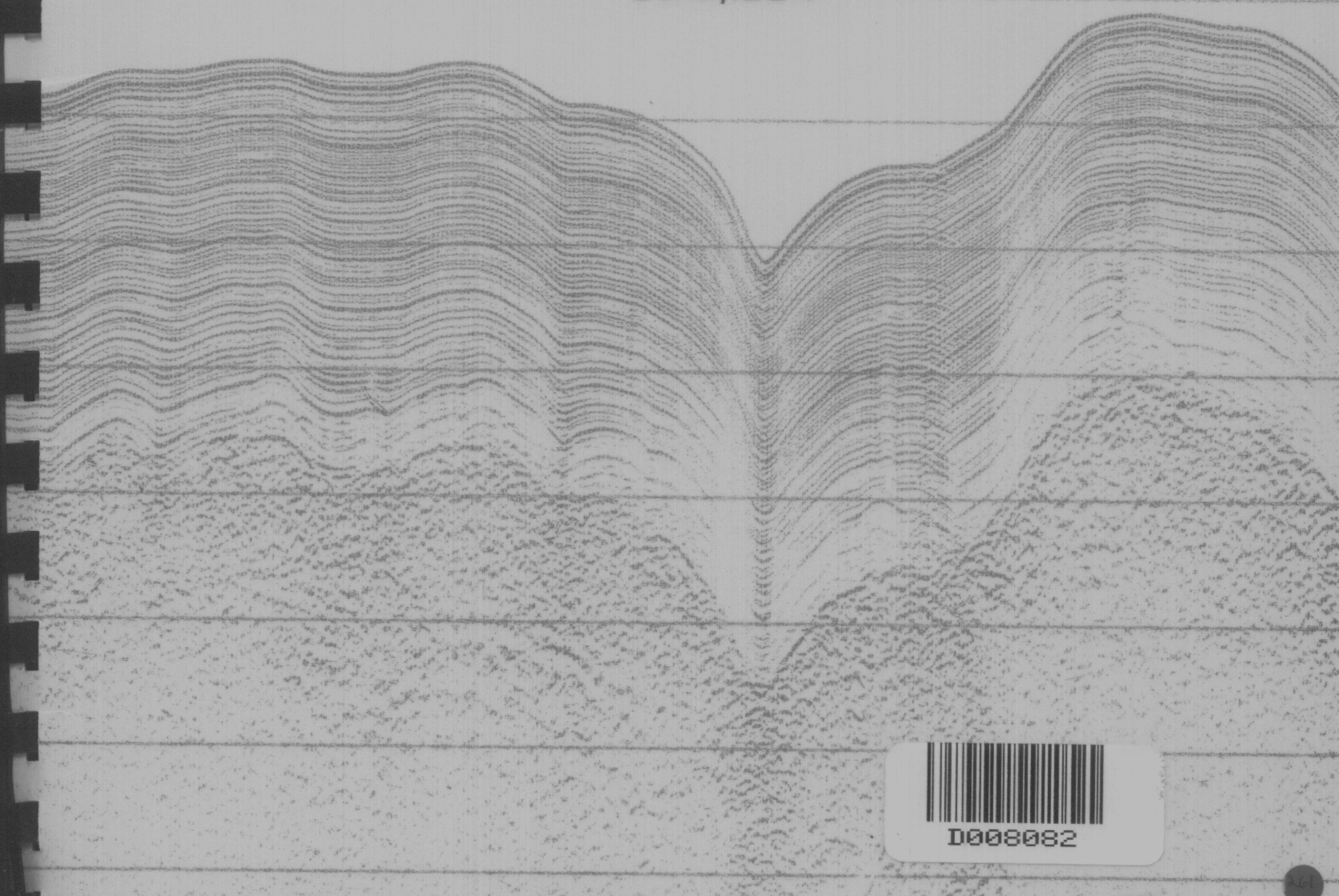
SURFICIAL GEOLOGY
and
GRANULAR RESOURCES
SOUTHEAST of HERSCHEL ISLAND

VOLUME I

Prepared for:

Indian and Northern Affairs Canada

June, 1984



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SURFICIAL GEOLOGY AND GRANULAR RESOURCES SOUTHEAST OF HERSCHEL ISLAND

10-260

Submitted to:

Indian and Northern Affairs Canada

Prepared by:

M. J. O'Connor & Associates Ltd.

June, 1985

M.J. O'CONNOR & ASSOCIATES LTD.

EXECUTIVE SUMMARY

At the request of the Department of Indian and Northern Affairs, a series of investigations were undertaken to locate and delineate prospective areas for the future development of offshore sand and gravel resources near Herschel Island, Yukon Territory. Because the nature of the seabed conditions along the Yukon Coast were largely unknown, the investigations were designed to first determine the regional surficial geological conditions in the study area, thereby providing a framework within which the nature and distribution of marine granular resources could be characterized.

A total of 564 km of high resolution shallow seismic records were collected in the study area in August, 1984. Geotechnical studies were subsequently carried out at 6 locations selected from the seismic data. A synthesis of this information with other existing data collected by both the federal government and the Beaufort Sea petroleum operators demonstrated that the study area is underlain by 4 separate surficial geological subregions, each of which has unique characteristics and differing granular resource potential.

The sill joining Collinson Head to Kay Point appears to be the most attractive area for future borrow development. It is estimated that a total of 127 000 000 m^3 of sand and gravel may presently exist on the sill. While only 17 000 000 m^3 of material may be considered to be proven, another 70 000 000 m^3 can probably be verified without too much additional groundtruthing.

The narrow shelf which borders the Yukon Coast west of Herschel Basin also appears to be prospective for granular resource development, although the quality of the available material may not be as good as that which can be obtained from the sill. Almost 10 000 000 m^3 of sand and gravel have been located by geotechnical studies at Stokes Point, Roland Bay and Catton Point. It is estimated that an additional 30 000 000 m^3 of material may eventually be located if further exploration is carried out.

The other 2 geologic subregions (Herschel Basin and the Babbage River paleochannel) exhibit little potential for future granular resource development.

The study concludes that between 100 000 000 m^3 and 171 650 000 m^3 of sand and gravel probably are present at or near the seabed in the study area. The degree to which these reserves are eventually exploited will depend on a number of factors, including the availability of suitable shallow water dredging equipment and the Beaufort Sea petroleum operators' future granular resource requirements.

TABLE OF CONTENTS

TABLE OF CONTENTS

APPENDICES

LIST OF DRAWINGS

LIST OF DRAWINGS cont'd.

LIST OF DRAWINGS cont'd.

LIST OF TABLES

LIST OF PLATES

1.0 INTRODUCTION

Under the authorization of Mr. Dale Longlitz, of the Department of Indian and Northern Affairs, a series of investigations was undertaken to locate and delineate prospective areas for the future development of offshore sand and gravel resources near Herschel Island, Yukon Territory (Drawing No. 1.1). The occurrence of granular resources in particular areas near Herschel Island had previously been established by the major Beaufort Sea petroleum operators and had been documented in a 1983 report entitled "Regional Inventory of Offshore Gravel Prospects Canadian Beaufort Sea", prepared by M. J. O'Connor & Associates Ltd. for Indian and Northern Affairs.

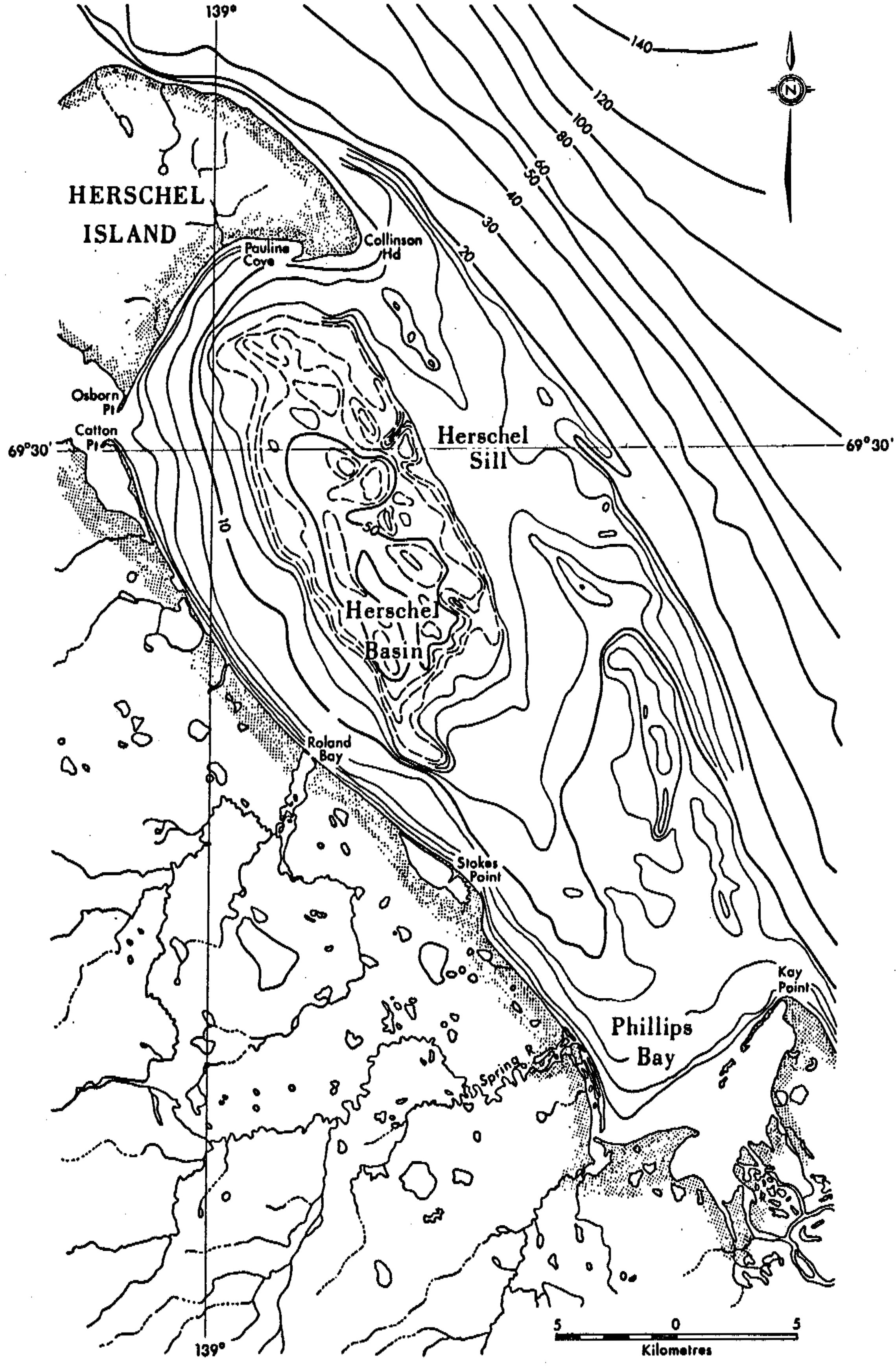
Unfortunately, all of the previous studies had been conducted on a rather site-specific basis, i.e. no attempt had been made to integrate the industry data with earlier studies sponsored by the Geological Survey of Canada, nor had there been any attempt at formulating a geological model of the area which might assist in describing the distribution and occurrence of granular resources over a much wider area. As a consequence, the present investigations were structured to provide a much broader understanding of the surficial geological conditions in and around Herschel Basin, and thereby ultimately provide a framework for the description of the occurrence of subsea granular resources.

1.1 Background

The construction of marine facilities for petroleum exploration and possible future production in the Canadian Beaufort Sea may require the use of substantial quantities of offshore granular resources. Independent studies undertaken by both the major Beaufort Sea petroleum operators and the Geological Survey of Canada have established that large quantities of sand-sized material are present either at or directly beneath the seafloor over a large portion of the continental shelf east of 135° W longitude, but west of this line such seabed granular resources occur only sporadically. West of Mackenzie Bay, one of the areas of greatest potential identified for future development was the submarine sill which joins Collinson Head to Kay Point, along the eastern margin of the bathymetric depression known as Herschel Basin (Drawing No. 1.2). A 1983 review and synthesis of information obtained from Dome Petroleum, Gulf Canada Resources, the Canadian Hydrographic Service and the Geological Survey of Canada suggested that gravel was present at the seabed over an area of at least 2700 ha along the crest of the sill (O'Connor, 1983). Mean water depths varied from 6 to 14 m, although gravel was found to be present to the 15 m isobath in some places and was suspected to occur as shallow as the 2 m isobath in others. Most of the gravel appeared to be located in spits and bars deposited since the most recent marine transgression. As a consequence, the thickness of the gravel appeared to be limited to 1 to 2 m in most areas, although some patchy areas as thick as 6 m were also suspected near Kay Point.

O'Connor (1983) estimated that perhaps 50 000 000 m^3 of gravel existed on the sill, but noted that only 20% of this volume could be considered proven reserves. At the same time he noted that the total volume could be several times the estimated volume if untested areas near Kay Point proved to be prospective.

Since it has already been demonstrated by Dome Petroleum that the quality of some of the surficial gravel is suitable for construction of artificial islands like Tarsiut and Uviluk, a comprehensive programme



General Bathymetry of the Study Area (m)

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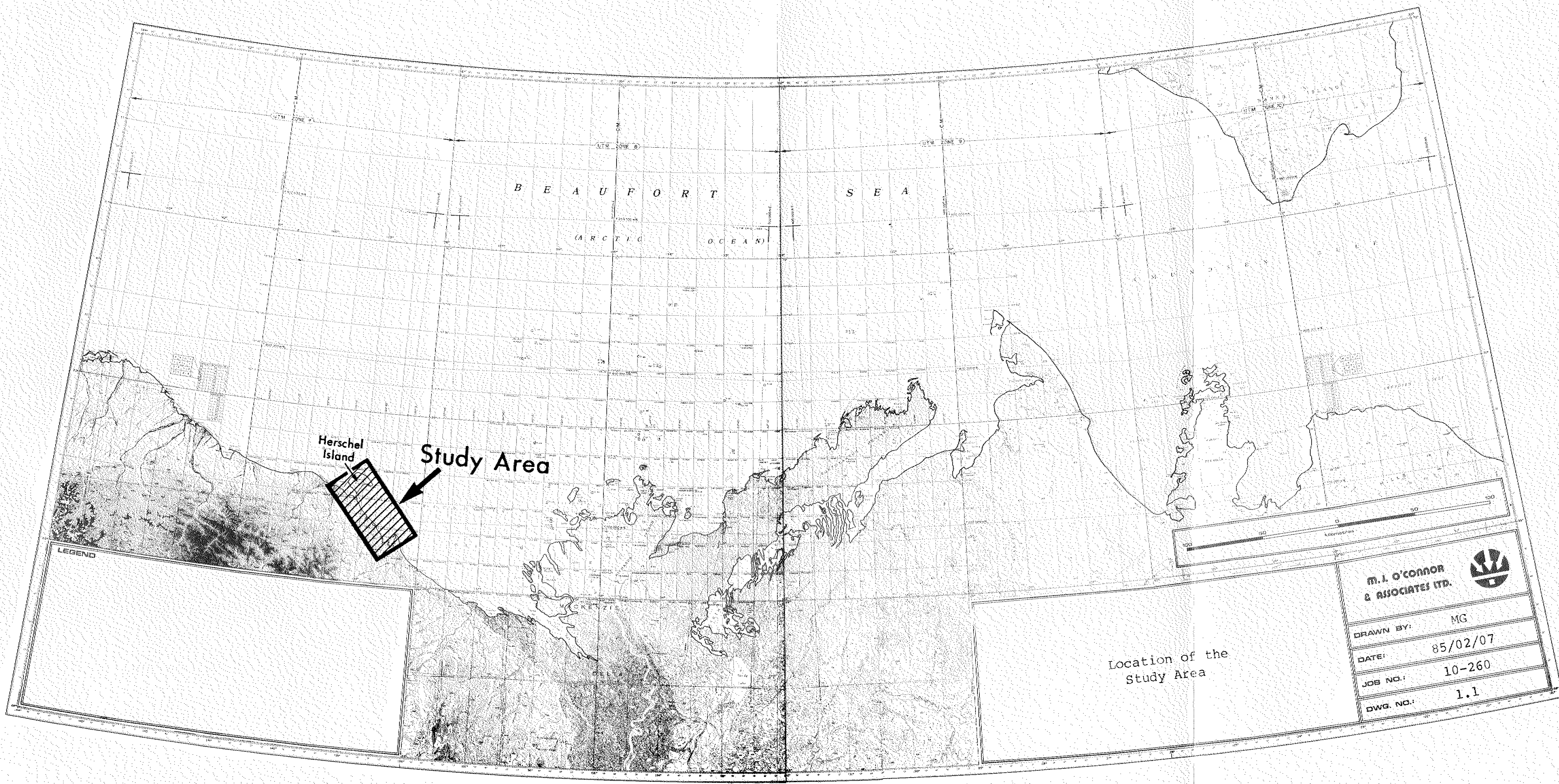
DRAWN BY: MG	**DWG. No.:** 1.2

was undertaken by DIAND to locate and delineate the full extent of the submarine granular resources which might exist in the area of Herschel sill.

1.2 Authorization

Authorization to proceed with the granular resource evaluation was granted through Department of Supply and Services Contract No. 19SV.A7134-4-0020. To ensure that the geological components of the programme were addressed at the required level of effort, Mr. S. M. Blasco, P. Eng., of the Geological Survey of Canada was appointed Scientific Authority for the contract.


BEAUFORT SEA
(ARCTIC OCEAN)
Herschel Island
Study Area
LEGEND
M. J. O'CONNOR & ASSOCIATES LTD.
DRAWN BY: MG
DATE: 85/02/07
JOB NO.: 10-260
DWG. NO.: 1.1
Location of the Study Area

2.0 METHODOLOGY

Determination of the geological conditions was accomplished through a 3-phased programme:

Phase I consisted of a short marine geophysical programme designed to provide high resolution seismic and side scan sonar information on the nature of the soil conditions in the study area.

Phase II consisted of a marine geotechnical drilling programme designed to confirm the geologic conditions interpreted from the seismic records and provide groundtruth information regarding the grain size distribution of the granular resource deposits at particular locations.

Phase III consisted of a synthesis of the above data with the regional geological information already available. In this manner the specific geological conditions which control the nature, distribution and thickness of submarine granular resources southwest of Herschel Island could be determined.

2.1 Geophysical Programme

The field data acquisition phase of the geophysical programme was conducted by Geoterrex Ltd. of Victoria, B.C., under subcontract to M. J. O'Connor & Associates Ltd., using the M.V. Norweta of Hay River, N.W.T. The survey commenced in Herschel Basin at approximately 2000 hours on 84/08/21 and was completed at 2100 hours on 84/08/25. Prior to the DIAND programme, the vessel had been utilized for ESRF ice scour studies. Following the programme the vessel commenced work near

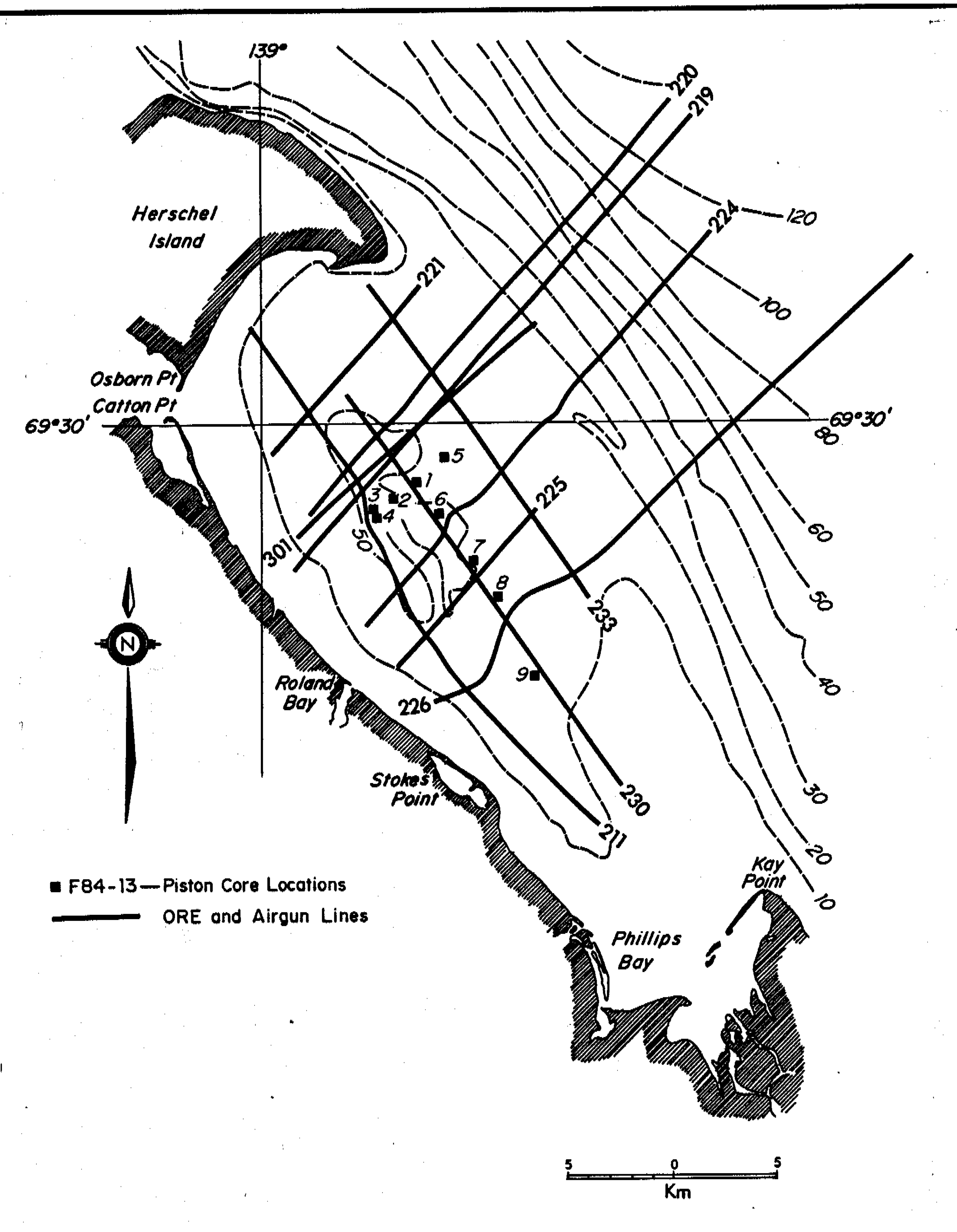
Tarsiut for Gulf Canada Resources. Time sharing of the survey vessel thus was a significant factor in reducing the overall cost of the geophysical programme.

A total of 564 km of geophysical data were collected during the programme, of which approximately 164 km were acquired during turns.

Drawing No. D.1, Appendix D, shows the location of all seismic lines acquired by DIAND during the present programme. For convenience, a reduced version of the same map is presented subsequently in the text of Section 3.0. For clarity, the fix locations during turns have been eliminated. A composite 1:50 000 scale map, showing all fix locations (including turns), is presented in Drawing No. D.2. Airgun, boomer, side scan sonar (with sub-bottom profiler), and echo sounder data were collected during the study. Equipment specifications and geophysical survey parameters provided by Geoterrex Ltd. are presented in Appendix A.

Record quality was highly variable during the investigation. One or both of the side scan sonar channels were inoperable for some of the survey, but the gear was left in the water because the sub-bottom data being collected by the towfish was generally excellent. Airgun information gathering was restricted to the first and last survey days, because crossfeed between the instrumentation was having a deleterious effect on the record quality of all the systems.

In addition, some time was lost and coverage of the study area diminished because ice conditions restricted access to some of the Herschel Sill areas, mostly near Kay Point. Fortunately, additional geophysical and shallow piston core data collected during a concurrent survey conducted by the M.V. Banksland Surveyor for the Geological Survey of Canada could be used to augment the present data base in some areas (Drawing No. 2.1). These fix locations have also been shown in Drawing No. D.1.



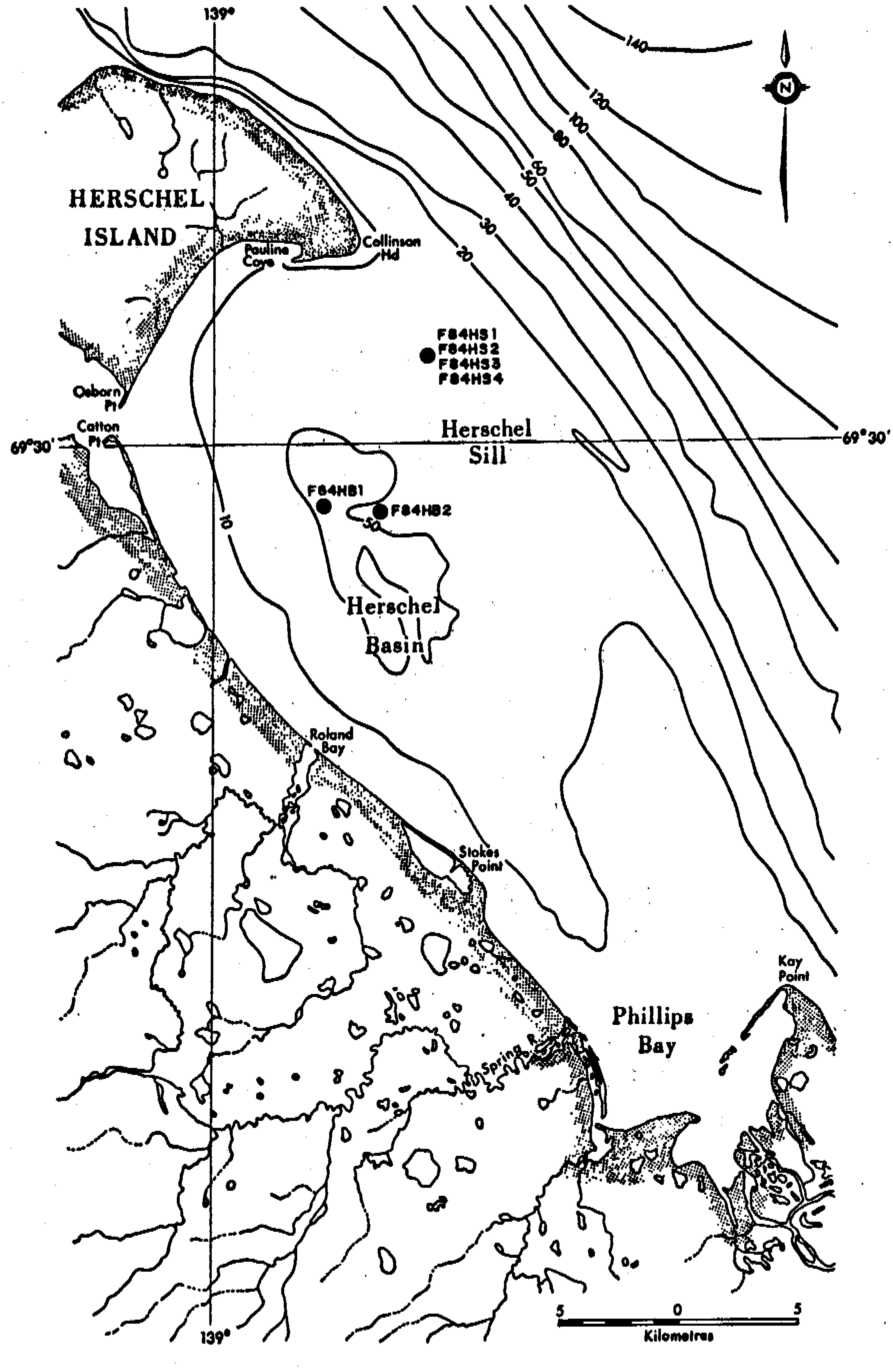
1984 Banksland Surveyor Data in Herschel Basin	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/05/20
	DRAWN BY: MG	DWG. No.: 2.1

2.2 Geotechnical Programme

The geotechnical field studies were carried out on DIAND's behalf from the Arctic Kiggiak, under a separate contract with BeauDril Ltd. Foundex Explorations Ltd. provided the drilling services, while EBA Engineering Consultants Ltd. provided the field geotechnical and laboratory services. As the regional map in Drawing No. 2.2 demonstrates, borehole locations were selected to determine the stratigraphy both on the sill joining Collinson Head to Kay Point and within Herschel Basin itself.

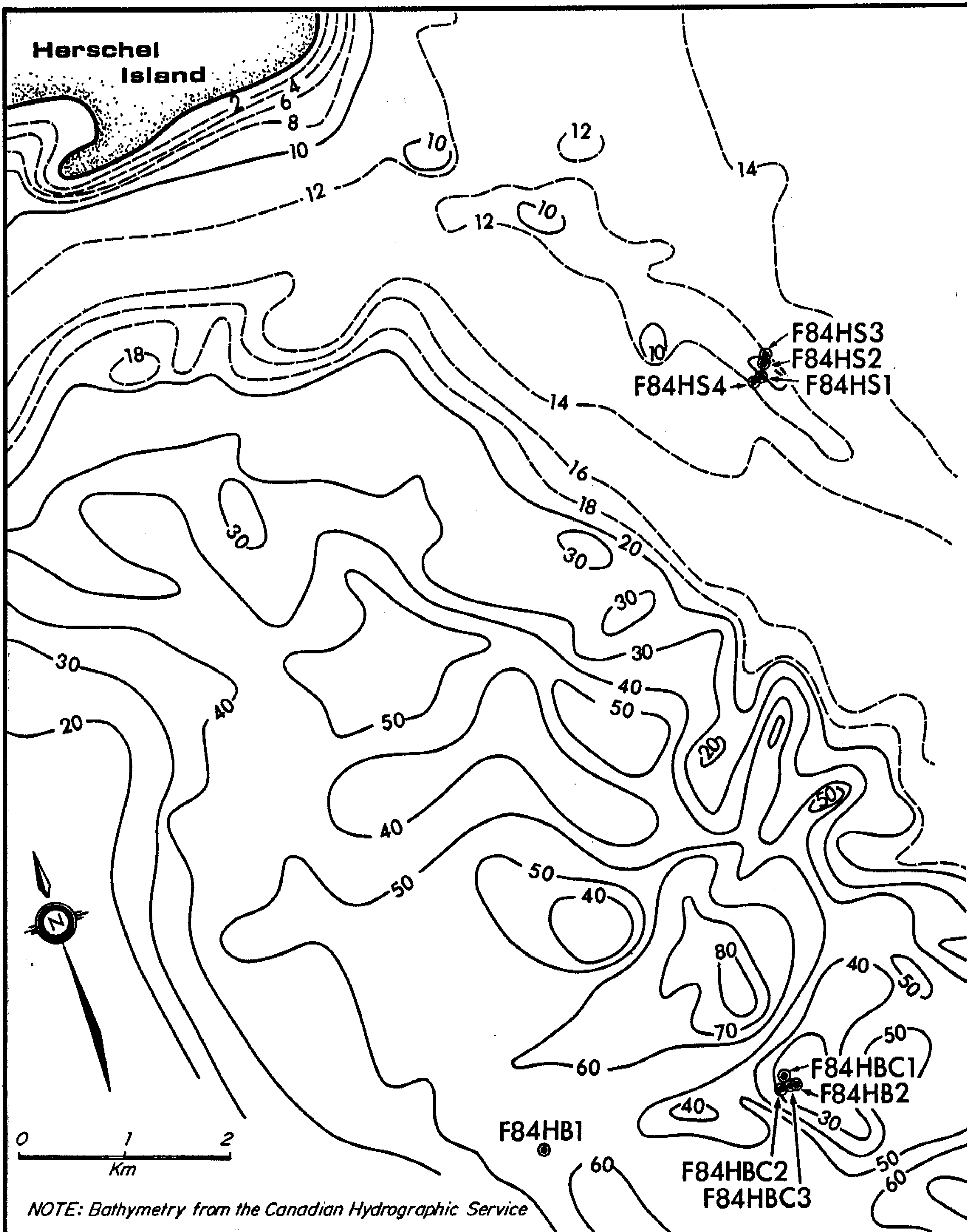
A total of 4 locations on the sill were investigated (Drawing No. 2.3). Two (2) boreholes were drilled and sampled to depths of 19.7 m and 5.7 m respectively beneath the seabed (F84HS1 and F84HS2), while 2 probeholes were drilled to test the thickness of gravel at other locations (F84HS3 and F84HS4). A sample of the surficial material at each of these locations was also obtained using the grab dredge on the Arctic Kiggiak (see Plates No. 2.1 and 2.2). A summary of the 1984 geotechnical site investigation on the Herschel Sill sites was prepared by EBA Engineering Consultants Ltd. Borehole logs from this report are included in Appendix C.

Two additional boreholes were drilled in Herschel Basin as part of the same programme (see Drawing No. 2.3). These boreholes were intended to provide important information on the surficial geologic conditions under the Basin itself, and test the theory that some of the anomolous bathymetry previously noted in the Basin might be due to glacially related granular resource deposits. At the time of preparation of the present report, the borehole logs from the Herschel Basin sites were available only in a letter report from EBA dated 85/03/01, but the logs have been included here for completeness.



1984 DIAND Boreholes
Near Herschel Island

M. J. O'CONNOR & ASSOCIATES LTD.	
JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 2.2



1984 DIAND Boreholes in the Study Area

M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.: 10-260	DATE: 85/05/22
DRAWN BY: MG	DWG. No.: 2.3

2.3 Previous Data

Wherever possible, data collected during previous studies in the Herschel Basin area were incorporated directly into the present study. A list of these studies is presented as Table 2.1.

TABLE 2.1

Other Studies Near Herschel Island

YEAR	COLLECTING AGENCY	DATA
1970	Geological Survey of Canada	Piston Cores
1974	Geological Survey of Canada	High Resolution Geophysics
1975	Geological Survey of Canada	Grab Samples
1980	Dome Petroleum	Reconnaissance High Resolution Geophysics
1981	Dome Petroleum	Detailed High Resolution Geophysics
1981	Dome Petroleum	Clam Shell Test Dredging
1982	Dome Petroleum	Testing of Hendrik Zanen Samples
1982	Gulf Canada Resources	Geotechnical Boreholes on the Sill
1982/83	Gulf Canada Resources	Geotechnical Boreholes near Stokes Point and Roland Bay
1984	Gulf Canada Resources	Geotechnical Boreholes and Cone Penetration Tests near Thetis Bay

3.0 SEABED FEATURES IN THE STUDY AREA

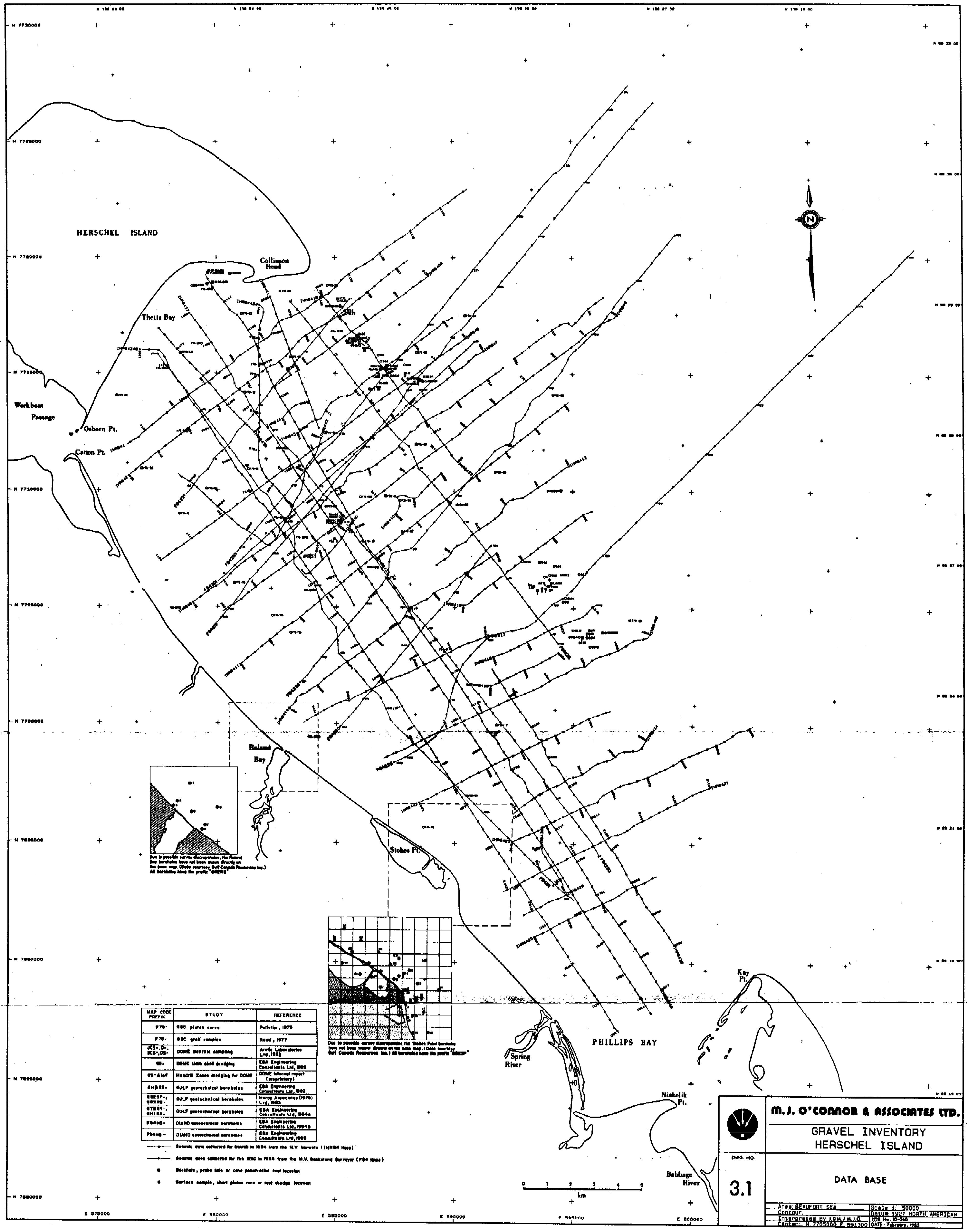
3.1 General

Information pertaining to the results of the study has been presented in map form in Appendix D at a scale of 1:50 000. For convenience in reading, 1:150 000 scale copies of several of these maps have also been included directly in the text. Where required, both maps have been referenced.

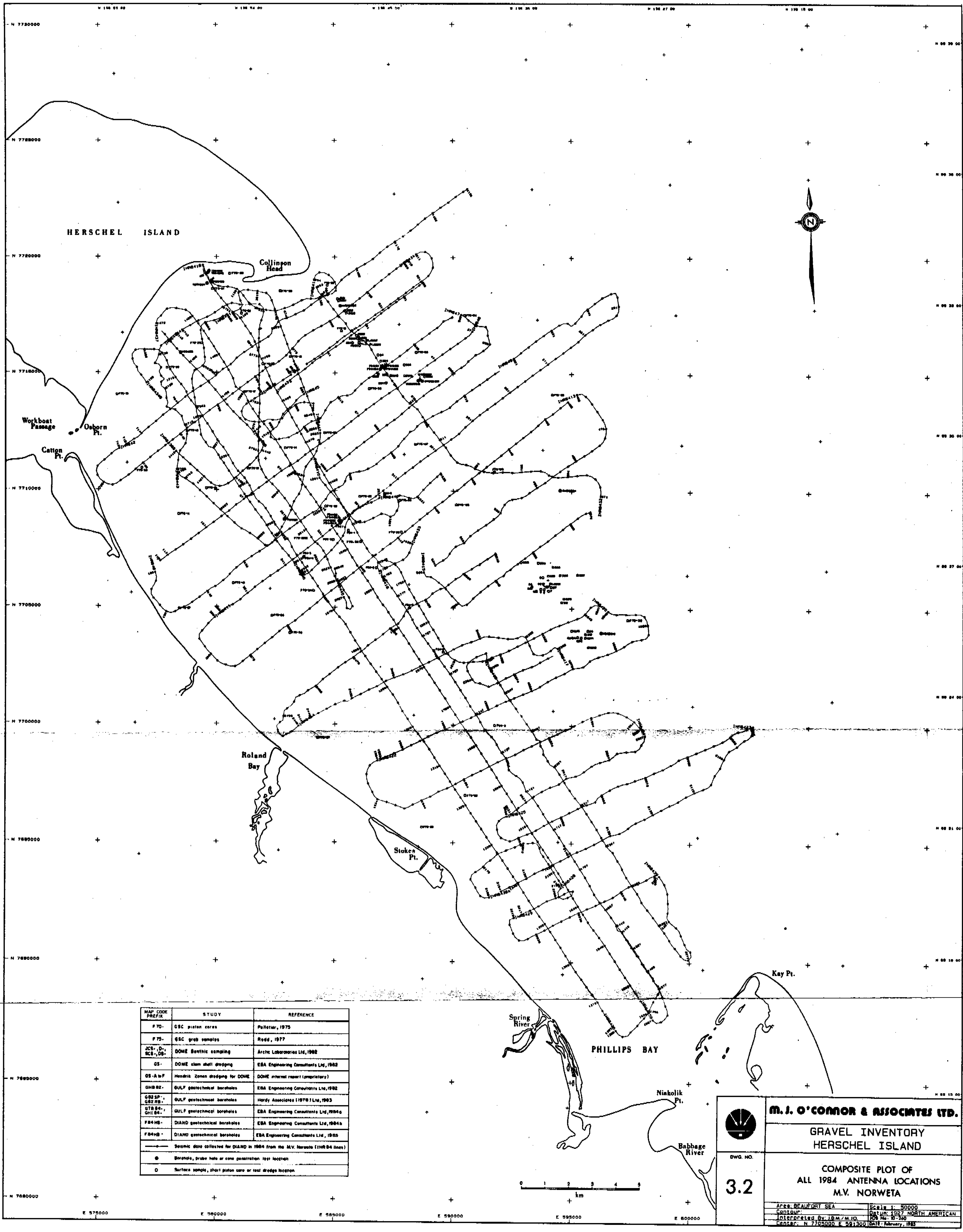
3.2 Data Base

Drawing No. 3.1 (Drawing No. D.1 in Appendix D) shows the seismic and groundtruth data bases used directly in the interpretation of seabed and subseabottom features during the present study. Seismic data collected as part of the present study are indicated by the open circles and designated with line numbers prefixed by IHR84. Data from the Banksland Surveyor are shown by closed circles and the line number prefix F84. Boreholes drilled from the Arctic Kiggiak are designated by the prefix F84HB (locations in the basin) or F84HS (locations on the sill).

