Summary and Review of
The Northern Oil and Gas Action Plan
(NOGAP) Project A4: Granular Resources
Inventory and Management Program

GEOTECHNICAL SCIENCE LABORATORIES

Carleton University

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EXECUTIVE SUMMARY

This report is an overview of the work undertaken in the execution of NOGAP Project A4, the Granular Resources Inventory and Management Program. The Northern Oil and Gas Action Plan (NOGAP) was a federally funded research and planning program established in 1984 to "advance the state of federal and territorial government preparedness for major hydrocarbon development north of 60°" (NOGAP Secretariat 1985). The specific objectives of the Granular Resources Inventory and Management Program were to ensure that adequate geotechnical and hydrographic information be available and to provide detailed information on borrow sources in the Beaufort Sea and Mackenzie Valley regions.

Project summaries for each NOGAP A4 report are given in Appendix II. Individual projects undertaken toward the execution of NOGAP Project A4 fall into 5 categories:

- **Onshore (primarily Mackenzie Valley) granular resource assessments**
  Prior to NOGAP, a considerable amount of geological/geotechnical survey work was undertaken in preparation for potential hydrocarbon development in the Mackenzie Valley, as well as for the construction of the proposed Mackenzie Valley highway. Initial onshore granular resource work consisted primarily of the retrieval and evaluation of a significant amount of this work. Resource evaluations considered local potential and actual granular resource demands. In general, class 1 and 2 aggregate show the greatest potential for local resource shortfalls. The granular resource potential of the Mackenzie River bed was also examined, and shown to be feasible in appropriate conditions. Later work filled some local gaps in regional assessments (such as Cameron Hills granular resource assessment).

  The NOGAP reports relating to the onshore resource will be of interest to many parties concerned with development issues in the Mackenzie Valley corridor. The proceedings of the Mackenzie Valley Pipeline Granular Resource Workshop summarize much of the resource material available (sponsored by NOGAP and others) The local resource information will be useful for government at community level, as well as for regional authorities, including First Nation Settlement Regions.

- **Offshore (Beaufort Sea) bathymetry/ granular resource assessments**
  Bathymetric and granular resource data are important components of the evaluation of borrow requirements for drilling platforms. Operating experience

and improved understanding of the risks associated with floating ice have allowed a significant reduction in estimated borrow requirements for drilling platforms on the Beaufort continental shelf.

In the current economic climate, offshore development of the Beaufort sea is seen as unlikely for at least a decade. None the less, work done in the assessment of the granular resource potential of Beaufort Sea artificial islands has provided significant scientific insights into erosion and sediment transport rates on the Beaufort Shelf, as well as information on the navigational hazards they present. In general, NOGAP data collected for the offshore environment provides information in a region for which little information is otherwise available for marine geological and other studies.

- **Database development and compilation**
  Centralized collection of borehole information and related geotechnical information into computer databases was identified as perhaps the most significant contribution of NOGAP project A4 to future oil and gas development in the Mackenzie valley. In addition to the benefits of rapid retrieval and analysis that computer databases allow, the work undertake for NOGAP project A-4 contained a significant element of "data rescue".

- **Techniques development (Resistivity; Digital Terrain Modelling)**
  Terrain modelling techniques were developed to allow improved visualization of sea bottom topography, allowing identification of potential resource deposits by emphasising features whose morphology is associated with these resources. At the time of their development, such visualization techniques were not commonly used: they are now readily available through improved commercially available GIS software. Marine resistivity techniques developed under NOGAP for use in the Beaufort sea are currently in use in the Atlantic. Significant advances in this technique are now possible with the use of improved algorithms and faster data processing technology.

- **Evaluations of granular resource supply and demand**
  The proceedings of the two workshops (onshore/offshore) on granular resource issues provide valuable summaries of the work undertaken within NOGAP, and provide pointers to the original reports. Assessments of potential future needs for borrow materials will be useful primarily in land and granular resource use planning activities.

Expansion of the databases to include data for other areas would have the greatest immediate value in extending the work undertaken for the NOGAP granular resource project. Other datasets which could usefully be placed in databases similar to the

Mackenzie Valley Geotechnical Database include Liard Highway and Dempster Highway geotechnical information. Implementation of advances in the real-time marine resistivity system would also be useful although the cost of this may be prohibitive in the current regime. A number of specific recommendations were made at the Beaufort Sea Granular Resources Workshop concerning improvements to Database/GIS utility, but it was suggested that NOGAP funding should be reserved only for developments relating directly to granular resource applications.

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TABLE OF CONTENTS

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The Northern Oil and Gas Action Plan (NOGAP) Project A4: Granular Resources Inventory and Management Program

INTRODUCTION

The Northern Oil and Gas Action Plan (NOGAP) was a federally funded research and planning program established in 1984 to "advance the state of federal and territorial government preparedness for major hydrocarbon development north of 60°" (NOGAP Secretariat 1985). NOGAP was established as the chief means of "...Implementing a federal/territorial coordinated and accelerated socio-economic, environmental and technical research and planning program to support government regulatory, policy and program responsibilities and to achieve a state of preparedness for northern hydrocarbon production". With a hiatus from 1988 and 1990, the program concluded in 1994.

The Granular Resources Inventory and Management Program, NOGAP Project A4, was a significant fraction of the NOGAP projects undertaken within Indian and Northern Affairs Canada. The specific objectives of the Granular Resources Inventory and Management Program were (from NOGAP Project progress reports):

- To ensure that adequate geotechnical and hydrographic information is available to support the granular resources management program [of the Department of Indian Affairs and Northern Development] related to hydrocarbon development;
- To provide detailed information on the location, type, quantities and qualities of each borrow source in the Beaufort sea region as is required to support conservation and utilization strategies and policies being developed under the Territorial Quarrying Regulations, Public Lands Grant Act and regulations, and the proposed Territorial Lands Pits and Quarrying Regulations.

This report is an overview of the work undertaken in the execution of NOGAP Project A4, the Granular Resources Inventory and Management Program. It consists of a

main report giving the general history, objectives and results of NOGAP Project A4, together with project summaries for each NOGAP A4 report. Project summaries are compiled as Appendix II of this report.

NOGAP

Several federal government departments were involved in NOGAP [1], as well as the Governments of the Northwest Territories and Yukon, examining a broad range of socio-economic, environmental and cultural aspects of the proposed developments:

> "NOGAP is intended to advance government preparedness for major hydrocarbon development in Canada's northern territories. This means acquiring the knowledge and analytical capability to make appropriate decisions concerning major northern development proposals. NOGAP funds have been used to accelerate work on current projects or to undertake new activities which existing budgets could not accommodate." (Report A4-26: Beaufort Sea Workshop)

With the refinement of oil and gas industry plans, and with the release in 1984 of the report of the Beaufort Environmental Assessment and Review Process Panel, the focus of the NOGAP program changed from a generic development scenario (production in the Beaufort Sea / Arctic Islands, with transportation by pipeline and/or tanker), to a program focused on three scenarios (from NOGAP Secretariat 1985):

- the potential hydrocarbon production area of the Beaufort Sea on-shore and near shore;
- a small-diameter, buried pipeline up the Mackenzie Valley from the Delta to Norman Wells, transporting oil from on-shore and near-shore sources; and

[1] Agriculture, Indian and Northern Affairs, Fisheries and Oceans, Environment, Energy, Mines and Resources, Transport, National Museum of Man

- all-year, ice strengthened tanker transportation of oil, using two tankers, from one or two artificial islands or platforms in the Beaufort Seas, eastward through the Northwest Passage.

The implications of these scenarios for the granular resources subproject were that efforts would need to concentrate on supplying granular material for exploration and production facilities in the offshore (where very limited information was available), as well as to supply material to support a pipeline down the Mackenzie Valley.

Beaufort Environmental Assessment Review Panel

"The Beaufort Sea Environmental Assessment Panel was appointed in may of 1981 by the Minister of the Environment to identify the major positive and negative effects of hydrocarbon production and transportation from the Beaufort Sea-Mackenzie Delta region upon the human and natural Environments in Canada's North, and to recommend ways and means of dealing with these effects" (FEARO 1984). In its final report it gave the recommendations of the panel concerning proposed hydrocarbon production in the Beaufort Sea, and the associated hydrocarbon transportation systems (pipelines and/or tankers):

- Production to a rate of about 15 000 m^3 oil / day
- Transportation by small diameter buried oil pipeline, or 2 Arctic Class 10 oil tankers.
- Higher production rates to be phased in with further environmental review.

The Panel report identifies NOGAP as an important contributor to government preparedness in a number of key areas. While the report does not explicitly identify the various NOGAP subprojects, many general statements and recommendations which touch on NOGAP project A4 are included. In brief summary (Relevant portions of the final report are quoted in Appendix I of this report.):

- **Pipelines**

  All alternative Beaufort Sea oil pipeline proposals are all routed along the Mackenzie Valley from Richards island in the Mackenzie Delta to Edmonton, Alberta (approximately 2250 kilometres). Approximately one million cubic metres of gravel could be required for a small diameter pipeline (the Panel's recommended pipeline).

- **Artificial Islands**

  Proposed offshore production systems must be designed to withstand the ice forces present or possible in the Beaufort Sea. There is a remote possibility of a large ice island (tabular iceberg) appearing in the deeper offshore waters. Improvements are constantly being made to the designs of artificial islands and further advances are expected as understanding increases. The Panel was satisfied that production islands can be designed, built, and safely operated.

  In the original Environmental Impact Statement it was estimated that a maximum of 50 to 70 km^2 of seafloor could be directly disturbed by dredging operations. The volume of dredged material needed has been dramatically reduced as a result of advances in technology for island building, and the use of caisson-retained islands and the SSDC (Single Steel Drilling Caisson).

- **Ports and Supply Bases**

  The Panel report suggests that environmental conditions at King Point are less restrictive for a deep water port to support production facilities than alternative sites.

- **Quarries**

  The Panel concluded that a quarry at Mt. Sedgewick to supply rock to King Point should not be developed, due to its situation within National Park boundaries, because of potential adverse effects on spring and summer caribou movements, and because of the potential for alternative island building technologies which reduce the need for these materials.

- **Oceanographic and Related Research**

  The Panel identified a need for research into environmental processes in the Beaufort Sea, and recommended that productive avenues of research associated with the proposed hydrocarbon projects be given priority. In particular, the Panel endorsed "research into seabed geological processes and hazards including: sediment dynamics, seabed ice scour, subsea permafrost, and seabed deformation and displacement..."

The review panel identified the principal issues to be addressed, with the scope of work to be done dependent to a large degree on the current state of knowledge. With very limited knowledge of the granular resource potential of the Beaufort Sea floor and adjacent land, NOGAP projects focused on the Mackenzie Delta and Offshore areas, and to alternatives to the Mount Sedgewick quarry. As the material in the following sections will show, the work undertaken for NOGAP project A4 has addressed the issues raised in the Review Panel report.

Granular Resource Evaluation and Use

The work of NOGAP project A4 is in support of a more general purpose northern granular resource inventory. "DIAND's role in the preparation of a granular resource inventory is as a resource manager, not as a resource user." (Gowan, p. 11, in report A4-26A). Other projects which have contributed to the inventory have been (initially)

the Mackenzie Highway project and (together with NOGAP and later) the Inuvialuit Final Agreement Implementation Program.

Prior to NOGAP, a considerable amount of geological/geotechnical survey work was undertaken (in the 1960's) in preparation for potential hydrocarbon development in the Mackenzie Valley, as well as for the construction of the proposed Mackenzie Valley highway. The original assessments were based on field reconnaissance, air photo interpretation, and interpretation of seismic data. Glacial features were identified and described, allowing an interpretation of the glacial history, as well as the potential of these features for granular resource extraction. Much of the borehole data was collected to help in more detailed pipeline and highway route selection. Consolidation of the data collected in the Mackenzie Valley into databases started in the early 1970's.

The granular resource inventory program was established when frontier hydrocarbon exploration activities were intensifying at a time of high petroleum prices. The need for accelerated inventory and management of granular resources information was apparent from the initiation of the Beaufort Environmental Assessment and Review Process. "The major Beaufort Sea petroleum operators... indicated a potential demand for up to 700 million cubic metres of granular material. Although it was well known that substantial quantities of sand-sized material existed at the seafloor, the distribution of offshore gravel resources was less certain. At about the same time, a regional overview study of the supply/demand situation for offshore granular resources was undertaken by the Department of Indian Affairs and Northern Development (DIAND) with the co-operation of the industry. The main finding of the study was that proven resources fell far short of the forecast long-term demand for an estimated 35 million cubic metres of gravel. " (From the preface, Beaufort Sea Granular Resources Workshop, NOGAP A4-26B.)

Exploration permits for the Beaufort Sea continental shelf were issued during the 1960's. The first artificial island was constructed in 1973. The first islands were built in the relatively shallow (<10 m) nearshore zone. Through the 1970's, development moved into deeper water as technology and experience improved. The earliest islands, referred to as "sacrificial beach" islands, were constructed using suction dredges. The principal design feature of these was a very low beach slope requiring no erosion protection. These required large quantities of granular material of relatively low quality (fine sands), and were practical only when a large source of suitable material was available nearby. While island technologies were developed which allowed for smaller quantities of higher quality fill, sacrificial beach islands continued to be employed where conditions made them appropriate (relatively shallow water, with nearby granular source). The more sophisticated island technologies required greater control and assurance of the quality of the fill and the conditions under which they were placed. The deepest sacrificial beach island was constructed in 19 m of water. Esso constructed most of the shallow water islands, with Dome (Amoco Canada) and Gulf operating in the deeper water.

The most pressing need at the initiation of NOGAP was to clarify the geological and geotechnical conditions in the Beaufort Sea. The first model of Beaufort Shelf surficial geology was proposed in 1980. Refinement of this model was necessary in order to help identify likely borrow sources as well as to refine estimates of borrow material volumes. Work undertaken for NOGAP in the Beaufort Sea was guided since 1985/86 by an informal working group that included representatives of each of the three major Beaufort operators and the Geological Survey of Canada (GSC).

Report Structure

The remainder of this report is divided into three sections. In order to place granular

resource issues and information needs into context, the physiology and glacial history of the region will be described. Following this, the projects undertaken for NOGAP project A4 will be discussed according to five categories: (Beaufort Sea, Mackenzie Valley, technique development, databases and GIS, and resource evaluation / scenario assessment). These categories, while arbitrary, allow discussion of groups of projects with common themes. Finally, the results of NOGAP project A4 are discussed as a whole, in the light of changes which have occurred since the establishment of the research program.

In the discussions of granular resource deposits here and in the individual report summaries, the borrow materials are classified according to the confidence with which estimates of quantity are made, and according to the quality of the resource material. These classification systems are briefly outlined in box 1.

Appendix I contains relevant excerpts from the final report of the Environmental Assessment Panel for Beaufort Sea Hydrocarbon Production and Transportation. Individual project report summaries are included at the back of the report as

These categories were used when discussing the delineation of deposits:

- **proven** : limits of a deposit are defined based on aerial and ground reconnaissance, and substantiated by adequate borehole information;

- **probable**: limits of a deposit are defined based on aerial and/or ground reconnaissance, and partially substantiated by limited borehole information;

- **possible**: limits of a deposit are defined based on aerial and/or ground reconnaissance, but not yet substantiated by adequate borehole information.

These categories were used when discussing the quality of granular deposits: (Hernandi, report A4-26A, p. 28):

- **Class 1**: Excellent quality material, such as well graded sands and gravels suitable for use as asphalt or concrete aggregates with a minimum of processing.

- **Class 2**: Good quality material, suitable for base and surface course aggregates or structure supporting fills. Production of concrete aggregates may also be possible with extensive processing.

- **Class 3**: Fair quality aggregates consisting generally of poorly graded sands and gravels with or without substantial silt content.

- **Class 4**: Poor quality materials generally consisting of silty, poorly grade fine sand, with minor gravel.

- **Class 5**: Bedrock of fair to good quality.

1 Granular resource classification schemes

Appendix II. A list of project summaries is given in box 2. Each summary contains information on the report's purpose, geographic focus, methodology, a summary of findings and a listing of data contained within the report where appropriate.

