REGIONAL INVENTORY

OF

OFFSHORE GRAVEL PROSPECTS

CANADIAN BEAUFORT SEA

submitted to

Indian and Northern Affairs

April 1983

M.J.O'CONNOR & ASSOCIATES LTD.

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CONSULTING ENGINEERS & EARTH SCIENTISTS

101, 4712 - 13th STREET N.E., CALGARY, ALBERTA T2E 6P1 TELEPHONE: (403) 276-8991

July 29, 1983 10-176

Northern Renewable Resources
Northern Environment, DIAND
Room 630, Les Terrasses de la Chaudiere
10 Wellington Street
HULL, P.Q., K1A OH4

Attention: Mr. Dale Longlitz

Dear Sir:

Enclosed please find our final report on the above captioned project, prepared using proprietary information supplied by the three major petroleum operators (Dome, Gulf, Esso) in the Canadian Beaufort Sea. We have received strong support in this endeavour from individuals in all three companies, and also from S. M. Blasco of the Geological Survey of Canada.

We trust you will find the enclosed suitable for your present purposes, and look forward to being of service to you in the future.

Yours very truly,

M. J. O'CONNOR & ASSOCIATES LTD.

M. J. O'Connor, P. Eng.

MJO/keh
encl.

REGIONAL INVENTORY

OF

OFFSHORE GRAVEL PROSPECTS

CANADIAN BEAUFORT SEA

Submitted to:

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Submitted by:

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April 1983

Job No. 10-176

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EXECUTIVE SUMMARY

The construction of marine facilities for hydrocarbon exploration and possible future production in the Canadian Beaufort Sea may require the use of substantial quantities of offshore granular resources. While independent studies undertaken by the petroleum operators and the Geological Survey of Canada have already established that substantial quanitites of sand-sized material are present at the seafloor, little information is currently available to DIAND regarding the distribution of offshore gravel.

In order to facilitate the preparation of a management plan for future development of these offshore resources, M. J. O'Connor & Associates Ltd. undertook the review and synthesis, on a confidential basis, of proprietary information supplied by the Dome Petroleum, Esso Resources Canada and Gulf Canada Resources pertaining to the location and extent of seabed gravel sources in the Canadian Beaufort Sea.

The report presented herein concludes that gravel sized material has been located at several sites on the continental shelf, and that the potential exists for the discovery for other borrow prospects if additional exploration is undertaken.

It is presently estimated that approximately 95 000 000 m^3 of gravel have already been discovered at the seabed near Hershel Island, Issigak, Isserk and Banks Island. While less than 25 000 000 m^3 may be considered "proven" reserves, and not all of this may actually be readily exploitable, it is speculated that perhaps as much as 300 000 000 m^3 of gravel may eventually be delineated at these sites. Since future gravel requirements of the petroleum operators are largely unknown, it is uncertain whether such gravel volumes will be of sufficient quantity to meet the future long-term offshore requirements of both DIAND and the petroleum industry.

It is concluded that an effective management plan can therefore be developed only if close cooperation is maintained between the appropriate government agencies and the major petroleum operators. It is recommended that future gravel studies undertaken by DIAND utilize the considerable expertise and experience available both within the major petroleum companies and the Geological Survey of Canada.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF DRAWINGS

LIST OF PLATES

LIST OF TABLES

1.0 INTRODUCTION

The construction of artificial islands for hydrocarbon exploration in the Canadian Beaufort Sea has, in the past, required the mining of significant amounts of seabed granular resources. Independent studies initiated by the major petroleum operators (Dome, Esso, Gulf) and the Geological Survey of Canada (GSC) have demonstrated that substantial quantities of sand-sized materials are readily available at or near the seabed, but the supply of gravel-sized materials is not as well understood. In recognition of this fact, the Director, Northern Renewable Resources, Indian and Northern Affairs Canada (DIAND), requested that M. J. O'Connor & Associates Ltd. compile and analyze available information on the distribution and occurrence of subsea gravel. The information to be examined was to include proprietary data supplied by each of the major petroleum operators in the Canadian Beaufort Sea, as well as data which was presently in the public domain. In order to protect the proprietary nature of much of the information, use of the data was conditional upon the following:

(a) Data provided by the individual petroleum operators were intended for the sole use of M. J. O'Connor & Associates Ltd. in this endeavour and hence were to be treated as strictly confidential.

(b) The results of the study were to be reported in a manner consistent with other similar regional-type studies that have been prepared under the auspices of the Beaufort Sea Seabed Synthesis Project. More specifically, gravel

inventories were to be identified on a semi-regional basis without reference to specific locations and/or pit outlines.

(c) Prior to distribution of the final report to DIAND and the operators, a draft version was to be submitted to and reviewed by S. M. Blasco, P. Eng. of the GSC to ensure that the contents remained consistent with the other aforementioned Beaufort Sea synthesis studies.

By proceeding in the above manner, it was agreed that a suitable document could be produced to serve as the basis for future discussions between the petroleum operators and DIAND to address the need for a comprehensive management plan to satisfy both the short-term and long-term demands for gravel in the Arctic offshore.

2.0 AUTHORIZATION

Authorization to proceed with the study was received by telex from G. N. Faulkner, Assistant Deputy Minister, Northern Affairs, on 83/02/15. Written confirmation of Contract No. 82-607 was received 83/03/04. Completion date for the work was specified as 83/03/31.

3.0 SCOPE OF THE STUDY

During the course of the study, M. J. O'Connor & Associates Ltd. was to:

1. Review all available industry and government data pertaining to granular resource inventories in the Canadian Beaufort Sea to determine the quality, quantity and location of known gravel sources.

2. Identify other possible areas for future gravel exploration and/or development.

3. Discuss possible constraints to development and provide recommendations regarding future short-term and long-term use of the resource.

4. Provide specific recommendations and budgetary requirements for future studies which might be carried out to complete a gravel inventory of the Canadian Beaufort Sea at a level consistent with the management and regulatory requirements of DIAND.

Throughout the study, M. J. O'Connor & Associates Ltd. was to interface directly with personnel from the major petroleum operators.

4.0 METHODOLOGY

4.1 Information Reviewed

During the course of the project the three major petroleum operators provided M. J. O'Connor & Associates Ltd. with extensive proprietary information relevant to the production of an overview gravel inventory of the Canadian Beaufort Sea. This data may be grouped into several categories, as shown below:

Geophysical Information -

Most of this information consisted of site-specific reports and maps based on an interpretation of shallow, high resolution reflection data. In many cases the original seismic records were also made available, but the nature and timing of the study precluded any detailed reinterpretation of the actual reflection records.

Geotechnical Information -

This data set consisted of borehole logs and geotechnical reports prepared during both foundation and borrow investigations. Some of the early studies provided only generalized stratigraphic information, but the more recent investigations also include detailed grain size distribution analyses. The results of a number of shallow grab sampling programs were also examined. In most of the latter cases, however, the results were reported in general (and sometimes non-standard) descriptive terms, and no actual grain size curves were available.

Environmental Information -

These data consist mainly of grab samples and photographs of the seabed obtained in support of baseline environmental studies to evaluate the effects of dredging on the submarine flora and fauna. Grain size information from these sources was usually only semi-quantitative, ie. it specified the relative quantities of silt/clay, sand, or gravel observed, but did not provide grain size distribution curves.

Dredging Information -

The dredging data may be divided into two sub-categories. The first category consists of information obtained while test-dredging to confirm the location and/or limits of specific borrow prospects. The second category consists of quality control information obtained during the course of normal dredging operations. In both cases, substantial data on the nature of the actual grading curves was commonly available.

While much of the above information had already been compiled into formal reports, some of it existed only as internal memos, notes and sketches. The reference list which follows this report has attempted to document these data sources completely, insofar as is possible given the nature of the information. DIAND, together with the GSC, established primary contacts for the author within each of the three major petroleum companies. In the course of compiling and synthesizing the gravel information, the author also interviewed additional personnel from the three petroleum companies to solicit their comments regarding both the short and long-term requirements for

construction grade gravel resources in the Beaufort Sea. While their sometimes diverse comments have not been incorporated directly in this report, this interaction has been most benefical in helping the present author to formulate an appropriate strategy for future gravel inventories in the Beaufort Sea. A list of these personnel is shown in Table 4.1.

4.2 Techniques used in Locating and Assessing Deposits

The nature and scope of the present study did not permit the author to undertake an exhaustive review of all the shallow seismic data which is presently available in the Beaufort Sea for the express purpose of identifying possible gravel sources. Instead, the author has compiled and synthesized site-specific information collected and/or interpreted by others to identify the characteristics of the known borrow sources. In order to locate other possible gravel sources, the author has relied primarily on regional geologic models developed during the Beaufort Sea Seabed Synthesis Project for the Geological Survey of Canada, as well as his familiarity with the extensive shallow seismic data base which has already been collected in the study area.

To assess the quantity and quality of gravel which might be present in each known gravel prospect, the information from all available sources was combined on a single work map of each site. The integration of these data proved most useful in evaluating the lateral extent and thickness of each deposit, since the combined information often covered a much larger area than the limits of the borrow prospect mapped by individual operators. Since the information for these work maps forms a major portion of the proprietary data base, their inclusion in the present report has been precluded as a condition of the study. Nevertheless, it is the author's opinion that the data which have been included herein are entirely adequate to support the nature and scope of the present study.

TABLE 4.1

PERSONNEL CONTACTED DURING THE STUDY

Dome Petroleum	-	E. Pessah* K. J. Hewitt G. Johnson M. Bradshaw D. Mitchell C. O'Rourke
Gulf Canada Resources	-	W. Livingstone* A. Stirbys H. Stewart
Esso Resources Canada	-	C. Williams* K. Nelson J. Beckman C. Mancini L. Green

* Primary Contact Person

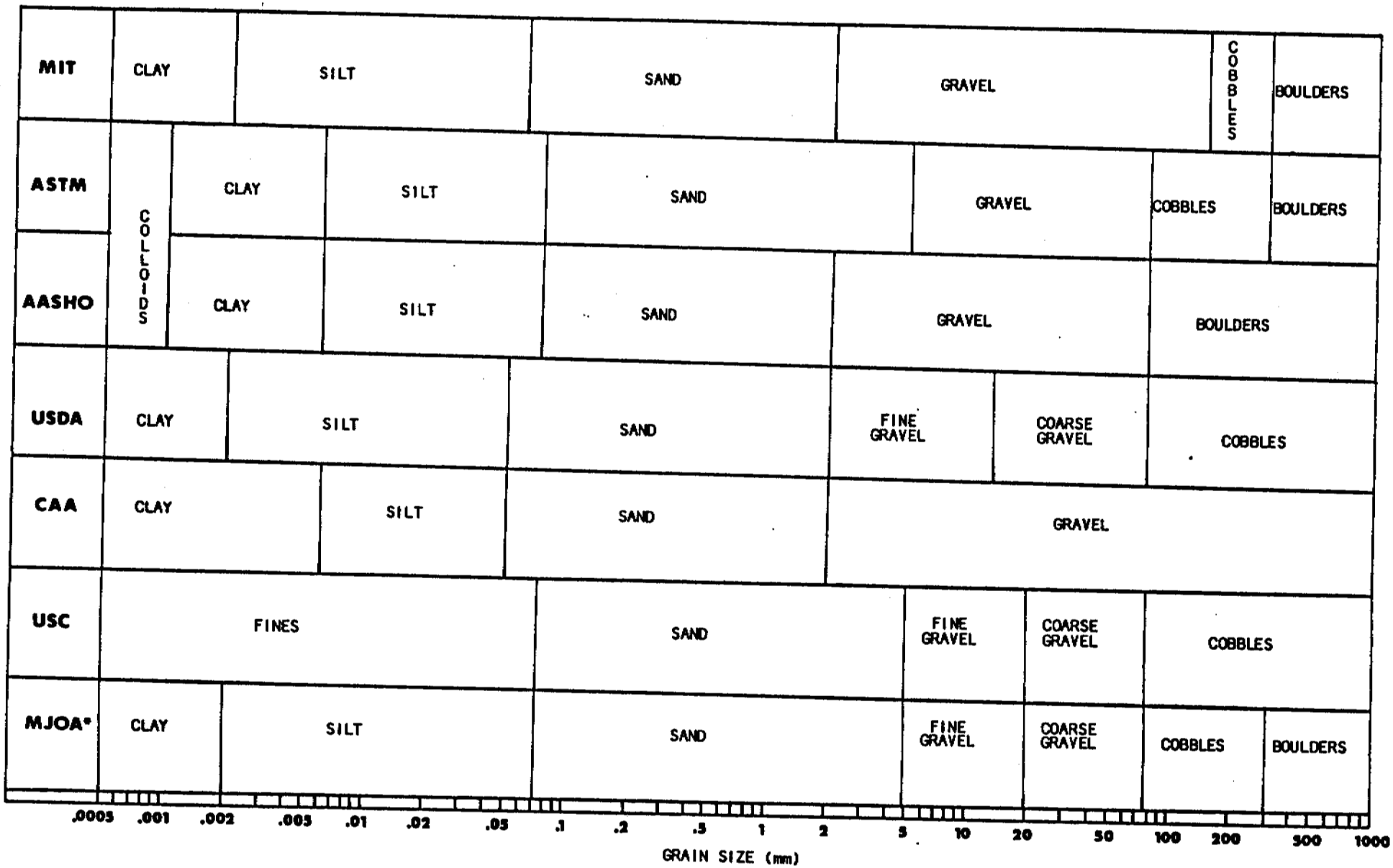
4.3 Definition of Gravel

Since this report focuses on the distribution of seabed gravel, as opposed to sand, it is useful to review the various grain size classification systems and clarify the nomenclature used in the present report.

