shallow water nearshore active erosion and redistribution environment. This environment has migrated shoreward with time associated with the most recent marine transgression of the area.

Figure 6 is an isopach contour representation of the soft surficial sediments overlying these prospective sands. This information is necessary for defining regions of prospective resource because of the limiting constraint of having a maximum of 3 m of overlying material that might have to be stripped away to get at the resource. Note from the structure map that the definitions of the supplementary physiographic regions are much more distinct where they were quite muted though still evident on the bathymetric map presented earlier.

These maps indicate that the physiographic highs typically have a thin or absent soft sediment accumulation and irregular patterns of distribution. Within the physiographic lows the accumulations of soft materials are controlled by the well developed topography of the underlying surface. The Kugmallit Channel shows thick accumulations (up to 24 m) of soft materials in the south and thinning toward the north (between 1 and 11 m). A similar pattern is noted in the Erksak Channel. In the east in the Uviluk Channel accumulations are not as well defined due to the general lack of data though range from 4 to 7 m in thickness.

DEPOSITIONAL SUMMARY

Based on the geophysical and sampling data a tentative depositional summary of the upper 20 m of the sedimentary column has been developed. The Beaufort sea shallow geological sequence consists of a number of repeated cycles of marine incursion separated by periods of subaerial exposure related to glacially induced low stands of sea level. This sequence has been built on top of a continued regional basin subsidence in the region and there are believed to be approximately six or more cycles preserved within the Quaternary section which constitutes the upper 400 to 600 m of sedimentary section in the Central Beaufort area. This study concentrates on the upper 20 m of this section which represents the sub-aerially exposed surface developed prior to the most recent marine incursion of the area and the post transgression deposited sediments. These sediments represent the accumulated deposition over approximately the last 12,000 to 14,000 years. During this period average sedimentation rates of up to 3 to 4 m per 1000 years during the early part of the cycle have occurred assuming age dating within the sections have been accurate.

The developmental history of this site essentially consisted of the very fast deposition of Unit C sands as a glacial outwash and braided stream system which existed during the last glaciation from about 14 - 18 ka until inundation by the re-advancing seas. These periglacial coarser grained materials were sub-aerially exposed and subject to significant permafrost aggradation prior to inundation. The 11 boreholes in the area which fully penetrate this unit indicate that Unit C is from 35 - 50 m thick.

The region was inundated by the advancing seas during approximately 8,000 (offshore) to about 3,000 (nearshore) years before present based on the current water depths and the presently understood Relative Sea Level curves for the area (Hill et.al., 1985).

The physiographic regions as defined in this study are believed to outline the last subaerially exposed topographic conditions prior to inundation. The Erksak High, James Shoal Extension and Uviluk High represented topographic promontories that were bounded by the Uviluk, Erksak and Kugmallit Channels. The channels were likely existent some time prior to inundation though because of the excessive downcutting in the Kugmallit Channel it is speculated that the Erksak and possibly the Uviluk Channels were abandoned some time prior to inundation. Thus the sand bar / channel island features noted in the Erksak channel are interpreted to be riverine and not transgressive in origin.

The deeper Kugmallit Channel was the first region to be inundated and as sea levels rose the Erksak Channel would have been inundated approximately coincident with the Ukalerk Slope. Since the remnant channel and knoll topography is still preserved on the Ukalerk Slope it is presumed this region was inundated rapidly. The broader contours of the Kogyuk Terrace imply that sea level rise slowed and the region was cut back further by shoreline retreat associated with the breaker zone. This factor suggests the region might be richer in concentrated gravels than other areas though this is not confirmed at this time. The last areas to be inundated would have been the upland Erksak Crest, James Shoal Extension and the Uviluk High.

Both prior to and during inundation of the higher areas subaerial erosion would have concentrated the coarser fraction materials along the edges of these highs. This is evident on the seismic records over the edges of both the Kugmallit and Erksak Channels. Just after inundation in any particular region the local areas would have undergone a high energy environment which transported the fine materials offshore while the coarser materials would remain virtually in place. These remnant materials formed the local bars and foreset bedded coarser materials of the surficial Unit B sediments which are quite variable throughout the area. As transgression continued and the regions passed below wave base a transition to finer sediment deposition occurred with eventual deposition of the finer facies Unit B clays and finally the Unit A clays. Areas where sands are still exposed at the seabed are presumably still under the influence of wave base erosion and winnowing of the finer sediments, though at present most of the Erksak block would only be significantly affected during major storm events.

GRANULAR RESOURCE MODEL AND EVALUATIONS

DISTRIBUTION

Figure 7 is a map of the granular resource prospects determined within the Erksak Borrow Block area. The tight horizontal hatching represents areas defined as proven resource zones based on the borehole sampling and the seismic information and the broader vertical hatching represent areas of prospective resource based on seismic evidence and some limited surface and borehole samples.

The outer boundaries of these prospective zones have been defined by the 3 m contours of the soft surficial sediment isopach map presented in Figure 6 as this is the present day economic limitation of conventional dredging equipment when overburden stripping is required. Areas with a zero-cover isopach might be considered higher priority from a site development point of view.

Because of the large extent of the region the potential borrow sites have been numbered from 1 to 33. In the large areas of virtually continuous accessible resource on the West Erksak High and the Uviluk High a subdivision has been made based on the localized areas of the zero-cover isopaches. Where possible the boundaries between individual sites follow the maximum thickness of soft sediment cover. Within the Erksak Channel and the Kugmallit Channel most of the resources have at least one metre of soft cover and therefore the boundaries of the prospective resource is defined by the 3 m isopach contours. In addition to these prospects two prospects on the James Shoal Extension have been defined by borehole and sample information only.

Table 1 indicates the surface areas of each of the prospects and is broken down into the area between each set of overburden isopach contours out to the 3 m maximum. It should be noted that some of the identified prospects, or at least portions of them have been concluded to be marginal in quality as far as their suitability of construction materials are concerned. Given the limited ground truthing available at this time they are included within the prospective volume estimates pending further direct sampling evaluations.

Prospects 1 to 12 are located on the West Erksak High, 13 to 20 within the Erksak Channel, 21 and 22 on the Uviluk High, 23 to 27 on James Shoal Extension, and 31 to 33 within the Kugmallit Channel. Prospects 28 to 30 are on the James Shoal Extension but have been defined by borehole and grab sampling only.

From the table summary 364 km^2 show no or virtually no surficial cover (30 cm or less from the acoustics), 146.8 km^2 lie between the 0 and 1 m contours, 294.1 km^2 lie between the 1 and 2 m contours, and 192.2 km^2 lie between the 2 and 3 m contours. In total 997 km^2 of the total 2574 km^2 Erksak Borrow Block area are considered to be prospective granular resource areas.

Within this thousand square kilometres a smaller subset of area has been designated as proven reserves based on the borehole and sample control which has allowed us to put a quality factor on the sediment resources. These tightly hatched areas on Figure 7 have been based on an arbitrary assumption that the borehole data represents a region within a one-half km radius of the boreholes. Thus a sub-prospect is defined either by a 1 km diameter circle or a perimeter defined by a grouping of these circles and also limited by the 3 m overburden contour when appropriate. These sub-prospects have been given designations such as "p4b" where the "p" indicate a proven resource, the "4" indicates that it is within prospective area #4 and the "b" is an alpha designator identifier for that particular sub-prospect.

No attempt has been made on the plot of Figure 7 to spatially define the probable resources within the area as limitations on the seismic coverage would not allow a clear definition that could be mapped. Within the following volume of resource discussion a summary attempt has been made to delineate the probable reserves available within the prospective zones.

RESOURCE PROSPECT GRANULAR VOLUME ESTIMATES

PROVEN

Of the 33 prospects outline above only 8 have been sampled by borehole testing with sufficient detailed analysis to allow designation of the sediments as a proven reserve. Table 2 summarizes the proven sub-prospects identifies the borehole control and assigns a short summary quality evaluation to each. In reviewing the boreholes an estimate of the volume of useable borrow material has been made either on the basis of sampling depths of the boreholes (limit of sample depth) or on layering within the sediments which would indicate that fines are below and it would not be worth deeper dredging. Their dredgeability in terms of dredge type has also been indicated. This is based primarily on the overburden cover and the granular materials.

In total there are 60.3 km^2 of proven resource areas defined and these areas provide a relatively firm potential for 720 million cubic metres of recoverable resource materials within the Erksak Borrow Block.

Within the original report there are detailed discussions on each of these sub-prospects which cannot be discussed here.

PROSPECTIVE

Table 3 combines Table 1 with an estimated volume calculation of granular resource that is dredgeable by various dredging techniques that are currently in use. This prospective resource estimate does not take into account a quality factor since only a few of the sites have been tested by borehole sampling.

The breakdown of this table assumes Hopper Trailer dredges that can mine the surface sands to a depth of 2 m below the seabed and are limited to 1 m or less of soft surficial sediment cover for stripping purposes. In this instance the potential resource recoverable is calculated in the 8th and 9th columns with the total resource recoverable by this method in column 10. Assuming a stationary suction dredge which can strip off up to 3 m of overburden and potentially mine to a depth of 20 m below the seabed, total prospective reserves for depths of 5 and 20 m sub-seabed are computed. These areas and volumes include the proven reserve areas of the previous section.

With these processes a volume of 948 million cubic metres is potentially recoverable by Hopper Trailer Dredge and if Stationary Suction Dredges are used a total region potential of 18.9 billion cubic metres of prospective resource are possible.

PROBABLE

The above two sections have provided estimates of the proven and prospective resources within the Erksak Borrow Block. An estimation of the probable proportion of useable reserve from the prospective total above is attempted here. Probable reserve is defined a sands and gravels whose existence and quality has been inferred on the basis of limited ground truthing information and/or several types of indirect evidence, including sidescan sonar, shallow high resolution seismic, echo sounding and/or bathymetric and/or geologic considerations. These estimates are based on an understanding of the proven reserves determined by boreholes and a comparison with the seismically mapped prospective zones to provide a "best estimate" of probable resource for planning purposes.

Within the Erksak borrow block there are basically three types of prospective granular resource deposits which have been outlined by the seismic mapping program. The upland regions of the West Erksak High, the Uviluk High and the James Shoal Extension contain two basic reserve types. The bar and island features within the Kugmallit and Erksak Channels are the third type. On the upland regions, the reserve consists of exposed remnants of Unit C sand materials as the basal material and of the reworked coarse materials which are noted as migrational ridges and progradational wedges that have extended the upland regions into the lower lying channels. The reworked materials may represent Unit C materials if they had been deposited prior to transgression within a subaerial or riverine environment or lower facies of Unit B materials if deposited in the nearshore breaker zone or current controlled deposition associated with the last transgression of the sea across the region.

The available data have been reviewed on the basis of probability of occurrence of unacceptable sediment layers or limiting zones within each deposit. Although it has not been possible to map, in detail, specific features which indicate a significant probability of containing higher quality materials, volumes have therefore been estimated by applying an interpretive reduction factor to the estimates of prospective resources. Table 4 summarizes these estimates of probable resources in the Erksak Block.

Utilizing these quality factors the Probable granular resource estimate for the Erksak Borrow block reduces to 7.4 billion cubic metres from the almost 19 billion cubic metre Prospective reserve. In particular the area of the James Shoal Extension has been significantly restricted in these evaluations because of the paucity of data over the feature. Therefore the larger area of the entire feature has been excluded from the tables presented here. If it were to be included an additional 4 to 6 billion cubic metres might be added within the prospective category of borrow reserve of which 2 to 3 billion might be considered probable.

CONCLUSIONS

The 2574 square kilometre area of the Erksak Borrow Block located in the south central Beaufort Sea continental shelf contains significant quantities of proven, prospective and probable fine to medium grained sandy granular resource materials. The analysis of this region did not indicate any significant concentrations of coarser grained sand or gravel materials though numerous trace indications were noted from the borehole records.

The region consists of a drowned upland region composed primarily of medium to fine grained sands (Unit C) which had been dissected by a series of channels prior to inundation by the sea within the last 3000 to 10,000 years. During this time range the low lying areas of the Kugmallit Channel were inundated toward the southern block area at approximately the same time as the northern upland areas of the prospect were just commencing the transgression process. During this period, the shallower regions of the possibly more ancient Erksak channel system were partially inundated and at some point left the Uviluk High and the West Erksak High as nearshore island features while the James Shoal Extension area was a promontory point either attached to the mainland or itself cut off from the mainland by the Uviluk/Niglik Channel system further to the east. All through this process the upland regions were being eroded both subaerially and by the nearshore breaker zone and wavebase effects of the advancing seas. As sea level rose further the upland regions were eventually inundated by the sea and were modified by the transgressive erosion activities as the sea progressed through the high energy breaker and wave base erosion zones toward the present day deeper water conditions.

Throughout the transgression process the surficial sediments of the upland areas were reworked to form a transgression unconformity with the finer components winnowed out and transported to quiescent regions for re-deposition as Unit B or Unit A materials. The coarser grained sands tended to be transported shorter distances, if at all, and in some cases formed progradational wedges along the edges of the highs or were localized into sand ridges or sand bar features when conditions were correct. These materials form a portion of the granular resource in the region while the main body of the resource is composed of the deeper Unit C materials.

Similar processes were at play prior to marine inundation within the subaerial channels of the study area. These process were river and or wind dominated and contributed to the progradational wedges seen adjacent to the higher regions and formed the river bar features noted within the Erksak Channel and the sub-channels noted within the eastern portion of the Kugmallit Channel. These sedimentary features are technically attached to Unit C, however in many cases the distinction between this unit and the higher energy transgressive facies of Unit B are not distinguishable from the seismic or borehole data.

As regions of the borrow site passed through these active zones, accumulations of finer grained sediments began to predominate. These accumulations first began in the deeper water zones and topographic lows and progressed higher on the upland areas as the transgression continued to its present condition.

The original pre-transgression topography and the effects of the transgression process have resulted in the present day conditions within the Erksak Borrow Block. The distribution of the potential borrow materials are concentrated on the upland areas, though significant recoverable materials are available within the Erksak Channel. Much of the eastern portion of the site has not been adequately evaluated within this study as little seismic or borehole data was available. However bathymetric studies suggest that this area likely to be relatively silt or clay covered which reduces its attraction.

The geophysical and geotechnical data utilized through this survey did indicate the presence of shallow subseabed permafrost in the area. It is however of the Hummocky type APF and relatively randomly distributed. In most cases, it is greater than 10 metres below the seabed. As a result this hazard to dredging will locally be significant to the utilization of deep Stationary dredging methods. On the regional basis however, it is felt that permafrost does not seriously degrade the assessment of the viable resource in the area.

Analysis of the geophysical and geotechnical data base has shown that almost 720 million cubic metres of relatively fine grained granular resource have been proven. Within the entire Borrow Block the geophysical data have outlined a maximum potential of some 19 billion cubic metres of prospective borrow material of which about 950 million m^3 could potentially be recovered by Hopper Trailer dredge (5%). Of this prospective recoverable material it is estimated that something in the order of 7.4 billion cubic metres would be in the category of probable recoverable resource when quality factors and an estimation of the variability of subsurface conditions are taken into account. It is noted here that the entire James Shoal Extension physiographic region may be considered as a prospective area but was not included in these volume estimates because of the paucity of available data in this area.

These estimations are based primarily on the relatively large, but variously distributed geophysical and geotechnical data sets that are presently available for the area. It is noted here that these data sets are not sufficient to define an actual borrow utilization development program and further detailed site survey and borehole quality assessment programs are required within any local area prior to commencing any actual dredging activities.

LIST OF FIGURES - ISSERK BORROW SITE

TABLE 1 AREAS OF GRANULAR RESOURCE PROSPECTS - ERKSAK

Site No.	Water Depth range (m)	AREA (sq. km) Overburden Cover Thickness 0 m	0-1 m	1-2 m	2-3 m	TOTAL
		West Erksak High				
1	15-26	217.0	42.1	47.8	21.8	328.7
2	26-28	16.8	10.2	16.4	8.4	51.8
3	23-25	10.2	5.8	10.9	5.6	32.5
4	26-34	32.1	13.4	19.6	11.7	76.8
5	36-48	2.1	2.0	7.2	1.7	13.0
6	34-36	2.9	7.2	5.7	2.0	17.8
7	36-38	1.8	3.9	7.8	10.6	24.1
8	37-38	1.2	1.6	7.7	2.7	13.2
9	32-35	5.7	8.7	18.0	6.7	39.1
10	32-34	0.7	2.4	4.6	2.0	9.7
11	28-33	1.6	8.6	14.7	6.9	31.8
12	24-29	8.9	21.0	14.3	15.5	59.7
		Erksak Channel				
13	30-35	-	1.1	13.5	7.8	22.4
14	30-33	-	-	7.3	7.2	14.5
15	28-31	-	-	7.0	5.4	12.4
16	14-19	-	3.3	8.4	15.6	27.3
17	20-33	2.2	4.4	30.9	22.5	60.0
18	16-23	-	-	20.4	6.2	26.6
19	15-19	-	-	-	6.5	6.5
20	14-20	-	-	9.5	10.9	20.4
		Uviluk High				
21	26-30	23.0	2.8	4.8	4.8	35.4
22	30-32	16.6	5.5	5.5	4.5	32.1
		James Shoal Extension				
23	26-28	-	1.1	1.4	0.7	3.2
24	27-30	-	1.1	8.4	1.6	11.1
25	28-30	-	-	0.2	0.3	0.5
26	28-30	-	-	0.1	0.3	0.4
27	28-30	-	-	0.3	0.6	0.9
		JSE (boreholes only)				
28	20-22	0.8	-	-	-	0.8
29	8-11	5.3	-	-	-	5.3
30	8-11	15.0	-	-	-	15.0
		Kugmallit Channel				
31	46-51	-	0.6	1.7	0.7	3.0
32	50	-	-	-	0.3	0.3
33	50-55	-	-	-	0.8	0.8
TOTAL AREAS		363.9	146.8	294.1	192.2	997.0

TABLE 2 PROVEN GRANULAR RESOURCE ESTIMATES

PROSPECT ID	WATER DEPTH m	AREA $X10^6$ m^2	BOREHOLES ID REFERENCE NO.'S	QUALITY COMMENTS	DREDGEABILITY	VOLUME $X10^6m^3$
p1a	14-17	8.57	EK84S01 - EK84S07, EK84S1A - EK84S7A, UB80-40, UB80-41	SP-SM tr silt & clay	variable Hop & Sta	85
p1b	20-23	7.06	UB82S04,S21,S22,S23,S24,S25,S3A, UB82V05,V06,V20,V21, SUB8301	SM to SP, some silt layers	Hop & Sta	141
p1c	23-25	12.67	BTN1-1,-4,-5,-6,-7,-8,-9, UB80-38, UB82S26, UB82V18,V19	SM, some silt clay layers	Hop & poss. Sta	123
p1d	23-24	0.79	UB80-39	SM to SP	Hop & Sta	16
p1e	25-26	0.44	KBVC03	SP, SP-SM loose S & org to 2.8m	Hop & ?Sta	8
p1f	26	1.52	KBBH1 - KBBH5	SM to SP, clean tr grav.	Sta	30
p1g	24	0.79	SUB83S01	SM to SP	Sta & Hop	16
p1h	25-26	0.79	NT82S01	SP, clay @ 5.5m peat @ 6.5	Hop	4.3
p1i	22-23	0.79	UB82S01,S02	SP to 10m tr silt	Hop & Sta	8
p1j	26-27	0.44	UB80-45	SP, SP-SM 2.5m clay, sand to 10.5m	n/a	0
p2a	26-28	3.36	UB82V09 - B82V14	SP occ SM tr silt	Hop to Sta	27
p4a	28-30	2.77	BTN1-12,-13,-14	SP to SC some silt & clay sampled to 5 m	Hop ?Sta	14
p4b	29	0.79	UB82V07, V08	excessive fines marginal	n/a	0
p4c	26	1.17	KY82S02, S03	SP, SP-SM, tr silt & grav	Sta	22
p14a	32	0.91	NU82S01, S03	SM to ML too much fines	n/a	0
p18a	21-22	0.085	UB80-42	SM only sampled to 7 m	Sta	0.4
p21a	26-28	0.79	UV80-54	SM w some silts sampled to 9 m	Hop & Sta	7
p22a	29-32	10.54	FUVI1,1A, UV80-46 to 52, UV80-55 to -58	SP - SM tr silt, clay & grav	Hop & Sta localized	105
p28a	22	0.79	UB80-44	SP-SM some thin silt/clay layers	Sta (to 14 m)	10
p29a	8-12	5.27	AL80-1 to -18	SP, SP - SM some thin silt	Hop & Sta localized	100
	TOTALS	60.335 km^2			TOTAL PROVEN VOLUME	720.7

