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PART 1

REPORTS ON NOGAP REGIONAL STUDIES

The Western Beaufort (Yukon) Continental Shelf
(NOGAP Project A4-05)

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1.0 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 (INAC). 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 on-shore or off-shore 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 5,000 km^2.

2.0 Data Bases

Prior to 1984/1985 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 14,055 km of heave compensated echo sounder data, 820 km of 10 in^3 air gun, 50 Khz side scan and 3.5 Khz profiler data, 14 piston cores to a maximum 1.5 m 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 1,950 km of 10 in^3 air gun, 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 m. 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 2 geotechnical boreholes, as shown in Figure 2. The high resolution geophysical data set shown in Figure 3 totalled 2,770 km of high resolution seismics which was supplemented by selected echo sounder data from a 14,055 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 seismo-stratigraphy of the area (Lewis and Meagher, 1991) and Mr. Jim Shearer was analyzing the side scan 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 well site. Data from these studies, though preliminary at the time of writing of this report, have been incorporated were relevant to the discussions here.

3.0 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.

3.1 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 In-Shore 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 Off-Shore 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 a 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 In-Shore 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 In-Shore 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. Sub-surface evidence suggests that the stamuki shoal has developed on an older shoal feature.

3.2 Surficial Cover

The surficial sedimentary cover on the Yukon Shelf represents a conflicting interpretational situation. From the sub-surface seismo-stratigraphy and borehole data that is available, all of the strata from just beyond the near shore zones to the off-shore 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 side scan data for the off-shore region indicate these regions to be a sand-gravel dominant facies. Based on this discrepancy, it is concluded that the coarser off-shore 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 (personal communication) has interpreted high gravel concentrations from the side scan 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 mega-ripples. The sand ripples are observed within the eastern and central Outer Trough while the mega-ripples 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.

3.3 Subsurface Geology

The sedimentary section beneath the shelf region thickens to seaward and rests unconformably and para-conformably of a region-wide Miocene erosion surface. The sub-surface sedimentary strata form a predominantly fine grained clastic wedge laid down under shelf, coastal, sub-aerial 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 off-shore extensions or re-worked components of alluvial fans on shore. The off-shore 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 sub-surface strata at this surface. With the possible exception of the near shore zone (Unit Q within the In-Shore 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 sub-aerially exposed and drowned the shelf. At least two of the unconformity surfaces form apparent buried shoreline topographies near the present day shelf edge suggesting sub-aerial 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 sub-surface 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 In-Shore 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 near shore 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.

3.4 Depositional Summary and Provenance

The sub-surface 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 near shore marine conditions with a fine grained source of supply from the south or possibly along shore from the east or west. As has been outlined 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 present day predominant source of new sediments to the Yukon Shelf is the coastal retreat on-going 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 re-worked into marine land forms of

bay mouth bars, islands and spits and they are also being transported off-shore a minimal distance where they form a thin veneer on top of the fine grained lacustrine or lagoonal materials which occupy the In-Shore 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 sub-surface source for these materials, it is 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 off-shore, possibly at a time of lower sea level when access by ice was restricted to the 40 to 50 m isobath.

4.0 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 on-shore 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 micro-profiler 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.

5.0 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 included 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 metres. The region in-shore 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 near shore region and it may or may not represent an economically recoverable resource for the region.

6.0 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 m isobath to the shelf edge is 557 - 842 million cubic metres.

- An additional 444 - 740 million cubic metres of probable resource is calculated for the area lying between the 10 m 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 m 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 metres.