A4-01 ■ Surficial Geology and Granular Resources, Southeast of Herschel Island.
A4-02 ■ Offshore Geotechnical Site Investigation: Herschel Sill Sites, Yukon Territory
A4-03 ■ Investigation of Subsurface Conditions at King Point, Yukon Territory
A4-04 ■ Report on the Analysis of Bathymetric Data - Western Beaufort (Yukon) Continental Shelf
A4-05 ■ Overview, Granular Resource Potential for the Western Beaufort (Yukon) Continental Shelf
A4-06 ■ Synthesis & Interpretation of Bathymetric, Geophysical and Geotechnical Data from Issigak Borrow Block
A4-07 ■ Granular Resource Evaluation Richards Island, NWT
A4-08 ■ Report on Evaluation of Granular Resource Potential Lower Mackenzie Valley
A4-09 ■ Report on Western Beaufort Region Concrete Aggregate Study
A4-10 ■ An Evaluation of the Feasibility of Developing Granular Borrow from the Bed of the Mackenzie River
A4-11 ■ Modelling & Mapping of Potential Granular Resource Features, South-Central Beaufort Sea, NWT
A4-12 ■ Report to DIAND on Beaufort Region Quarry Rock Study
A4-13 ■ Real Time Marine Resistivity System
A4-15 ■ Compilation & Cataloguing Of Beaufort Bathymetric & High Res.Shallow Geophysical Data
A4-16 ■ Interpretation and Synthesis of High Resolution Reflection Seismic Data from Banks Island Borrow Area
A4-19 ■ Updating of the Northern Granular Resources Information Mapping System
A4-19 ■ Digitization of Beaufort Granular Resource Information - Final Report
A4-20 ■ Synthesis and Interpretation of Bathymetric, Geophysical, Geological and Geotechnical Data: Isserk Borrow Block - South Central Beaufort Sea
A4-21 ■ Synthesis and Interpretation of Bathymetric, Geophysical, Geological and Geotechnical Data: Erksak Borrow Block - South Central Beaufort Sea
A4-22 ■ Beaufort Sea Geotechnical and Geophysical Databases
A4-22 ■ Beaufort Sea Geotechnical and Surficial Sediment Database
A4-24 ■ Review of Granular Resource Potential: South-Central Beaufort Sea with Identification of Field Investigation Targets
A4-24D ■ Inversion of Electrical Resistivity Data to Identify Granular Resources in Arctic
A4-26A ■ Granular Resource Requirements For Proposed Mackenzie Valley Pipelines: Technical Papers and Workshop Proceedings
A4-26B ■ Proceedings of the Beaufort Sea Granular Resources Workshop
A4-26C ■ Granular Resource Req.for Potential Hydrocarbon Developments in the Western NWT
A4-27 ■ Geotechnical/Geological Investigation,Selected Granular Resource Prospects Beaufort Sea
A4-27 ■ Granular Resource Investigation, Source 222, Dempster Highway #8, km 222, Caribou creek, NWT
A4-27 ■ Granular Resource Investigation Northern Richards Island, NWT
A4-28 ■ Environmental Constraints Analysis, Granular Resource Development in the Beaufort Sea - A New Methodology using Low Cost Raster GIS
A4-30 ■ Granular Resource Potential, Beaufort Sea Artificial Islands
A4-31 ■ Potential Granular Resources and Their Geological Constraints Northern Richards Island
A4-32 ■ Compilation Inventory of Granular Resources Information Within Cameron Hills Area
A4-32 ■ Potential Granular Deposits & Terrain Analysis,Selected Areas on the Cameron Hills, NWT

2 A list of NOGAP project A4 subprojects, by subproject number.

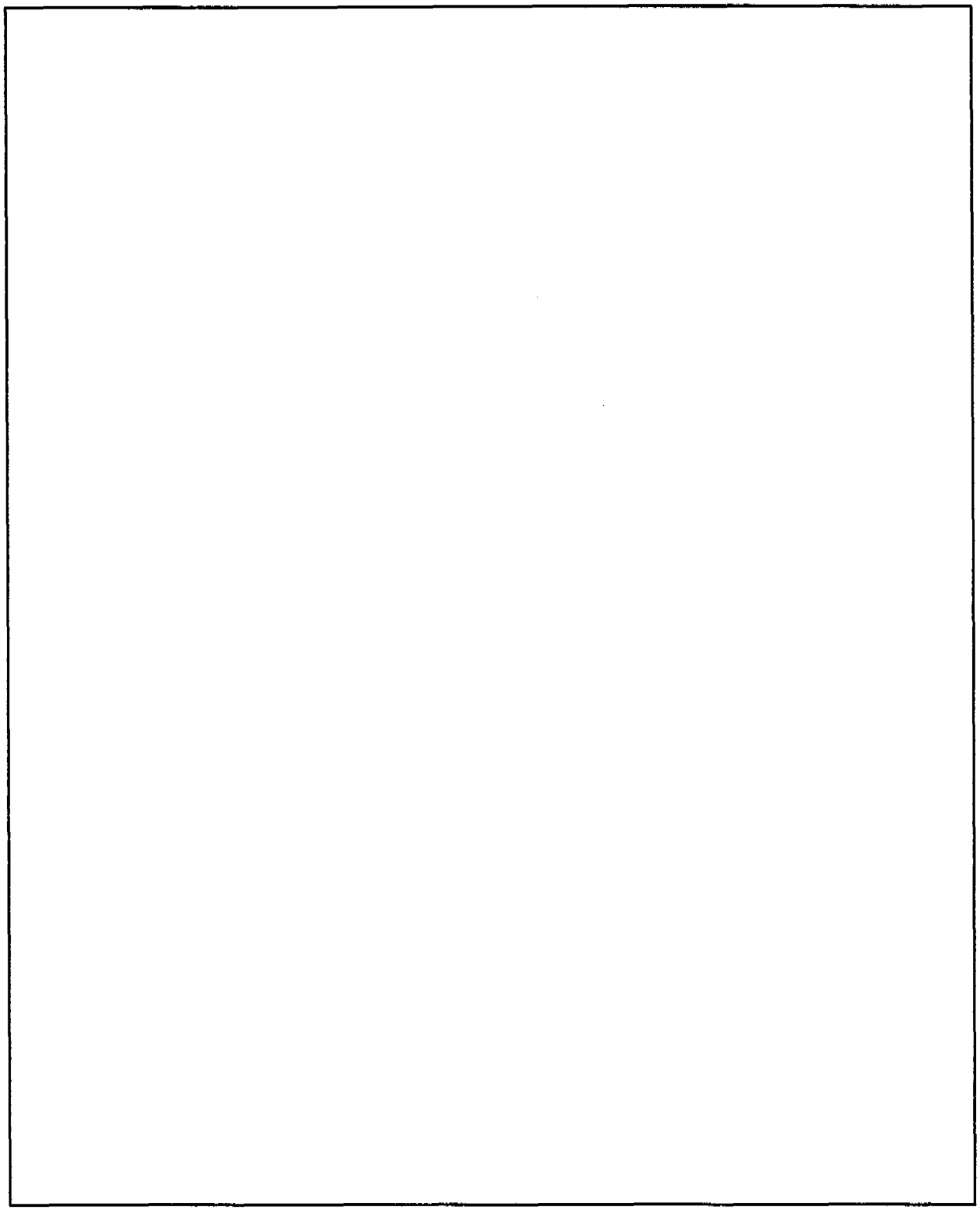

Figure 1 Mackenzie Valley and Beaufort Sea Region

ORIGIN AND DISTRIBUTION OF GRANULAR RESOURCES, MACKENZIE VALLEY - BEAUFORT SEA AREA, NWT.

Aggregate is hard, inert construction material, which forms an essential and major commodity in the construction of Canadian transportation systems, settlements, and engineered structures. It is derived from deposits of sand and gravel, though, locally, crushed rock may be used. Most sand and gravel deposits in northern Canada are from glacial outwash, glaciofluvial, or fluvial systems. The location and extent of granular resources in the Mackenzie valley and delta area, including the nearshore Beaufort Sea, stems from the various sedimentary environments that have occupied the region over the last 100,000 years. The sedimentary history of the region is such as to explain not only deposition of materials suitable for use as aggregate, but also the relative scarcity of these materials in accessible, surficial settings.

Physiographic setting

The Mackenzie Valley lies in both the northern extension of the Interior Plains of Canada, and the eastern margins of the Cordilleran Orogen (from Camsell Bend to Norman Wells; Mathews 1986). The Interior Plains have received sediments from the Canadian Shield and the eastern Cordillera over geologic time, and reservoirs of petroleum and natural gas have formed in and from these materials. The hydrocarbon reserves delineated so far are concentrated in Mackenzie Lowland, strictly part of the Cordillera, and in the Tuktoyaktuk Coastlands of the Arctic Coastal Plain.

Granular deposits in the area are derived from either glacial sources, laid down during successive glaciations of the last two million years, or develop today in the floodplains of high energy streams descending from the eastern ranges of the Cordillera. Mackenzie Lowland contains, on average, about 50 m of Quaternary

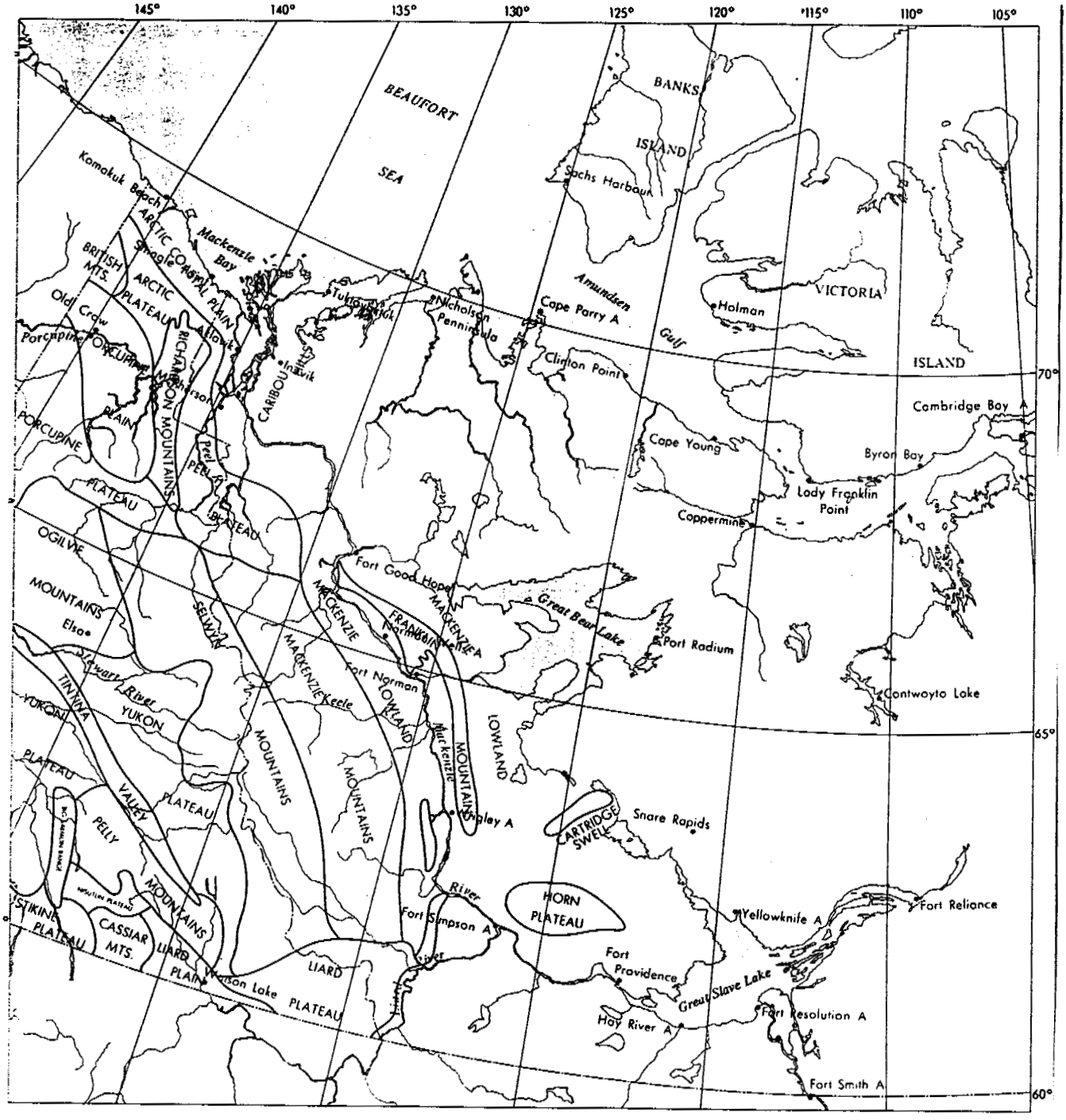

Figure 2 Physiographic Regions of The Western Arctic (from Burns 1973)

sediments, locally up to double this amount (Mackay and Mathews 1973), and in the delta and offshore areas, the thickness is also greater.

The Mackenzie's passage from Great Slave Lake to the coast begins through Great Slave Plain. This is a basin of little relief, and hence confluent streams are of relatively low energy. The subdued topography provides few steep exposures where the bedrock might shatter, and, hence, gravel deposits were laid down during and immediately following glaciation; little gravel is being created today.

At Camsell Bend, Mackenzie River reaches the eastern extent of the Cordillera, and from here to the confluence with Mountain River, north of Norman Wells, tributary streams descending from the western mountains, or Franklin Mountains to the east, often carry substantial quantities of gravel in their bedload. Most of the gravel is paraglacial sediment, with the streams still mining sedimentary sources created by the last glaciation. However, the steep relief of the Cordilleran ranges, and the abundant fractured bedrock in the region provide fresh aggregate.

North of Mountain River, the Mackenzie flows through Peel Plain, another area of low relief, until it reaches the delta. As in Great Slave Plain, little new gravel is being created in these areas, although streams draining the Richardson Mountains, west of the delta, carry a coarse bedload. Since large areas are of low relief, again the influence of glacial processes on aggregate distribution is prominent.

Glaciation

During the Pleistocene, valley glaciers, descending from the Cordilleran ice fields, and the Laurentide ice sheet, spreading north and west from ice divides over the Canadian Shield, have met in the vicinity of Mackenzie Valley. At times the Laurentide ice sheet impinged on and occupied eastern valleys of the Cordillera, while at others

the Cordilleran glaciers advanced down valley, and their proglacial streams discharged into Mackenzie Lowland.

Laurentide ice extended northwards into Tuktoyaktuk Coastlands, covered most of modern Mackenzie Delta, and, at one time, extended along Yukon Coastal Plain to near Herschel Island. The limit of glaciation on Tuktoyaktuk Peninsula extends in a line west from Toker Point, north of Tuktoyaktuk, to Nicholson Peninsula on the south side of Liverpool Bay (Rampton 1987). The lowering of sea level which accompanied glaciation led to exposure of much of Mackenzie Shelf, up to 100 km north of the present coastline.

The timing of various glacial limits is not well established, but the most recent Sitidgi stage, with ice in the current delta but south of the Eskimo Lakes, appears to have culminated before 13 - 11 thousand years ago (Rampton 1988, p. 71). Ice covered Mackenzie Valley, from the Sitidgi limit to Great Slave Lake.

During deglaciation, the ice front retreated northeastward and eastward, and deglaciation occurred first in the north, and last in upper Mackenzie Valley. The large quantities of water which were released during deglaciation formed glacial lakes within valleys tributary to the Mackenzie, while ice blocked those valleys, and then a 800 km long lake in Mackenzie Valley, from the Ramparts, just south of Fort Good Hope, to Rabbitskin River, 50 km east of Fort Simpson (Smith 1992). Glacial Lake Mackenzie formed in the isostatic depression south of the limestone barrier at the Ramparts (Mackay and Mathews 1973). Differential isostatic rebound over the length of the valley moved the lake southwards over its lifetime. Over time, the lake covered a large portion of Mackenzie Lowland. The lake had drained, and the present fluvial regime was established 10,000 years ago (Smith 1992). The valley upstream from Rabbitskin River was, in turn, covered by a separate lake, Glacial Lake McConnell, a

vast feature, which incorporated the basins of present Great Bear and Great Slave lakes.