TABLE 3   PROSPECTIVE GRANULAR RESOURCE VOLUME ESTIMATES

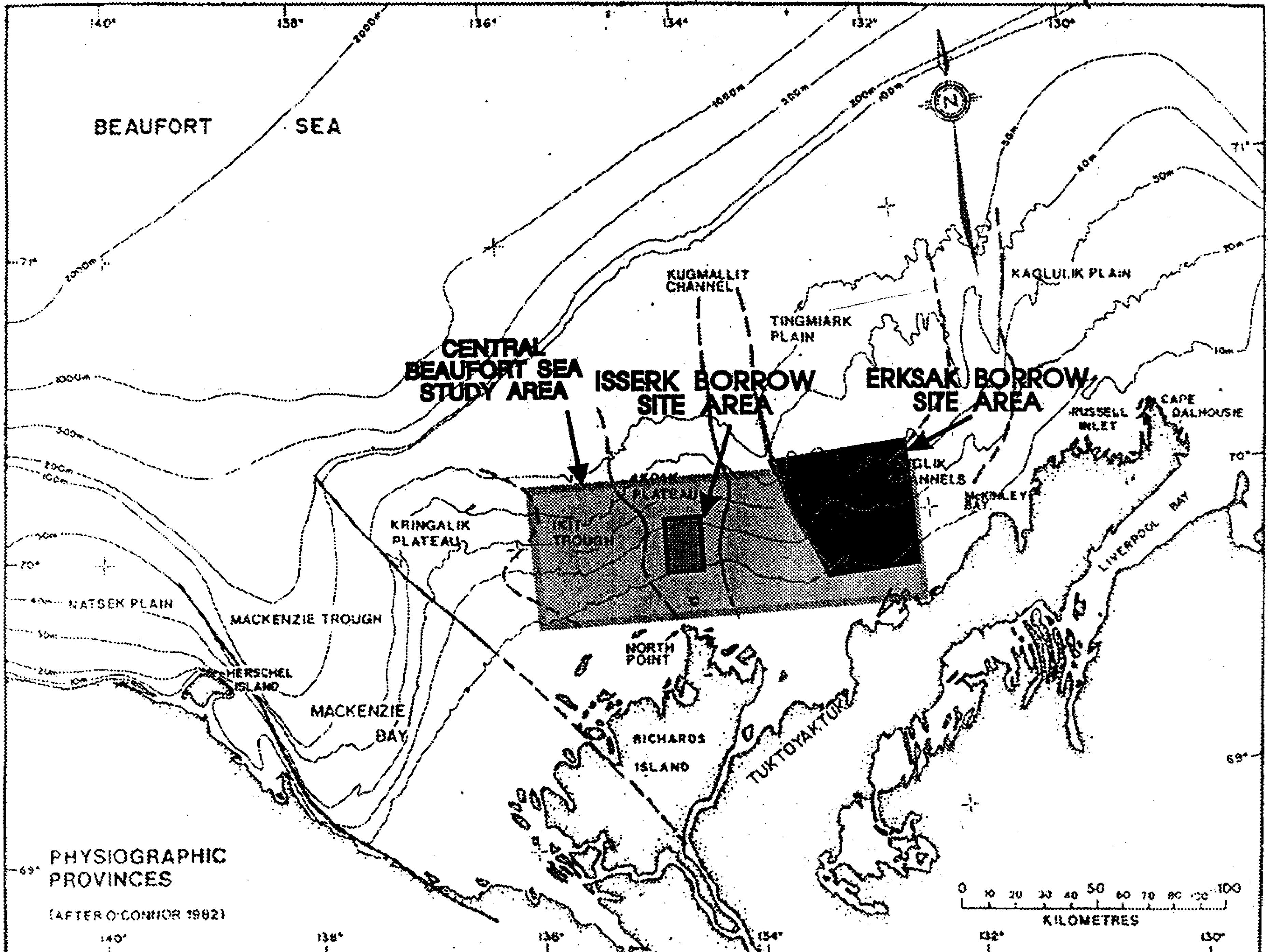
	BORROW SITE	WD m range	AREA 0m cont km^2	AREA 0-1m cont km^2	AREA 1-2m cont km^2	AREA 2-3m cont km^2	VOLUME ESTIMATES TIMES 10^6 cubic m. HOPPER DREDGE TO 2m DEPTH under 0m	HOPPER DREDGE TO 2m DEPTH under 0-1m	TOTAL HOPPER	STATIONARY SUCTION TO 3m OF COVER 5m DEPTH	STATIONARY SUCTION TO 3m OF COVER 20m DEPTH
						West Erksak High					
*	1	15-26	217.0	42.1	47.8	21.8	434.0	63.2	497.2	1,496.3	6,426.8
*	2	26-28	16.8	10.2	16.4	8.4	33.6	15.3	48.9	208.3	985.3
	3	23-25	10.2	5.8	10.9	5.6	20.4	8.7	29.1	129.3	616.8
*	4	26-34	32.1	13.4	19.6	11.7	64.2	20.1	84.3	318.7	1,470.7
	5	36-48	2.1	2.0	7.2	1.7	4.2	3.0	7.2	49.0	244.0
	6	34-36	2.9	7.2	5.7	2.0	5.8	10.8	16.6	71.9	338.9
	7	36-38	1.8	3.9	7.8	10.6	3.6	5.9	9.5	80.4	441.9
	8	37-38	1.2	1.6	7.7	2.7	2.4	2.4	4.8	46.9	244.9
	9	32-35	5.7	8.7	18.0	6.7	11.4	13.1	24.5	147.4	733.9
	10	32-34	0.7	2.4	4.6	2.0	1.4	3.6	5.0	35.4	180.9
	11	28-33	1.6	8.6	14.7	6.9	3.2	12.9	16.1	115.4	592.4
	12	24-29	8.9	21.0	14.3	15.5	17.8	31.5	49.3	227.8	1,123.3
						Erksak Channel					
	13	30-35		1.1	13.5	7.8	0.0	1.7	1.7	71.7	407.7
*	14	30-33			7.3	7.2	0.0	0.0	0.0	43.6	261.1
	15	28-31			7.0	5.4	0.0	0.0	0.0	38.0	224.0
	16	14-19		3.3	8.4	15.6	0.0	5.0	5.0	83.3	492.8
	17	20-33	2.2	4.4	30.9	22.5	4.4	6.6	11.0	195.2	1,095.2
*	18	16-23			20.4	6.2	0.0	0.0	0.0	86.9	485.9
	19	15-19				6.5	0.0	0.0	0.0	16.3	113.8
	20	14-20			9.5	10.9	0.0	0.0	0.0	60.5	366.5
						Uviluk High					
*	21	26-30	23.0	2.8	4.8	4.8	46.0	4.2	50.2	156.4	687.4
*	22	30-32	16.6	5.5	5.5	4.5	33.2	8.3	41.5	138.3	619.8
	27	28-30			0.3	0.6	0.0	0.0	0.0	2.6	16.1
						James Shoal Extension					
	23	26-28		1.1	1.4	0.7	0.0	1.7	1.7	11.6	59.6
	24	27-30		1.1	8.4	1.6	0.0	1.7	1.7	38.4	204.9
	25	28-30			0.2	0.3	0.0	0.0	0.0	1.5	9.0
	26	28-30			0.1	0.3	0.0	0.0	0.0	1.1	7.1
						JSE (boreholes only)					
*	28	20-22	0.8				1.6	0.0	1.6	4.0	16.0
*	29	8-11	5.3				10.6	0.0	10.6	26.5	106.0
	30	8-11	15.0				30.0	0.0	30.0	75.0	300.0
						Kugmallit Channel					
	31	46-51		0.6	1.7	0.7	0.0	0.9	0.9	10.4	55.4
	32	50				0.3	0.0	0.0	0.0	0.6	4.4
	33	50-55				0.8	0.0	0.0	0.0	1.9	13.1
TOTALS			**363.9**	**146.8**	**294.1**	**192.2**	**727.8**	**220.2**	**948.0**	**3,990.0**	**18,945.0**

Note: "*" indicates borehole control within the Prospect Area

TABLE 4 PROBABLE GRANULAR RESOURCE ESTIMATE

SITE ID	PROVEN 10^6 m^3	PROSPECTIVE 10^6 m^3	PROBABLE 10^6 m^3	COMMENTS
		West Erksak High		
1	431.3	6,426.9	3,000	|- Trend toward increasing fines in a northerly
2	27	985.3	400	| direction with considerable fine bedding noted
3	na	616.8	300	| on the seismic records suggesting an increase
4	36	1,470.7	500	| in the silt and clay component of the sediments.
5	na	244.0	100	| Resource quality is noted to vary significantly
6	na	338.9	100	| with small positional change in borehole tests
7	na	441.9	150	| thus estimate 50 to 60 percent of the prospective
8	na	244.9	100	| resource will be unacceptable though on a
9	na	733.9	200	| localized basis.
10	na	180.9	75	|
11	na	592.4	200	|
12	na	1,123.3	400	|-
		Erksak Channel		
13	na	407.7	40	- Northern reworked - assume low quality factor
14	0	261.1	25	- " " " " " "
15	na	224.0	20	- " " " " " "
16	na	492.8	120	- increasing quality southward
17	na	1095.2	210	- increasing quality southward
18	0.4	485.9	240	- good quality proven borehole
19	na	113.8	70	- J.S. Extension
20	na	366.5	220	- J.S. Extension
		Uviluk High		
21	7	687.4	350	|- good proven component, therefore estimate
22	105	619.8	310	| 50% utility with some localized fine lenses
27	na	16.1		|- and ignore prospect 27
		James Shoal Extension		
23	na	59.6	10	|- small targets with probable fair to good
24	na	204.9	40	| quality but sediment cover reduces probability
25	na	9.0	2	| of utilization
26	na	7.1	1	|-
		JSE (boreholes only		
28	10	16.0	6	|- Good potential with some fines component
29	100	106.0	75	| and moderately well proven though significant
30	30	300.0	150	|- surficial cover striping required
		Kugmallit Channel		
31	na	55.4	0	| small targets of reworked sediment likely
32	na	4.4	0	| containing significant fines and significant
33	na	13.1	0	| surficial cover to strip off.
TOTAL	**747.7**	**18,945.0**	**7,414**	

Note: na = no samples available to prove reserve



LOCATION DIAGRAM

FIGURE 1

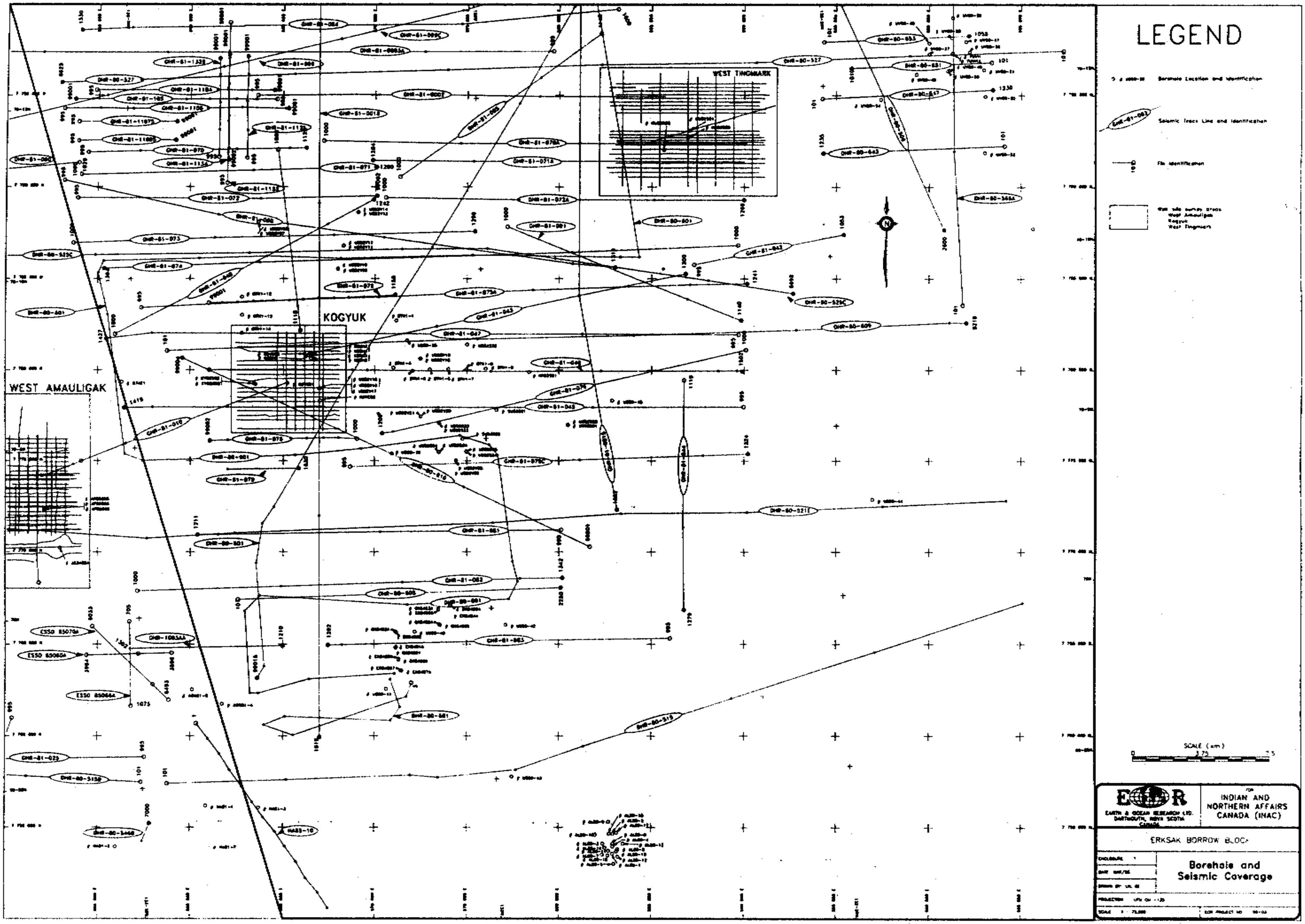
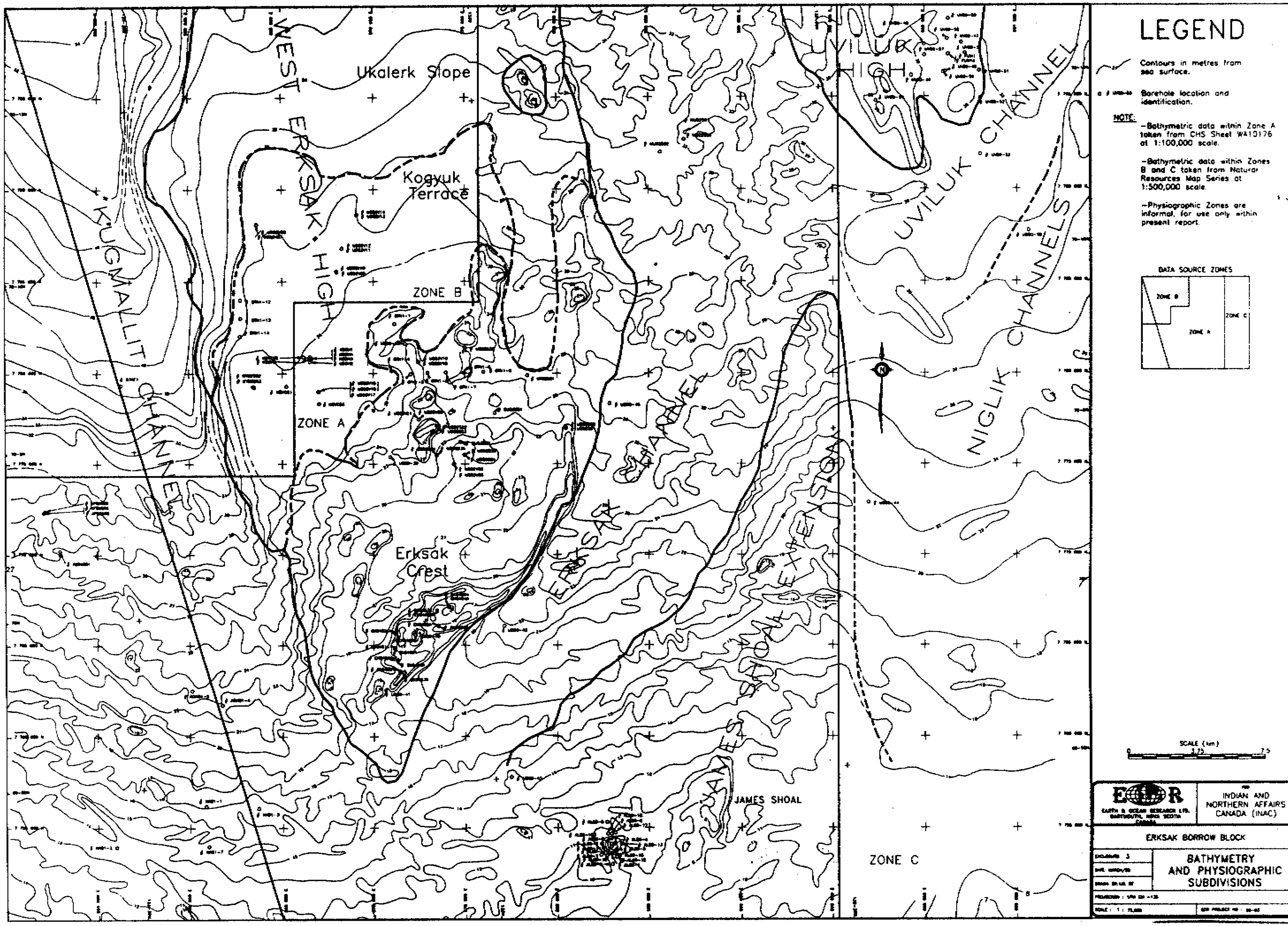
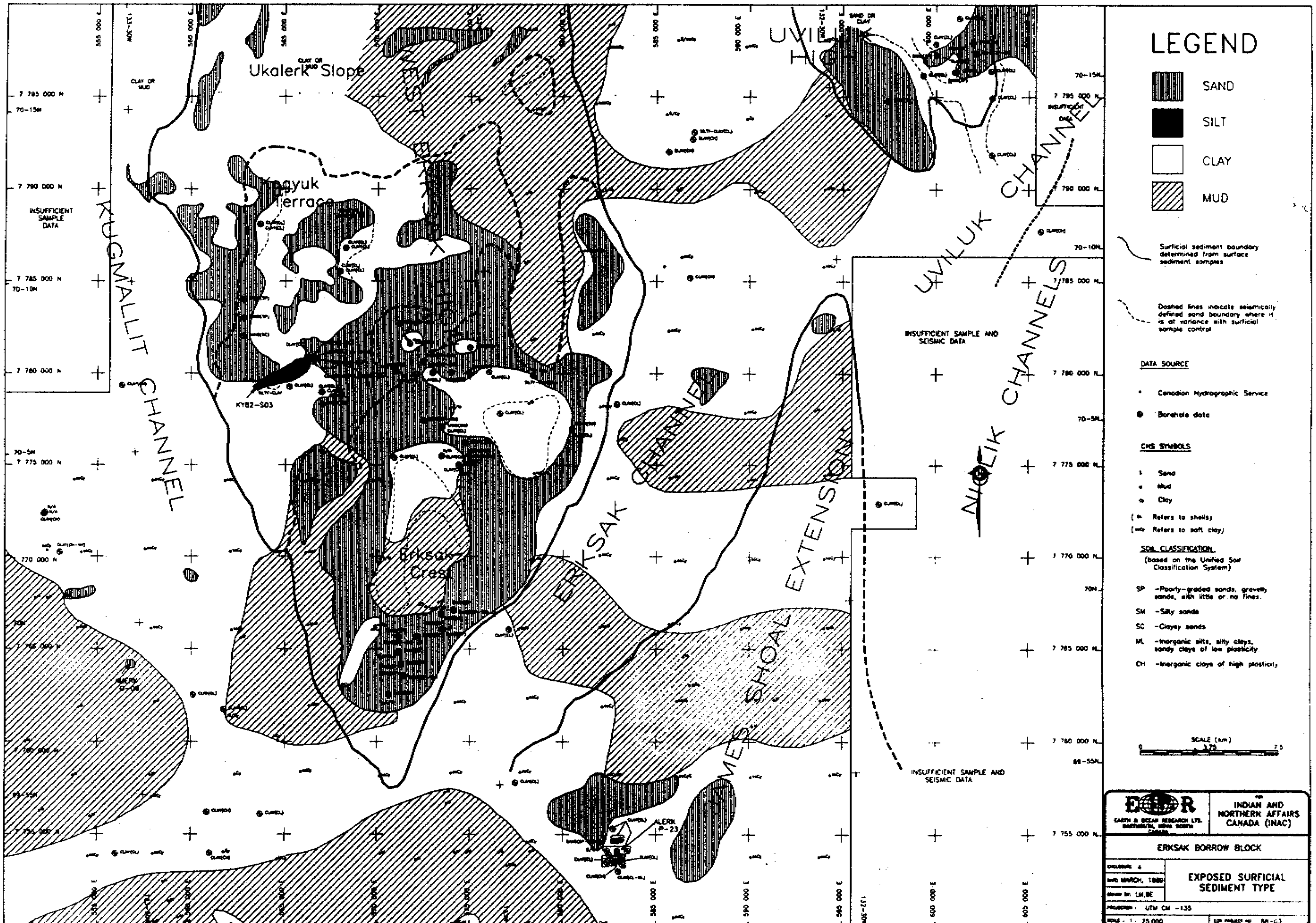

LEGEND
WEST THINGMARK
KOGYUK
WEST AMAULIGAK
SCALE (km)
INDIAN AND
NORTHERN AFFAIRS
CANADA (INAC)
EARTH & OCEAN RESEARCH LTD.
DARTMOUTH, NOVA SCOTIA
CANADA
ERKSAK BORROW BLOCK
Borehole and
Seismic Coverage