Table 4.2 shows information presented by Winterkorn and Fang (1975, p. 68) which has been modified using additional data presented in the Annual Book of ASTM Standards (1981) and Lambe and Whitman (1969, p. 40). According to the table, gravel size materials have grain sizes greater than 2 or 5 mm, depending on the classification system. Some disparity is also evident in the grain size limits and the accepted nomenclature for the more coarse grained gravel components such as cobbles and boulders.

For purposes of the present report, it has been necessary to generalize the terminology somewhat to account for the various classification systems adopted by the original authors of the resource documents. As Table 4.2 demonstrates, in this report all materials greater than 5 mm in diameter will be referred to as gravel. Additional identifiers such as fine, coarse, cobbles and/or boulders will be presented only when such precise information was available from the original engineering reports. The boundaries between such sub-classes have been shown on the table.

Although much of the gravel in the Beaufort Sea is relatively fine grained, i.e. grain sizes often range from 5 to 20 mm, some examples of more coarse grained materials were also noted. In order to accommodate these occurrences and provide some indication of those locations where the coarser material may be obtained, an upper limit of 100 mm has been used on the grain size diagrams presented in this report.



*Classification system used in this report.

TABLE 4.2 GRAIN SIZE CLASSIFICATION SYSTEMS (after Winterkorn and Fang, 1975)

Since some of the information reviewed does not make any distinction between sand and gravel, it has been necessary to use the more general term "granular resource" in describing the total volume of sand and gravel in some borrow deposits. Wherever possible, however, the estimated volume of gravel in such granular deposits has been explicitly noted in the text.

5.0 RESULTS

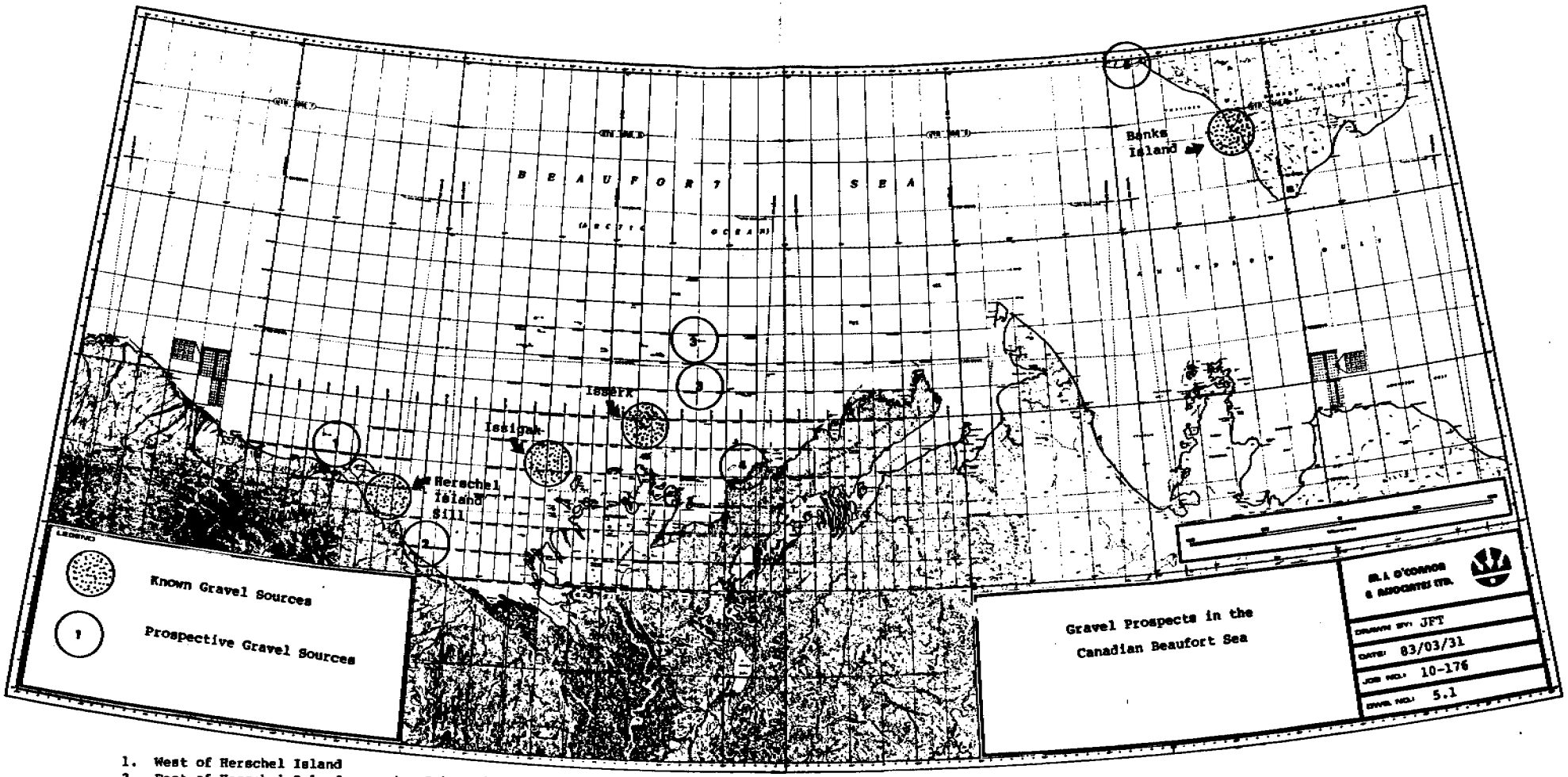
5.1 Proven Gravel Prospects

At the present time, only four borrow prospects are known to contain sufficient quantities of gravel to warrant consideration in this category. As Drawing No. 5.1 shows, these are the Herschel Island sill, Issigak (also known as South Tarsiut and Kadluk), Isserk and Banks Island. Although the level of groundtruth information at some of these locations makes an accurate assessment of either the quality or quantity of gravel in the entire borrow prospect very difficult, it is clear that all four prospects contain some gravel-sized granular material at the seabed and each exists at a suitable water depth to permit at least partial development by dredging plants which are currently operating in the Beaufort Sea.

5.1.1 Herschel Island Sill

This prospect is so named because it comprises several deposits along the crest of the sill which runs from Kay Point northwest to Collinson Head, the eastern tip of Herschel Island.

As Table 5.1 demonstrates, most of the granular resource information which is available at this location, appears to have been collected by Dome Petroleum, although important information is also available from the Canadian Hydrograph Service, the Geological Survey of Canada, and more recently, from Gulf Resources Canada.



1. West of Herschel Island
2. East of Herschel Island
3. Kugmallit Channel
4. Tuk Peninsula
5. Banks Island

Note: Original basemap courtesy
Canadian Engineering Surveys Ltd.

TABLE 5.1

Data Base Examined for the Herschel Island Sill

Year	Collecting Agency	Date	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

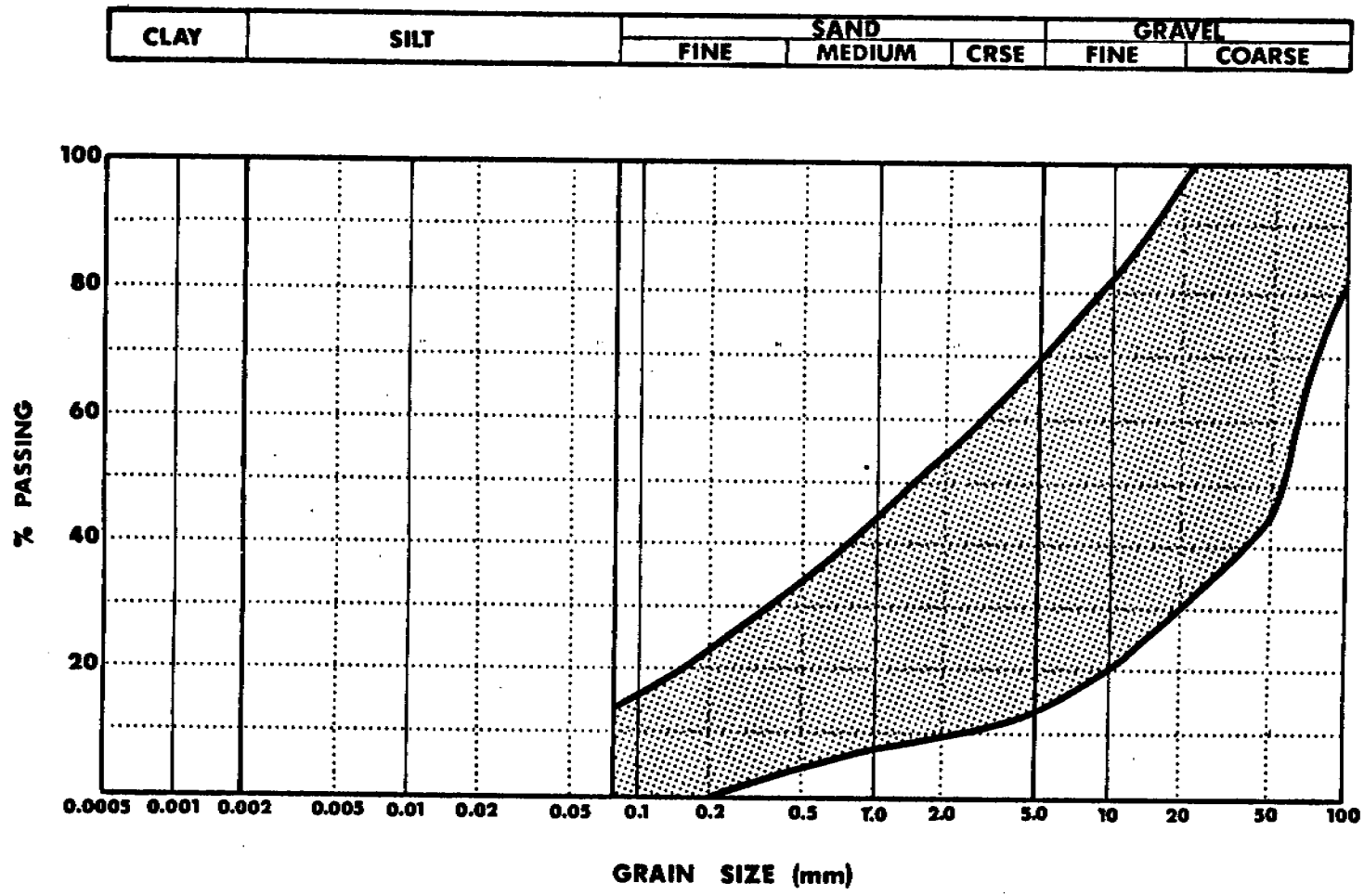
Synthesis of the above information suggests that gravel exists at the seabed over an area of at least 2700 ha along the crest of the sill. Mean water depths for the gravel deposits vary from 6 to 14 m, although gravel is present to the 15 m isobath in some places and is suspected to occur as shallow as the 2 m isobath in others. Most of the deposits appear to consist of a thin gravel veneer, perhaps only 1 or 2 m thick, although some patches as much as 6 m thick may exist near Kay Point.