During the course of the geophysical survey conducted from the M.V. Norweta, operation of the survey instruments was continued during turns to come on line wherever possible. This resulted in the collection of a significant quantity (approximately 164 km) of additional seismic data which have also been incorporated directly into the present report. Drawing No. 3.2 (Drawing No. D.2 in Appendix D) shows a composite plot of all antenna locations recorded during the study.



HERSCHEL ISLAND
Collinson Head
Thetis Bay
Workboat Passage
Osborn Pt.
Catton Pt.
Roland Bay
Stokes Pt.
Kay Pt.
PHILLIPS BAY
Spring River
Niakolik Pt.
Babbage River
Due to possible survey discrepancies, the Roland Bay boreholes have not been shown directly on the base map. (Data courtesy Gulf Canada Resources Inc.) All boreholes have the prefix "G82RB"
Due to possible survey discrepancies, the Stokes Point boreholes have not been shown directly on the base map. (Data courtesy Gulf Canada Resources Inc.) All boreholes have the prefix "G82SP"
MAP CODE PREFIX | STUDY | REFERENCE
F70- | GSC piston cores | Pelletier, 1978
F76- | GSC grab samples | Rodd, 1977
JCS-, D-, SCS-, DS- | DOME Benthic sampling | Arctic Laboratories Ltd, 1982
GS- | DOME clam shell dredging | EBA Engineering Consultants Ltd, 1982
GS-A to F | Hendrik Zanen dredging for DOME | DOME internal report (proprietary)
GHB82- | GULF geotechnical boreholes | EBA Engineering Consultants Ltd, 1982
G82SP-, G82RB- | GULF geotechnical boreholes | Hardy Associates (1978) Ltd, 1983
GTB84-, GHI84- | GULF geotechnical boreholes | EBA Engineering Consultants Ltd, 1984a
F84HS- | DIAND geotechnical boreholes | EBA Engineering Consultants Ltd, 1984b
F84HB- | DIAND geotechnical boreholes | EBA Engineering Consultants Ltd, 1985
Seismic data collected for DIAND in 1984 from the M.V. Norweta (IHR84 lines)
Seismic data collected for the GSC in 1984 from the M.V. Banksland Surveyor (F84 lines)
Borehole, probe hole or cone penetration test location
Surface sample, short piston core or test dredge location
km
0 1 2 3 4 5
N
M. J. O'CONNOR & ASSOCIATES LTD.
GRAVEL INVENTORY
HERSCHEL ISLAND
DWG. NO.
3.1
DATA BASE
Area: BEAUFORT SEA
Contour:
Interpreted By: J.D.M. / M.J.O.
Center: N 7705000 E 591300
Scale 1: 50000
Datum: 1927 NORTH AMERICAN
JOB No: 10-260
E 575000
E 580000
E 585000
E 590000
E 595000
E 600000
N 7730000
N 7725000
N 7720000
N 7715000
N 7710000
N 7705000
N 7700000
N 7695000
N 7690000
N 7685000
N 7680000



MAP CODE PREFIX	STUDY	REFERENCE
F 70-	GSC piston cores	Pelletier, 1975
F 75-	GSC grab samples	Rodd, 1977
JCS-, D-, SCS-, DS-	DOME Benthic sampling	Arctic Laboratories Ltd, 1982
GS-	DOME clam shell dredging	EBA Engineering Consultants Ltd, 1982
GS-A to F	Hendrik Zonen dredging for DOME	DOME internal report (proprietary)
GHB 82-	GULF geotechnical boreholes	EBA Engineering Consultants Ltd, 1982
G82 SP-, G82 RB-	GULF geotechnical boreholes	Hardy Associates (1978) Ltd, 1983
GTB 84-, GHI 84-	GULF geotechnical boreholes	EBA Engineering Consultants Ltd, 1984a
F84 HS-	DIAND geotechnical boreholes	EBA Engineering Consultants Ltd, 1984b
F84 HB-	DIAND geotechnical boreholes	EBA Engineering Consultants Ltd, 1985
—•—	Seismic data collected for DIAND in 1984 from the M.V. Norweta (IHR 84 lines)	
●	Borehole, probe hole or cone penetration test location	
O	Surface sample, short piston core or test dredge location	

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GRAVEL INVENTORY
HERSCHEL ISLAND

DWG. NO.
3.2

COMPOSITE PLOT OF
ALL 1984 ANTENNA LOCATIONS
M.V. NORWETA

Area: BEAUFORT SEA	Scale 1: 50000
Contour:	Datum: 1927 NORTH AMERICAN
Interpreted By: I.D.M./M.J.O.	JOB No: 10-260
Center: N 7705000 E 591300	DATE: February, 1985

3.3 Bathymetry

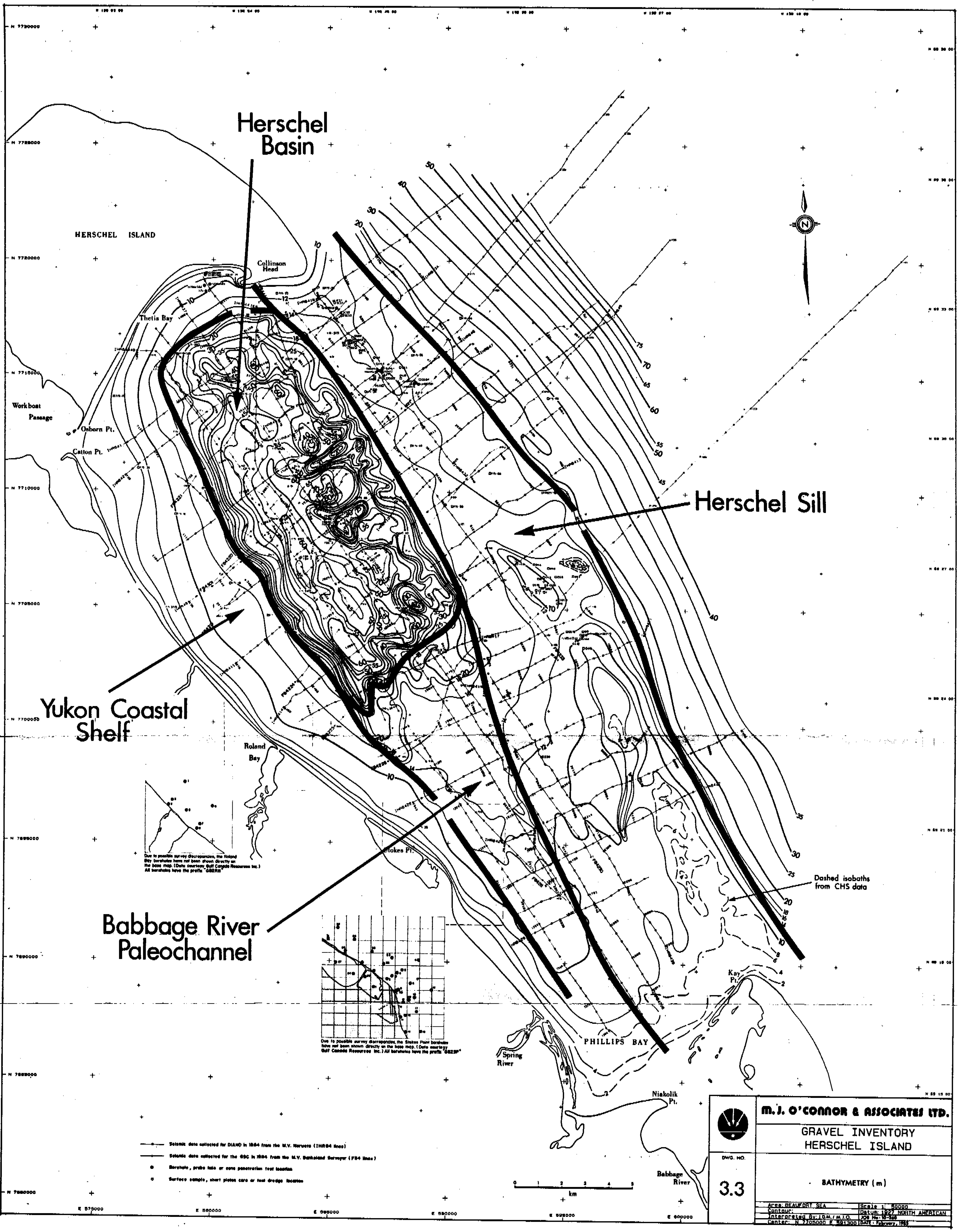
Drawing No. 3.3 (see also Drawing No. D.3) shows the bathymetry of the study area as interpreted from the echo sounder data obtained during the 1984 geophysical programme.

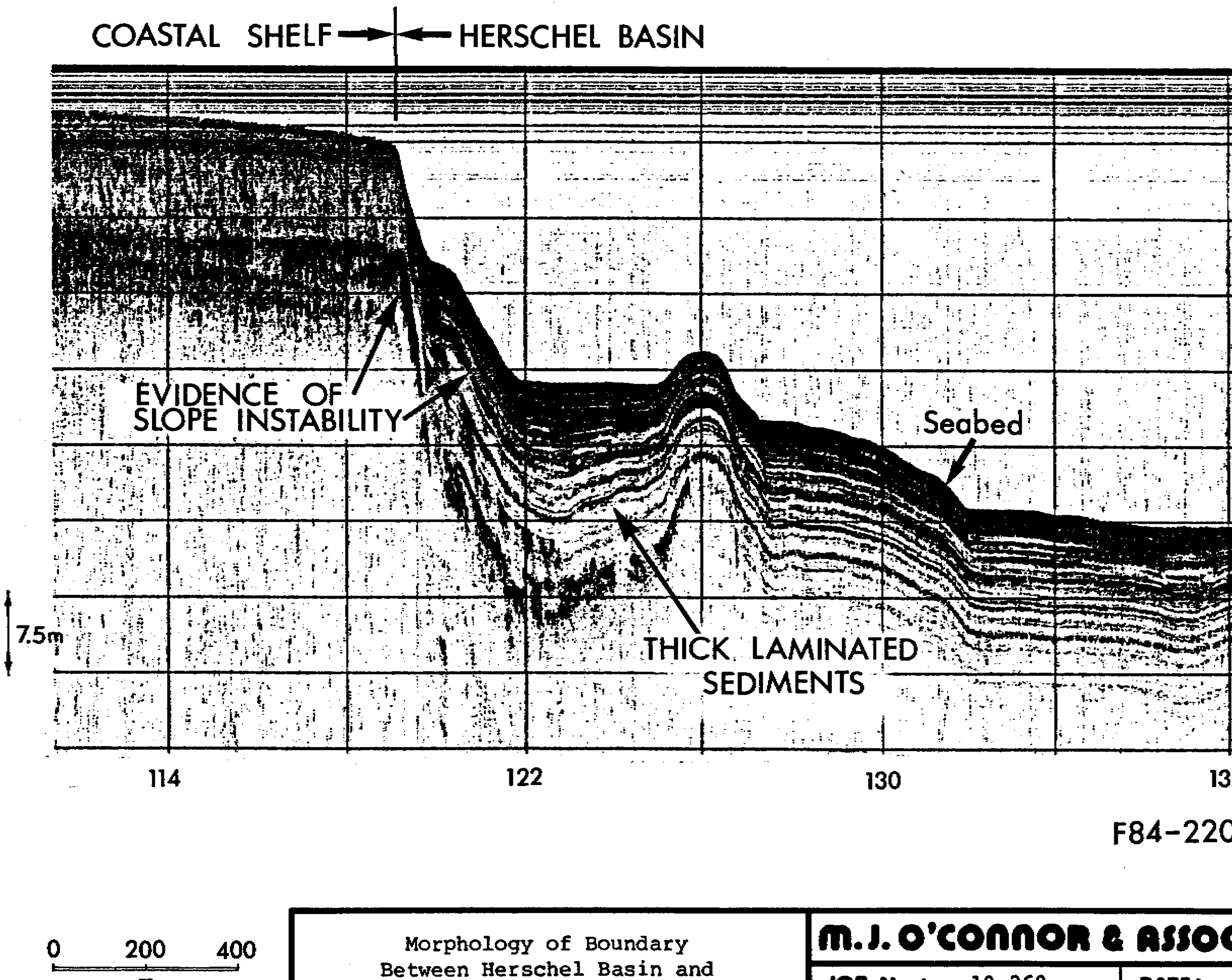
Four (4) distinct bathymetric regions may be noted. These are Herschel Basin, Herschel Sill, the Yukon Coastal Shelf and the Babbage River Paleochannel. The boundaries between these regions are shown on Drawing No. 3.3.

3.3.1 Herschel Basin

The greatest water depths were encountered in Herschel Basin, an elongate area extending from Thetis Bay southeastward towards Phillips Bay for a distance of approximately 18 km. Its maximum width is approximately 7 km. The edge of the basin is marked by an abrupt change in the slope of the seafloor. Along the west side this change begins at about the 14 m isobath (Drawing No. 3.4). On the north and south ends it begins at about the 16 m isobath, but along the east (seaward) side the boundary between the basin edge and the Sill is marked by the 18 m isobath. As Drawings No. 3.4 and 3.5 demonstrate, slumping is a common feature along the basin margin adjacent to both the Sill and the coastal shelf. The bottom of the basin is effectively enclosed by the 50 m isobath, with long narrow closed depressions extending commonly to more than 60 m bsl* and in 2 cases to more than 75 m bsl (Drawing No. 3.6).

*bsl - below sea level


Herschel Basin
Herschel Sill
Yukon Coastal Shelf
Babbage River Paleochannel
HERSCHEL ISLAND
Collinson Head
Thetis Bay
Workboat Passage
Osborn Pt.
Catton Pt.
Roland Bay
Stokes Pt.
Dashed isobaths from CHS data
PHILLIPS BAY
Spring River
Kay Pt.
Niakolik Pt.
Babbage River
km
M.J. O'CONNOR & ASSOCIATES LTD.
GRAVEL INVENTORY
HERSCHEL ISLAND
DWG. NO.
3.3
BATHYMETRY (m)
Area: BEAUFORT SEA
Scale 1: 50000
Datum: 1927 NORTH AMERICAN



Morphology of Boundary Between Herschel Basin and the Coastal Shelf	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/07/22
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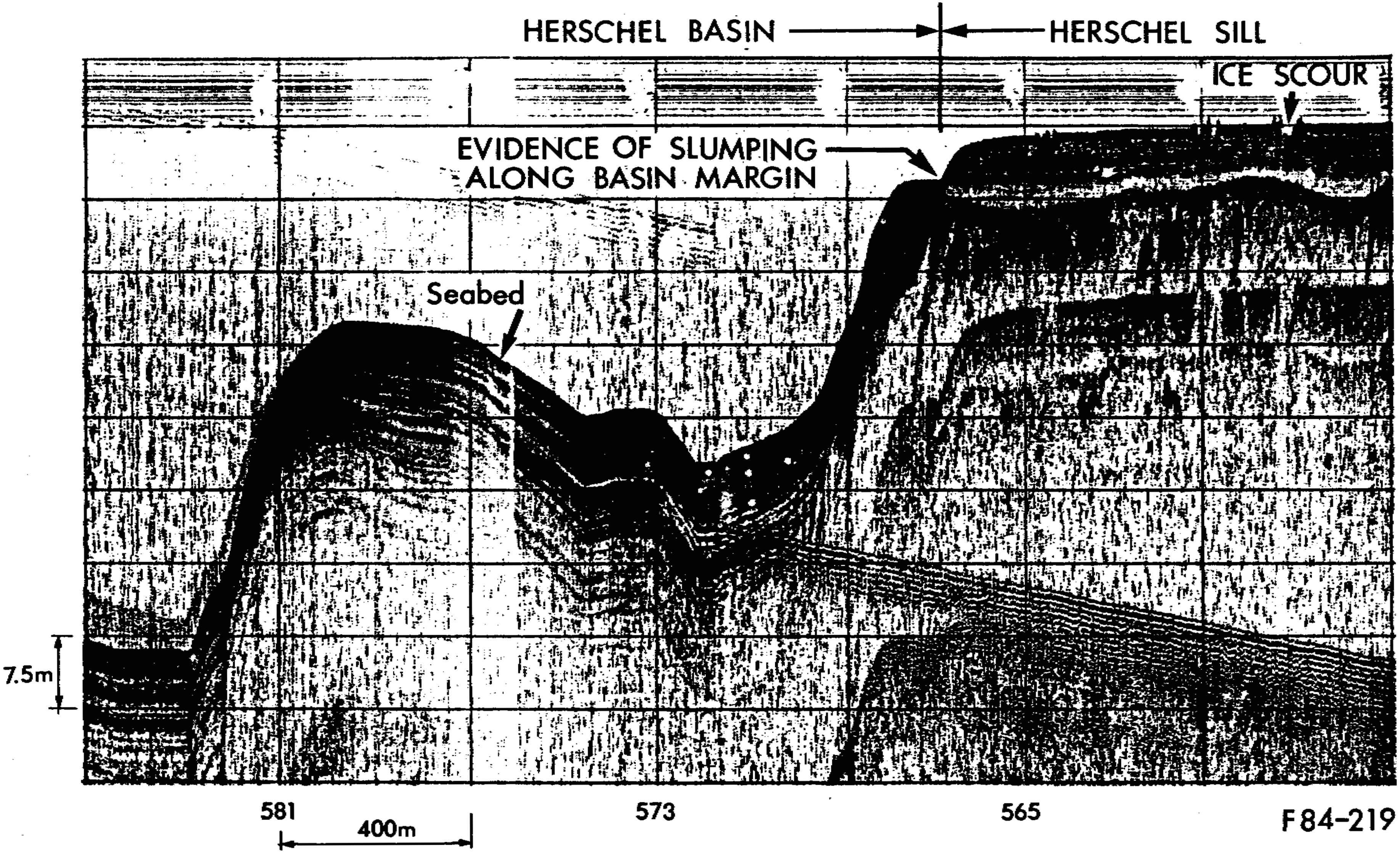
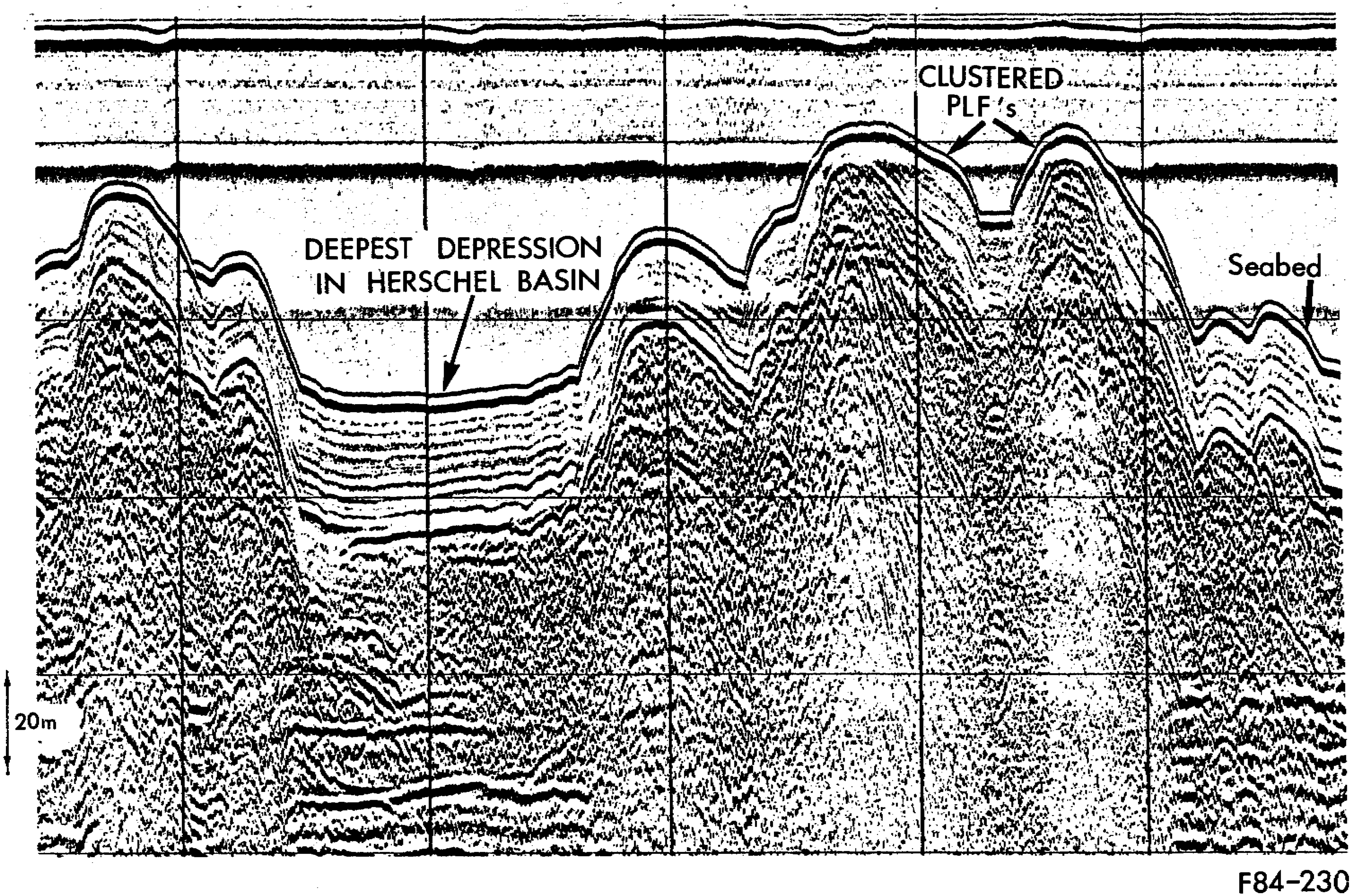


Morphology of the Basin
Margin Adjacent to
The Herschel Sill

M.J. O'CONNOR & ASSOCIATES LTD.

JOB No.:	10-260	DATE:	85/07/22
DRAWN BY:	MG	DWG. No.:	3.5



Airgun Record of
Herschel Basin

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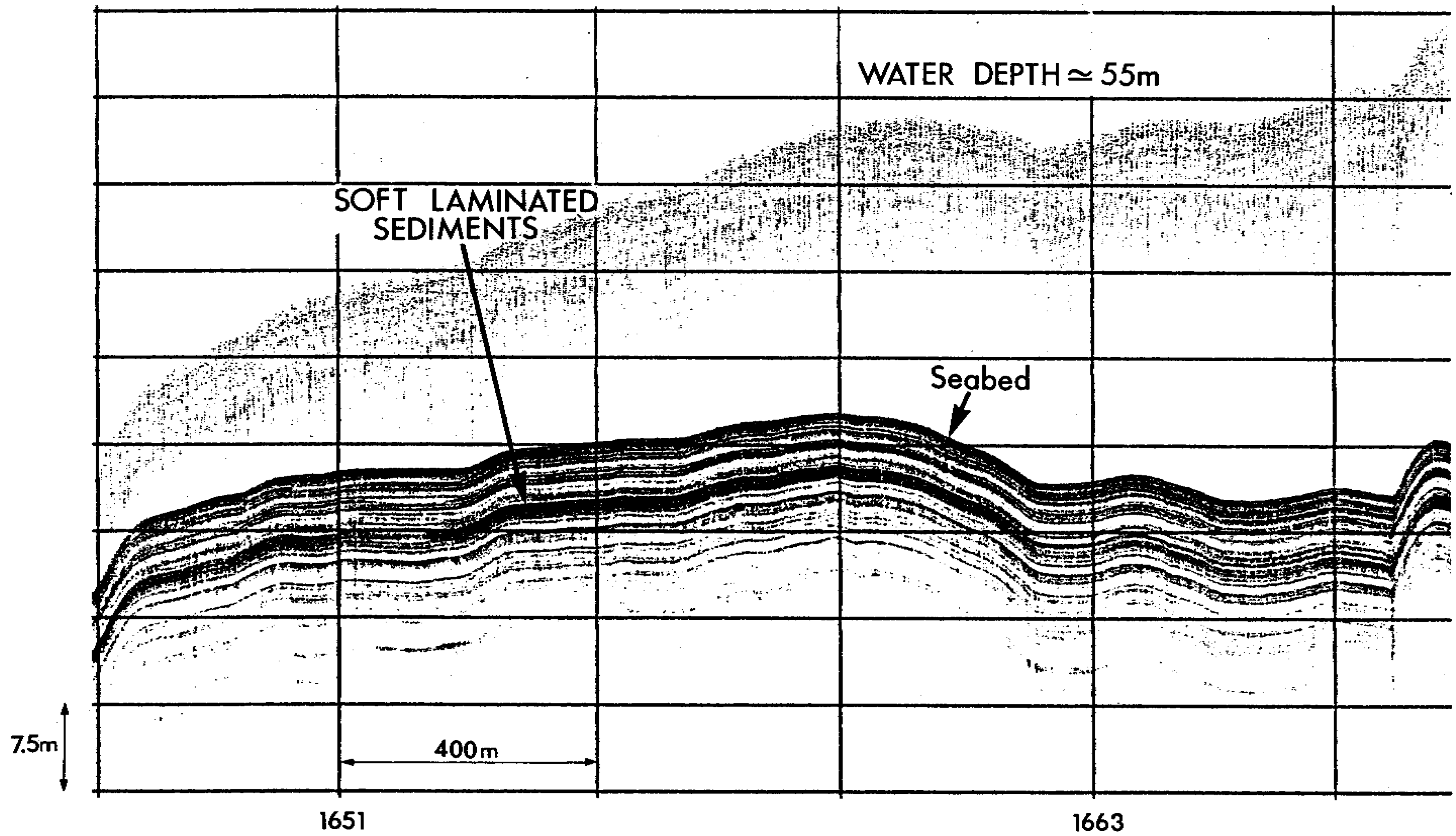
JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 3.6

The west side of the basin floor is relatively smooth, but not flat (Drawing No. 3.7). The east half, however, is characterized by pingo-like features (PLF's) which rise steeply to within 20 or 25 m of the sea surface. These PLF's may occur singly, as shown in Drawing No. 3.8, or in clusters of 2 or 3, as shown in Drawings No. 3.6 and 3.9. Most have relatively flat crests, but flanks which may dip at up to 6°.

For the most part, these PLF's do not occur as isolated sea mounds, but appear to be semi-attached to the eastern flank of the basin. Their effect on the basin topography is all the more evident because their occurrences appear to be directly associated with adjacent basin lows, as if the origin of the basin bottom depressions and the PLF's were somehow related.

3.3.2 Herschel Sill

Herschel Basin is separated from the Mackenzie Trough to the east by a submarine ridge or sill which joins Collinson Head to Kay Point. The sill is a maximum of 15 m deep near N7711000 E589500, but is considerably more shallow than this over most of its length. To the north, the crest of the sill is enclosed by the 14 m isobath, and rises rather abruptly to the coastline only 1 km from Collinson Head (Drawing No. 3.10). To the south the crest is much shallower and the sill widens significantly to the west, where the Canadian Hydrographic Service information suggests that several areas exist where such shoals may rise to within less than 3 m of the sea surface. This was partly confirmed by the Norweta data but adverse ice conditions and normal safety procedures precluded detailed surveying over the shallowest parts of the sill.



F84-211

ORE Record Along
the West Side of
Herschel Basin

M. J. O'CONNOR & ASSOCIATES LTD.	
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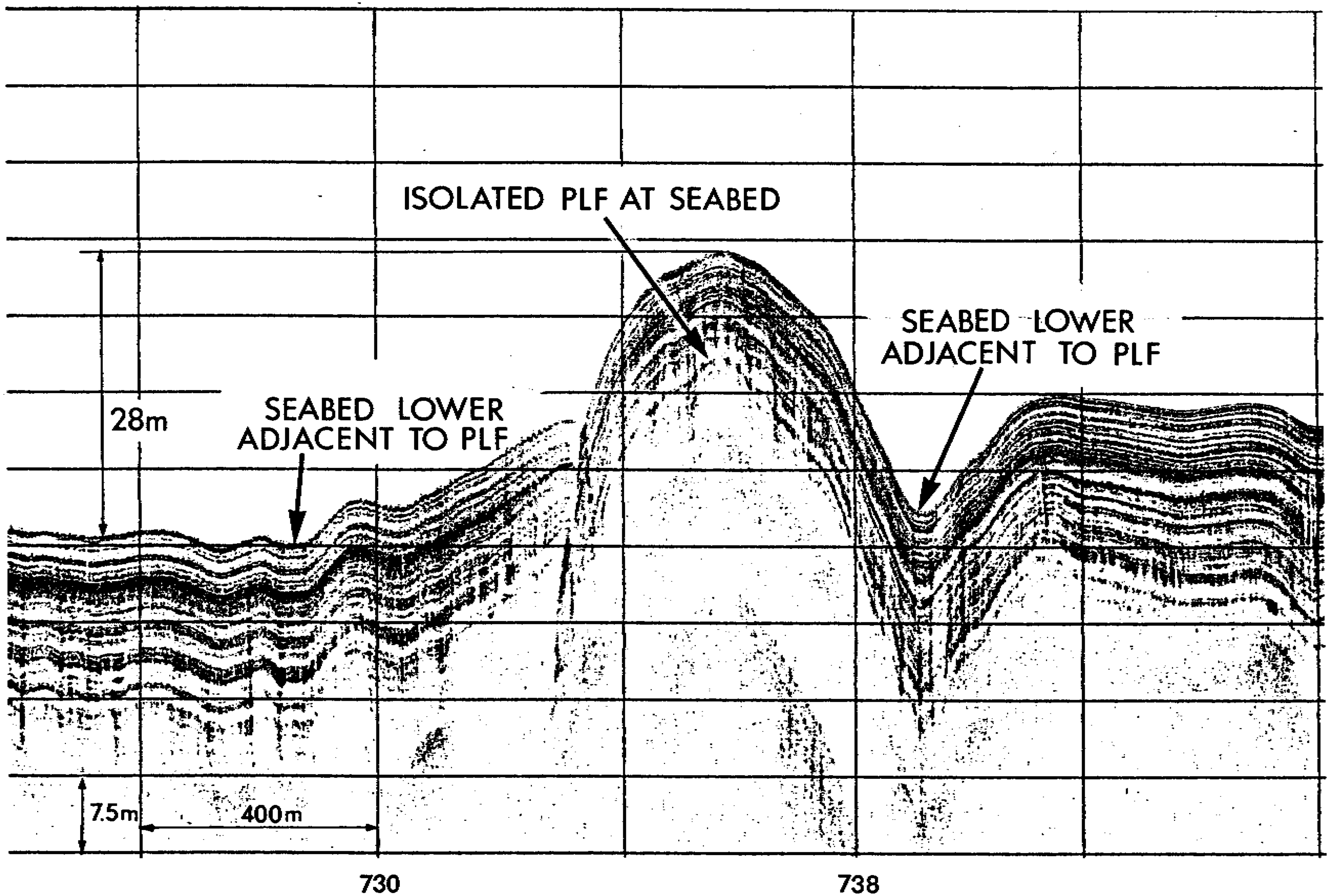

F84-223

Example of Isolated PLF
in Herschel Basin

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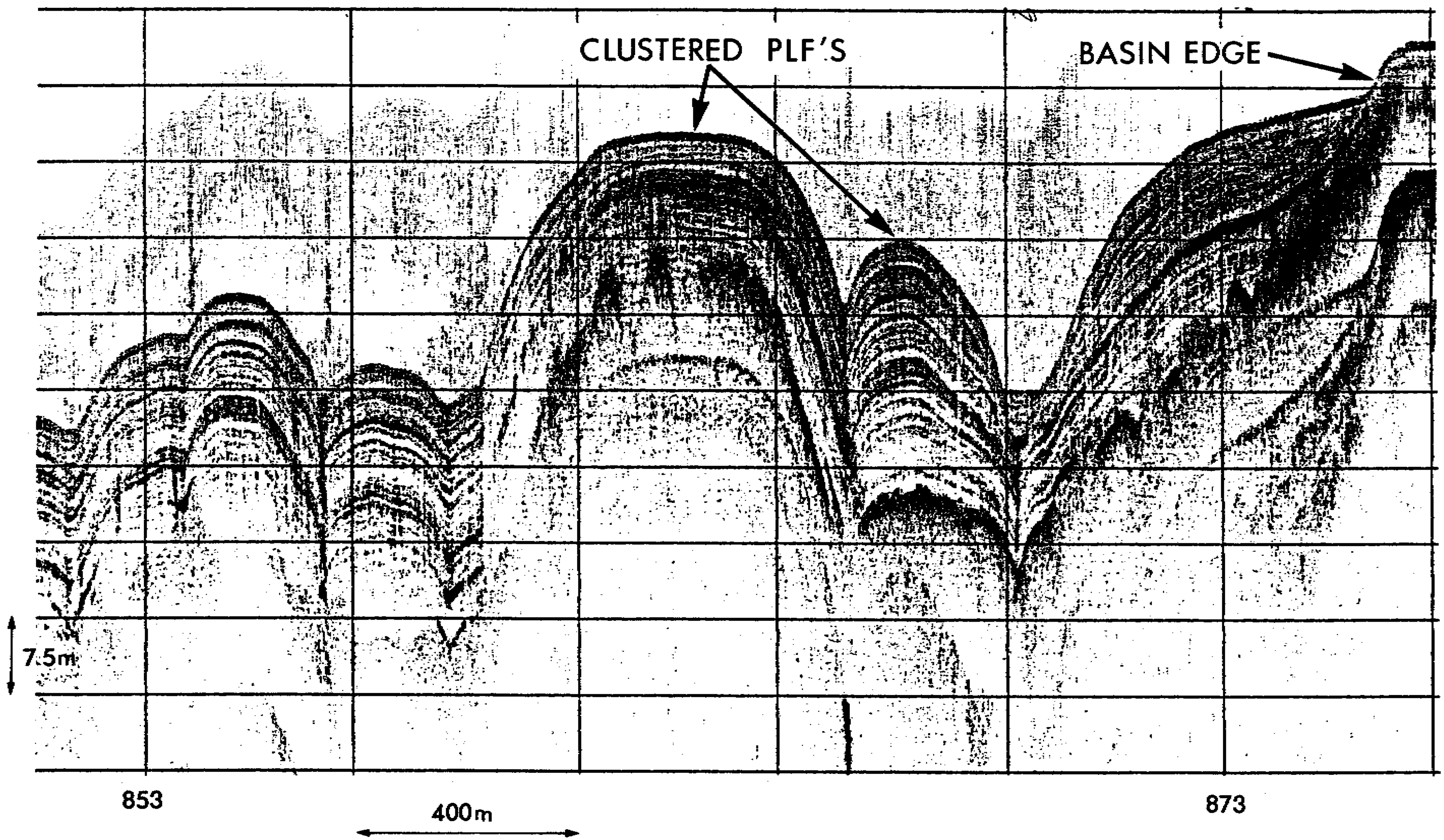

F84-225

Example of Clustered PLF's in Herschel Basin

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JOB No.:	10-260	DATE:	85/07/22
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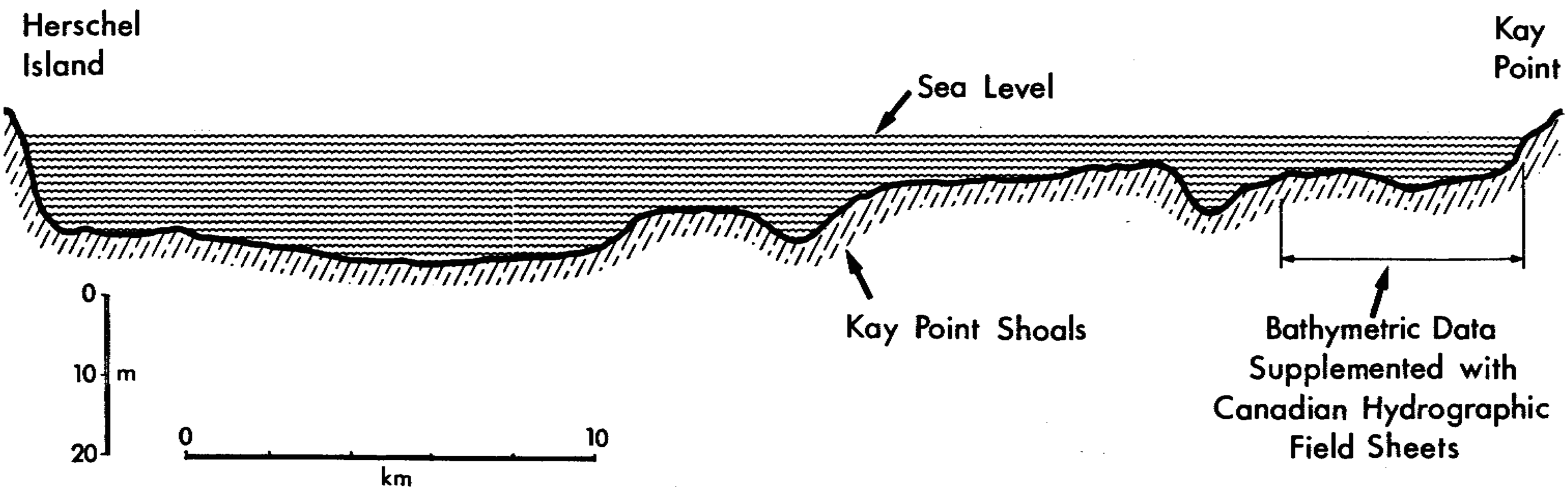


Bathymetric Profile
Along Herschel Sill

M.J. O'CONNOR & ASSOCIATES LTD.

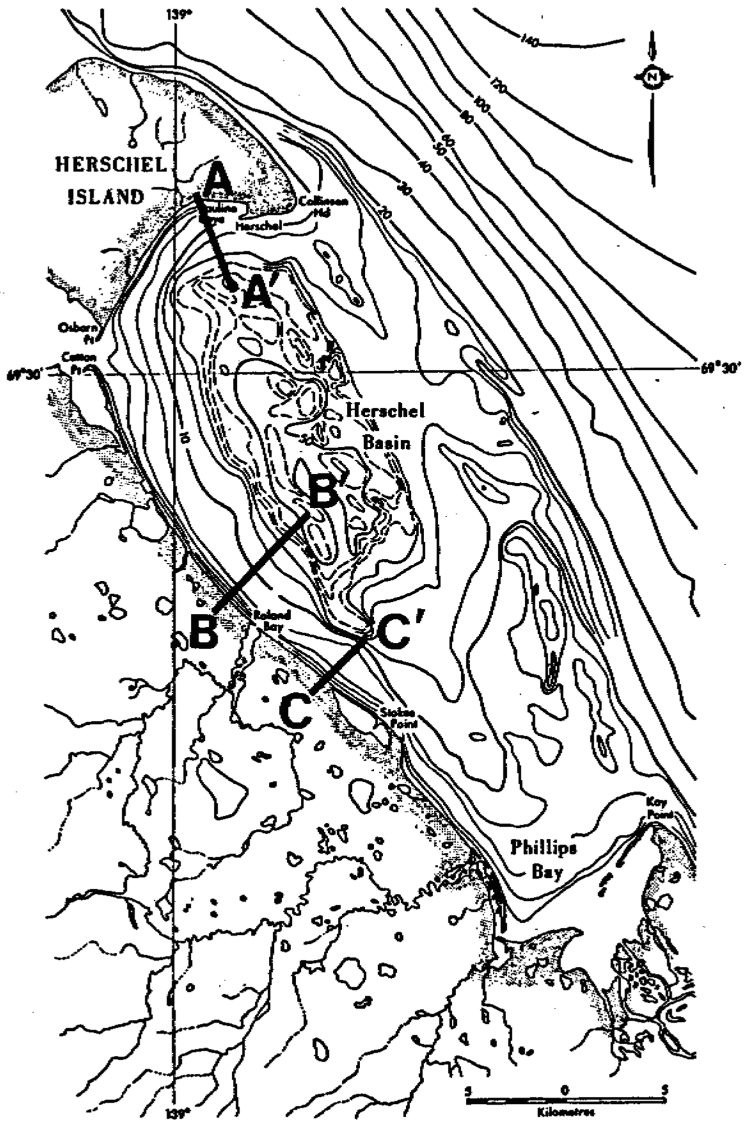
JOB No.:	10-260	DATE:	85/07/22
DRAWN BY:	MG	DWG. No.:	3.10

3.3.3 Yukon Coastal Shelf

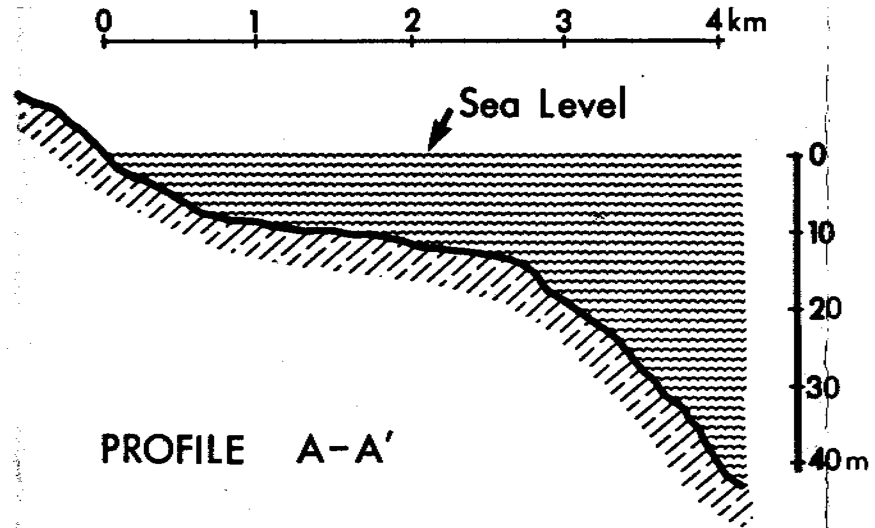
West from Collinson Head and south along the Yukon coast from Catton Point to Niokolik Point, Herschel Basin is flanked by a shelf extending from the coastline to approximately the 14 m isobath. In some areas the shelf is only 1 or 2 km wide, but immediately west of the centre of the basin it widens to about 5 km for some distance. The 4 m isobath usually occurs within a few hundred metres of the shoreline, but further offshore the average shelf slopes are much more gentle, ranging from a 0.30° near Stokes Point to less than 0.10° immediately west of the basin (Drawing No. 3.11). Slopes of as low as 0.05° are common in the central shelf areas north of Roland Bay. Although the coastal shelf represents the remains of the old land surface which has been eroded since the last marine transgression, there is little bathymetric evidence to suggest that any of the original landforms have been preserved. On the contrary, the only present day relief on the shelf appears to be confined to spits and bars being constructed along the coastline.