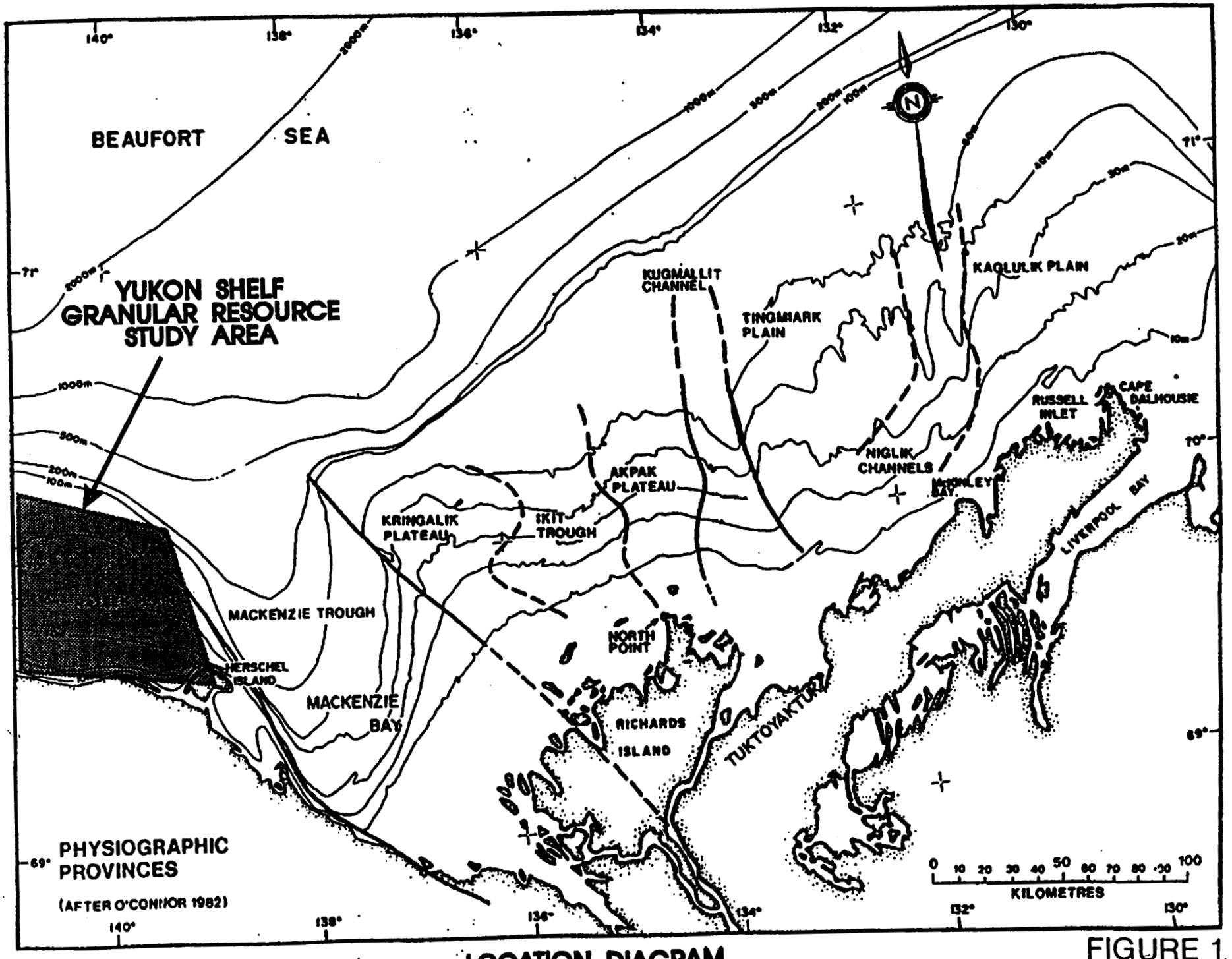
- The Outer Shelf zone has an area of 1,400 million square metres, but no thickness is attributed to the deposit at this time.

- 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

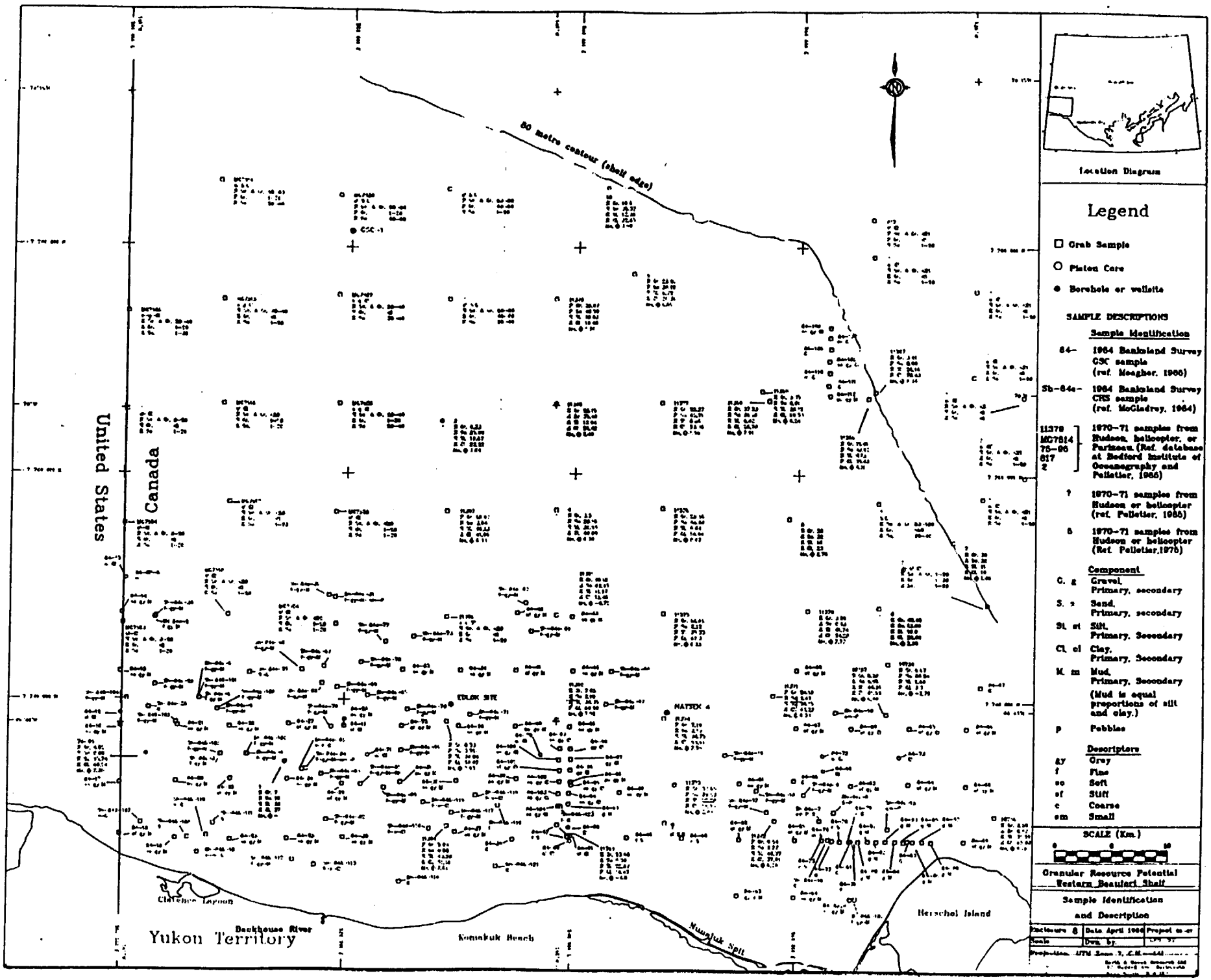
Prospect	Area $m^2 \times 10^6$	Average Thick (m)	Probable $m^3 \times 10^6$	Prospective $m^3 \times 10^6$	Confidence Level
Beach Zone (volume not included in total)					
1B (0-10m)	73.99	6-10	444-740		High
Coastal Zone					
1 (10-20m)	71.35	6-10	428-713.5		High
1A	74.65	-			Moderate
2	2.4	2.5	6.0		High
3	2.9	2.0	5.8		High
4	25.1	2.0	50.2		High
Middle Shelf Zone					
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 Zone					
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 1,400 million square metres.