It is apparent that some 50 000 000 m^3 of gravel probably exist in this area, although only about 20% of this volume can actually be considered to be proven reserves. Of course, if the largely untested shallow deposits near Kay Point also prove to be prospective (and exploitable), more than 200 000 000 m^3 of gravel may be available for future construction purposes.

The quality of the gravel appears to vary somewhat according to the nature and location of the individual deposits on the sill. Most of the gravel, however, appears to fall within the grading envelope shown in Drawing No. 5.2. Those deposits near Collinson Head typically exhibit a slightly finer and more uniformly well graded envelope than do the deposits to the southeast. In the latter case, fines* contents seldom exceeded 2% and cobbles to 150 mm diameter were observed frequently, but in the former case, silt contents sometimes exceeded 5% while the maximum grain size seldom exceeded 75 mm.

The Herschel Island Sill was utilized as a gravel source by Dome Petroleum in both 1981 for construction at Tarsiut and in 1982, for the SSDC at Uviluk. Materials inspection tests conducted during the 1982 program confirmed that the quality of

*grain sizes less than 74 μm



Generalized Grain Size Envelope from the Herschel Island Sill

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JOB NO.: 10-176	DATE: 83/03/31
DRAWN BY: WAO	DWG. NO.: 5.2

the dredged material compared favourably with the grain size analyses reported in the earlier studies and that the gravel could be used as a construction material for artificial islands.

5.1.2 Issigak

The Issigak borrow site is located approximately 20 km northwest of Pelly Island on a small bathymetric high. Esso Resources first surveyed this location in the early months of 1975. In 1980 and 1981 Dome Petroleum resurveyed the site and designated this prospect as the South Tarsiut borrow pit, because of its obvious geographic location relative to the nearby Tarsiut exploration site. As Table 5.2 demonstrates, Esso Resources Canada and Gulf Canada Resources both conducted additional work at the site in 1982. This time the Esso reports refer to the site as the Kadluk Borrow Area while the Gulf reports use the original term Issigak. While it is true that the actual borrow prospect crosses the boundary between the Kadluk and the Issigak grid zones, the larger part of the prospect appears to occur within the latter area. In view of the above, and at the risk of perpetuating the confusion in nomenclature which already exists, the present report will refer to the prospect as the Issigak Borrow site.

As Table 5.2 shows, the three major petroleum operators have already conducted more than 50 km of high resolution shallow seismic and bathymetric profiling at this site. In addition to the 37 grab samples and 52 boreholes drilled on and near the site, some 22 locations have also been test dredged to delineate the quantity and quality of granular material which

TABLE 5.2

Data Base Examined at Issigak

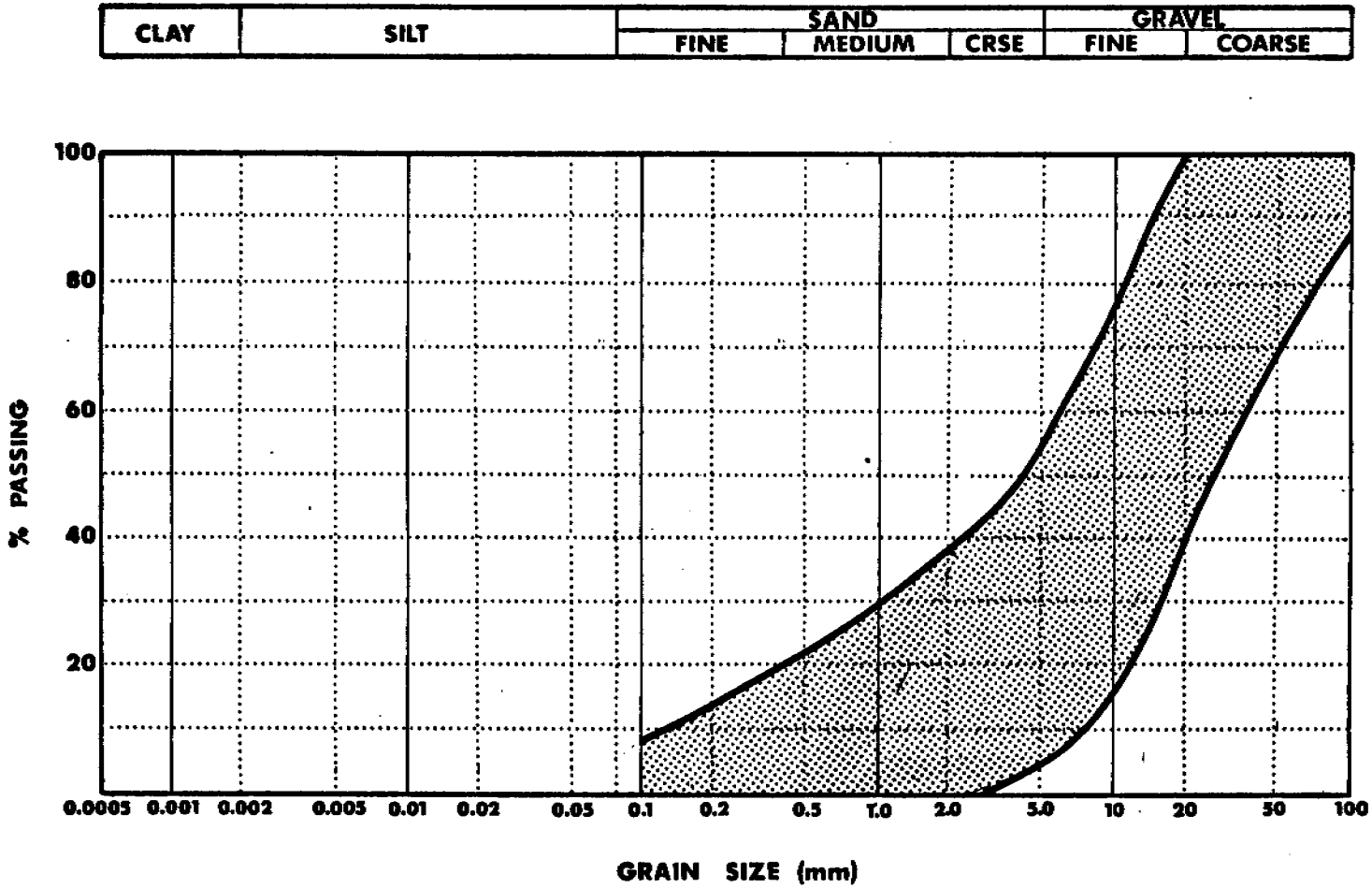
Year	Collecting Agency	Data	Quantity
1974	Esso Resources Canada Ltd.	Geotechnical Boreholes	6
1975	Esso Resources Canada Ltd.	Geotechnical Boreholes	4
1980	Dome Petroleum	High Resolution Shallow Seismic	40 km
1980	Dome Petroleum	Geotechnical Boreholes	10
1981	Dome Petroleum	Shallow Boreholes Shallow Vibracores Test Dredging	4 21 22 locations
1981	Gulf Canada Resources	High Resolution Shallow Seismic	10 km
1982	Gulf Canada Resources	Production Dredging Quality Assessment Analysis	11
1982	Esso Resources Canada	Geotechnical Boreholes	7
1982	Esso Resources Canada	Detailed Bathymetric Profiling	Unknown
1982	Esso Resources Canada	Grab Samples	37

may be present. These data demonstrate that the prospect occurs in 7 to 11 m of water and includes an area of 1500 to 2000 ha. The mean water depth over the feature is approximately 8.5 m, making it difficult to develop with the larger trailer-hopper suction dredges now operating in the Beaufort Sea.

The average thickness of the deposit appears to be about 2 m. Thin (<1 m) gravel areas are also common, although areas having up to 3 m of granular borrow may be found in some places, and one local area reported to contain sand and gravel at least 7 m thick has been identified.

According to the information presently available, the total volume of granular material in the deposit appears to be somewhere in excess of 15 000 000 m^3. While only about 70% of this may currently be considered "proven" reserves, it is possible that additional borehole information at both the south and northeast ends of the deposit may ultimately establish reserves in the 35 000 000 to 40 000 000 m^3 range.

Both fine and coarse gravel are available at the Issigak site (Drawing No. 5.3), with most samples having a D_{50} between 10 and 20 mm. Sand commonly constitutes 5% to 45% of any recovered samples, including those obtained from the dredges. Fines generally constitute only 1% or 2%, although this may exceed 5% in some local areas, typically near the edge of the prospect. Samples obtained from geotechnical drillholes usually provide a good indication of the grain size



Generalized Grain Size Envelope
Issigak Borrow Site

M.J. O'CONNOR & ASSOCIATES LTD.

JOB NO.: 10-176	DATE: 83/03/31
DRAWN BY: JFT	DWG. NO.: 5.3

distribution of the material, but because the diameter of the borehole sampling device may be less than the diameter of some of the gravel components, the actual percentage of coarse gravel which is present may be underestimated.

Although this site has been utilized as a source of coarse building material in both 1981 and 1982, it is estimated that less than 50 000 m^3 of the deposit have been mined to date. Thus more than 99% of the original volume may still be available for future use.

5.1.3 Isserk

The Isserk borrow site occurs approximately 20 km north of Pullen Island, in a physiographic region which has been designated by O'Connor (1982) as the Akpak Plateau. Granular material outcrops at the seabed along the crest of a gentle, north-trending ridge. Water depths vary from 12 to 16 m, with most of the borrow occurring about the 13 m isobath. The total area of the deposit appears to exceed 2000 ha, but granular material along the flanks of the feature is blanketed by a thin veneer of recent marine silty clay.

More than 40 km of shallow seismic data have been collected at this site by a combination of all three petroleum operators. In addition, 25 boreholes and 21 grab samples are known to have been acquired on the same feature. Production dredging at Isserk was carried out briefly by Dome in 1981, while Gulf conducted some test dredging over this deposit the following year.

• material which passes the 75 μm sieve, including both silt and clay.

On the basis of the above, it appears that more than 50 000 000 m^3 of granular material is present at the Isserk location, but sand comprises approximately 80% of this volume. Of the remaining 10 000 000 m^3 of gravel, only 2 000 000 m^3 may be considered "proven" reserves*. Borehole, seismic and test dredging results all indicate that some additional reserves may be present outside the main borrow area already identified, and hence further groundtruthing may eventually demonstrate that some 14 000 000 m^3 of gravel are available from this prospect.

Although four boreholes at this location encountered gravel, only two grain size analyses of the gravel material were available for examination. Drawing No. 5.4 demonstrates that the gravel tends to be very sandy. Even when it is not, most of the gravel appears to be relatively fine grained, with no evidence of material greater than 20 mm in diameter. Test dredging conducted by Gulf in 1982 supports this finding: the mean D_{50} of material recovered from the deposit was only about 230 m, and only 2 of 151 samples tested contained granular material with a D_{90} in the gravel range (greater than 5 mm).