Glacial deposits

Glaciers are efficient geomorphological agents, being responsible for substantial erosion, transportation and deposition of surficial materials. Glaciers are indiscriminate in the material they entrain, and can competently transport rock particles of any size. Glaciers that originate in mountainous terrain commonly carry a variety of material, that has either fallen onto the glacier, or is incorporated in the bed of the glacier as it slides along the valley floor. This material is of a range of particle sizes, and becomes suitable for use as aggregate if it is washed by meltwater streams, which remove the fine material. The granular material may form eskers, the deposits of subglacial meltwater streams, or kames, the lateral deposits washed by peripheral meltwater streams. Rarely are direct deposits of glacial debris, till or moraine, suitable for use in construction, because the content of fines is too high. Large portions of the uplands in the Mackenzie Delta area, and of terrain further south in Mackenzie Valley, are covered with a layer of till. This is the result of ice melting in situ, leaving debris unsorted.

Glaciers emanating from the Cordilleran ice sheet would have possessed many of the characteristics of valley glaciers, for in their lower reaches they were confined by the terrain. The Laurentide ice sheet, however, which formed over the relatively flat Canadian Shield, was not bounded by terrain. The mineral material transported by Laurentide ice was derived in general from subglacial erosion of the relatively resistant bedrock. The bulk of the ice sheet was, therefore, relatively clean, and only relatively small amounts of debris were transported. Large areas of the Shield, and the Interior Plains, are today covered by little till, or are exposed bedrock, as a result. Again, these deposits are only suitable for use as aggregate if they were sorted by

subglacial streams. Laurentide ice which flowed over significant undulations in bedrock, such as the margins of the Caribou Hills north of Inuvik, or the Franklin Mountains east of the present course of Mackenzie River, entrained a readier supply of debris than that provided by the Shield.

The nature of stream deposits is directly associated with the velocity, or energy, of the stream, and the distance the particles have travelled. As particles travel longer distances they suffer more collisions with other particles and with the stream bed, and hence decline in size. High velocity streams can move larger, heavier particles, than slower streams. The velocity of water travelling under an ice sheet depends on various factors, principally the size of subglacial channel, the nature of the glacier bed, and the hydraulic head.

As soon as water discharges from the confinement of a glacier or ice sheet, the tendency, over a flat surface, is for the flow to disseminate laterally into a multitude of channels, which develop easily in the glacially-derived debris. For our region, the result is that at the margins of the Laurentide ice, outwash from the all-time limit on Tuktoyaktuk Peninsula supplied areas to the north with sand, either directly, or after additional eolian transport. These extensive sheets of sand contain few cobbles and a little gravel. The proglacial deposits extend onto Beaufort Shelf, now offshore, but above sea level during the glaciations (Hill et al. 1985). Where subglacial flow was concentrated in channels, eskers formed, such as at the well-known Ya-Ya Lake site on southern Richards Island.

Mackenzie Valley was likely a major conduit for subglacial meltwater during the Pleistocene, because of the erosion of Mackenzie trough in the continental shelf of the Beaufort Sea, presumably by continuing discharge. Extensive till deposits are also found within the Valley itself, some of which show features of glacial erosion at

the surface, indicating they are from an earlier glacial advance (Mackay and Mathews 1973). Sands and gravel are often recorded in the Quaternary deposits throughout the valley, but often these are at depth, and are covered by either till (Savigny 1989) or lake deposits, which covered the granular material with a veneer of fine-grained sediment.

Glacial Lake Mackenzie, which covered the middle reach of the valley at the end of glaciation, deposited thick sequences of silt and clay, through which the present course of the river has been incised. These deposits extend for several km on each side of the river. In this terrain aggregate is not readily found. However, where rivers flowed into the glacial lake, substantial deltaic deposits accumulated, particularly at the mouths of the Liard, Little Bear, Carcajou and Mountain Rivers, draining from the Cordillera (Smith 1992). These rivers dropped their coarse material at the deltas, as the stream velocity rapidly declined.

Finally, development of the Mackenzie Delta itself, has covered a substantial northern portion of the region. The fine-grained sediments carried into the delta are deposited on top of coarser material (Johnston and Brown 1965), but the depth of accumulation prevents utilization of the resource.

Other factors

The ready availability of aggregate is also hindered in the region by two other factors, namely the presence of ground ice in surficial deposits, and the requirements for the aggregate at locations associated with Glacial Lake McConnell. First, the presence of permafrost, which is typically icy in near-surface sediments, hinders recovery of aggregate. The ice must be melted before recovery is feasible, and in areas of massive ground ice, as at Ya-Ya Lake (Dallimore and Wolfe 1988), or Inuvik (Johnston 1981, Fig 2.22), the workability of pit operations may be considerably hindered by its

presence (Hayley and MacLeod 1977).

Second, aggregate is required for construction purposes, either at settlements, or for transportation infrastructure linking settlements. For historical reasons, all settlements in Mackenzie Valley, are located on the river, and, hence, are largely in terrain covered by glacial lake sediments. The pipeline route taken southwards from Norman Wells, and proposed between the Wells and the Mackenzie delta area also traverses extensive tracts of glacial lake sediments. The importance of conditions during deglaciation is therefore magnified, in a sense inadvertently.

PROJECTS BY TYPE

The work undertaken in the execution of the Granular Resources Inventory and Management project of NOGAP will be discussed according to five categories:

1: Beaufort Sea Investigations
2: Onshore (Mackenzie Valley) Investigations
3: Techniques Developments
4: Database/GIS development and maintenance
5: Resource Evaluation / Scenario assessment

Project A4 was guided by an informal working group that included representatives of each of the three major Beaufort operators and the Geological Survey of Canada (GSC). A total of 32 subprojects were identified in the planning and execution of NOGAP project A4. In several cases the scope of the subproject was sufficiently broad that more than one report was produced. Some subprojects were not executed before the conclusion of the NOGAP program. The lists of project reports provided for each category includes all reports submitted, so that some duplication of project numbers is apparent.

The work undertaken for NOGAP can be divided into two distinct phases, with the evaluation of the first phase establishing the work to be done in the second phase. The earlier phase consisted of a systematic compilation and evaluation of the geophysical, geotechnical and geological work. In the second period, the work involved field work based on a review of results to date.

1 : BEAUFORT SEA

A4-01	■ Surficial Geology and Granular Resources, Southeast of Herschel Island. M.J. O'Connor and Associates Ltd., 1985
A4-02	■ Offshore Geotechnical Site Investigation: Herschel Sill Sites, Yukon Territory, EBA Engineering Consultants Ltd., 1984
A4-05	■ Overview of Granular Resource Potential for the Western Beaufort (Yukon) Continental Shelf, Earth and Ocean Research Ltd., 1986
A4-06	■ Synthesis and Interpretation of Bathymetric, Geophysical and Geotechnical Data from Issigak Borrow Block, EBA Engineering Consultants Ltd., 1987
A4-16	■ Interpretation and Synthesis of High Resolution Reflection Seismic Data from Banks Island Borrow Area, H. R. Seismic Interpretation Services Inc., 1987
A4-20	■ Synthesis & Interpretation of Bathymetric, Geophysical, Geological & Geotechnical Data: Isserk Borrow Block, South Central Beaufort Sea, Earth and Ocean Research Ltd., 1988
A4-21	■ Synthesis & Interpretation of Bathymetric, Geophysical, Geological & Geotechnical Data: Erksak Borrow Block - South Central Beaufort Sea, Earth and Ocean Research Ltd., 1994
A4-24	■ Review of Granular Resource Potential: South-Central Beaufort Sea with Identification of Field Investigation Targets, Lewis Geophysical Consulting, 1994
A4-27	■ Geotechnical/Geological Investigation of Selected Granular Resource Prospects Beaufort Sea, EBA Engineering Consultants Ltd., 1994
A4-30	■ Granular Resource Potential, Beaufort Sea Artificial Islands, Klohn - Crippen Consultants Limited, 1995

Beaufort Sea Subproject Reports

A total of 10 subproject reports dealing with offshore granular resource delineation in the Beaufort Sea have been completed under NOGAP. The early NOGAP work in the Beaufort Sea consisted of a systematic compilation and evaluation of the geophysical, geotechnical and geological work done in the various granular resource prospect areas on the Beaufort continental shelf (from west to east: Yukon Continental Shelf, Herschel Island, Issigak deposit, Isserk borrow block, Erksak borrow block, southwest coast of Banks Island). In the later period, the work undertaken in the offshore which followed the Beaufort Workshop (discussed below) involved field work based on a review of data gleaned from reports published prior to 1993. Of the several investigations proposed, only the geotechnical program was undertaken.

Early granular resource exploration (prior to NOGAP: 1980-81) was based on

interpretations in which the shelf had been glaciated. Subsequent models have no glaciation and are based instead on marine transgression and fluvial outwash (fine sand). The geological models developed subsequently in the granular resource borrow areas reflect the need/ability to distinguish local geological events for each of the borrow sites.

The first model of Beaufort Shelf surficial geology was proposed in 1980 (O'Connor, 1980). This was based on a review of previous geotechnical geological and geophysical work in the region. This model identified three stratigraphic units:

- Unit A, consisting of recent marine sediments;
- Unit B, consisting of "sediments deposited in a complex transitional environment which existed during the last sea level rise" (O'Connor 1980);
- Unit C, consisting of a "much older sequence whose depositional environment is presently unknown, but which probably contains sediments derived from former continental (glacial, fluvial and eolian) and transitional (deltaic, littoral) environments". (O'Connor 1980)

With the exception of the field investigations undertaken in the Herschel Island and area projects (A4-01 and A4-02) (boreholes, probeholes and shallow test pits), these "syntheses" were undertaken using existing data from industry (Esso Resources Canada Ltd., Dome petroleum Ltd. and Gulf Canada Resources Ltd.), the Canadian Hydrographic Service, and the Atlantic Geoscience Centre, Geological Survey of Canada.

Granular resource evaluations for the western and eastern extremes of the exploration region are problematic. Data for the Herschel Island and Yukon Continental Shelf do not allow accurate assessments because the thickness of deposits is not known. For Banks Island, the very uneven seafloor relief and/or the complexity of stratigraphic

conditions encountered in several places present challenging environmental obstacles to the safe and efficient dredging of these resources. In addition, the complex geology, diversity of source deposits and poor seismic coverage make it impossible to make a quantitative evaluation of the resource. For these reasons as well as the greater distance of these regions from the hydrocarbon resource, It was recommended at the Beaufort Sea Granular Resources Workshop that future granular resource exploration concentrate on the central Beaufort Continental Shelf.

Offshore geological models do not agree with onshore models, in particular the age of sediments below unit C. Efforts have been made to reconcile onshore and offshore geological models, most notably in the "megatransect" project (Dallimore 1991), involving borehole and seismic investigations on an onshore-offshore transect in the vicinity of northern Richards Island. While good correlations between onshore and offshore stratigraphy were established, the geological models for the two regimes have not been satisfactorily resolved. Steve Blasco (Atlantic Geoscience Centre, Geological Survey of Canada) has identified the triangle formed by Amauligak, Issigak, and North Head as the best area for field studies to resolve the "stratigraphic schism" .

The major project undertaken offshore during the second period was a study of the granular resource potential of the artificial islands constructed for exploratory drilling. The study provides a summary of the location, type, quantity and quality of granular materials available in 37 islands, and provide selected examples of island erosion and sediment transport rates. The results are directly useful to the goals of NOGAP project A4 because they indicate the extent of the resource at the present time and indicate the future potential of the islands as they erode through time. In addition, they are a significant aid to understanding marine surficial geology of the Beaufort continental shelf, by providing what amounts to a full scale controlled erosion

experiment: rates and mechanisms of erosion are clearly identified through comparison of current island profiles with original profiles. In general, the environmental conditions responsible for erosion become increasingly severe with increasing water depth/ distance offshore; the rate of island submergence is most rapid in the first 2-3 years after abandonment, and is faster for islands in deeper water. Islands stabilize and sediment loss decreases as they submerge, with island migration in the direction of summer storm tracks.

The information gathered in the artificial islands study will be useful for its original purpose, primarily for future development. The importance of the project lies primarily in the identification and cataloguing of data collected for this purpose, to keep it accessible when it will be of greatest use. This information has been incorporated into the inFOcus database/mapping system. The artificial islands represent the potential granular resource in the offshore environment about which the most precise information is available: they also represent a significant hazard to navigation. The information available about their current state as well as the likely evolution over time will be useful in any consideration of future bathymetric surveys.

The artificial islands study was a followup to work done in 1989 on four of the islands, as a preliminary assessment of the erosion and sediment transport rates and as a test of sidescan radar as a technique to detect the presence of debris on the islands surface. The earlier study (Canadian Seabed Research, 1989) identified the sacrificial beach islands as most likely to have hazardous debris remaining on the surface. The report recommended a comprehensive study of the remaining islands, with the data collected into a database: these recommendations have essentially been fulfilled in the study done for this project.

David Monahan (Director of Geomatics, Canadian Hydrographic Survey) indicated an

interest in the Artificial Islands study, for a number of reasons:

1) There is so little data for Arctic waters that "almost anything" of concern to marine traffic will be used and indicated as "reported" so clients know its provenance.

"2) Much of the Arctic has never been surveyed at all and we are far more interested in doing a first survey than a re-survey, which the Beaufort Sea would be".

"3) rates of deposition and erosion are interesting, but they would have to be incredibly high to overcome point 2) "

4) Current financial constraints leave little money to do much field work anywhere, "so the Arctic does not fare well in our priorities unless someone else wants to fund us."

The data from the artificial islands will be of immediate use to the Coast Guard, whose operating timescale is much shorter that the Hydrographic Service. The CHS updates navigational charts primarily according to changes in the deployment of navigational aids, with a resurvey not expected for at least ten years (Jake Kean, CHS, personal communication).

2 : MACKENZIE VALLEY

A4-03	■ Investigation of Subsurface Conditions at King Point, Yukon Territory, M. J. O'Connor & Associates Ltd., 1986
A4-07	■ Granular Resource Evaluation Richards Island, NWT, EBA Engineering Consultants Ltd., 1986
A4-08	■ Report on Evaluation of Granular Resource Potential Lower Mackenzie Valley , Hardy Associates Ltd., 1986
A4-09	■ Report on Western Beaufort Region Concrete Aggregate Study, Klohn Leonoff Ltd., 1989
A4-10	■ An Evaluation of the Feasibility of Developing Granular Borrow from the Bed of the Mackenzie River, EBA Engineering Consultants Ltd., 1987
A4-12	■ Report to DIAND on Beaufort Region Quarry Rock Study , Golder Associates (Western Canada) Ltd., 1987
A4-12	■ Supplementary Report to DIAND on Beaufort Region Quarry Rock Study , Golder Associates (Western Canada) Ltd., 1988
A4-27	■ Granular Resource Investigation, Source 222, Dempster Highway #8, km 222, Caribou creek, NWT, EBA Engineering Consultants Ltd., 1994
A4-27	■ Granular Resource Investigation Northern Richards Island, NWT, EBA Engineering Consultants Ltd., 1994
A4-31	■ Potential Granular Resources and Their Geological Constraints Northern Richards Island, Terrain Analysis and Mapping Services Ltd, 1993
A4-32	■ Compilation Inventory of Granular Resources Information Within Cameron Hills Area , J. D. Mollard and Associates Limited, 1993
A4-32	■ Potential Granular Deposits and Terrain Analysis of Selected Areas on the Cameron Hills, Northwest Territories, J. D. Mollard and Associates Limited, 1994

Mackenzie Valley Subproject Reports

Geological and geotechnical investigations in the Mackenzie Valley started in the 1960's in response to hydrocarbon exploration activities, in preparation for oil and gas production and transportation proposals. Onshore (Mackenzie Valley) granular resource assessments undertaken were only partially funded through NOGAP project A4. In particular, the granular resource assessment for the Mackenzie Delta region was funded exclusively under the Inuvialuit Final Agreement Implementation Program task 7: Sand and Gravel Inventory Management.