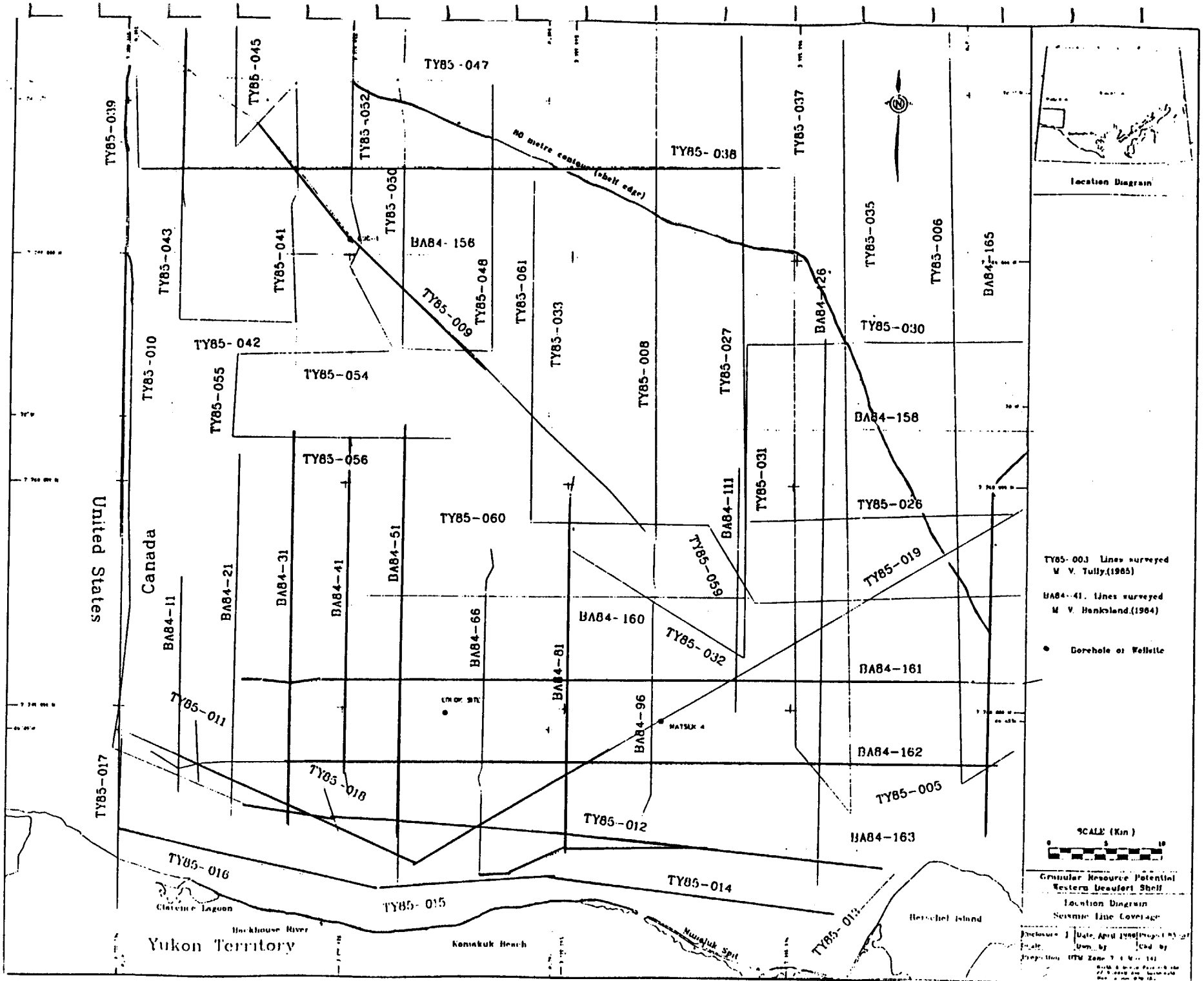
LOCATION DIAGRAM

FIGURE 1



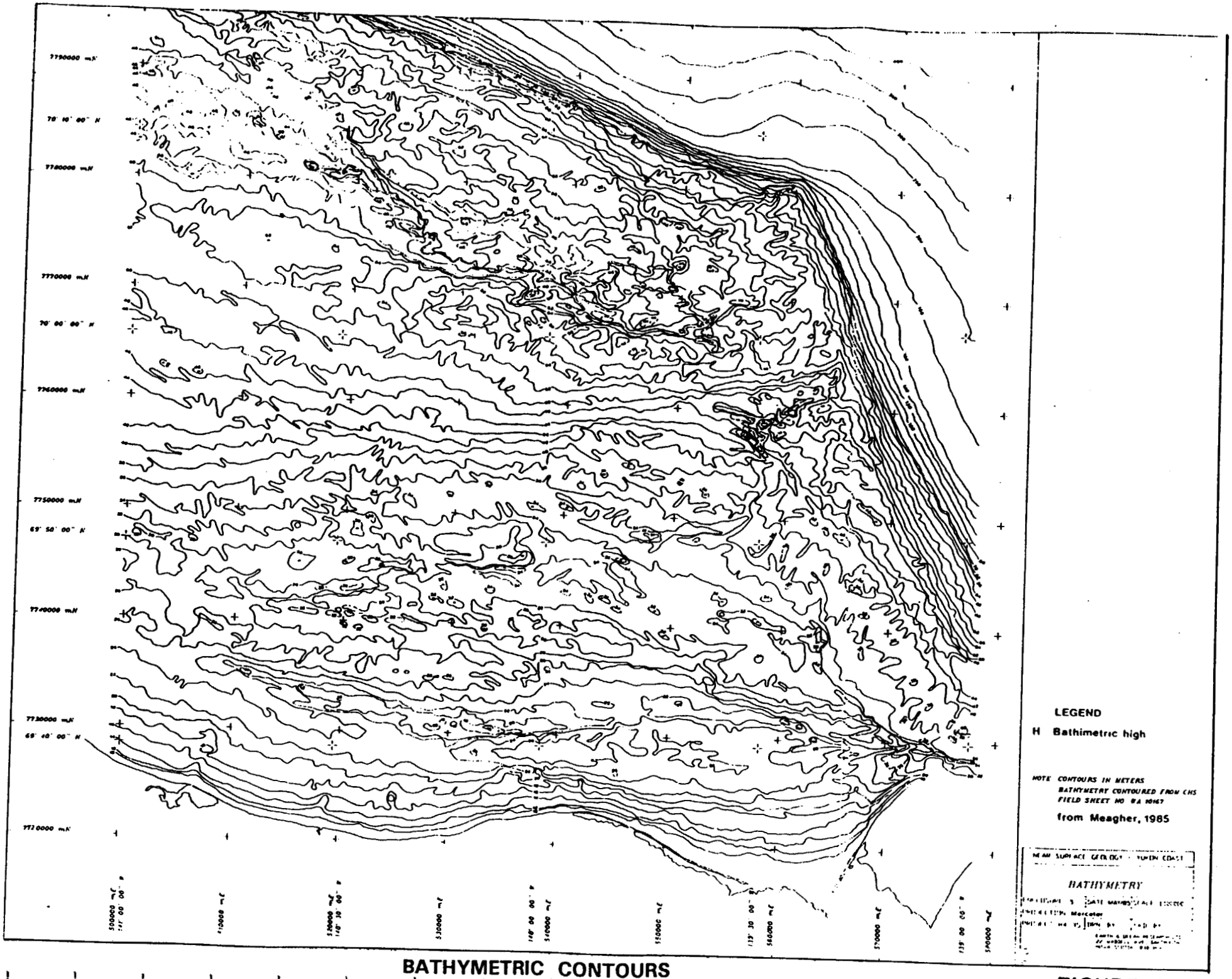