It therefore appears that Isserk borrow site must presently be considered primarily a source of sand. While gravel is known to exist at the site, substantially more work is required to prove up the exact quantity and quality of the coarser grained material which may be present. Without this additional work

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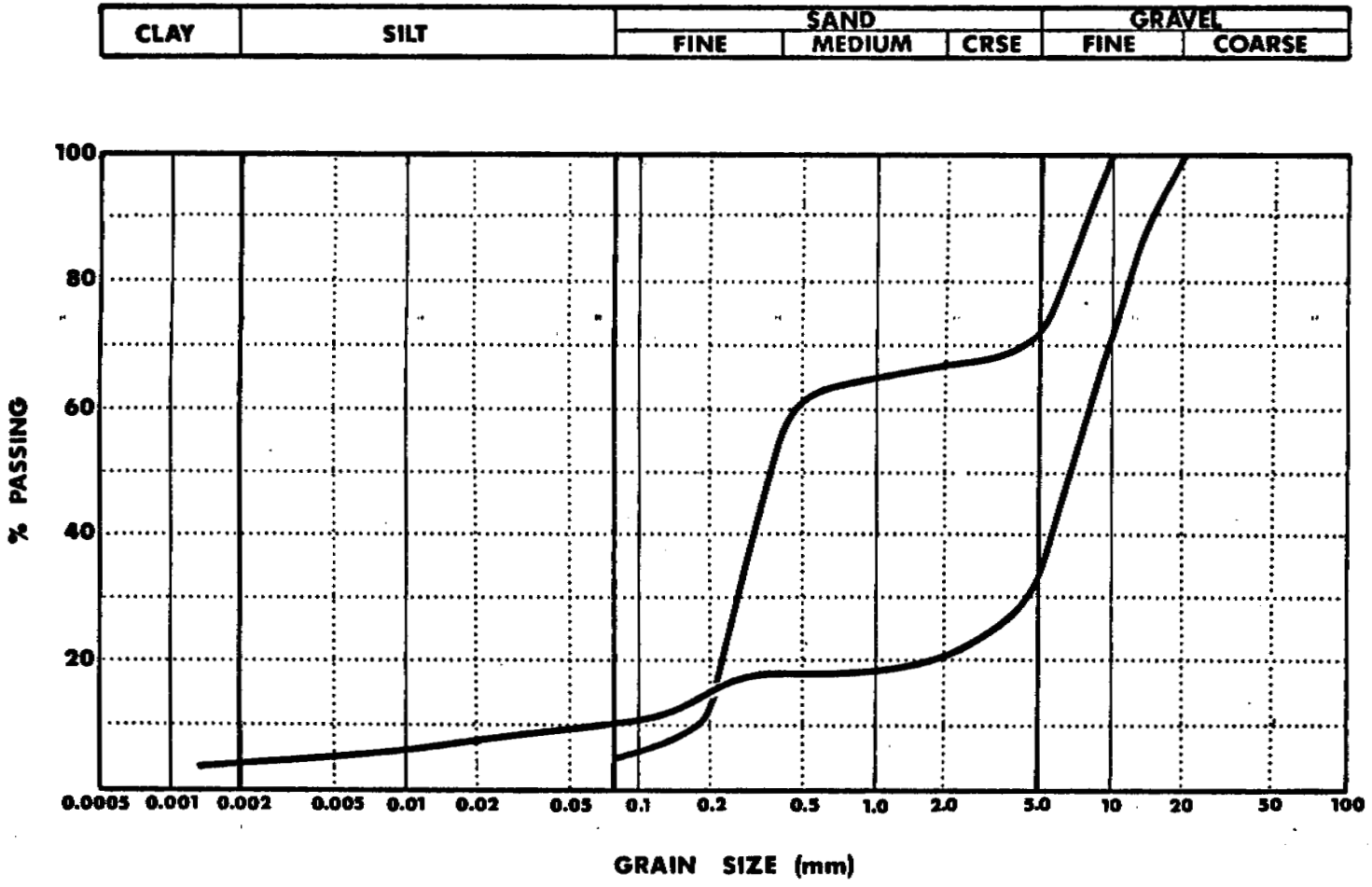
*Approximately 35 000 000 m^3 of the entire deposit may be considered proven.



Examples of Coarse Granular Material from Isserk

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DRAWN BY: JFT | DWG. NO.: 5.4

it is difficult to establish whether the Isserk deposit may ever be considered a viable source of gravel borrow for the petroleum industry.

5.1.4 Banks Island

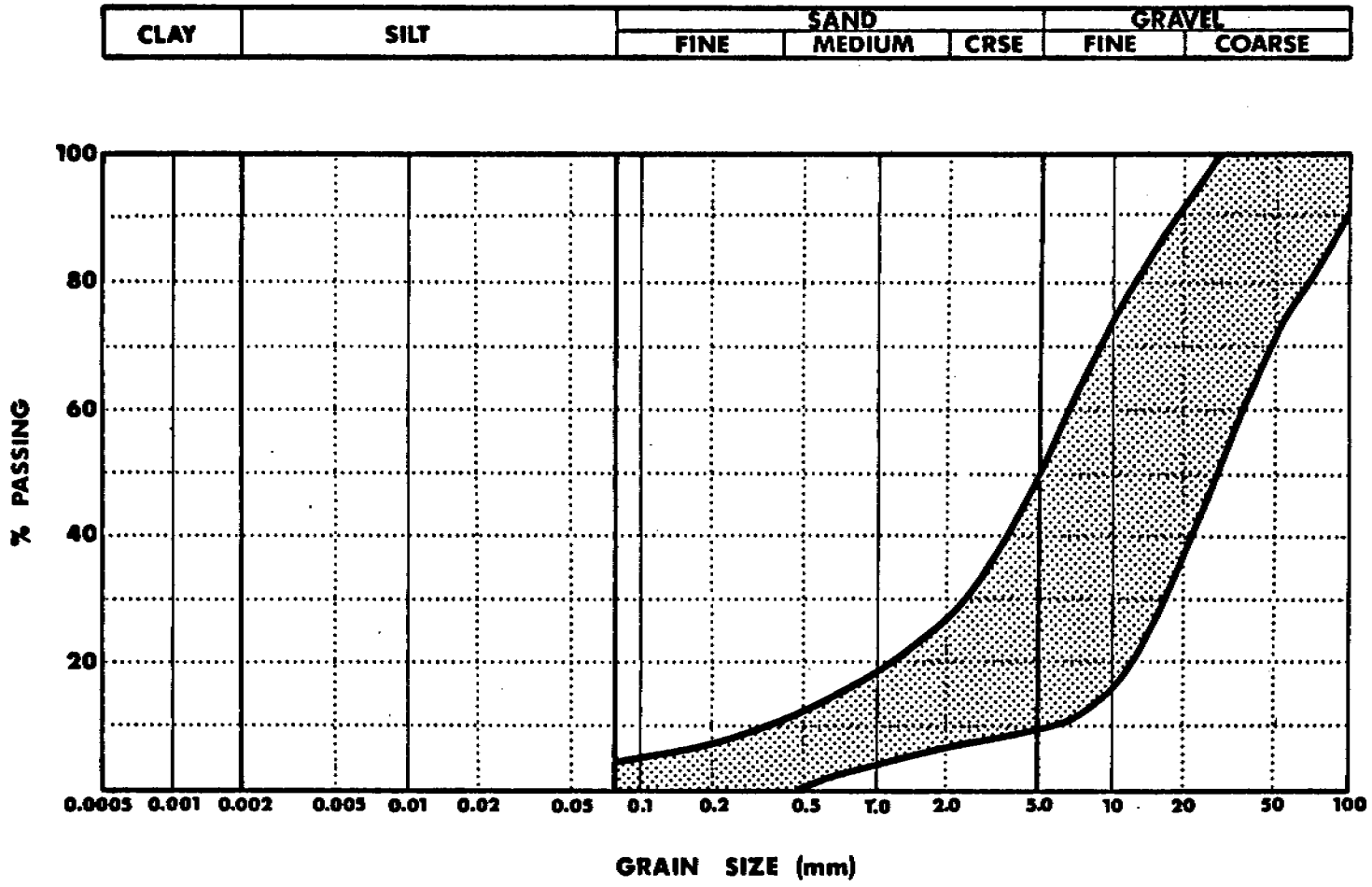
Since 1980 there has been considerable interest in delineating and exploiting gravel resources near Banks Island. Although the sailing distances to this prospect from exploration sites in the central Beaufort Sea tend to be large (see Drawing No. 5.1), the particular characteristics of this area can presently make it cost- effective to develop the borrow using large dredges such as the Geopotes X.

In 1980, Dome Petroleum conducted test dredging along the southwest coast, concentrating mainly in areas near the mouths of the steeper rivers which empty into the Beaufort Sea. Positioning on the dredge was limited to radar images of the shoreline supplemented by satellite navigation. During the program, 7 representative samples were obtained at widely spaced locations for subsequent laboratory analysis of their grain size distribution characteristics.

During the following summer, Dome conducted additional exploration for granular material at one of the specific sites previously identified. A detailed geophysical program was conducted with a 100 m line spacing to delineate the areas where potential borrow outcropped at the seafloor or had only a minimum thickness of soft surficial sediment cover. Based on

the results of the echo sounder, side scan sonar, 3.5 kH, subbottom profiler, NSRF sub-tow boomer and Huntec deep tow boomer data, a prospective area of some 2500 ha was delineated. No geotechnical boreholes were available to calibrate the seismic interpretation, but the data quality was excellent and the characteristic seismic signature of the gravel area was evident enough that a reasonable degree of confidence could be placed in the results. During the 1981 field season, further environmental studies were conducted at the same site. In addition to photographing the various species of benthic fauna indigenous to the area, the environmental program also recorded the bottom sediment type at 12 specific locations. These data were sufficient to permit production dredging of more than 55 000 m^3 of gravel from this borrow site during the 1982 field season.

Grain size analyses of samples recovered from the test dredging in 1980 and the production dredging in 1982 permit some assessment of the gradation characteristics of the gravel deposits. Drawing No. 5.5 shows a composite grain size curve from all available sources. Unlike some of the other borrow prospects in the Beaufort Sea, the Banks Island deposits contain a substantial amount of coarse gravel. Cobbles and boulders up to 300 mm in diameter were found to be common at some locations. Material of this size is difficult to mine with a trailer-hopper suction dredge, because it may damage the dredge pumps and pipes and often clogs up the draghead (see Plate 5.1).



Generalized Grain Size
Envelope of Gravel near
Banks Island

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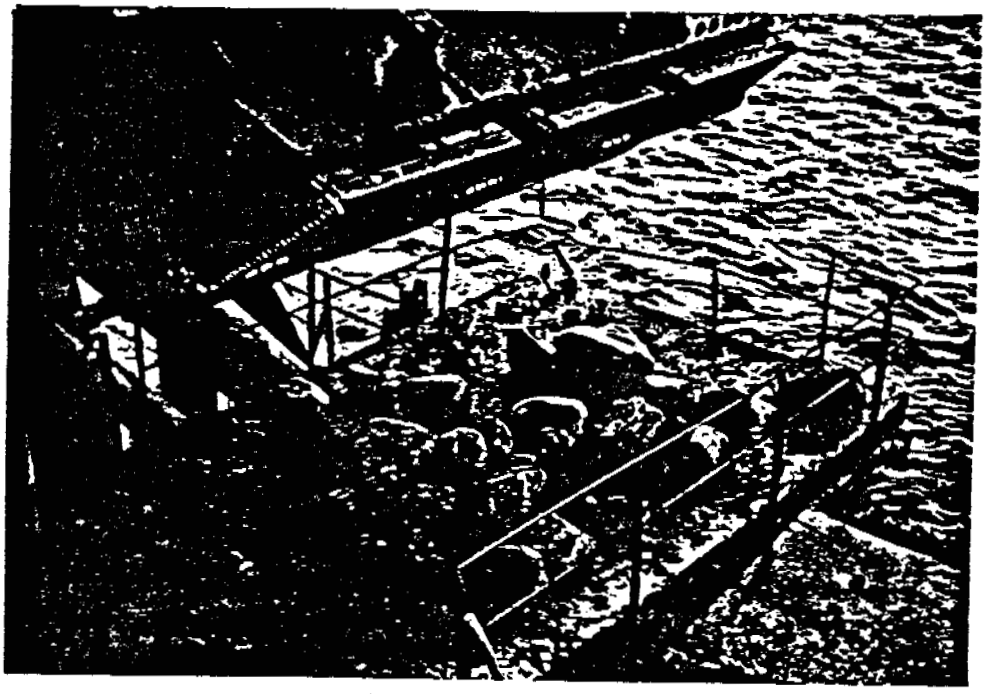


Plate 5.1 Boulders which lodged in draghead during dredging near Banks Island. Photographs courtesy of Dome Petroleum Limited.

Sandy areas also exist along the coast. Test dredging has shown that the boundary between gravelly and sandy areas is often a sharp one, creating some quality control difficulties unless the deposits can be mapped with some precision prior to exploitation.

Recent quality assurance inspections have demonstrated that clayey materials may also exist near the seabed in some of these gravel prospects. There is considerable speculation that the clay may be part of an underlying glacial till unit, but insufficient information is available to determine the glacial and post-glacial stratigraphy of the marine sediments with any certainty.

In spite of these efforts, the gravel potential of Banks Island remains relatively unexplored. No detailed (contoured) bathymetric charts have been published for the southwest coast, but hydrographic information which is currently available indicates that the seafloor drops off quite rapidly* to about the 100 m isobath, and then continues at a much gentler slope to greater depths. Gravel has been identified between the 6 and 40 m isobaths. Production dredging has been carried out betweem the 15 m and 20 m isobaths.