The granular resource investigation and assessment for the Mackenzie Valley proceeded in two phases as in the Beaufort Sea, with the significant difference being

that much more work had been done prior to the initiation of NOGAP. Geological models were already established (by Rampton, Hughes, and others), with a significant amount of field reconnaissance of granular resources already undertaken (e.g. Lawrence et al. 1972) more than a decade before NOGAP was established. NOGAP work began with a review of the considerable knowledge already available for the particular sites under investigation.

In the second phase, site investigations were undertaken to obtain quantitative estimates of resource quantities by type, and to obtain test specimens for laboratory analysis. Laboratory tests were undertaken on several potential gravel sources to determine the physical characteristics of the resource, and its suitability for use as aggregate. Considerable work was undertaken in the Mackenzie Delta and at coastal sites, in anticipation of the need to supply offshore facilities with gravel and to establish site conditions at King Point (A4-03). Following the Mackenzie Valley Granular Resource Workshop (A4-26A), new work extending the Granular Resource Inventory to the Cameron Hills was undertaken (A4-32).

Reports for the Mackenzie Valley studies have a greater potential for use in activities not directly related to hydrocarbon resource development than those for the Beaufort Sea. They are directly useful in the location of some gravel and sand resources for highways and shore protection for some communities. The records contained in the appended drill logs will be of use in local geological and geotechnical investigations. These may be of future use not only for resource extraction, but also land management requiring knowledge of near-surface conditions. Territorial, Community and First Nations agencies will find the work of service. Territorial Departments directly responsible for projects requiring borrow material (Energy Mines and Petroleum Resources, Public Works and Services, Transportation) could benefit directly from the data which is available in the databases as well as the reports, while

Departments involved in land use planning (such as Municipal and Community Affairs) will be able to better protect the resource with access to this data.

The more advanced state of geological/geotechnical knowledge in the Mackenzie Valley limits the geological utility of studies to assess site specific granular information, since these studies tended to be undertaken at sites where geological information yield is not the greatest. In addition, the suite of information necessary for granular resource evaluation is less than is required for geological investigations, so that the additional geological information is not gathered unless site investigations have been jointly funded for geological and granular resource work.

3 : RESEARCH AND DEVELOPMENT PROJECTS

A4-04	■ Report on the "Computer-based Analysis of Digital Bathymetric Data" (Beaufort Sea), Challenger Surveys and Services Ltd., 1988
A4-04	■ Report on the Analysis of Bathymetric Data - Western Beaufort (Yukon) Continental Shelf, Challenger Surveys and Services Ltd., 1986
A4-11	■ Modelling and Mapping of Potential Granular Resource Features in the South-Central Beaufort Sea, NWT, Challenger Surveys and Services Ltd., 1994
A4-13	■ Real Time Marine Resistivity System , Hardy BBT Ltd. , 1987
A4-24D	■ Inversion of Electrical Resistivity Data to Identify Granular Resources in Arctic Waters, C-CORE,1994

Research and Development Subproject Reports

Projects classified as "Research and Development" were directed toward two goals. First, methods of analyzing bathymetric data for the interpretation of subtle bathymetric variations were developed and applied. Second, studies of real-time marine resistivity involved the establishment of the feasibility of the system developed at Hardy, and the subsequent examination of real-time inversion algorithms.

The purpose of the bathymetric study was to develop, test and implement a method

of detecting subtle bathymetric anomalies and provide a description of the regional bathymetry. Available granular resource data for the Beaufort Sea indicate that nearly all of the gravel deposits identified are located on subtle bathymetric highs, within a relatively narrow range of water depths. In 1986, Challenger undertook to develop, test and implement a method of detecting subtle bathymetric anomalies using digital terrain modelling techniques. That study revealed that such anomalies can be identified efficiently from the raw digital data of hydrographic surveys. A methodology was developed by which digital terrain models are plotted in perspective view to facilitate the visual interpretation of bathymetric data, for the purpose of identifying these undersea features. Some difficulties were encountered in obtaining the raw data from the Canadian Hydrographic Service, due to concerns within CHS that the information could be used for navigation.

The application of digital terrain modelling techniques to sea bottom mapping results in improved resolution compared to charts, and permits large volumes of data to be processed and interpreted relatively quickly. Output may be visualised in a variety of forms useful for analyzing seabed topography. By exaggerating the vertical depth component, subtle bathymetric features are enhanced, and thus are easier to detect. When used in conjunction with available geophysical and geological stratigraphic information, bathymetric data may be used to identify sub-sea anomalies as targets for more detailed investigations of their granular resource potential.

The electrical resistivity of sea bottom sediments can be used to indicate whether coarse grained materials are present, and whether permafrost lies within the depths of interest. Prior to the projects undertaken as part of NOGAP, marine resistivity survey was a proven geophysical technique whose utility for support of dredging and granular resource assessment in remote regions was limited. Previous Beaufort Sea

resistivity surveys demonstrated the need for real time interpretation. The cost of deployment in remote regions requires that the effectiveness of an individual expedition be maximized, since later surveys may be prohibitively expensive. The ability to evaluate preliminary results to define targets for detailed investigation can help maximize the effectiveness of time spent in the field.

The objective of NOGAP marine resistivity projects was to develop the capability to carry out interpretation in real-time, to allow reconnaissance surveys to be performed immediately ahead of dredging. Real time survey capabilities do not replace detailed analysis and verification of results following completion of resistivity surveys. An important conclusion of the tests of the real time resistivity system was that the sea floor configuration predicted by the system was influenced to some extent by the initial guess at the configuration which was supplied by the user. While this limits the ultimate utility of the interpretations supplied by the system, this is not a significant problem for the intended use. In an actual resistivity survey, if the starting model is selected to correspond to a desired stratigraphy, then a poor model fit (in real time) indicates that the data represent an area which probably does not have the desired characteristics for granular resource use.

The marine resistivity survey methods developed under NOGAP represent an additional tool in shipborn geophysical surveys (seismic), allowing discrimination between gravel and ice bonded (permafrost) sediments. Prior to the real-time capabilities developed, resistivity results were typically available months after the survey. The real-time interpretation makes it possible to plan survey lines in the field based on results obtained. The subsequent study undertaken to find the best algorithmic approach to real time inversion of marine resistivity data suggested the utility of alternate dipole geometries, an increase in the number of dipoles, and possible use of a bottom towed streamer. These modifications would require

additional engineering and program development.

4 : DATABASES

A4-15	■ Compilation and Cataloguing Of Beaufort Bathymetric and High Resolution Shallow Geophysical Survey Data, McElhanney Geosurveys Ltd , 1988
A4-19	■ Updating of the Northern Granular Resources Information Mapping System, Earth & Ocean Research Limited, 1992
A4-19	■ Digitization of Beaufort Granular Resource Information - Final Report, Earth & Ocean Research Limited, 1988
A4-22	■ Beaufort Sea Geotechnical and Geophysical Databases, EBA Engineering Consultants Ltd., 1991
A4-22	■ Beaufort Sea Geotechnical Database, EBA Engineering Consultants Ltd., 1988
A4-22	■ Beaufort Sea Geotechnical and Surficial Sediment Database, EBA Engineering Consultants Limited, 1989
A4-22	■ Beaufort Sea Geotechnical and Surficial Sediment Database, EBA Engineering Consultants Limited, 1989
A4-28	■ Environmental Constraints Analysis for Granular Resource Development in the Beaufort Sea - A New Methodology using Low Cost Raster GIS, Earth & Ocean Research Limited, 1993

Database Subproject Reports

The work in creating and maintaining granular resource databases began prior to NOGAP. The Geological Survey of Canada prepared a Mackenzie Valley geotechnical database in the early 1970's as a project of PERD and the Terrain Sciences Division. Data for a total of approximately 11,000 boreholes were included. The original data were obtained from GSC borehole records, consultants working for the oil and gas industry, pipeline companies, DPW records for both the Mackenzie highway (both proposed and as built) and the proposed Dempster highway north of Inuvik. While several copies of this database were obtained by geotechnical consultants, standard database searches were difficult to execute in its original form.

EBA engineering developed the ESEbase and ESELog software (partially with funding from NOGAP) in order to establish a PC-based and more user friendly method of

working with geotechnical data. According to MacGregor and Ruffell (1985):

> "The Land Management Division of Indian and Northern Affairs, Canada are faced with a problem of aggregate resources management. A large volume of data had been collected in the past which is of variable quality and presentation. Access to this data was through filing cabinets full of paper records spread over many geographic locations. There is a requirement within this Department for a large amount of future data acquisition. There is also a requirement that Governmental and quasi-Governmental organizations have access to this data on a day to day basis.
>
> "The Atlantic Geoscience Centre of the Geological Survey of Canada has collected several thousand samples during cruises of exploration in both the Beaufort Sea and North Atlantic. This data had been stored in paper files in many locations throughout the Centre and very few people were aware of its total extent. There was a need to access to this data by many scientists working in these areas on a variety of problems.
>
> "The answer to both the problems above was to implement the use of ESELog and ESEBase in a data collection and database function. Information to date was collated, reviewed and entered by clerical staff supervised by a project geotechnical engineer..."

In a separate section of MacGregor and Ruffell (1985) :

> "The use of a computerized data storage and retrieval system compels users to standardize their borehole logging and data presentation formats, irrespective of which software is selected. One of the frequent obstructions to the implementation of this software by many companies is their reticence to change formats developed over many years. They fear that their standards may be compromised.
>
> "North America has no standard for the presentation of borehole data, such as that adopted in the United Kingdom. Software developers are faced with the problem that their package must reflect the wide range of company formats available, providing the maximum possible flexibility in output styles.
>
> "If the use of this data processing technology is to become widespread, standardization has to be addressed, even to the limited extent of recommending which data appear on the borehole log. With this in place, it will become possible to share all data between the data owners

and the data users using database methods. Until that time, limited use of such software will provide the de facto standard."

The GSC Mackenzie Valley database and the DIAND Database are both implemented and available in ESEBase format, but are not integrated. GSC database is referred to as the Mackenzie valley geotechnical database, while the DIAND database includes records specifically undertaken in the search for granular resources for NOGAP.
Coverage in the database is biased toward those areas most likely to be traversed by pipelines, although most physiographic regions are represented.

EBA has prepared separate databases organised according to individual reports (maps, contract reports, fieldwork reports, etc.), to individual deposits, and a geotechnical borehole database. The granular resources report catalog for the Mackenzie Valley identifies "... sources of granular resource related information including reports, maps, field work, and other data. This information was acquired from government departments, major petroleum and pipeline companies, and geotechnical consultants". (Olthof, NOGAP report A4-26A) . The information in the databases is keyed to common study reference numbers and granular source reference numbers, allowing investigations to proceed from any database to the information held in the others. The database allows data searches within specified geographic boundaries, searches by sponsor, by consultant, and so on. The database includes an assessment of the data quality as well.

Database creation and maintenance work has been undertaken separately for the Mackenzie Valley and for the Beaufort Sea. Numerous Databases have been created, modified, or updated which catalog the granular resources work done in the Mackenzie Valley. Much of this work was funded at least in part by NOGAP project A4, with much other work funded by DIAND (from alternate sources within

the department, or prior to NOGAP) or other public and private agencies. In 1986, HBT AGRA summarized data from granular resource reports prepared for the Lower Mackenzie Valley; A computerized summary of reports for the lower Mackenzie Valley excluding the Mackenzie Delta was prepared by L. Bennett in 1988. EBA Consultants Ltd. compiled a computerized summary of studies conducted in the Upper Mackenzie Valley.

A significant amount of the work undertaken in establishing the databases involved tracking down data from earlier fieldwork. The objective of the first database project, A4-15 was to locate, compile and organize bathymetric and high-resolution, shallow geophysical survey data that had been acquired by both Government and Industry agencies from the Beaufort Sea up to 1988. Ninety surveys were catalogued, with data collected from the files of Dome Petroleum (41 studies), Esso Resources (10), Gulf Canada (18), the Canadian Hydrographic Service (16), and the Atlantic Geoscience Centre, Geological Survey of Canada (5). Survey foci were the Isserk and Erksak Borrow Blocks of the near-shore Beaufort Sea. The database compiled to that time had all but four reports of major near-surface geophysical and hydrographic surveys conducted in the Isserk-Erksak Borrow Blocks of the Beaufort Sea. These four were completed by Esso in 1980-82, but were not located. The database provided an inventory of available granular resource information pertaining to the offshore.

The **inFOcus** mapping system was developed to allow rapid access and visualization of the data contained in these databases. While it was originally designed for resource evaluation in Atlantic Canada, it has been modified for application to granular resource and related information for the Northwest and Yukon Territories and the Beaufort Sea. InFOcus provides database management functions, together with data query and analysis capability. The result is a desktop

Geographic Information System that enables the end-user to have rapid access to map information and hard copy output.

In addition to the links to these databases, additional work was undertaken to build a digital database of seismic and sidescan track information from Beaufort Sea in the inFOcus format.

The offshore database will be of principal interest to companies intending to develop offshore oil and gas reserves, and to the Environmental Assessment Panel that will examine such plans. The database should be accessible to the oil and gas industry and to consulting engineering firms who may be involved in future developments offshore. The data are also of direct use to government and other regulatory bodies, particularly agencies established under the Inuvialuit Final Agreement, which may need to assess plans for offshore construction. The database also includes reports concerning the approaches to Tuktoyaktuk harbour, and therefore the information will be useful for barge operators and others concerned with docking facilities.

The Mackenzie valley database is currently being used in the preparation of the Climate Change Atlas. The intent is to determine "typical" geotechnical conditions for physiographic regions in the Mackenzie valley, as represented by a "typical" borehole log. Some assessment of predicted thaw strains (associated with melting of excess ground ice) under anticipated global warming scenarios may be included.

5 : SCENARIOS / EVALUATIONS

A4-26A	■ Granular Resource Requirements For Proposed Mackenzie Valley Pipelines: Technical Papers & Workshop Proceedings, Stanley Associates Engineering Ltd. 1993
A4-26B	■ Proceedings of the Beaufort Sea Granular Resources Workshop, EBA Engineering Consultants Limited, 1993
A4-26C	■ Granular Resource Requirements for Potential Hydrocarbon Developments in the Western Region of NWT, North of 60 Engineering Limited, 1993

Scenario / Evaluation Subproject Reports

While there are only a few projects which fall into this category, they are listed separately because they each represent a synthesis. The two workshop proceedings provide an overview of the projects undertaken to date, and provide the perspectives of the report's authors as well as potential users. The study of Granular Resource Requirements for Potential Hydrocarbon Developments examines the demand for granular resources in the light of current economic outlooks. As such, they provide an overview which will be valuable to many parties concerned with development issues. One additional subproject discussed below had no report produced (a transcript of the workshop was prepared) was a workshop to examine the possible causes of the failure of artificial island Nerlerk.

The Proceedings of the Mackenzie Valley Workshop (A4-26A) summarizes activities conducted during NOGAP project 4A which contribute to a full assessment of potential and proven gravel resources, possible future demands on such resources, and social and environmental considerations regarding development of the deposits. Nine of the papers concern the inventory of gravel resources that have been delineated during the project. Six papers concern environmental and cultural considerations in borrow pit development resources, especially the influence of land claims agreements on resource management. The

workshop proceedings provide an effective summary of the state of granular resource knowledge in the region. Information on resource delineation is clearly presented, and will be of considerable use in both future hydrocarbon development and in improvements to transportation infrastructure in the region. The timing of future oil and gas development is not known, and the requirements for pipeline construction are design-dependent. There is, however, a good estimate of the demand presented by development of transportation infrastructure in the region.

The report will be of interest in the Mackenzie Valley corridor. The summaries are informative of local resource databases, and hence will be useful for government at community level, as well as for regional authorities, including First Nation Settlement Regions. The proceedings will also be useful at management level in both industry and government, to inform and point personnel not directly familiar with the region as to the status of granular resources. For example, the volume would be an excellent briefing document for any panel charged with examination of future development projects. Finally, the proceedings will be useful to students and the general public concerned with issues in northern development, who may appreciate the nature of the exchange contained in the volume between parties approaching northern development from different perspectives.