FIGURE 2



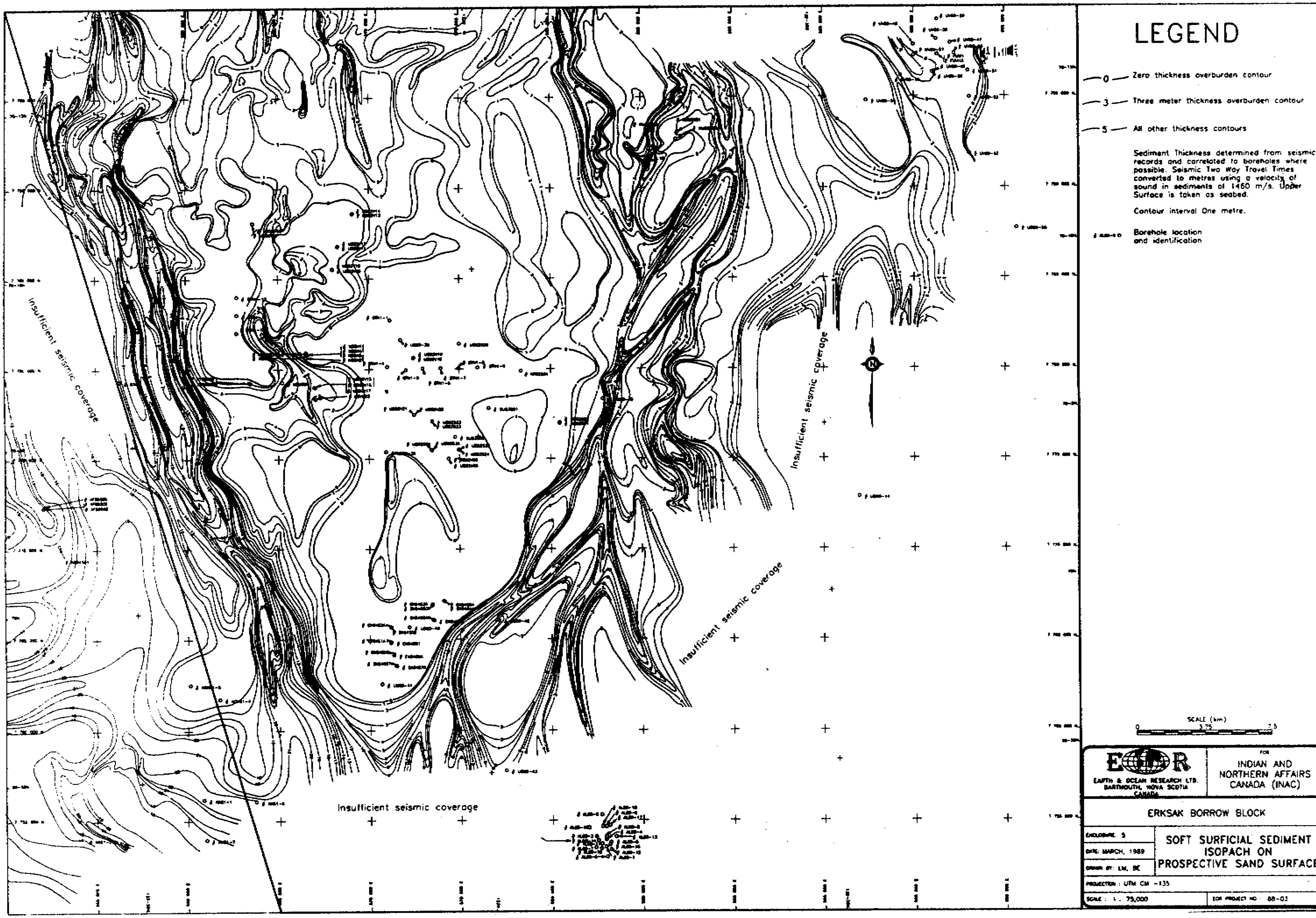
WEST ERKSAK HIGH
Ukalerk Slope
Kogyuk Terrace
KUGMALLIT CHANNEL
ZONE B
ZONE A
Erksak Crest
ERKSAK CHANNEL
ERKSAK SHOAL EXTENSION
JAMES SHOAL
ZONE C
UVILUK HIGH
UVILUK CHANNEL
NIGLIK CHANNELS
LEGEND
Contours in metres from sea surface.
Borehole location and identification.
NOTE:
–Bathymetric data within Zone A taken from CHS Sheet WA10176 at 1:100,000 scale.
–Bathymetric data within Zones B and C taken from Natural Resources Map Series at 1:500,000 scale.
–Physiographic Zones are informal, for use only within present report.
DATA SOURCE ZONES
ZONE B
ZONE A
ZONE C
SCALE (km)
0
3.75
7.5
EOR
EARTH & OCEAN RESEARCH LTD.
INDIAN AND NORTHERN AFFAIRS CANADA (INAC)
ERKSAK BORROW BLOCK
BATHYMETRY AND PHYSIOGRAPHIC SUBDIVISIONS

FIGURE 3



LEGEND
SAND
SILT
CLAY
MUD
Surficial sediment boundary determined from surface sediment samples
Dashed lines indicate seismically defined sand boundary where it is at variance with surficial sample control
DATA SOURCE
Canadian Hydrographic Service
Borehole data
CHS SYMBOLS
Sand
Mud
Clay
SOIL CLASSIFICATION
(based on the Unified Soil Classification System)
SP -Poorly-graded sands, gravelly sands, with little or no fines.
SM -Silty sands
SC -Clayey sands
ML -Inorganic silts, silty clays, sandy clays of low plasticity.
CH -Inorganic clays of high plasticity
Ukalerk Slope
Kogyuk Terrace
KUGMALLIT CHANNEL
Erksak Crest
ERKSAK CHANNEL
EXTENSION
JAMES SHOAL
UVILUK CHANNELS
UVILUK CHANNEL
NUKTAK CHANNELS
INSUFFICIENT SAMPLE DATA
INSUFFICIENT SAMPLE AND SEISMIC DATA
KYB2-S03
ALERK P-23
INDIAN AND NORTHERN AFFAIRS CANADA (INAC)
ERKSAK BORROW BLOCK
EXPOSED SURFICIAL SEDIMENT TYPE

FIGURE 4



LEGEND
0 Zero thickness overburden contour
3 Three meter thickness overburden contour
5 All other thickness contours
Sediment Thickness determined from seismic records and correlated to boreholes where possible. Seismic Two Way Travel Times converted to metres using a velocity of sound in sediments of 1460 m/s. Upper Surface is taken as seabed.
Contour interval One metre.
Borehole location and identification
Insufficient seismic coverage
Insufficient seismic coverage
Insufficient seismic coverage
Insufficient seismic coverage
SCALE (km)
0
3.75
7.5
EARTH & OCEAN RESEARCH LTD.
DARTMOUTH, NOVA SCOTIA
CANADA
FOR
INDIAN AND NORTHERN AFFAIRS CANADA (INAC)
ERKSAK BORROW BLOCK
ENCLOSURE 5
DATE: MARCH, 1989
DRAWN BY: LM, BE
SOFT SURFICIAL SEDIMENT ISOPACH ON PROSPECTIVE SAND SURFACE
PROJECTION : UTM CM -135
SCALE : 1 : 75,000
EOR PROJECT NO 88-03

FIGURE 5

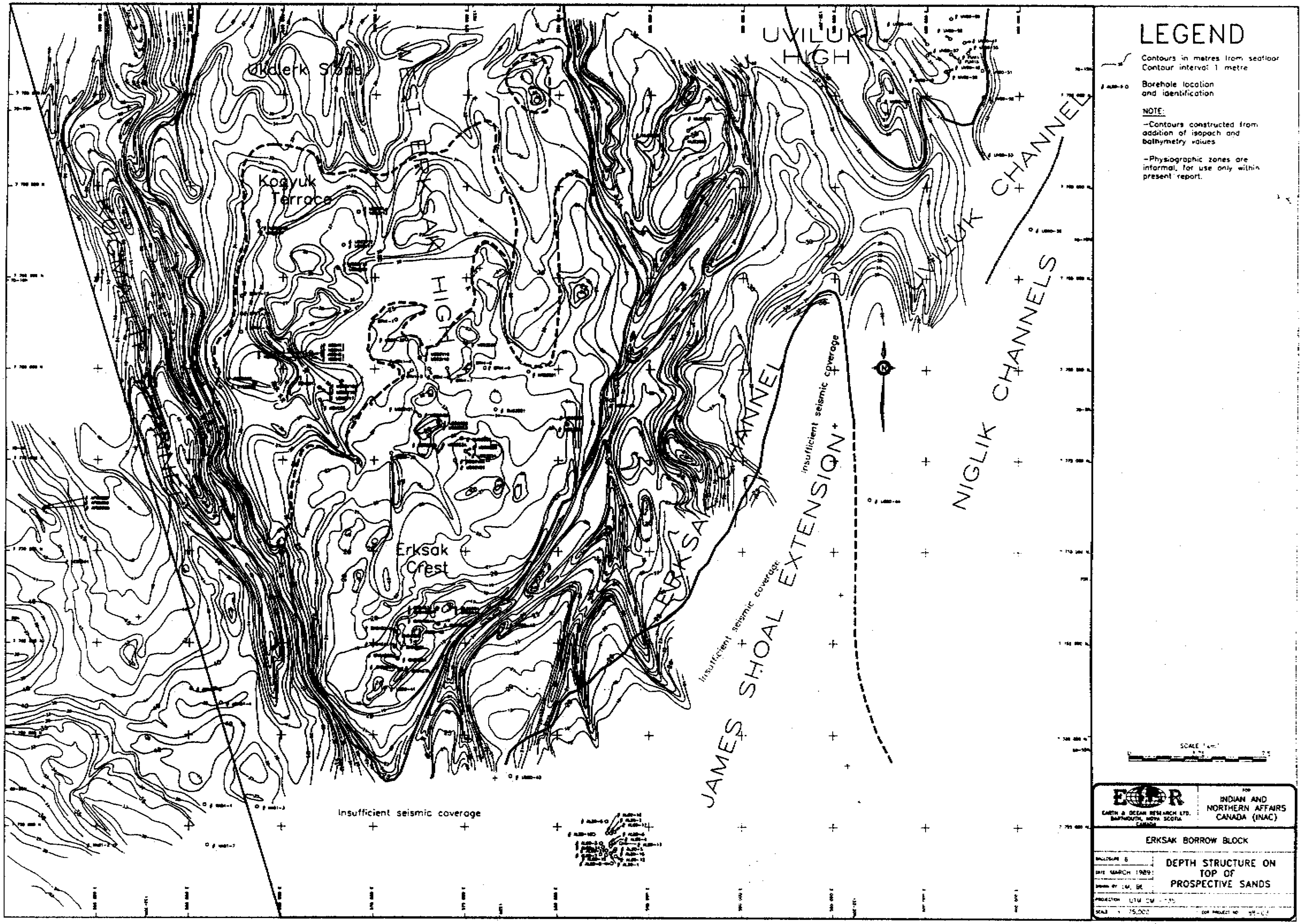
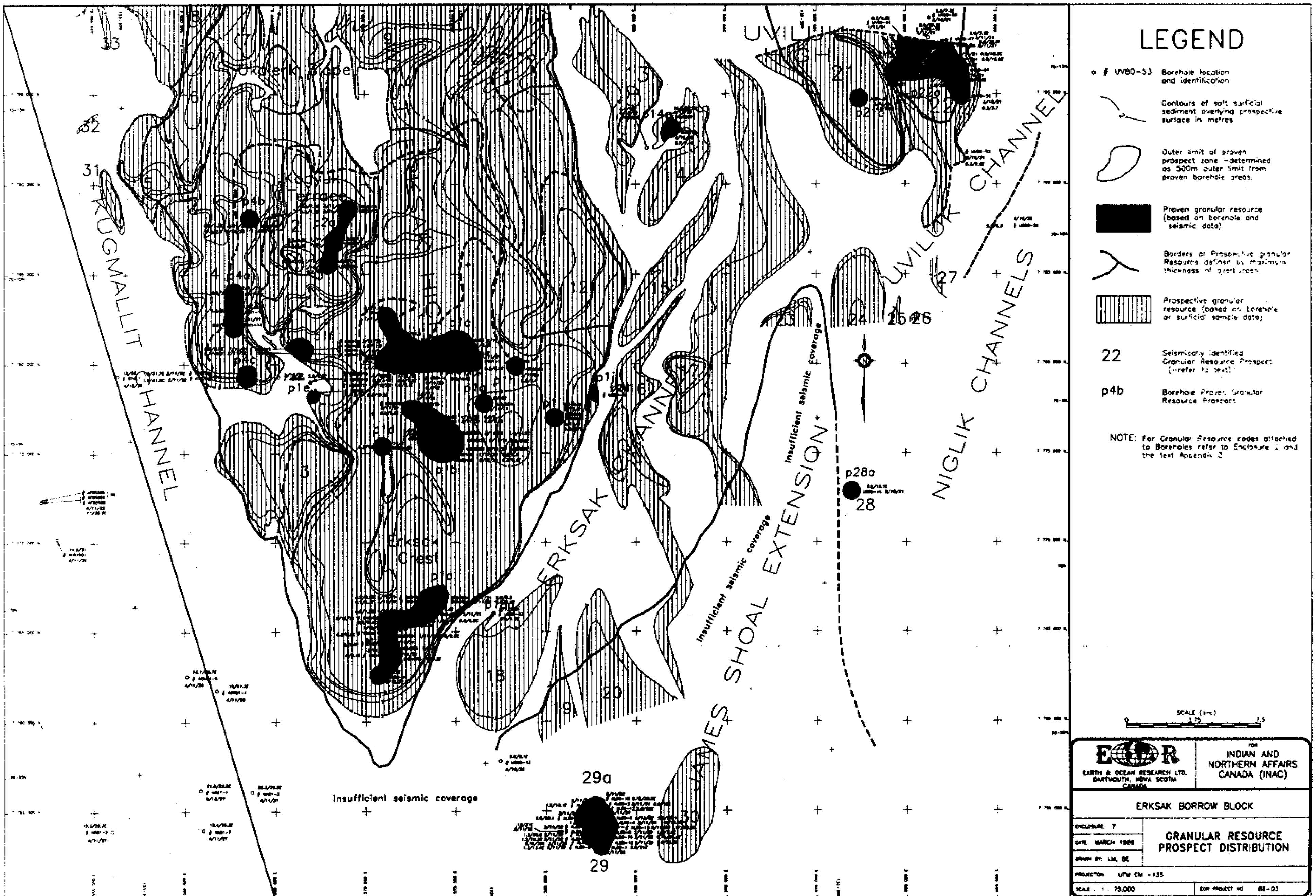

LEGEND
Contours in metres from seafloor
Contour interval 1 metre
Borehole location and identification
NOTE:
–Contours constructed from addition of isopach and bathymetry values
–Physiographic zones are informal, for use only within present report.
UVILUK HIGH
Ukalerk Slope
Kogyuk Terrace
HIGH
Erksak Crest
ERKSAK CHANNEL
JAMES SHOAL EXTENSION
NIGLIK CHANNELS
CHANNEL
Insufficient seismic coverage
Insufficient seismic coverage
Insufficient seismic coverage
EOR
EARTH & OCEAN RESEARCH LTD.
DARTMOUTH, NOVA SCOTIA
CANADA
INDIAN AND NORTHERN AFFAIRS CANADA (INAC)
ERKSAK BORROW BLOCK
DEPTH STRUCTURE ON TOP OF PROSPECTIVE SANDS

FIGURE 6



LEGEND
UV80-53 Borehole location and identification
Contours of soft surficial sediment overlying prospective surface in metres
Outer limit of proven prospect zone - determined as 500m outer limit from proven borehole areas.
Proven granular resource (based on borehole and seismic data)
Prospective granular resource (based on borehole or surficial sample data)
22 Seismically identified Granular Resource Prospect
p4b Borehole Proven Granular Resource Prospect
KUGMALLIT CHANNEL
ERKSAK CHANNEL
JAMES SHOAL EXTENSION
NIGLIK CHANNELS
UVILUK CHANNEL
Insufficient seismic coverage
Erksak Crest
EARTH & OCEAN RESEARCH LTD. DARTMOUTH, NOVA SCOTIA CANADA
INDIAN AND NORTHERN AFFAIRS CANADA (INAC)
ERKSAK BORROW BLOCK
GRANULAR RESOURCE PROSPECT DISTRIBUTION
DATE: MARCH 1989
SCALE 1 : 75,000

FIGURE 7

BEAUFORT SEA GRANULAR RESOURCES WORKSHOP
GEOTECHNICAL AND GEOPHYSICAL DATABASES
PRESENTATION SUMMARY

Part of the Northern Oil and Gas
Action Program (NOGAP - Projects A4-22 and A4-25)

Prepared for:
Indian and Northern Affairs Canada
Natural Resources and Economic Development

Prepared by:
EBA Engineering Consultants Ltd.

0306-34786

Presented by:

Rita I. Olthof
EBA Engineering Consultants Ltd.
6111-36 Street S.E.
Calgary, AB
T2C 3W2

DSS File No: 038ST.A7134-0-0037

1992 January 22

1.0 INTRODUCTION

In 1988, EBA Engineering Consultants Ltd. (EBA) compiled a geotechnical report catalogue and a database of 1288 borehole logs completed in the Canadian Beaufort Sea between 1973 and 1987. In 1989 the database was expanded to include 1053 surficial sediment corehole logs completed prior to 1988, and 46 borehole logs completed in 1988. In 1991, the geotechnical database compiled by EBA was expanded, and a geophysical database compiled in 1988 by McElhanney Geosurveys Ltd was expanded. Logs compiled in 1991 include 80 relatively deep boreholes or coreholes, and 334 surficial sediment samples. To date (as of 1991), a total of 2801 logs have been compiled in the database. The assignments were carried out for Indian and Northern Affairs Canada, under funding provided by the Northern Oil and Gas Action Program (NOGAP).

Amoco Canada Petroleum Ltd. (Dome/Canmar), ESSO Resources Canada Ltd., Gulf Canada Resources Ltd., the Geological Survey of Canada (GSC), Indian and Northern Affairs Canada, and the Canadian Hydrographic Service (CHS) have provided valuable data for the database. Although the database now includes over 2800 log entries, it is not yet complete. Five borehole logs from the GSC database which were incomplete were not included in the database. Twelve logs are available from Amoco which have not yet been included. Also, there are estimated to be several hundred more shallow corehole logs available at GSC from the 1970 and 1971 M.V. Hudson Surveys which should be included in future additions to the database. Several geophysical reports were not obtained; one from Gulf (1990 program) and the remaining reports from ESSO. The now-defunct organizations Arctic Petroleum Operators Association and Beaufort-Delta Oil Project Ltd. also have numerous reports which thus far have not been obtained or checked for relevant information.

Including work done in 1991 by Indian and Northern Affairs Canada (INAC), the databases now comprise a report catalogue, an ESEBase borehole database, and a source database which describes specific sources of granular materials. These databases are linked by use of common granular source numbers, study numbers and UTM locations. Information contained in the databases can be (and has already been) used to evaluate as much as possible of the available geophysical and geotechnical data in the Canadian Beaufort Sea, primarily with respect to quantifying the locations and volumes of proven, probable, and prospective granular resources. Some evaluation projects conducted to date using the databases are presented at this seminar/workshop, including the Isserk and Erksak Borrow Site study programs (presented by John Lewis of Lewis Geophysical Consulting) and a regional surficial geology program for the South Central Beaufort Sea region (presented by Steve Blasco of the Atlantic Geoscience Centre).

Figure 1 presents a location map of the study area, the Beaufort Sea. Table 1 summarizes the numbers and type of logs compiled in each year of the project. Table 2 summarizes the numbers of reports reviewed in each year and the range of dates of the reports.

It is our understanding that the report catalogue is available from INAC on an as-requested basis in digital or paper format. The ESEBase borehole database has a more restricted distribution. A subset of the ESEBase borehole database has been extracted by INAC for borehole location mapping purposes, and consent was obtained from the operators for use of this general information. The detailed information remains protected and confidential, with the exception of future· by the Geological Survey of Canada (GSC), whose purpose is scientific.

2.0 PROJECT OUTLINE

2.1 Objectives

The primary objective of the work has been to compile, in a standardized (ESEBase) format, a database of surficial sediment core and deep borehole data from the Canadian Beaufort Sea. The database is intended for use in the evaluation of granular resources for construction materials. The database logs are intended to be accurate stratigraphic and textural interpretations of the originals; however, some detailed engineering (for example: strength, consolidation, etc.) data has been omitted.

A second significant part of EBA's work has been to compile a bibliography or report catalogue of the various operator and consultant reports containing subsurface geotechnical information. In 1991, existing geotechnical and geophysical report catalogues (compiled in

1988 by EBA and McElhanney, respectively) were updated to reflect additions made to the data base in 1989 and 1991.

2.2 Data Presentation

A report catalogue sample entry is presented as Figure 2. The geotechnical report cataloque is shown in graphic form on Figure 3, with the minimum and maximum boundaries of each report area outlined. Figure 4 shows the report areas for the geophysical report catalogue. EBA's previous reports (1988, 1989, 1991) list the original reports from which information was obtained. Figure 5 shows a scatterplot of boreholes in the ESEBase borehole database.

Geotechnical and geophysical information for the databases was obtained from a total of 148 reports. This number is somewhat misleading as some reports cover larger geographic areas than others. For example, some reports may contain only one or two boreholes at a single site, others may contain over 200 holes dispersed over a large area. Therefore, in order to facilitate searching for this data, the catalogue of field activities includes 179 entries with separate entries for 'sub-projects' from smaller geographic zones.

3.0 DATABASE DESCRIPTION

The Beaufort Sea Database was originally prepared with ESEBase Version 3.0. ESEBase Version 4.0 is now available: all files created with Version 3.0 are upwardly compatible, with a one-time conversion when the database is first used. Figure 6 presents a typical borehole log, as produced by the ESEBase progrâm.

The difficulty in preparing a large database or series of databases from almost 150 different reports is with standardization. The original format, numbering system, datum, etc., were generally not consistent for the raw borehole data received for many logs, thus some modifications were required to standardize the logs to ESEBase format for inclusion in the present database. There was also a need to standardize borehole name formats for coding into the system. Thus, as shown in Table 3 and Figure 7, a borehole code would include a code for area location, year drilled, type of sample, and borehole number. Borehole logs themselves were standardized according to sample types (for example, core, SPT, Shelby tube), datums were referenced to seabed, soil description (order of priority of terms), soil classification, and ground ice descriptions.

3.1 Soil Description

The stratigraphic information on the logs includes the following components (also summarized as Figure 8) where available.