Gravel has been confirmed at the seafloor at several other areas along the coast, estimated to have a combined area of approximately 1000 ha. Seismic information at one of these locations suggests that the gravel deposit is probably 2 to 3 m

*Slopes of 8° to 12° have been measured in some areas.

thick in some places, resulting in a conservative volume estimate of 20 000 000 m^3, of which only about 10% may actually be considered to be "proven" reserves. It is possible, however, that more than 50 000 000 m^3 of gravel may exist at suitable depths for dredging along the coast between Sachs Harbour and Cape Lambton. It is speculated that a similar volume of granular material may also exist along the coast north of Sachs Harbour. At the present time, the most promising area appears to be in the vicinity of Duck Hawk Bluff and the adjacent spit at Cape Kellet. Since the seafloor in the latter area is somewhat flatter than observed farther south, the development of these potential gravel resources may also be facilitated by superior dredging conditions.

5.2 Other Potential Gravel Sources

In addition to the four sites described above, several other possible sites where gravel may be located at the seabed have been identified. Some of these sites have already been surveyed at a reconnaissance level, while others may presently be considered to be little more than geological speculation. All require substantially more exploration before any reliable estimate can be made of the quality and quantity of gravel material which may be available at the seabed.

5.2.1 Yukon Coast West of Herschel Island

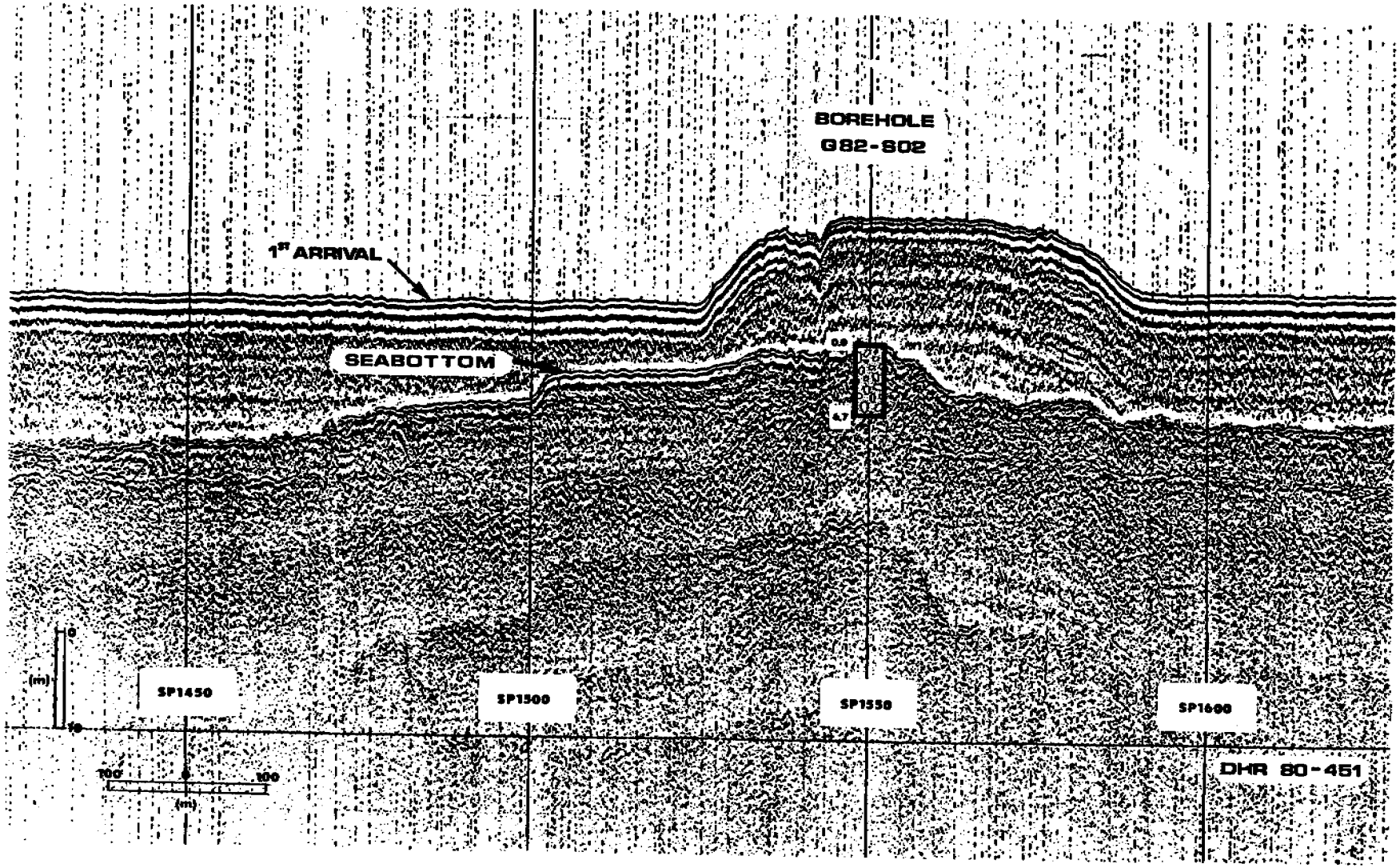
West of Herschel Island the Yukon Coast is characterized by broad flood plains of the Malcolm and Firth Rivers. Two shallow seismic programs have been conducted in this area. The first was carried out in 1980 and formed part of Dome Petroleum's regional survey of the continental shelf. The

second, conducted in 1981, was part of a borrow search program carried out by Dome Petroleum at several prospective sites in the Beaufort Sea. The 80 km of seismic data which have been collected in this area are somewhat difficult to interpret reliably, a fact which has been confirmed by six geotechnical boreholes drilled on selected seismic anomolies by Gulf Canada in 1982. The combined geophysical/geotechnical evidence suggests that gravel material may comprise a major component of several narrow seafloor ridges which occur between the 17 and 25 m isobaths (Drawing No. 5.6). The number, orientation, and distribution of these ridges have not yet been determined, but it is speculated that they may contain a combined volume of 30 000 000 to 100 000 000 m^3 of gravel at depths suitable for extraction by trailer-hopper equipment now operating in the Beaufort Sea. Since only about 1 000 000 m^3 of gravel may presently be considered to constitute "proven" resources, it is evident that substantially more work must be carried out before the actual reserves can be estimated with an appropriate degree of confidence.

On the basis of several regional grab samples, Pelletier (1975) suggests that gravel may be present at the seabed over a large area between the 50 m and 100 m isobaths northwest of Herschel Island. This area may also be considered prospective if and when hopper trailer dredges having deep water capabilities become operational in the Beaufort Sea.

5.2.2 Yukon Coast East of Herschel Island

The Yukon Coast east of Herschel Island may also be considered prospective for gravel, although little information is presently available to support this contention. From Kay Point



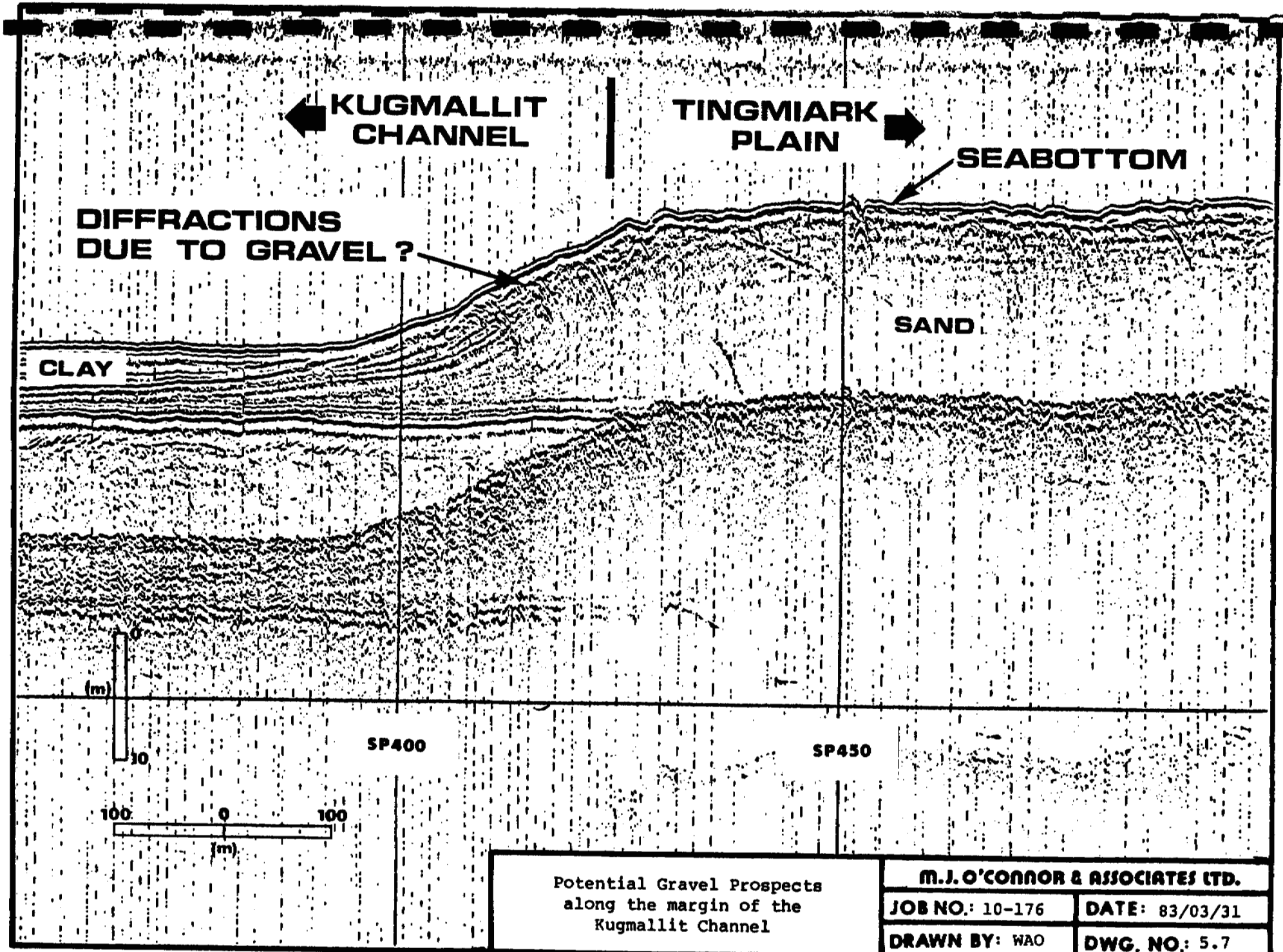
Seabed Morphology of Gravel Prospects West of Herschel Island	M.J. O'CONNOR & ASSOCIATES LTD.	
	JOB NO.: 10-176	DATE: 83/03/31
	DRAWN BY: WAO	DWG NO.: 5.6

southeast to Sabine Point, the seafloor slopes rapidly away from the coastline, providing a narrow band of isobaths for production dredging. While the onshore coastal sediments described by Rampton (1982) do not appear to be particularly prospective as gravel sources, it is presumed that both the present and historic hydrodynamic regimes offshore may have been conducive to the local accumulation of any small amounts of granular material which may have existed in this area.

5.2.3 Kugmallit Channel

Gravel has been identified in at least one borehole drilled by the Geological Survey of Canada along the eastern margin of Kugmallit Bay. Because the location was jet-drilled from the winter ice, no samples were recovered for laboratory testing and hence the precise gradation characteristics are presently unknown. Although this particular gravel deposit occurs close to the seabed and has been logged as being several metres thick, the shallow water depth (4 m) at this particular location may preclude its eventual exploration and development.