SAMPLE IDENTIFICATION AND DESCRIPTION

FIGURE 2



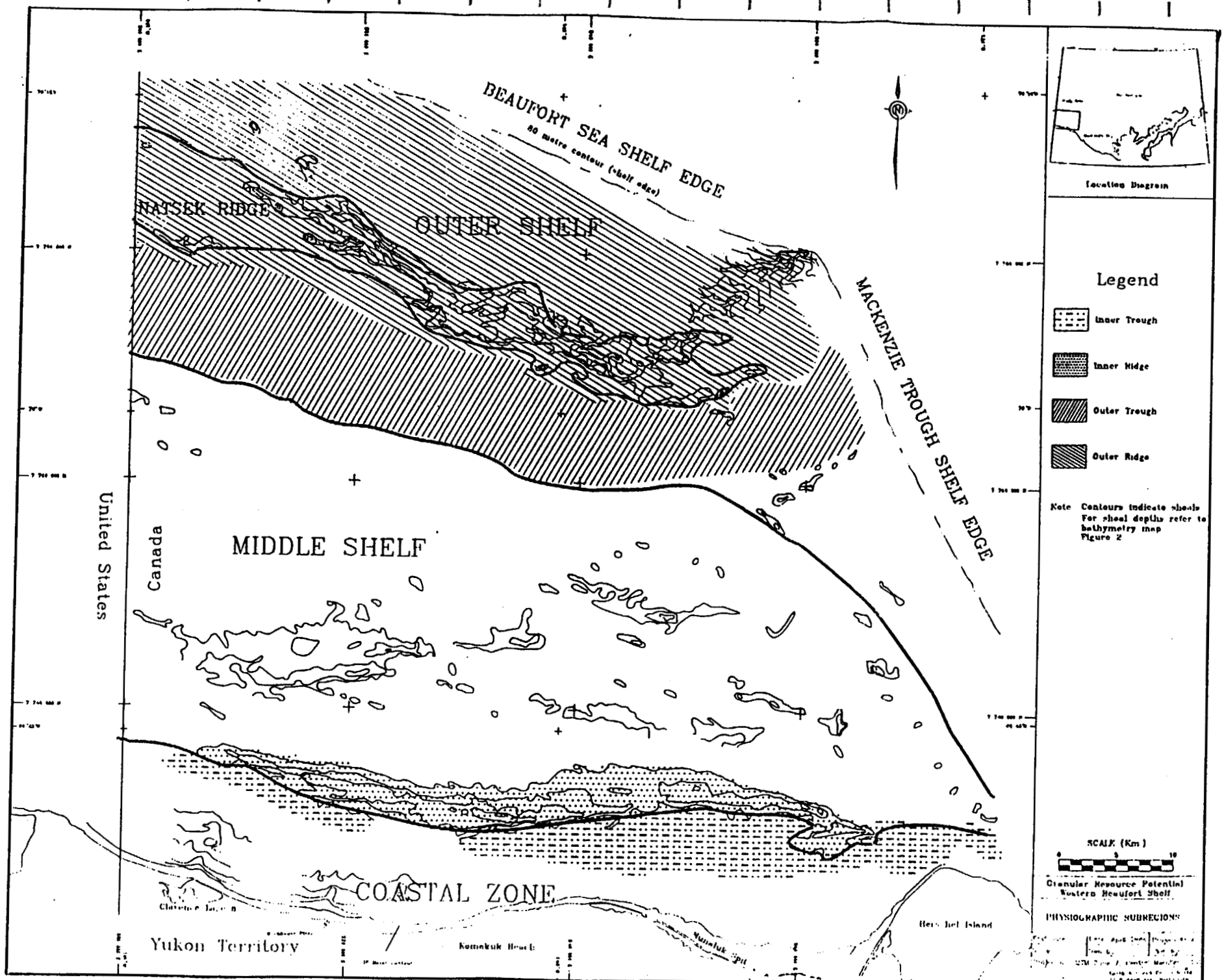
SEISMIC LINE COVERAGE