3.3.4 Babbage River Paleochannel

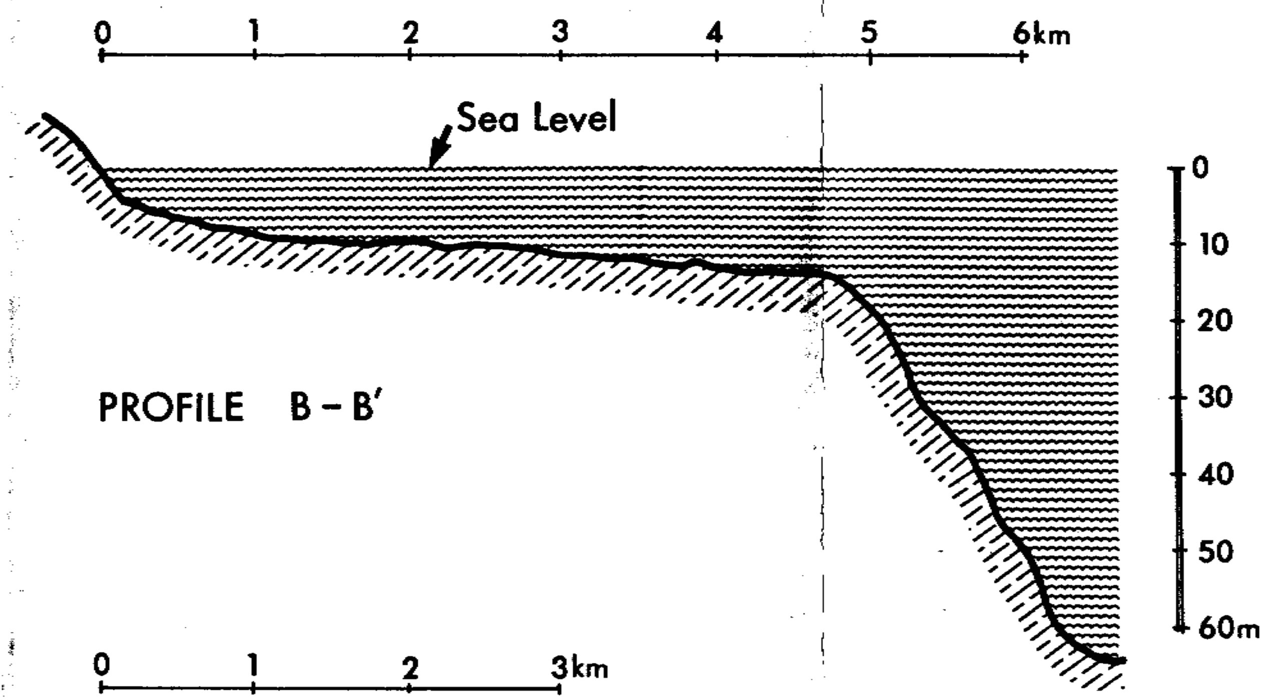
Prior to the last marine transgression the Babbage River entered directly into Herschel Basin. The location of the drowned Babbage River Channel is still clearly evident from both the isobaths (concave basinward) and the echo sounder records (Drawing No. 3.12). In water depths beyond 16 m, the drowned channel is deepest along its west side, but from 12 m



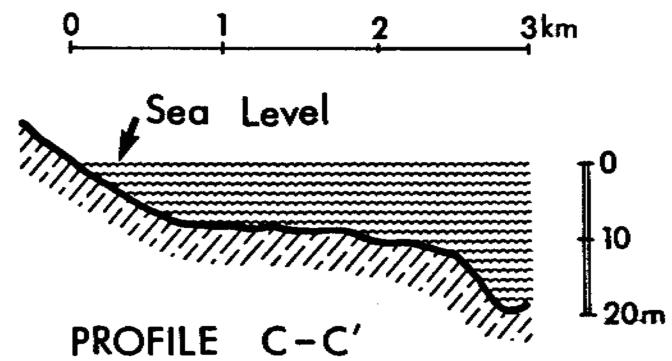
KEY PLAN



PROFILE A–A'

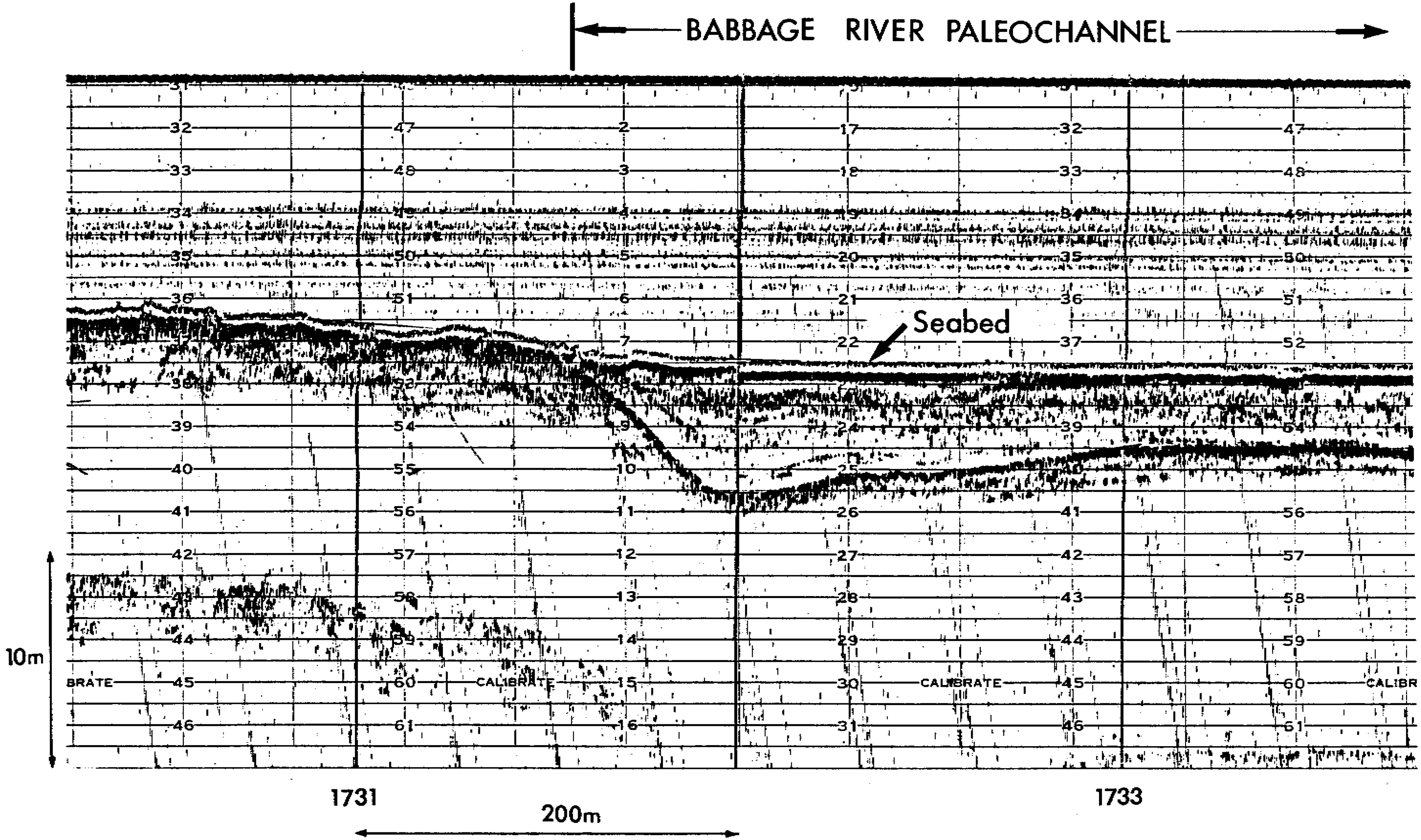


PROFILE B–B'



PROFILE C–C'

Bathymetric Profiles Yukon Coastal Shelf	**M.J. O'CONNOR & ASSOCIATES LTD.**	
	JOB No.: 10-260	**DATE:** 85/07/22
	DRAWN BY: MG	**DWG. No.:** 3.11



IHR84-35B

Echo Sounder Record
East of Edge of Babbage
River Paleochannel

M.J. O'CONNOR & ASSOCIATES LTD.	
JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 3.12

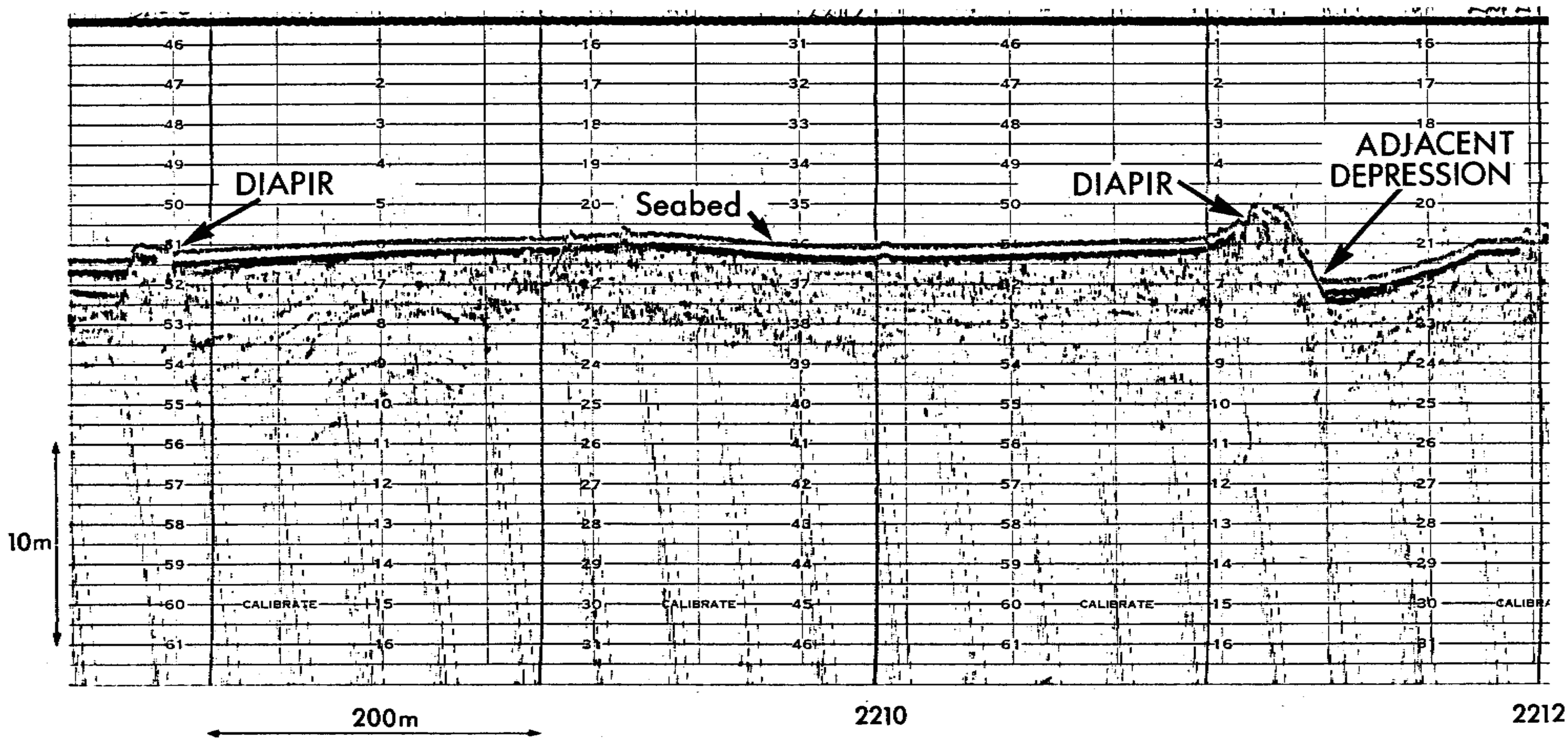
to 15 m, it is the eastern side which is deepest. The present data base does not permit an evaluation of the channel morphology in water depths less than 10 m, but Canadian Hydrographic Services field sheets suggest that the bathymetric expression of the channel is not evident inshore of the 6 or 7 m isobaths.

The hydrographic data also demonstrate in greater detail the complex nature of the channel bottom in certain areas. Near N7694000 E594000 for instance, the echo sounder records show that the channel bottom is characterized by isolated diapirs, probably associated with instability in the recent sediments (Drawing No. 3.13). To the present author's knowledge, such features have not been noted elsewhere in the Beaufort Sea continental shelf, except along the eastern margin of the Mackenzie Trough and at the shelf edge itself.

3.4 Ice Scouring

The distribution and occurrence of ice scours in the study area were examined by reviewing both the side scan sonar and echo sounder records. Three aspects were examined:

1. scour depth
2. scour frequency
3. scour orientation



IHR84-38A

Isolated Seabed Diapir
in the Babbage River
Paleochannel

M. J. O'CONNOR & ASSOCIATES LTD.

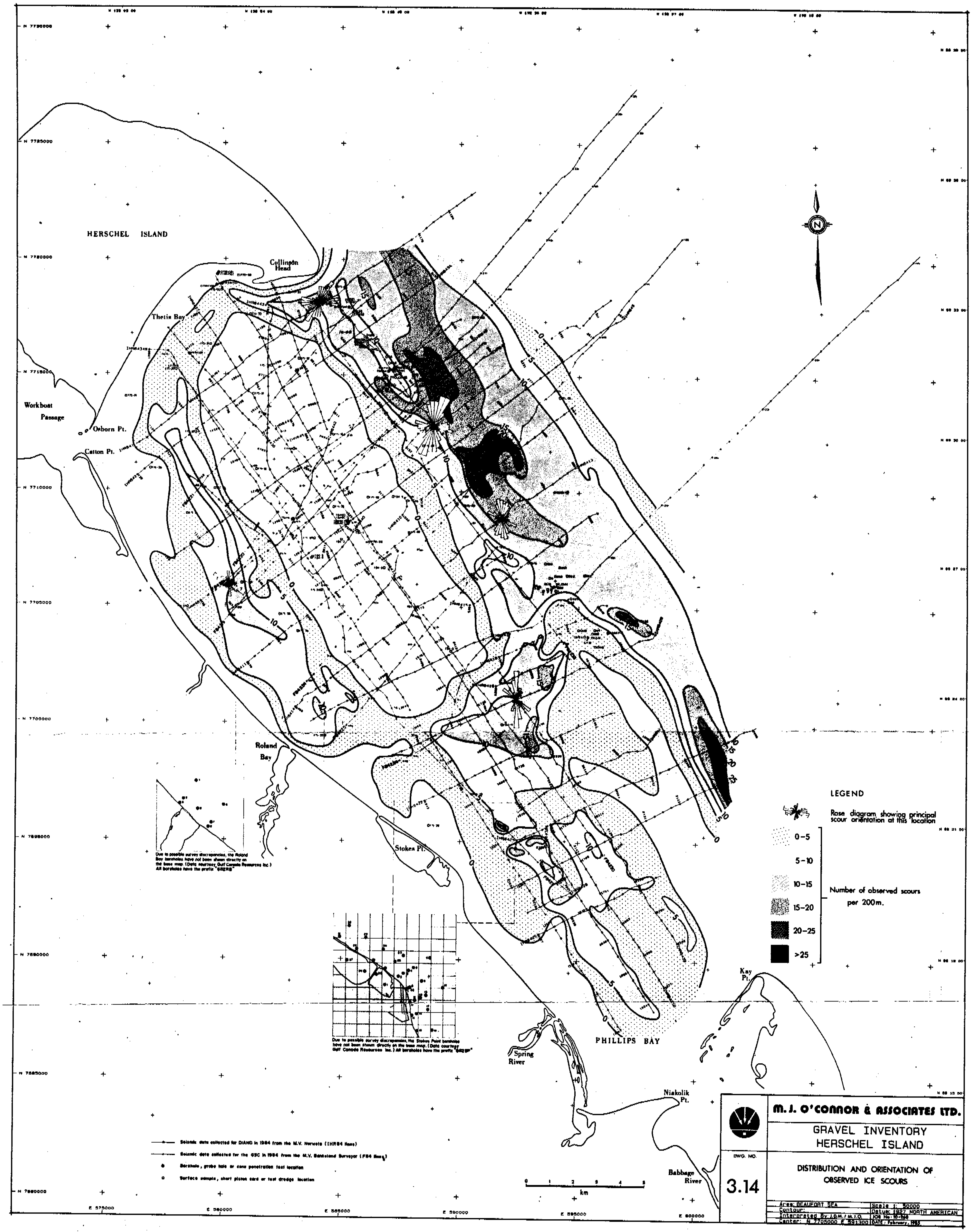
JOB No.: 10-260	**DATE:** 85/07/22
DRAWN BY: MG	**DWG. No.:** 3.13

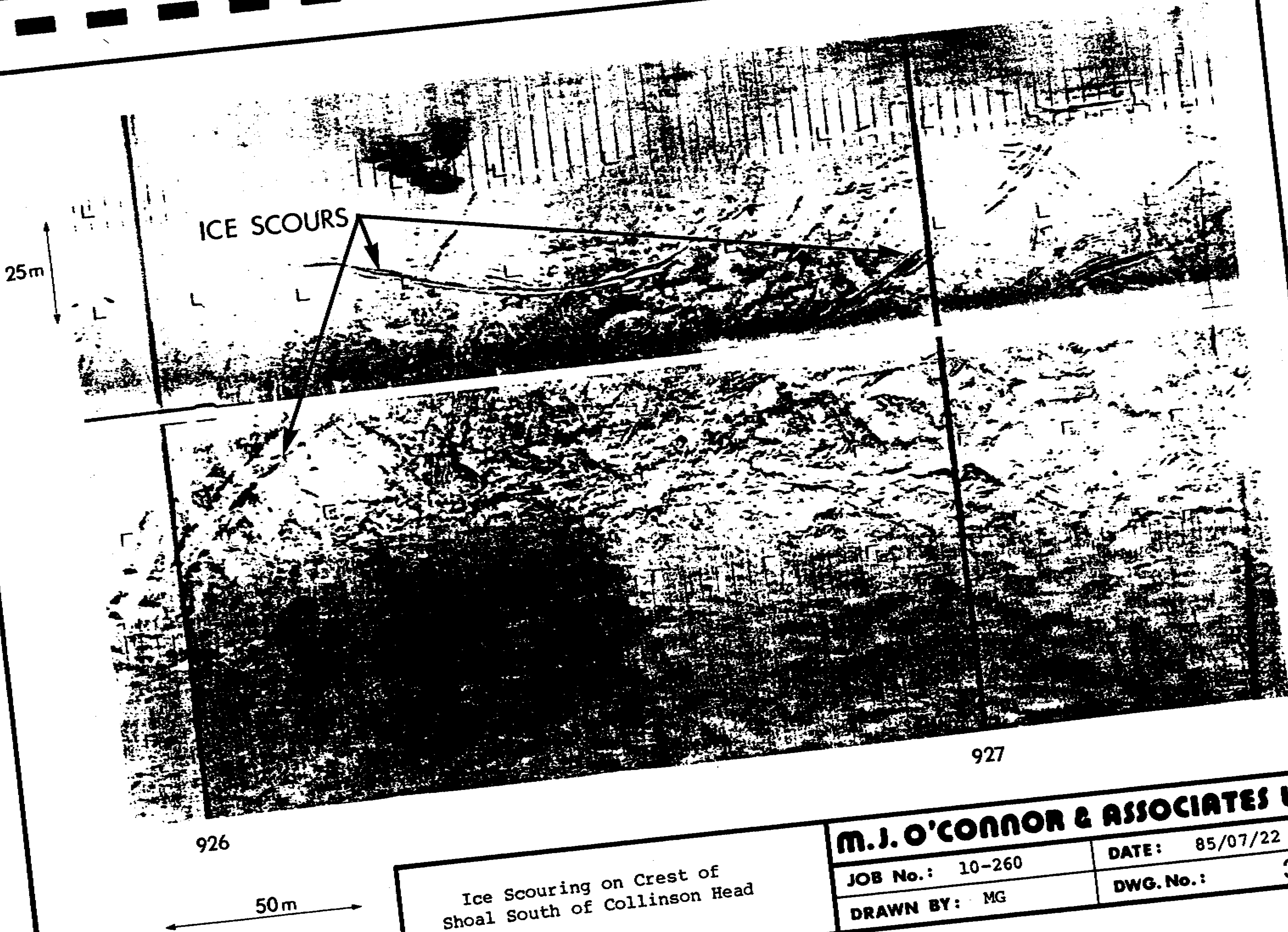
An estimated 95% of the ice scours observed in the study area were found to be less than 1 m deep. The remainder were predominantly in the 1 to 2 m range, although a few scours deeper than 2 m were noted, expecially on the seaward side of the sill in water depths exceeding 30 m.

Scour frequency was measured by counting the number of detectable ice scours per 200 m of seismic line. No correction was applied to the data to account for frequency variations which might result from changes in line direction. Such variations were most noticeable at line intersections. Where discrepancies at line intersections were noted, the larger values were used for contouring purposes.

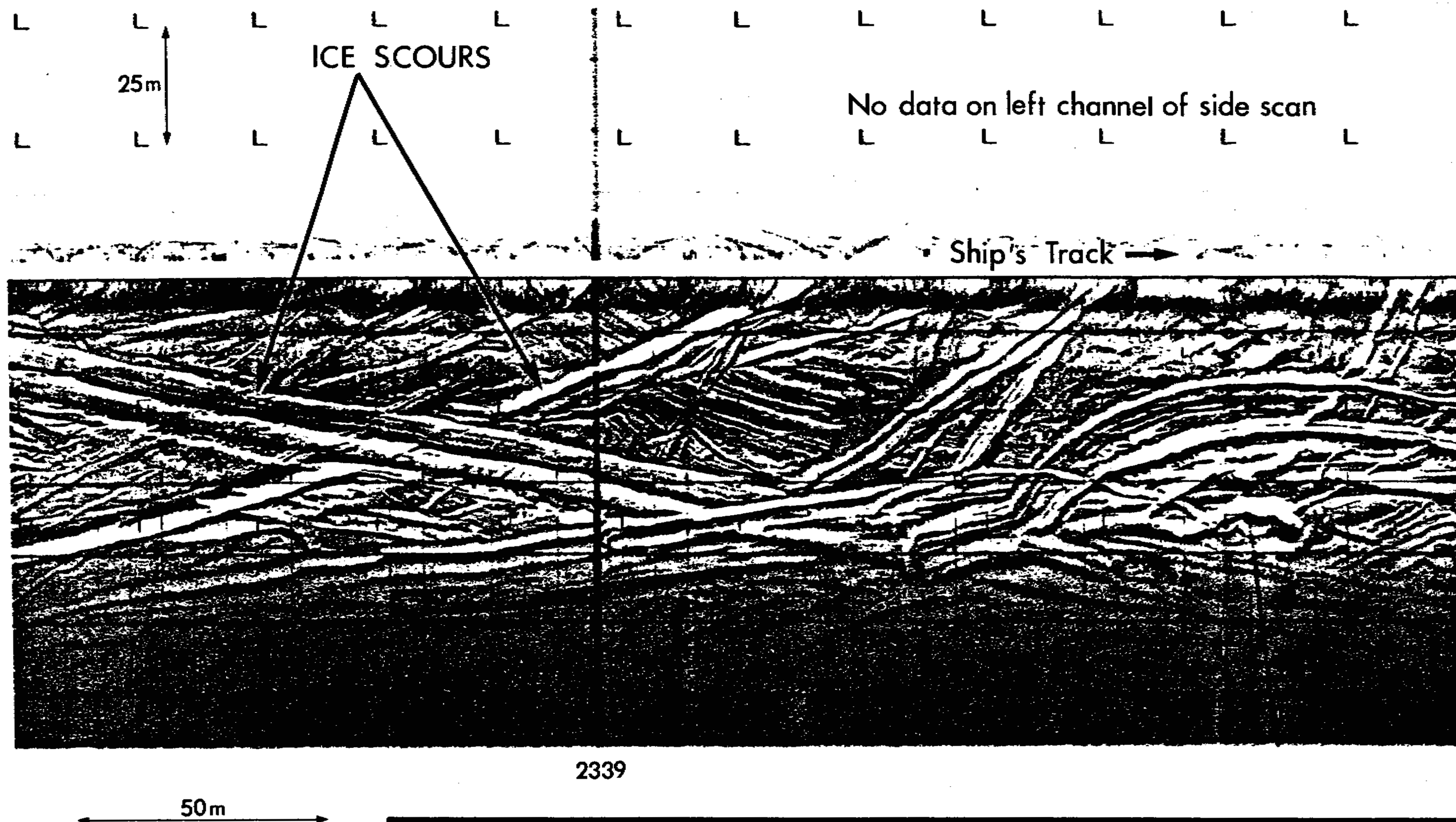
Drawing No. 3.14 (see also Drawing No. D.4) shows the frequency of ice scouring observed at the seabed in August, 1984. Scour density was observed to be highest on the seaward side of the shoals north of Kay Point and immediately south of Collinson Head. In the former area, little or no scouring was observed directly on the shoal itself, but in the latter area some scouring was observed even along the crest (Drawing No. 3.15). No scours were observed on the seaward side of the sill (in the Mackenzie Trough) in water depths exceeding 30 m. On the west side of the sill scouring is evident to the edge of the basin, but the frequency of occurrence near the north end is somewhat reduced. Near the south end, scour frequencies as high as 16 per 200 m were measured on the landward side of the sill (Drawing No. 3.16), but the observed scour frequency diminishes rapidly in Phillips Bay, with somewhat higher concentrations being observed along the drowned reaches of the Babbage River Channel.

As anticipated, no scours were observed in the deep waters of Herschel Basin, because the sill morphology restricts the maximum depth of scouring keels which may enter the basin to 17 or 18 m.


HERSCHEL ISLAND
Collinson Head
Thetis Bay
Workboat Passage
Osborn Pt.
Catton Pt.
Roland Bay
Stokes Pt.
Spring River
PHILLIPS BAY
Kay Pt.
Niakolik Pt.
Babbage River
LEGEND
Rose diagram showing principal scour orientation at this location
0–5
5–10
10–15
15–20
20–25
>25
Number of observed scours per 200m.
Due to possible survey discrepancies, the Roland Bay boreholes have not been shown directly on the base map. (Data courtesy Gulf Canada Resources Inc.) All boreholes have the prefix "82RB"
Due to possible survey discrepancies, the Stokes Point boreholes have not been shown directly on the base map. (Data courtesy Gulf Canada Resources Inc.) All boreholes have the prefix "82SP"
Borehole, probe hole or cone penetration test location
Surface sample, short piston core or test dredge location
km
E 575000
E 580000
E 585000
E 590000
E 595000
E 600000
N 7725000
N 7720000
N 7715000
N 7710000
N 7705000
N 7700000
N 7695000
N 7690000
N 7685000
N 7680000
M. J. O'CONNOR & ASSOCIATES LTD.
GRAVEL INVENTORY
HERSCHEL ISLAND
DWG. NO.
3.14
DISTRIBUTION AND ORIENTATION OF
OBSERVED ICE SCOURS
Area: BEAUFORT SEA
Contour:
Interpreted By: J.D.M./M.J.O.
Center: N 7705000 E 591300
Scale 1: 50000
Datum: 1927 NORTH AMERICAN
DATE: February, 1985



Ice Scouring on Crest of Shoal South of Collinson Head	M. J. O'CONNOR & ASSOCIATES LTD.		
	JOB No.: 10-260	DATE: 85/07/22	
	DRAWN BY: MG	DWG. No.:	3.15



High Scour Density on
Landward Side of Sill
Near Kay Point

M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 3.16

Ice scours are common, however, along the shallow shelf between the Yukon coast and the basin. Maximum scour frequencies on the shelf were observed north of Roland Bay. Protected areas like Thetis Bay exhibited only minor scouring, as did the area immediately offshore from Stokes Point. The latter area is relatively unprotected, so the lack of scouring in this particular area is something of a mystery. It may be that any scours which are found near Stokes Point are quickly removed again by the local current regime.

Drawing No. 3.14 also shows the principal directions of observed ice scours at several locations. On the major part of the sill most of the ice scours have a north-south orientation, with a secondary direction ranging from east-west to northwest-southeast. These same directions are also common inside the sill at the south end of the basin. Immediately south of Collinson Head, however, the principal direction is east-west (parallel to the coastline) with a secondary direction oriented north-south. North of Roland Bay, where scour frequencies on the coastal shelf are highest, the principal direction is clearly northwest-southeast, subparallel to the shoreline. The secondary direction at this location is north-south.

It appears from the above that most of the scouring is due to ice keels impinging on the seaward side of the sill from a northerly direction. Where keel depths and driving forces permit, some of these keels may cross the sill and scour into Phillips Bay or on to the adjoining coastal shelf. Scouring is probably also common on the shoals which occur along the crest of the sill north of Kay Point, but the granular nature of the surficial sediments which comprise these features may not permit long-term preservation of the scour evidence.

3.5 Ripple Marks

The presence of ripple marks is generally taken as an indication of non-cohesive sediments at the seafloor, although as Reinech and Singh (1980, p. 20) point out, they may also be found (infrequently) in muddy sediments. In the present study, the occurrence of ripple marks has been interpreted to indicate sandy bottom, it being presumed that no ripples will form in the recent clayey silts which blanket much of the Beaufort Sea continental shelf, while the current regime is inappropriate for the formation of ripple marks in seabed gravel deposits.

According to Drawing No. 3.17 (also Drawing No. D.5), the majority of the ripple marks occur in the southern half of the study area. Many of these are concentrated on the flanks of the major shoal north of Kay Point centred about N7700000 E597000, but large areas were also encountered within and along the eastern margin of the Babbage River channel and on the shelf north of Stokes Point.

Near Stokes Point both undulatory and discontinuously crested ripple trains were observed oriented parallel to the shoreline. As Drawing No. 3.18 illustrates, these forms are transitional, grading one into the other over relatively short distances. The ripple length* at this location varies from about 1.3 to 1.4 m. The ripple height is difficult to discern on the echo sounding record, but does not appear to exceed 10 cm.

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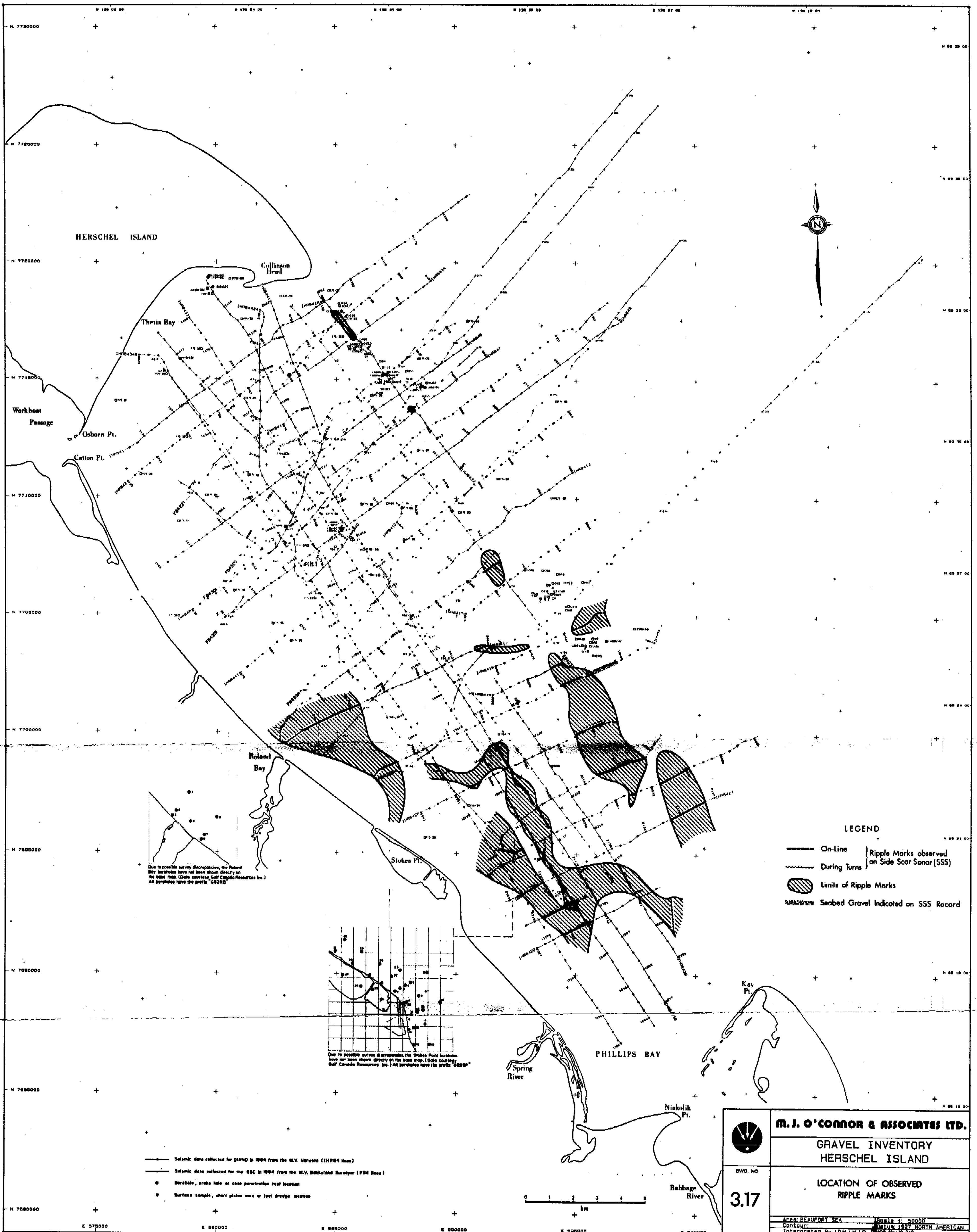
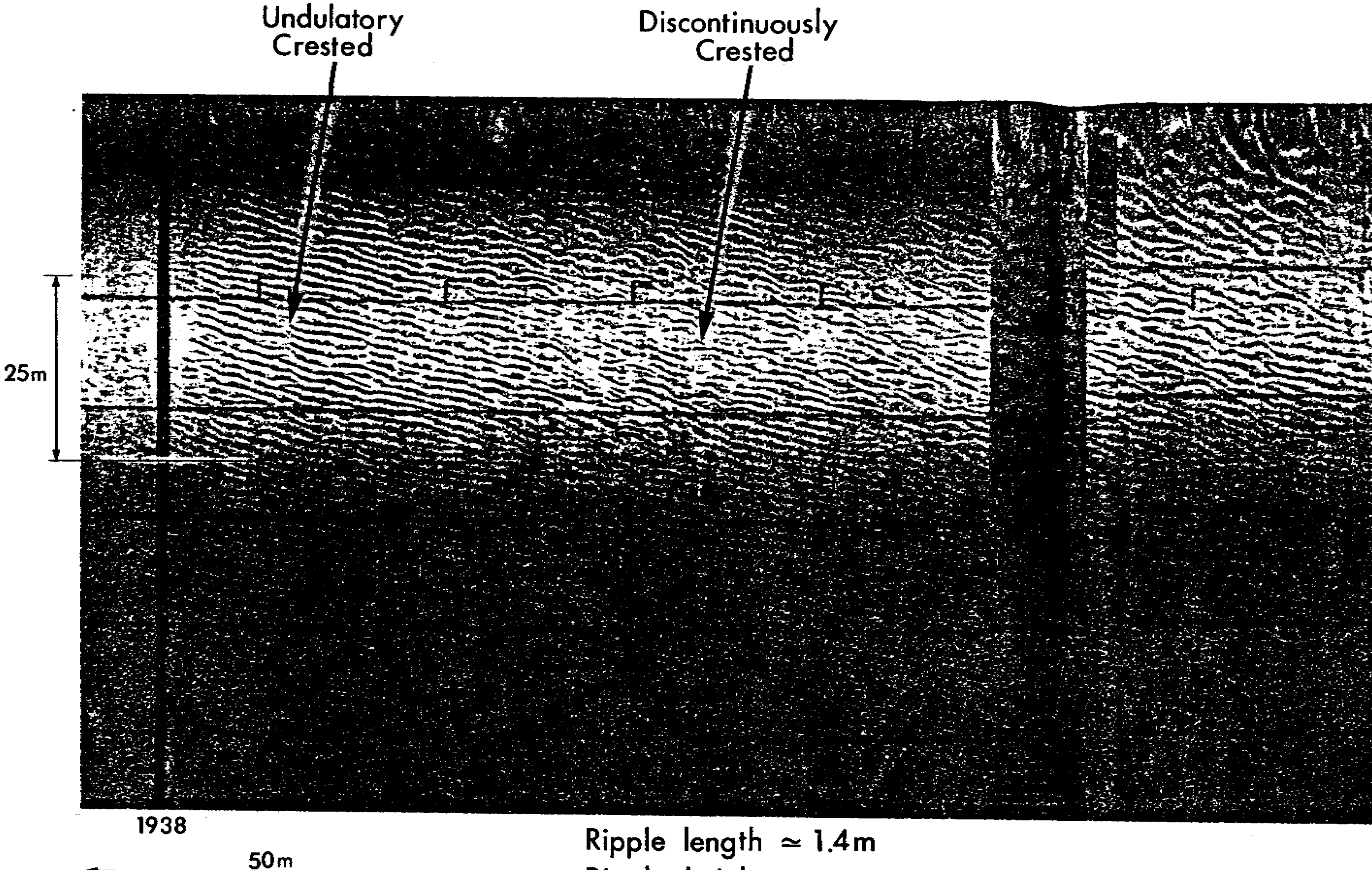
*ripple length is defined as the distance between trough points



HERSCHEL ISLAND
Collinson Head
Thetis Bay
Workboat Passage
Osborn Pt.
Catton Pt.
Roland Bay
Stokes Pt.
PHILLIPS BAY
Spring River
Kay Pt.
Niakolik Pt.
Babbage River
LEGEND
On-Line
During Turns
Ripple Marks observed on Side Scan Sonar (SSS)
Limits of Ripple Marks
Seabed Gravel Indicated on SSS Record
Borehole, probe hole or cone penetration test location
Surface sample, short piston core or test dredge location
km
0 1 2 3 4 5
M. J. O'CONNOR & ASSOCIATES LTD.
GRAVEL INVENTORY
HERSCHEL ISLAND
DWG. NO.
3.17
LOCATION OF OBSERVED
RIPPLE MARKS
Area: BEAUFORT SEA
Contour:
Interpreted By: J.O.M./M.J.O.
Center: N 7705000 E 591300
Scale 1: 50000
Datum: 1927 NORTH AMERICAN
Date: February, 1985



Ripple length ≃ 1.4m
Ripple height ≃ 0.1m

Ripple Trains Observed on Side Scan Records Near Stokes Point

M. J. O'CONNOR & ASSOCIATES LTD.

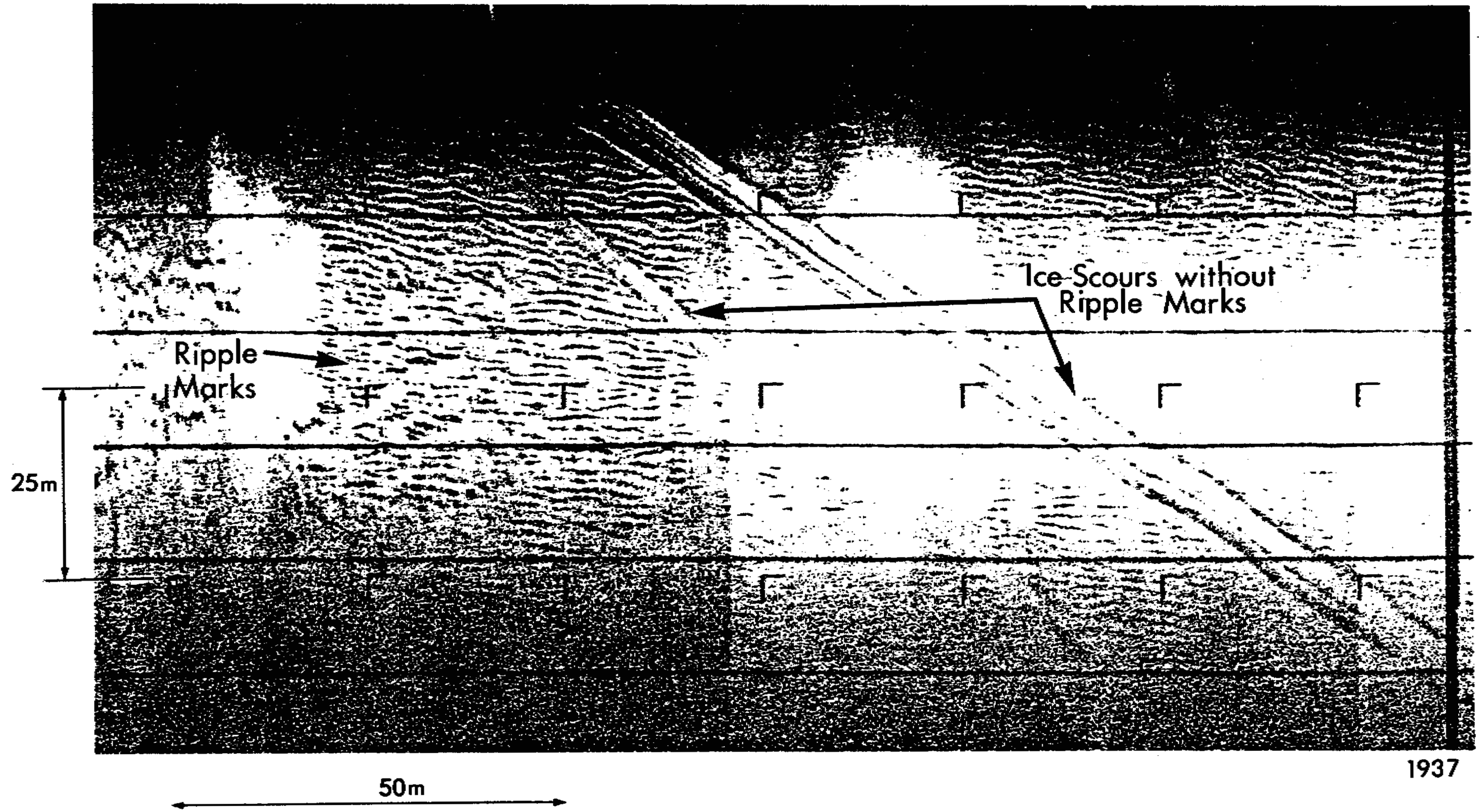
JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 3.18

Drawing No. 3.19 shows another side scan sonar record in the same vicinity, where the ripple trains have apparently been intersected by two ice scours. It is interesting to note that no ripple marks occur within the scour track itself, although the undisturbed seabed immediately adjacent to the scour is clearly rippled. There are several possible explanations for this phenomenon:

1. The scour is a very recent one, and insufficient time has been available for development of ripples inside the scour track.
2. The scour has altered the hydrodynamic interaction of the wave/current regime with the seabed so that the proper conditions for formation of the ripples no longer exist.
3. The seabed is comprised of only a thin veneer of non-cohesive soils underlain by cohesive material, and the scouring keel has exposed the underlying cohesive sediments in which ripples do not normally form.