Further offshore there are two prospective areas within the Channel which do not appear to have been tested with geotechnical boreholes. The first of these also lies along the eastern margin of the Channel, where the bathymetry rises rapidly to the Tingmiark Plain. As Drawing No. 5.7 demonstrates, diffractions originating at or near the seabed occur frequently where the Channel margin is steepest, suggesting that cobble and boulder sized material may exist at



Potential Gravel Prospects along the margin of the Kugmallit Channel

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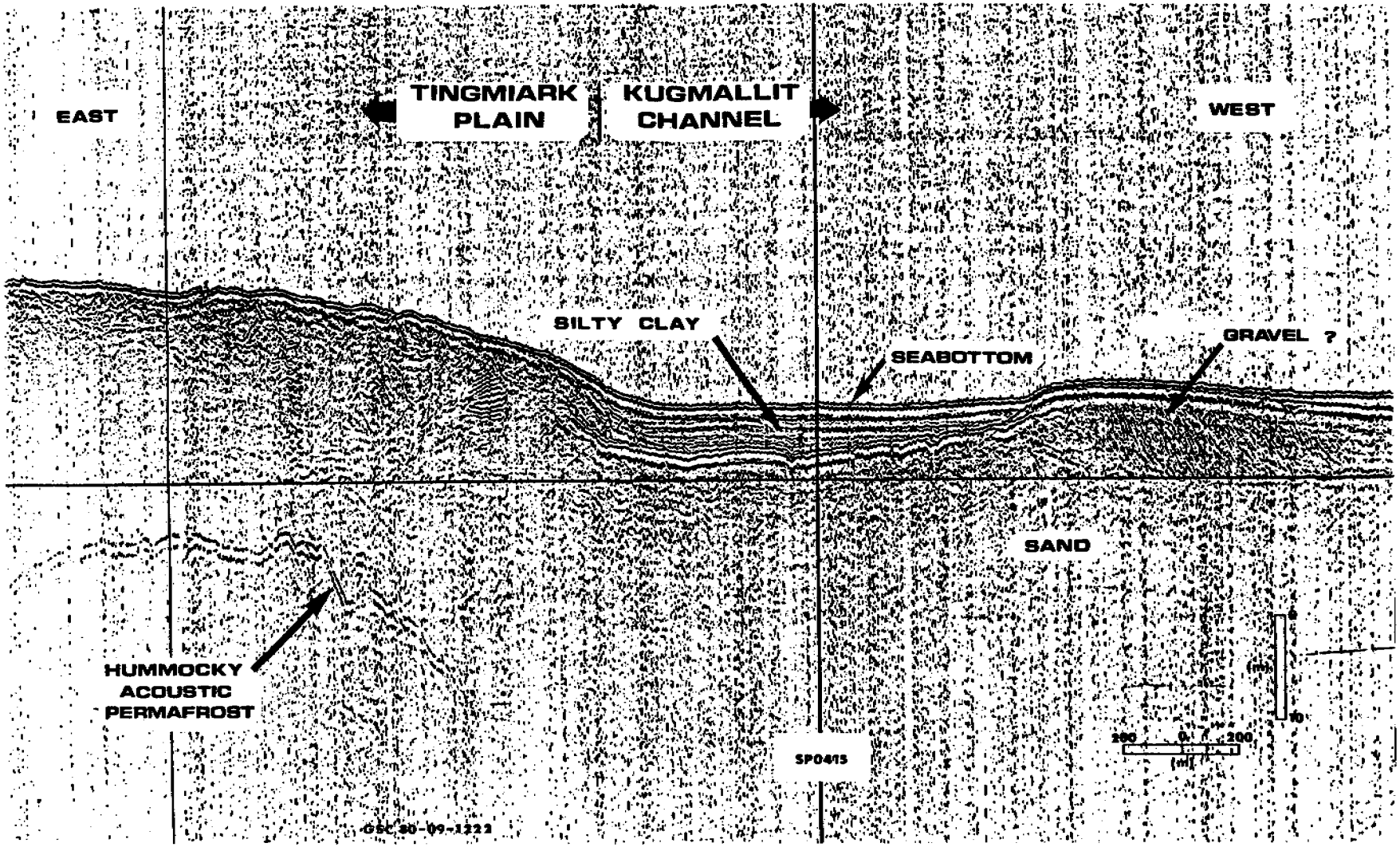
JOB NO.: 10-176	DATE: 83/03/31
DRAWN BY: WAO	DWG. NO.: 5.7

the seafloor. Although it is possible that such a feature may parallel the edge of the Kugmallit Channel for some distance in the north-south directions, it appears that the width of this potential gravel zone may be quite narrow (perhaps less than 100 m in some places). This would make detailed exploration and subsequent development more difficult to accomplish; however, the proximity of this prospect to several well-site locations may justify the additional exploitation effort required.

The second prospective location within the Kugmallit Channel has also been identified only on a high resolution shallow seismic section. As Drawing No. 5.8 demonstrates, the characteristic diffractive seismic signature observed in what appears to be a submarine paleo-island has been interpreted as being due to the possible presence of gravel-sized material. Since only this single seismic profile exists in this area, and no geotechnical boreholes have been drilled to confirm the stratigraphy, the interpretation offered must be considered somewhat speculative. This is especially true in view of the rather poor geotechnical and geophysical correlations observed at some of the other (known) borrow sites on the continental shelf. This second site also lies in much deeper water than conventional hopper trailer dredges can presently access. If, however, the prospect can ultimately be proven to contain several million cubic metres of suitable granular material, then there is every possibility that dredging plants capable of developing such a deep borrow site could be made available.



Potential Gravel Deposit in Kugmallit Channel

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JOB NO.: 10-176	DATE: 83/03/31
DRAWN BY: WAO	DWG NO.: 5.8

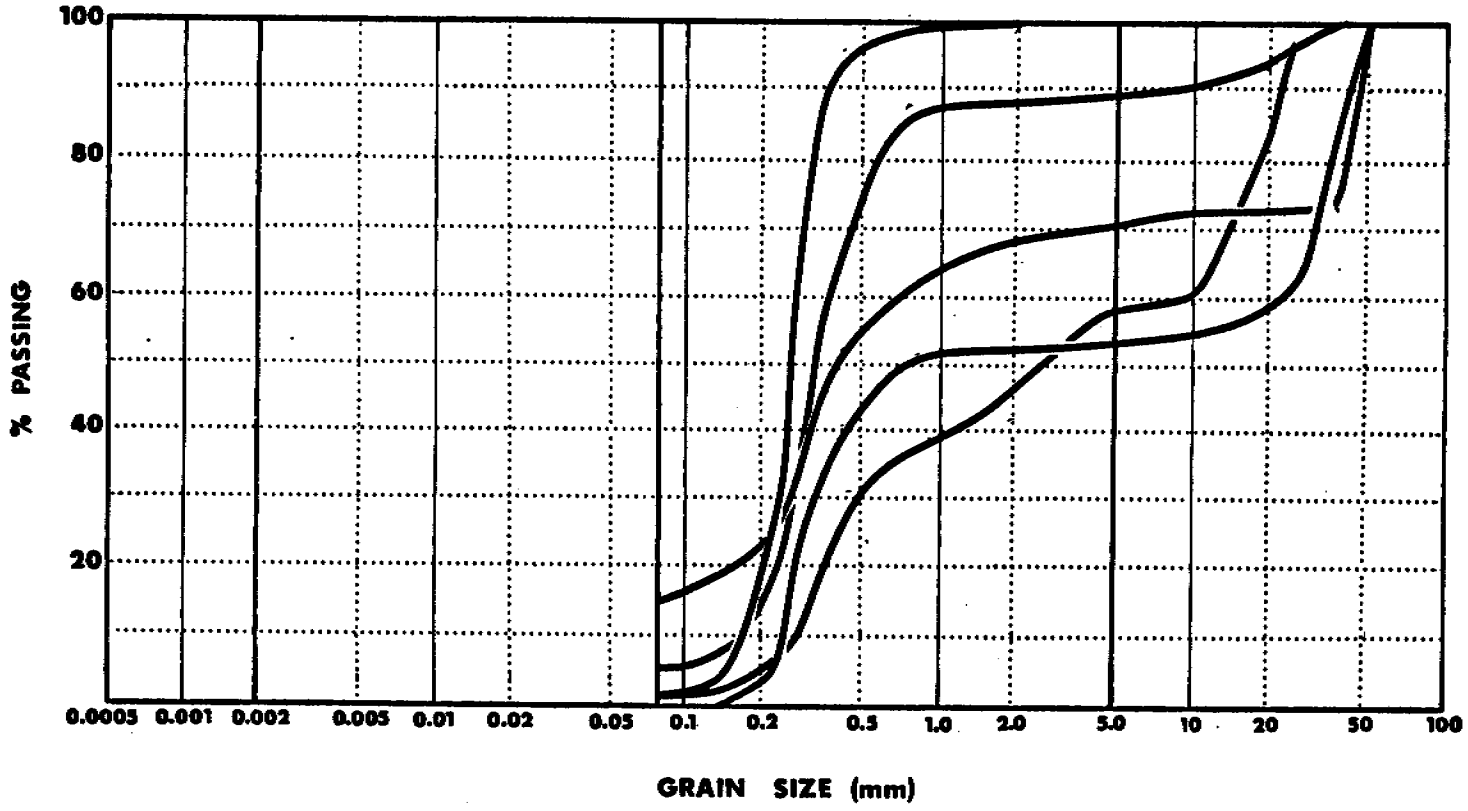
5.2.4 Offshore of the Tuk Peninsula

Extensive borrow searches have already been conducted inshore of the 20 m isobath along the Tuk Peninsula, mainly for Esso Resources Canada Ltd. While the vast majority of boreholes have encountered only fine to medium grained sand containing a trace to some silt, information from several boreholes suggests that deposits of sandy gravel 1 m to 3 m thick may also occur (Drawing No. 5.9). Near Tuft Point there is sufficient borehole information to confirm that the seabed gravel probably only occurs in a very patchy fashion or in longshore bars less than 100 m wide. Offshore from Tininerk Bay and Toker Point, however, the borehole control is much less well developed and hence the gravel potential may be much greater. Of seven regional boreholes drilled in these latter areas, two encountered gravel near the seabed. This suggests that further borehole programs based on detailed bathymetric and/or sub-bottom geophysical information may delineate more prospective areas for gravel development.

5.2.5 Baillie Islands

Based on surficial geological data along the coastline, a short (20 km) marine regional, geophysical program was conducted near the Baillie Islands in 1981 to determine whether the potential existed for development of gravel deposits in the offshore. Two lines were surveyed in water depths ranging from 12 m to 37 m. In certain areas the interpreters noted "megaripples...and sand waves" at the seafloor which they believed was evidence of the presence of coarse granular

CLAY	SILT	SAND			GRAVEL	
		FINE	MEDIUM	CRSE	FINE	COARSE



Particle Size Distribution of Granular Material along the Tuk Peninsula

M.J. O'CONNOR & ASSOCIATES LTD.

JOB NO.: 10-176	DATE: 83/03/31
DRAWN BY: JFT	DWG. NO.: 5.9

material. A geotechnical field program carried out by Dome Petroleum the following year was designed to evaluate the seabed material in these seismic anomolies, but ice problems prevented the identical locations from being resurveyed. Some samples recovered from the seafloor during the geotechnical program were found to be granular in nature, but most of the material consisted only of fine to medium grained sand with some silt. Because of the surveying difficulties noted above, it appears that the offshore area near Baillie Islands has not yet been evaluated at a level suitable for either confirming or denying its gravel potential. In view of its relative proximity to the eastern exploration sites in the Beaufort Sea, it may be worthwhile investigating this prospect in a more rigorous fashion in the future.

6.0 DISCUSSION

6.1 Current Dredging Capabilities

The search for potential gravel borrow sources must consider both the development capabilities and the depth requirements of the dredges currently operating in, or planned, for the Canadian Beaufort Sea.

Gravel prospects which occur at locations remote from intended construction sites are developed most cost-effectively by utilizing the highly mobile trailer-hopper dredges. For optimum development, however, the gravel deposit should either outcrop directly at the seafloor or, less preferably, be covered with only a minimum thickness of overburden which could be stripped prior to exploitation. Large gravel deposits which are buried beneath a significant (say 3 m)

thickness of overburden may be developed by stationary suction dredges, but these dredges are best utilized only when the dump site is within a short distance of the borrow pit (usually 1500 m or less). Stationary dredges can also be utilized to access deep borrow remote from a potential construction site, but the additional costs required for equipment such as transport barges and tender vessels usually triples the borrow development costs, making the process non-cost-effective (J. Beckman; 1983, pers. comm.).

While sailing distance and overburden cover are important factors, the depth capabilities of the dredges must also be considered. Table 6.1 lists several dredges now operating in the Beaufort Sea and their depth limitations, which of course are also dependent to some extent on the sea state and the seabed morphology. Most of the hopper-trailer dredges achieve optimum dredging rates somewhere between the 15 m and 25 m isobaths, and therefore borrow prospects in this depth range tend to be better investigated than those in greater or lesser water depths.