FIGURE 3



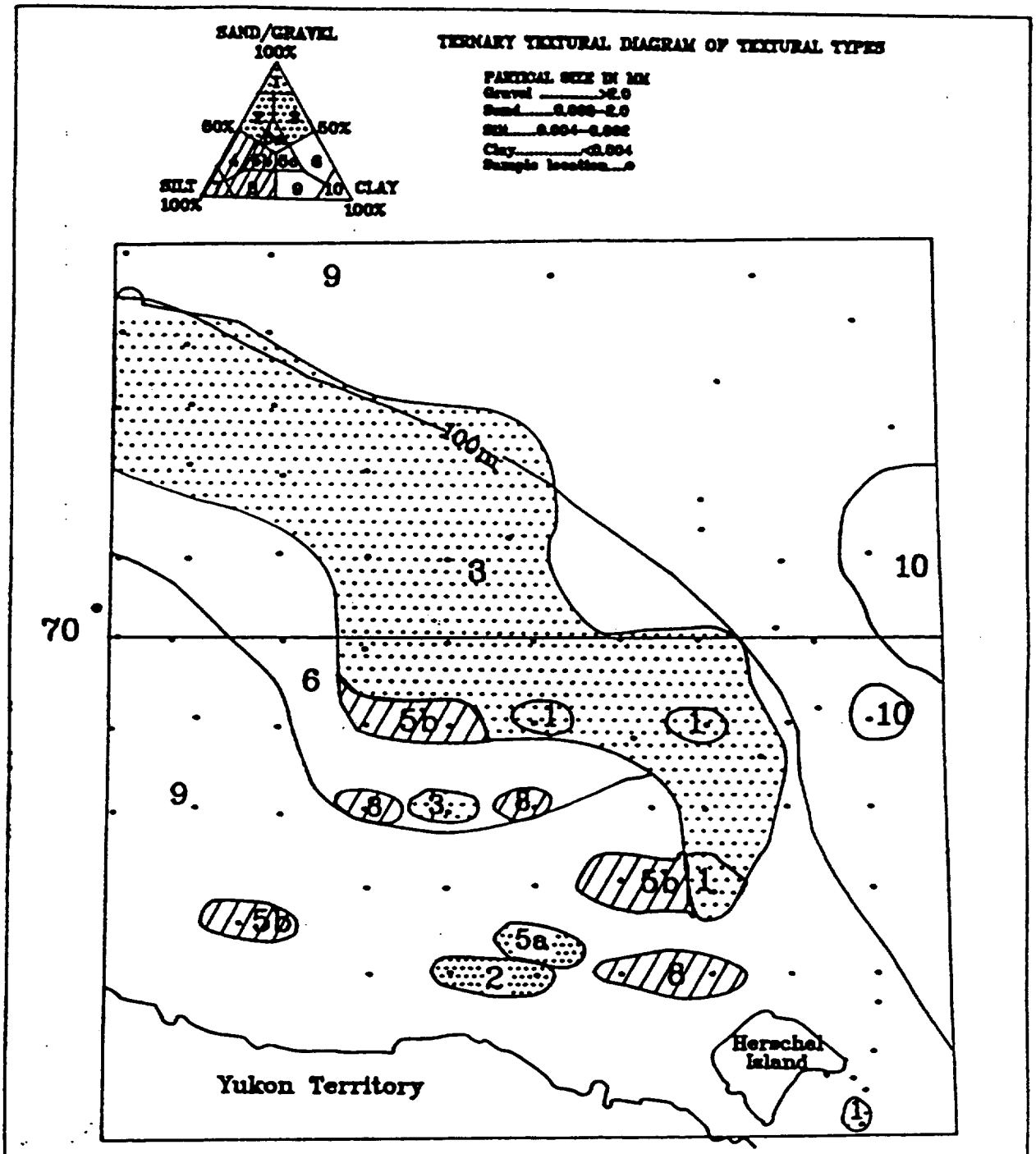
BATHYMETRIC CONTOURS

FIGURE 1



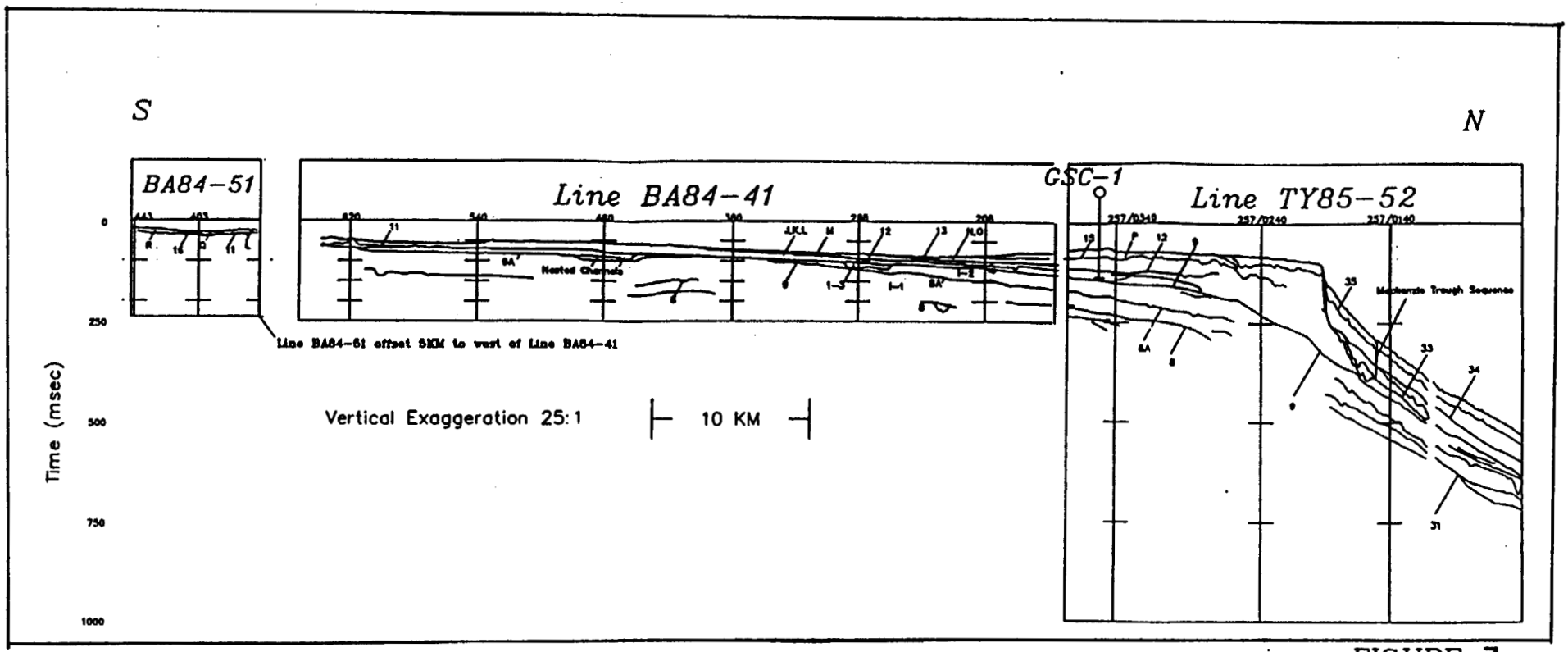
PHYSIOGRAPHIC SUBREGIONS

FIGURE 5



Distribution of bottom sediment types
(After Pelletier, 1985)