The Proceedings of the Beaufort Sea Workshop contains text versions of workshop presentations on regional studies and research undertaken as part of Beaufort-related tasks for NOGAP project A4, invited presentations from partners contributing to and interested in Beaufort sea granular resource delineation and utilization. This is followed by the edited transcript of a round-table discussion of the state of knowledge and identification of the future research required for particular regions and for particular techniques.

Report A26C summarizes several potential hydrocarbon development scenarios which have potential to be economic under current price outlooks, and examines the granular resource implications of each. Four potential development scenarios were considered:

- development of a small onshore oil or gas field for local energy demands;
- seasonal production from the Amauligak reservoir;
- a generic 200 million barrel onshore oilfield;
- processing of onshore gas for sale to southern markets;

Timing of these scenarios was "phased to reflect the ongoing level of exploration, the time frame required to develop a particular scenario, and the current economic outlook. Using existing experience, computer models and input from industry contacts, the types and quantities and timing of granular resources requirements were determined fore each of the scenarios identified above.

This report will be primarily of interest to land and resource use planners, since the scenarios are intended to aid in forecasting granular resource use rather that to forecast hydrocarbon production per se. To this end, the Inuvialuit Land Administrator has engaged North of 60 to assist in the development of land use and borrow material plans, with the same model used in generating the predictions presented in the report.

One project for which no report was prepared was the Nerlerk workshop (although a transcript of the workshop was prepared). This workshop was held in order to address issues surrounding slope failures in the construction of artificial island Nerlerk B-67. Prior to Nerlerk, islands were being constructed in waters of increasing depth, with Nerlerk constructed in the deepest water to that date (45 m). None of the islands constructed after Nerlerk were in water deeper than 32 m.

Quoting from Project report A4-30 (Granular Resource Potential, Beaufort Sea Artificial Islands),

> "Nerlerk B-67 was a berm constructed by Dome in the 1982-83 open water season in 45.1 m of water that was intended to support the SSDC unit. A number of slope failures were observed in the latter part of construction, and the berm was abandoned. A second berm, Nerlerk 2 Site, was attempted adjacent to the original location, but was also abandoned because cone tests indicated the berm was not sufficiently dense. A third berm was attempted, but abandoned just as construction started. The berm was founded on soft clay and silt overlying sand interbedded with silt and clay, which in turn overlay clean sand, physiographically on the Tingmiark Plain. Hopper dredges collected sand from the Ukalerk borrow area, and bottom dumped the sand on the berm. Sand fill was also excavated using a stationary suction cutter dredge from the nearby Nerlerk borrow area, and placed using a floating pipeline. The initial sand dredged from the local pit was contaminated with the surficial clay. A total of 4 million m^3 of sand fill was deposited at the site creating a berm which rose to within 9 m of sea level. Side slopes varied from 9H:1V to 15H:1V prior to the slope failures. The second berm (Nerlerk 2 Site) was attempted approximately 1 km south southwest of the original island. A total of 2.1 million m^3 of sand was dredged from various sites, including the abandoned berm. Sand fill did not meet the appropriate density requirements, and construction was abandoned. Nerlerk 3 was attempted, but abandoned after placing 8000 m^3 of sand fill"

The workshop was held to discuss the role of the fill material properties in the slope failures. The question addressed at the workshop was the strength of fine grained sand: what percentage fines is the limit for load bearing fill. It was not possible to resolve the issue because the question was analyzed in the context of these particular failures. It was not possible to determine whether the failures were the result of failure within the sand or in the underlying clay. The ultimate conclusion of the workshop was a difference of expert opinion.

DISCUSSION

▪ General Information Needs.

The needs of the pipeline industry for geotechnical information (for route selection and for identification of borrow material sites) become increasingly specific as a project moves from feasibility, environmental assessment, design, construction, and operating modes. Site specific information is not required until the design stage: sufficient information currently exists in geotechnical reports and databases for the Mackenzie Valley in order to accurately assess the feasibility and environmental impact of pipeline developments there.

There was disagreement among the consultants interviewed over the information required to make informed decisions. At on extreme, Don Hayley (EBA Engineering Ltd.) suggests that about 80% of the borehole data necessary to build a pipeline is required in order to establish the feasibility of a proposed design. In contrast, James MacDougall (North of 60 Engineering Ltd.) considers that granular resource information plays such a minor role in the cost evaluation of a pipeline project that very limited information is required for assessment of feasibility. These viewpoints are not irreconcilable: firstly, borehole data provides geotechnical information for purposes beyond the granular resource assessment; secondly, a distinction can be made between economic versus technical feasibility. A project may be feasible economically, with geotechnical feasibility having considerable importance in determining the details of route selection and construction scheduling. John Ellwood suggested that Foothills Pipe Lines would be more interested in direct project management at the construction stage than the design stage for pipelines, since possible problems encountered during construction are more likely to adversely affect operating conditions. As a result, more detailed granular resource data will be required by the pipeline company for the construction phase of pipelines.

- **Research Opportunities / Research Needs**

Research is driven by specific needs and by opportunity, but progress is fastest when research opportunities are mature. NOGAP work in the Beaufort Sea is an example of needs and opportunities working together. The granular resource studies have been directly useful to the interpretation of the sedimentary history, in part because of the lack of detailed information available for the seabed, or even a detailed geological model on which to base work. In the Mackenzie Valley, the NOGAP granular resource work has been less useful to geological interpretations than other geotechnical information, primarily because a significant part of the effort has been expended on relatively detailed studies of granular resource targets.

- **Technological Change**

Economics and technological change go hand in hand. When resources are scarce, or the logistics involved in extraction and placement can cause scheduling problems, economic costs increase. Increased costs for existing technologies improve the likelihood that alternative technologies can be more cost effective. The costs associated with the large volumes of granular materials for the artificial islands was in part responsible for the increased use of SSDC and other technologies which minimize or eliminate the need for granular drilling platforms.

The granular resource requirements for Beaufort sea drilling platforms has declined substantially in the last decade, due in part to changing platform design, but primarily because of an improved understanding of the risk associated with floating ice. In the mid 1980's, the design ice load was 1 500 000 tonnes, based on the size of the largest floating ice bodies then identified in the Beaufort. This was reduced to 500 000 tonnes when it was recognized that large floating ice bodies do not load structures monolithically, since they are weakened by

fracturing. Ultimately, experience has shown that very large ice bodies are sufficiently slow moving that the risk of impact on drilling structures is primarily economic (well capping and evacuation would always be possible because the risk would be identified weeks if not months in advance), making new technologies feasible.

Fitzpatrick (1994) :

> " In 1980, if a structure were to operate successfully in a water depth of 60 M in the Canadian Arctic, it was believed that it had to be protected by a sand berm some 30 m thick with a diameter of around 1 km. Even then, the thinner ice features of 30 m or less were thought to be able to deliver a load of about 1 500 000 tonnes to the unprotected structural neck. Of course, virtually no naturally occurring foundation had the capacity of resiting the base shear and bearing stresses that would result from such an impact and massive excavation and replacement with dense sand was considered necessary for satisfactory performance.
>
> "The belief that such large ice loads were possible arose as a result of the extrapolation of small scale competent ice crushing tests directly to a global scenario. While it was suspected that the presence of large flaws in such a brittle material would greatly reduce its overall strength, the extent of such a reduction was exceedingly difficult to quantify from a theoretical viewpoint alone.
>
> "Throughout the 1980s, many large scale measurements of ice loads on rigid objects took place. The Hans Island experiments, in Kennedy Channel, were critical to the confirmation of the theories that global loads were significantly less than hypothesized. So also were the actual interaction experiences between exploration structures and thick multi-year ice. Throughout the past 15 years the most probable, largest credible ice that has been measures or experienced by any unit operating in the Canadian or US Beaufort Sea is believed to be only about 10 000 tonnes. This gives strong anecdotal support to the soundness of the present 100-year exceedance load for this region of about 100 000 tonnes, for a structure 100m wide in 30 m of water. Even in significantly deeper water, design loads are not expected to be substantially larger than this figure.
>
> "With 100-year design global ice load levels at around 100 000 tonnes, for regions with extensive multi-year ice, nearly all but a few foundations

in the Canadian Beaufort can provide resistance to this magnitude of load without excavation and backfill.

"Thus, a combination of operational experience, full scale research and analysis has resulted in a proven load reduction factor of about 15 since the early 1980s. This factor has a direct bearing on the global size and cost of a structure necessary to resist such ice conditions, as the resistance that it provides is proportional to its overall size. "

- **Changes in Information Technology and Computing**

Changes in computer technology have had a significant influence on NOGAP projects in which this technology has played a role: In the development of the real-time resistivity system, the technology became feasible only with the availability of low-cost field-portable computer equipment. Subsequent advances in computer power and speed have made it possible to explore the use of algorithms which process more data in real time, and with more dipoles in the dipole array. Significant advances in GPS, data acquisition, and heave compensation hold the potential to significantly improve resistivity and bathymetric survey techniques.

Database technologies, especially Geographic Information Systems have moved forward significantly in the period of NOGAP funded research. Computer based mapping systems have improved in their analytical capabilities, have become more user friendly, and have become more affordable. This is evident in the refinement of the inFOcus and other databases which have been developed under NOGAP. In some cases, such as the early work by Challenger (Project A4-04) on analytical techniques to evaluate variations in bathymetry, these improvements have overtaken the recommendations of that report. Improved interpolation algorithms, higher data handling capacity, analytical possibilities including material volumes, slope determination, slope shading and so on are available in commonly available software.

■ **Economic Change**

Current granular resource requirements for the oil and gas industry are modest. The conventional wisdom is that offshore oil extraction is not likely until more reserves are discovered. Given the modest reserves that have been discovered to date, granular resource requirements (already reduced due to changing technology) will likely be further reduced. The original Environmental Impact Statement for Beaufort Sea transportation included "all-year, ice strengthened tanker transportation of oil, using two tankers, from one or two artificial islands or platforms in the Beaufort Seas, eastward through the Northwest Passage." This scenario is now considered unlikely, since "Discoveries to date total several million barrels which do not support the capital costs of APLA [Arctic Production and Loading Atoll] type structures."... " Today's concept for a production platform would consist of a water ballasted steel plated structure, potentially sitting directly on the seabed." (Hewitt, Beaufort Sea Granular Resource Workshop, A4-26B, p 185.)

Possible extensions to NOGAP granular resource research

■ **Database extension/ data rescue**

The most obvious activity having value in extending the NOGAP granular resource project would be the expansion of the databases to include data for other areas. Other existing datasets which could usefully be placed in databases similar to the Mackenzie Valley Geotechnical Database include Liard Highway and Dempster Highway geotechnical information. Data for the Dempster highway was obtained and formerly held by the Department of Public Works, but is now archived by the Yukon Territorial Government. Data for the Liard highway was obtained by and is now archived by the Government of the Northwest Territories. In addition, possible alternate routes for oil and gas transportation corridors have been suggested along the Yukon coastal plain (as well as along the Dempster

Highway). Little geotechnical information is included in the NOGAP databases for these regions. It was suggested by some of the geotechnical consultants that much information has been collected in these areas.

As discussed by Gowan (NOGAP A4-26A, p.11), a problem may exist in adequately recording the information available for these projects, since:

> "DIAND's role in the preparation of a granular resource inventory is as a resource manager, not as a resource user. Therefore, it attempts to classify granular materials according to their natural condition (without processing) and their broadest range of potential uses, by all potential users. In contrast, a more specialized (e.g. highways) user oriented inventory might classify materials according to their adherence to precise material specifications (e.g. surfacing material or concrete aggregate)...."

Data obtained for specific purposes therefore might not always be suitable for inclusion in existing databases, although the data itself would be of value.

Other data may be available which is at risk of being lost. While the primary effect of current government efforts to reduce its labour force is a loss of the expertise of those leaving the civil service, an additional potential consequence could be the loss of data collected by or otherwise in the keeping of those who are leaving. The effort involved in recovering seismic and other data for many of the reports reviewed in this document testifies to the cost of "data rescue" relative to the cost of data preservation. Unfortunately, the cost of preservation is also high, in part because of the change from paper-based and analog recording methods to computer based and digital ones. Newer, "better" technologies can often diminish the utility of older datasets as well.

Even data in easily transferred formats (computer tapes, for example) can be expensive to process into a form usable by people other than the original user. Data which is obtained and immediately analyzed and reported is often difficult for

third parties to use, since much contextual information is not stored with the data, if at all.

A greater challenge will be the difficult decisions to be made about the potential value of existing data. With limited budgets it may be difficult to justify expenditures on the preservation of old data whose value for currently mandated projects has not been established. As In the previous discussion concerning research opportunities and research needs, the greatest opportunities (to recover data) may not be where the greatest (data) needs are, at least within the organization which currently retains the data.

The recovery and reconsideration of existing data would be a useful task in the current funding environment, where resources for new data acquisition are limited. This was in fact the earliest mode of operation in the granular resource assessments undertaken under NOGAP. Those data rescue efforts illustrated the need for foresight in data preservation. A preliminary step in assigning resources from appropriate budgets would be the identification of and communication among of those hold data, and those who have potential use of existing data. A data rescue operation of this type is currently underway within the Canadian permafrost research community.

■ Extension of Research and Development studies

Possible advances in the real-time marine resistivity system have be mentioned above, based on the advances in computing power as well as on the findings of the review of real-time interpretation algorithms undertaken for NOGAP A4-24D.

A number of specific recommendations were made at the Beaufort Sea Granular Resources Workshop concerning improvements to Database/GIS utility, but it was

suggested that NOGAP funding should be reserved only for developments relating directly to granular resource applications.

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Appendix I: excerpts from BEARP Final Report

Relevant portions of the Final Report of the Environmental Assessment Panel on Beaufort Sea Hydrocarbon Production and Transportation (FEARO 1984).

■ 3.6.1 Pipelines

"The Proponents' Present development plans contain several alternative pipeline proposals, all using the Mackenzie Valley route from Richards island in the Mackenzie Delta to Edmonton, Alberta for transporting oil from the Beaufort Sea. One alternative is a small diameter pipeline that would carry low viscosity oil and would be buried in a manner similar to the Norman Wells oil pipeline currently under construction. Other alternatives would involve the use of a number of small diameter buried lines, or a large diameter line, extending from a site such as North Point on Richards Island to Edmonton. The pipeline would be approximately 2250 kilometres (1400 miles) long.

" In the case of a small-diameter pipeline (e.g. 400 mm), oil would be chilled to a temperature just below 0°C before it is pumped into the line. The pipe would be buried throughout its length with a minimum of soil fill cover. When the pipeline is at maximum capacity, the pumping stations would be about 100 km apart. Approximately one million cubic metres of gravel could be required for the small diameter pipeline."

■ 6.2.2 Artificial Islands

"The forces resulting from moving ice would be the most important design consideration for construction of artificial islands in the Beaufort Sea. The Beaufort Sea differs from most other areas where hydrocarbons are produced because of the presence of ice for most of the year. Accordingly, any proposed offshore production systems must be designed to withstand the ice forces present or possible in the Beaufort Sea. These forces include those of impact of first-year ice as well as multi-year ice features. While there are no icebergs of the Greenland type in the Beaufort Sea, there is a remote possibility of a large ice island (tabular iceberg) appearing in the deeper offshore waters. These ice islands break off of the ice shelves of northern Ellesmere Island and generally move slowly southwest with the Beaufort Gyre."

[Later in the same section:]

"The Panel recognizes that improvements are constantly being made to the designs of artificial islands and that further advances will occur as understanding increases. Given the substantial experience available to the Proponents from exploration drilling in the Beaufort Sea, the Panel is satisfied that production

islands can be designed, built, and safely operated."

■ 6.3.2 Ocean Dredging

"The construction of artificial islands and the dredging for sub-sea pipelines will result in extensive dredging in offshore areas of the Beaufort Sea. The Proponents have constructed many artificial islands from dredged materials for exploratory purposes. This experience has demonstrated their island-building capacity and increased their technological expertise in Arctic conditions.

"The Proponents stated in their EIS [Environmental Impact Statement] that a maximum of 50 to 70 km^2 of seafloor could be directly disturbed during the period considered (1982-2000) if dredging was limited to 10 metre deep excavations. It is expected that some dredging will occur to depths of 20 metres below the seafloor, which would result in less total area being disturbed.