As noted previously, the three western borrow sites (Herschel Island Sill, Issigak and Isserk) all occur in relatively shallow water. This makes them somewhat difficult to develop with large hopper dredges such as the Geopotes IX and X. Stationary dredges such as the Aquarius and the Beaver McKenzie, however, could easily access these shallow deposits, although the cost of transporting the borrow to a distant dump site could preclude their use for many construction projects.

In spite of the above, it is important that future gravel inventories not be restricted to the presumed depth limitations presented herein. Even gravel prospects which are poor quality, or too small, or too

TABLE 6.1

Capabilities of Beaufort Sea Dredges*

Vessel	Minimum Working Depth (m)	Maximum Working Depth (m)	Maximum Draft (m)
HOPPER DREDGES			
Hendrik Zanen	9.0	32	9.5
Geopotes X	11.0	35	12.0
Geopotes IX	10.0	40	10.0
Gateway	9.0	30	10.6
Cornelis Zanen	7.0	32	8.0
STATIONARY DREDGES			
Aquarius (Cutter)	4.4	26	4.9
(Suction)	4.4	70	4.9
Mackenzie	4.0	45	4.0

* Information provided by Dome Petroleum, 1983

shallow to be developed cost-effectively must be considered, because these deposits may represent important environmental habitats. Moreover, future technology will probably be available to access whatever gravel resources are eventually identified, provided that these prospects can be developed in a cost-effective manner.

6.2 Factors Hampering the Development of Granular Borrow in the Beaufort Sea

Until very recently, the search for granular borrow material in the Canadian Beaufort Sea has been hampered by two factors: the lack of a regional geologic framework from which to confidently deduce prospective borrow locations, and the absence of an integrated systematic approach to borrow exploration and development.

The first factor is now being dealt with by the Beaufort Sea Seabed Synthesis Project, a joint industry - government study to determine the surficial geological conditions of the continental shelf and assess, in a regional sense, their engineering implications for future resource development. While the geological concepts which evolved during the synthesis have played an important part in developing exploration programs for sand borrow, they have not yet advanced to a point which permits the identification of all potential gravel sources.

The importance of the second factor is only now being appreciated. Examination of proprietary data provided by the three major petroleum operators indicates that their borrow exploration programs have sometimes been independently carried out at virtually the same geographic locations. Integration of this proprietary information

conducted during the present study suggests that these independent data bases often complement each other, and together provide a superior basis for evaluating the borrow source than each of the individual data bases provides alone. To maximize the cost-effectiveness of future granular borrow exploration, it may be worthwhile for the major operators to sell or trade their borrow information at locations of mutual interest. Future studies could be planned on a participating basis so that overlap and duplication of effort no longer occurs.

6.3 Information Deficiencies

The location of gravel borrow sources is most easily accomplished when the following information is available: regional geophysical/ geological control, detailed bathymetry, geotechnical boreholes and test dredging results. When all of these are available over the same site, the reliability of the borrow evaluation is extremely high. When only some are available, or they are all available but only over restricted portions of the site, such reliability is reduced accordingly.

While all of the known gravel sites already have a substantial amount of information available, each suffers from a lack of information in certain areas.

The Herschel Island gravel prospect requires a significantly more comprehensive and detailed bathymetric survey to define the precise locations of the borrow. Geotechnical boreholes are required to verify the quality and thickness of the surficial gravel layer, especially in

areas where water depths may make development by hopper-trailer dredges feasible.

Detailed bathymetry at the Issigak borrow site has already been carried out by Esso Resources, but additional boreholes are also needed throughout the south half of the prospect to confirm the nature of the borrow material and its thickness.

Gravel has been located at Isserk in only a few of the many boreholes already drilled. Since the majority of this gravel appears to be located near the edge of the current pit, it may be necessary to carry out further detailed bathymetric mapping of the prospect and drill additional boreholes before the true extent of the gravel reserves is known.

Only a paucity of groundtruth information presently exists at Banks Island. While this has been sufficient in the past for obtaining the small quantities of gravel necessary for protection of subsea berms at exploration island sites, continued development of the gravel would be facilitated if a systematic inventory of the quality and quantity of the available resources was to be undertaken. Some detailed geophysical work has already been conducted near Rufus River, but no geotechnical boreholes have been drilled to confirm the thickness of the deposit. Moreover, it is possible that there may be other borrow sites along the southwest coast which could provide superior gravel material and somewhat easier dredging conditions, these include some talus deposits along the shoreline which might be developed as a source of armour stone (J.S. Vincent, 1983; pers. comm. with S.M. Blasco). To delineate these locations, a detailed coastal bathymetric and shallow subsurface geophysical survey is required, supplemented by geotechnical boreholes on the most promising anomolies.

All of the other prospective sites suffer from the same information deficiencies. A detailed bathymetric and shallow sub-bottom survey followed up by additional geotechnical drilling is necessary to prove up potential gravel reserves both west and east of Herschel Island. Additional field work is also necessary on the geophysical anomolies identified in Kugmallit Channel, but this should be confined to a couple of geotechnical boreholes drilled to test the origin of the observed seismic signatures, and should not be undertaken without first briefly reviewing the available geophysical data to select the most appropriate locations. Detailed bathymetric studies may be the key to development of potential gravel resources along the Tuk Peninsula. Correlation of positive bathymetric features with the geotechnical borehole data already available may provide the necessary background to undertake the more detailed studies required at specific locations.

6.4 Resources and Requirements

The development of future gravel management policies will depend, to a large extent, on the relationship between offshore construction requirements, the volume of available granular resources, and the nature and sensitivity of unique environmental habitats which may be associated with the gravel deposits. Consideration of the latter factor is clearly beyond the scope of the present study. The other two factors can be addressed only at the level to which they are presently understood.

Table 6.2 presents a summary of the gravel resources in the Canadian Beaufort Sea as they are described in this report. According to the table, a total of 25 000 000 m^3 of gravel can be considered as proven

TABLE 6.2

Volume of Gravel at Known Borrow Sources

	VOLUME ($m^3 \times 10^6$)			DISTANCE TO WELLSITES (km)		
	Proven	Probable	Possible	Tarsiut	Issigak	Uviluk
Herschel Island Sill	10	50	200	100	180	260
Issigak	10	15	40	25	75	150
Isserk	2	10	14	75	20	90
Banks Island	2	20	100	500	420	340
Others	1	30	100	--	--	--
TOTAL	25	125	454			

reserves, with most of this being located in the two known deposits at Herschel Island and Issigak. Since the present inventories at most of the four known borrow sites have been far from exhaustive, substantially greater volumes of gravel may ultimately be shown to exist at these sites. Due to the limited thickness of the deposits, however, less than one half of the total in situ volume should be considered exploitable for construction purposes.

Conservative estimates provided by the petroleum operators suggest that the the projected future gravel requirements for exploration islands is not likely to exceed 500 000 m^3/a for the next several years (D. Mitchell; 1983, pers. comm.) and may actually be much less than this amount. Total granular borrow for production purposes is estimated in the EIS to be approximately 700 000 000 m^3 (S.M. Blasco, 1983, pers. comm.), of which perhaps 5% (35 000 000 m^3) would be gravel (W. Livingstone; 1983, pers. comm.). It therefore appears that proven exploitable reserves* constitute less than one third of the anticipated total long-term gravel requirements for production of offshore facilities. It is apparent, however, that more exploration at the four known borrow sites would probably be adequate to prove up the additional exploitable reserves required.

Furthermore, it is possible that the reserves discovered to date represent only a small portion of the total gravel resources available in the Canadian Beaufort Sea. The adoption of a comprehensive, systematic exploration approach may lead to the identification of other gravel deposits in the central areas of the shelf, nearer those locations where future production facilities are more likely to be constructed.

*Calculated as 50% of the "proven reserves".

6.5 Options for Future Studies

If the inventory presented in this report is deemed to be sufficient for DIAND's present purposes, then DIAND may consider adopting a purely monitoring approach by letting the major petroleum operators develop their own inventories as their gravel requirements dictate. This option has the advantage of being the least expensive approach for DIAND, but may create some difficulties in managing the resources in both the short and long-term. On the other hand, it must be recognized that up to now the petroleum operators have been able to explore for and develop significant quantities of sand borrow on an independent basis. Over the long-term, they may also be able to do likewise with gravel.

If a more definitive inventory of offshore gravel resources than presented here is required by DIAND, then additional exploration work will have to be conducted. There are several approaches which DIAND may take to ensure preparation of such an expanded inventory:

Option 1 - Adopt a go-slow approach by conducting limited but systematic independent exploration for gravel during the next four or five years.

Option 2 - Undertake an accelerated independent study on a regional basis to establish sufficient gravel reserves to meet all of DIAND's immediate management and policy requirements.

Option 3 - Develop either a moderate or major exploration program jointly with the principal Beaufort Sea petroleum operators to ensure that sufficient gravel borrow reserves are available to meet DIAND's projected long-term needs, and

in so doing, prepare a mutually agreeable management plan for their development.

Each of these options is discussed in more detail below:

Option 1 offers some distinct advantages, because future gravel studies could be carried out in conjunction with other regional offshore programs being conducted by federal government agencies such as the Canadian Hydrographic Service and the Geological Survey of Canada. Moreover, it is likely that the geological factors which control the present distribution of gravel deposits will eventually be more fully understood through these associated studies. Coordination of DIAND's gravel searches with the ongoing offshore studies being carried out by other agencies may require financial support of approximately $200 000 to $500 000 per annum. If such a program were continued for each of the next 3 to 5 years, this would probably be an adequate level of effort to define and groundtruth sufficient gravel resources to meet most of both DIAND's and the petroleum industry's long-term requirements.

If DIAND's needs are perceived as being more immediate, then Option 2 may be considered. A typical regional search to explore for gravel might include all or most of the components listed in Table 6.3. The first year's program is designed to locate prospective areas, determine their bathymetric and subsurface character by geophysical methods, and groundtruth the quantity and quality of the gravel resources present. As the table shows, the total cost of such a program may exceed $2 000 000. Based on the results of this initial program, follow-up field and office studies to detail specific prospects and provide more definitive geotechnical properties might also be required. Costs for

TABLE 6.3

Accelerated Regional Gravel Inventory

COMPONENT	DESCRIPTION	TIMETABLE	COST
Preliminary Planning	Office study to compile regional geophysical/geotechnical information already available and select prospective areas requiring more information	May-June 1st year	$ 40 000
Field Survey	Regional geophysical/geotechnical program from a vessel such as the Arctic Sounder. Geophysical gear to include precision fathometer for detailed bathymetry, sub-bottom profiler to determine thickness of recent marine silty clays (overburden), a high resolution shallow seismic device such as the EG & G Uniboom, to provide detailed stratigraphy in the upper 30 m, and perhaps a small airgun for geologic and permafrost mapping to 65 m beneath the seabed. A side scan sonar to provide lateral coverage of the seabed would also be recommended. Geotechnical equipment should include a shallow grab sampling device for rapid testing of the nature of the seabed soils and a vibracore rig to confirm the thickness of any gravel prospects located. Onboard laboratory facilities for grain size determinations on selected samples would be recommended. Cost estimate assumes a minimum 60-day contract at $25 000/day for the vessel, personnel and all geophysical/geotechnical gear.	July-Sept. 1st year	$1 500 000 - 2 000 000
Interpretation	Compilation, analyses and interpretation of the field data to evaluate the principal gravel borrow sources located during the field program. Determine the quantity and quality of gravel located in each deposit. Assess the need for follow-up studies at specific locations. Provide recommendations for usage of the resources.	Oct-March 1st year	$ 200 000
Follow-up Studies	To be determined on the basis of foregoing results and recommendations. Additional field programs and interpretation may be required, but a somewhat lower total level of effort is anticipated.	July-March	say $1 000 000 to 2 000 000

these subsequent possible studies are extremely uncertain, but a budget of perhaps $1 000 000 to $2 000 000 can be used for preliminary planning purposes.

Option 3, the joint venture approach with the three major petroleum operators, is theoretically attractive, but is also likely to be somewhat difficult to accomplish from a practical standpoint. There are two reasons for this difficulty, as discussed below:

The first, and in our opinion the most important, is that the future gravel requirements of the three major operators, as indicated to M. J. O'Connor & Associates Ltd. during the present study, are largely undefined. Historically there has been little gravel required for exploration islands. Esso Resources, whose acreage is primarily in shallow water, has in the recent past developed negligible volumes. Even Dome and Gulf, whose acreages both lie in somewhat deeper water, have only required relatively small volumtes to date. To a large extent, the projected gravel requirements of each of the operators will be dependent on the type of production facilities ultimately adopted and the water depth in which such structures are situated.