- principal component (e.g. CLAY, SAND, SILT, etc.)
- Unified Soil Classification (USC)
- principal component modifier(s) (e.g. silty, some sand, etc.)
- particle shape
- structure
- moisture
- consistency
- plasticity
- colour
- ground ice description

It should be noted that soil strength parameters were generally not included in the original versions of the ESEBase database, except in a few cases where the original borehole logs were already in ESEBase or ESELog and required little modification to standardize. However, at the request of Indian and Northern Affairs Canada, some original borehole logs including strength data were provided (1988 May) after database completion. Therefore, the strength data is readily accessible for addition to the database at some later time.

3.2 Soil Classification Data

Moisture content, Atterberg Limits, limited grain size analyses and Unified Soil Classification (USC) data have been included in the database. Atterberg Limits and grain size analyses were used to check and provide Unified Soil Classification System (USC) classifications. All available grain size data has been included in the database. 'D50' data was not available for the logs and was not calculated due to time constraints. This data would be a valuable addition to the logs. Silt and clay contents are presented in separate fields in the 'Basic Soil Characteristics Data' file.

3.3 Ground Ice Description and Sample Temperature

The ground ice description standard used for this database follows the guidelines established by NRC. Where available and readily interpreted, ground ice information and soil temperature has been recorded in the ESEBase borehole database.

4.0 COMPUTER DATA HANDLING ROUTINES

For some similar onshore databases, computer data handling routines were required to extract data from ESEBase files and update the Granular Resource (source) database maintained by INAC. All data for boreholes, testpits, or exposures for a given source/study number was extracted from ESEBase files. The parameters needed for the source database database were then calculated and the source database record was either updated (for existing entries) or created (for new entries). When the granular sources and their boundaries are better defined, the same operation can be done for the Beaufort Sea databases to create a source database.

5.0 USE OF THE DATABASES

The report catalogue is useful for determining what has been done in a specified area. For example, in dBase, a listing of all reports with a specified UTM zone, minimum and maximum northing and easting can be made, and/or a report catalogue summary sheet can be printed for each relevant report. The report catalogue summaries give information regarding contact names for the project, study type, size, and quality of data, level of detail, and so on. The researcher could then refer to ESEBase borehole database for further details, or obtain the original reports themselves.

In ESEBase, printouts of actual logs from a specified area can be made, as well as profiles or stratigraphic cross-sections through the area, maps of borehole locations, and plots of laboratory data. Or, for example, if one wanted a plot of all areas with a soil of gravel content of 20 percent or more, ESEBase could sort and select the required boreholes for plotting. One can also sort boreholes by operator.

When constructed, a source database could be used similarly. For example, for a specified area, further details on soils in the area including numbers of boreholes, type and thickness of overburden, details on proportions of gravel/sand/fines in the granular resource, and test result summaries can be obtained. This database will summarize data found in the ESEBase borehole database.

Plots can also be made in conjunction with other software programs, for example, InFocus and Quikmap are used. Further development is being undertaken for easier use of these programs in conjunction with ESEBase. John Peters' presentation discusses this aspect further. A sample plot showing geophysical trackplots and borehole locations is presented as Figure 9. Figure 10 shows a sample plot of a borehole cross-section or soil stratigraphy profile.

6.0 CLOSURE

In total, 2801 corehole, borehole, and surficial sediment logs from the Beaufort Sea have been summarized in a database intended to allow interpretation of the distribution of granular resources and restrictions on their development. In the future, logs not yet included in the database could be added. Regular maintenance of the database by updating annually with new borehole data will provide a reliable source of data on Beaufort Sea granular resources.

It should be realized that some errors in the databases are inevitable. Also, the data can only be as good as the original data source, which may vary according to weather and/or sampling conditions. Therefore, use should be for information purposes only, and confirmation of original reports or independent confirmation should take place as required on a project specific basis.

0121sem.786
RIO/rio

TABLE 1

SUMMARY OF BOREHOLES AND SURFICIAL SEDIMENT SAMPLES

YEAR OF COMPILATION	AMOCO	ESSO	GULF	GSC	INAC	CHEVRON	SUNOCO	TOTAL
	NUMBER OF BOREHOLES/SAMPLES FOR EACH OPERATOR							
1988	302BH	816BH	165BH	-	5BH	(147BH)		1288
1989	45SS	460SS	387SS 46BH	114SS 46PC 1BH				1099
1991	99SS	13BH	235SS	65CH				414
TOTAL	446	1289	835	226	5			2801
TOTAL NOT INCLUDED	12BH		2BH* 6GC*	5BH& MV HUDSON#		147BH		172

* Gulf data not released for use.
& Boreholes with insufficient data.
\# Number of M.V. Hudson cores unknown, not included in total.

Abbreviations in order of appearance in table:

BH borehole
SS surficial sediment sample
PC piston core
CH corehole
GC gravity core

TABLE 2

SUMMARY OF REPORTS REVIEWED

YEAR	NUMBER OF REPORTS	YEAR OF REPORTS
1988	87	(1973-1987)
1989	17	(1981-1988)
1991	44	(1970-1990)

TABLE 3

EXPLORATION BLOCK NAMES AND ABBREVIATIONS (portion of)
(includes 1988, 1989 and 1991 work)

BLOCK NAME	ABBREVIATION
Aagnerk	AA
Adlartok	AD
Amauligak	AE, AW, AF, AM
Akpak	AK
Alerk	AL
Angasak	AN
Aok	AOK
Arnak	AR
Amerk	AS
Baillie Island	BI
Nerlerk (Borrow)	BNR
Blow River	BR
Tingmiark (Borrow)	BTN
Tarsiut (Borrow)	BTAR
East Amauligak	EA
Arksak Borrow	EK
Ernerk	ERK
Irkaluk (Foundation)	FIRK
Natiak (Foundation)	FNAT
Nerlerk (Foundation)	FNR
Garry Island	G, GI
Herschel (borrow)	HB
Herschel Island	HI
Hooper/Pelly Region	HP
Isserk (Borrow)	IB
Isserk (I-15)	IR, 1SRK
Issigak (Borrow)	IBS, IK, ISGK
Immerark	IE
Igaluk	IG

LIST OF FIGURES

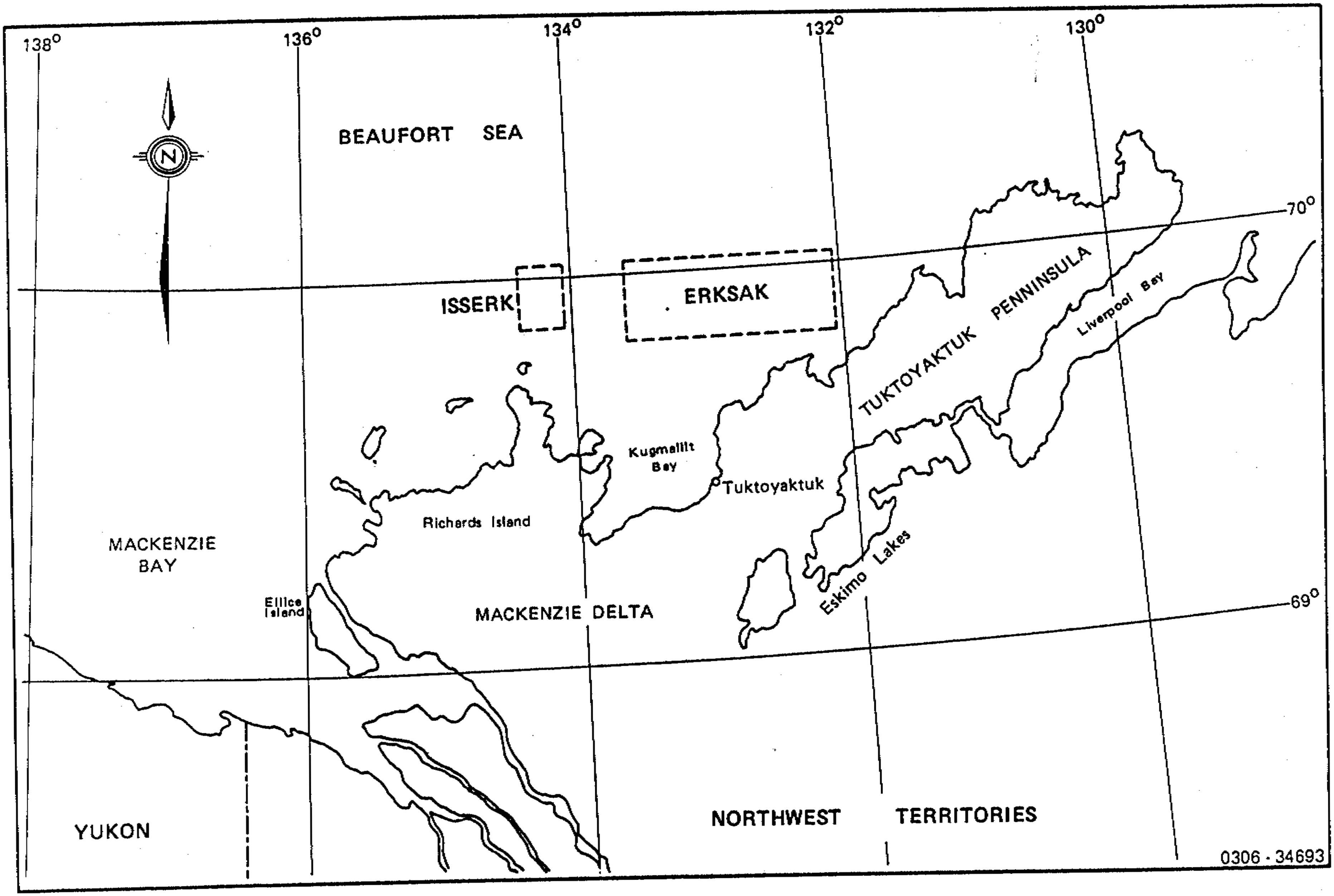


FIGURE 1 AREA MAP OF THE BEAUFORT SEA

EBA Engineering Consultants Ltd.

FIGURE 2 - REPORT CATALOGUE SAMPLE FORM

BEAUFORT SEA
INDIAN AND NORTHERN AFFAIRS CANADA
CATALOGUE OF GRANULAR RESOURCE-RELATED INFORMATION

STUDY NUMBER: D-82-002 MONTH: 7 YEAR: 1982

SPONSOR : AMOCO CANADA PETROLEUM CO LTD. (DOME,CANMAR)
JOB NO : CONTACT: K. Hewitt
CONTRACTOR : EBA Engineering Consultants Ltd. and McClelland Engineers, Inc.
JOB NO : 101-3605 CONTACT: MR. KEVIN JONES
REPORT TITLE: 1982 OFFSHORE GEOTECHNICAL SITE INVESTIGATION, BAILLIE ISLAND GRAVEL SEARCH, BEAUFORT SEA

COORDINATES :	MINIMUM	CENTRE	MAXIMUM
UTM: ZONE:	8	0	8
EASTING:	512180	0	584090
NORTHING:	7765050	0	7885520
OR: LATITUDE:	0.00000		0.00000
LONGITUDE:	0.00000	0.00000	0.00000

LOCATION:

	GENERAL LOCATION	SITE PLAN
NAME :		Baillie Island
NUMBER:	1,A.1,A.2	1,A.1,A.2
SCALE :	1:2272727	1:2272727,270270,675
FORMAT:		
ARCHIV:		
DIG NO:		

SOURCE NUMBER(S):

SURVEY LINES / LOCATION DETAILS:

DESCRIPTION OF STUDY AND SURVEY DETAILS:
TYPE : dredging
SCOPE: 1 site
LEVEL: stratigraphy, delineation

SIZE : 22 clam-shell samples
SURVEY PATTERN: random
SURVEY SPACING: random
SEASON: summer PROGRAM LENGTH:

EQUIPMENT : clam-shell sampler, bucket dredge sampler

PENETRATION: seabed surface

RESOLUTION : good

INFORMATION ON SAMPLES OR SURVEY RECORDS:
RATE : N.A.
QUALITY: disturbed
TYPE : clam-shell samples
SIZE : 22 grab

LEVEL OF DETAIL: INTERPRETATION/ANALYSIS/REPORTING:
INTERP : grain distribution
REPORT : summary/data compilation report
DISTRIB: sponsor/contractors
OTHER :

ARCHIVING OF INFORMATION:
REPORT :
DATA : sponsor/contractors

DATA COMPILATION AND UPDATING:
COMPILED BY:
DATE : 88/03 COMPILATION PROJECT NO.:
UPDATED BY : EBA ENGINEERING CONSULTANTS LTD.
DATE : 91/03/27 UPDATE PROJECT NO.: 0306-34693

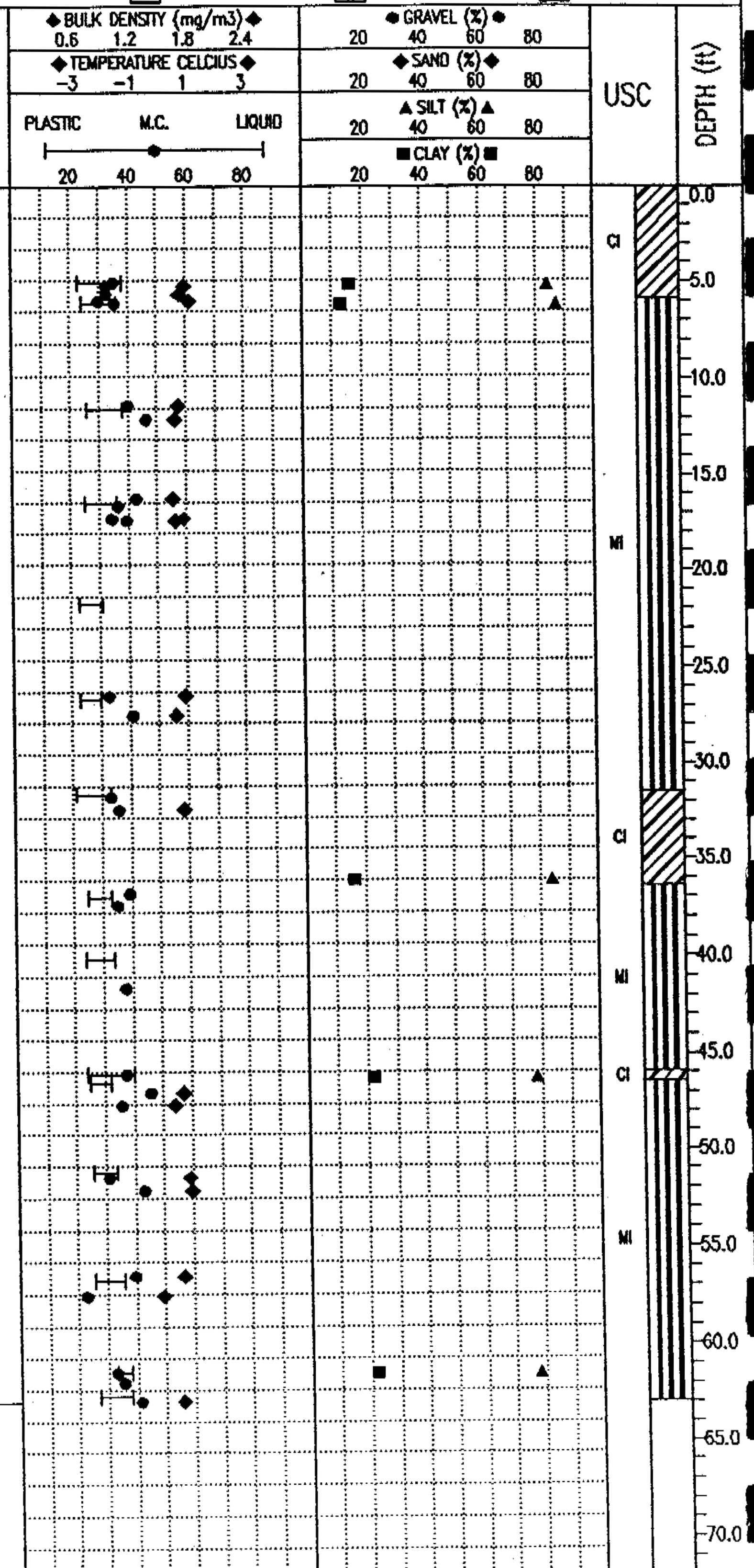
FIGURE 6 TYPICAL ESEBASE BOREHOLE LOG

BELUGA BAY 1984	DEPTHS ARE REFERENCED TO SEABED.	TESTHOLE No. UK84TT01
GEOLOGICAL SURVEY OF CANADA	WATER DEPTH – UNKNOWN	Project No:
ORIGINAL BOREHOLE NO. BH 0 + 00	UTM ZONE: 8 N7728586.00 E516967.00	ELEVATION 0.00 (m)

SAMPLE TYPE: SHELBY TUBE, NO RECOVERY, SPLIT SPOON, CORE, SHIPEK GRAB, GRAVITY CORE

DEPTH (m)	SAMPLE TYPE	SAMPLE NO	SOIL DESCRIPTION
0.0			SILT (ci) – some clay, medium plastic
2.0			– (MI)
10.0			– (CI), low plastic
11.0			– (MI)
14.0			– (CI), clayey, medium plastic – (MI), some clay
19.2			END OF BOREHOLE 19.2 m

Depth (m) scale: 0.0, 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 22.0



EBA Engineering Consultants Ltd. Calgary, Alberta	COMPLETION DEPTH 19.2 m	COMPLETE 84/ /
	LOGGED BY	DWG NO. — Page 1 of 1

FIGURE 7 TYPICAL BOREHOLE/COREHOLE/SAMPLE NUMBER

Area Abbreviation (Eg. MacKenzie Bay)

MB 86 GC 72

Corehole Number (Eg. 72)

Year Drilled (Eg. 1986)

Sample Method (Eg. Gravity Core)

FIGURE 8 SOIL DESCRIPTION

- principal component (e.g. CLAY, SAND, SILT, etc.)
- Unified Soil Classification (USC)
- principal component modifier(s) (e.g. silty, some sand, etc.)
- particle shape
- structure
- moisture
- consistency
- plasticity
- colour
- ground ice description

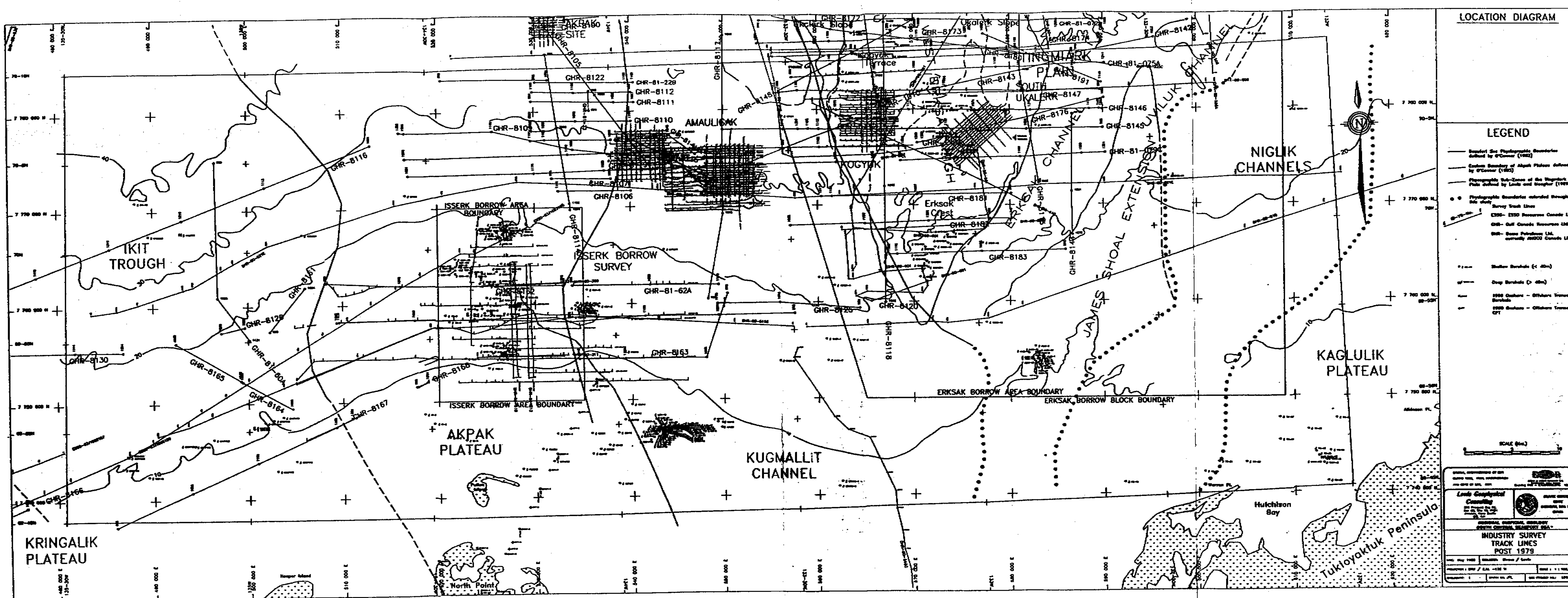
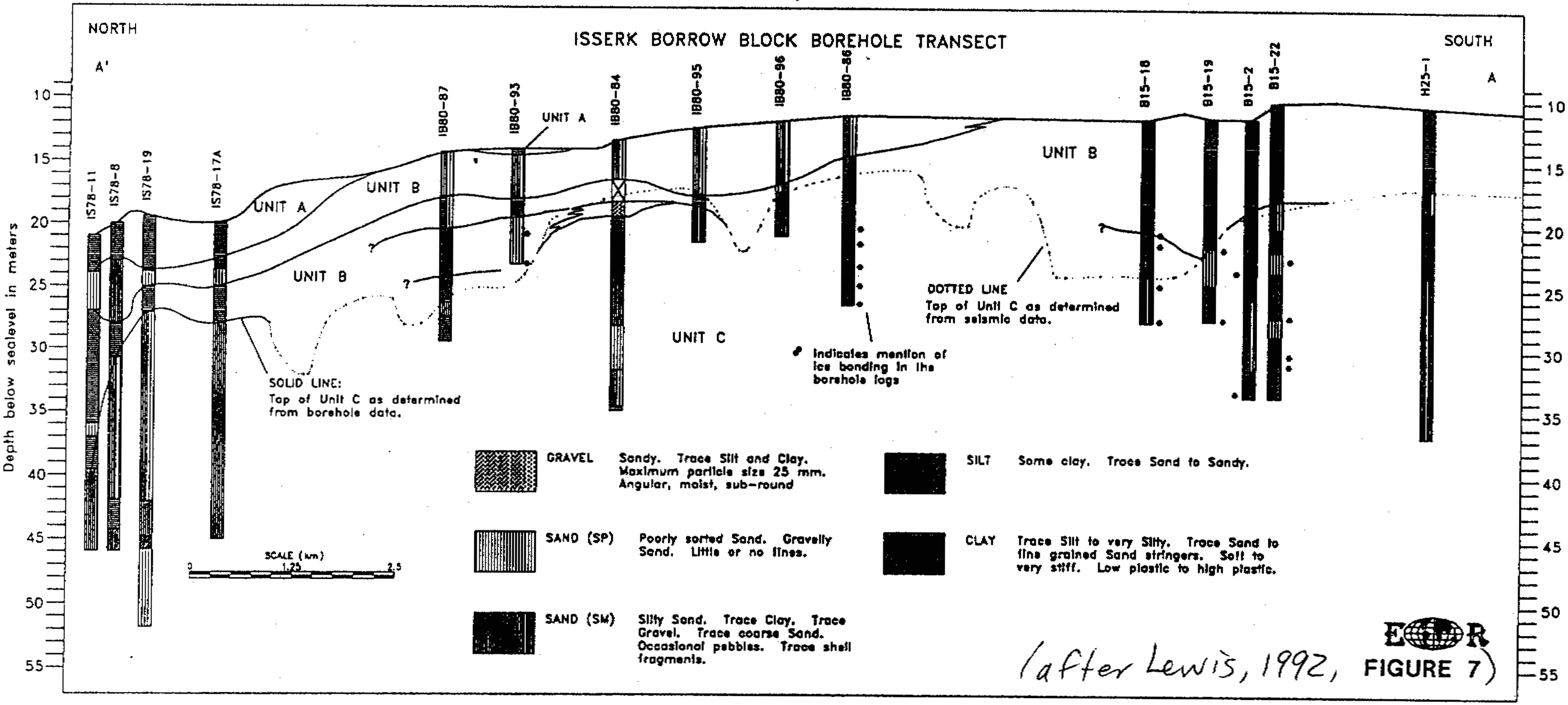