" At the General Sessions, the Proponents stated that they now plan less dredging than is indicated in the EIS. They noted that advances in technology for island building are occurring rapidly, and since the EIS was written, the use of caisson-retained islands and the SSDC (Single Steel Drilling Caisson) has dramatically reduced dredging requirements. In addition, the small-scale and phased developments recommended by the Panel would require less initial dredging than would the larger scale production scenarios of the EIS."

In addition to its use for the construction of artificial islands, the granular materials dredged from the Beaufort Sea would be used "for the excavation of shore approaches for subsea pipelines and for mooring basins or docks at shorebase sites."

■ 6.6.1 Ports and Supply Bases

The proponents indicated that "a deep water port will eventually be necessary to support production facilities and believe that not of the sites now in use may be suitable." Of the two sites considered, "the Panel agrees with the intervenors that the environmental conditions for a port facility at King Point are less restrictive...".

■ 6.6.3 Quarries

"The Proponents consider that Mt. Sedgewick, to the southwest of King Point, would make an excellent source of rock if linked to King Point by road. The expert opinion on caribou is that heave traffic on a road to Mt. Sedgewick would have little or no environmental effects during the winter, but such traffic could have serious adverse effects during periods of spring and summer caribou movements.

"Parks Canada expressed the wish to incorporate Mt. Sedgewick within the proposed national park boundaries as this site is integral to the wilderness values

of the area. There is a possibility that other potential rock types and sources would be available such as Mt Fitton and they should be investigated. The need for rock for offshore drilling and production structures may not be as great as originally expected because of changing technologies for these facilities.

"The panel believes it would be unfortunate to build a road to Mt. Sedgewick from King Point if the need for rock can be met by another source or if an alternative method of island building reduces that need. For these reasons, the Panel concludes that a quarry at Mt. Sedgewick should not be developed until all these aspects are completely investigated"

[Mt. Sedgewick lies within Ivvavik National Park (Northern Yukon National Park) which was established in 1984.]

■ 6.9.5.1 Oceanographic and Related Research

"The Panel concludes that there is a need for better understanding of the physical and biological processes in Arctic environments in general and the Beaufort Sea in particular. A new major multidisciplinary oceanographic program incorporating existing research programs would be a desirable basis for research studies but the Panel recognises the practical difficulties in providing adequate funding for this work. It is important, therefore, that the most efficient and productive avenues of research associated with the Proponents projects be identified rather than that a general endorsement be given to investigation of all basic physical and biological processes."

Appendix II Subproject Report Summaries.

NOGAP PROJECT A4
Subproject Report Summaries.

NOGAP A4-01
DSS # 19SV.A7134-4-0020
MJO 10-260

Report Title: Surficial Geology and Granular Resources, Southeast of Herschel Island

Prepared by: M. J. O'Connor and Associates

Date: June, 1984

Geographical Area : The study was undertaken in the Beaufort Sea, between Herschel Island and Kay point, and concentrated on the sea bottom features known as the Herschel Sill and Herschel Basin.

PURPOSE

The purpose of this study was to:

- determine the regional surficial geological conditions in the study area, thereby providing a framework within which it would be possible to characterize the distribution of local granular resources.

- locate and delineate prospective areas for the future development of offshore sand and gravel resources near Herschel Island.

METHODOLOGY

- a marine geophysical program was undertaken, providing 564 km of high resolution shallow seismic records, as well as more limited side scan radar data

- marine geotechnical drilling provided probehole, borehole, and piston core specimens from the sill and within the basin.

- the data collected were combined with existing geophysical and geotechnical data from a number of sources, to synthesize a local model for the geological conditions controlling the distribution and thickness of granular resources.

SUMMARY OF FINDINGS

- The study area comprises four separate surficial geological subregions, each with unique characteristics and granular resource potential: Herschel Sill, Herschel Basin, The Yukon Coastal Shelf, and the Babbage River Paleochannel. Of these, only the Herschel Sill and The Yukon Coastal Shelf show a reasonable potential for future granular resource development.

- The Herschel Sill (connecting Collinson Head to Kay Point) appears to be the most attractive area for future borrow development. It is estimated that 127 000 000 m^3 of

sand and gravel may be present, of which 17 000 000 m^3 may be considered proven, with an additional 70 000 000 m^3 provable without too much additional groundtruthing.

- The Yukon Coastal Shelf west of Herschel Basin also appears to be prospective for granular resources development, although the quality of available material may be lower than for the sill. About 10 000 000 m^3 of material has been located by geotechnical studies at Stokes Point, Roland Bay and Catton Point. An additional 30 000 000 m^3 of material may be located with further exploration.

- The study concludes that between 100 000 000 m^3 and 171650 000 m^3 of sand and gravel are present at or near the seabed in the study area. The future exploitation of these deposits will depend on the availability of suitable shallow water dredging equipment and future offshore granular resource requirements.

DATA

Figures

Location plan,
Bathymetry map
borehole and survey line location Maps
interpreted seismic and sidescan radar tracks
gravel inventory - distribution of granular resources
assumed thickness of gravel on Herschel Sill.
grain size distribution curves, including a summary of grain size characteristics in the study area.

Appendix A Geophysical Survey Parameters
Appendix B Daily log of Geophysical Survey
Appendix C Borehole Logs
Appendix D 1:50,000 Maps
Appendix E Grain Size Distribution Curves

NOGAP A4-2
DSS#
EBA 101C-4133

Title: 1984 Offshore Geotechnical Site Investigation: Herschel Sill Sites, Yukon Territory

Prepared by: EBA Engineering Consultants Ltd.

Date: 3 December 1984

Geographical Area: The Herschel Site is located approximately ten kilometers southeast of Herschel Island on a small, elongated bathymetric high at 69°32'N latitude 138°46'W longitude.

PURPOSE

The investigation was performed to determine the distribution, thickness and quality of potential sand and gravel deposits on the Herschel Sill, and the general stratigraphy and geotechnical properties of the area.

METHODOLOGY

The field investigation consisted of drilling a series of holes along the short axis of the bathymetric high. Two sampled boreholes were drilled to depths of 19.7 and 5.7m respectively. Two shallow probeholes and four shallow test pits were excavated. Soil temperature, moisture content, gradation and salinity determinations were carried out on board.

Laboratory testing consisted of particle size distribution determination by the hydrometer method, as well as determination of Atterberg limits.

SUMMARY OF FINDINGS

The investigation indicates that thin deposits of clean gravel and sand are present on the seabed in small, ridge-like features. The base of the granular deposits consists of silty sands.

The underlying clays are thought to represent the intact pre-Buckland sediments not scoured by the ice-thrusting event at Herschel Island. The clays are believed to be similar to the upper part of the marine sequence exposed on Herschel Island.

DATA

- Appendix A: Borehole logs with bulk density, undrained shear strength and salinity determinations.

- Appendix B: Tabular summary of test results - temperature, moisture content, bulk density, grain size distribution and shear strength (Pilcon Vane).

NOGAP A4-03
DSS# 0ST84-00494

Title: Investigation of Subsurface Conditions at King Point, Yukon Territory

Prepared by: M.J. O'Connor & Associates Ltd.

Date: April 1986

Geographical Area: King Point is a cliffed promontory overlooking Mackenzie Bay at latitude 69°85'N and longitude 137°58'W on the Yukon coastal plain.

PURPOSE

The purpose of this study was to conduct an engineering investigation of the general subsurface conditions near King Point with the following specific objectives:

- to determine the soil stratigraphy and *in situ* strength and deformation properties in order to provide sufficient geotechnical information for preliminary coastal engineering studies, foundation design and evaluation of marine dredging conditions.
- to evaluate the coastal regime, to identify the potential impacts of development on the existing coastal processes and any constraints to development.
- to characterize the terrain types with respect to soil type and ground ice conditions in order to provide sufficient information to permit preliminary evaluation of the engineering implications of developing King Point.

METHODOLOGY

The principal investigative methods were the following:

- a survey of the existing literature and data including logs of shot holes, boreholes, test pits, and natural exposures.
- drilling, logging, and extracting samples from boreholes in both offshore and coastal areas.
- laboratory and *in situ* testing of samples to provide a preliminary geotechnical assessment of the strength and deformation behaviour of the offshore sediments.
- construction of a coastal sediment dynamics model to illustrate the probable evolution of the King Point shoreline over the previous 5,000 to 10,000 years and to evaluate probable distributions and thicknesses of nearshore gravels.

SUMMARY OF FINDINGS

Development of the King Point area as a multi-user port facility and/or a base for quarrying operations is considered to be generally feasible.

Some of the important impacts and constraints related to harbour development which should be addressed in detailed engineering design studies include:

- erosion of unconsolidated cliff sediments.
- accumulation of sediment adjacent to structures in dredged channels and mooring basins.
- nearshore ice conditions.
- dredgability of stiff and/or ice-bonded sediments.
- stability of submarine trench slopes.
- offshore and coastal foundation conditions.
- impact of backfilling the coastal lagoon.
- impact of dredging lagoonal sediments and breaching the barrier bar.

The following major factors which may constrain onshore development have been identified:

- potential instability of foundations due to thermal degradation of near-surface ice-rich sediments or massive ground ice and/or permafrost aggradation into drained or infilled lake basins.
- natural hazards such as landslides (thaw-destabilized slopes) and poor surface drainage.
- the relative inaccessibility of granular resources for development.

DATA

The study data has been consolidated in Volume II of the report as follows:

- Appendix A - Borehole Logs
- Appendix B - Laboratory Test Data (tabular and X-Y graphs)
- Appendix C - Cone Penetration Test Results (tabular and X-Y graphs)
- Appendix D - Ground Temperature Data (bar graphs)
- Appendix E - Coastal Sediment Size Data (test hole logs and line graphs)
- Appendix F - Numerical Estimates of Sediment Transport (tabular and bar graphs)
- Appendix G - Proposed Development Scenarios (map plans)
- Appendix H - Maps (topographic)

NOGAP A4-04
DSS # 25 ST-A7134-5-0033
SERIAL# 0ST85-00383

Report Title: Report on the Analysis of Bathemetric Data - Western Beaufort (Yukon) Continental Shelf

Prepared by: Challenger Surveys and Services Ltd., Edmonton, Alberta

Date: 1986

Geographical Area: The study area is located in the western Beaufort Sea, extending northward from the Yukon coast to 70°N latitude. East-west boundaries are between 139°W and 141°W longitude. A subset of this area (18 x18 km) was selected as a test site.

PURPOSE

The purpose of the study was to develop, test and implement a method of detecting subtle bathymetric anomalies and provide a description of the regional bathymetry. The study was carried out on behalf of Indian and Northern Affairs Canada (INAC) and is intended for use in the evaluation of granular resources for construction materials.

SUMMARY OF CONTENT

Available granular resource data forthe Beaufort Sea indicate that nearly all of the gravel deposits identified are located on subtle bathymetric highs, within a relatively narrow range of water depths. A methodology was developed by which digital terrain models are plotted in perspective view to facilitate the visual interpretation of bathymetric data, for the purpose of identifying these undersea features.

Major elements of the analysis:

- A brief review of digital terrain model generation, data sources, products and display alternatives
    - evaluation of source bathymetric survey data vs field sheets, bathymetric charts
    - data acquisition and inspection - data density and resolution - data integration
    - criteria for selection of a test area
    - visualisation techniques - contours, mesh grid perspective views, vertical exaggeration
    - data processing - techniques, hardware, interpolation, plotting

Interpretation of the analysis:

- geological history of the Yukon Shelf - glaciation, sea level changes - river mouths
- seabed features apparent in plots - morphological implications - granular deposition
- ground truthing - potential sources

CONCLUSIONS

The application of digital terrain modeling techniques to sea bottom mapping results in improved resolution compared to charts, and permits large volumes of data to be processed and interpreted relatively quickly. Output may be visualised in a variety of forms useful for analysing seabed topography. By exaggerating the vertical depth component, subtle bathymetric features are enhanced, and thus are easier to detect.

Suggestions for future analysis projects:

- need improved interpolation algorithms
- faster, higher data handling capacity
- need for the consolidation of source data in useable form
- utility of available ground truthing data
- further analytical possibilities:
  - material volumes,
  - slope determination,
  - slope shading

Additional Information:

Appendix A: 64 selected bathymetric cross sections of the study area

Appendix B: Isometric grid mosaic (in pocket)

NOGAP A4-04
DSS # A7134-6-0038-01ST

Title: Report on the "Computer-based Analysis of Digital Bathymetric Data" (Beaufort Sea)

Prepared by: Challenger Surveys and Services Ltd., Edmonton, Alberta

Date: 1988

Geographical Area: The original study area is located in the western Beaufort Sea, extending northward from the Yukon coast to 70' N latitude. East-west boundaries are between 139' W and 141'° W longitude. The Erksak borrow area is located at approximately 70' N latitude and 133'°W longitude.

PURPOSE

Available granular resource data for the Beaufort Sea indicate that nearly all of the gravel deposits identified are located on subtle bathymetric highs, within a relatively narrow range of water depths. In 1986, Challenger undertook to develop, test and implement a method of detecting subtle bathymetric anomalies using digital terrain modelling techniques. That study revealed that subtle bathymetric anomalies can be identified efficiently from the raw digital data of hydrographic surveys.

The current study involves a more detailed analysis of the original study area, and extends this analysis to an addition location (Erksak borrow area) .The study was carried out on behalf of Indian and Northern Affairs Canada (INAC) and is intended for use in the evaluation of granular resources for construction materials.

SUMMARY OF CONTENT

Major elements of the analysis:

- A brief review of digital terrain model generation, data sources, products and display
- selection of an additional analysis areas - subareas - list of coordinates
- data density - data sorting and thinning - sampling bias
- visualisation techniques
  - true perspective mesh views
  - contours
  - profiles
  - vertical exaggeration
- description of selected regional features
  - seabed features apparent on plots
  - morphological associations with granular deposits

- evaluation of granular resource potential

- alternative analysis method
  - calculation of regional mean slope
  - plotting of residuals to enhance anomaly identification

- other potential applications
  - underwater pipelines - route selection
  - coastline responses to water currents, waves, storm surges

CONCLUSIONS

Computer-based bathymetric analysis techniques are potentially of great utility for application to geological-granular resource assessment studies. When used in conjunction with available geophysical and geological stratigraphic information, bathymetric data may be used to identify sub-sea anomalies as targets for more detailed investigations of their granular resource potential.

Suggestions for further development:

- development of PC versions of mesh software to facilitate off-site interpretation of bathymetric data.

Additional information:

- 100 figures depicting bathymetric contours, mesh perspectives, profiles and data plots for the study area and selected sub-areas.

NOGAP A4-05
DSS# 0ST85-0034
EOR 85-37

Title: Overview of Granular Resource Potential for the Western Beaufort (Yukon) Continental Shelf

Prepared by: Earth and Ocean Research Ltd.

Date: June 1986

Geographical Area: The study area extends from the Yukon Coast of the Western Beaufort Sea to the shelf edge at approximately the 80 meter contour, and westward from the eastern end of Herschel Island at approximately 139°W to the Yukon/Alaska boundary at 141°W.

PURPOSE

The purpose of the study was to provide an overview of the granular resource base of the area which would assist in planning future exploration studies to delineate granular materials for use in onshore or offshore construction by industry and government.

METHODOLOGY

This was a two-month study consisting of interpretation and integration of previously collected bathymetric, geophysical, and geological data. The data set consisted of 240 grab samples, 18 piston cores, 2 boreholes, and 2770 line km of high resolution seismic data. Additionally, selected echo sounder profiles were examined from a data base of 14055 line km.

SUMMARY OF FINDINGS

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

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

- The total volume of material identified as probable resource from the 10m isobath to the shelf edge is 557 to 842 million m^3.

- An additional 444 to 740 million m^3 of probable resource is calculated for the area lying

between the 10m isobath and the shoreline.

- Prospective areas include a number of shoals on the Middle Shelf and virtually the entire Outer Shelf from the 40-50m isobath to the shelf edge.

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

- The prospective areas, exclusive of the general area of the Outer Shelf represents a total volume of 329 million m^3.