Since various conceptual designs for these facilities are currently being considered, it is difficult for the operators to provide a reliable estimate of the total gravel resources which they may eventually require. Thus the uncertainties in each of the operators' needs may make the task of conducting future gravel search programs on a joint basis with all three petroleum companies somewhat difficult to achieve, unless some reasonable system is developed to share the costs and the benefits of such joint venture programs with the operators in an equitable manner.

The second problem with the joint venture approach arises due to the anticipated funding level. If a major regional gravel search program can be funded by DIAND and the three petroleum operators each providing $500 000, then the $2 000 000 total budget would be sufficient to conduct a similar program to that shown in Table 6.3. If, on the other hand, $500 000 for gravel exploration is provided only by DIAND, then it might be necessary to consider a tag-on type of program, where DIAND would pay for a certain number of days use of equipment already contracted for exploration work in the Beaufort Sea. Since most of the geophysical or geotechnical surveys conducted by the petroleum industry are currently costing approximately in the order of $50 000/day, it may be assumed for present purposes that at least 10 days of ship's time would be available for such a gravel search*. While this type of program offers some cost savings in terms of the total contract price, it also includes some built-in disadvantages. For one thing, the tag-on program assumes both that the major petroleum operators are going to be undertaking a geophysical/geotechnical program, and that they will have some uncommitted vessel time available for use by DIAND. While scheduling aspects and down-time costs can probably be worked out with the other joint operators prior to mobilization, DIAND must recognize that the typical industry field programs generally include substantially more equipment than is necessary to undertake a gravel search, and thus part of the daily costs funded by DIAND may go towards providing unnecessary auxillary equipment and personnel. Alternatively, it has been suggested that demobilization of some of this ancilliary equipment may be undertaken prior to embarking on the gravel search. It is doubtful whether much demobilzation could be undertaken in a cost-effective manner except near the end of the field season, when the other operators programs had been completed. Although

*Down-time due to weather, ice and equipment problems may decrease the actual productive ship's time by 50%.

the author considers the joint venture approach to be preferable to the tag-on program, the latter is still considered to be a viable option for future gravel searches, especially if DIAND recognizes that careful planning and coordination with the operators' programs would be required to complete such field studies in a cost-effective manner.

It is evident that each of the various options noted above carries with it important implications regarding both the timing and the budget which would be required for the preparation of a more comprehensive gravel inventory than is presented here. Integration of the proprietary gravel information has, however, provided an important perspective from which to assess DIAND's future gravel management objectives. On the basis of this study, and in consideration of the options outlined above, it is possible to recommend a course of action to DIAND which may fulfill their long-term management requirements on a cost-effective basis.

6.6 Significance of the Present Study

The present study has provided important regional documentation of the distribution of gravel resources in the Canadian Beaufort Sea. Because of the redundancy in some of the industry exploration programs, it has also been possible during the study to assess objectively the reliability of the information provided. This redundancy has demonstrated, for instance, that:

1. Geophysical studies, by themselves, are of limited use in distinguishing gravel from sand or hard clay at most borrow sites.

2. Borehole information by itself cannot be considered totally reliable as a means of evaluating a prospective borrow source's gravel potential.

3. Grab sampling and test dredging with a hopper-trailer dredge may underestimate the total extent of a gravel source where the margins of the deposit are covered with a thin blanket of recent marine clay.

Yet by integrating the data available from all geophysical, geotechnical, dredging and environmental sources, it has been possible to establish some geological parameters which might be considered characteristic of other, yet unidentified gravel deposits. The most important of these is the fact that almost all gravel deposits examined are located on subtle bathymetric highs. These highs cannot be reliably identified on the natural resource series bathymetric maps, partly due to the 2 m contour interval used in preparing the maps. It is possible, however, that such anomolies could be identified on the original hydrographic records and the unpublished field sheets prepared by the Canadian Hydrographic Service, especially if computer aided techniques were utilized to eliminate the regional trend surfaces. Of lesser importance is the fact that most of the known gravel deposits have been found between the 8 m and 14 m isobaths. It has been speculated that this bathymetric control arises due to the historical geology of the area: sea level rise has slowed considerably in the past 5000 years, increasing the time that these particular sediments

may have existed in nearshore, high energy environments suitable for the production of lag deposits comprised primarily of coarser grained materials. Systematic investigation of the seabed morphology and bathymetry may therefore provide the most cost-effective method of obtaining a more extensive inventory of gravel resources in the Canadian Beaufort Sea.

6.7 Proposed Strategy for Future Studies

It is recommended that DIAND combine the most favourable attributes of options 1 and 3 listed above, by undertaking small-scale systematic studies (option 1) on a regional basis. Wherever possible, these should be conducted either in conjunction with, or in cooperation with related seabed studies being carried out by the major petroleum petroleum operators. This approach would involve close liason with the operators to determine the nature and extent of their ongoing programs, but could provide significant financial benefits whenever logistics, support costs, and/or the information collected could be shared.

As a first step in these further studies, it is recommended that DIAND investigate the relationship between seabed morphology/bathymetry and the distribution of gravel resources in the Canadian Beaufort Sea. The study should involve examination of the original bathymetric records and hydrographic field sheets available from both government and industry sources to determine:

1. the characteristic morphology and acoustic signature of the bathymetric anomolies at known gravel borrow sources;

2. the relationship of these bathymetric anomolies to the regional surficial geology of the continental shelf as currently being established through the Beaufort Sea Synthesis Projects;

3. the location of other positive bathymetric anomolies on the shelf;

4. the correlation between the acoustic signatures observed at each of the anomolies and the character of the acoustic signature noted in (1) above.

It is anticipated that such a study might take perhaps six months and a budget of $180 000 to $200 000 to complete, depending on the computing costs. The final report would recommend specific anomolies requiring additional geophysical and/or geotechnical evaluation to be undertaken during subsequent field seasons as budgetary provision permitted.

In a subsequent year, for instance, when only $300 000 in additional funds were available for field studies, then this could be used to acquire several days ship time on either a geophysical or geotechnical vessel already contracted to one of the petroleum operators. Under such conditions the exploration would undoubtedly be constrained to the equipment already on board, and would probably be limited by the time available for a brief survey at one specific site.

If, however, $500 000 to $600 000 was made available for a single field season, then the recommended approach would be somewhat different: There are several prospective areas already identified where a small vessel and auxiliary high speed launch could acquire sufficient

bathymetric, geophysical and geotechnical information to delineate gravel sources with a reasonable degree of precision. Additional areas would be determined during the initial office studies suggested above. Using similar equipment to that configured in Table 6.4, it would be possible to conduct a comprehensive gravel search at several areas proximate to one another during a 45-day program. Small vessels such as the one shown in the table can only operate within a fixed distance of the shoreline, but this would not appear to be a problem for some of the more prospective areas already identified. Alternatively, a slightly larger vessel such as the M. V. Norweta could be used for the survey, if a short contract could be arranged.

Operation from the latter vessel could be conducted on a 24 hours/day basis, and this might actually increase the total quantity of data collected, even considering the shorter time frame.

Adoption of the systematic approach suggested here would probably delay commencement of the first field program until at least the summer of 1984, but there is every possibility that the results of the study might subsequently save substantial expenditures by limiting future exploration programs to specific sites within those general areas which appear to offer maximum opportunity for success. At the moment these general areas include the Yukon coast (both west and east of Herschel Island and along the sill itself), the coast of the Tuk Peninsula, and the southwest coast of Banks Island. More importantly, the initial office studies recommended here may identify additional gravel prospects in the central areas of the continental shelf. Future field studies could then be conducted on a priority basis considering the proximity of these prospects to potential production sites such as Tarsiut, Kopanoar and Issigak.

TABLE 6.4

Estimated Costs for a Gravel Search from a Small Vessel

	DAILY RATE
SURVEY VESSEL Small craft and high speed launch and Zodiac	$ 1 000 to $ 3 000.
EQUIPMENT includes precision echo sounder, sub-bottom profiler, boomer, side scan sonar, portable Wink vibracore, tide gauge, positioning system	$ 2 500.
PERSONNEL for surveying, sampling and reducing field data	$ 3 000.
SUPPORT CHARGES including consumables, flying time and fuel	say $300.
MOB/DEMOB TO INUVIK depends on location of a suitable vessel	$ 10 000 to $ 60 000.
TOTAL COST 45-day FIELD PROGRAM	$316 000 to $456 000.
Date reduction, laboratory analysis and report preparation	$120 000 to $140 000.
TOTAL PROGRAM COST	$426 000 to $596 000.

7.0 CONCLUSIONS

On the basis of the information examined during the present study, it may be concluded that:

1. Over the next three to five years, the three major petroleum operators together will not probably require more than about 500 000 m^3 of gravel per year for their presently anticipated exploration-related construction projects. Their combined short-term requirements are therefore very modest and can be easily met by the present "proven" resources.

2. The design of offshore production facilities is presently only in the conceptual phase, and hence the long-term gravel requirements of the petroleum industry are much more difficult to identify. According to the joint Environmental Impact Assessment, the total quantity of granular borrow required is not likely to exceed 700 000 000 m^3. It is speculated that perhaps 5% (35 000 000 m^3) of these requirements could be for gravel. More detailed information on the quantity and quality of gravel required for specific applications cannot be provided until the conceptual plans for offshore production facilities are more firmly developed.

3. Four known gravel borrow sources have already been identified in the Canadian Beaufort Sea by the petroleum operators. A total of 95 000 000 m^3 of gravel appear to be present near the seabed at Herschel Island, Issigak, Isserk and Banks Island. While less than 25% of this volume may be considered

to be "proven" reserves, additional studies may eventually confirm that perhaps as much as three times this volume exists at these locations.

4. Not all of this gravel is easily exploitable. Water depths at Herschel Island, Issigak and Isserk are too shallow to permit ready access by the larger trailer-hopper dredges currently operating in the Beaufort Sea. Moreover, all the deposits appear to be a maximum of only a few metres thick near their centre. This latter consideration may reduce the mineable volume to perhaps 40% or 50% of the total gravel volume in situ.

5. Because of the apparent uncertainties in both reserves and requirements, it is not known whether the gravel resources already identified will be of sufficient quantity to meet the long-term offshore requirements of both DIAND and the petroleum industry.

6. Information examined during the present study suggests, however, that further studies may eventually prove up additional gravel reserves, not only at borrow sites which have already been identified, but at other sites which may be closer to the future production facilities.

7. It is our opinion that DIAND can prepare an effective management plan which meets the needs of all petroleum operators in the Beaufort Sea only by developing close cooperation with the operators themselves. Future gravel studies undertaken by DIAND should attempt to utilize the

considerable expertise and experience available within both the major petroleum companies and the Geological Survey of Canada. Continued cooperation will establish mutual confidence and credibility among all those involved in the studies.

8.0 RECOMMENDATIONS

1. It is recommended that DIAND undertake a systematic approach to the development of a more comprehensive regional gravel inventory in the Canadian Beaufort Sea.

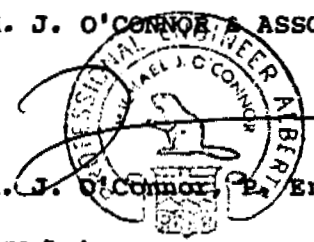
2. As a first step in preparing this expanded inventory, it is recommended that the available hydrographic and sub-bottom geophysical data be correlated with known borrow sources to identify the particular geophysical and morphological parameters unique to gravel deposits in the Beaufort Sea. Using these parameters, the study should examine original hydrographic information available from the Canadian Hydrographic Service to determine other possible locations where gravel deposits may be located.

3. Following this study, it is recommended that additional field programs be undertaken to groundtruth potential anomolies developed in (#2) above and provide additional bathymetric and geophysical information in prospective areas where the information presently available is deemed to be inadequate.

4. It is recommended that all future studies be conducted in full cooperation with both the petroleum operators and the Geological Survey of Canada, so that DIAND can benefit from the expertise and proprietary information already available in these two sources, and be kept abreast of ongoing developments which impact the demand for future gravel exploitation in the Canadian Beaufort Sea.

Respectfully submitted,

M. J. O'CONNOR & ASSOCIATES LTD.



M. J. O'Connor, P. Eng. P. Geoph.

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