FIGURE 6



COMPOSITE LINE DRAWING ACROSS THE WESTERN BEAUFORT (YUKON) SHELF

FIGURE 7

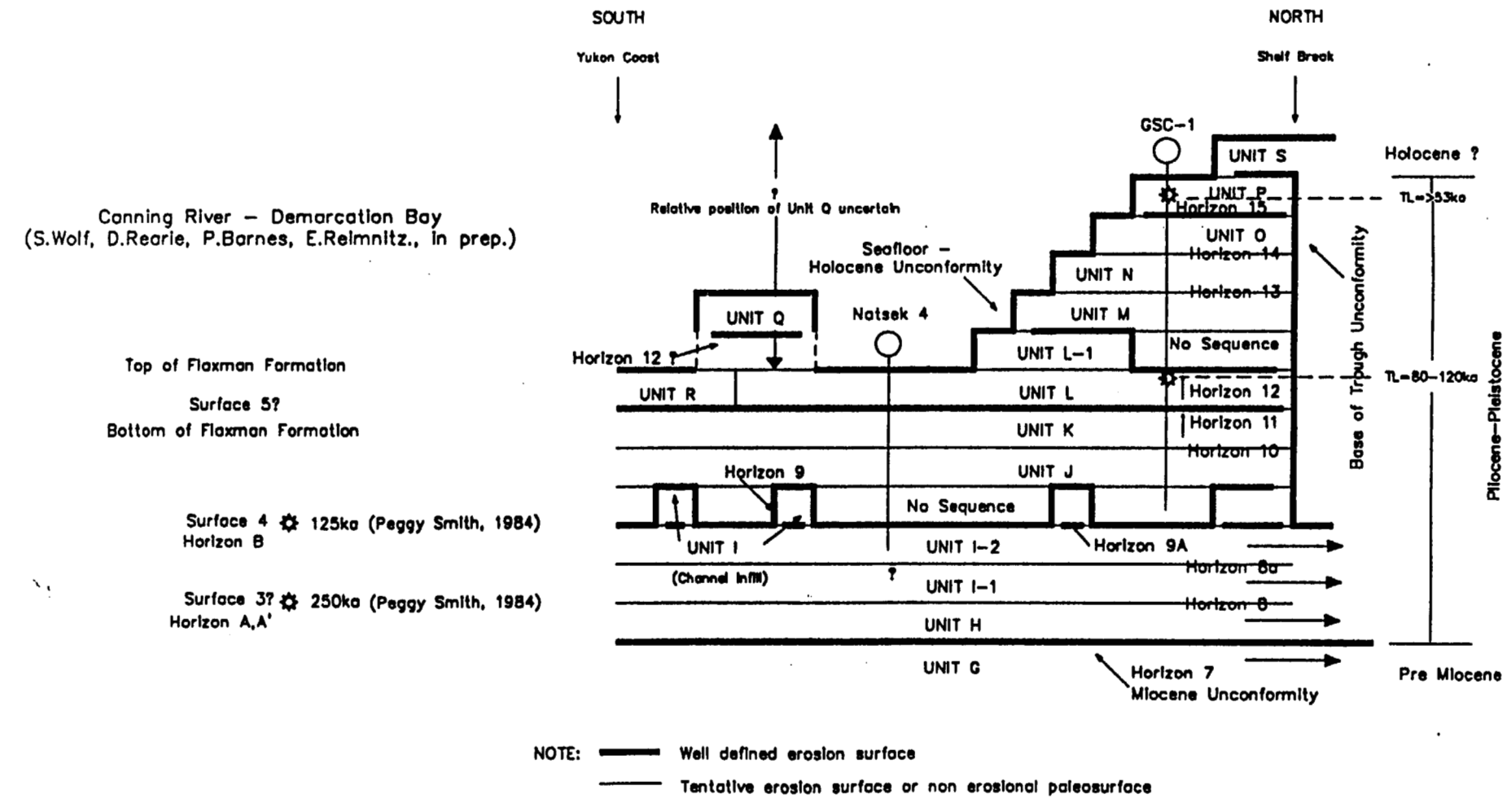
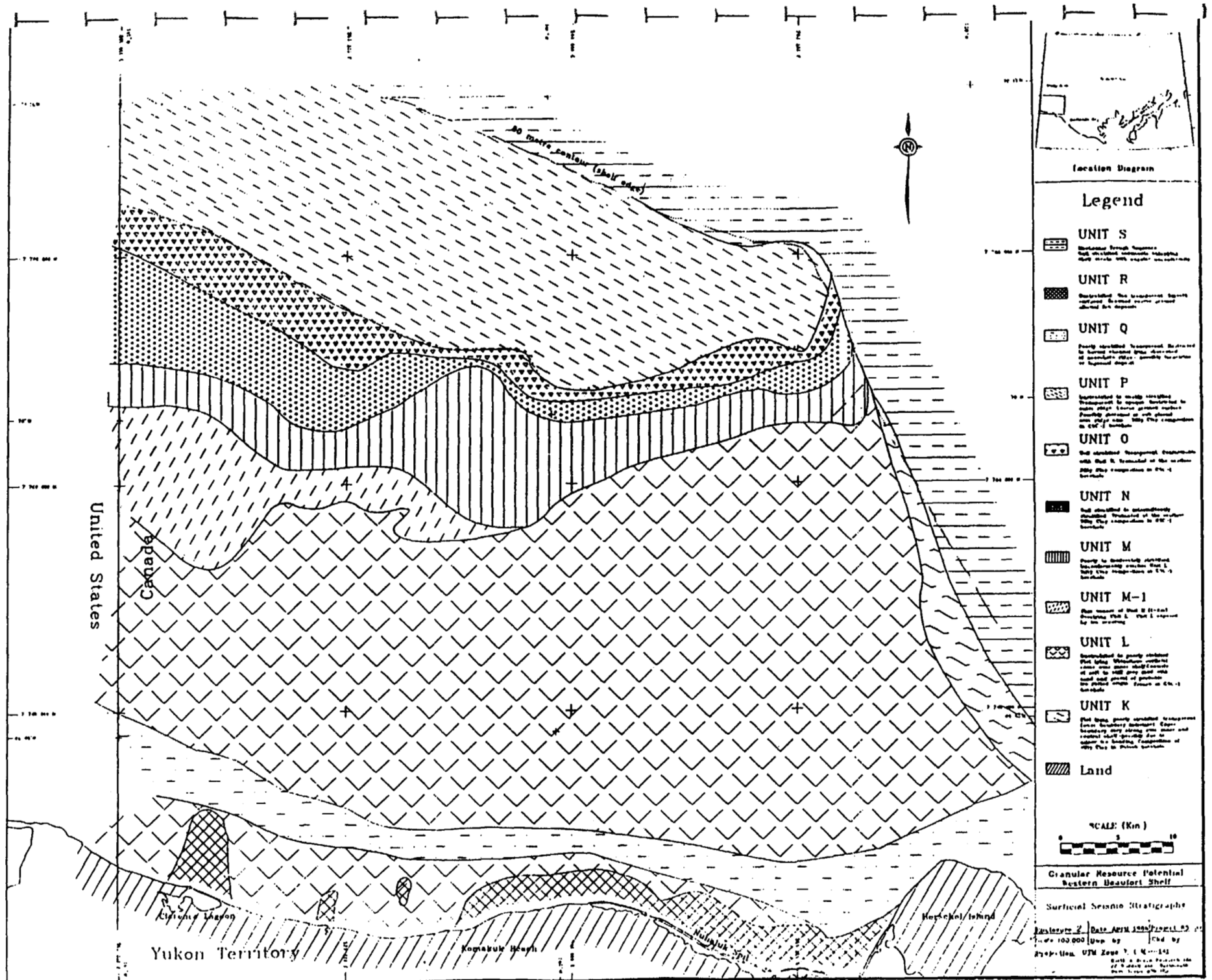