- The Outer Shelf zone has an area of 1.4 billion m^2, but no thickness is attributed to the deposit at this time.

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

DATA

- Table 1: Summary of source data (referenced)

- Table 2: Summary of stratigraphic units (relative positioning)

- Table 3: Summary of granular resource potential on the Western Beaufort (Yukon) continental shelf

- Appendix 1: Distribution of surficial cover on the Western Beaufort (Yukon) Shelf (including % size composition)

- Appendix 2: Piston core visual descriptions (verbal)

- Appendix 3: Sample data (including % size composition)

NOGAP A4-6
DSS# 0ST85-0041
EBA 0301-34241

Title: Synthesis and Interpretation of Bathymetric, Geophysical and Geotechnical Data from Issigak Borrow Block

Prepared by: EBA Engineering Consultants Ltd.

Date: April 1987

Geographical Area: The Issigak granular borrow deposit is located 20km northwest of Pelly Island in the Beaufort Sea.

PURPOSE

The primary objectives of the study were:

- to develop an interpretation of the Issigak geology
- to quantify the remaining borrow reserves.

METHODOLOGY

This study was based on a compilation and interpretation of geotechnical, geophysical, dredging and bathymetric data that had been acquired between 1974 and 1986 by Esso Resources Canada Ltd., Dome petroleum Ltd. and Gulf Canada Resources Ltd.

SUMMARY OF FINDINGS

The Issigak deposit is interpreted to be fluvial-deltaic in nature and correlated with sediments of early Holocene age. Thus it appears to have been emplaced before the latest marine transgression, near the top of a non-marine deltaic sequence. The presence of cobbles, comprising up to 10 percent by volume of parts of the deposit, and boulders up to 500 mm in diameter suggest that both fluvial and ice rafting processes were active in the formation of the deposits.

Proven, probable and prospective resources were estimated to be 3.3, 5.1 and 5.8 million cubic meters respectively as of the end of 1986. The gravel and sand fraction were estimated to be 1.2 and 4.6 million cubic meters respectively for all prospective resources.

DATA

- Table 2.1: History of Activities in the Issigak Borrow Deposits
- Table 2.2: Comparison of Data from Adjacent Boreholes
- Table 3.1: Regional Stratigraphic Comparison
- Table 5.1: Borrow Resource Quantities
- Table 5.2: Calculated Gravel and Sand Resources

NOGAP A4-7
DSS# 0ST85-00413
EBA 0101-4480

Title: Granular Resource Evaluation Richards Island, N.W.T.

Prepared by: EBA Engineering Consultants Ltd., Edmonton, Alberta

Date: December 1986

Geographical Area: The study area is Richards Island, N.W.T., 69°N latitude, 135°W longitude

PURPOSE

The purpose of this study was to evaluate both the qualitative and quantitative granular resource potential on Richards Island, N.W.T. and to develop a borrow source management plan.

METHODOLOGY

- In the initial stages of the study a review was conducted of existing granular resource inventory studies which had been undertaken on Richards Island since 1972.

- Interpretation of air photos at a scale of 1:60,000 was used to locate potential borrow sources, to make quantitative estimations, and to assist in making qualitative estimations.

- A series of 39 boreholes were drilled at eight sites.

- Samples obtained through the drilling program were subjected to laboratory testing as follows:
  - Moisture content determinations were conducted on 320 samples.
  - Sieve analyses were done on 77 samples to determine particle size distribution.
  - Petrographic analyses were conducted on samples from Source 219 and 211.

SUMMARY OF FINDINGS

Of the nine potential sites investigated, only two (Source 211 and 219) were considered to be candidates for development.

From Source 211 a total of 8500m^3 of type II (acceptable quality borrow) and 50,00om^3 of type IV (sand) is recoverable from the southern sector of the source. An additional total volume of 6000m^3 of type II and 81,00m^3 of type IV material with moisture content over ten percent is available. With proper pit development, this additional material should thaw and drain to be recoverable in subsequent years.

The volume and quality of the material available at Source 219 is less well defined. Further delineation is recommended. Currently, a small area containing a proven volume of 30,000m^3 of type II material has been located at this source. In the portion of the source where the most exploration drilling has been conducted, a volume of 200,000m^3 is estimated to exist, However, further exploration is required before this larger area can be developed.

The following sites should be further investigated in a summer reconnaissance program: 206 North, 211 East, 216, 216 South, 217, 218, and 219.

DATA

Study area maps are shown in Figures 1 and 2.

Appendices "B" through "J" contain the following:

- Verbal description of each source,
- A site plan,
- Borehole logs, and
- Laboratory test results

NOGAP A4-8
DSS# 0ST85-00393
HARDY CG10219

Title: Report on Evaluation of Granular Resource Potential Lower Mackenzie Valley

Prepared by: Hardy Associates Ltd., 221-18 St. S.E., Calgary, Alberta T2E 6J5

Date: 31 March 1986

Geographical Area: The study area is centred upon the Lower Mackenzie River Valley between Richards Island in the north and Norman Wells in the south. The northern boundary to the study area is taken as the East Channel of the Mackenzie River.

PURPOSE

The purpose of the study was to provide a review of borrow material studies completed in the vicinity of the proposed Lower Mackenzie Valley pipeline corridor, and to assess the granular resource potential of the area relative to projected future pipeline and community requirements for granular materials.

METHODOLOGY

The assessment of granular resource potential was based on a review of published and unpublished geological and geotechnical literature pertinent to the distribution of surficial materials along the proposed Mackenzie Valley pipeline route.

SUMMARY OF FINDINGS

- The study identified 292 potential granular sources in the Lower Mackenzie Valley. An overall assessment of these sources has further identified 52 deposits which are excellent or good prospects by virtue of the quality of granular material which they contain. These 52 deposits should be considered as high priority for additional exploration work and testing to fully evaluate their potential as sources of excellent to fair quality granular material.

- Since some bedrock sources have the potential to provide granular material of excellent quality, a more detailed evaluation of bedrock sources is warranted particularly in areas where surficial granular materials are scarce.

- Good alternatives to granular material for use as general fill, are ice-poor glacial till (ground moraine deposits) and shale bedrock.

- The occurrence of massive ice bodies within granular deposits is of particular concern during borrow pit development. The massive ice represents waste material which must often be removed to gain access to granular materials. Melt water from stockpiled ice must be controlled to prevent silting of streams; and if left *in situ* care must be taken to prevent melting and degradation of pit slope/faces.

- The authors note that comments on the environmental impact of borrow resource development are based on studies conducted up to 15 years earlier. In the light of more recent data, increased environmental knowledge and modern philosophies concerning environmental protection, a comprehensive environmental study would be appropriate to identify environmental constraints to borrow resource development in the Lower mackenzie Valley

DATA

- Table 1: Summary of Granular Material Volumes (p.43)

- Table 2: Projected Granular Material Demand (Communities) (p.44)

- Table 3: Granular Material Forecast by Material Type (Communities) (p.45)

- Appendix "A": List of Cross Referenced Reports and Explanation Sheets

- Appendix "B": Tabular Summaries (six) of Potential Borrow Source Data

- Figure 1: Map of Study Area

- Figure 2: Map of Borrow Management Areas and Physiographic Regions

NOGAP A4-9
DSS# A7134-6-0015/01-ST
K L PA 2291

Title: Report on Western Beaufort Region Concrete Aggregate Study

Prepared by: Klohn Leonoff Ltd., #15, 6320 - 11th Street S.E., Calgary, Alberta

Date: 17 March, 1989

Geographical Area: Six designated aggregate sites along the western shores of the Mackenzie Delta and the Beaufort Sea, generally between the Aklavik Area, N.W.T. and King Point, Yukon Territory were investigated. The locations of these sites are as follows:

- Shingle Point, Y.T. 68°56'N, 137°12'W
- Running River, Y.T.
- King Point, Y.T. 60°06'N, 138°04'W
- Jacobs Ridge, Y.T. 68°59'N, 137°38'W
- Moose Creek, Y.T. 68°45'N, 136°30'W
- Willow River, N.W.T. 68°12'N, 135°27'W.

PURPOSE

The purpose of this study was to assess aggregate materials at these sites in terms of their physical and chemical suitability for use in concrete in the Arctic.

METHODOLOGY

Field investigative methods included:

- reconnaissance and photography by helicopter and from the ground to evaluate accessibility, site conditions, and deposit characteristics,
- shallow test pit excavation,
- collection of 160-180 kg gravel and sand samples from each site.

The following laboratory tests were conducted on samples from all six sites:

- Soundness,
- L.A. Abrasion,
- Petrographic,
- Density,
- Absorption/Coarse,
- Absorption/Fine,

- Durability Absorption Ratio,
- Durability Index,
- Organic,
- Cleanness Coarse,
- Cleanness Fine,
- 3 mos. Expansion Fine,
- 3 mos Expansion Coarse,
- Expansion Brine.

SUMMARY OF FINDINGS

Materials from two of the six sites, namely Willow River and Moose Creek, were found to be deficient in many durability attributes. Access and transportation problems also limit the usefulness of these sites.

The four remaining sites warrant further exploration for possible future development as aggregate sources. However, one of these, namely Shingle Point, may create security problems due to its proximity to the Shingle Point Distant Early Warning Station.

DATA

- Summary of Test Results: tabular (nominal scale), p.20.
- Summary of Pit Run Grading Analysis: tabular (ratio scale), p.21.
- Fine Aggregate Test Summary: tabular (ratio scale), p.21.
- Coarse Aggregate Test Summary: tabular (ratio scale), p.22.
- Standard Alkali-Reactivity Test Results: line graphs, pp.24-29.
- Non-Standard Brine Reactivity Test Results: line graphs, pp.32-37.
- Location Plans and Miscellaneous Drawings: Appendix I.
- Air and Ground Level Photos: Appendices II-VII.
- Test Hole Logs: Appendices II-VII.
- Pit Run Grading Analyses: X-Y graphs, Appendix VIII.
- Plot of Conformance to Concrete Aggregate Grading Limits: X-Y graphs, Appendix IX.

NOGAP A4-10
DSS# A7134-6-0017/01-ST
EBA 0301-34288

Title: An Evaluation of the Feasibility of Developing Granular Borrow from the Bed of the Mackenzie River

Prepared by: EBA Engineering Consultants Ltd., Calgary, Alta

Date: April 1987

Geographical Area: The study area was restricted to the main channel of the Mackenzie River and did not consider the tributary streams and rivers except as sedimentary sources. The upstream end of the study was at Great Slave Lake (km 0.0 on the hydrographic (navigation) charts). The downstream end was Point Separation (km 1475) where the Mackenzie Delta begins.

PURPOSE

The purpose of the study was to identify where the development of riverbed alluvium as a source of granular borrow materials would be feasible. The primary questions to answer were as follows:

- where do geologic and hydrologic evidence suggest that coarse granular alluvium will be found in the riverbed?
- where might these deposits satisfy local shortages in conventional (upland) borrow material supplies?
- how do the economics of dredging and transporting riverbed alluvium compare with conventional borrow pit development?
- What environmental constraints might affect riverbed dredging?

METHODOLOGY

The study is based on existing data from various geotechnical and geological investigations including the Norman Wells Expansion Project (NWEP) completed between 1978 and 1983 by ESSO Resources Canada Ltd.

SUMMARY OF FINDINGS

Approximately 22 percent of the riverbed was interpreted to have a high potential to supply granular borrow. The area between Camsell Bend and Fort Good Hope appears to have the greatest potential; however, local areas between Fort Providence and Fort Simpson have a moderate to high potential.

Almost 66 percent of the length of the Mackenzie Valley appears to be deficient in upland borrow resources. In particular, the 500 km section upstream of Willowlake River and the 175 km section immediately upstream of the mackenzie Delta have noticeable shortages of upland granular resources.

A cost comparison of conventional versus dredge and barge haul borrow development demonstrated the economic feasibility of riverine borrow production. Evidence is presented suggesting that for hauls of greater than 7 km, river operation may be more practical. For high production rates, the potential cost benefits are even greater.

Environmental considerations primarily focused on the fish population and the impact of dredging on water quality and suspended sediments. Generally it was concluded that the Mackenzie River's naturally high flow rate and high suspended sediment during open water season will mask any effects summer dredging might have. Similarly resuspension of heavy metals and hydrocarbons is not expected to be a major concern. Some concern does exist, however, for the interference dredging may have on the migration of fish along the Mackenzie and spawning areas could be impacted. Therefore site specific evaluation will be required before major borrow operations are initiated. Site specific information of the riverbed materials and fish populations is virtually non-existent, except for the Norman Wells Area and tributary streams and rivers.

DATA

The principal data records are:

- Table 4.2: Mackenzie River Terrain and Borrow Summary
- Table 5.1: Mackenzie Valley Upland and Channel Deposits - Reserves of Known Granular Materials.
- Table 5.2: Anticipated Granular Borrow Requirements for the Major Mackenzie Valley Communities
- Table 5.3: Cost Comparison for Conventional and Riverbed Borrow Production
- Table 6.1: Summary of Discharge Records for the Mackenzie River to 1984
- Table 6.2: Fish Species Located Within the Mackenzie Valley Study Area
- Table 7.2: Evaluation of River Regime Characteristics for Each River Zone
- Table 7.3: Riverbed Borrow Potential for Each River Zone
- Table 7.4: Areas Where Development of Riverbed Borrow Appears Feasible

NOGAP A4-11
DSS# A7134-3-0049/01-ST

Title: Modelling and Mapping of Potential Granular Resource Features in the South-Central Beaufort Sea, NWT (**Draft**)

Prepared by: Challenger Surveys and Services Ltd., 190, 7330 Fisher St. S. E., Calgary, Alta, T2H 2H8

Date: 1994

Geographical Area: The study area is a 6,400 km^2 tract of sea bottom comprising the Akpak Plateau and adjacent areas of the Beaufort Sea, NWT. The center of the study area is 70°00'N, 135°20'W.

PURPOSE

The purpose of this study was to acquire existing bathymetric data in digital form covering the area and to process, model and map the data in usable form for the purposes of identifying seabed features.

METHODOLOGY

Bathymetric data was obtained from the Canadian Hydrographic Service and was based on data collected during various field survey campaigns dating from 1978 to 1989. Digitized sounding data was corrected for tidal fluctuation and sound velocity. This data set is not considered to be of navigational quality. Sounding line spacing was for the most part 100 meters and sounding line sampling was taken at approximately 50 to 75 meter intervals. Data for the area surrounding Pullen Island were digitized manually.

Ground truthing was provided through helicopter and ground supported global positioning surveys to sub-meter accuracy for geophysical lines and ground truthing sites.

SUMMARY OF FINDINGS

Accurate representation of sea bottom topography is dependent on bathymetric surveys. The Canadian Hydrographic Service has surveyed most navigable Canadian waters. These surveys were intended to identify hazards to navigation, but the bathymetric data sets collected are useful for geological and engineering purposes. Quality bathymetric data in digital form, derived from Canadian Hydrographic Service surveys can now be obtained from Nautical Data International, This will simplify the process of acquiring future data sets.

The graphical products presented in this report were intended as an overview of the study area, The digital data set (not incorporated in this report but available from Nautical Data

International) allows the user the ability to examine features in detail and generate graphical images suited for the particular study undertaken.

DATA

- Contour Plan Beaufort Sea Study Area - Appendix B
- 16 Grid Mesh Perspective Views of Beaufort Sea Bathymetric Data - Appendix B.