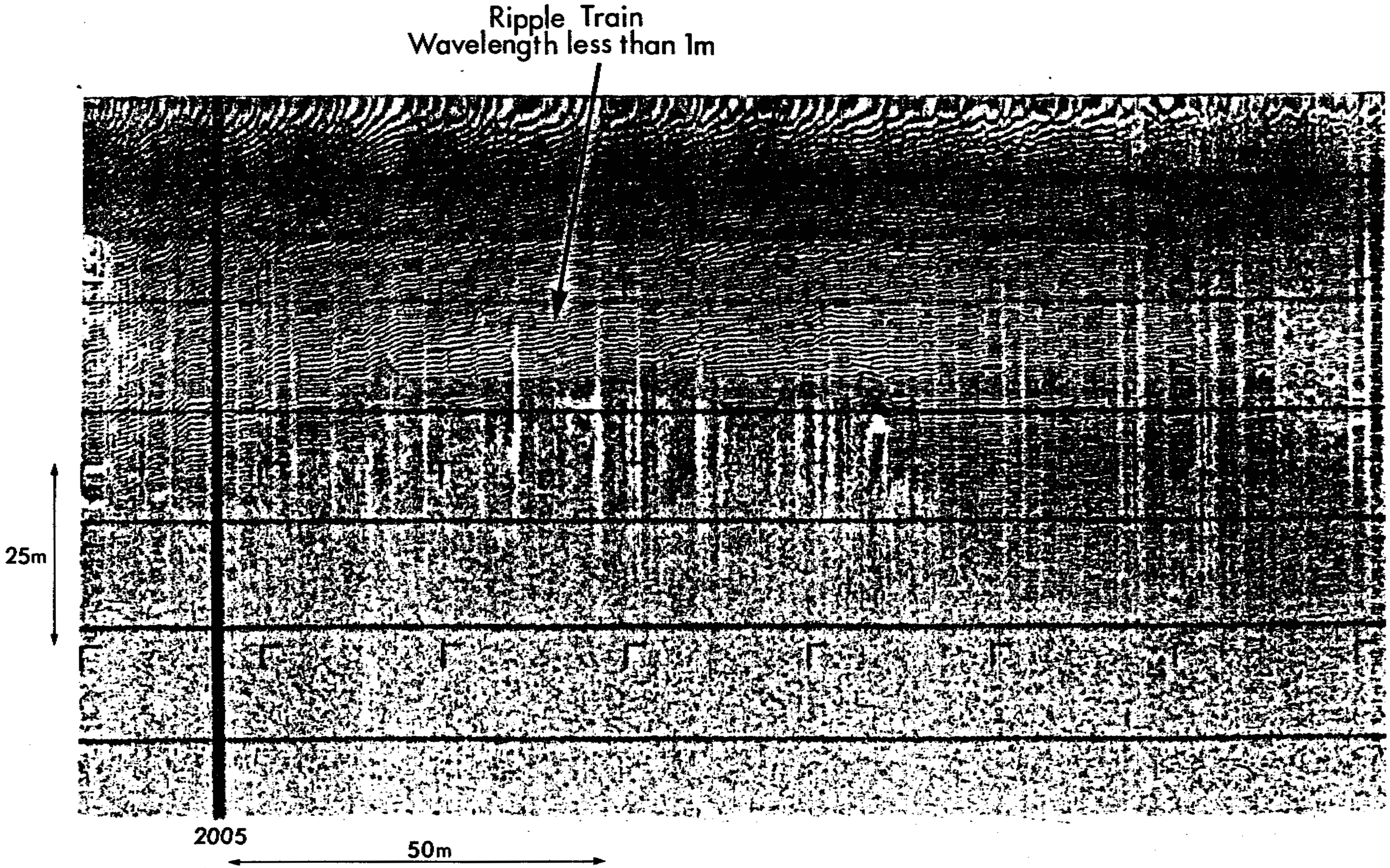
According to borehole information obtained by Gulf Canada Resources near Stokes Point in 1982/83, the third explanation may be the most likely.

Like the Stokes Point ripples, the ripple trains observed in other areas also varied from undulating to discontinuous. On the landward side of the shoal north of Kay Point, well developed ripple trains were often evident, but shorter ripple lengths (as low as 0.5 m) were more frequently observed (Drawing No. 3.20).



Absence of Rippling
Within Ice Scour Tracks

M. J. O'CONNOR & ASSOCIATES LTD.	
JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 3.19



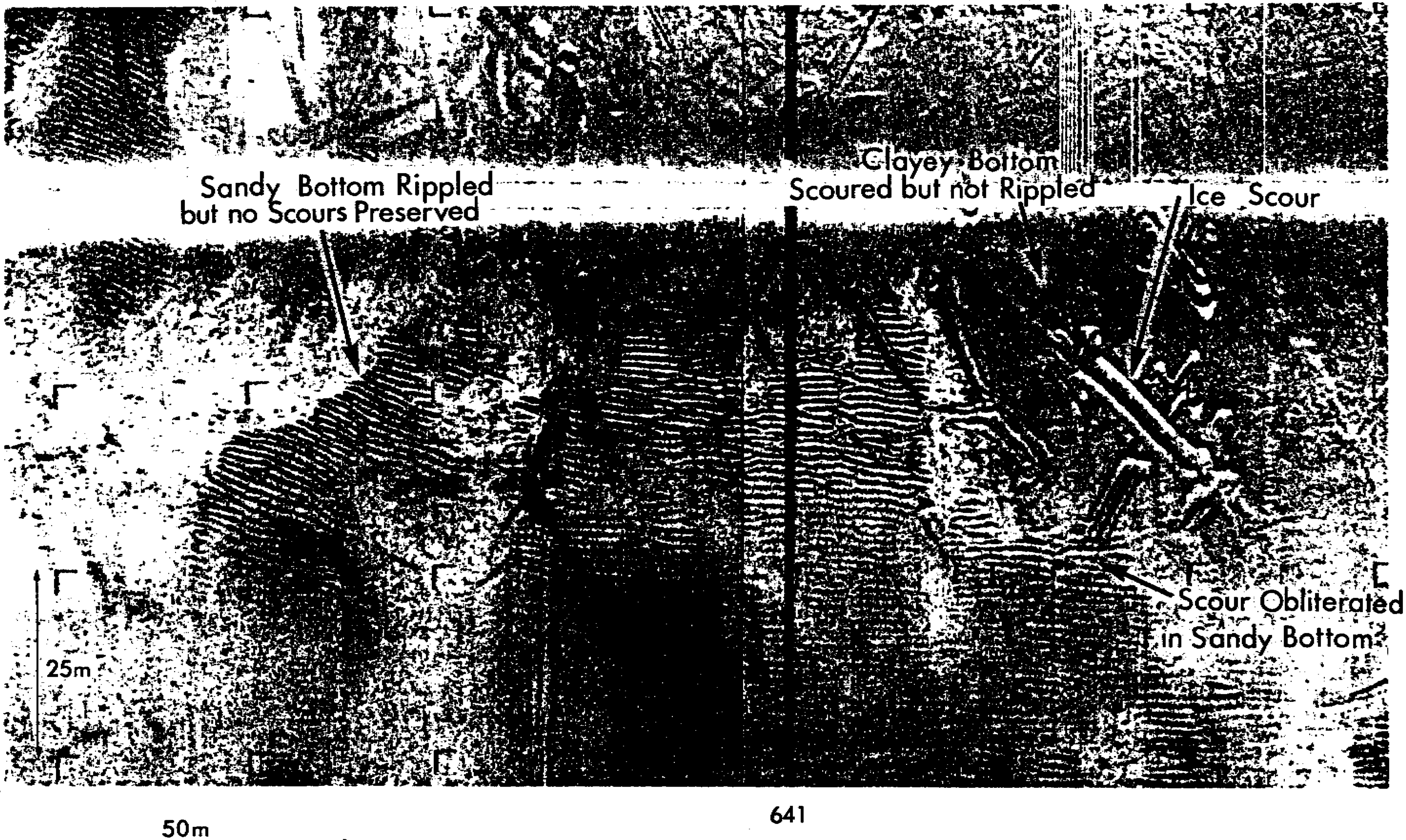
Short Ripple Lengths
Observed Near Kay Point

M. J. O'CONNOR & ASSOCIATES LTD.	
JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 3.20

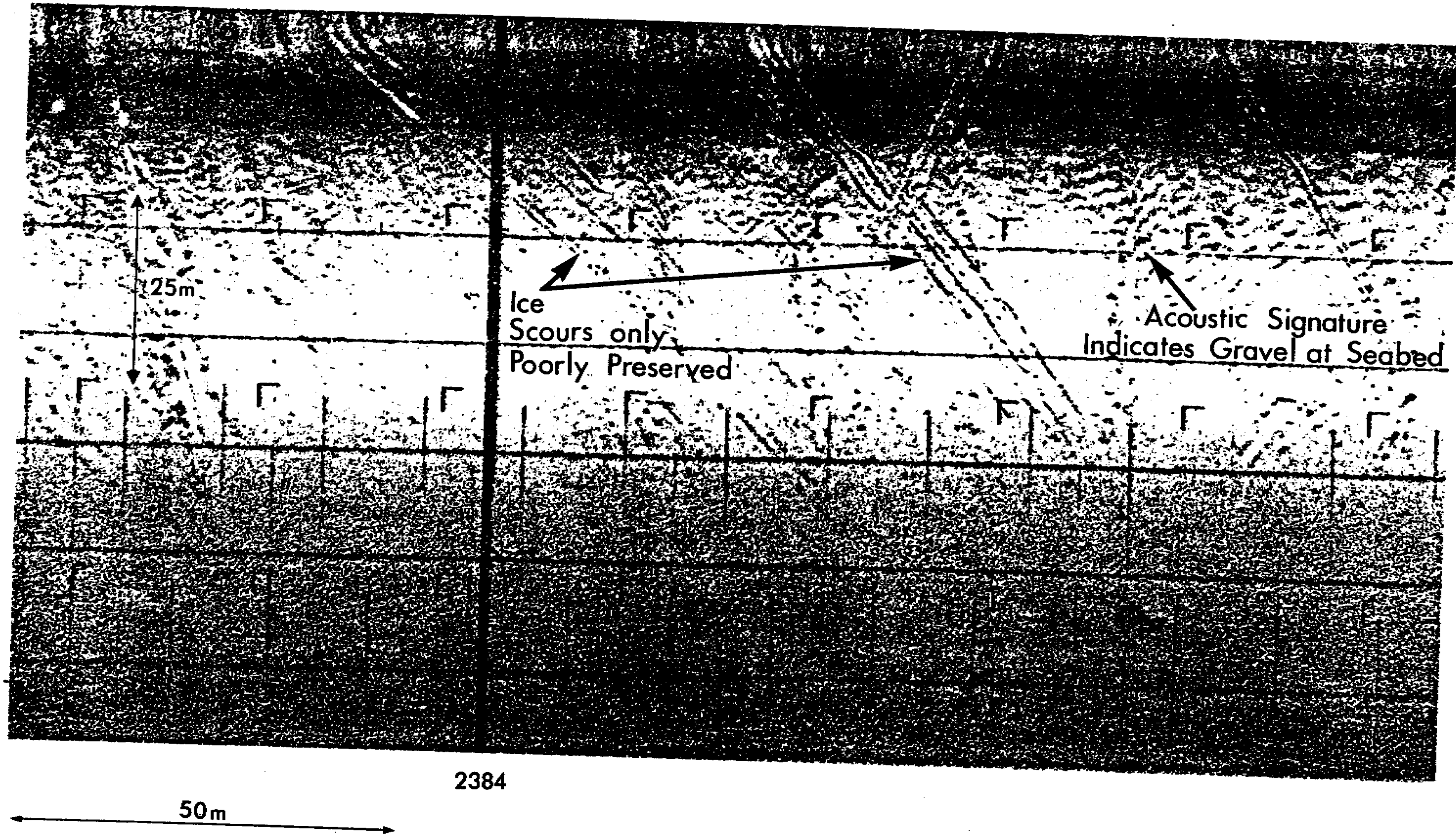
Ripple marks were particularly helpful in delineating both the nature of the surficial strata in some areas and the lateral limits of individual soil types. On Drawing No. 3.21, for instance, the boundary between the sandy and clayey soils at the seabed can be clearly seen on the side scan record. Note that the clayey soils are not rippled, but exhibit well preserved ice scour tracks. In the sandy areas these same scour tracks are almost obliterated by the formation of ripple trains. Drawing No. 3.22 shows a side scan record obtained in an area of the shoal where ripple marks were common. The acoustic signature suggests that gravelly sediments are probably present at the seabed in this area, thereby accounting for the much lower number of ripples observed on the side scan record.

Lastly, Drawing No. 3.23 shows a side scan record in Phillips Bay where ripple marks occur only within the track of an ice scour. Like those recorded elsewhere, these ripples may be classified as undulating, exhibiting a ripple length of approximately 1.3 m and a northwest to north-northwest orientation. The occurrence of ripple marks only in the scour track is interpreted as evidence that shallow sandy seabed soils are overlain by a thin veneer of more cohesive material. It is evident from the side scan record that the distribution of this clay veneer is somewhat patchy, because ripple trains are also evident over large areas to the right of the diagram. Moreover, the bathymetric data suggests that the scour depth is less than 0.2 m, so the total thickness of clay veneer must be somewhat less.

It is evident from the foregoing that ripple marks can provide substantial indirect evidence regarding the nature of the seafloor and the distribution of surficial granular resources in the study area. The west side of the shoal north of Kay Point, for instance, appears to



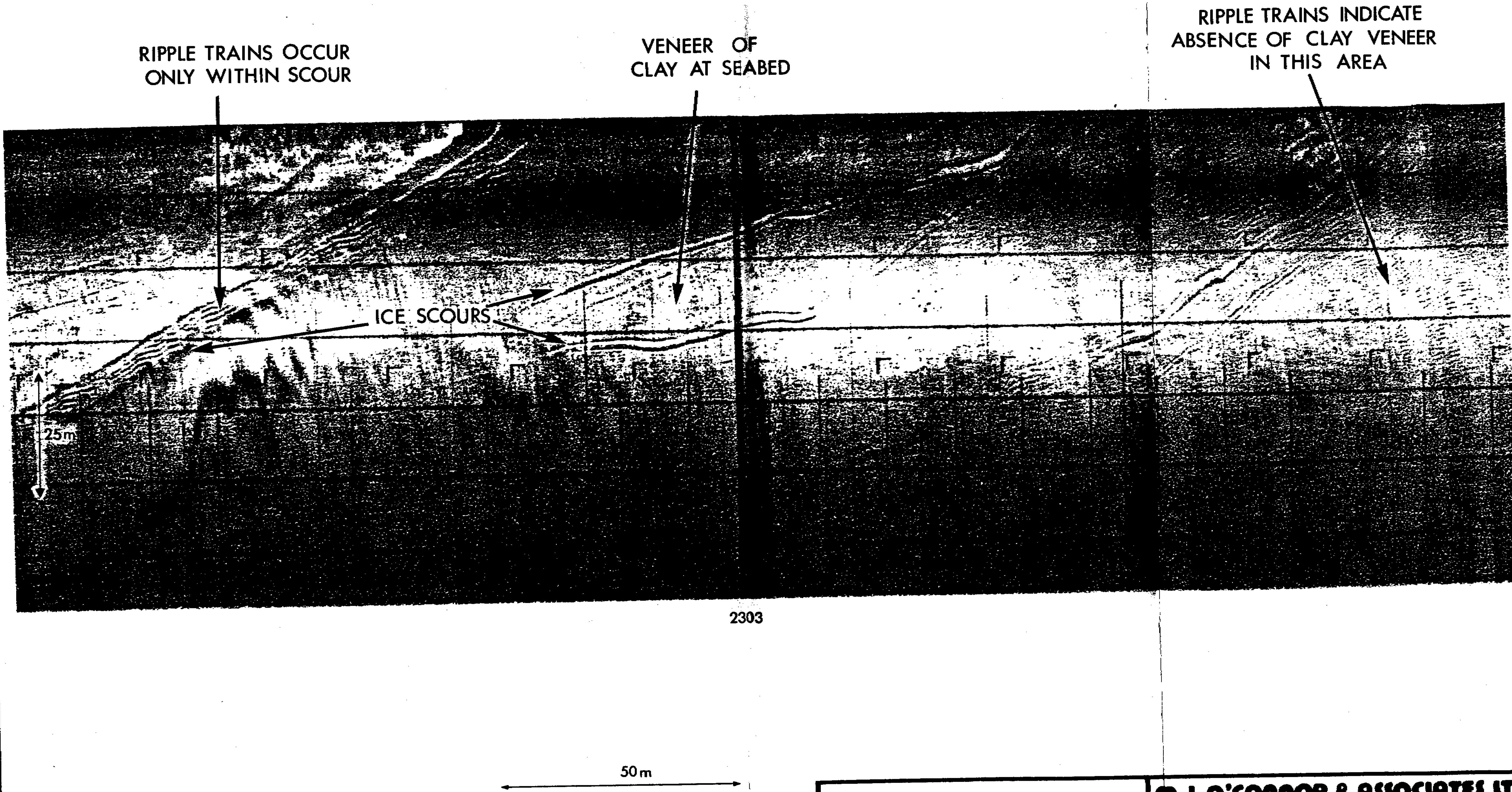
Ripple Marks Delineate Seabed Soil Type	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/07/22
	DRAWN BY: MG	DWG. No.: 3.21



Side Scan Evidence
of Seabed Gravel

M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 3.22



Side Scan Evidence of Sandy Bottom Partially Blanketed by Clay Veneer

M. J. O'CONNOR & ASSOCIATES LTD.	
JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 3.23

be predominantly sandy. The crest of this shoal, particularly near the north end, is apparently comprised of gravel-sized material. Sandy sediments are also present at the seabed on the coastal shelf between Roland Bay and Stokes Point, as well as in the Babbage River Paleochannel and the adjacent areas of Phillips Bay. In some areas, like the coastal shelf, the sand probably consists of only a thin veneer. In other areas, like Phillips Bay and part of the shoal south of Collinson Head, the sand may be blanketed by a thin layer of recent clayey silt. The distribution and thickness of this clayey silt layer are both important factors which must be considered in any engineering evaluation of the granular resource potential of the study area, but a more detailed assessment is precluded without substantial detailed groundtruth information.

4.0 SUBSURFACE CONDITIONS IN THE STUDY AREA

4.1 Herschel Basin

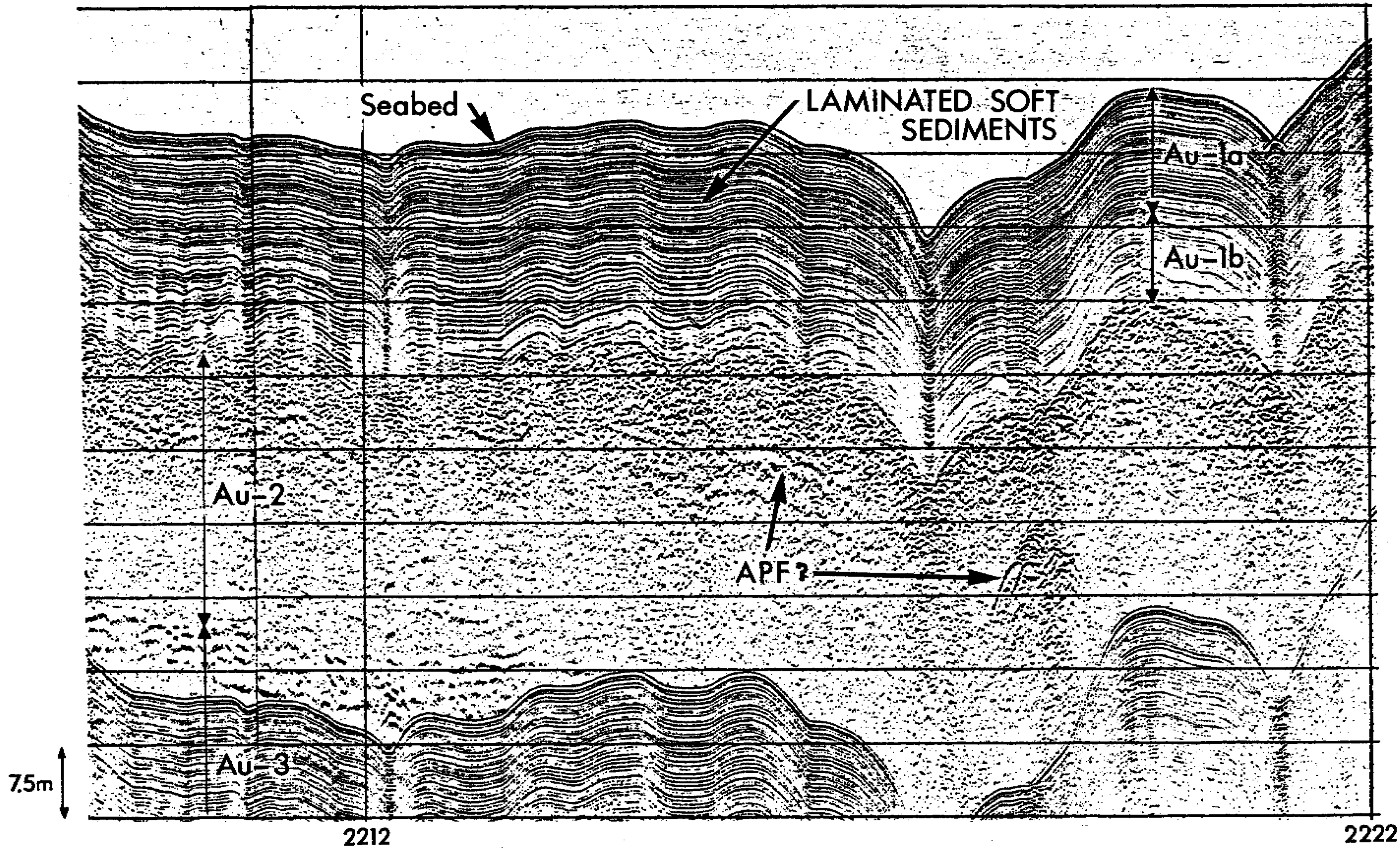
The acoustic stratigraphy of Herschel Basin was originally described by O'Connor (1984) on the basis of shallow seismic records collected by the Geological Survey of Canada between 1970 and 1975.

In the deeper parts of the basin, the surficial sediments were divided into several units, based on their apparent seismic signature.

According to O'Connor (1984) the shallowest strata (acoustic Unit AU-1) were found to consist of approximately 20 m of laminated soft sediments (Drawing No. 4.1). Since the upper half of the acoustic unit appeared to be more highly laminated than the lower half, and the boundary between the different acoustic signatures could be traced over the entire basin, O'Connor (1984) divided the laminated surficial stratum into sub-units AU-1a and AU-1b.

The laminated unit AU-1 was found to rest conformably on an underlying acoustically transparent unit (AU-2) which is distinctive by its homogeneous but extremely discontinuous bedding. Unit AU-2 appeared to be generally thicker than 30 m near the centre of the basin. Along the basin margins, however, its thickness could not be determined, because multiple interference obscured the deeper reflectors when the seabed is shallower.

The precise contact between Units AU-1 and AU-2 is, as Drawing No. 4.1 shows, not generally marked by a good reflector. On the contrary, the contact is only evident because of the change in the acoustic signature from the highly laminated sequences evident in AU-1 to the almost



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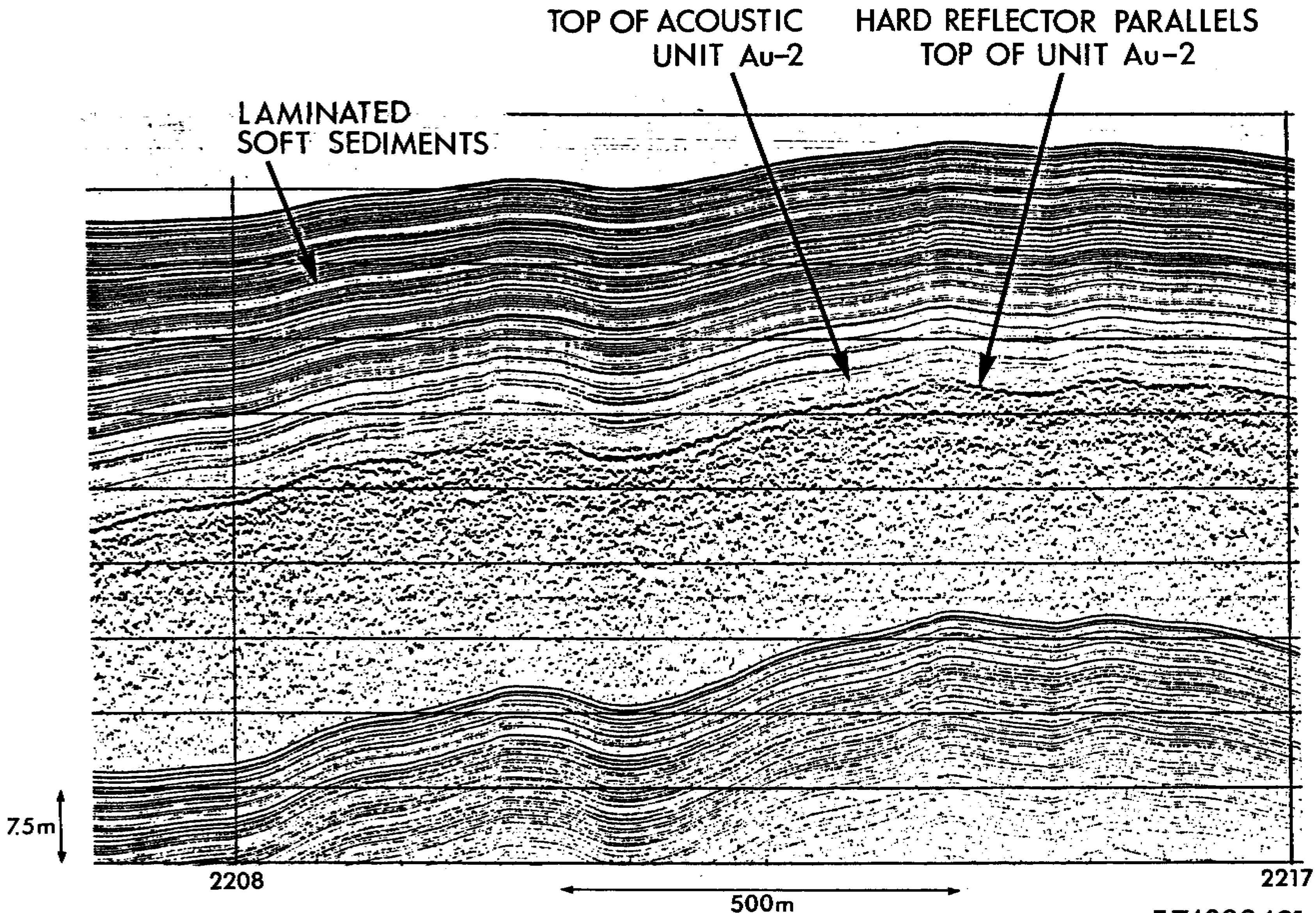
Acoustic Units Au-1 and Au-2	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/07/22
	DRAWN BY: MG	DWG. No.: 4.1

randomly discontinuous sequence which characterizes AU-2. This lack of any distinct marker reflection at the boundary suggests that the acoustic impedance across the boundary does not change, an observation which led O'Connor (1984) to suggest that both acoustic units are probably comprised of similar soil types of approximately the same density.

Other locations were noted, however, where Unit AU-2 was characterized by a strong reflector near its upper boundary. As Drawing No. 4.2 illustrates, this reflector was not necessarily coincident with the change in acoustic signature from laminated to discontinuous, but occurred a few metres below the boundary. In such cases the boundary itself might be marked by a complete absence of any reflectors whatsoever.

In spite of the almost complete lack of any internal acoustic order in Unit AU-2, weak and discontinuous low frequency reflections were often observed within the stratum. In rare cases higher frequency and high amplitude hyperbolae were also observed at about the same elevation. O'Connor (1984) interpreted these reflectors to be hummocky acoustic permafrost (APF), i.e. the irregular top of ice-bonding in the sediments (see Drawing No. 4.1).

Where it was not obscured by multiple interference from the seabottom, the base of Unit AU-2 was found to be marked by a distinct, if only weakly continuous low frequency reflection. O'Connor (1984) interpreted this reflection to be the uppermost boundary of Unit AU-3, a harder layer (till, gravel, bedrock, or possibly continuously



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Acoustic Signature of the Top of Unit Au-2

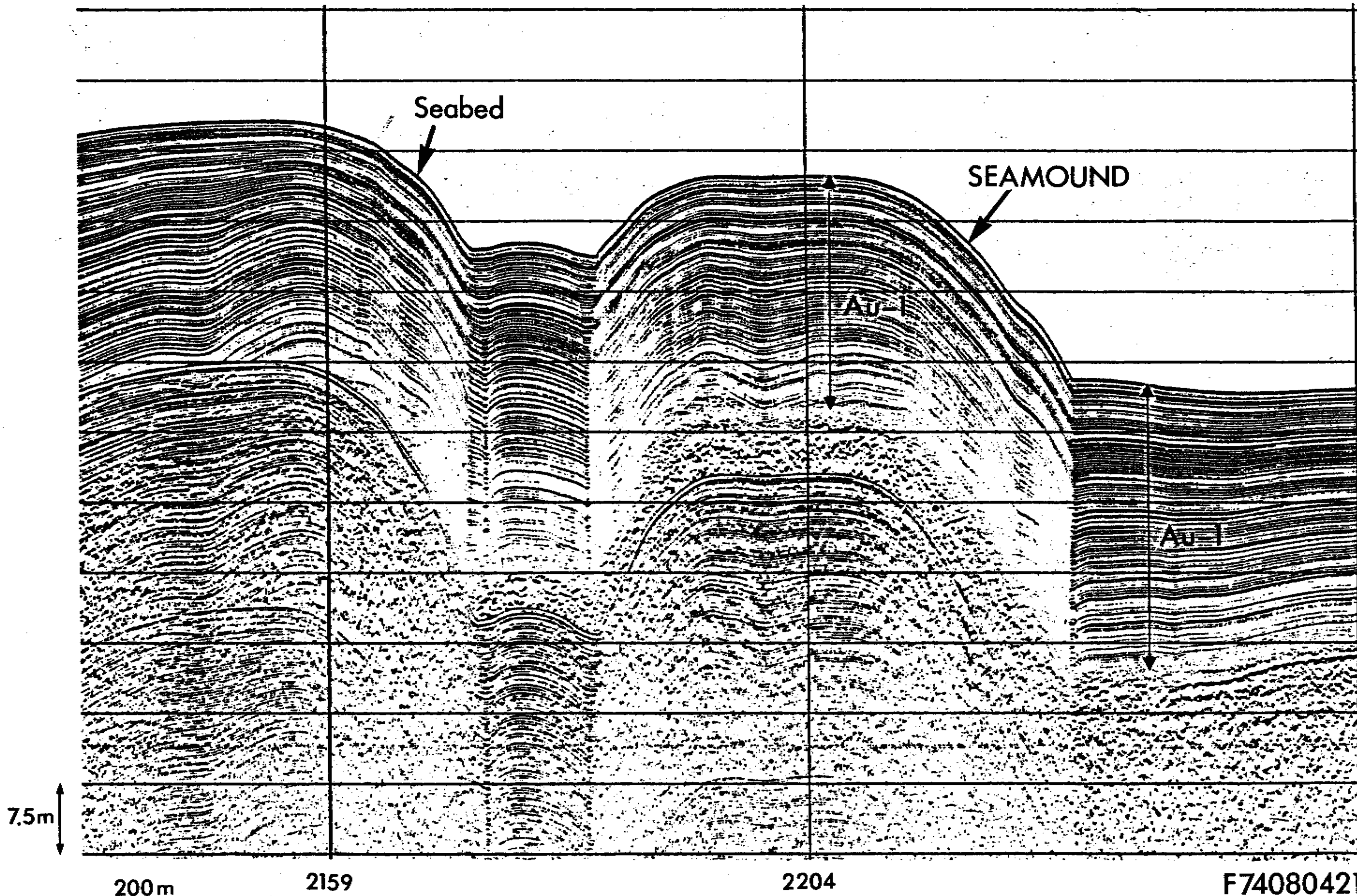
M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 4.2

ice-bonded permafrost) whose lateral extent could not be determined. There appeared to be some general correlation between subtle changes in elevation of the seafloor and the structure contours on the top of Unit AU-3. The latter usually rises, for instance, near the basin margin and is somewhat deeper near the basin centre. In some cases even very minor seafloor morphological features appeared to be related to similar structure features at the top of Unit AU-3, but in other cases some of the major seafloor features apparently bore no relationship to structure contours on the lower unit.

For the most part, the internal acoustic stratigraphy of the seamounds remained unresolved in the earlier study conducted by O'Connor (1984). It was clear that both units AU-1 and AU-2 are present beneath these seafloor features, but it was never clear to what extent these features might be an indication of deeper structure. Isopach determinations appeared to provide somewhat conflicting evidence. In Drawing No. 4.3, for instance, the thickness of Unit AU-1 is not significantly different on top of the seamound than it is in the adjacent areas, thereby suggesting that formation of the seamound is probably a relatively recent (post deposition to much of AU-1) feature. In Drawing No. 4.4, however, Unit AU-1 is clearly much thinner on top of the seamound than it is on the flanks or the adjacent basin bottom. This suggests that the structural relief probably preceded, or at least was was penecontemporaneous with the deposition of Unit AU-1. In neither of the above cases was it possible to discern the nature of the acoustic stratigraphy in the deeper geologic section.