FIGURE 9 SAMPLE PLOT OF TRACKLINES AND BOREHOLES

(after Lewis, 1992, FIGURE 2)

FIGURE 10 SAMPLE PLOT OF BOREHOLE CROSS-SECTION



(after Lewis, 1992, FIGURE 7)

CANADIAN HYDROGRAPHIC SERVICE BEAUFORT SEA ACTIVITY

For Presentation At:
BEAUFORT SEA GRANULAR RESOURCE SEMINAR, FEB. 31, 1992

George Eaton, CHS, Institute of Ocean Sciences, Sidney B.C.

Background

Hydrographic efforts in the Beaufort Sea began in the 1950s when the U.S. ship STORIS conducted surveys in support of the DEW Line project. During the early 1960s several CHS personnel accompanied both U.S. and Canadian Coast Guard Icebreakers operating in the area. Soundings taken on the vessel's track were recorded at every opportunity but this sort of data gathering falls far short of what is required to make a complete and accurate chart. Further endeavours included spot soundings taken through the ice during the winter and finally some small rigorous surveys were undertaken from the 65 foot RICHARDSON from 1962 to 1969. The RICHARDSON remained in Tuktoyaktuk for most of these winters.

More extensive surveys were made in the 1970s with the four-launch ship PARIZEAU. Each July the ship made the passage from Victoria through the Bering Sea and fought the ice along Alaska's north slope to arrive in the Beaufort Sea survey areas near the first of August. Six or seven weeks of intensive work followed during which the launches sounded 16 hours per day. Often the Atlantic Geoscience Centre would undertake a limited program at the end of the season before the PARIZEAU began her southern mid-September passage.

Hydrographic Ships HUDSON and BAFFIN have worked in the Beaufort, the most notable being the first survey of a portion of a shipping corridor in 1981. A number of other surveys were carried out from the chartered vessels PANDORA and POLAR CIRCLE in the 1970s and 80s and in many cases there was a multidisciplinary aspect to these projects. A contract was let in 1984 to a private survey co. Cansite Surveys using the BANKSLAND SURVEYOR for work along the Yukon coast from the 141st meridian to Herschel Island. The new government ship TULLY has spent three seasons in the Beaufort since 1985.

Survey Characteristics:

All of these surveys presented some problems for the CHS. The cost of operating in the Beaufort is high. Ships based in Victoria spent a month or more in transit to and from the survey area, and only a limited amount of useful data was gathered on these passages. Ice in the survey areas was frequently encountered and on some days the seas were too rough for launch sounding.

Positioning systems, including Decca, Minifix, Argo and Syledis were expensive to deploy and recover, and in the early years before satellite positioning, there were sizeable distortions in the geodetic framework. Positioning accuracy of some of these systems was always a source a worry. GPS fixes this.

A characteristic of most of this work is the limited detail resulting from the wide line spacing associated with 100,000 scale resource mapping. Not until the 1981 corridor survey did the line spacing decrease to 100 metres. Most of the recent work has been completed with this density. The line spacing while suitable for charting and reconaissance will likely not be sufficient for pipeline or artificial island construction.

Accurate tidal data throughout the Beaufort is difficult to come by. The rule used in the first surveys was to subtract 2 feet from all the soundings since little was known about the datums. Later a permament gauge was installed in Tuk Harbour and tides were extrapolated into the survey area. More recently, temporary gauges were installed closer to the survey areas and this data was used for the reduction of soundings and comparisons to the Tuk gauge data.

Coastline data shown on most charts throughout the Beaufort Sea comes from the NTS series of maps. Most of these maps were compiled from 1950s aerial photography and the effects of wind, seas and ice have been responsible for substantial changes in the last 30 or 40 years. More up to date photography is now becoming available and contracts have been let to Stewart Weir however it will not be incorporated until new chart editions are published.

tidal ~~data~~ still a concern, little certainty
- don't understand tides but accumulating base of data

- slow return updating of charts since little demand for charts.

Some New Methods and Technology

The short period of operation, expense of deploying positioning systems and uncertainty of ice coverage, amongst other factors, led the Hydrographic Service to explore other cost effective methods of acquiring soundings.

In the early 1960s some data was gathered with hovercraft. This platform worked well in shallow waters but was limited by fuel consumption. Stern tow fish, similar to mine sweeping gear, were deployed in 1983 with the POLAR CIRCLE. These fish, fitted with transducers and a positioning beacon, permitted three profiles to be gathered at once. Unfortunately the cables frayed prematurely and the system was not an entire success.

LARSEN:

A system, not used in the Beaufort but showing great promise in other parts of the arctic where the water is not muddied by the Mackenzie River, is the LARSEN system. This hardware operated by Terra Surveys consists of an airborne laser which produces pulses in the blue-green and infrared spectrums. The blue-green light pentrates the water and is reflected off the bottom, while the infrared is reflected from the surface. Depths can be calculated from the time difference of the returning pulses. Soundings can be obtained to 50 metres or more in ideal conditions. The laser, currently operating at 20 Hz, provides a swath of 9 spot soundings 25 to 30 metres apart. Photogrammetric work is often carried out from the same aircraft.

TIBS:

Another system, being used in its first production survey in Pelly Bay this winter, is TIBS, an acronym for Through the Ice Bathymeter System. This equipment was developed in part by Geotech Limited in Markham Ont.,from techniques used in the mining industry for locating ore bodies. The electromagnetic system measures the amplitude and phase shift of a secondary magnetic field induced by transmitting coils in the bottom sediment. Translating these measurements to soundings is not straightforward and much of the development effort has focused on this data processing aspect. The equipment, which includes a large bird slung from an A-Star helicopter, is flown over the ice at 60 knots and produces continuous profiles. Sounding accuracies decrease with depth; however accoustic quality can usually be realized in depths up to 50 metres. Water clarity, bottom reflectivity and cloud cover do not affect the system. Depths to 100 metres can be measured but, as with the Larsen system, ground truthing and calibration are extremely important.

DOLPHIN:

Dolphin (Deep Ocean Logging Platform with Hydrographic Instrumentation and Navigation) is a semi-submersible intended for bathymetric surveying in offshore waters. It is unmanned and remote controlled, designed to operate in up to 4 metre swells at speeds up to 15 knots. With a number of these vehicles abreast of a mother ship, a swath of data can be gathered with multibeam echosounders. The hazards of people working in small boats is avoided as well.

These vehicles, designed and built by International Submarine Engineering in Port Moody B.C., are controlled through a radio link to the mother ship. The quality of the accoustic data is first rate and since the transducers are mounted in a semi-submersible, heave is less of a problem. Applications for this system include mine countermeasures and route surveys for cables and pipelines as well as general bathymetry. A major hurdle with the Dolphins is a ship handling system that can be used for easy deployment and recovery. Recently a Newfoundland company, Georesources, has been contracted to carry out futher development.

GeoResources - Nfld.

GPS:

The Global Positioning System is having a profound effect on the entire Hydrogaphic Service. Virtually every platform used to acquire data can now be positioned to better than 5 metres in real time using differential techniques. The high costs of deploying radio positioning are avoided and the flexibility of choosing ice free survey areas is extremely attractive. Receivers are being purchased currently and work is now underway building radio links for the application of differential corrections.

The CHS has being following the progress of GPS over the last 10 years. A number of contracts have been let to Nortech Surveys Ltd. for R and D in hydrographic kinematic applications. One of the deliverables of this work was software known as Hydrostar whose function it is to take any receiver's signals and compute positions. This generic software has become the tool to compare receiver performance, determine differential corrections and log raw data. Other software capabilities include real-time error estimates and heave compensation.

Swath Sounders:

Surveying in the Beaufort Sea is complicated by the ice pack and shallow water. Traditional methods are slow and generally lead to less than 3% of the bottom being ensonified. To maximize the benefit of the multi-disciplinary approach, total bottom coverage is desireable since this allows profile data from oceanographic and geophysical measurements to be interpolated with the greatest degree of certainty. Security of navigation in hazardous areas is, of course, increased with complete bottom coverage. There have been no CHS swath sounding surveys in the Beaufort to date.

Four Simrad EM100 sounders have been purchased by the CHS and are all currently deployed on east coast vessels. These systems operate at 95 kHz giving maximum slant ranges to 550 metres. Fans of 32 beams can be stabilized for ship motions and the swath widths can be up to 1.7 times the depth.

One characteristic of all swath sounders is the large volume of data they can produce in comparatively short periods of time. Powerful computers are needed to process and store the data and although a number of production surveys have been completed with these instruments, data management and processing techniques are still under development.

TRENDS IN THE HYDROGRAPHIC SERVICE

Fisheries and Oceans, Pacific Region lost one of their major vessels, the PARIZEAU, to the east coast. Consequently ship time is scarce and the CHS surveys must compete for vessel usage with all the other marine science projects on this coast.

As a result of the Brander-Smith Inquiry, electronic charts have taken on a greater significance in the CHS. The vast majority of our data exists on paper and a large job lies ahead to get this data into digital form and build an infrastructure to deal with it. About 50% of the Beaufort surveys exist in digital form.

There is a general move into the digital domain throughout the CHS. The lack of equipment and software tailored to hydrographic needs has made this a long drawn out process. Almost all survey data is now acquired and processed digitally and charts are directly constructed from these files with Universal Systems CARIS software.

OUTLOOK FOR CHS BEAUFORT SEA INVOLVEMENT

The Hydrographic Service's first priority is to provide adequate charting for safe navigation throughout Canadian waters. A substantial survey effort was made in the Beaufort Sea in the 1970s and 80s when there was a distinct possibility that world oil prices would push the Beaufort resouces into production and large oil tankers of the famed MANHATTAN's size would be plying these waters. Since that time there has been a reduction in Beaufort activity and the CHS has shifted their focus to other portions of the southern Northwest Passage.

The most recent work is a LARSEN survey of Dolphin and Union Strait and small surveys conducted in conjunction with the Coast Guard for a suggested barge landing site in the Hamlet of Coppermine and site plan for Echo Bay Mines. These last surveys were funded by the clients.

Surveys of Victoria and James Ross Strait have a high priority for the future.

Rode - contact A-Code

- can measure leave - cont's update
est including real-time monit
to include 'in'

ARCTIC OFFSHORE EXPLORATION STRUCTURES - A GEOTECHNICAL PERSPECTIVE

HEWITT, KEVIN J.
CANADIAN MARINE DRILLING LTD.

SLADEN, JAMES A.
HARDY BBT LIMITED

ABSTRACT

This paper presents a general overview of the evolution, design, and performance of Arctic offshore exploration structures from a geotechnical perspective. Such structures include sandbag retained islands, sacrificial beach islands, ice islands, gravel islands, caisson and caisson-retained islands, and most recently, fully mobile bottom-founded structures.

INTRODUCTION

Since 1969, 142 exploratory wells have been successfully drilled in the Beaufort Sea (Masterson, et al; 1991). Of this total, approximately 100 wells have been drilled from a variety of islands and bottom-founded structures in water depths up to 32 metres (Figure 1). The remaining wells have been from floating structures in water depths up to 67 metres.

The marine environment in the Arctic is characterized by sea ice cover for approximately 9 months of the year. The design of bottom-founded structures, from which drilling is performed during the winter months, is dominated by the requirement to resist forces imposed by this ice. This requirement becomes more critical in the "shear" zone, which is the transition zone between the landfast ice zone and the polar ice pack (i.e., beyond approximately 20 metres water depth).

The variety of bottom-founded structures utilized has ranged from sandbag retained islands through to fully mobile bottom-founded structures. The diversity includes sacrificial beach islands, ice islands, gravel islands, caisson-retained islands and caisson/berm structures. The design and operation of these structures has been largely governed by geotechnical considerations. This paper reviews the evolution of the structures from this perspective. The intent of the paper is to provide a general overview for those unfamiliar with the Arctic experience. The reference list will hopefully be a useful starting point for those who wish to acquaint themselves further.

Surficial Geology of the Beaufort Sea

The exploration area relevant to this paper includes both the Canadian and US portions of the Beaufort Sea continental shelf. The surficial geology east of Herschel Island (i.e. Canada) is more complex than to the west due to the dominant influence of the Mackenzie Delta. A geologic model has been developed for this area (O'Connor & Associates, 1980) which divides the shelf into nine physiographic regions, based on the combination of seafloor bathymetry, sediment types, and the paleotopography of the most recent unconformity. The nine regions consist of five plains (or plateaus) separated by four troughs (or channels). The troughs (channels) are generally characterized by fine-grained weaker soils. The plains (plateaus) in some instances contain relict sand ridges which have been the primary source of borrow material for island construction in the Canadian Beaufort Sea.

The continental shelf of the Alaskan Beaufort Sea is a seaward extension of the Arctic Coastal Plain. Sediments of the shelf consist of clay, silt, sand and gravel with the major constituents being silt and clay. Sand and gravel are more common in the nearshore and shallow offshore. Sources of sand and gravel may appear as shoals, sand ridges, lag deposits, and as seafloor sediments. The soils in the Alaskan Beaufort Sea are generally competent, although weak soils with shear strengths less than 50 kPa are present in some areas. These weak soils are generally limited to a thin surficial veneer typically less than a metre thick.

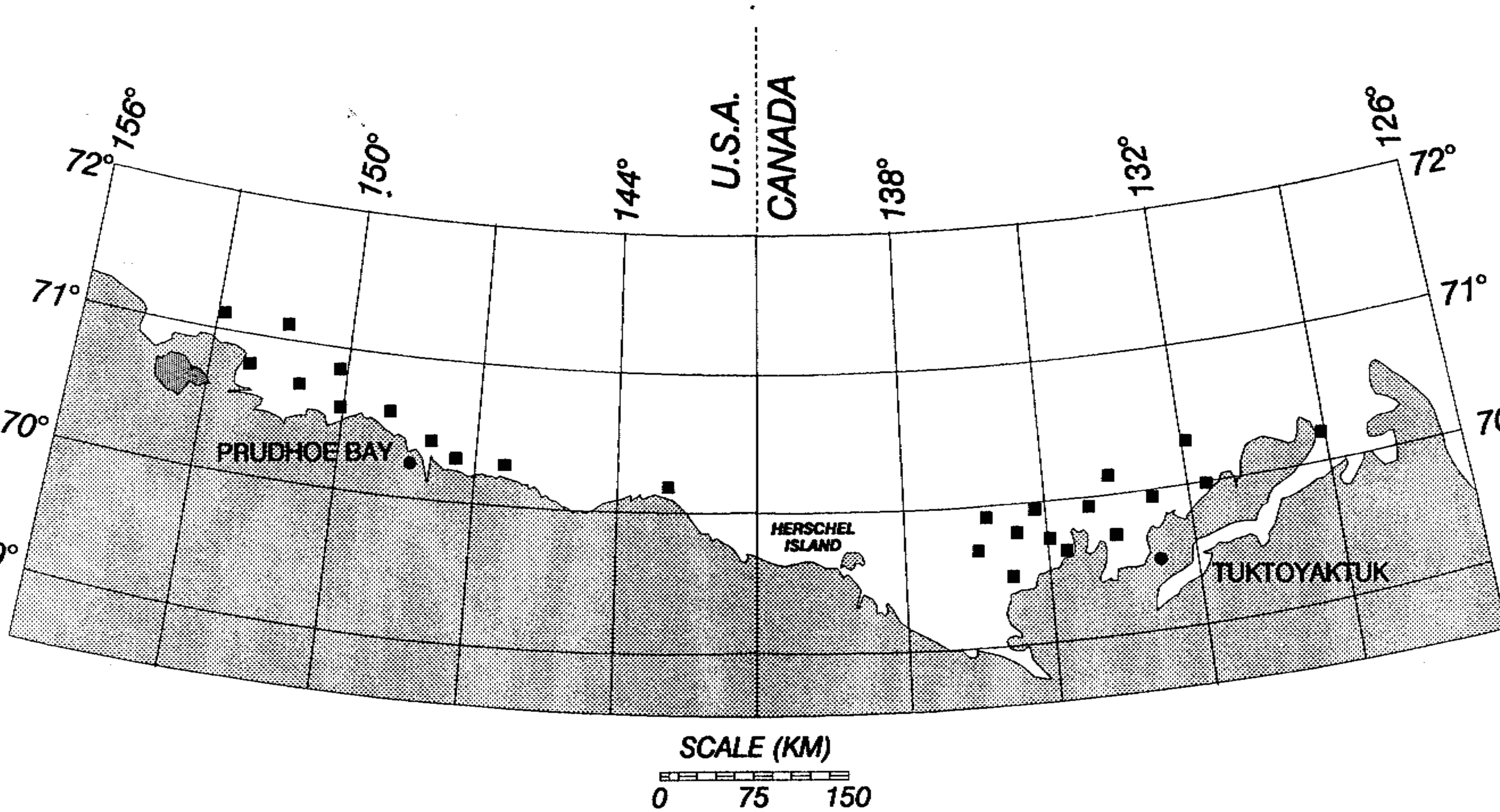
The seafloor is considered flat on a regional basis. However the microtopography is characterized by sharp relief as a result of ice ridge gouging. Elevations may vary locally over a range of 0.6 metres to 2.4 metres or more, particularly in water depths of 15 to 25 metres. This ice gouging has remolded the uppermost soils and reduced their strengths.

STRUCTURE TYPES

Apart from the truly mobile units (i.e. those requiring no on-site construction), almost every "structure" has had its unique aspects. However, they can be divided into general categories and the seven listed below have been chosen to broadly classify the structures utilized to date (see Tables 1 and 2).

FIGURE 1

LOCATION OF OFFSHORE STRUCTURES BEAUFORT SEA



TYPE	MAX. WATER DEPTH	NUMBER OF LOCATIONS	DESCRIPTION	SCHEMATIC ILLUSTRATION
Sandbag Retained Islands	7	13	Ring dyke of sandbags retaining internal hydraulic fill E.g. Adgo F-28,Ellice L-39	
Sacrificial Beach Islands	19	11	Hydraulically placed sand fill with flat-side slopes E.g. Alerk P-33 ,Immerk B-48	
Ice Islands	8	5	Seasonal ice thickened by flooding or spraying until base in contact with seabed. E.g. Mars, Angasak	
Gravel Islands	15	30	Coarse fill placed usually by barge dumping or trucking on ice. Erosion protection usually provided E.g. Pullen E-17, North star	

TABLE 1 NON - CAISSON ISLANDS

TYPE	MAX. WATER DEPTH	NUMBER OF LOCATIONS	DESCRIPTION	SCHEMATIC ILLUSTRATION
Caisson Retained Islands	21m + Berm Height	8	Similar to sandbag retained island but caisson used to retain fill allowing greater depth range E.g. Tarsiut Caissons, CRI, Molikpaq	
Water Ballasted Caisson/Berm	9m + Berm Height	2	Water ballasted caisson used in place of fill in wave and ice scour zone, placed on hydraulic sand berm. E.g.SSDC	
Bottom Founded Structures	25	6	Bottom founded structure , mobile and avoiding need for any fill berm E.g. CIDS, SSDC/MAT.	