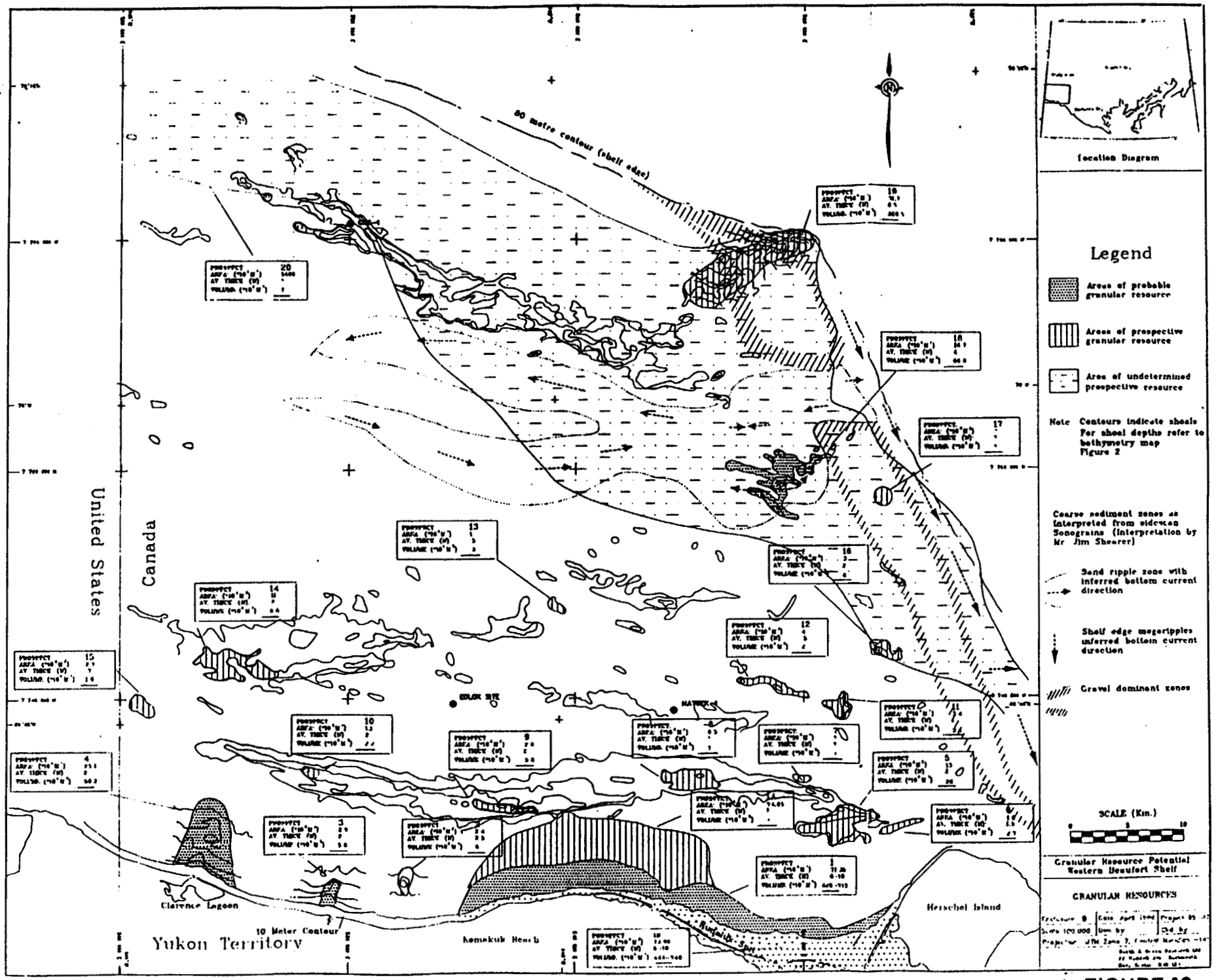


FIGURE 8 SEISMO-STRATIGRAPHIC RELATIONSHIPS AND AGES - WESTERN BEAUFORT (YUKON) SHELF



SURFICIAL SEISMO - STRATIGRAPHY

FIGURE 9



GRANULAR RESOURCES **FIGURE 10**