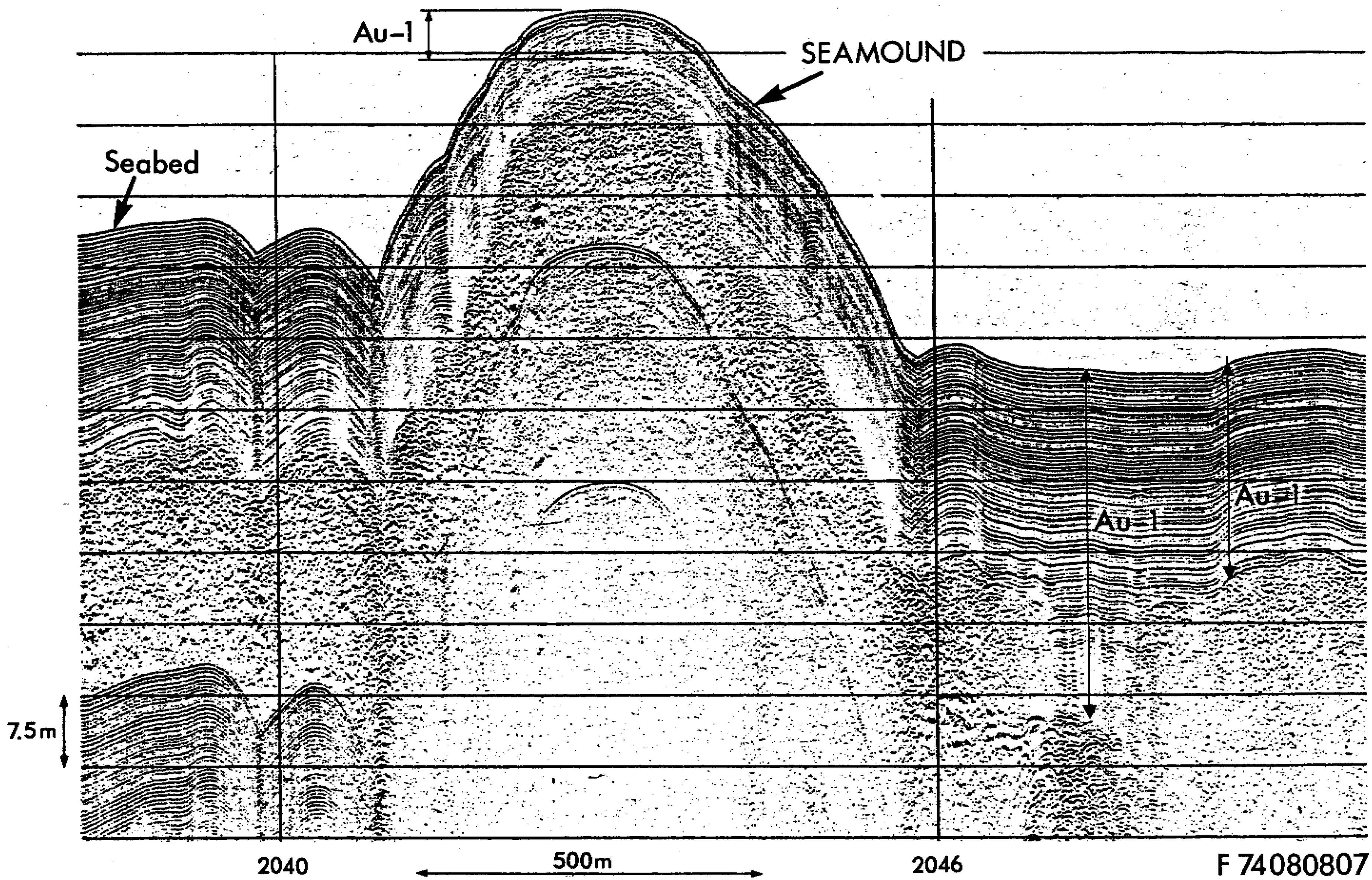
Following the drilling of several geotechnical boreholes for DIAND in Herschel Basin from the barge Arctic Kiggiak in 1984, the true nature



M. J. O'CONNOR & ASSOCIATES LTD.

Small Changes in
Au-1 Thickness from
Seamound to Adjacent Area

JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 4.3



Large Changes in
Au-1 Thickness from
Seamound to Adjacent Area

M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.:	10-260	**DATE:**	85/07/22
DRAWN BY:	MG	**DWG. No.:**	4.4

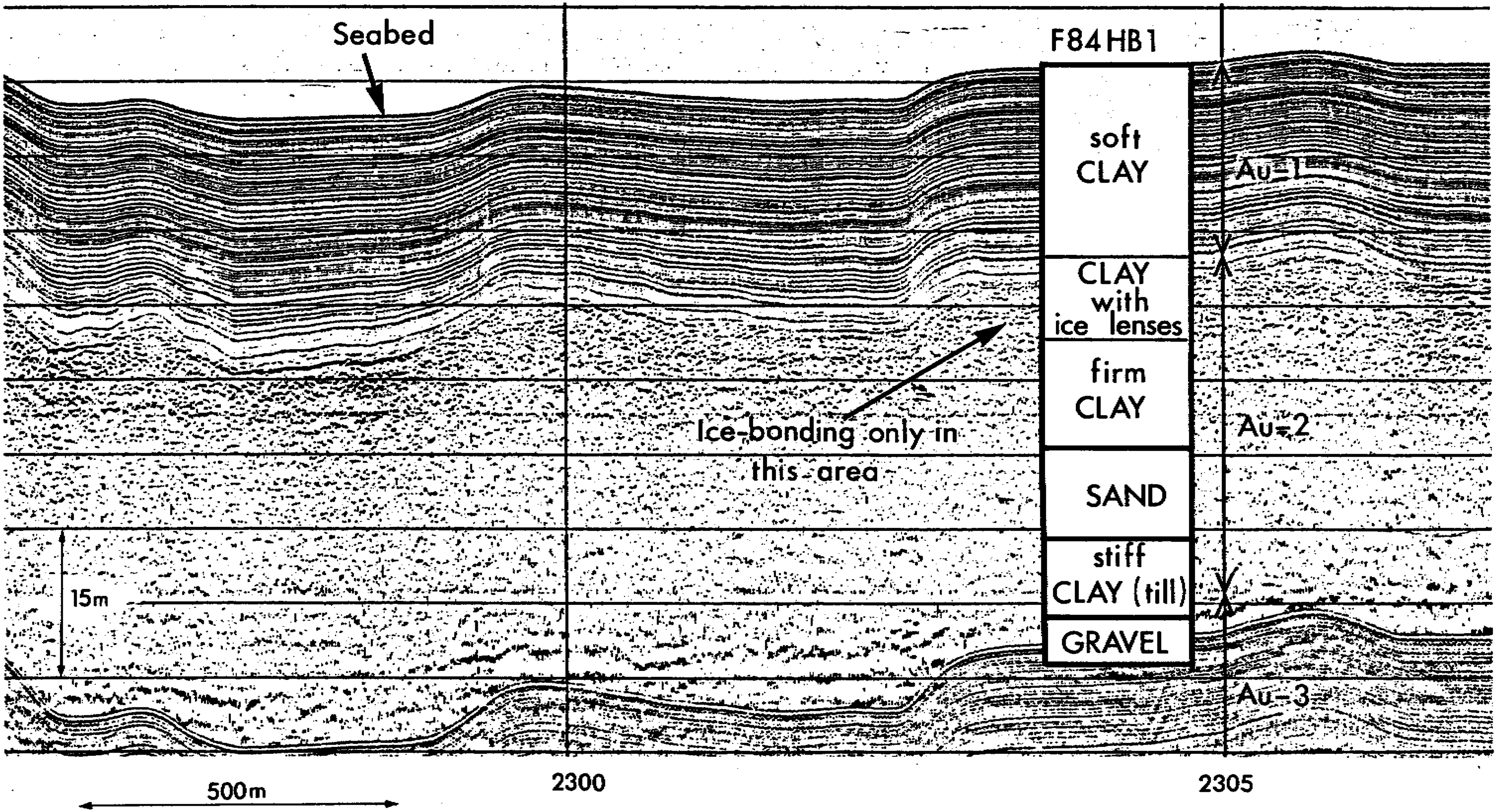
of the subsurface stratigraphy under the basin became apparent. Drawing No. 4.5 shows the borehole log for F84HB1 superimposed on a 1974 seismic section which runs near the location drilled. An exact tie to the seismic line is impossible, of course, because of poor positioning accuracy during acquisition of the 1974 data, but the proximity of the borehole location to the seismic line is apparent from the good correlation obtained between the two.

According to the borehole information, the upper stratum consists of a very soft to soft, thinly laminated, mostly high plastic silty clay, olive brown to brownish grey in colour and having a trace of organics, either as pockets or as thin laminae, and occasional shell fragments. At approximately 19 m beneath the seabed, the soil consistency became firm. From 20.7 m to 27.4 m clear to white cloudy ice lenses ranging from 25 mm to 200 mm thick were found associated with the clay and the observed soil strengths exceeded 50 kPa. From 27.4 to 38.5 m the observed soil strengths varied from 30 to 40 kPa and no ice-bonding of the strata was observed.

From 38.5 to 47.0 m the sediments consist of a dark olive grey uniform fine sand with a trace to some silt. Some interbedded clay layers were observed near the top of the stratum. No evidence of ice-bonding was noted during drilling.

Between 47.0 m and 55.4 m the soil was logged as a stiff to very stiff, dark grey clay and silt with a trace of gravel. The soil was dry to moist and exhibited low plasticity.

At 55.4 m the borehole encountered a grey silty sand and gravel stratum. Aggregate particles up to 35 mm in diameter were recovered, but drilling was halted at 57.9 m because of the suspected presence of cobbles. No ice-bonding was noted in samples recovered from either the



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Borehole Correlation with High Resolution Seismic

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JOB No.: 10-260	DATE: 85/07/22
DRAWN BY: MG	DWG. No.: 4.5

clay and silt stratum or the underlying gravel, although the sampling frequency was generally low and the recovered samples were often too disturbed to be necessarily representative of the in-situ temperature conditions.

Correlation of the borehole and seismic information suggests that the stratigraphy is probably more complicated than originally envisaged from the seismic information above. As suspected, surficial acoustic unit AU-1 is comprised of laminated soft, silty clays. The change in acoustic signature at approximately 20 m appears to be due to the presence of ice lensing within the soil. Independent observations made by the author during drilling suggests that laminae within the silty clay samples collected from 20 to 40 m bsb tended to be much more discontinuous than those observed in the shallower section. In addition, the laminae were not always horizontal, but often occurred at angles up to 15° or more.

The weakly discontinuous low frequency reflector previously interpreted as hummocky acoustic permafrost by O'Connor (1984) appears to represent the top of the upper sand unit on the borehole log. The signal penetration on the 1974 seismic records was insufficient to readily record the top of the lower clay unit, but the higher amplitude low frequency reflector representing the top of acoustic unit AU-3 correlates well with the top of the sandy gravel stratum which could not be penetrated during drilling.

Airgun records collected by the Geological Survey of Canada in 1985 from the M. V. Banksland Surveyor provide much better definition of the acoustic stratigraphy of the deeper strata under the basin than was available previously. Drawing No. 4.6 shows an airgun record from line F84-301, which crosses Herschel Basin in a southwest to northwest direction and passes almost directly through borehole F84-HB1. Major reflectors were found to correspond closely to each of the stratigraphic changes noted on the borehole log.

The sand and gravel stratum noted near the base of the borehole, for instance, may be correlated with a strong, mostly continuous reflector which dips to the northwest at about 0.6%. In the western part of Herschel Basin, where the seabed is relatively flat, the top of this stratum may be traced easily, but in the deeper part of the basin, where PLF's are more common, the occurrence of the sand and gravel reflector is difficult to follow.

Overlying the sand and gravel stratum in the borehole is a stiff clay which was originally logged as a till. It's glacial history was not, of course, determined during the present study, but the high consistencies measured in the recovered samples certainly suggest that some overconsolidation has occurred. According to the seismic record the stiff clay may be up to 16 m thick near the western basin edge, but is possibly thin or absent where the seamounds occur.

The seismic evidence suggests that, like the clay till, the silty sand stratum is not of uniform thickness throughout the basin, but varies from as little as 4 m to as much as 19 m in some places. As interpreted on Drawing No. 4.6, there is also evidence that the sand stratum may be traced under some of the PLF's, thereby indicating that they probably originate at shallow depth rather than deeper in the geological section.

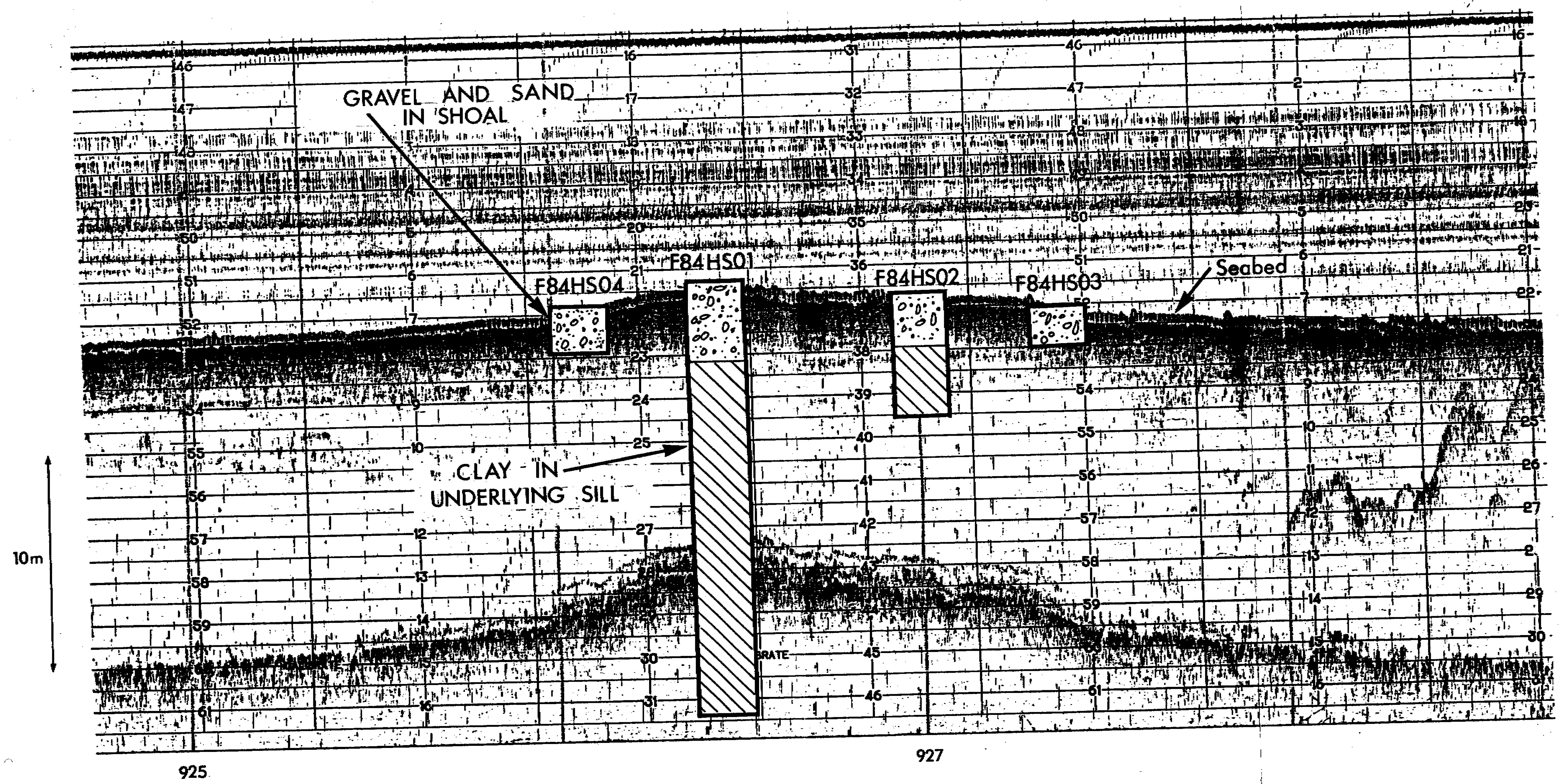
The airgun records also provide considerable information regarding the distribution and occurrence of the surficial clay unit in the basin. The base of the laminated sediments, which is also coincident with the top of observed ice lensing (APF) in the clay, can be easily traced from the edge of the basin northeastward through the borehole to the edge of the PLF's. It appears that the base of the ice-bonded clays can also be traced laterally for some distance, making this one of the few examples where both the top and the bottom of an acoustic permafrost layer have both been visible on the same shallow seismic record. According to the seismic evidence, this ice-bonded clay layer is probably not present continuously under the basin, but thins and then terminates abruptly where the PLF's occur. Although the airgun records can hardly be considered definitive, there is also evidence that the discontinuously laminated clay stratum which underlies the ice-bonded layer may also terminate near the edge of the seamounds.

Except for those reflectors which underlie the small PLF at Fix 56, there is little seismic evidence regarding the nature of the core of these features. This originally led to speculation that they may be glacial in origin, and perhaps might be comprised of granular materials, but the geotechnical borehole F84HB2 drilled into the crest of the seamound at N7711770 E350500 (Drawing No. 4.7) provided quite different evidence. According to the borehole log the seafloor sediments at this location consist of 7.8 m of bioturbated, homogeneous, high plastic silty clay. The sediments varied from dark olive grey to very dark grey in colour and contained a trace of organics. Shear strengths immediately beneath the seabed were less than 5 kPa, but increased almost linearily with depth to about 25 kPa at 7.7 m.

Drawing No. 4.8 shows an ORE record obtained across the sill south of Collinson Head. The interpreted stratigraphic conditions are shown on the same drawing. The deepest unit which can be resolved on the sill consists of firm to stiff (becoming very hard at depth) dark grey to black silty clay. Boreholes drilled on the sill by Gulf Canada in 1982 and by DIAND in 1984 suggest that the detailed geotechnical properties of the clay may vary from place to place, but the general stratigraphy appears to be uniform. The clay is characterized by low to high plasticity, a trace to some organics, and continuous, even, parallel laminations which are commonly horizontal or exhibit only slight dips (up to 10°). Ice-bonding has been noted in boreholes on the sill at depths of 8 m or more beneath the seabed, usually occurring as ice lenses a few millimetres thick. Evidence of widespread ice-bonding in the clay is also available from the shallow seismic information, which indicates that hummocky acoustic permafrost (APF) is sometimes present as little as 3 m beneath the seafloor on the seaward side of the sill.

The crest of the sill immediately south of Collinson Head is characterized by a sand and gravel shoal containing subrounded to subangular particles having a maximum diameter well in excess of 100 mm (see Plate No. 2.2). The thickness of the granular deposit was measured to be 3.4 m in borehole F84HS1, the single location tested along the crest of the shoal. According to the probehole data, thinner values may be expected along the flanks (Drawing No. 4.9).

Basinward of the shoal, the underlying stiff silty clay sequence is mantled by a recent soft clay sequence which varies in thickness from 3 to about 8 m. Acoustically, this sequence appears to be thinly laminated, similar to the surficial sediments which now occupy the



100m

IHR 845

Stratigraphy of the Shoal South of Collinson Head

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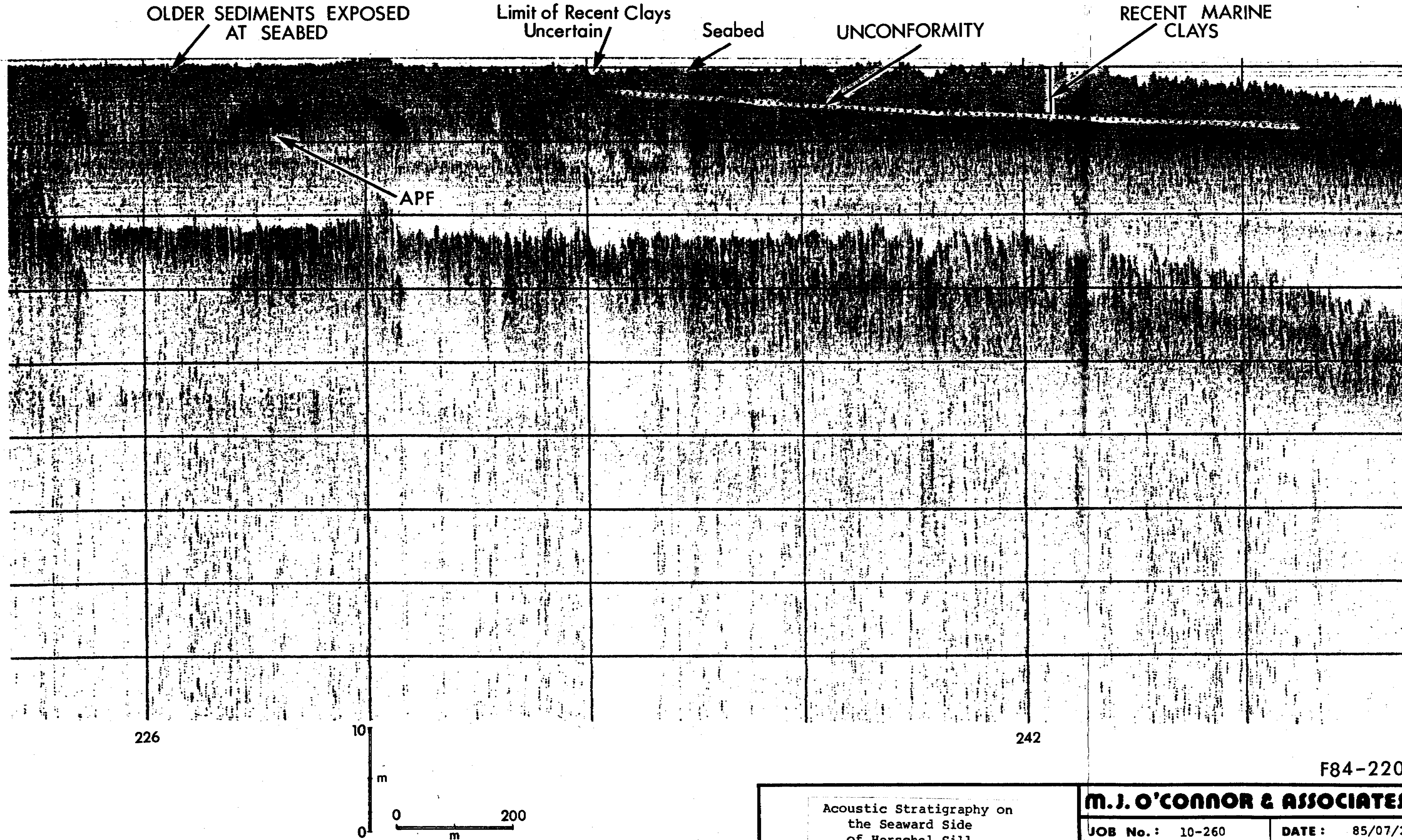
JOB No.:	10-260	DATE:	85/07/22
DRAWN BY:	MG	DWG. No.:	4.9

bottom of Herschel Basin. The granular sediments appear to be stratigraphically equivalent to these soft clays, the boundary being somewhat transitional, as shown on Drawing No. 4.8.

Immediately south of Collinson Head a few metres of recent soft silty clay may also be found on the seaward side of the shoal, sometimes covering the flanks of the granular deposit. Southeastward towards the deepest part of the shoal, however, this recent clay sequence thins significantly, often leaving the older clay sequence exposed at or near the seafloor. Since the granular materials which comprise the shoal and the older clay sequence both have a relatively high reflectivity, the exact seaward limit of the granular materials which comprise the shoal is very difficult to define using shallow seismic techniques. Further east, near the edge of the Mackenzie Trough, Drawing No. 4.10 demonstrates that the thick recent marine sequence which characterizes the Trough can be seen on-lapping the sill, but the precise edge of this sequence is difficult to discern from the acoustic data. For clarity, the position of the unconformity has been enhanced on the seismic section shown on the drawing.

The gravel shoal appears to be absent along the deepest part of the sill crest, but is very extensive in the area northwest of Kay Point, where it can be easily observed on the bathymetric records. The anastomosing crest of the sill trends in a generally southeastward direction towards Kay Point, reaching to within 2 or 3 m of the sea surface in certain areas, accompanied by an increase in the thickness of granular materials to perhaps 7 m or more (Drawing No. 4.11). While the crest itself is relatively narrow, boreholes, surface samples and test dredging results indicate that the granular deposits are much wider here than at the north end near Collinson Head. Shallow water



F84-220

Acoustic Stratigraphy on the Seaward Side of Herschel Sill

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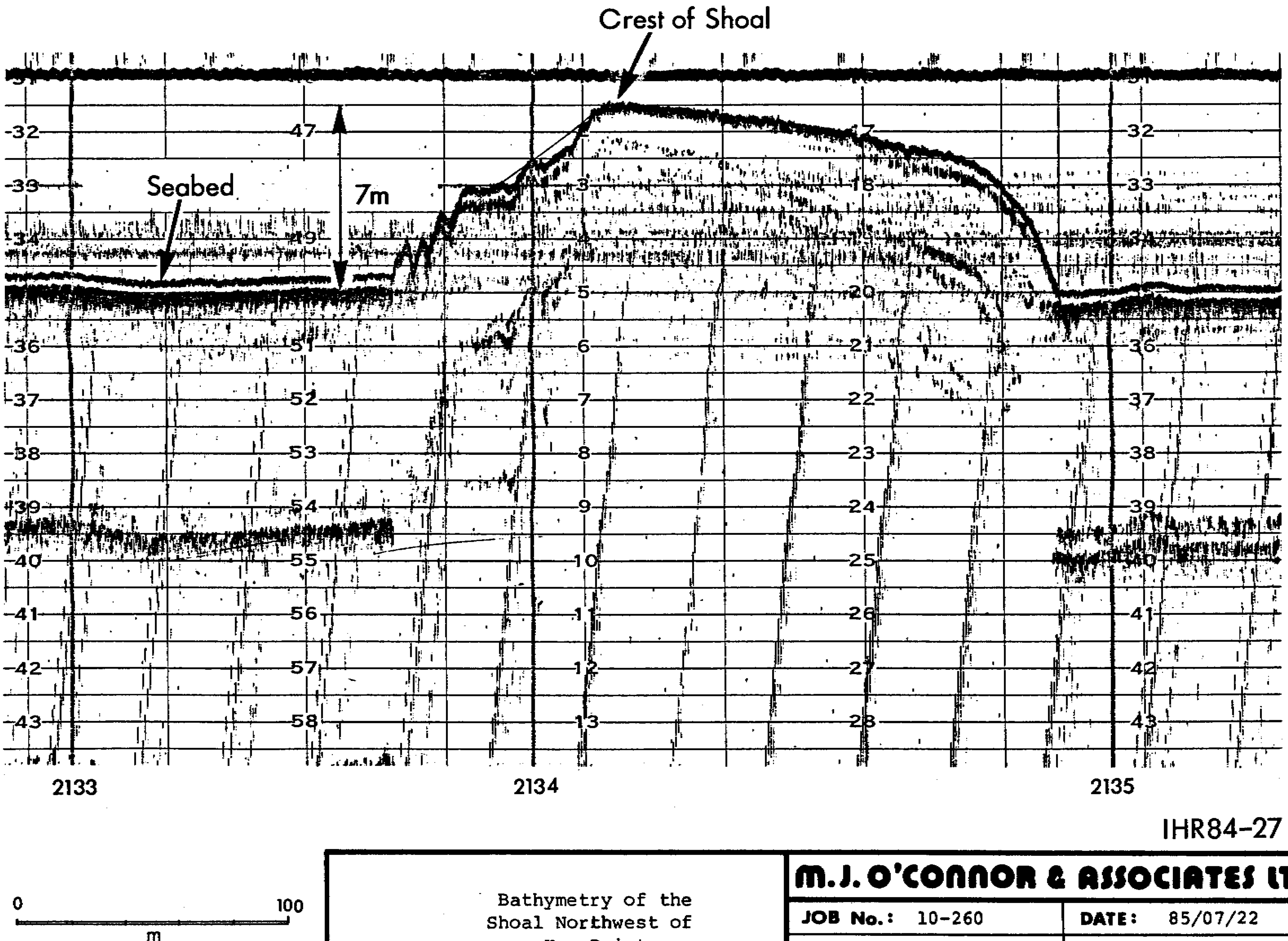
DRAWN BY: MG	DWG. No.: 4.10



IHR84-27

Bathymetry of the Shoal Northwest of Kay Point

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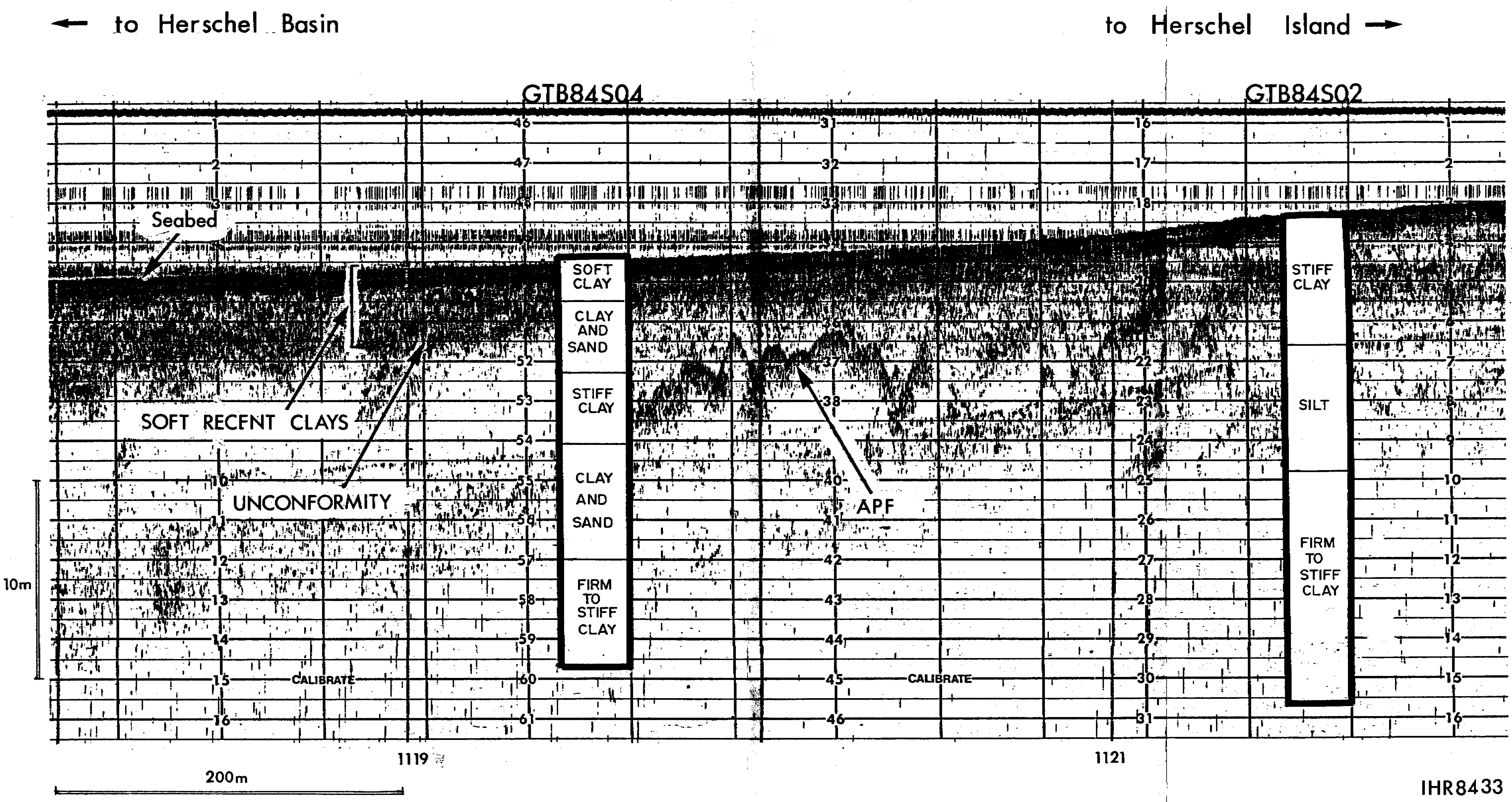
DRAWN BY: MG	DWG. No.: 4.11

depths and the incursion of ice into the south part of the study area prevented seismic profiling or drilling in the immediate vicinity of Kay Point, so the exact nature and extent of the subsurface stratigraphy remains uncertain. Geologic considerations suggest, however, that the sequence of gravel/sand overlying a stiff clay probably continues southward to Kay Point, although the surficial granular deposits may not necessarily extend westward to the Babbage River paleochannel.

Discontinuous hyperbolic reflectors noted close to the seabed in this area are thought to be due to ice-bonding, rather than gravel deposits, but the exact nature of the subseabottom conditions cannot be reliably determined without further extensive drilling.

4.3 Yukon Coastal Shelf

Like the sill, stratigraphy of the narrow coastal shelf which borders the north and west sides of Herschel Basin is difficult to resolve acoustically because the signal penetration into the older sediments which comprise the shelf is usually poor. Drawing No. 4.12 shows an echo sounder record near Thetis Bay, along the south shore of Herschel Island. The record shows a surficial wedge of recent soft sediments which rest unconformably on an older unit and thicken in a southward direction into the basin. They appear to be thin or entirely absent north of Fix 1121. These soft sediments are comprised primarily of silt (48% to 67%) and clay (28% to 51%) sized particles with trace (1% to 5%) amounts of sand. According to laboratory tests, the surficial sediments exhibit an intermediate plasticity, even though the measured silt contents are relatively high.



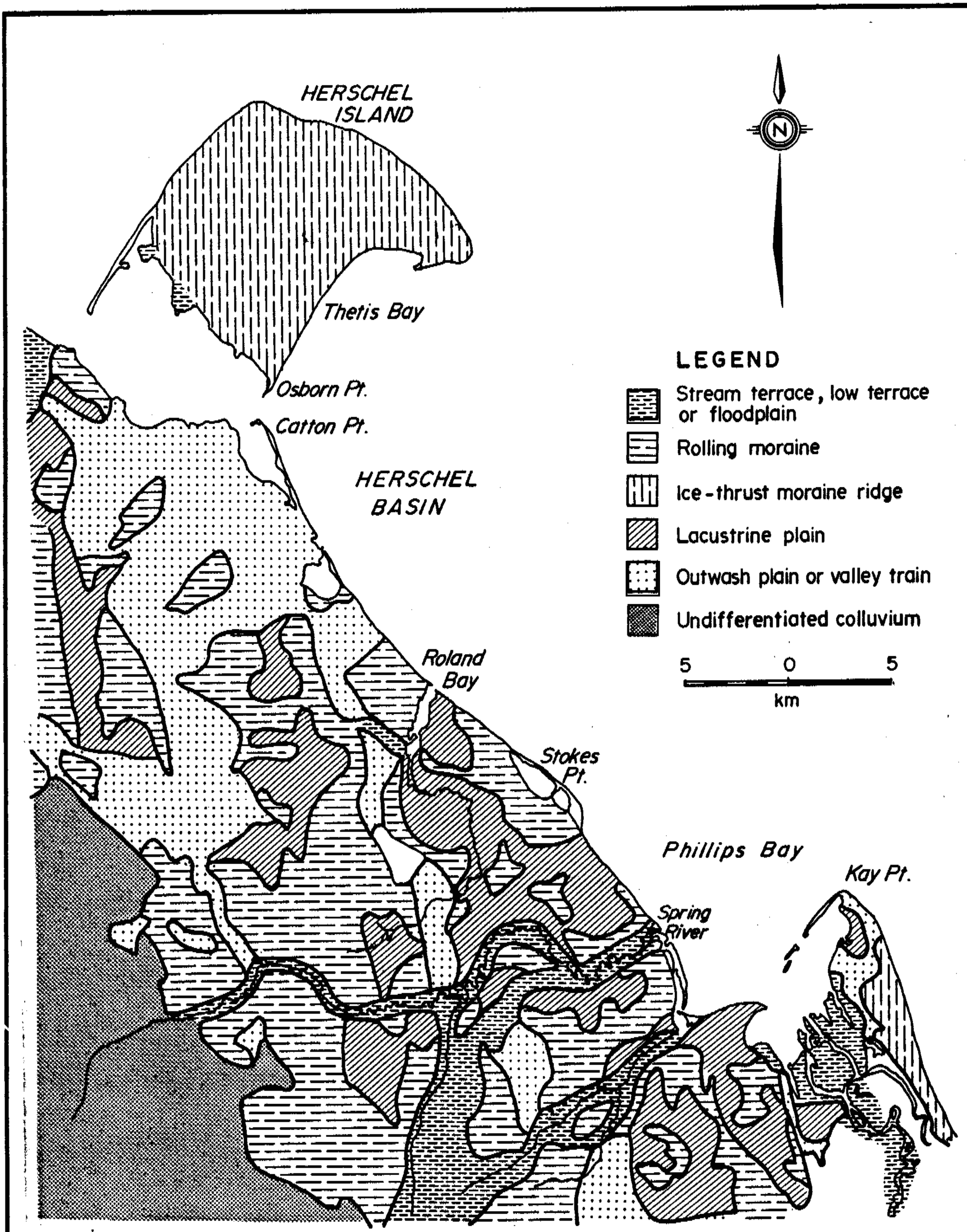
Borehole Data Courtesy Gulf Canada Resources Inc.

Acoustic Stratigraphy of the Coastal Shelf Near Thetis Bay	**M.J. O'CONNOR & ASSOCIATES LTD.**	
	JOB No.: 10-260	**DATE:** 85/06/27
	DRAWN BY: MG	**DWG. No.:** 4.12

Borehole information near the seismic line suggests that the pre-unconformity strata are mainly fine grained, but some interbedding of clays and sands may be expected. Materials encountered in these boreholes are believed to be representative of the ice thrust moraine which constitutes Herschel Island. Hummocky reflectors which occur as shallow as 4 m beneath the seabed are probably due to local ice-bonding, but frozen (Nbn) sediments were noted in the adjacent boreholes only at much deeper depths.

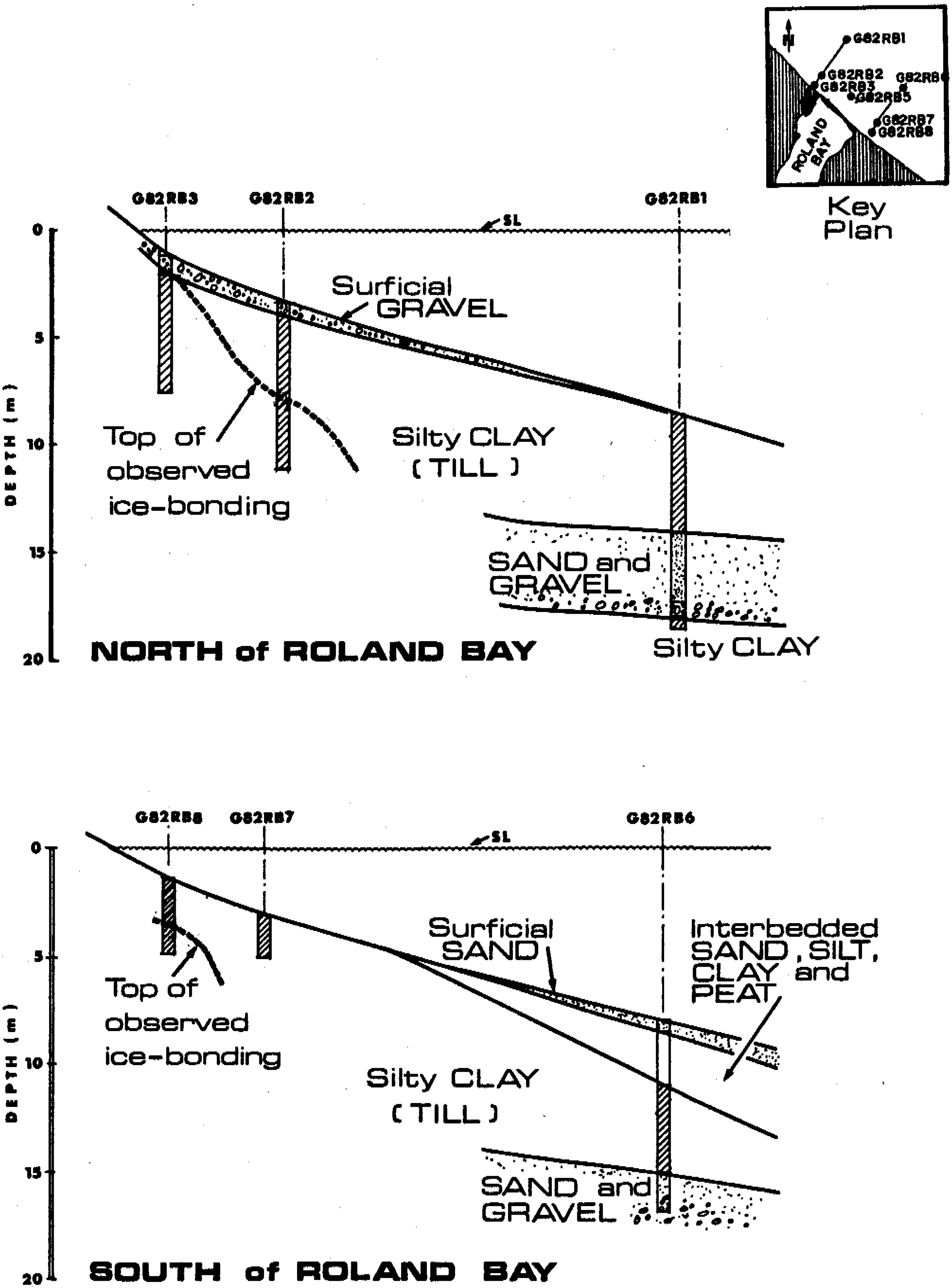
Between Thetis Bay and Roland Bay no geotechnical boreholes have been drilled on the coastal shelf. Indirect evidence of the surficial geology underlying the shelf is available from Rampton (1982), who suggests that the coastal sediments in this area are primarily of glaciofluvial origin (outwash plains and valley trains), and consist of poorly sorted, pebbly to cobbly gravels with some sandy layers, similar to the material which presently comprises the spit at Catton Point (Drawing No. 4.13). High resolution shallow seismic records do not provide such detailed information regarding the subsurface stratigraphy. The acoustic data do confirm, however, that recent soft sediments are not generally present at the seafloor on the shelf, except at distances of several kilometres or more away from the present coastline (Drawing No. D.6).