TABLE 2 CAISSON ISLANDS

1. Sandbag Retained Islands: 14 wells (13 "structures"). Maximum water depth of 7.0 metres.

2. Sacrificial Beach Islands: 12 wells (11 "structures"). Maximum water depth of 18.6 metres.

3. Ice Islands: 5 wells. Maximum water depth of 7.6 metres.

4. Gravel Islands: 46 wells (30 "structures"). Maximum water depth of 14.6 metres.

5. Caisson Retained Islands: 14 wells (8 locations). Maximum water depth of 32 metres.

6. Water Ballasted Caisson on Berm: 2 wells. Maximum water depth of 31 metres.

7. Mobile Bottom-Founded Structures: 7 wells (6 locations). Maximum water depth to date of 21 metres.

Each of these structures is described below, with emphasis on the geotechnical aspects.

<u>Sandbag Retained Islands</u>:

A sandbag retained island is one where a ring dyke of sandbags is placed on the seafloor to retain the fill. The purpose of the sandbags is to retain fine grained fill materials and hence, achieve steeper island slopes, and to protect against wave attack. The geotechnical design considerations include slope failure, edge failure (a local passive failure due to the ice load), truncation failure (decapitation), and bottom sliding. Fill quality has not been a major design issue. The criterion has been to utilize fill of sufficient quality to support the drilling package. Borrow sources have included clam shelled local seabed materials and soils barged to the site from a remote submarine borrow pit. An example of the design of a sandbag retained island is provided by Riley (1975).

<u>Sacrificial Beach Islands</u>:

Sacrificial beach islands have flat beach slopes (1:15 to 1:25) which are intended to attenuate wave energy and provide an erosion buffer, thus protecting the island top from wave attack. This type of island is usually constructed when the island is located near a large borrow source, since a large amount of fill is required. The major advantage of a sacrificial beach island is the reduced requirements on slope protection which is both costly and difficult to construct. Barge hauling of fill from a distant source is usually prohibitive in terms of cost and construction time.

The construction method for a sacrificial beach island is simple. The island fill is dredged and place hydraulically using plain suction dredges and floating pipelines.

The geotechnical performance of these fills is difficult to quantify owing to a number of factors. First, the acceptance criteria for borrow material have been set only to ensure the dissipation of pore pressures built up during construction. The quality of the placed fill has not generally been verified. Second, no attempt is made to achieve steep slopes. Flat slopes are desirable to dissipate wave energy. A geotechnical "failure" of a locally steep slope during construction has not been considered a failure but, rather, a part of the construction process. Further, such a "failure" would be difficult to distinguish from slope flattening due to wave erosion. However, there are several observations which indicate that liquefaction "failures" have occurred. Third, because these islands have been situated in the landfast ice region, and have generally been surrounded by large rubble fields, it is likely that they have not experienced significant horizontal shear loads.

The very flat sideslopes have precluded the economical use of this approach at deeper water sites. Volume increases exponentially with water depth. Geotechnical considerations related to the construction of two sacrificial beach islands are outlined by Shinde, et al (1986).

<u>Ice Islands</u>:

Spray ice islands have become a fairly routine option for prospects located in favourable water depths and ice regimes. The controlling issue is whether or not adequate drilling time is available in the winter period remaining after completion of island construction. The major advantage of such islands is the ready availability of the construction material, and the subsequent natural decay.

Apart from the requirement for global sliding stability, a spray ice structure introduces unique considerations, as it is made of a material that is significantly weaker than the sea ice which surrounds it. The time-dependent behaviour becomes an important operational consideration. Island settlement during drilling, as well as lateral deformations associated with relatively low levels of load caused by pressure buildup and/or movement in the surrounding ice sheet, must be considered. The design and construction of the Mars Spray Ice Island is described by Funegard, et al (1987).

<u>Gravel Islands (Armoured - Slope Islands)</u>:

The advantage of using good quality gravel for island construction is the reduced fill quantities resulting from steep slopes (1:3 to 1:5). These islands have been the most common type in the Alaskan Beaufort Sea where abundant sand is not available and non-U.S. registered dredges are not permitted to work. The gravel has been obtained from onshore sources and either dumped on site by barges during the summer or, more commonly, hauled directly to the island site in winter via an ice road. The source of this gravel is described by Schlegel and Mahmood (1985). It is relatively abundant east of the Colville River to the Canadian border. These islands have been protected by a revetment, normally consisting of large sandbags overlying filter cloths, although other types of armour have been used. The disadvantage of this island type is that the placement of the slope protection can be very time consuming, especially below water.

The geotechnical design issues for this island type are similar to those for sandbag retained islands, although slope failure obviously becomes more critical. Consideration can also be given to strength gain at the seabed interface due to consolidation between the time of placement and the time of maximum anticipated ice load. Thaw settlement of loose frozen fill placed in the water, especially the underwater portion, has to be considered. The engineering and construction of Mukluk Island in 14.6 metres of water is described by Ashford (1984).

<u>Caisson and Caisson Retained Islands</u>:

The 1980's saw the introduction of a number of hybrid exploration islands designed primarily to reduce the fill volume requirements at deeper water locations. Four waterline penetration systems were developed: Canmar's concrete caisson system, the "Tarsiut caissons" (1981) (Fitzpatrick and Stenning, 1983); Canmar's single steel drilling caisson, the "SSDC" (1982) (Fitzpatrick, 1983); Esso's segmented steel caisson, the "CRI" (1983) (de Jong and Bruce, 1978); and Gulf Canada Resources Ltd.'s monolithic annular caisson the "Molikpaq" (1984) (Bruce and Harrington, 1982; McCreath et al, 1982).

Although the details of each system vary, deployment of all systems has commenced with the building of a steep-sided (1:6 - 1:8) subsea sand berm on which the caisson is placed. As most proposed sites did not possess suitable local borrow material, trailing suction hopper dredges were introduced to transport sand from remote locations. Trailing suction hopper dredges pick up material from a submarine borrow source by dragging an arm along the seabed. They are capable of carrying up to 8000 cubic metres of sand per load. Apart from the SSDC, which was ballasted onto the berm with water, all the systems required backfilling of a central core with sand.

The deployment of these new systems demanded a significant increase in design effort from that required for the previous more rudimentary structures. The basic design issues are not appreciably different from those of any other major civil work. However, the unique environmental loads and the restrictions in construction season length, construction plant, and borrow materials created some major challenges. The geotechnical components included site investigations, stability and deformation analyses, quality assurance programs, and performance monitoring.

The location of these structures, in the unstable "shear" zone, precluded the prior technique of conducting the investigations from the landfast ice surface in the spring using conventional terrestrial methods. Hence, marine supported operations were employed during the short open-water season. These operations also incorporated the routine use of insitu testing techniques, including the cone penetration test (CPT), vane shear tests, and the self-boring pressuremeter (Ruffell et al, 1985). The introduction of the trailing suction hopper dredges required the identification of acceptable sand deposits at or close to the surface. This was accomplished by conducting regional shallow seismic surveys in conjunction with extensive shallow boring programs.

Beyond static stability issues, the requirement to place a heavy structure on a berm capable of resisting the large horizontal ice loads that were anticipated in the "shear" zone required that the issue of dynamic stability be addressed. The consequences of liquefaction failure of such islands are potentially catastrophic. The criterion first proposed was based on a pseudo-static approach which called for a gradational specification to inhibit pore pressure generation and a relative density which ensured dilative behaviour during shear. Use of the "steady state" method (Poulos, 1981) was subsequently successfully employed. There are, however, problems related to insitu determination of sand state (Sladen and Hewitt, 1989; Sladen, 1989).

In order to assess structure performance and, in particular, to develop well safety criteria based on monitoring of instrumentation, it is necessary to make an accurate prediction of load deformation behaviour under ice loading. For these structures resting on sand berms, the non-linear elastic hyperbolic model of Duncan and Chang (1970) was utilized.

Fill quality assurance and insitu density evaluation became a significant component of construction operations. This involved monitoring of material loaded into the dredges, post placement coring, and CPT testing. This also implied that a material specific correlation between tip resistance and density had to be developed (Berzins and Hewitt, 1984).

A number of instruments were employed to assess the response of the structures and foundations to ice loads. The primary monitoring method utilized manual and inplace inclinometer systems. Other instruments and methods included piezometers, total pressure cells, extensometers, tiltmeters, settlement systems, and conventional survey methods.

The performance of these "caisson" structures has generally been acceptable (Blanchet, et al, 1991). Actual ice loadings have been well below design values and therefore the corresponding deformations have been small (Blanchet, et al, 1991).

Mobile Bottom-Founded Structures

The most recent generation of offshore exploration structures developed for use in the Beaufort Sea have been mobile bottom-founded structures. Although similar in some respects to gravity base structures that have been used widely in non-Arctic oceans, they have some unique characteristics that have been dictated by the need to resist high horizontal ice loading. Two such units have been built and deployed, the Concrete Island Drilling System, 'CIDS', operated by Global Marine Ltd. (Masonheimer, et al, 1986) and the steel SSDC/MAT system operated by Canadian Marine Drilling Ltd. (Hewitt, et al, 1988). The latter was a development of the SSDC caisson that had previously been based on an hydraulic fill berm. For the new system, the berm was replaced by a specially fabricated steel base or mat which was mated to the SSDC.

These systems offer two major advantages over the earlier units. Firstly, they can operate in relatively deep water (up to 17 m for the CIDS and 25 m for the SSDC/MAT) without the need for an artificial berm or sand core. This avoids the cost of berm construction and the need for suitable berm material. In the Canadian Beaufort Sea, where sand had been the traditional construction material, the need to undertake costly densification to eliminate the risk of liquefaction was also avoided. The second advantage is that there is no need for site preparation.

The base design for these structures is governed by geotechnical considerations. The features of the surficial sediments in the Beaufort Sea have been described previously. Some typical shear strength profiles are illustrated in Figure 2. The structures develop high lateral load resistances in these conditions by means of their large bases which incorporate a grid of horizontal strip anchors. These 'skirts' project from the base and are forced into the seabed when the unit is ballasted down (Figure 3). As a result, they accommodate some unevenness in the seafloor and efficiently develop lateral resistance. The components of lateral resistance are passive resistance and base friction. The depth of penetration of the skirts is controlled by the soil strength in relation to the available ballast weight. For relatively stiff soils, the penetration is low and the majority of resistance is derived from the skirt tips. For soft soils, the skirts can penetrate until the base comes into contact with the soil. In such soils, the passive resistance is the major component.

As with caisson islands, geotechnical assessments of these structures must address not only the overall stability but also deformations under ice loading. Detailed predictions of foundation deformation have made use of non-linear finite element analysis (Sladen, et al, 1990). These are important, not only from the viewpoint of serviceability but also with respect to monitoring. As direct measurement of ice loads is impracticable, geotechnical instrumentation (predominantly inplace inclinometers) has been the primary means of setting well safety criteria. Foundation deformations can be related to ice load level and hence to the margin of safety.

More recently, the use of geotechnical instrumentation in conjunction with detailed predictions of deformation has been explored as a means of measuring ice loads from observed ice events thus assisting in the rationalization of ice design criteria. Although estimated ice loads are approximate, results have been encouraging and the method is arguably as reliable as any other method of estimating actual ice load (Blanchet, et al, 1991).

Table 3 (from Blanchet, et al, 1991) shows the results of ice load estimations for six sites (four caisson locations and two SSDC/MAT locations). For comparison, the range of ice loads measured by other methods is also indicated. As can be seen, estimated ice loads have all been less than 200 MN. This is significantly lower than design loads that would have been predicted for the ice events, based on data available during the early stages of offshore development in the Beaufort Sea. The accommodation of ice loads is one of the major engineering challenges that must be met if offshore production facilities are to be developed in the Arctic. Detailed geotechnical modelling and instrumentation have provided valuable data that have shown that traditional design ice loads were very conservative. By providing a rational basis for lower design ice loads, one of the major potential barriers to development has been reduced.

SUMMARY

Exploratory drilling for hydrocarbons has been conducted from offshore "structures" in the Beaufort Sea for over twenty years. The initial "structures" consisted of a variety of earth fill islands in very shallow water depths. In the late 1970's, this concept, with variations and refinements, was extended into deeper waters. In the early 1980's, composite caisson/earth fill structures were introduced. The limited data base on ice at that time lead to high design ice loads with the result that massive structures were required. These large earth fill structures were, however, limited by problems such as liquefaction and decommissioning.

By the mid-1980's, with the accumulation of considerable design and operational experience, it became feasible to utilize fully mobile structures. These units develop lateral resistance by mobilizing the shear strength of relatively competent soils immediately below the seabed surface. Today, exploratory drilling is efficiently conducted from such structures on a routine basis.

REFERENCES

Ashford, R.A., 1984: "Engineering and Construction of Mukluk Island", Proceedings, 16th Annual Offshore Technology Conference, Houston, OTC Paper 4670, pp. 205-212.

Berzins, W.E., and Hewitt, K.J., 1984: "The Use of Hydraulically Placed Sand in Island Construction", Proceedings, 16th Annual Offshore Technology Conference, Houston, OTC Paper 4671, pp. 213-221.

Blanchet, D., Hewitt, K.J., and Sladen, J.A., 1991: "Comparison Between Measured Global Ice Loads and Geotechnical Response of Arctic Offshore Structures", International Arctic Technology Conference, Anchorage, May 29-31, 1991. SPE 22088.

Bruce, J., and Harrington, G., 1982: "Design Aspects of a Mobile Arctic Caisson", Proceedings, 14th Annual Offshore Technology Conference, Vol. 3, Paper OTC 4333, pp. 405-416.

DeJong, J., and Bruce, J., 1978: "Design and Construction of a Caisson Retained Island Drilling Platform for the Beaufort Sea", Proceedings, 10th Annual Offshore Technology Conference, Vol. 4, Paper OTC 3294, pp. 2111-2120.

Duncan, J.M., and Chang, C.Y., 1970: "Nonlinear Analysis of Stress and Strain in Soils", Proceedings, ASCE, Vol. 96, No. SM5, pp. 1629-1653.

Fitzpatrick, J., 1983: "The Single Steel Drilling Caisson--A Novel Approach to Bottom Founded Structures in Arctic Waters", Society of Petroleum Engineers, 58th Annual Conference, San Francisco, CA, SPE 11999.

Fitzpatrick, J., and Stenning, D.G., 1983: "Design and Construction of Tarsiut Island in the Canadian Beaufort Sea", Proceedings, 15th Annual Offshore Technology Conference, Vol. 2, Paper OTC 4517, pp. 51-60.

Funegard, E.G., Nagel, R.H. and Olson, G.G., 1987: "Design and Construction of the MARS Spray Ice Island", Proceedings of Offshore Mechanics and Arctic Engineering, OMAE, Houston.

Hewitt, K.J., Sladen, J.A., Williams, D.R., and Brown, J., 1988: "Geotechnical Evaluation and Performance of the Canmar SSDC/MAT Mobile Offshore Drilling Unit", 41st Canadian Geotechnical Conference, Kitchener, Ontario, 1988. Canadian Geotechnical Society.

Masonheimer, R.A., Deily, F.H., and Knorr, G.D., 1986: "A Review of CIDS First-Year Operations", Proceedings, 18th Annual Offshore Technology Conference, Houston, TX, OTC Paper 5288, pp. 555-564

Masterson, D.M., Bruce, J.C., Sisodiya, R., Maddock, W., 1991: "Beaufort Sea Exploration: Past and Future", Proceedings, 23rd Annual Offshore Technology Conference, Houston, Paper OTC 6530.

McCreath, D.R., Hodge, W.E., and Harrington, A.G., 1982: "Geotechnical Design Considerations for the Gulf Oil Mobil Arctic Caisson", 2nd Canadian Conference on Marine Geotechnical Engineering, Halifax, N.S., Section IV.

O'Connor, M.J. & Associates, 1980: "Development of a Proposed Model to Account for the Surficial Geology of the Southern Beaufort Sea", Open File Report #954, Geological Survey of Canada.

Poulos, S.J., 1981: "The Steady State of Deformation", ASCE Journal of the Geotechnical Engineering Division, 107(GT5), pp. 553-562.

Riley, J.G., 1975: "The Construction of Artificial Islands in the Beaufort Sea", Proceedings of the 9th

Annual Offshore Technology Conference, Paper No. 2167.

Ruffell, J.P., Romeril, P.M., and Jones, K.W., "A Critique of Arctic Marine Site Investigation Techniques", Arctic '85 (ASCE), San Francisco, March, 1985.

Schlegel, M.G. and Mahmood, A., "Arctic Earth Materials for Offshore Construction in Alaska", Arctic '85 (ASCE), San Francisco, March, 1985.

Shinde, S.B., Crooks, J.H.A., James, D.A., and Williams-Fitzpatrick, S., 1986: "Geotechnical Design for Beaufort Sea Structures", Proceedings, 3rd Canadian Conference on Marine Geotechnical Engineering, St. John's, Newfoundland, Vol. 1, pp. 347-362.

Sladen, J.A., 1989: "Problems with Interpretation of Sand State From Cone Penetration Test", Geotechnique, Vol. 39, No. 2, June, 1989.

Sladen, J.A. and Hewitt, K.J., 1989: "Influence of Placement Method on the In Situ Density of Hydraulic Sand Fills", Canadian Geotechnical Journal, 26, 3, 453-466, August 1989.

Sladen, J.A., Hewitt, K.J., and Sparrow, D., 1990: "Some Aspects of the Behaviour of Beaufort Sea Clays", 43rd Canadian Geotechnical Conference, Quebec, 1990. Canadian Geotechnical Society.

TABLE 3

CASE HISTORY	MAXIMUM INTERPRETED ICE LOAD (MN) FROM ICE MONITORING	FROM GEOTECHNICAL RESPONSE
1. Tarsiut	140	20
2. Uviluk	80	<30
	70 (June)	N/A
3. Kogyuk	<100 (setdown)	<100
	N/A	<30
	100 (June)	N/A
4. Amauligak	500+ (Jefferies & Wright)	<110
	230 (Blanchet)	
5. Phoenix	70	20
6. Aurora	<70	<35