Rampton (1982) suggests that the Yukon coast immediately north of Roland Bay is comprised of morainic deposits, but that the south side of the Bay is lacustrine plain. According to geotechnical information acquired by Hardy Associates (1978) Ltd. for Gulf Canada Resources in 1982 and 1983, the morainic deposits extend offshore under the coastal shelf as well. As Drawing No. 4.14 demonstrates, boreholes drilled north of the Bay were found to contain frozen silty clay (till)



Surficial Geology of the
Yukon Coastal Plain
(after Rampton, 1982)

M.J. O'CONNOR & ASSOCIATES LTD.	
JOB No.: 10-260	DATE: 85/03/01
DRAWN BY: MG	DWG. No.: 4.13

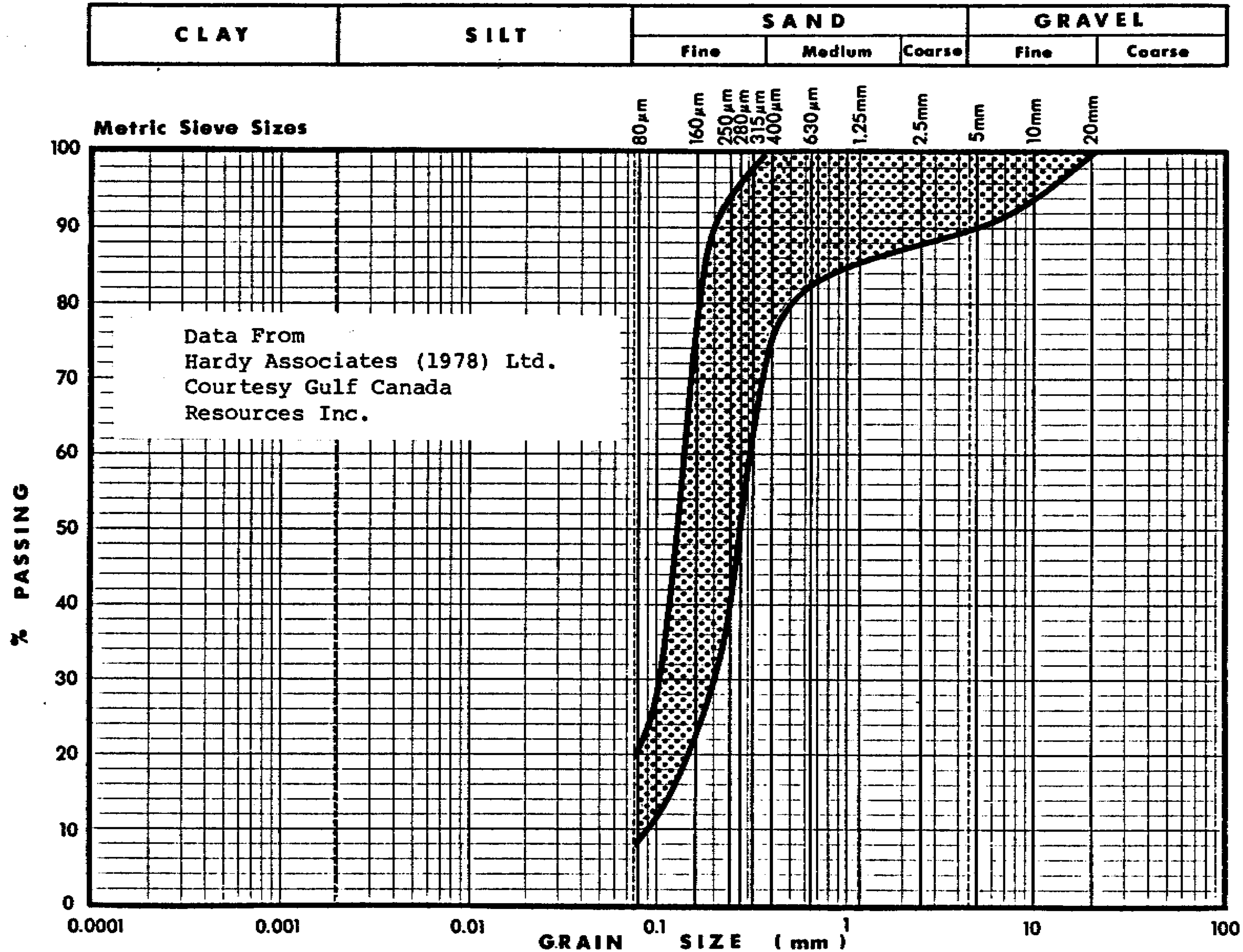


Simplified Cross-Sections near Roland Bay	M.J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/02/06
	DRAWN BY: MG	DWG. No.: 4.14

sequences at relatively shallow depths beneath a surficial sandy gravel stratum. The till was classified as medium plastic, grey, firm to stiff (in the unfrozen state), and contained occasional organics. Where the sediments were found to be ice-bonded, ice crystals, veins and lenses were common (V_x, V_r, V_s to 10%, some N_{bn}). These ice contents are slightly lower than those which are normally encountered in morainic deposits along the coast, but more massive icy sediments may be expected at depth.

South of Roland Bay the frozen till was also present close to the shoreline, but the interbedded peat, sands, silts, and clays which occur in the offshore borehole B82RB6 are more characteristic of lacustrine deposits of thermokarst origin, as mapped by Rampton (1982) along the coast. The stiff silty clay which underlies the lacustrine deposits is probably the same till material which occurs north of the Bay, although it has not been recorded as such on the borehole logs.

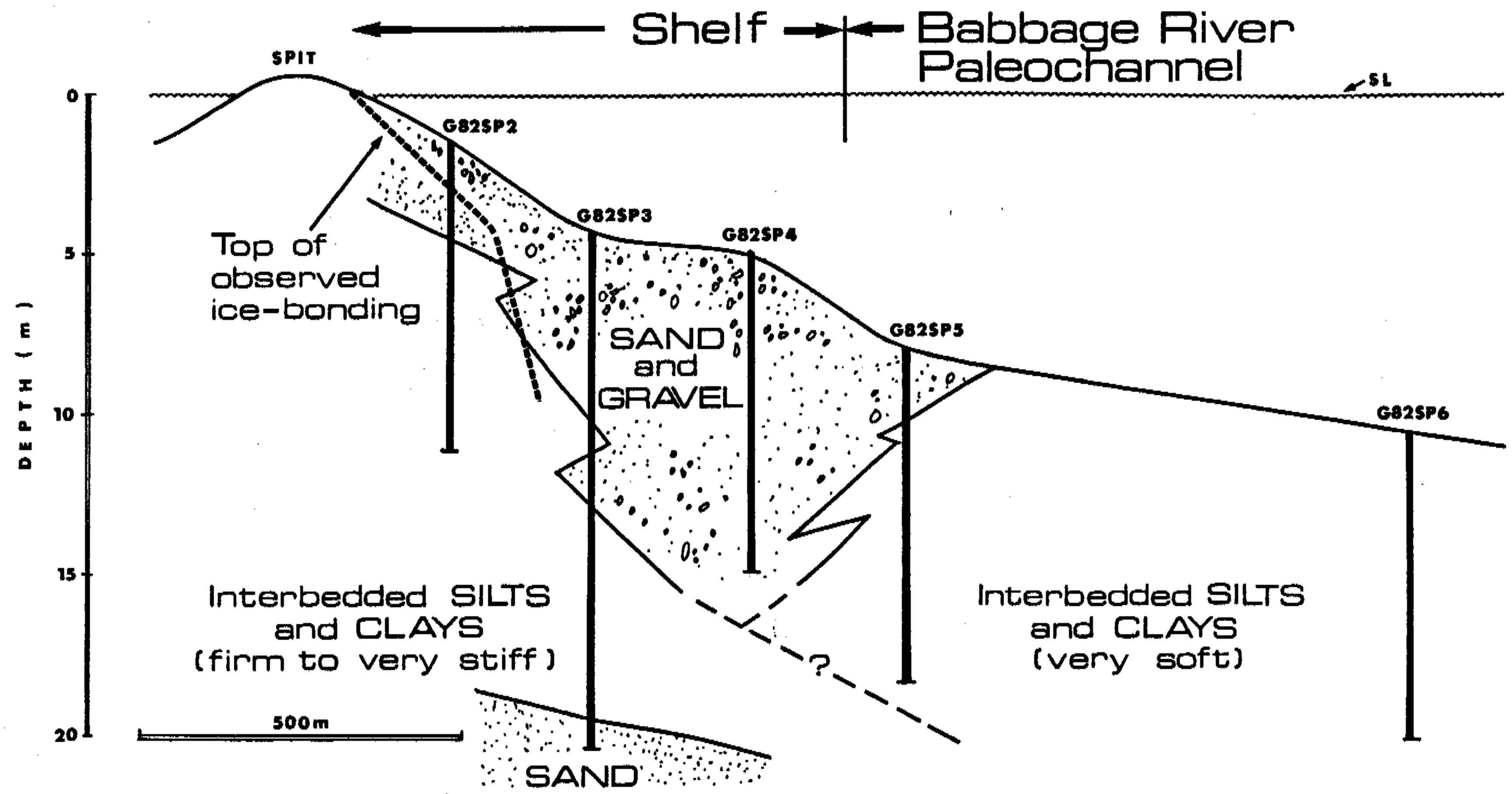
A total of 8 cone pushes and 24 boreholes were drilled at Stokes Point during Gulf's 1982/83 programme to assess the suitability of the site as a future marine base. The boreholes demonstrated that this area of the shelf is underlain by somewhat more complicated stratigraphy than is found further north along the coast, and includes extensive deposits of granular material. The material consists of uniform fine sand with a trace to some fines, extending from the seabed to at least 12 m beneath the seabed. Gravel size material was present in some samples (Drawing No. 4.15), as were thin layers of compact silt. The sand appears to be in a loose to dense condition and generally exhibits ice-bonding only near the shoreline. As Drawing No. 4.16 demonstrates, the rather complicated subseabottom stratigraphy may be simplified into 3 geologic units:



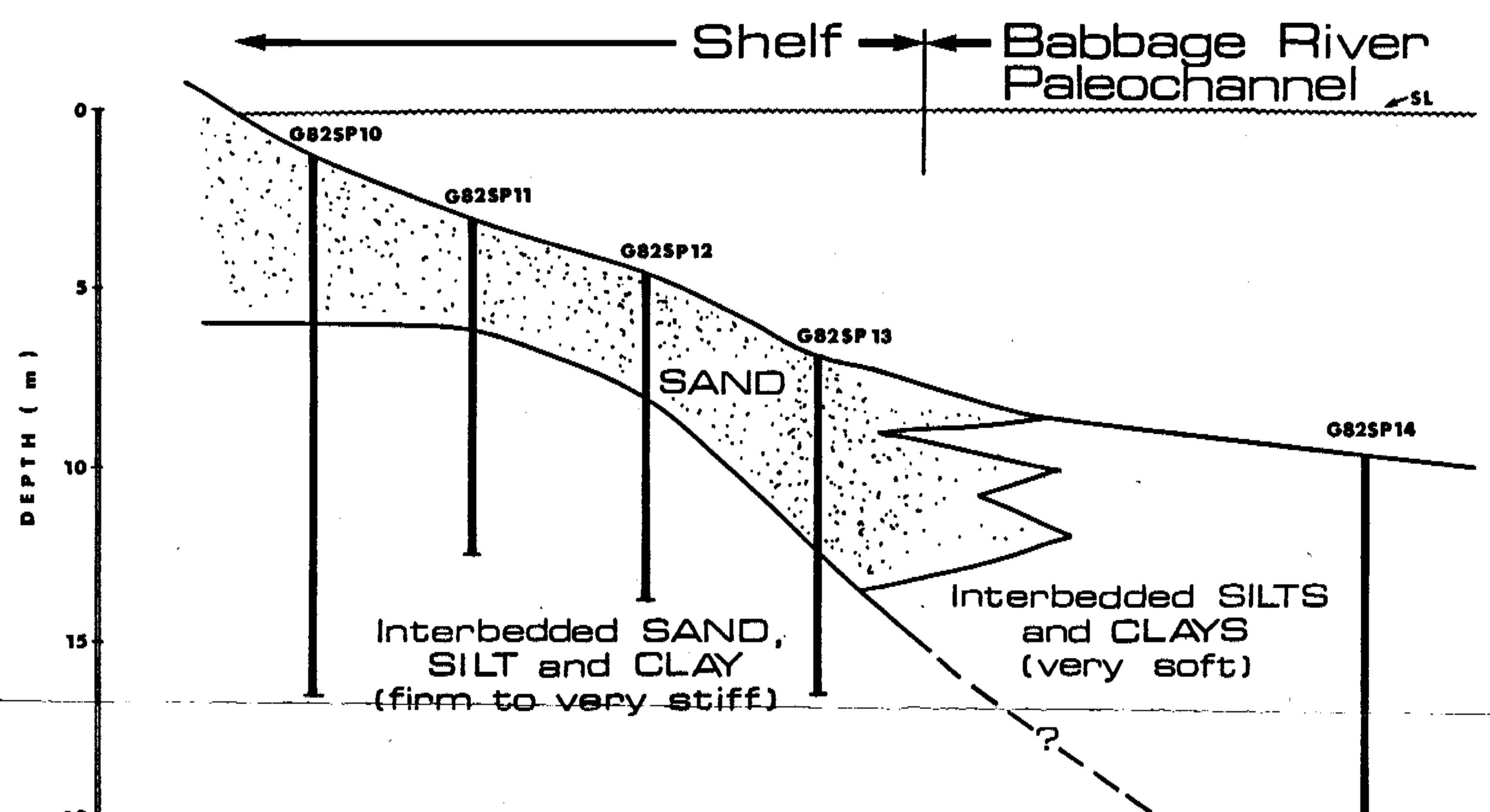
Gradation Range of Potential
Borrow Material Near
Stokes Point

M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.:	10-260	**DATE:**	85/07/22
DRAWN BY:		**DWG. No.:**	4.15



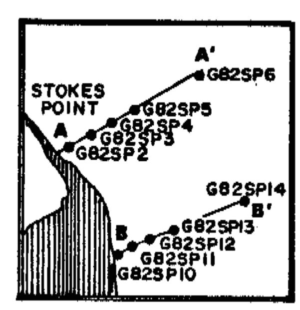
CROSS-SECTION A – A'



CROSS-SECTION B – B'

500m

Key Plan



Simplified Geologic Cross-Sections
Near Stokes Point

M.J. O'CONNOR & ASSOCIATES LTD.

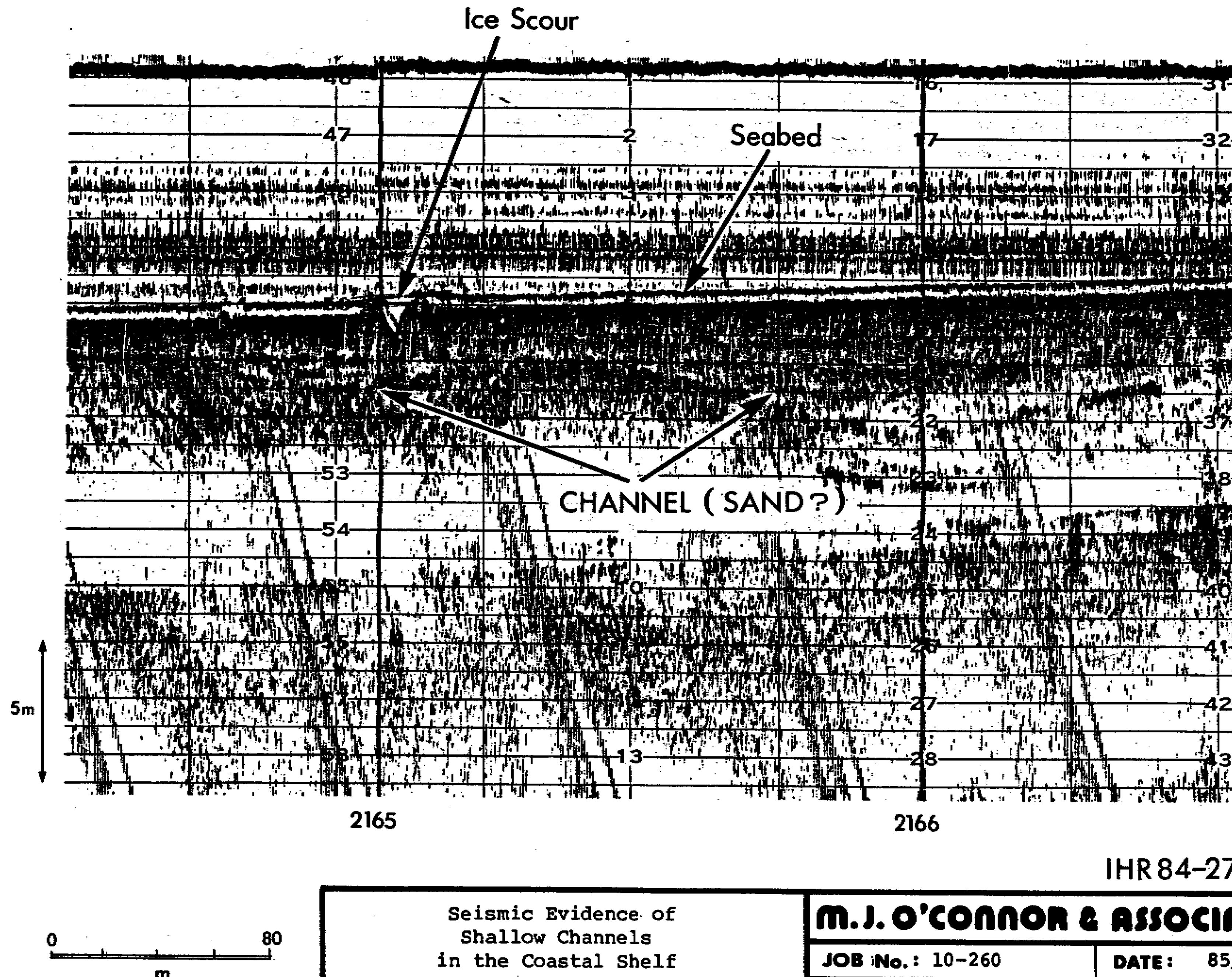
SCALE:	DATE:	JOB No.:	DWG. No.:
as shown	85/02/07	10-260	4.16

In the nearshore zone a sequence of interbedded sands, silts and clays occur at depth. Their firm to very stiff consistency distinguishes them as part of the morainic sequence mapped by Rampton (1982) onshore.

This unit is overlain by the surficial sand and gravel unit. The origin of the deposit is presently the subject of some discussion (Harper, 1984, pers. comm.). From the bathymetric data it appears that the upper surface of the deposit at one time formed a beach ridge along the west side of the Babbage River paleochannel. The borehole data suggest, however, that the sand has a distinctly channel-like cross-section, the total length and depth of which have not yet been determined. Orientation of the channel appears to be north-northwest, at an angle of 30° to 40° from the coastline, suggesting perhaps some relationship with the drowned reaches of the Spring River to the southeast. The 1984 seismic records collected near Stokes Point also show some evidence of channel stratigraphy in approximately the same direction on the shelf (Drawing No. 4.17), but it is unclear whether such channels are actually connected to the Spring River, or whether they are related to the former Babbage River system.

As the geologic cross-sections shown in Drawing No. 4.16 demonstrate, both the firm to stiff till and the sand deposit are limited in extent to the shelf zone. Gulf boreholes drilled into the adjacent Babbage River paleochannel encountered only a thick sequence of interbedded very soft silts and clays, the total depth of which was not determined during the programme.

Extrapolation of Rampton's (1982) data suggests that deposits of mostly morainic and lacustrine materials may be expected to occur southeast of



IHR 84-27

Seismic Evidence of
Shallow Channels
in the Coastal Shelf

M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.: 10-260	**DATE:** 85/07/22
DRAWN BY: MG	**DWG. No.:** 4.17

Stokes Point along the coastline. Coarser material may also be present, especially near the mouth of the Spring River.

4.4 Babbage River Paleochannel

The drowned reach of the Babbage River channel extends northwest from Phillips Bay, becoming progressively wider as it enters into Herschel Basin east of Roland Bay. It appears to be occupied, for the most part, by a relatively thick sequence of very soft, fine grained sediments. According to Gulf boreholes G82SP-6 and G82SP-14, these are principally dark grey silty clays with a trace of fine sand and local organics. Plasticity varies from medium to high. Unlike the laminated surficial sediments of the basin, these clays have been described as structureless, although interbedded sequences of black organic clay (up to 9% organics) and clayey silts are also common. Undrained shear strengths in these sediments usually vary between 5 and 20 kPa, with some slightly higher consistencies (up to 30 kPa) being recorded at depth. Moisture contents on the samples tested were equal to or greater than the liquid limit of the soils, resulting in liquidity indices varying from 1.0 to as high as 4.67 in the organic rich material. Bulk densities ranged from 1712 kg/m^3 to 1922 kg/m^3, with values in the lower range being by far the most common. Computed dry densities were generally close to 1150 kg/m^3, but one sample of peaty clay exhibited a dry density of only 875 kg/m^3.

The nature of the surficial sediments which occupy the paleochannel can be deduced not only from the geotechnical information described above, but also from the shallow seismic information. According to ORE records collected near the mouth of the paleochannel where it previously entered Herschel Basin, the seabed is underlain by a highly complex sequence of folded, laminated sediments, intruded from below by diapiric structures 100 to 200 m in diameter (Drawing No. 4.18). Many of these diapirs are internally structureless or acoustically opaque, but some also exhibit weak evidence of internal collapse structures (see, for example, Fix 1537.5). The laminated sediments which immediately overlie the diapirs are generally conformable with the intrusive structures. Their very soft consistency is apparent from the good signal penetration which can be noted at some locations, indicating that the strata may be more than 20 m thick in certain places.

Unlike the submarine pingos which occur on the floor of Herschel Basin, there is little bathymetric expression of the underlying diapiric structures. Instead, many of these features appear to have been planed off at the seafloor, suggesting that the seabottom environment is presently erosional rather than depositional. This erosion may be limited to certain water depths, however, as there is evidence from the echo sounder record shown in Drawing No. 4.19 that horizontally laminated strata have recently been deposited unconformably on deformed strata along the western edge of the paleochannel, where the water depths exceed 18 m (see Fix 1917.5). Only a short distance away in slightly shallower water depths, folded sediments have clearly been eroded at the seafloor (see Fix 1914.5). This latter location is also one of the few instances where some internal structural elements of the diapir itself may be visible on the high resolution records.

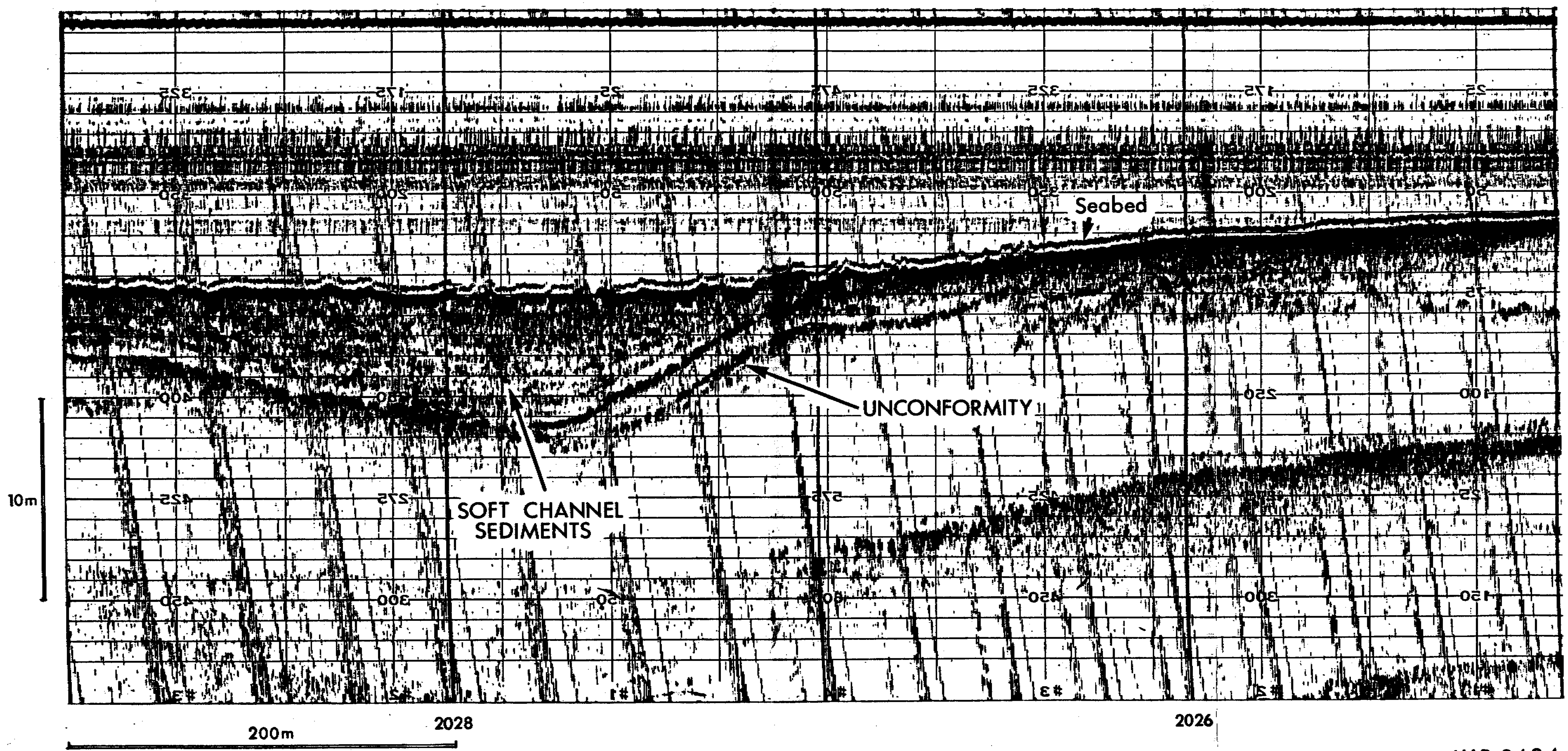
As Drawing No. 4.20 shows, the eastern margin of the paleochannel is sharply defined on the echo sounder records, especially in the deeper reaches. According to other data, however, some shifting of the channel may have occurred with time, as soft surficial sediments appear to underlie the seabed between Fix 1969 and 1965 (Drawing No. 4.21).

The western edge of the paleochannel is clearly visible in deep water (Drawing No. 4.19), but becomes progressively less distinct towards Phillips Bay. In Drawing No. 4.22, for instance, the margin occurs between Fixes 1946 and 1947, but it is not marked by a strong reflector. Near Stokes Point, the boundary between the shelf and the paleochannel is almost impossible to discern on the acoustic records, and hence is best located on the basis of the drill hole information.

As noted previously, the diapiric structures which underlie the deep water parts of the paleochannel have been eroded down to the seabed. In shallow water many of these diapirs penetrate the seafloor, forming isolated features which are clearly evident on detailed bathymetric and sub-bottom records (Drawing No. 4.18). They vary in size from about 20 m in diameter (Drawing No. 4.23) to 200 m in diameter (Drawing No. 4.24) and seem to be preferentially located near the eastern margin of the paleochannel. Some appear to be associated with adjacent areas of seafloor collapse. Modern sedimentation has only partially infilled these collapse areas and hence the features are believed to be very recent in origin.

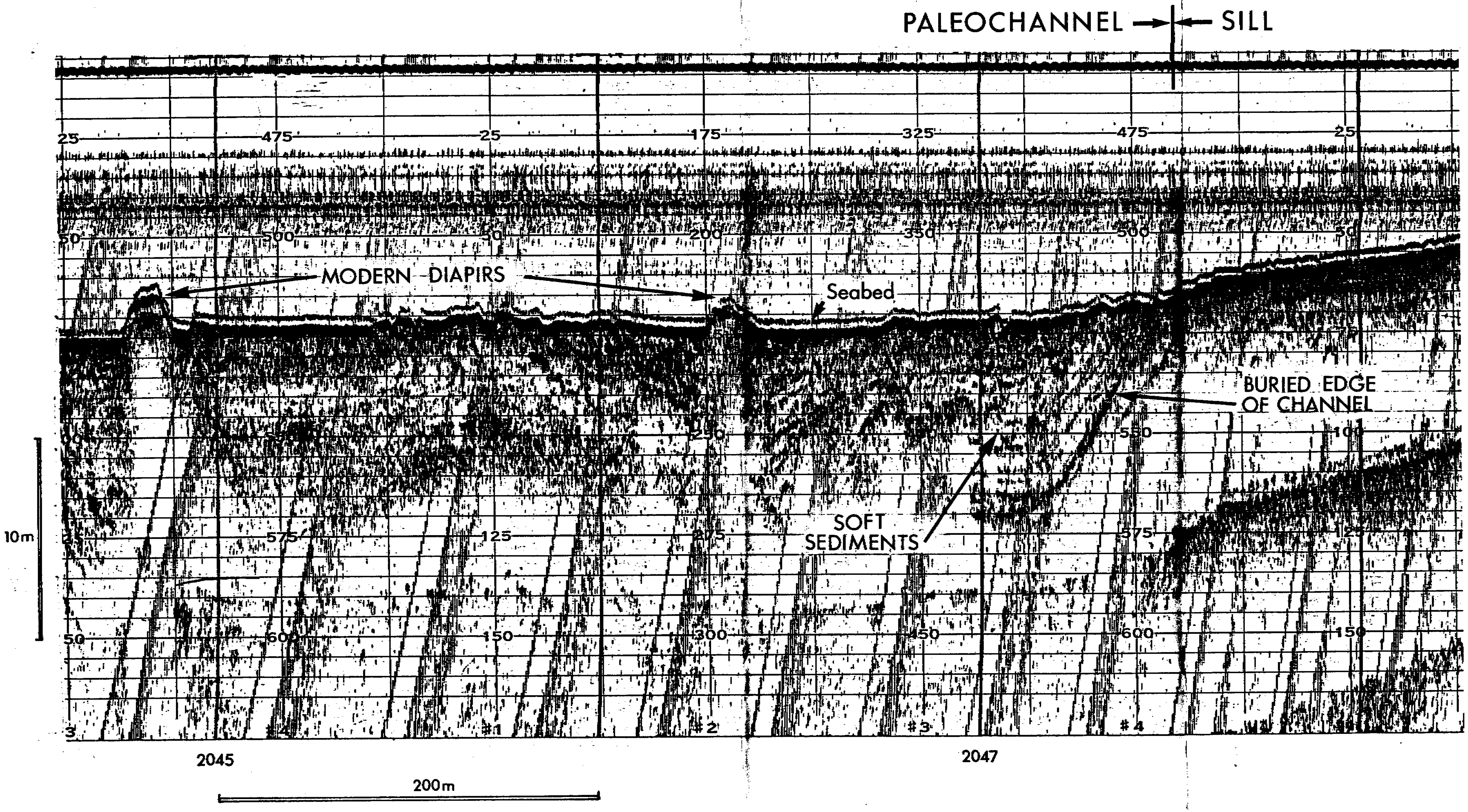
One of these features was profiled several times in order to provide a more detailed understanding of its morphology. The east to west profile through Fix 2151 shown in Drawing No. D.7 suggests that the

BABBAGE RIVER PALEOCHANNEL →|← HERSCHEL SILL



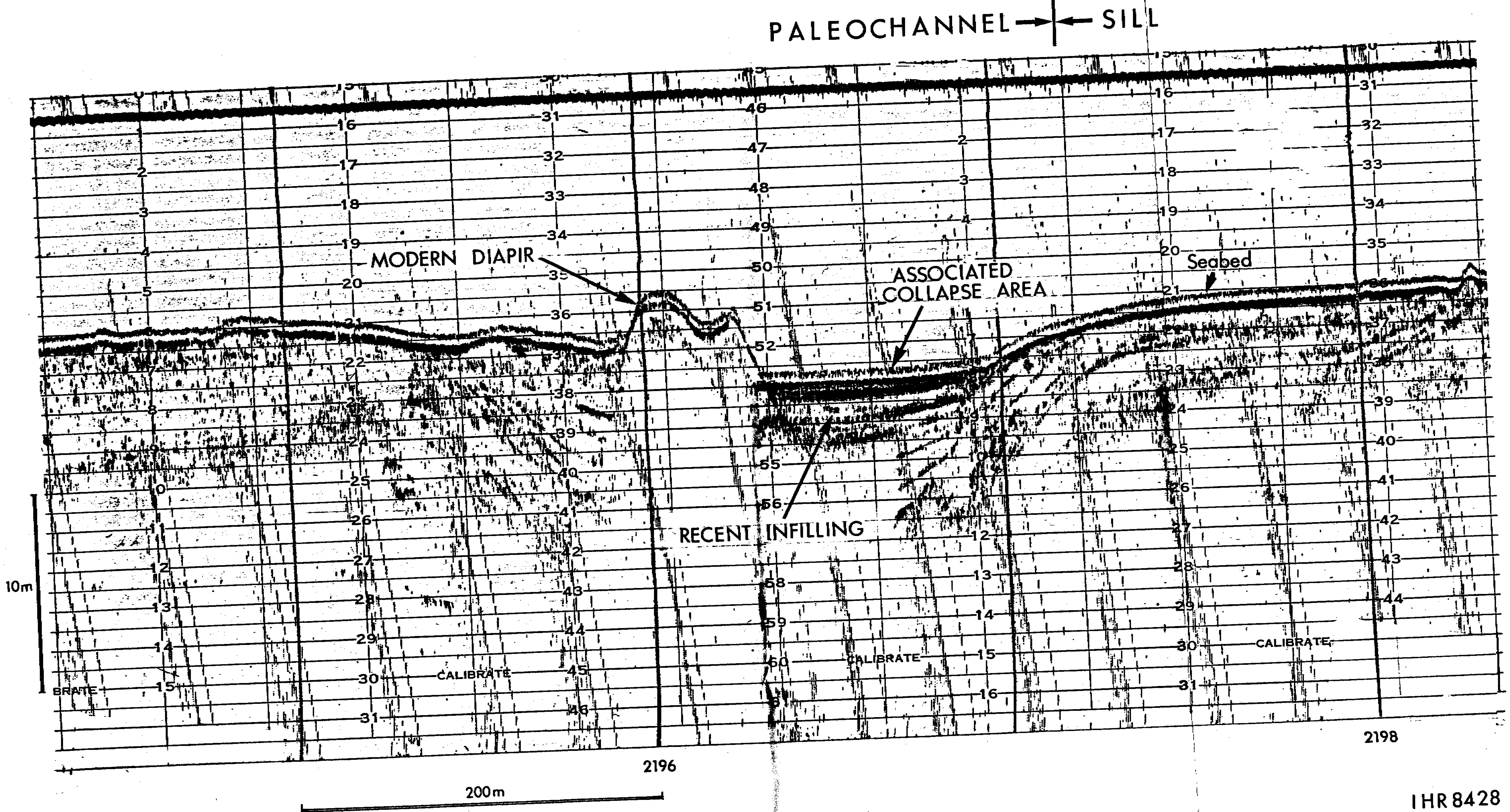
IHR 8424

Eastern Margin of the Babbage River Paleochannel	M.J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/01/21
	DRAWN BY: MG	DWG. No.: 4.20



IHR 8425

Small Modern Diapirs Near the East Edge of the Babbage River Paleochannel	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/02/21
	DRAWN BY: MG	DWG. No.: 4.23



Modern Diapir and Associated Area of Collapse Near East Edge of Babbage River Paleochannel

M.J. O'CONNOR & ASSOCIATES LTD.	
JOB No.: 10-260	DATE: 85/03/21
DRAWN BY: MG	DWG. No.: 4.24

structure is a rather complex one and like the diapir in Drawing No. 4.24, consists of both positive and negative elements. The top of the diapir stands approximately 3 m above the surrounding seabed. The crest appears to be very rough, but the flanks are generally smooth. Structure in the core of the diapir is not evident, as the feature is acoustically opaque. The small depression immediately adjacent to the diapir shows no evidence of recent sedimentation, but the larger area near Fix 2152.4 appears to have been infilled to within 1 or 2 m of the original seafloor with very soft stratified sediments. The acoustic stratigraphy within the collapse feature suggests that the collapse was a progressive, rather than a catastrophic, event. It is speculated that formation of the diapir was probably accomplished in a similar time frame.

Other seismic profiles obtained near the diapir do not all exhibit the same features. One of the north-south profiles, for instance, contained only positive elements (see Fix 2192) but the adjacent strata digs into (towards) the core of the diapir. An adjacent parallel profile run only 150 m to the east exhibited a major depression in the seafloor collapse more than 7 m deep at Fix 1628 on both the echo sounder and side scan sonar* records. Since little or no sedimentation is evident at the base of the collapse feature, it is presumed to be even more recent in origin than those discussed previously. According to the side scan record, the roughness observed near the crest of the diapir is likely due, at least partially, to ice scour effects, but some other more circular features are also evident. The origin of these circular features is uncertain. They may be gas or water vents associated with the formation of the diapir.

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* only one channel of the side scan sonar record is shown here

The profiles demonstrate clearly that these seabed diapirs have a relatively complex morphology. They appear to be modern in origin and are probably dynamic in nature. The rates of growth and collapse are unknown at present, but could probably be determined by repetitive surveying.

As far as the present author is aware, recent diapirism of this type is unreported elsewhere along the Arctic coast, although such features are certainly well documented along the edge of the continental shelf (O'Connor, 1981, Pelletier, 1979) and along the geologic discontinuity which forms the eastern edge of the Mackenzie Trough (O'Connor, 1980, 1984). Similar features have also been reported in the modern Mississippi Delta. The Phillips Bay diapirs have not yet been drilled, so any discussion of their origin is somewhat speculative, but it postulated that they may have formed as a result of rapid sedimentation and the subsequent development of high pore water pressures in the diapir channel strata. The diapirs are therefore probably comprised of low strength layers, buried by more recent sedimentation and then squeezed to the surface by the weight of the overlying strata. The discovery of collapse features raises the possibility that shallow gas may also be a contributing or driving mechanism for the process.

5.0 GRANULAR RESOURCES IN THE STUDY AREA

5.1 General

Prior to the present study the granular resource potential of the Herschel Basin and its environs had been examined only in a cursory fashion (O'Connor, 1983). Emphasis at that time had been on assessing the quantity and quality of sand and gravel on the sill, and hence little attention was focussed on potential deposits in other submarine areas within and adjacent to the Basin.

During the present investigation, however, the potential for development of submarine granular resources near Herschel Island was approached in a more rigorous manner. As a consequence, each of the physiographic subregions which constitutes the Basin area was examined separately, and the evaluation of granular resource potential was made on several grounds, as described below:

PROVEN RESOURCES:

These are granular resources whose distribution, thickness, or occurrence is supported by groundtruth information such as test dredging, surface sampling, ocean bottom photography and/or geotechnical drilling.

PROBABLE RESOURCES:

These are sand or gravel deposits whose existence has been inferred on the basis of several different types of indirect evidence, including: side scan sonar data, shallow seismic information, bathymetric data, surficial or coastal dynamics considerations.

PROSPECTIVE RESOURCES:

Granular resource prospects are those deposits whose existence is postulated on the basis of only one type of indirect evidence, e.g. ripple marks on a side scan sonar record, or general geological considerations such as the projection of terrain types into the offshore.

For present purposes the distribution of PROVEN granular resources has been confined to specific areas around the boreholes or sampling locations, even when it is evident that the borehole stratigraphy may be assumed to be representative of a much wider area. This procedure has been used to eliminate the inadvertent projection of granular resource quality from one part of the study area to another, a particularly important consideration when dealing with deposits whose grain size characteristics may change over relatively short distances.

Likewise, the boundaries of PROSPECTIVE granular resource deposits should be considered to be only poorly defined at best. In some cases, the data show conflicting results, e.g. ripple marks in presumed clayey areas, and hence some may eventually prove to be entirely erroneous. Nevertheless, the inclusion of such information is considered to be appropriate for the present regional study because it helps to highlight particular areas which certainly bear further investigation in any future granular resource study.

5.2 Herschel Basin

Prior to conducting the 1984 geotechnical drilling programme from the Arctic Kiggiak, it was considered possible that the PLF's which occupy the floor of the Basin were remnant glaciofluvial features comprised of sand and gravel. The geotechnical borehole (F84HB2) drilled on one of these seamounds demonstrated that the PLF's are not glaciofluvial features, but are ice-cored submarine pingos formed following the partial drainage of Herschel Basin at some time in the past.

Sand and gravel was encountered at depth in the other borehole (F84HB1) which penetrated the basin floor. The seismic information suggests that this granular stratum is probably widespread within the Basin, but both the water depth and the thickness of cover overlying the gravel precludes its development as an offshore borrow source.

5.3 Herschel Sill

Information regarding the distribution, extent and quality of the granular resources on the sill has been collected by both government agencies and some of the major petroleum operators (Table 5.1).

The earliest documented studies in the area were conducted by the Geological Survey of Canada during the Hudson 70 cruise. Shipek samples analyzed by Pelletier (1975) and presented in his report on sediment dispersal in the Canadian Beaufort Sea indicated that some granular sediments might be located on or near the Herschel Sill (see Table 5.2, station F70-33).

Shipek samples recovered during the 1975 GSC programme from the M. V. Theta were reported by Rodd (1975). A total of 8 locations on the sill were examined (Table 5.3). Although no detailed grain size distribution curves are presented, the report indicates that the highest sand contents were recorded near Collinson Head (F75-23).

TABLE 5.1

Granular Resource Information Available on the Herschel Sill

Year	Collecting Agency	Data	Quantity
1977	Geological Survey of Canada	Grab Samples	3 locations
1980	Dome Petroleum	Reconnaissance high resolution geophysics	50 km
1981	Dome Petroleum	Detailed high resolution geophysics	300 km
1981	Dome Petroleum	Clam shell test dredging	16 locations
1981	Dome Petroleum	Bottom grab samples, video and still photographs for environmental control	24 stations
1982	Gulf Canada Resources	Geotechnical boreholes	6 boreholes
1984	Indian and Northern Affairs	Boomer, echo sounder and side scan records	180 km
1984	Geological Survey of Canada	ORE records	60 km
1984	Indian and Northern Affairs	Geotechnical boreholes and clam shell dredging	4 locations

TABLE 5.2

Grain Size Information Obtained During the Hudson 70 Cruise (from Pelletier, 1975)

Station	% Sand	% Silt	% Clay
F70-29	4	47	49
F70-32	1	40	59
F70-33	26	31	43

TABLE 5.3

Grain Size Analysis of Shipek Samples from Herschel Sill reported by Rodd (1977)

Station	% Sand	% Silt	% Clay
F75-3	34	32	34
F75-4	40	33	27
F75-7	44	34	22
F75-23	90	7	3
F75-30	69	18	13
F75-31	52	22	26
F75-32	27	25	48
F75-35	33	41	26

In 1980 and 1981 Dome Petroleum conducted reconnaissance and detailed high resolution shallow seismic programmes on the sill in an attempt to delineate the extent of any granular resources which might be present. Although some very detailed maps were produced from the second survey (Geoterrex, 1982), both programmes found it difficult to differentiate between granular and cohesive materials at the seabed.

During the summer of 1981 Dome Petroleum also conducted a series of studies to investigate the impact of dredging on any benthos which might be present on the Sill. In July, 12 stations were examined by diving biologists to record the types and abundance of macrobenthos (large bottom-living organisms) and benthic infauna (animals living in the bottom sediments) at potential gravel borrow sites prior to dredging. An additional 14 stations in the same area were examined in September, 1981. Sediment samples for particle size analysis were obtained in July by a large crane-operated clam shell bucket. In September, sediment samples were collected in a 470 cm^3 plastic jar by the divers. The results of the grain size analyses and divers' observations of soil type reported by Arctic Laboratories (1982) are presented in Table 5.4.

Clam shell test dredging was also conducted by Dome Petroleum at locations other than where the benthic surveys were carried out. Three principal areas on the Herschel Sill were investigated. Area 1 was centered at N7716400 E586000. Area 2 was located near N7714900 E587900, and Area 3 was centered at approximately N7706400 E594500. Sampling depths varied from 0.6 m to 1.0 m below the seabed at all locations except GS03, where samples were retrieved by digging repeatedly in the same hole. Some gradation analyses were completed on

TABLE 5.4

Sedimentary Characteristics of Herschel Island Benthic Stations
(modified from Arctic Laboratories Ltd., 1982)

Station	% Gravel	% Sand	% Silt-Clay
JULY, 1981			
JCS-1		-	M/G
JCS-2		-	M-C/G
D-1	49	41	10
D-2	46	49	5
D-3	53	46	1
D-4	1	59	40
D-5	G	-	-
D-6	0	99	1
D-7	0	99	1
D-8	33	65	2
D-9	16	67	17
D-10	41	59	0
SEPTEMBER, 1981			
SCS-1	-	-	M/G
SCS-2	G	-	-
DS-1	20	72	8
DS-2	1	22	77
DS-3	36	20	44
DS-4	0	87	13
DS-5	14	81	5
DS-6*	-	S/G	-
DS-7*	-	-	M-C/G
DS-8	24	24	52
DS-9	4	15	81
DS-10**	-	S/G	-
DS-11	88	10	2
DS-12	53	44	3

* remote video survey
** remote video and grab samples
C Clay G Gravel
S Sand M Silt
"/" over

selected samples on board the M. V. Supplier V and further analyses were conducted at EBA's Edmonton laboratory. Results of the grain size analyses in each area are presented in Tables No. 5.5 to 5.7 inclusive, while the individual grain size curves are shown in Appendices E.1, E.2 and E.3. The material recovered in Areas 1 and 3 was predominantly sand and gravel, while the Area 2 material was principally silt and fine sand. The latter differed considerably from the surface sediment characteristics determined during the benthic survey (see stations DS5, DS10, D5 and D12) in the same general area, and clearly illustrated the abrupt changes in material type that occur over relatively short distances on the Sill. Grain size envelopes for Areas 1 and 3 presented in Drawing No. 5.1 demonstrate that the typical grain size distribution is not significantly different in the 2 areas. Area 1 samples exhibited much lower dispersion than Area 3 samples, but the area over which the latter were collected is also much greater. Although 2 samples (GS14 and GS15) from the south end of Area 3 were found to be particularly coarse grained, it is important to note that no distinct gradation trends along this deposit can be deduced. Much more groundtruth information will be required before any such trends become defined.

On the basis of all the clam shell test results, the Geopotes X dredged a total of 60 302 m^3 from the Herschel Sill for the construction of the Tarsiut caisson retained island in 1981. The borrow site was approximately 250 000 m^2 in area, centered about N7715300 E587900 (near Area 2). Samples recovered from the dredged material exhibited an average D_{50} of approximately 6000 μm and an average fines content of 6%, similar to the nearest clam shell test results at stations DS5 and DS10.

TABLE 5.5

Results of Clam Shell Dredging in AREA 1
(from EBA Engineering Consultants Ltd., 1981)

Station	Silt %	Sand %	Gravel %	D_{50} (mm)	Soil Description
GS03-1A	10	41	49	4.5	GRAVEL AND SAND (GP-GM) - trace of silt, some cobble sizes up to 100 mm diameter
GS03-1B	5	36	59	8.0	GRAVEL AND SAND (GW) - trace of silt, some till-like zones, gravel sizes common up to 75 mm dia., one 200 mm dia. boulder
*	3	38	59	7.8	
GS03-1C	7	49	44	3.0	SAND AND GRAVEL (SP-SM) - poorly drained, one 90 mm cobble, organic, black
GS03-2C	6	40	54	6.4	GRAVEL AND SAND (GP-GM) - trace of silt, some till-like material
GS03-1D	6	35	59	6.3	GRAVEL AND SAND (GW-GM)
GS03-2D	1	41	58	6.1	GRAVEL AND SAND (GW) - clean
*	1	37	62	7.5	
GS03-1E	2	45	53	5.5	GRAVEL AND SAND (GP) - lots of 50 mm diameter gravel sizes near top, fines washed out
GS03-2E	3	41	56	7.0	GRAVEL AND SAND (GP)
GS03-3E	6	43	51	5.0	GRAVEL AND SAND (GP-GM) - lots of weeds in sample
•	7	54	39	2.2	(SP-SM)

TABLE 5.5 cont'd.

Station	Silt %	Sand %	Gravel %	D_{50} (mm)	Soil Description
GS03-4E	7	55	38	2.1	SAND AND GRAVEL (SP-SM) - some cobble sizes up to 100 mm diameter
GS03-5E	3	47	50	5.0	SAND AND GRAVEL (GP) - gravel sizes common up to 40 mm diameter
GS03-6E	3	51	46	3.4	SAND AND GRAVEL (SP)
GS03-7E	4	39	57	8.0	GRAVEL AND SAND (GP)
GS03-8E*	13	48	39	2.0	SAND AND GRAVEL (SM) - some silt, some till-like zones
GS06-1A	4	46	50	5.0	GRAVEL AND SAND (GP) - gravel sizes common to 80 mm diameter
•	4	48	48	4.3	
GS06-1B	4	46	50	5.0	2nd run, as above, one 200 mm diameter boulder
GS07-1A	5	49	46	3.8	SAND AND GRAVEL (SP) - one 130 mm dia. boulder
GS07-1A	5	49	46	3.8	SAND AND GRAVEL (SP) - one 130 mm dia. boulder
GS08-1A	2	67	31	1.4	SAND (SP) - gravelly, some till-like material, gravel sizes common to 75 mm diameter, trace of cobbles
GS09-1A	4	54	42	2.8	SAND AND GRAVEL (SP) - cobble sizes common to 100 mm diameter
*	3	45	52	6.0	(GP)

*Grain size results obtained in EBA's Edmonton laboratory

TABLE 5.6

Results of Clam Shell Dredging in AREA 2
(from EBA Engineering Consultants Ltd., 1981)

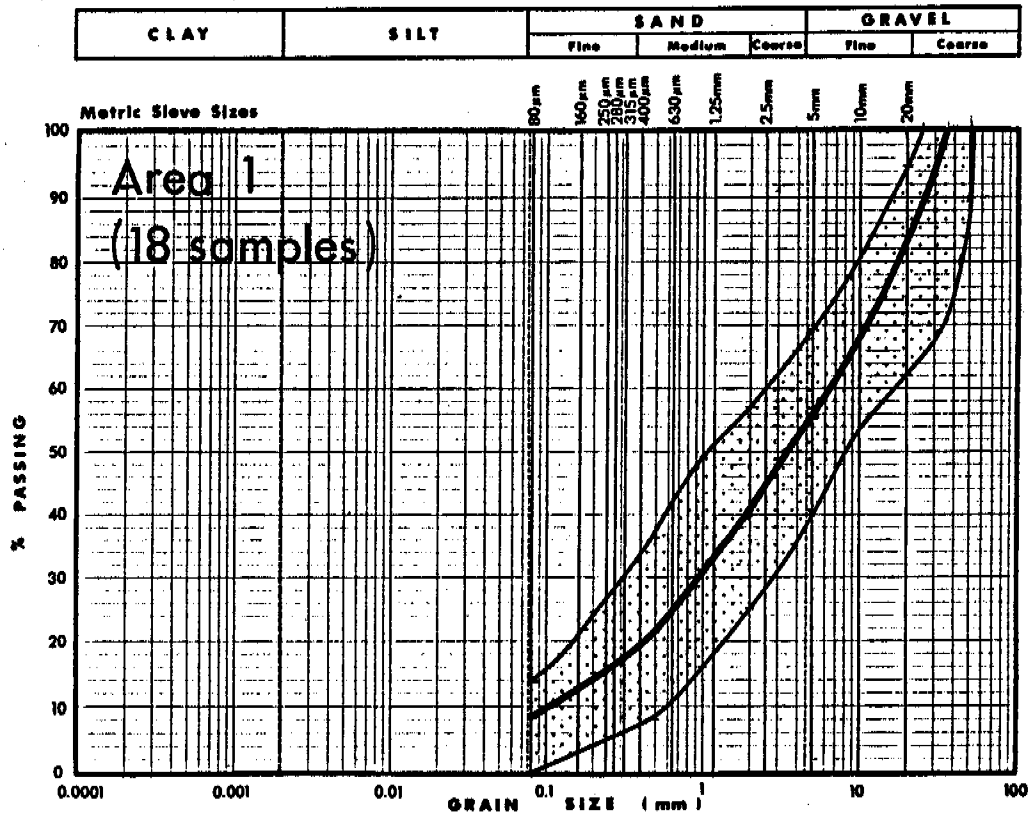
Station	Silt %	Sand %	Gravel %	D_{50} (mm)	Soil Description
GS04-1A					SILT - some clay, some sand to sandy, trace of gravel
GS04-1B					as above - (taken at bottom of clam-shell sampler), less clay (trace), laminated in 10 mm layers with organic rich sandy silt
GS-5					SILT - sandy, clayey, (no samples retained)
GS05-1B	40	59	1	0.12	SAND AND SILT (SM) - medium to low plastic

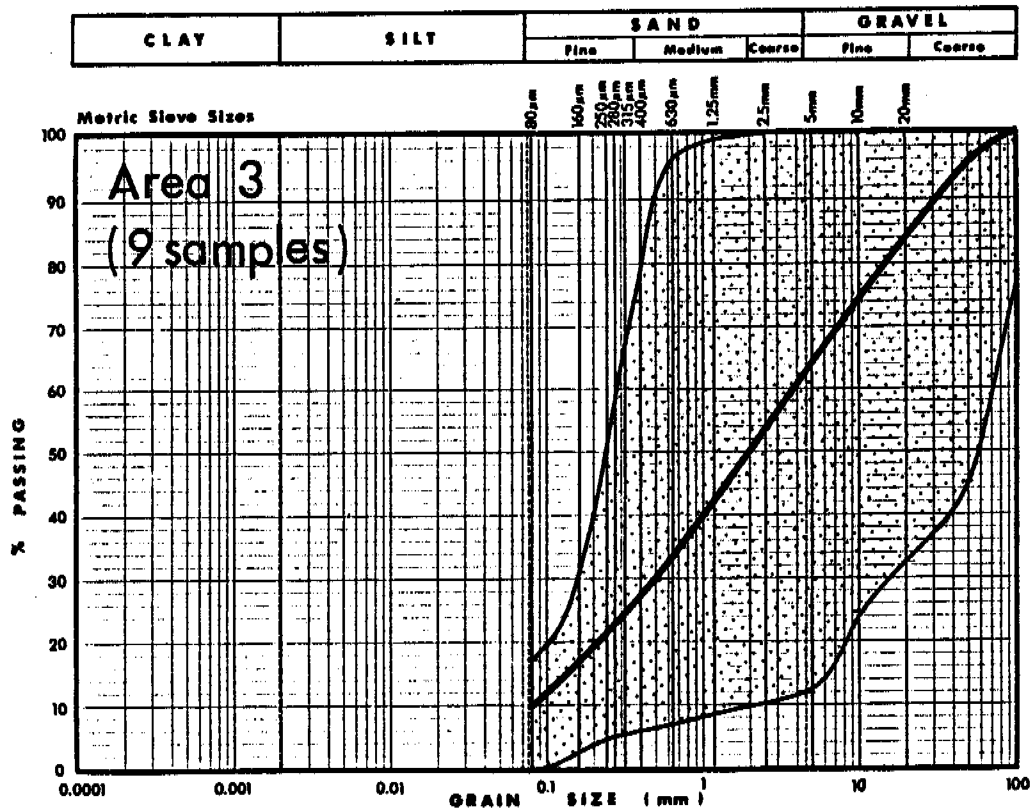
TABLE 5.7

Results of Clam Shell Dredging in AREA 3
(from EBA Engineering Consultants Ltd., 1981)

Station	Silt %	Sand %	Gravel %	D_{50} (mm)	Soil Description
GS01-1A	0	38	62	13.0	GRAVEL AND SAND (GP) - cobbles common to 100 mm diameter
•	1	46	53	6.2	
GS01-1B					as above, finer grained
GS01-1C	0	46	54	6.0	GRAVEL AND SAND (GP)
GS01-1D					as above, finer grained
GS10-1A	1	99	0	0.28	SAND (SP) - very fine grained, uniform
GS11-1A	2	65	33	1.9	SAND (SP) - gravelly, some cobble sizes up to 150 mm diameter
GS12-1A	0	59	41	3.2	SAND AND GRAVEL (SP) - sizes up to 150 mm dia.
GS13-1A	17	67	16	0.25	SAND (SM) - some silt and gravel, frequent silt pockets, some gravel sizes up to 50 mm dia.
GS14-1A	3	19	78	24.0	GRAVEL (GP) - some sand, trace of silt, coarse subangular gravel and cobbles up to 120 mm dia.
*	1	10	89	57.0	(GW)
GS15-1A	1	40	59	10.0	GRAVEL AND SAND (SP) - subangular cobbles up to 150 mm diameter, some till-like zones
*	4	35	61	10.0	(GW)
GS16-1A	1	54	34	2.5	SAND (SP) - gravelly, subangular cobble sizes up to 120 mm diameter
GS17					Crane broke down

*Grain size results obtained in EBA's Edmonton laboratory





Typical Grain Size
Curves & Envelopes
(after EBA Engineering Consultants
Ltd., 1981)

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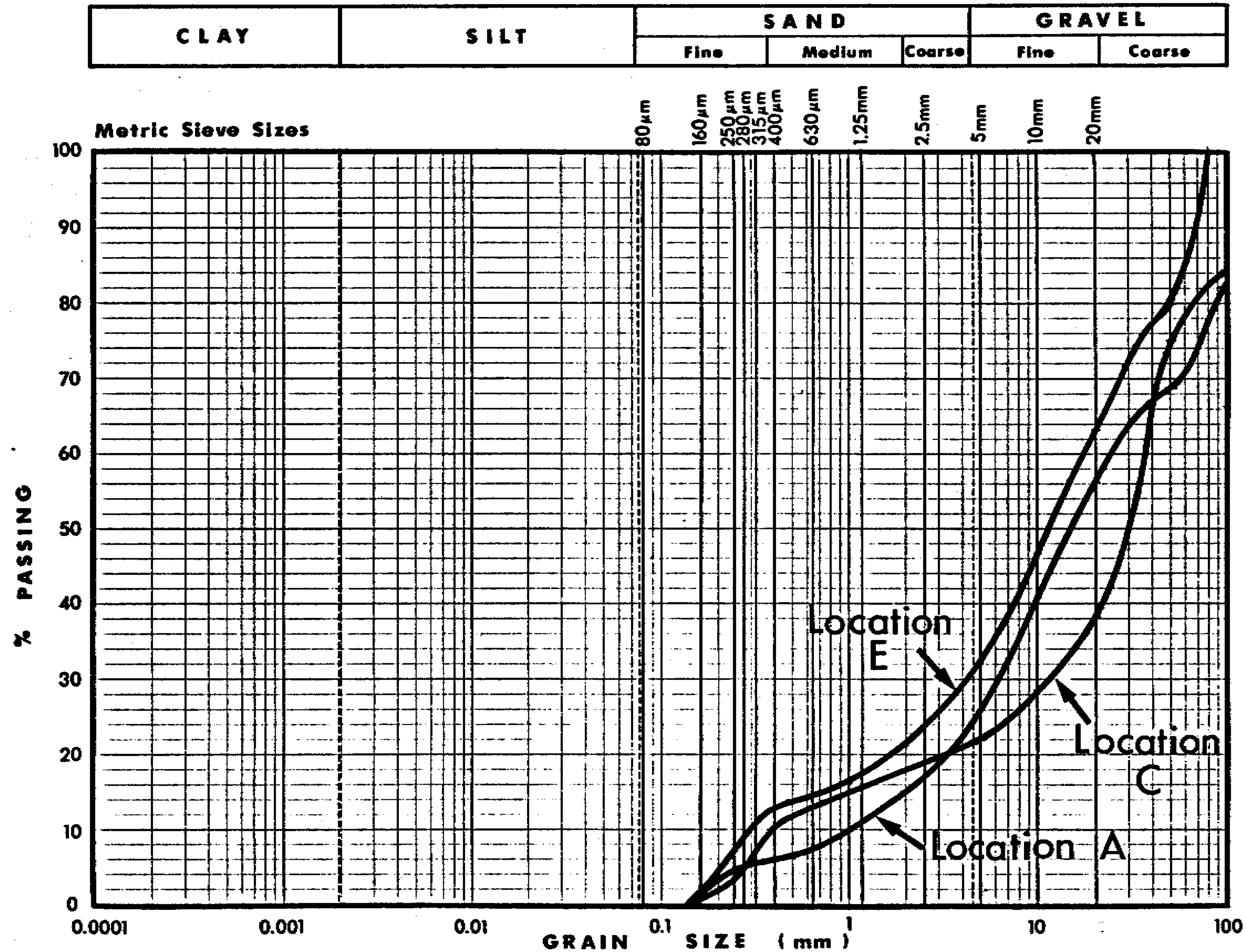
JOB No.: 10-260	DATE: 85/09/23
DRAWN BY: MG	DWG. No.: 5.1

The following summer (1982) the Hendrik Zanen removed 4481 m^3 of granular material from the north end of Area 3. Samples were retrieved at 6 stations (see locations A through F in Drawing No. D.1). Grain size determinations made on 3 of these samples showed that the material was a sandy gravel (Drawing No. 5.2) and hence was approved for placement on the Uviluk berm.

Gulf Canada Resources Inc. also carried out granular resource studies in 1982, drilling 6 boreholes on the Herschel Sill. A total of 3 of the boreholes (GHB82.508, 509 and 510) failed to encounter any granular deposits at the seabed, in spite of the fact that they were located relatively close to other sampling stations where granular materials were previously detected. Borehole GHB82501, located near Collinson Head, encountered a sand unit beneath 0.3 m of silty clay, but its thickness was not determined. Borehole GHB82511, located along the seaward side of the Sill, penetrated a thin (0.3 m) gravel layer before entering the underlying hard clay. Only borehole GHB82512, situated on the bathymetric high which extends northward from Kay Point, encountered a significant thickness of granular material. According to the borehole log presented by EBA Engineering Consultants Ltd. (1982), the seabed consists of 2.3 m of fine and medium grained gravel exhibiting some sand and a trace of silt. Two grain size distribution analyses performed on samples recovered during drilling showed that the gravel content varied from 55% to 70%, while the sand content varied from 26% to 44%. Measured silt contents were low (3% to 4%). D_{50} for these samples ranged from 5.2 to 7.1 mm.



Herschel Island Gravel
Dredged by Hendrik Zanen
in 1982

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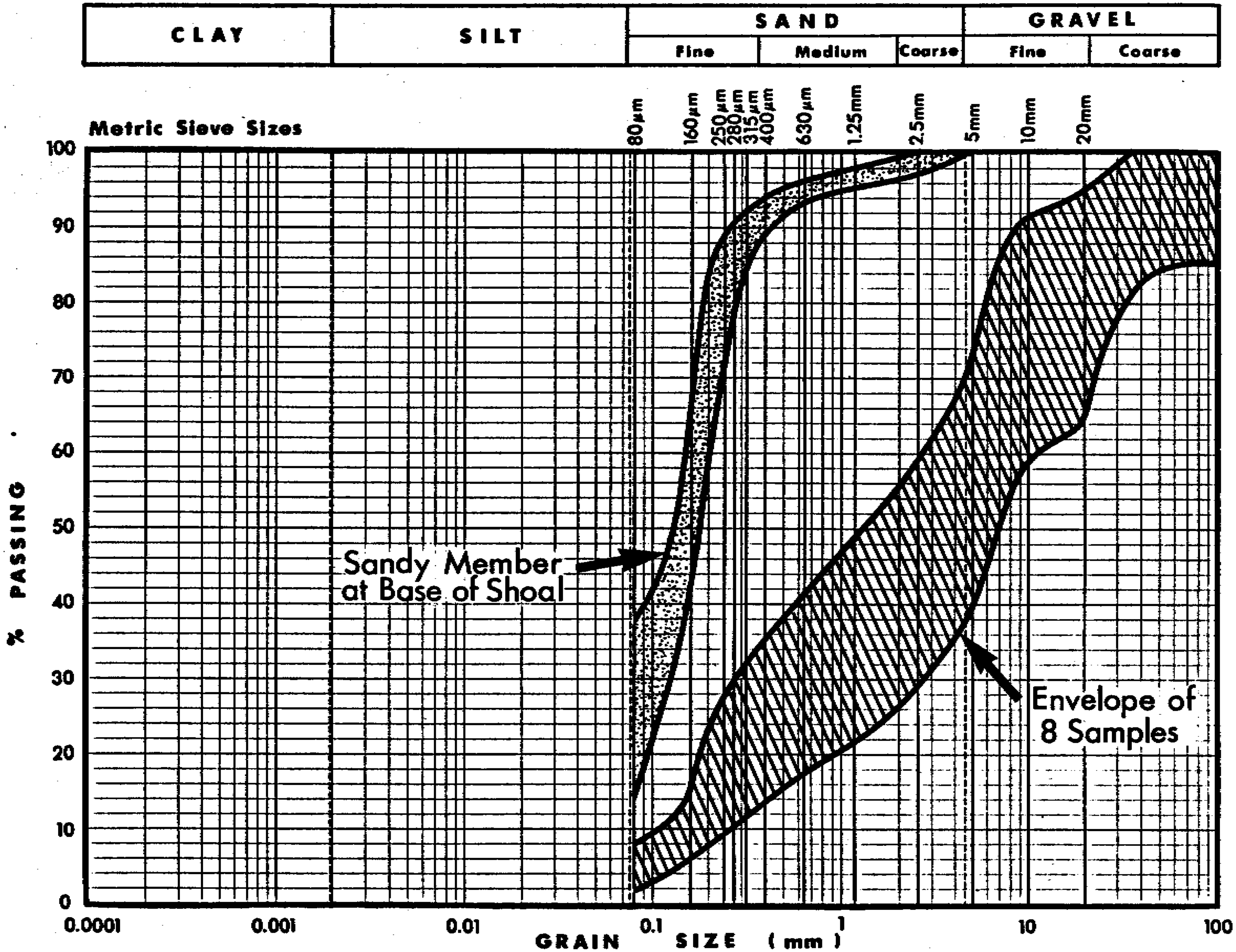
JOB No.: 10-260	DATE: 85/09/23
DRAWN BY: M.G.	DWG. No.: 5.2

The most recent drilling programme on the Herschel Sill was conducted by DIAND in 1984, as part of the present study to evaluate the potential for development of submarine granular resources near Herschel Island. The boreholes, probe holes and test dredging locations demonstrated that the shoal immediately southeast of Collinson Head is comprised of gravel and sand up to 3.4 m in thickness. The gravel is subrounded to subangular, poorly to well graded and appears to be in a dense condition. Silt contents are relatively low in the gravel, but range slightly higher in some of the more sandy samples recovered near the base of the deposit (see grain size curves in Appendix E4). Composite gradation envelopes for these samples appear in Drawing No. 5.3.

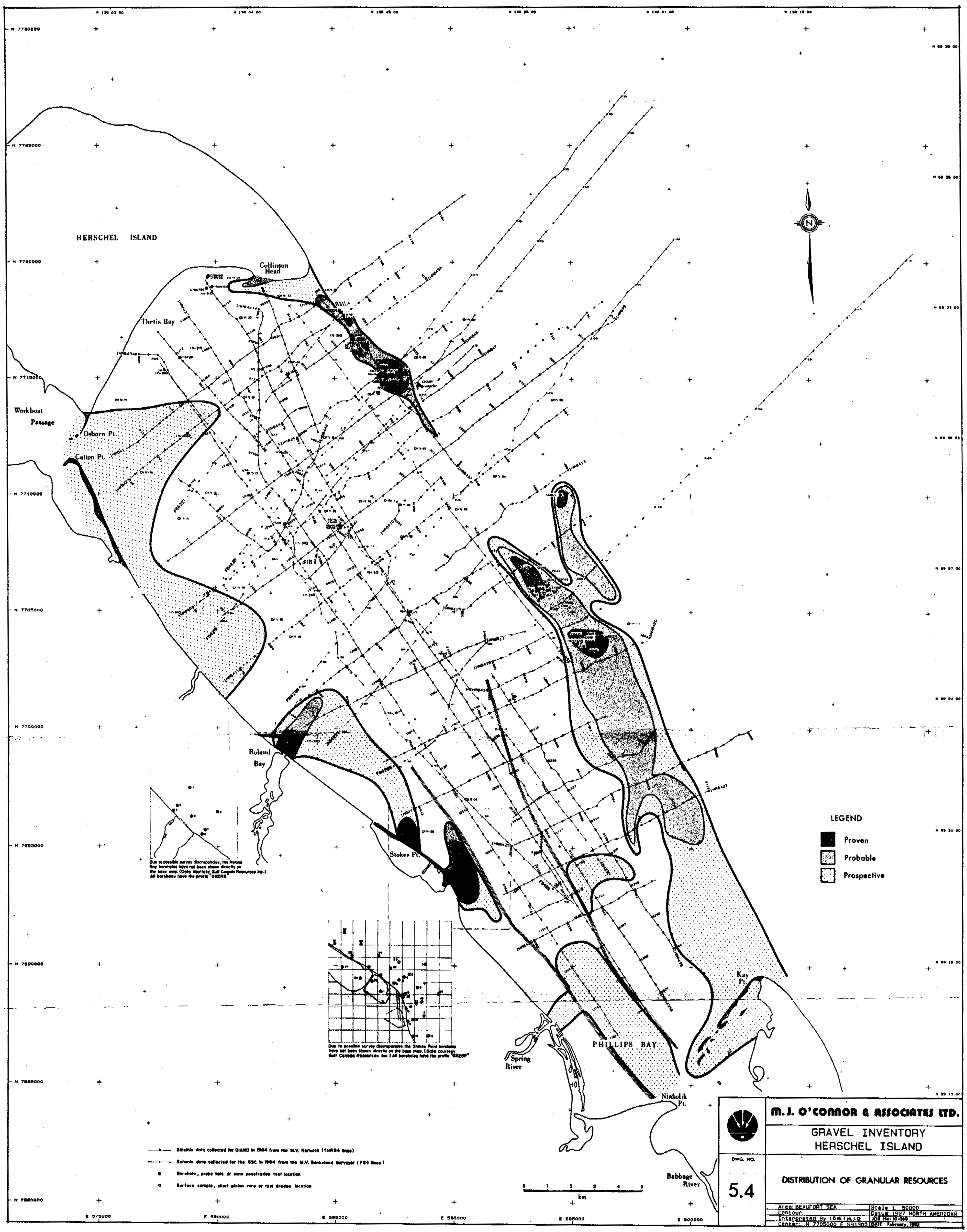
Integration of all the geological, geotechnical and geophysical data collected since 1970 demonstrates that most of the granular resources which occur on the Sill may be found in the narrow shoals which occupy the crest between Collinson Head and Kay Point. Two distinct granular resource deposits have been recognized.

The first, termed the Collinson Head shoal, extends southeastward from Collinson Head a distance of approximately 9 km. It varies in width from about 200 m to more than 1500 m and covers an area of approximately 750 ha. As Drawings No. 5.4 and D.8 illustrate, this deposit also includes the small spit at Pauline Cove, although it is questionable whether such material might be exploitable, given the historical significance and present land use of this area (see Plates 5.1 and 5.2). According to the recent DIAND boreholes shown in Drawing No. 4.9, there is a strong relationship between bathymetry and the thickness of sand and gravel in the shoal, especially on the northeast



Note: Gradation analyses reported by EBA Engineering Consultants Ltd. 1984

Gradation of Granular Material from Collinson Head Shoal	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/07/22
	DRAWN BY: MG	DWG. No.: 5.3


HERSCHEL ISLAND
Collinson Head
Thetis Bay
Workboat Passage
Osborn Pt.
Catton Pt.
Roland Bay
Stokes Pt.
PHILLIPS BAY
Spring River
Niakolik Pt.
Kay Pt.
Babbage River
LEGEND
Proven
Probable
Prospective
Seismic data collected for DIAND in 1984 from the M.V. Norweta (IHR84 lines)
Seismic data collected for the GSC in 1984 from the M.V. Banksland Surveyor (F84 lines)
Borehole, probe hole or cone penetration test location
Surface sample, short piston core or test dredge location
km
N 7720000
N 7715000
N 7710000
N 7705000
N 7700000
N 7695000
N 7690000
N 7685000
N 7680000
E 575000
E 580000
E 585000
E 590000
E 595000
E 600000
M. J. O'CONNOR & ASSOCIATES LTD.
GRAVEL INVENTORY
HERSCHEL ISLAND
DWG. NO.
5.4
DISTRIBUTION OF GRANULAR RESOURCES
Area: BEAUFORT SEA
Scale 1: 50000
Contour:
Datum: 1927 NORTH AMERICAN
Interpreted By: J.D.M. / M.J.O.
Center: N 7705000 E 591300
DATE: February, 1985

(seaward) side of the feature. On the southwest (basin) side of the shoal this relationship is not as well defined, since the granular materials may grade laterally into and/or intertongue with recent fine grained cohesive sediments over a relatively short distance. The maximum thickness of granular material encountered in the Collinson Head shoal is 3.4 m (borehole F84HS1). The observed water depth at this location was 12.34 m.

Volumes of granular material in the Collinson Head shoal were calculated by assuming that sand and gravel is an average of 2 m thick along the crest of the shoal, but only 1 m thick elsewhere (see Drawing No. 5.5). On this basis, the shoal contains approximately 3 500 000 m^3 of proven reserves, of which 200 000 m^3 are contained in the spit at Pauline Cove. The shoal probably contains at least another 2 600 000 m^3 of material, most of which is along the crest in water depths of between 12 and 15 m. The area immediately adjacent to Collinson Head possibly contains an additional 2 700 000 m^3, but the shallow water depths in this area may make dredging somewhat difficult. Total reserves in the Collinson Head shoal are estimated to be 8 800 000 m^3.

As noted previously, the south part of the Sill is occupied by a complex series of shoals. Some of these are attached directly to Kay Point, while others have now been separated from the shoreline as the shoreline rapidly eroded to the southeast. As Drawings No. D.8 and 5.4 demonstrate, the Kay Point shoals occupy a much larger area than the single shoal near Collinson Head. Conservative estimates suggest that at least 7500 ha of the sill may contain granular resources suitable for marine development. Bathymetric, side scan and sub-bottom profiler evidence indicate that both sand and gravel are probably present in the major shoals north of Northing 7695000 m. No groundtruthing has been conducted south of this point. Sand and gravel thicknesses of up to 7 m may be expected along the crest of some of these shoals (see Drawing No. 4.11), but this probably represents a maximum value which is atypical of most of the shoals; an average thickness along the crest of approximately 4 m is considered to be more representative (see Drawing No. 5.5).

According to the surface and borehole samples which are available from the north end of the deposit, these shoals appear to contain granular material whose quality varies according to location. While the data are insufficient to determine any specific trends, they suggest that the material generally falls within the grading curve* previously shown by O'Connor (1983) (Drawing No. 5.6).

Using the assumed thicknesses shown in Drawing No. 5.5, it is concluded that a total of approximately 118 500 000 m^3 of sand and gravel may be present within the Kay Point shoals. Some 13 800 000 m^3 of these reserves may already be considered to be proven. This includes about 1 600 000 m^3 in the shoal which extends south and west from Kay Point. Current information suggests that 67 500 000 m^3 of granular material probably exist in the northern half of the feature, but additional large areas of the sill are also considered to be prospective for future gravel resources. While no groundtruth or subbottom data are presently available to confirm the nature of the seabed immediately north of Kay Point, preliminary estimates suggest that this area may ultimately yield an additional 37 700 000 m^3 of granular material suitable for engineering purposes. It remains to be seen, however, what impact the shallow water depths may have in restricting the ultimate development of these resources.

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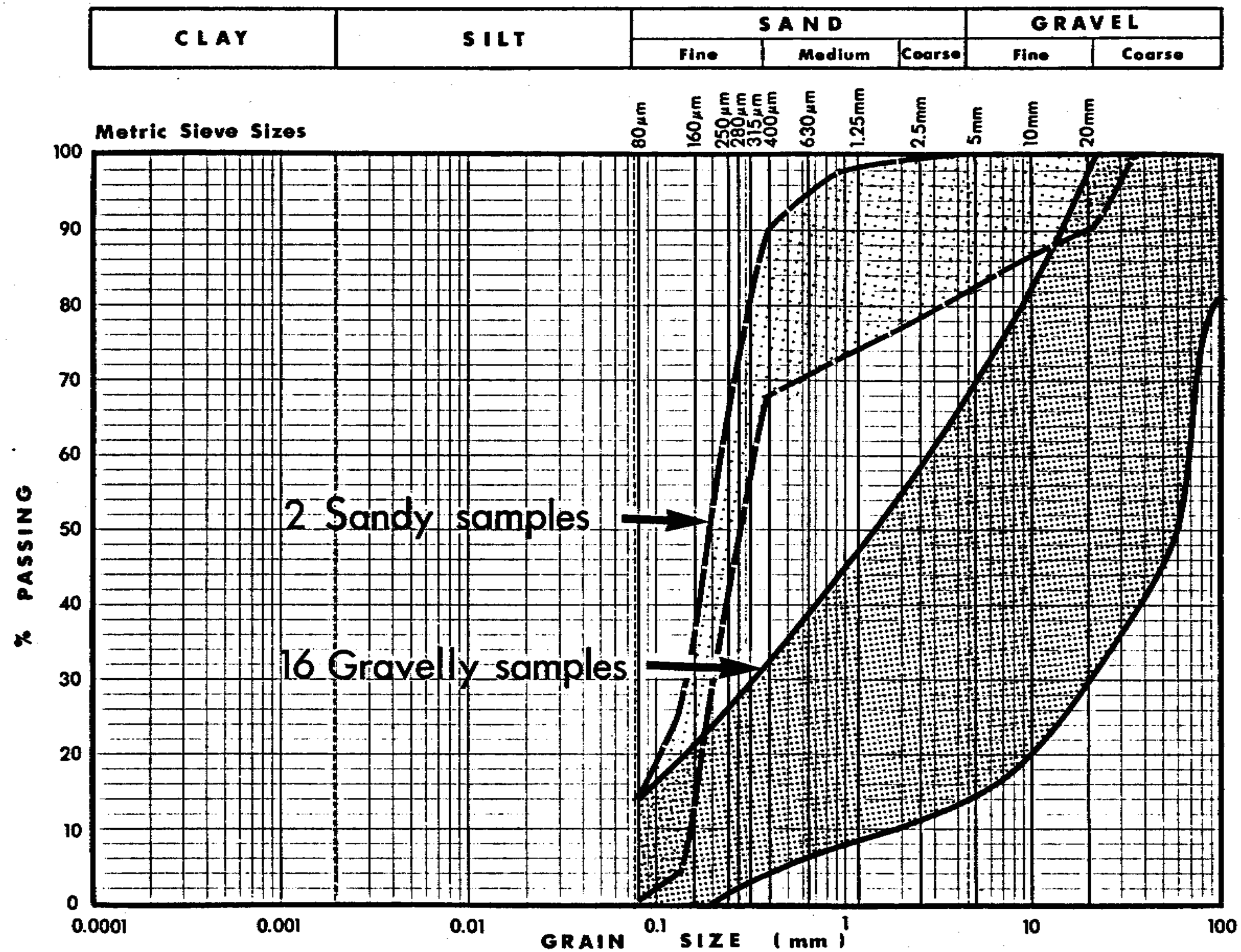
*Data include 15 samples from clam shell dredging (EBA Engineering Consultants Ltd., 1981) and 3 samples taken from a load dredged by the Hendrik Zanen in 1982 (locations A, C and E)



Grain Size Distribution
of the Kay Point Shoals

M. J. O'CONNOR & ASSOCIATES LTD.			
JOB No.:	10-260	DATE:	85/07/22
DRAWN BY:	MG	DWG. No.:	5.6

5.4 Yukon Coastal Shelf

Ample evidence exists to support the occurrence of nearshore granular resource deposits along the Yukon Coast.

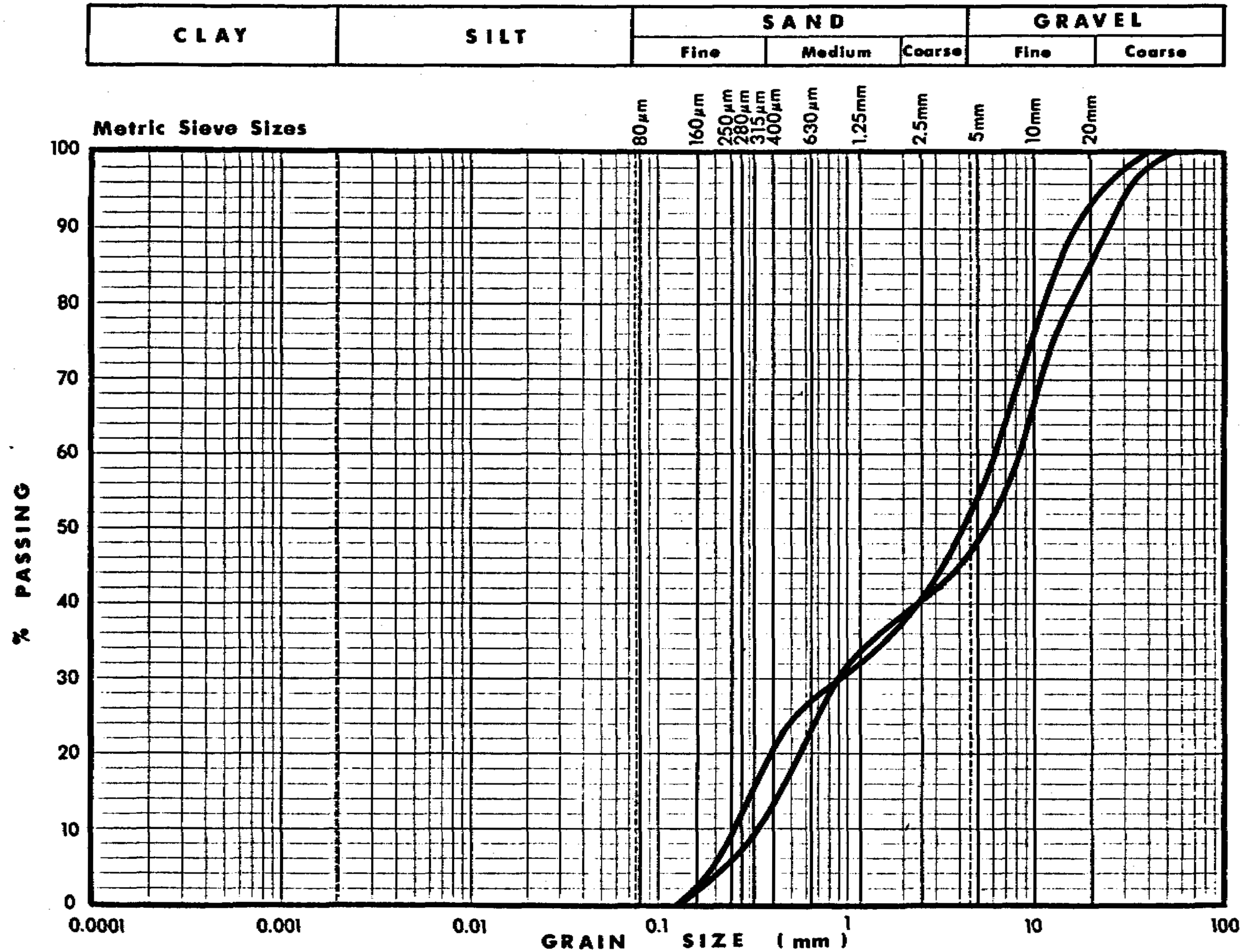
It is estimated, for instance, that perhaps 100 000 m^3 of granular materials are contained in the spit which has formed at the mouth of Workboat Passage. In addition, Rampton (1982) has mapped extensive glaciofluvial deposits consisting of poorly sorted pebbly to cobbly gravels both inland and along the Yukon coast immediately south of Herschel Island (see Drawing No. 4.13). The seismic evidence available on the narrow shelf area east and southeast of Catton Point does not provide any direct evidence as to the possible extension of these granular resource deposits into the offshore, except perhaps for the indication of a deltaic or channel-fill feature which occurs near the intersection of lines IHR842 and IHR8434B. Rather, the subbottom profiler data suggest that much of the seabed east of Catton Point may consist of a thin (1 m to 3 m) blanket of recent clay. Any granular deposits which are present are therefore likely confined to the deeper sediments which existed on the shelf prior to the last marine transgression.

In spite of this lack of geophysical support, the geological conditions which presently exist along the coastline are considered to be sufficiently promising that we estimate some 4125 ha of the shelf may be prospective for granular resource development. Using an estimated average thickness of 0.5 m for these deposits results in a prospective volume of 20 600 000 m^3 of granular material.