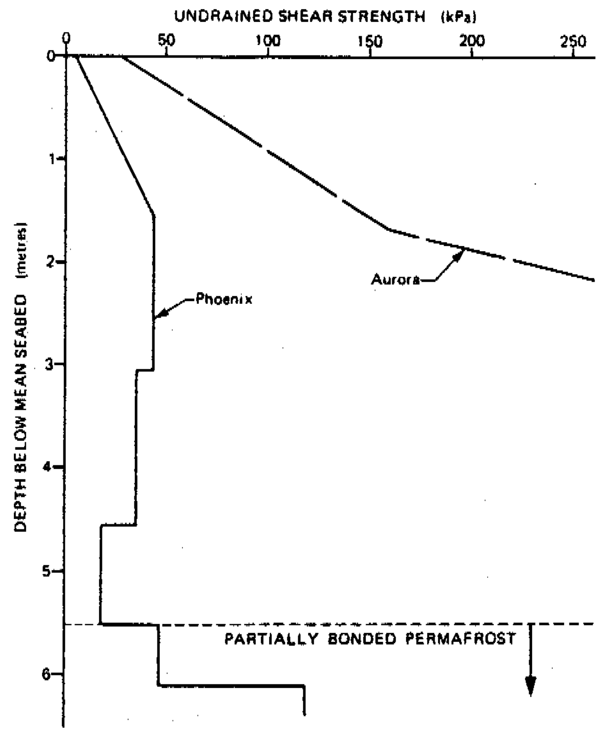


FIGURE 2

DESIGN UNDRAINED SHEAR STRENGTH PROFILES

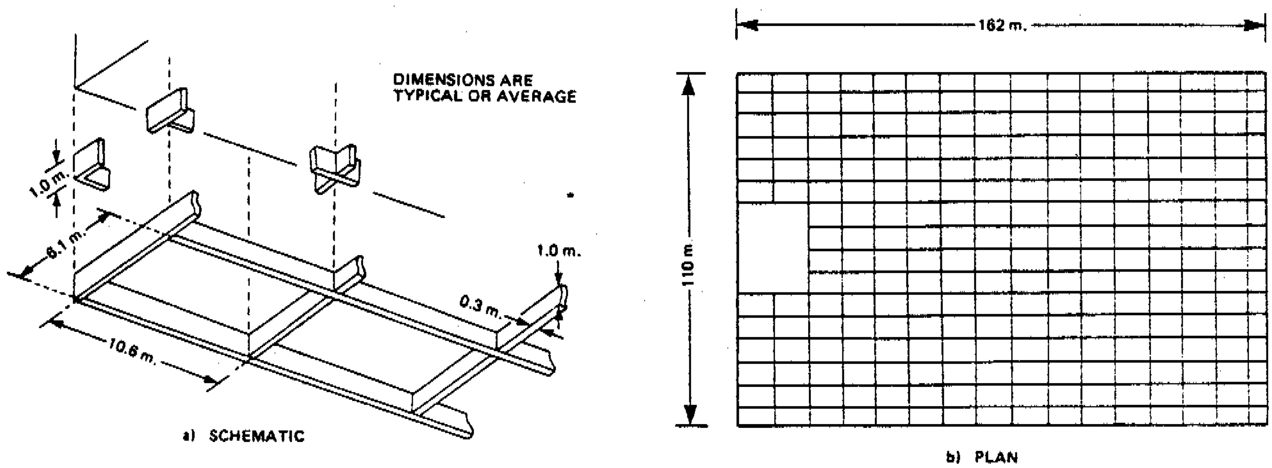
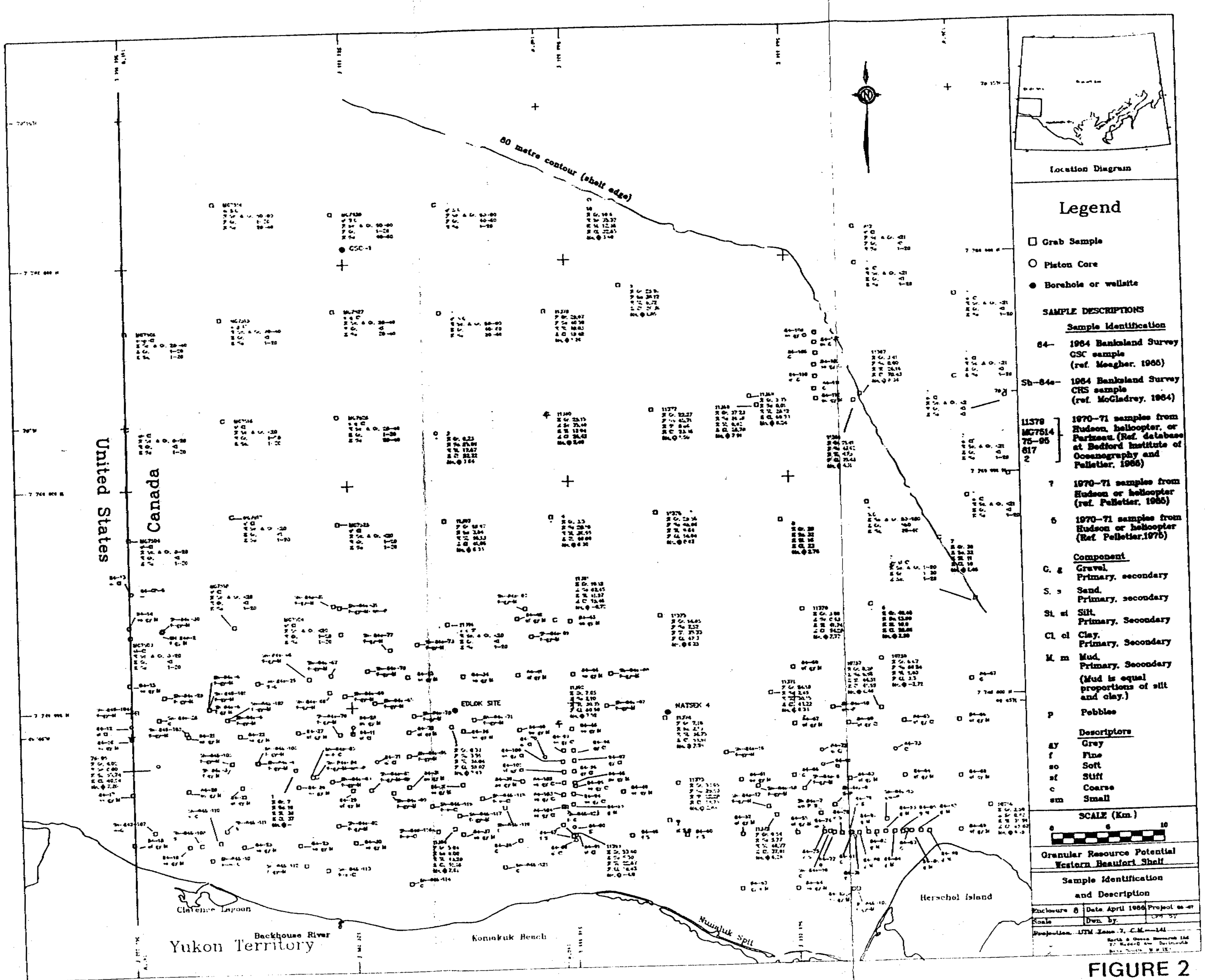


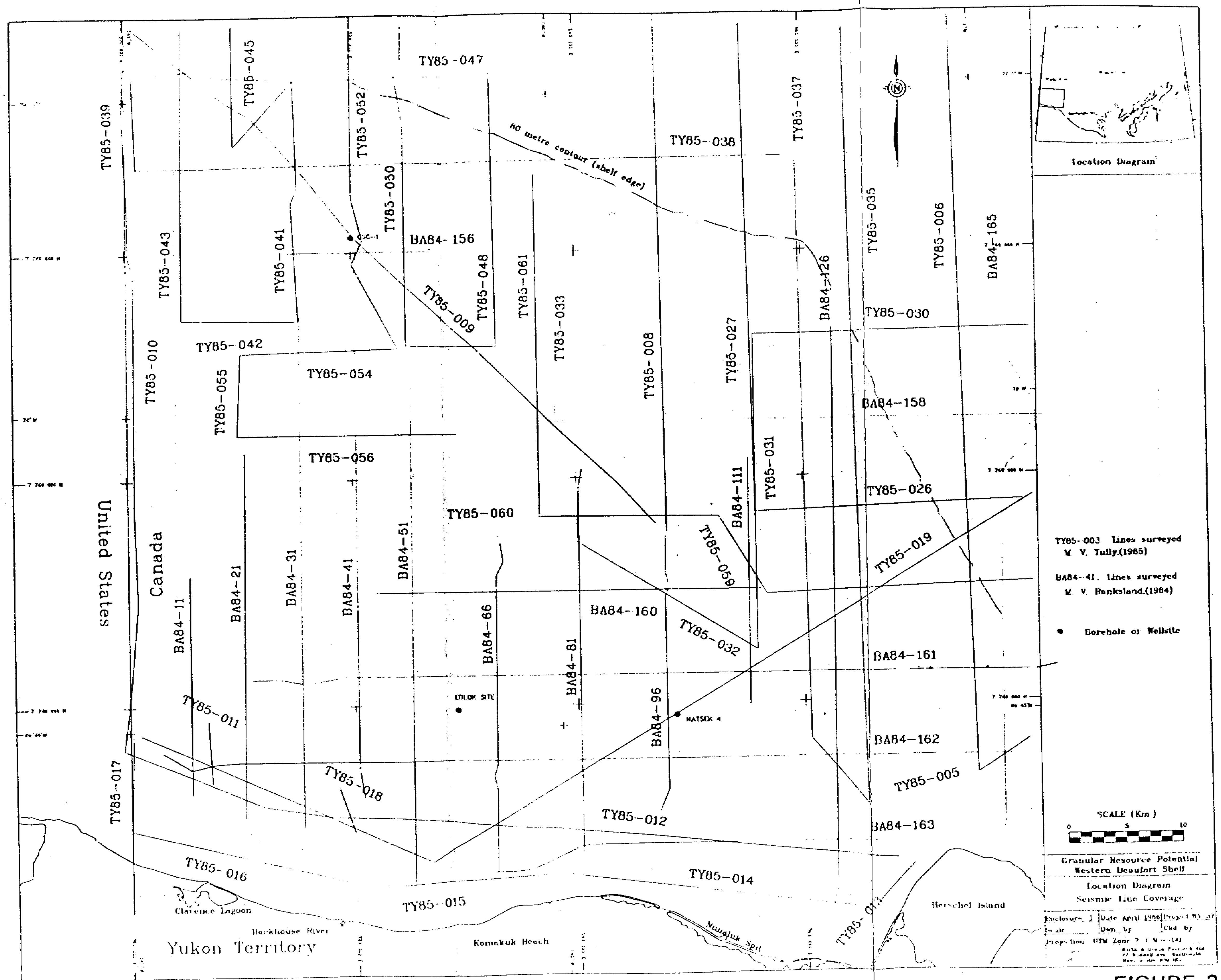
FIGURE 3

ARRANGEMENT OF BASE SKIRTS SSDC/MAT



Location Diagram
Legend
Grab Sample
Piston Core
Borehole or wellsite
SAMPLE DESCRIPTIONS
Sample Identification
64– 1964 Bankisland Survey GSC sample (ref. Meagher, 1965)
Sb–64e– 1964 Bankisland Survey CHS sample (ref. McGladrey, 1964)
11379 MC7514 75–95 617 2 1970–71 samples from Hudson, helicopter, or Parizeau. (Ref. database at Bedford Institute of Oceanography and Pelletier, 1985)
? 1970–71 samples from Hudson or helicopter (ref. Pelletier, 1985)
6 1970–71 samples from Hudson or helicopter (Ref. Pelletier,1975)
Component
G, g Gravel, Primary, secondary
S, s Sand, Primary, secondary
Si, si Silt, Primary, Secondary
Cl, cl Clay, Primary, Secondary
M, m Mud, Primary, Secondary
(Mud is equal proportions of silt and clay.)
p Pebbles
Descriptors
gy Grey
f Fine
so Soft
sf Stiff
c Coarse
sm Small
SCALE (Km.)
0 5 10
Granular Resource Potential
Western Beaufort Shelf
Sample Identification and Description
Enclosure 8
Date April 1986
Scale
Projection UTM Zone 7, C.M. 141
80 metre contour (shelf edge)
United States
Canada
EDLOK SITE
NATSEK 4
Clarence Lagoon
Backhouse River
Yukon Territory
Komakuk Beach
Nunaluk Spit
Herschel Island

FIGURE 2



Location Diagram
TY85-047
80 metre contour (shelf edge)
TY85-038
TY85-039
TY85-045
TY85-052
TY85-037
TY85-030
BA84-156
TY85-043
TY85-041
TY85-048
TY85-061
TY85-009
TY85-033
TY85-035
TY85-006
BA84-165
BA84-126
TY85-030
TY85-042
TY85-010
TY85-054
TY85-055
TY85-008
TY85-027
BA84-158
TY85-056
TY85-031
BA84-111
TY85-026
TY85-060
TY85-059
United States
Canada
BA84-51
BA84-41
BA84-31
BA84-21
BA84-11
BA84-66
BA84-160
TY85-019
TY85-032
BA84-81
BA84-161
BA84-96
NATSEK 4
TY85-011
BA84-162
TY85-017
TY85-018
TY85-005
TY85-012
BA84-163
TY85-016
TY85-014
TY85-015
Clarence Lagoon
Backhouse River
Yukon Territory
Komakuk Beach
Nunaluk Spit
TY85-013
Herschel Island
TY85-003 Lines surveyed M. V. Tully.(1985)
BA84-41. lines surveyed M. V. Banksland.(1984)
Borehole or Wellsite
SCALE (Km)
0
5
10
Granular Resource Potential Western Beaufort Shelf
Location Diagram
Seismic Line Coverage
Enclosure 1
Date April 1986
Scale
Dwn by
Chd by
Projection UTM Zone 7

FIGURE 3

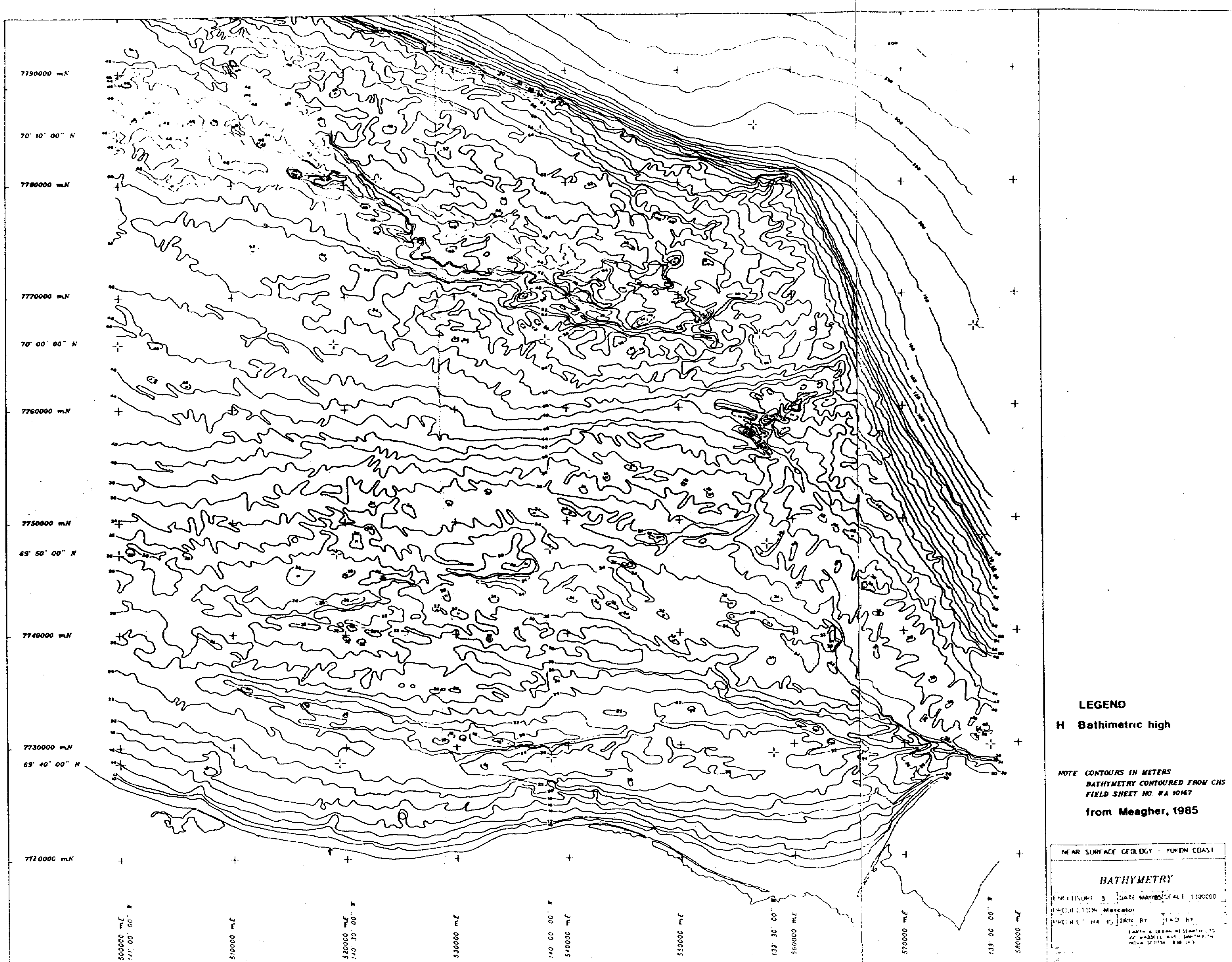
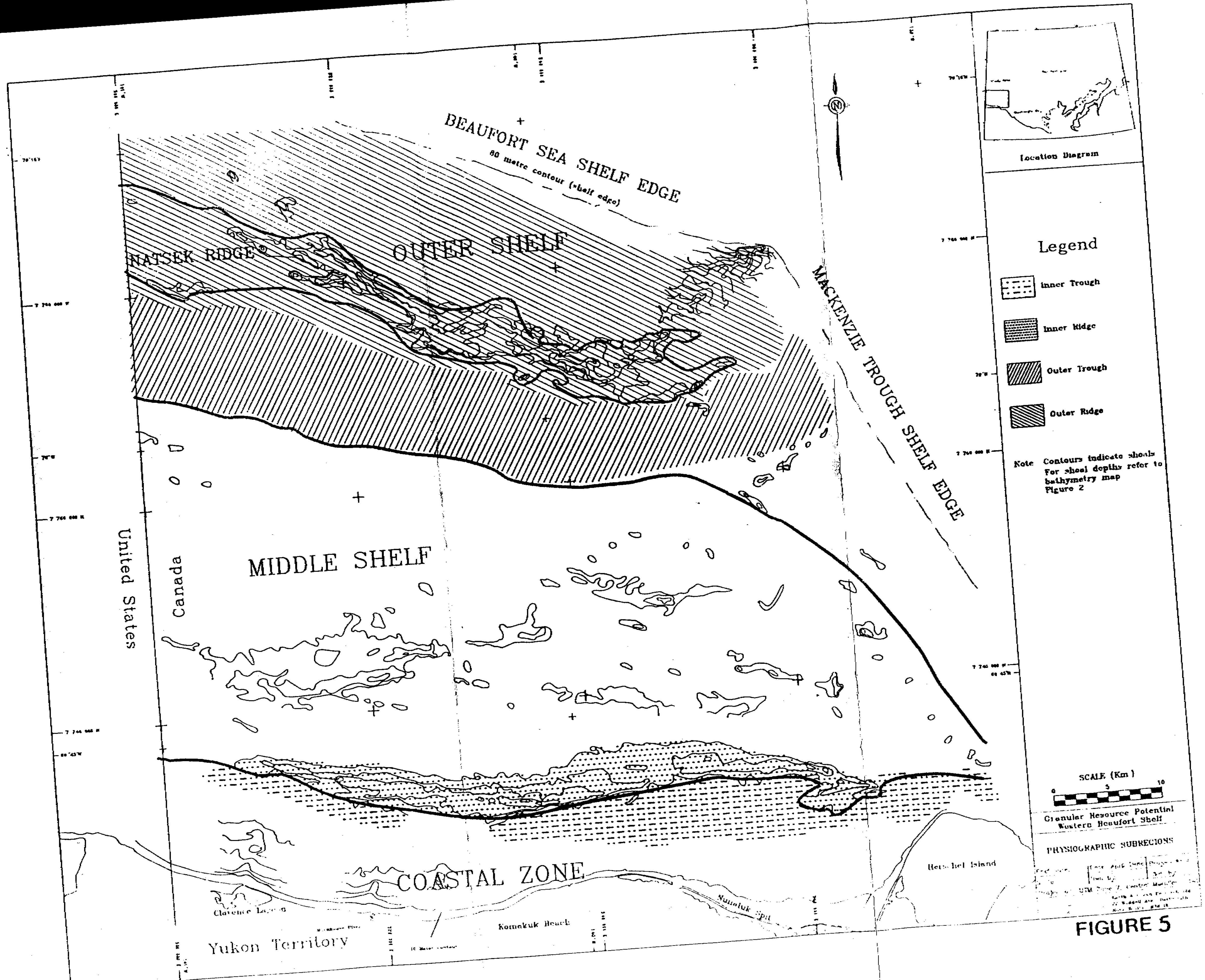

7790000 mN
70° 10' 00" N
7780000 mN
7770000 mN
70° 00' 00" N
7760000 mN
7750000 mN
69° 50' 00" N
7740000 mN
7730000 mN
69° 40' 00" N
7720000 mN
500000 mE
141° 00' 00" W
510000 mE
520000 mE
140° 30' 00" W
530000 mE
140° 00' 00" W
540000 mE
550000 mE
139° 30' 00" W
560000 mE
570000 mE
139° 00' 00" W
580000 mE
LEGEND
H Bathimetric high
NOTE CONTOURS IN METERS
BATHYMETRY CONTOURED FROM CHS
FIELD SHEET NO. WA 10167
from Meagher, 1985
NEAR SURFACE GEOLOGY - YUKON COAST
BATHYMETRY
ENCLOSURE 3 DATE MAY/85 SCALE 1:100000
PROJECTION Mercator

FIGURE: 4



BEAUFORT SEA SHELF EDGE
60 metre contour (shelf edge)
OUTER SHELF
NATSEK RIDGE
MACKENZIE TROUGH SHELF EDGE
MIDDLE SHELF
United States
Canada
COASTAL ZONE
Clarence Lagoon
Yukon Territory
Komakuk Beach
Nunaluk Spit
Herschel Island
Location Diagram
Legend
Inner Trough
Inner Ridge
Outer Trough
Outer Ridge
Note Contours indicate shoals For shoal depths refer to bathymetry map Figure 2
SCALE (Km)
0
5
10
Granular Resource Potential Western Beaufort Shelf
PHYSIOGRAPHIC SUBREGIONS