While no subsea groundtruth information is available to test these assumptions, a DIAND study completed jointly by R. M. Hardy and Associates Ltd. and Terrain Analysis and Mapping Services Ltd. in 1976 provides information on both the quantity and quality of the granular sediments which comprise the narrow spit at Catton Point. According to this study, the deposit is approximately 50 m wide and more than 5 km long. Its crest is approximately 1 m above sea level and hence it is completely inundated during major storm surges. Like many other similar features along the Yukon Coast, this spit is bare of most vegetation, save for tufts of grass and driftwood concentrated along its crest.

On the basis of 4 test pits excavated on the spit (see Appendix E.5), the 1976 report suggests that the deposit contains fair to good quality granular material consisting of stratified, poor to well-graded, fine to medium gravel with some medium to coarse sand as well as poor to well-graded sand with some fine gravel (Drawing No. 5.7). Larger clasts are mainly rounded to subangular sandstone but some chert, argillite and (rarely) quartz are also present. The total volume of the spit is estimated to be approximately 900 000 m^3, of which perhaps only one half is actually recoverable. This total volume therefore represents only about 5% of the prospective volume which may be present under the adjacent shelf.

Echo sounder and side scan sonar records collected by DIAND in 1984 suggest that other areas of the Yukon coastal shelf south of Catton Point may also be prospective. The echo sounder records indicate that recent soft clayey sediments are either very thin or entirely absent along much of the coastal shelf, while ripple marks evident on some of the side scan records suggest that some of the bottom sediments are probably granular rather than cohesive in nature. This rather weak evidence is supported, at least in part, by geotechnical information obtained in 1976 by DIAND at Stokes Point and in 1982/83 by Gulf Canada at both Stokes Point and Roland Bay.



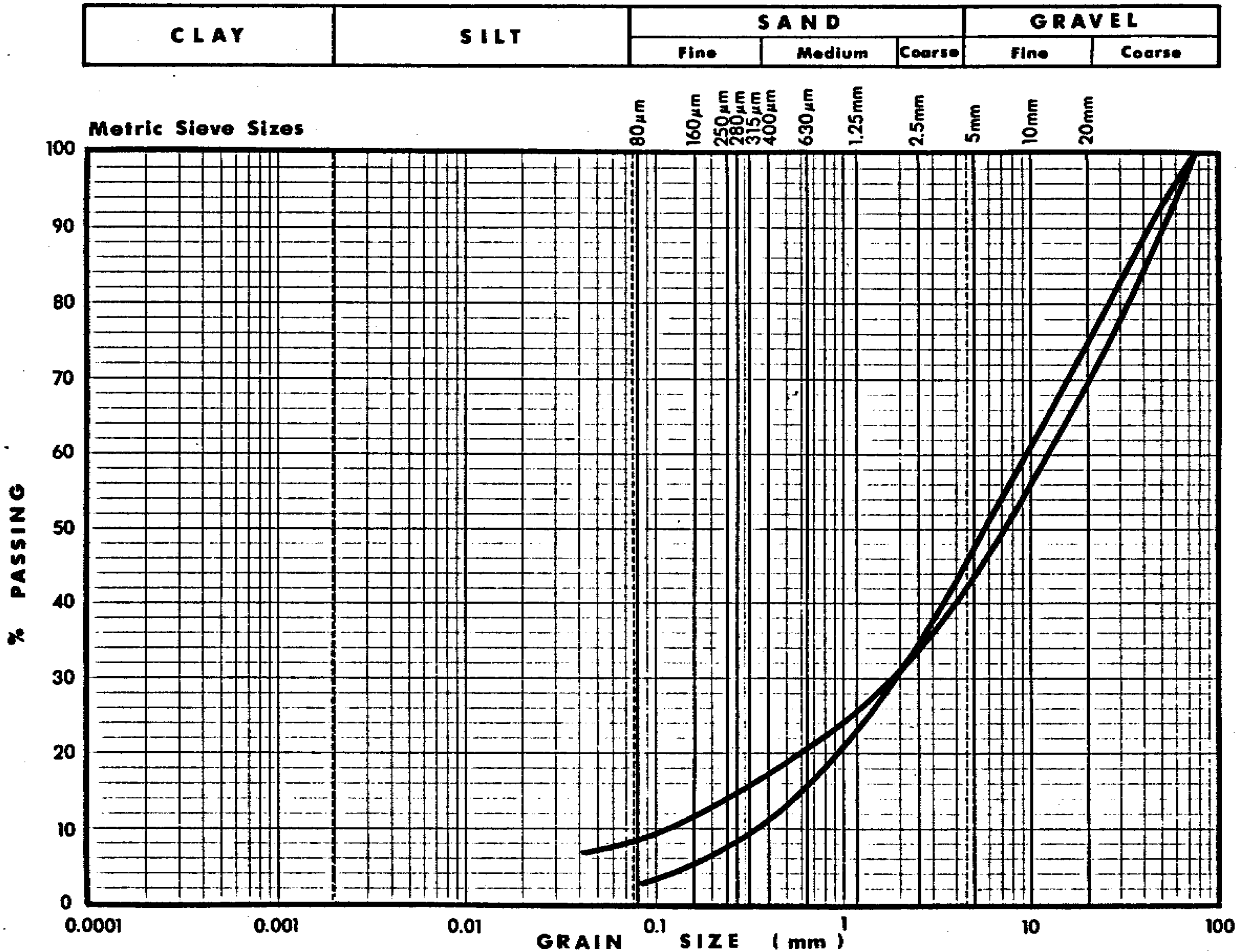
Grain Size Curves from Catton Point Spit (after R.M. Hardy and Associates Ltd., 1976)	**M.J. O'CONNOR & ASSOCIATES LTD.**
	JOB No.: 10-260 **DATE:** 85/09/15
	DRAWN BY: MG **DWG. No.:** 5.7

The DIAND study (op. cit.) noted that the Stokes Point spit is approximately 50 m wide and contains stratified, poorly graded, fine to medium gravel with medium to coarse sand, as well as poorly graded fine to coarse sand with fine gravel (see Appendix E.6 and Drawing No. 5.8). Pebbles rarely exceed 40 mm in diameter, especially at the eastern end where the sandier fraction predominates. The study noted that the larger clasts are mainly rounded to subrounded sandstone and quartzite with rare limestone, chert and granite, but chert is much more common in the fines. The volume of the spit was estimated to be 1 050 000 m^3, but the report suggests that static water levels may limit the recoverable volume to about 400 000 m^3.

Drilling by Gulf Canada in 1982/83 demonstrated that the granular deposit is not limited to the spit at Stokes Point, but also extends under the shelf area (Drawing No. 4.16). The deposit is described as a uniform fine sand with a trace to some silt, interbedded with thin layers of compact silt and sandy gravel.

Grain size envelopes for both the sand and gravelly members are shown in Drawing No. 5.9. According to the individual grain size distribution curves shown in Appendix E.7, some of the sand strata have relatively high fines contents, especially near the edge of the deposit (see boreholes 82-SP-9 and 82-SP-13). None of the offshore samples appear to be as coarse grained as those recovered from the spit in 1976, but it is difficult to ascertain whether this is a condition of the material in situ, or whether it merely reflects the different sampling techniques utilized during the 2 investigations.

The surficial sand varies in thickness between 1 m and 5 m over most of the area near Stokes Point, but thicknesses of 10 m or more were observed along a narrow (generally less than 200 m wide) channel



Grain Size Distribution Curves from the Spit at Stokes Point (after R.M. Hardy and Associates Ltd., 1976)

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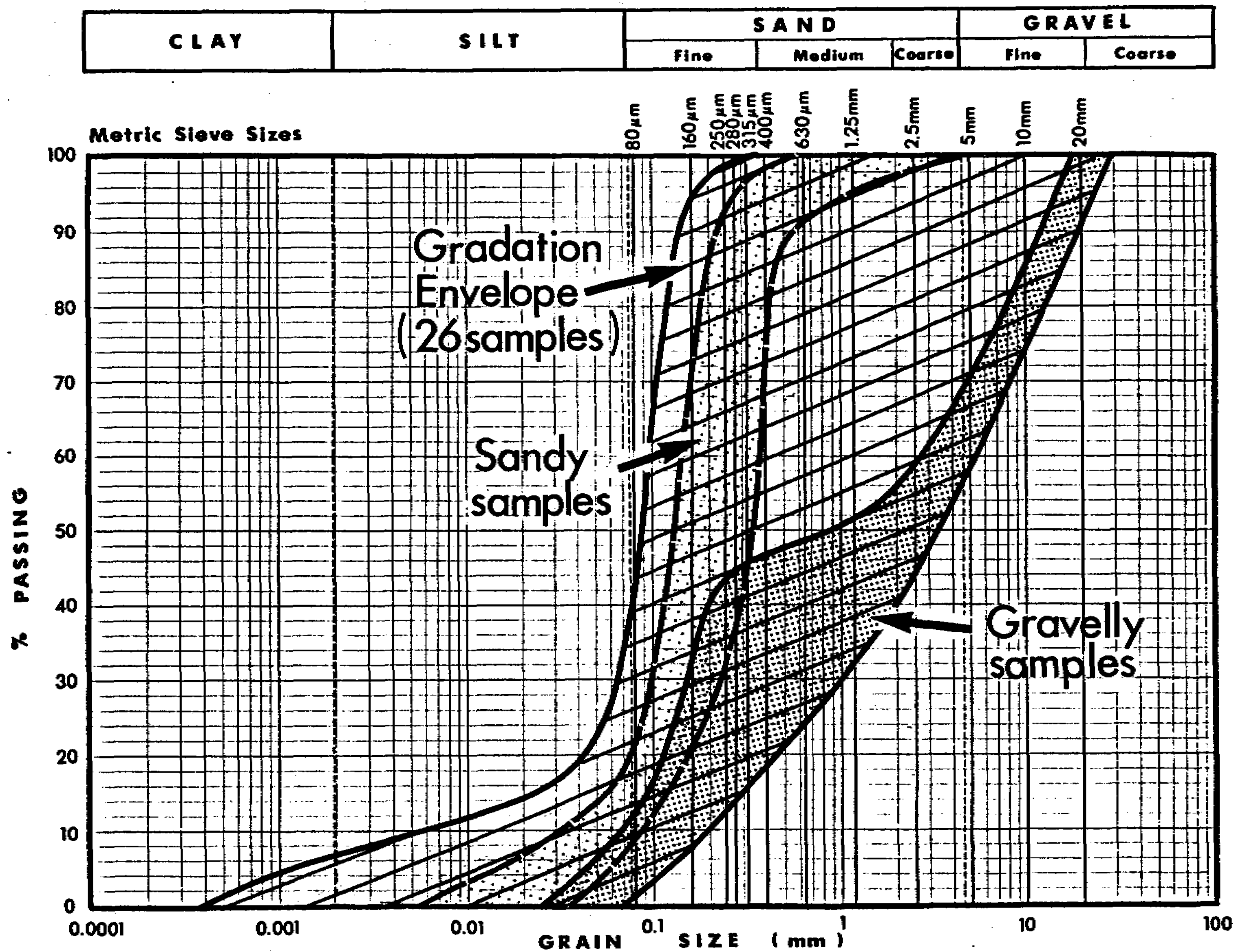

Grain Size Envelopes from Stokes Point (data courtesy Gulf Canada Resources Inc.)

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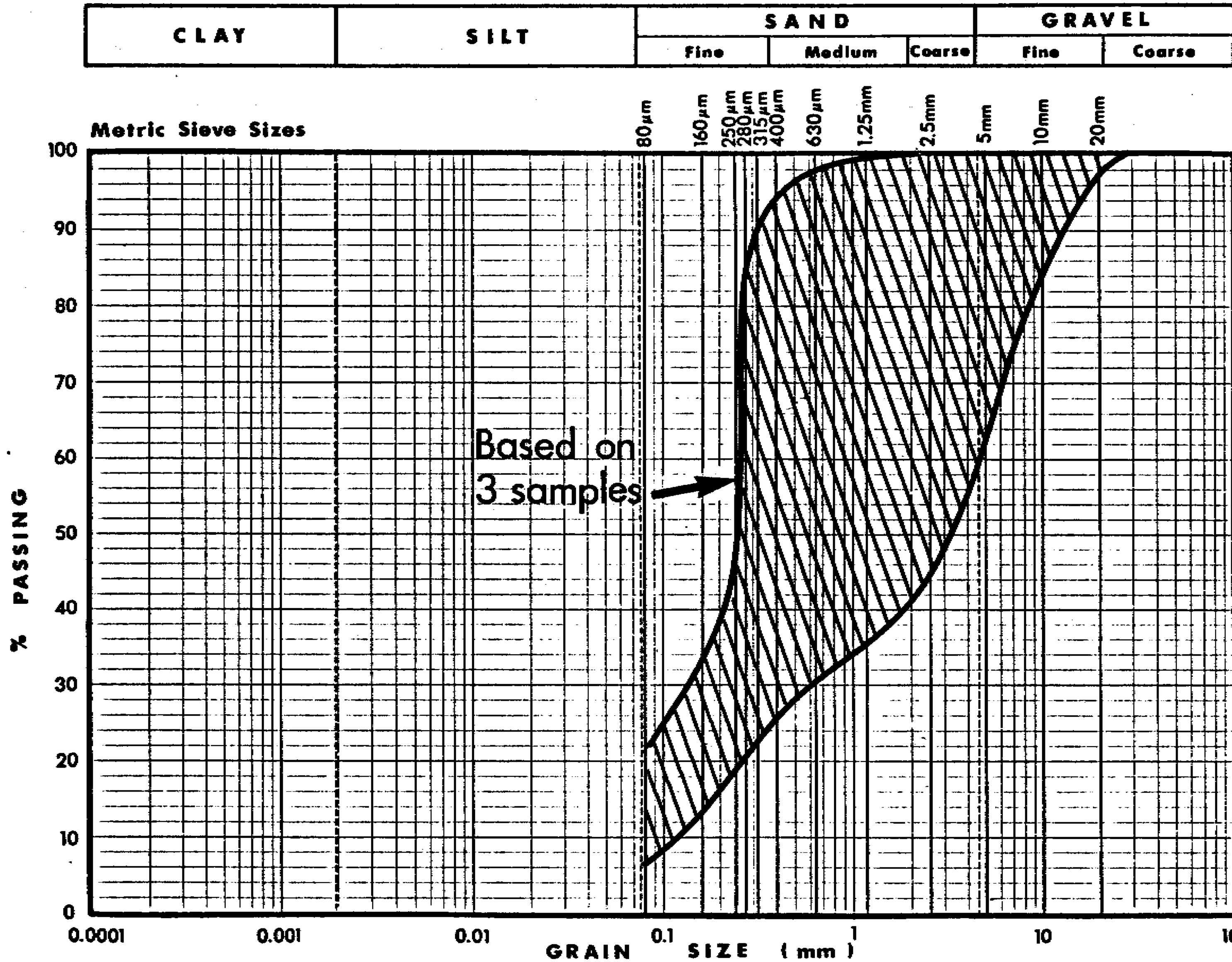
trending in a northerly direction from the south part of the spit. The seaward limit of the channel was not detected during the drilling program, but geological considerations suggest that it probably does not extend much beyond the western edge of the Babbage River paleochannel.

The 1982/83 geotechnical drilling by Gulf Canada at Roland Bay confirmed the cohesionless nature of the seabed soils but also demonstrated that the surficial granular deposit is generally confined to a thin (less than 0.5 m) veneer blanketing the seafloor. Sand thicknesses in excess of 4 m may be present, however, along the axis of the drowned reaches of the Roland River. The orientation and extent of this paleochannel was not determined during the present study, but like the sand-filled channel near Stokes Point, it probably does not extend past the 12 or 14 m isobath. The channel deposits at Roland Bay consist of fine to coarse sand and fine gravel with a trace of silt, interbedded with fine sand having a trace to some silt and a trace of fine gravel (see Appendix E.8 and Drawing No. 5.10). Unfortunately, the sand was also found to contain medium plastic silty clay, organic silt and peat layers, some of which ranged up to 0.6 m in thickness. Thus although the Roland River paleochannel is known to contain cohesionless material, the high fines content and the presence of organic beds probably limit its value as a source of offshore granular resources.

Similar limitations may also be present in the drowned reaches of the Spring River south of Stokes Point, the existence and orientation of which has only been speculated to date.



Grain Size Distribution Curve from Roland Bay (after Hardy Associates (1978) Ltd., 1983)	M.J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-260	DATE: 85/05/20
	DRAWN BY: MG	DWG. No.: 5.10

The present information suggests that the granular resource deposits at Roland Bay and Stokes Point may occupy as much as 1900 ha on the shelf. As noted previously, 1 050 000 m^3 of sand and gravel are contained in the spit at Stokes Point, while a total of another 7 800 000 m^3 are known (proven) to be present at 3 locations immediately offshore from the coast. An additional 3 500 000 m^3 are probably present in close proximity to these 3 deposits, while perhaps as much as another 6 150 000 m^3 of granular material* may underlie the shelf in the adjacent areas.

Prospective volume of any granular deposits associated with the Spring River are estimated to be only 850 000 m^3.

It is evident, therefore that a total of 40 850 000 m^3 of sand and gravel may be available for borrow development on the Yukon coastal shelf. About 25% of this volume is considered to be already proven. Additional geotechnical studies will certainly be required to assess in greater detail both the quality and the specific location of the remaining reserves.

5.5 Babbage River Paleochannel

In spite of the occurrence of ripple marks within some parts of the Babbage River paleochannel, the good signal penetration achieved on the echo sounder records suggests that it is unlikely that the offshore reaches of this particular feature provide much opportunity for the development of submarine granular resource deposits. Signal penetration in the shallow reaches is not as good, a fact which may be

assuming an average thickness of 0.5 over 1230 ha attributed to the occurrence of coarse grained material at or near the seabed. A tentative prospective volume of 3 500 000 m^3 has been proposed for purposes of the present report, but this should be considered only as a first guess. Geotechnical drilling is required if the nature of the channel sediments is to be understood at the required level for engineering planning purposes.

5.6 Summary of Granular Resource Potential

It is apparent from the foregoing that substantial granular resources are available from marine and coastal deposits southeast of Herschel Island (Table 5.8). Geotechnical and geophysical information evaluated during the present study confirm that more than 26 000 000 m^3 of sand and gravel are present at at the seabed, principally on the Herschel Sill and along the shelf between Herschel Basin and the Yukon coast. The data further demonstrate that an additional 73 600 000 m^3 are probably also available, mostly in the area immediately north of Kay Point. General geological, geophysical and bathymetric data suggest that additional volumes of granular material exceeding 71 500 000 m^3 may possibly be present, but a large scale drilling programme would be necessary to prove up these additional reserves. Total volume of granular resources in the Herschel area are currently estimated to be more than 171 000 000 m^3.

The coastal spits examined in the study area contain almost entirely gravel-size material, but all the submarine deposits investigated have both sand and gravel members. These members generally fall within the grading curves shown in Drawing No. 5.11. On the basis of the gradation curves obtained from the Stokes Point area, it appears that

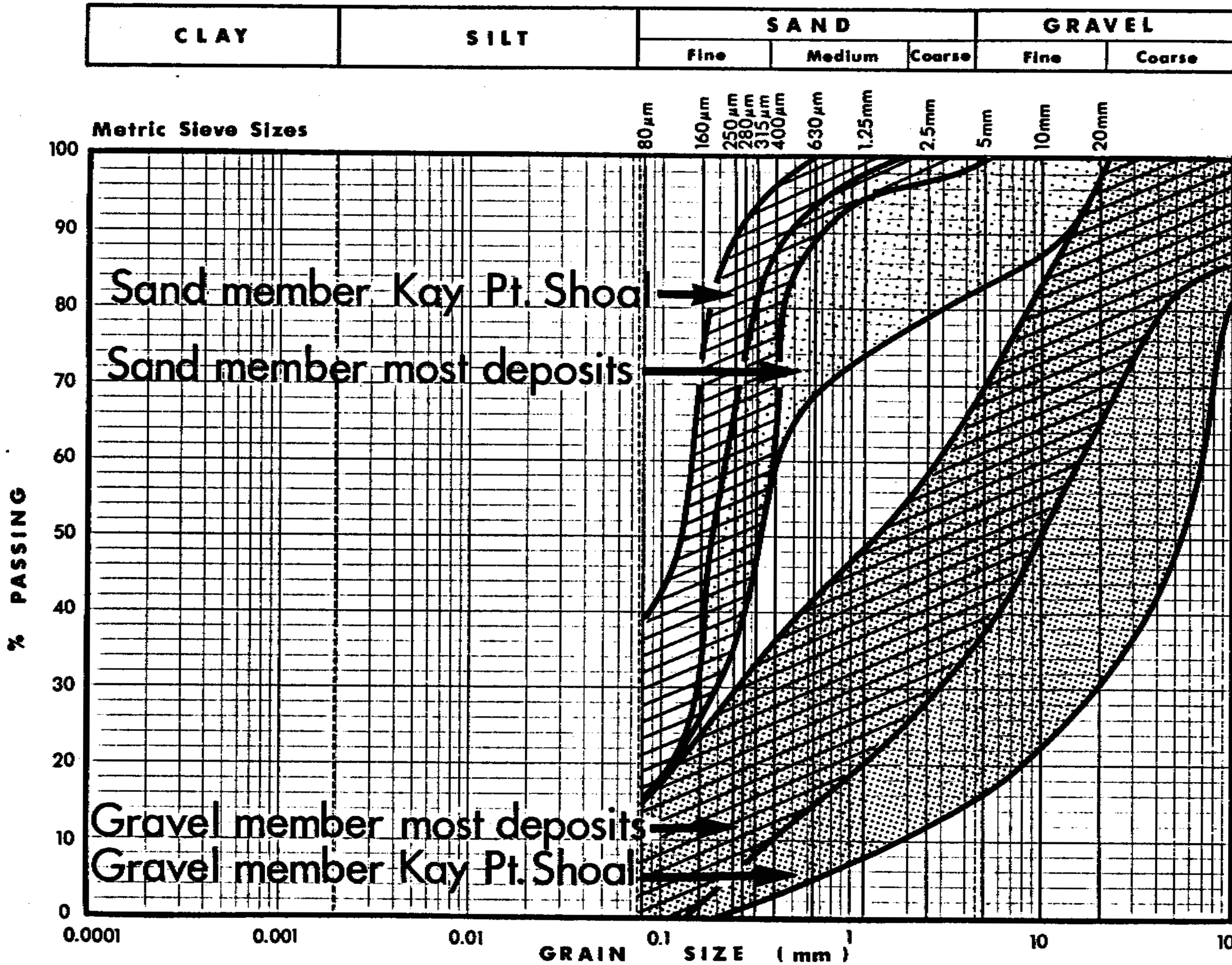
* based on an estimated area of 1400 ha and an average thickness of 0.25 m

TABLE 5.8

Summary of Granular Resource Potential in the Study Area

AREA		TOTAL VOLUME (m^3)	VOLUMES (m^3) PROSPECTIVE	PROBABLE	PROVEN
Herschel Basin		0	0	0	0
Herschel Sill	Collinson Head Shoal	8 800 000	2 700 000	2 600 000	3 500 000
	Kay Point Shoals	118 500 000	37 700 000	67 500 000	13 300 000
Yukon Coastal Shelf		40 850 000	27 600 000	3 500 000	9 750 000
Babbage River Paleochannel		3 500 000	3 500 000	0	0
TOTAL		171 650 000	71 500 000	73 600 000	26 550 000

TOTAL 171 650 000



Summary of Grain Size Characteristics in the Study Area

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DRAWN BY: MG	DWG. No.: 5.11

the submarine deposits on the coastal shelf areas probably are comprised of more sand-sized material than those granular resource deposits located on the Herschel Sill. Furthermore, the present evidence suggests that both the sand and gravel members of the Kay Point shoals are measurably coarser than most of the deposits examined elsewhere.

Future studies should therefore be concentrated on the Kay Point shoal, where superior quality material has already been located, but additional investigations are required to confirm the nature and extent of the other prospective deposits in the study area. If such deposits are also found to contain material suitable for marine construction purposes, and if such resources are required by the petroleum industry, it may be anticipated that the shallow water depths which presently exist at most sites will not be a deterrent to exploitation.

6.0 SIGNIFICANCE OF THE STUDY

The original purpose of this study was to evaluate the granular resource potential of the submarine areas southeast of Herschel Island. In the course of conducting the study, however, valuable information was also obtained about the regional geological conditions under which Herschel Basin developed its present form as well as the engineering implications of the submarine conditions which presently exist there. While a complete assessment of all of these topics is beyond the scope of the present report, it is worthwhile to review the significance of some of the major findings.

6.1 Granular Resource Potential of the Study Area

O'Connor (1983) originally estimated that 50 000 000 m^3 of gravel might exist on the Herschel Sill, even though only 10 000 000 m^3 could be considered proven reserves. The original report also suggested that another 150 000 000 m^3 of gravel might underlie the shallow waters of Phillips Bay, since it appeared from the bathymetry that this area of Herschel Basin may be occupied by fluviodeltaic sediments of the Babbage River.

Geophysical information collected during the present study has permitted the further refinement of these original volume estimates to those shown in Table 5.8. Not only has the volume of proven reserves on the Sill increased significantly to 16 800 000m^3, but an additional 9 750 000 m^3 of granular material has been proven up on the Yukon coastal shelf, thereby increasing the total proven reserves in the study area to more than 26 000 000 m^3.

The study has also demonstrated than an additional 70 100 000 m^3 of sand and gravel are also present at or near the seabed between Collinson Head and Kay Point, where perhaps another 35 000 000 m^3 are available in the subseabottom soils of the Yukon Coastal Shelf.

Information examined during the original borrow study by O'Connor (1983) suggested that the Phillips Bay area was probably underlain by floodplain or fluviodeltaic sediments consisting of a blanket of silt overlying sands and gravels. The present study was therefore designed, in part, to examine these sediments and map the occurrence of any granular materials present in the subsurface. Unfortunately, the high resolution seismic signals were not generally able to penetrate the sub-bottom sediments of Phillips Bay, and therefore no delineation of the acoustic stratigraphy in this area has been possible. At the same time, it is this very lack of signal penetration which now indicates that the shallow Phillips Bay strata are probably not of fluviodeltaic origin, as originally assumed, but are merely the eroded remnants of the same stratigraphic complex which now constitutes Kay Point and the rest of the Sill. Such strata are probably comprised mainly of fine grained moraine or lacustrine plain sediments, although Rampton (1982) has also mapped some terraced remnants of coalescing outwash fans along the northern edge of the Babbage estuary. These latter deposits consist of silty, poorly graded, fine to medium grained sand with pockets of stratified fine to coarse gravel. Recent erosion of these deposits may have contributed significantly to the present sandy shoals which currently extend southwestward from the tip of Kay Point to the mouth of the Babbage River, and they may also have formed a thin veneer over parts of the seabed in Phillips Bay. Although the thickness of this veneer could not be determined during the present study, the geological, geotechnical and geophysical information indicates that potential additional reserves of more than 40 000 000 m^3 may be present on the Sill, with about 90% of this volume existing in the shallow waters of Phillips Bay near Kay Point.

According to the present study there are no exploitable sand or gravel deposits in Herschel Basin itself, but it is estimated that some unexplored areas of the coastal shelf which borders the basin may possibly contain an additional 27 600 000 m^3 of granular material. Delineation of any submarine deposits which exist on the shelf is expected to involve relatively detailed drilling programmes, similar to those already carried out near Stokes Point, unless improved high resolution geophysical records can be obtained during future geophysical studies.

Substantial geotechnical drilling will also be required if the granular resource deposits which probably exist under Phillips Bay are to be mapped in sufficient detail for engineering purposes. Far fewer boreholes are necessary to prove up the nature of the shoals on the Sill, but sufficient detail should be provided in any future programmes so that the nature, extent, volume and quality of granular resources can be assessed in some detail. This is especially important when the deposits contain gravel-sized material, since such marine resources are not known to be abundant in the Canadian Beaufort Sea.

Lastly, it is important to note that the development of the granular resources which are known to exist near Herschel Island may not necessarily be accomplished with the same ease as some of the other borrow areas on the continental shelf. This is because many of the deposits:

1. are located in water depths which are too shallow for the conventional hopper trailer suction dredges which are presently available in the Beaufort Sea;

2. have configurations which are long and narrow over variable water depths, and hence are difficult to dredge;

3. contain material of marginal or unsuitable quality interbedded with construction grade material (this is more true of the coastal shelf deposits than those on the sill);

4. are located close to or along the coastline, where environmental restrictions may preclude development or where extensive dredging may alter the coastal dynamics and present shoreline erosion rates.

In spite of these limitations, it is envisaged that development of at least some of these resources will take place in the future, once the requirements for gravel-sized material become more firmly established.

6.2 Engineering Implications

The information collected during the present study also has a number of implications with regard to the marine engineering considerations for future development southeast of Herschel Island.

6.2.1 Surficial Soil Conditions

The study has shown that the surficial soil types may change very quickly over short distances in the study area. This is an important consideration for subsea pipelines, because such non-uniform conditions must be accounted for not only in pipe stress/foundation analyses, but also in the selection of the optimum dredging equipment to be used for pipeline trenching. Pipeline routes which cross the Herschel Sill, for example, would have to contend with surficial sediments consisting of thick sequences of recent marine clay along the edge of the Mackenzie Trough, stiff to hard lacustrine plain or morainal clays at the seabed along the seaward side of the sill (some of which might be ice-bonded at shallow depths), sand and gravel in the shoals along the crest, thin sequences of recent marine clay on the landward side of the sill and similar, but much thicker sequences in the bottom of Herschel Basin, followed by morainal, lacustrine plain, glaciofluvial or coastal deposits comprised of dense sand, or stiff to hard silt and clay on the shelf which borders the Yukon Coast. In some cases, several changes in soil type and/or consistency may occur over a distance of as little as 200 m. The foundation conditions for proposed marine structures which are sensitive to such changes must therefore be investigated very carefully.

6.2.2 Submarine Pingos

The occurrence of submarine pingos in Herschel Basin has several important engineering implications. Firstly, the discovery that such features are ice-cored means that they would not be stable under thawed conditions. They could not therefore be used as locations for marine structures or warm oil pipeline routes which might induce heating of the subseabottom sediments. Secondly, there is some evidence (O'Connor, 1984a) to suggest that some of these features may still be growing, although the rate of such growth is presently unknown. Until more detailed engineering information regarding the long term stability of these pingos is available, it is recommended that the entire seabed on and adjacent to these features be avoided.

6.2.3 Recent Diapirism

The discovery of what appears to be recent shallow diapirism in the Babbage River paleochannel suggests that the stability of the seafloor sediments should be carefully examined prior to the selection of locations for engineered structures. Although such diapirism has to date been noted only in the one area, special attention should be given to the stability of all areas of the shelf where infilled paleochannels may exist, e.g. Roland Bay, Spring River, Workboat Passage. Since such features appear to be somewhat anomalous on the continental shelf, a special effort should be made to study their nature and occurrence in more detail. Of particular interest are the specific geotechnical/geological conditions under which these features may form beneath Arctic waters, and how they may be similar in origin and/or structure to the "mud lumps" which presently form in the Mississippi Delta. Unlike the diapirs which may currently be found further offshore near the shelf edge and along the eastern edge of the Mackenzie Trough, these features are located in close proximity to land and may therefore be studied in detail under both summer and winter conditions, thereby permitting the identification of any new growth or collapse.

6.2.4 Coastal Dynamics

The geological/geophysical evidence suggests that the coastal dynamics systems in the study area may be particularly complex. While Herschel Basin consists entirely of a depositional environment, the shelf, sill and paleochannel areas appear to have both depositional and erosional elements. Careful mapping of these elements and the specific conditions (currents, sediment supply, etc.) which presently control their development is required so that the effects of any future marine development may be predicted with the appropriate level of confidence.

6.2.5 Slope Stability

Subbottom and bathymetric information show clearly that the seabed slopes which constitute the margins of Herschel Basin are generally in an unstable condition. While major sediment gravity flows into the Basin do not appear to be common, there is substantial evidence of slumping of both the lacustrine and the recent marine clays along the basin margins. Some of these slumps intersect the seabed well back of what is now the bathymetric edge of the basin. Setbacks for structures located near the edge of the basin should be determined from both geophysical and geotechnical data, as it will probably not be possible to recognize previous failure planes from the geotechnical data alone. Pipeline routes which must cross the basin edge should be located only in the most stable areas, and should be oriented such that any future slumping will result in minimal damage to the pipeline.

6.2.6 Shallow Gas

The widespread occurrence of shallow gas in the surficial sediments of Herschel Basin and the surrounding areas was not noted from the geophysical evidence examined during the present study. It is possible, however, that at least some of the reflectors which have been interpreted as acoustic permafrost are actually due to low concentrations of shallow gas in the soil. This is particularly true in the shelf, sill and paleochannel areas, where signal penetration and resolution was generally poor. There is little geophysical evidence, however, to suggest that shallow gas occurs in the study area at concentrations which may pose an engineering hazard, except perhaps in the Babbage River paleochannel and on the seaward side of the Sill.

In the Babbage River paleochannel there is good bathymetric and subbottom data to suggest that some of the recent diapirs, or at least portions of these diapirs, may have collapsed very rapidly, leaving behind large depressions on the seafloor. Similar features were also observed on the seaward side of the Herschel Sill, along the west edge of the Mackenzie Trough.

As O'Connor (1977, 1980, 1984b) and others have reported, such collapse features may often be due to venting of shallow gas at the seafloor. The collapse depressions observed on the edge of the sill are much larger than those observed in the paleochannel, but they are thought to be somewhat older and perhaps more stable at the present time. The modern features observed in the paleochannel, however, may presently be active and hence may indicate the extremely unstable nature of these recent sediments.

6.3 Historical Geology

The present study has provided important new information regarding the historical geology of the study area.

Drilling through the floor of the basin has confirmed the presence of ice-bonding in (presumed) lacustrine sediments underlying what is evidently recent marine and lacustrine clays. These ice-bonded strata, which presently appear to be about 7 m thick, must have formed when all or most of Lake Herschel was drained. It is speculated that the draining and subsequent ground freezing initiated the growth of the submarine pingos which presently exist along the east side of the basin floor. These have subsequently been buried by recent sediments, but some have apparently continued to grow, even perhaps under present marine conditions.

According to the geophysical evidence, the top of these ice-bonded strata occurs at between 80 and 85 m below present sea level. The most recent sea level curves proposed for the Beaufort Sea (see O'Connor, 1984b) suggest that draining to such an elevation may have occurred more than 20 000 years ago, or as recently as 10 000 years ago. Consideration of the nature and thickness of the ice-bonded strata suggests that the latter date is probably more likely than the former, but age dating will have to be performed on recovered samples before this hypothesis can be confirmed.

7.0 SUMMARY AND CONCLUSIONS

Recent geophysical and geotechnical studies conducted by both government agencies and some of the major petroleum operators in the Beaufort Sea have greatly enhanced our understanding of the marine geology of Herschel Basin and the surrounding area.

These studies demonstrate that the area may be divided into 4 subregions, based on bathymetry and surficial geology. These subregions are the Herschel Basin, the adjoining Yukon Coastal Shelf, the Herschel Sill, and the Babbage River Paleochannel. Each of these subregions is characterized by a unique set of seabed and subseabed conditions which has particular implications for the future development of both granular resources and marine structures.

The Herschel Basin encloses an area of approximately 100 km^2. Maximum water depths in the Basin exceed 80 m, but the east half is characterized by submarine pingos, some of which rise to within 25 m of the sea surface. Geotechnical and geophysical studies demonstrate that the floor of the basin consists of approximately 40 m of laminated silty clay overlying sand, stiff clay (presumed till) and gravel strata. Ice lensing observed in the surficial clay unit suggests that the basin was drained and the bottom sediments exposed for some period of time in the past. Growth of the submarine pingos which presently occupy the basin is believed to have been initiated at this time.

Although extensive sand and gravel layers were noted in the subseabottom sediments, the extreme water depths and the presence of thick surficial clay unit preclude the development of any granular resources in Herschel Basin.

The precise subsurface conditions which underlie the sill joining Collinson Head to Kay Point are difficult to resolve acoustically, but surface sampling, test dredging and several geotechnical boreholes have been useful in determining the surficial geology. For the most part, it appears that the sill is comprised of the same terrain units which now are 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. Maximum water depths along the crest may reach 17 m, but most of the sill is much shallower (4 - 12 m). 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. 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.

The narrow coastal shelf which borders the north and west side of Herschel Basin is, 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.

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.

In addition, the Babbage River Paleochannel contains several bathymetric features interpreted to be recent mudlumps or diapirs. Similar examples of seabed instability have not been reported previously in such shallow water depths on the Beaufort Sea continental shelf. Verification of the nature of the subbottom sediments in the paleochannel will require additional borehole information.

In summary, the geophysical and geotechnical evidence acquired to date suggests that Herschel Basin and its environs is a uniquely complex area of the continental shelf which contains a diversity of geologic features whose origins are only now beginning to be understood. These features include ice-cored submarine pingos, unstable slopes, thick soft recent sediments, sand and gravel shoals, subsea permafrost and recent diapirs. Preliminary granular resource estimates suggest that between 100 000 000 m^3 and 171 650 000 m^3 of sand and gravel may be located at the seabed in the area, although extensive drilling will be necessary to prove up the larger quantities. Unfortunately, many of these granular resources are located in areas which are not readily accessible by hopper trailer suction dredges, and therefore alternative mining methods may be required if exploitation is to proceed.

8.0 RECOMMENDATIONS

1. Additional drilling is required to prove up the quantity and quality of granular resources which are present in the study area.

   <u>Immediate drilling</u> should be specifically undertaken:

   a) to determine the thickness and lateral extent of the Kay Point shoal, especially in water depths where geophysical prospecting is not of benefit.

   b) on the sill northwest of the Kay Point spit to determine whether glaciofluvial gravels mapped along the coastline also extend offshore.

   c) on the Herschel Basin shelf between Roland Bay and Catton Point, to determine whether the large deposits of glaciofluvial gravels mapped on the Yukon Coastal Plain also occur in the offshore.

   Of <u>secondary importance</u> is a limited drilling programme to:

   a) determine the southern limits of the Collinson Head shoal.

   b) determine the total extent of the granular deposits offshore from Stokes Point.

   c) assess the potential for granular resource development of the Babbage River Paleochannel.

2. Additional drilling should be undertaken to evaluate the historical geology of Herschel Basin. In order to complete the stratigraphic sequence, a minimum of 2 boreholes with detailed

sampling are recommended. One should be drilled through the floor of the Basin into bedrock (total depth approximately 80 m below the seabed). The second should be drilled through the centre of one of the submarine pingos into bedrock (total depth approximately 160 m below the seabed). A third hole through the sill into bedrock (depth unknown) would also be beneficial. Particular attention should be paid to obtaining material which is suitable for age dating.

3. The occurrence of diapiric structures at the seabed in the Babbage River Paleochannel offers a unique opportunity to investigate the mechanisms by which such unstable features occur in the Canadian Arctic deltaic environments. Every effort should be made to obtain detailed hydrographic and subbottom evidence over one of these diapirs, so that its stratigraphy can be better understood. In addition, we recommend that a detailed geotechnical drilling programme be undertaken to provide information on the nature and strength of the subbottom soils which comprise the diapir. Special attention should be paid to determining the significance of any nearby shallow gas occurrences as well as to the strength and in situ density of the subseabed soils. Repetitive measurements are required to discern whether the diapirs are presently growing, and at what rate.

4. Collapse features identified on the Mackenzie Trough side of the sill also bear further investigation, because they may represent a significant constraint to be considered before the development of any subsea pipeline routes across the Trough can safely proceed. Such investigations should include both geotechnical drilling and additional high resolution seismic profiling.

5. Lastly, additional efforts should now be made to understand the granular resource potential of the areas of the Natsek Plain along the coastline northwest of Herschel Island. Using the diversity of geologic subregions mapped near Herschel Basin as an analogue, it should now be possible to construct a more appropriate geologic model demonstrating the occurrence of sand and gravel in the marine areas along the Yukon Coast. The investigative programme should be completed in 3 phases: an initial examination of the bathymetric records and original CHS field sheets in order to identify the most prospective areas; a detailed examination of the geophysical data which are currently available in order to prioritize the most prospective features; and a follow-up drilling programme designed to verify the soil conditions at those locations having the greatest granular resource potential. Only through such an integrated, systematic approach will the true granular resource potential of the western Canadian Beaufort Shelf be realized.

9.0 ACKNOWLEDGEMENTS

Grateful appreciation is expressed to Gulf Canada Resources Inc. and Dome Petroleum Ltd. for permission to include proprietary data in the Herschel Basin study.

CLOSURE

This report has been prepared in accordance with generally accepted principles of geology, geophysics and engineering in order to provide Indian and Northern Affairs Canada with an overview of the geological conditions and granular resource potential of the seabed near Herschel Island. Conclusions and recommendations have been formulated by synthesizing data recently acquired for DIAND with other information obtained previously by others in the same study area. Both the quality and the quantity of data available for interpretation vary across the study area, and careful consideration of these factors is recommended in designing future programmes to further delineate or mine these seabed resources.

Respectfully submitted,

M. J. O'CONNOR & ASSOCIATES LTD.

PROFESSIONAL
YUKON
MICHAEL J. O'CONNOR
TERRITORY
ENGINEER

PROFESSIONAL ENGINEER
R.D. KING
ALBERTA

M. J. O'Connor, P. Eng., P. Geoph. | R. D. King, P. Eng., P. Geol.

MJO/ked

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