FIGURE 5

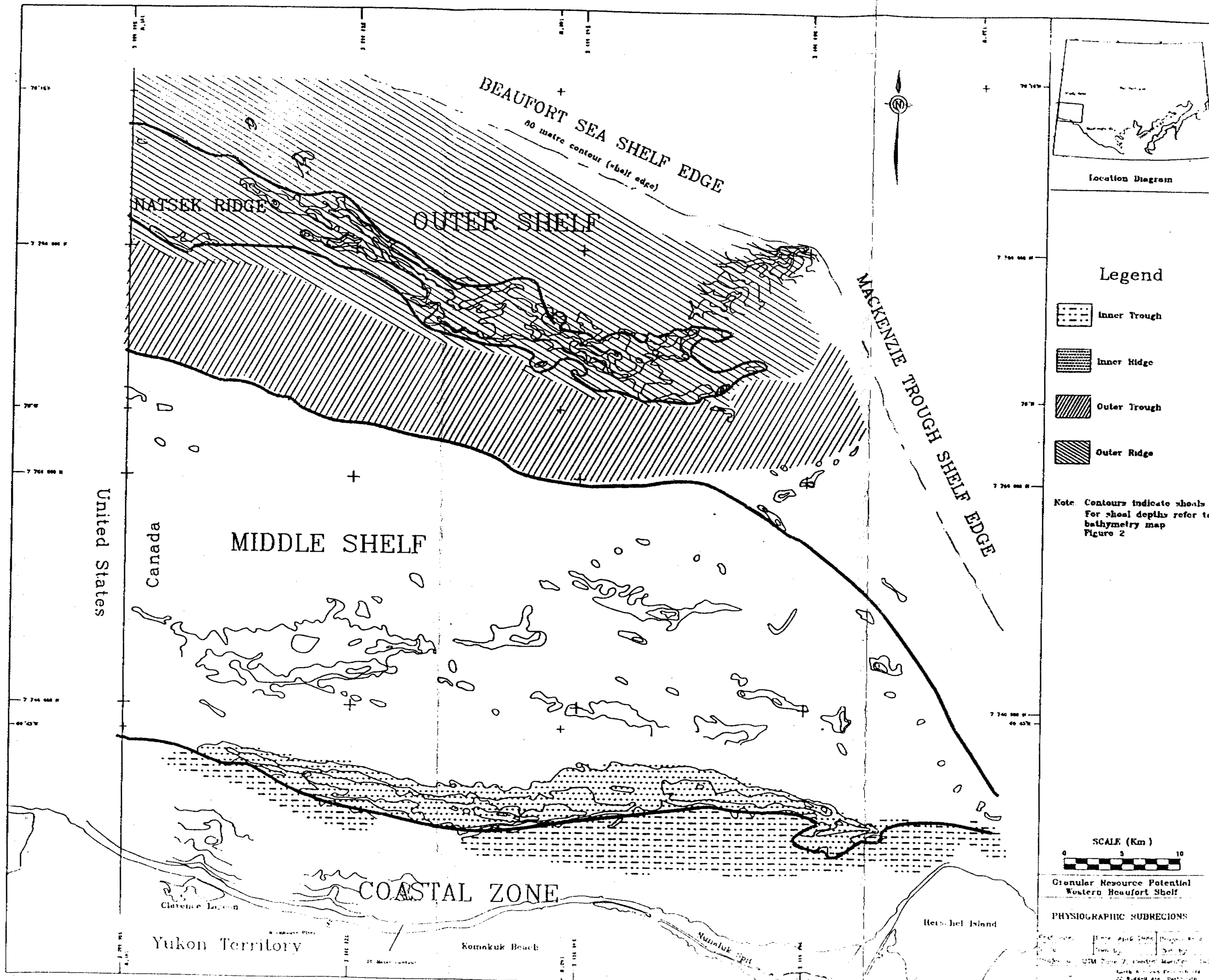
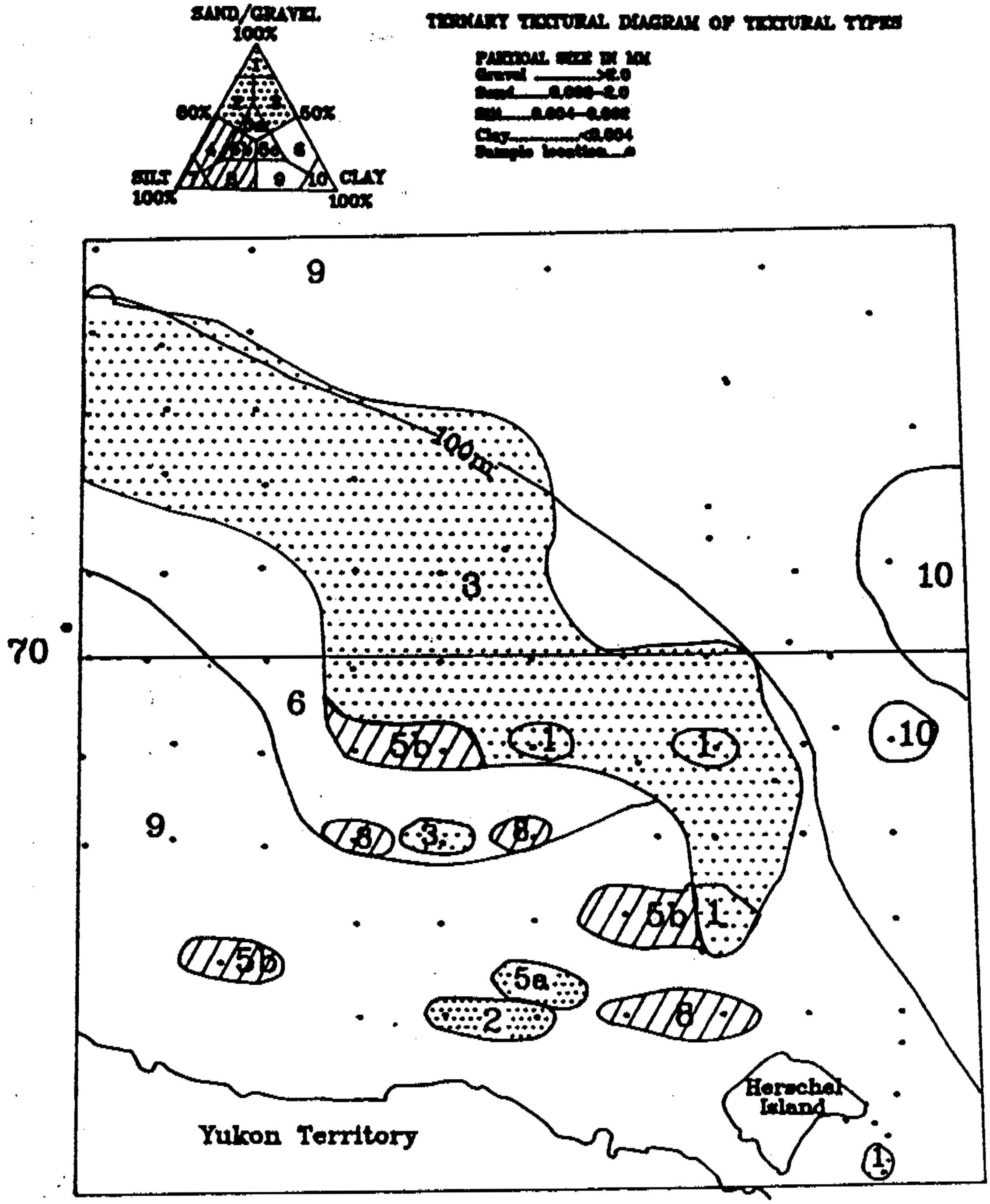
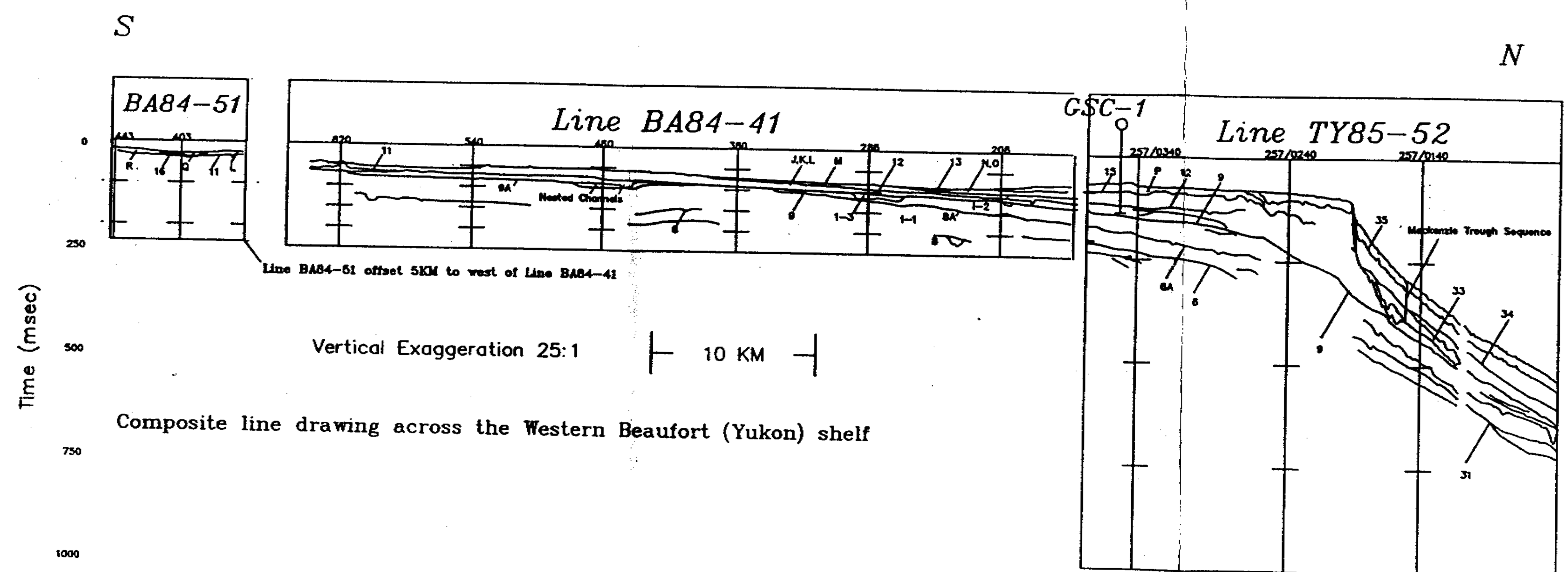

BEAUFORT SEA SHELF EDGE
80 metre contour (shelf edge)
NATSEK RIDGE
OUTER SHELF
MACKENZIE TROUGH SHELF EDGE
MIDDLE SHELF
United States
Canada
COASTAL ZONE
Clarence Lagoon
Yukon Territory
Komakuk Beach
Nunaluk Spit
Herschel Island
Location Diagram
Legend
Inner Trough
Inner Ridge
Outer Trough
Outer Ridge
Note: Contours indicate shoals For shoal depths refer to bathymetry map Figure 2
SCALE (Km)
0
5
10
Granular Resource Potential Western Beaufort Shelf
PHYSIOGRAPHIC SUBREGIONS

FIGURE 5



Distribution of bottom sediment types
(After Pelletier, 1985)

FIGURE 6



Composite line drawing across the Western Beaufort (Yukon) shelf

FIGURE 7

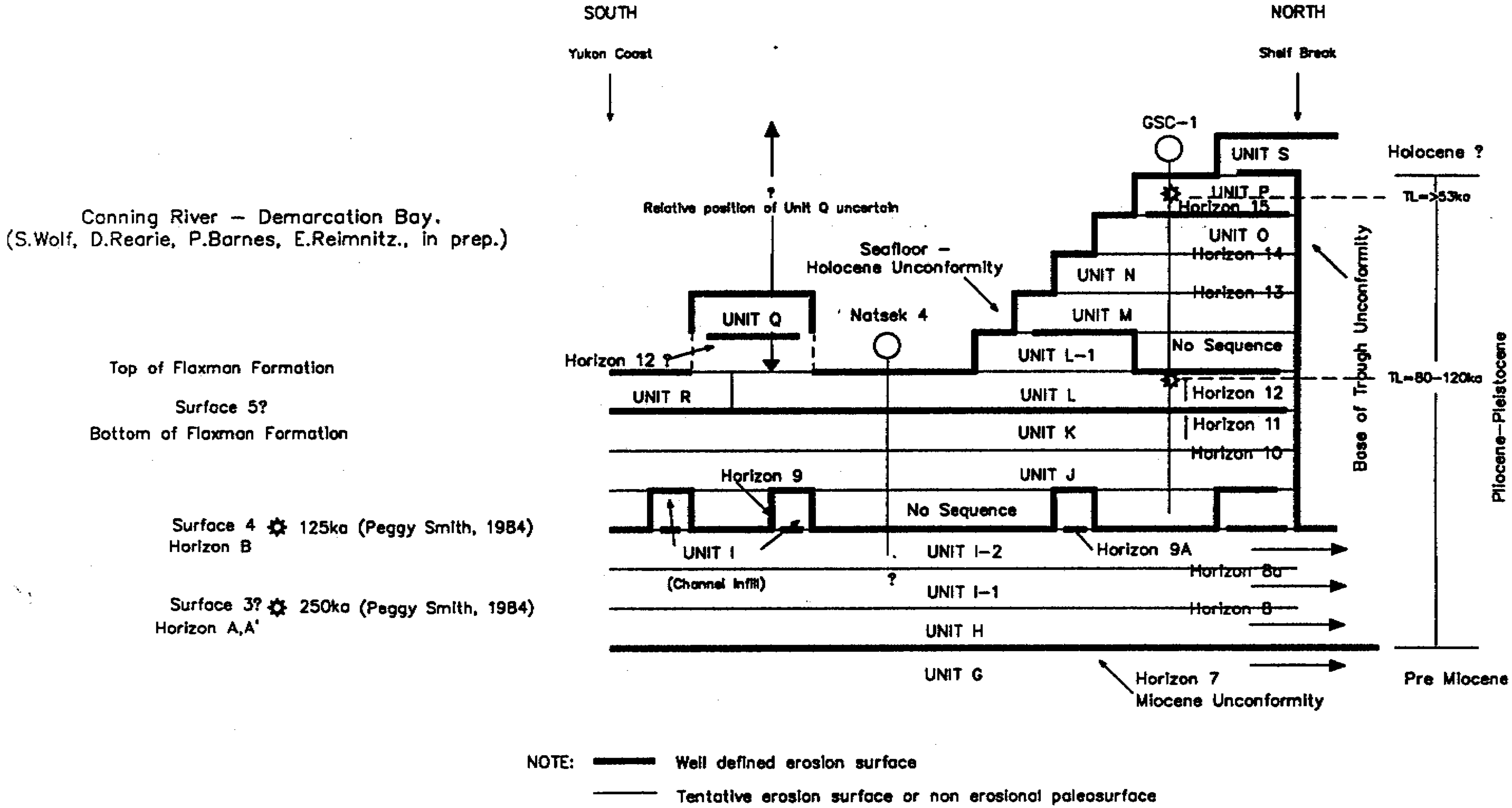


FIGURE 8 SEISMO-STRATIGRAPHIC RELATIONSHIPS AND AGES - WESTERN BEAUFORT (YUKON) SHELF

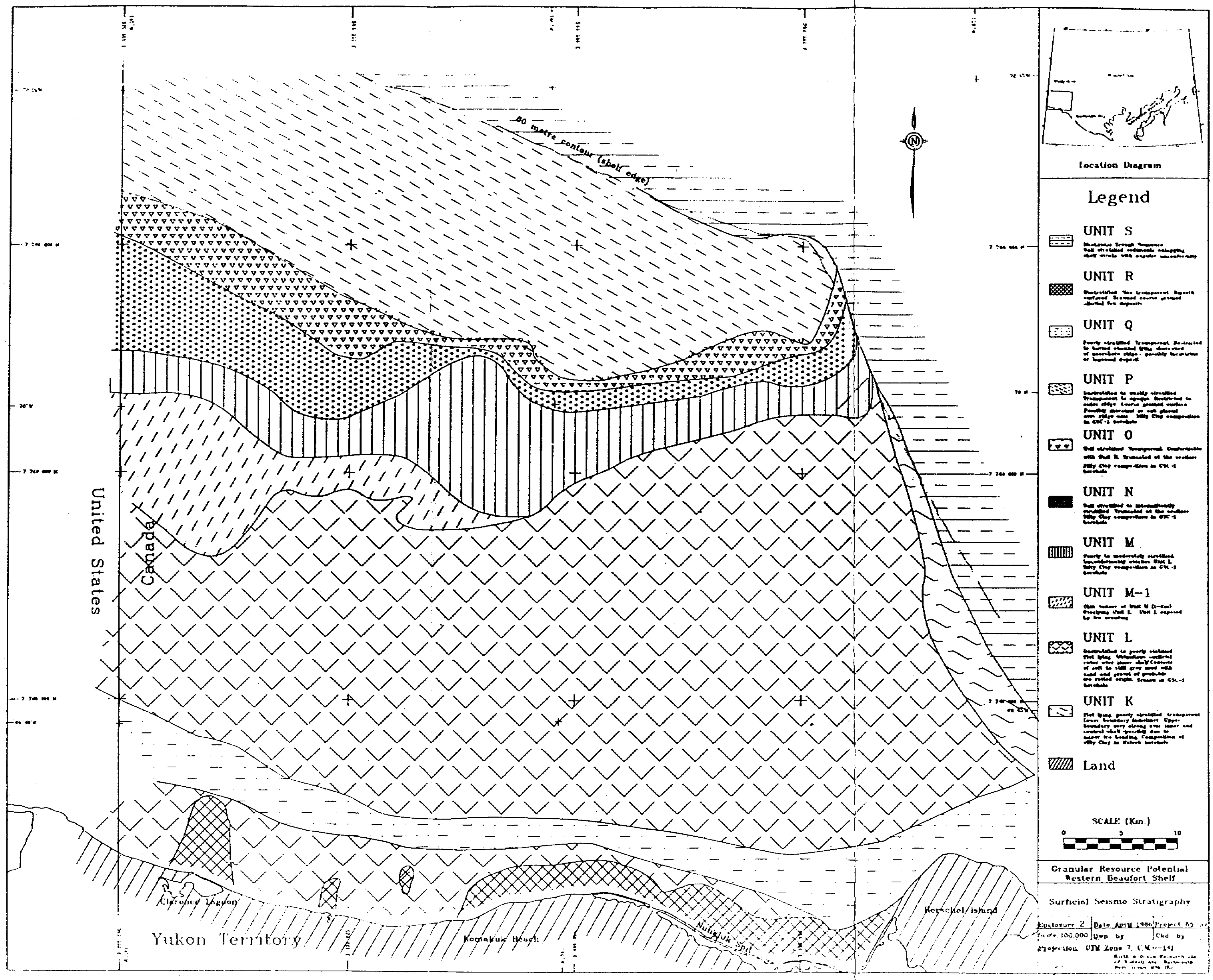

60 metre contour (shelf edge)
United States
Canada
Yukon Territory
Clarence Lagoon
Komakuk Beach
Nunaluk Spit
Herschel Island
Location Diagram
Legend
UNIT S
UNIT R
UNIT Q
UNIT P
UNIT O
UNIT N
UNIT M
UNIT M-1
UNIT L
UNIT K
Land
SCALE (Km.)
0
5
10
Granular Resource Potential
Western Beaufort Shelf
Surficial Seismo Stratigraphy
Enclosure 2
Date April 1986
Scale 100,000
Dwn by
Chd by
Projection UTM Zone 7, C.M. 141

FIGURE 9

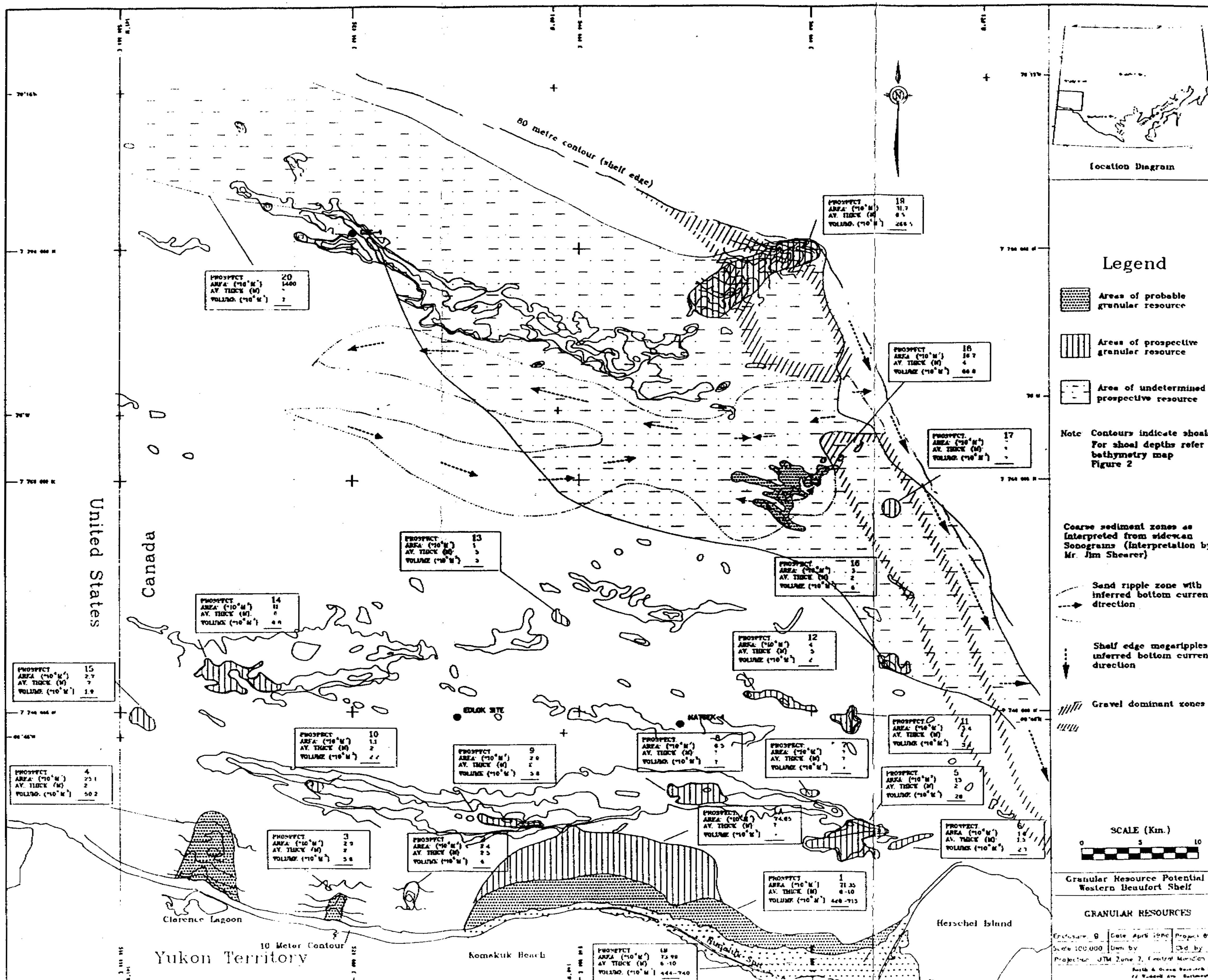

Location Diagram
80 metre contour (shelf edge)
United States
Canada
EDLOK SITE
Clarence Lagoon
10 Meter Contour
Yukon Territory
Komakuk Beach
Herschel Island
Legend
Areas of probable granular resource
Areas of prospective granular resource
Area of undetermined prospective resource
Note Contours indicate shoals
For shoal depths refer to bathymetry map
Figure 2
Coarse sediment zones as interpreted from sidescan Sonograms (interpretation by Mr. Jim Shearer)
Sand ripple zone with inferred bottom current direction
Shelf edge megaripples, inferred bottom current direction
Gravel dominant zones
SCALE (Km.)
0
5
10
Granular Resource Potential
Western Beaufort Shelf
GRANULAR RESOURCES

FIGURE 10