NOGAP A4-12
DSS# 38ST.A7134-6-0016
GOLDER 862-1806

Title: Report to Department of Indian Affairs and Northern Development on Beaufort Region Quarry Rock Study

Prepared by: Golder Associates (Western Canada) Ltd., 224 West 8th Ave., Vancouver, B.C., V5Y 1N5

Date: August 1987

Geographical Area: The investigation was carried out at nine sites in the Northwest Territories and the Yukon Territory close to the Mackenzie Delta at the following locations:

- Mount Fitton, Y.T. 68°27'N, 137°58'W
- Mount Davies Gilbert, Y.T. 68°33'N, 136°43'W
- Mount Gifford, N.W.T. 68°09'N, 135°26'W
- Gull Creek Quartzite, N.W.T. 68°11'N, 133°48'W
- Gull Creek Dolomite, N.W.T. 68°10'N, 133°45'W
- Delta Outliers, N.W.T. 68°03'N, 134°00'W
- West Delta *roche moutonnée*, N.W.T. 68°29'N, 135°45'W
- DPW Quarry, N.W.T., 68°11'N, 133°25'W
- Campbell Pit, N.W.T., 68°17'N, 133°19'W

PURPOSE

The purpose of this study was to identify technically feasible quarry prospects in the vicinity of the Mackenzie Delta which may be used to provide a variety of grades of rock at some time in the future. The rock would be needed for the development of shore protection for port facilities, concrete structures associated with port or off-shore facilities, or for the construction of artificial drilling islands in the Beaufort Sea.

METHODOLOGY

The following investigative methods were employed:

- Review of existing data and air photo interpretation.

- Detailed site investigation including helicopter overview.

- Laboratory testing, specifically the following:
  - Rock strength.
  - Unit weight and specific gravity.
  - Los Angeles abrasion.
  - Sulphate soundness.
  - Slake durability.
  - Petrographic analysis.

SUMMARY OF FINDINGS

Laboratory testing indicated the granite of Mount Fitton, the quartzite and dolomite of Gull Creek and the Mount Davies Gilbert quartzite are essentially equal, and generally superior to the Mount Gifford sandstone. The Delta Outlier limestone and the sandstone from the isolated *roche moutonnée* did not perform adequately.

The report concludes that all sites could be developed from a technical viewpoint, but only Mount Fitton and the Gull Creek dolomite could supply a large quantity of excellent quality armour stone. Of these two sites, Mount Fitton would require an extensive camp, an estimated 75 km haul to the coast and seasonal constraints to operation during the caribou migration. By contrast, the Gull Creek site would have relatively easy product delivery by river in the ice-free season and by ice road in the winter.

DATA

- Table 11: Summary of Laboratory Test Results
- Table 12: Summary of Rock Mass Descriptions
- Table 13: Summary of Quarry Design Parameters

NOGAP A4-12
DSS# 38ST.A7134-6-0016
GOLDER 862-1806

Title: Supplementary Report to Department of Indian Affairs and Northern Development on Beaufort Region Quarry Rock Study

Prepared by: Golder Associates (Western Canada) Ltd., 224 West 8th Ave., Vancouver, B.C., V5Y 1N5

Date: March 1988

Geographical Area: The original investigation was carried out at nine sites in the Northwest Territories and the Yukon Territory close to the Mackenzie Delta at the following locations:

- Mount Fitton, Y.T. 68°27'N, 137°58'W
- Mount Davies Gilbert, Y.T. 68°33'N, 136°43'W
- Mount Gifford, N.W.T. 68°09'N, 135°26'W
- Gull Creek Quartzite, N.W.T. 68°11'N, 133°48'W
- Gull Creek Dolomite, N.W.T. 68°10'N, 133°45'W
- Delta Outliers, N.W.T. 68°03'N, 134°00'W
- West Delta *roche moutonnée*, N.W.T. 68°29'N, 135°45'W
- DPW Quarry, N.W.T., 68°11'N, 133°25'W
- Campbell Pit, N.W.T., 68°17'N, 133°19'W

The supplementary report includes new data arising from additional work done at the DPW Quarry and the Campbell Pit sites.

PURPOSE

The purpose of this study was to identify technically feasible quarry prospects in the vicinity of the Mackenzie Delta which may be used to provide a variety of grades of rock at some time in the future. The rock would be needed for the development of shore protection for port facilities, concrete structures associated with port or off-shore facilities, or for the construction of artificial drilling islands in the Beaufort Sea.

METHODOLOGY

The following investigative methods were employed:

- Review of existing data and air photo interpretation.
- Detailed site investigation including helicopter overview.

- Laboratory testing, specifically the following:

  - Rock strength.
  - Unit weight and specific gravity.
  - Los Angeles abrasion.
  - Sulphate soundness.
  - Slake durability.
  - Petrographic analysis.

SUMMARY OF FINDINGS

The new work establishes that the most technically feasible sites for the production of large quantities of armour stone and riprap are Mount Fitton, Gull Creek (Dolomite) and Campbell Pit. Further evaluation of DPW Quarry indicates that there is unlikely to be an acceptable quantity of the better grades of rock.

The report states that further exploratory work is required at the three sites to support feasibility-level studies on the three recommended prospects.

DATA

- Table 6: Rock Strength Results
- Table 7: Unit Weight and Specific Gravity
- Table 8: Los Angeles Abrasion
- Table 9: Sodium Sulphate Soundness
- Table 10: Slake Durability Index
- Table 11: Summary of Laboratory Test Results
- Table 14: Overall Comparative Rating

NOGAP A4-13
DSS#
HARDY CP12100

Title: Real Time Marine Resistivity System

Prepared by: Hardy BBT Ltd.

Date: March 1987

Geographical Area: The system is intended for use in Beaufort Sea coastal waters.

PURPOSE

The electrical resistivity of sea bottom sediments can be used to indicate whether coarse grained materials are present, and whether permafrost lies within the depths of interest. This report details the design and testing of a system to measure marine sub-bottom apparent resistivity with capability for real-time interpretation. Details of the equipment design, bench tests, and field results are included in the report.

- Previous Beaufort Sea resistivity surveys demonstrated the need for real time interpretation. Costs associated with field mobilization are such that the ability to evaluate preliminary results to define targets for detailed investigation can help maximize the effectiveness of time spent in the field.

- The objective "was to develop the capability to carry out interpretation in real-time, in order that reconnaissance surveys could be performed immediately ahead of dredging, and expensive stand-by time for the dredge could be avoided" (report, page 9)

METHODOLOGY

Development of the real-time measurement system was based on the following:

- Model inversion to derive layer thicknesses becomes problematic for situations in which more than three layers (including water) are encountered, due primarily to the limit of six dilpoles imposed by signal attenuation. This limitation can be overcome if independent information about layer boundaries (e.g. depths determined from seismic surveys) can be included in the analysis. Such information could not be fed into real-time modelling at time of writing.

- The sea/seabed were modelled as a four layer system: seawater, surface sediment, underlying sediment, and bottom sediment assumed to have infinite depth. Analysis is simplified somewhat with independent measurement of the first layer (water) depth.

■ To provide real-time interpretation, a system was developed to calculate apparent resistivities and subsequently fit these to the model of the sea/seabed, as described above. resistivity calculations were handled by the data acquisition system, while model parameters were subsequently fit using a separate computer.

■ After these devices were built and debugged, a bench test trial was carried out using a simulator designed to replicate voltage waveforms obtained during previous offshore surveys. Three of the most likely geologic configurations were built into the physical simulator(two with granular material over permafrost, one with fine grained material over permafrost). Transitional models were also constructed in order to simulate a smooth transition between subsurface configurations.

■ The dipole array was modified from that used previously to give a configuration in which dipole spacing increased exponentially with distance from the source: this was found to provide better definition of near surface resistivities as well as better resolution of deep features.

■ Field testing was carried out on a suitable vessel on Okanagan Lake, British Columbia. Both water and sub-bottom resistivities are about 30 times greater than their counterparts in the Beaufort sea, so that the water/sediment resistivity contrast is approximately the same.

SUMMARY OF FINDINGS

■ Anomalously low resistivities in a layer between the surface sediment and the frozen sublayer was interpreted as a layer containing water of enhanced salinity above degrading permafrost.

■ Physical simulations demonstrated that model inversion reproduced the simulated resistivities. The poorest resolution was for the saline layer above permafrost (noted above), for which resistivity was determined to within 7%.

■ Only minor adjustments were necessary to provide smooth functioning of the apparatus in the field: these included improvements to grounding and shielding of the data acquisition and transmitter system and control box, and filtering of the transmitted wave form.

■ The eight metre survey vessel used in the trials provided sufficient cabin space and deck space to operate a normal survey. The authors recognize that offshore survey in the Beaufort Sea would not be performed in this vessel without a mothership because of the requirements of sea worthiness, although surveys in coastal area would be feasible. Furthermore, any long term survey would require crew accommodations on the vessel. (report, page 28).

■ An anticipated production rate of from ten to twenty line kilometres is expected during

a commercial survey in a twelve hour day. (p. 28-29), using a technical crew of three persons.

■ One inversion is carried out for every thirty-two seconds worth of data, representing approximately sixteen metres at a survey speed of one knot. The volume for which resistivities are measured depends on the transmitter and receiver pair.

■ Distinction can be made between frozen fine-grained material and unfrozen coarse grained material (both of which exhibit high resistivities) by measuring induced polarization (I.P.) effects. Measurement of I.P. effects is more noise sensitive than resistivity measurement. It appears that realistic measurements of induced polarization effects can only be made at survey speeds of one knot or less. In Beaufort Sea granular resource surveys, induced polarization effects would not be measured unless required to distinguish frozen fine grained sediments.

■ It is recommended that field trials of the system be undertaken in an area of the Beaufort Sea where borehole control information can verify results.

DATA

- Appendix A - Specifications for the Data Acquisition System
- Appendix B - Software Listings
- Appendix C - Copies of published papers on Marine Resistivity
- Appendix D - Typical Configurations of Near-Bottom Granular Deposits

NOGAP A4-15
DSS#

Title: Compilation and Cataloguing Of Beaufort Bathymetric and High Resolution Shallow Geophysical Survey Data 1988

Prepared by: McElhanney Geosurveys Ltd

Date: March 1988

Geographical Area: The study area includes both the Isserk and Erksak Borrow Blocks , with boundaries defined as:

N.W. corner: 70°20'N latitude and 135°30'W longitude.
S.E. corner: 69°45'N latitude and 131°00'W longitude.

PURPOSE

The objective of the project was to locate, compile and organize bathymetric and high-resolution, shallow geophysical survey data that had been acquired by both Government and Industry agencies from the Beaufort Sea up to 1988.

METHODOLOGY

Ninety surveys are catalogued, with data collected from the files of:

Dome Petroleum (41 studies),
Esso Resources (10),
Gulf Canada (18),
Canadian Hydrographic Service (16),
Atlantic Geoscience Centre, Geological Survey of Canada (5).

Survey foci were the Isserk and Erksak Borrow Blocks of the near-shore Beaufort Sea. The catalogue is a dBase III+ file, with 50 fields for each record. Key fields include: sponsor and contractor of the survey; limiting geographic coordinates and location of survey; type and nature of survey; equipment used; extent of sampling and testing; archiving of report and data. The database contains all but four reports of major near-surface geophysical and hydrographic surveys conducted in the Isserk-Erksak Borrow Blocks of the Beaufort Sea. These four were completed by Esso in 1980-82, but were not located. The database provides an inventory of available granular resource information pertaining to the offshore.

DATA

- Source agencies for Data - Table 1, p.2.

- Field names included in Database - Table 2, p.3; p 9-10.

- Sample worksheet - Table 3, p.4.

- Isserk and Erksak Borrow Block Surveys (Year/Sponsor/Site name only) - Table 4, p.11.

- Borrow Block Surveys Not Cataloged (Year/Sponsor/Site name only) -Table 5, p.13.

- Trackplot lists:
    - Dome - Table 6, p15.
    - Gulf - Table 7, p17.
    - Esso - Table 8, p18.
    - Atlantic Geoscience Center, Table 9 p.19.
    - Canadian Hydrographic Service - Table 10, p20.

- Catalog of Geophysical and Bathymetric Surveys, By company/agency Block Surveys Not Cataloged (Year/Sponsor/Site name/study type only) -Table 11, p.21.

NOGAP A4-16
DSS# 38ST.A7134-6-0028

Title: Interpretation and Synthesis of High Resolution Reflection Seismic Data from Banks Island Borrow Area

Prepared by: H.R. Seismic Interpretation Services Inc., 66-Lanctot Street, Hull, P.Q., J8Y 1B6
Date: 1987

Geographical Area: The study area lies off the southwest coast of Banks Island in the Beaufort Sea between Sachs Harbour and Masik River, a distance of approximately 70 km. The center of the study area lies at 71°45'N latitude and 124°45'W longitude.

PURPOSE

The purpose of this study was to identify and delineate previously ignored sites of potential borrow gravel deposits along the southwest coast of Banks Island for future regional and/or site specific granular resource evaluation studies.

METHODOLOGY

This study is an interpretation of geophysical data collected during the 1983 Teal program by Geoterrex Ltd. The survey devices used were precision echo sounder, side scan sonar, seabottom profiler, boomer and airgun systems. In addition, bottom samples were collected by means of a drag sampler device or scoop. A seismic data base was created which includes six regional lines totalling 130 km of seismic data. Water depths along the course of these lines oscillate generally between 10 and 25m.

SUMMARY OF FINDINGS

The study concludes that the potential for granular resource deposits is very important in this area. However, the very uneven seafloor relief and/or the complexity of stratigraphic conditions encountered in several places present challenging environmental obstacles to the safe and efficient dredging of these resources. With regard to the complex geology, great diversity of source deposits and the poor seismic coverage, a quantitative evaluation would be meaningless.

Despite this, eleven target areas have been identified for more detailed specific studies. The most promising sites appear to be offshore extensions of the Sachs Till and the associated morainic system. These relatively old deposits may have been reworked several times resulting in good sorting and flat relief.

The portion of the coast between Middle Lake and Mary Sachs Creek is designated for future regional projects, The potential for gravel resources in the vicinity of the Duck Hawk Bluffs and in the Cape Kellett Spit area appears to be marginal due to the absence of submerged source deposits.

Although gravel resources are likely associated with the offshore extension of the Carpenter Till, this deposit has a low potential as a result of its high seabed relief, its "young" appearance (little reworking) and the occurrence of numerous erratics on top of the till sheet.

DATA

- Seabed sampling program - Table 1, p.10.
- Seismic data base - Table 2, p.11.
- Table of formations - Table 3, p.14.
- Till properties - Table 4, p.16.
- Summary table of borrow prospects - Table 5, p.58.
- Seismic profiles - Figures 4-13.
- Maps - Plates I-III.

NOGAP A4-18
DSS# 38ST.A7134-2-0037
EOR 92-23

Title: Granular Resource Information Mapping System for Northern Canada

Prepared by: Earth & Ocean Research Limited, Dartmouth, Nova Scotia

Date: March 31, 1993

Geographical Area: Yukon and Northwest Territories and the Canadian Beaufort Sea

PURPOSE

The purpose of this report was to build on the existing inFOcus application described in earlier reports. In this application update, new data has been incorporated into the information system, and the functionality of existing data has been increased.

SUMMARY OF WORK

Inclusion of Source Map References
- corner points, name, data type, client, date and project name for approximately 400 maps relating to geotechnical data in Canada's Arctic were added to the database

Database Consolidation
- the large number of individual database files associated with this application were found by users to be cumbersome. Composite databases were generated to reduce the number of individual databases to six, which duplicate all other application data for Boreholes, Prospects, Regional Fixes, Regional Track Lines, Site Survey Fixes, and Site Survey Track Lines.

Beaufort Borrow Prospects Database Conversion
- basemaps of borrow deposit potential have been traced as database polylines for the Isserk, Erksak, Issigak, Herschel Sill and Yukon Shelf borrow regions, and coded according to their prospective, probable or proven borrow potential.

Issigak Borrow Study Maps
- tabloid page size geological maps resulting from the study of the Issigak Borrow Block (EBA Engineering) were included in the database. The scale of the source information limits data resolution, but should be suitable for general purpose application.

Akpak Plateau and Nahidik Site 'D'

- target areas from the H.R. Seismic Interpretation Services Inc. plot (PL.I) of the Akpak Plateau were digitized and imported into the application as a basemap.
- target areas, as well as the boundaries of prospective resources for Site'D" (PL.II) were also included in the database.

Granular Materials Inventory of The Yukon Coastal Plain

- information from air photos, index maps and 1;125,000 mylar plots were used to digitize borrow resource boundary data were digitized directly into DIAND database format, within the QUICKMap environment.

Management and Claim Areas

- Polylines of the Nunavut Settlement Area, The Guitch'in Settlement Area and a low resolution map of DIAND Resource Management Areas were digitized into a database titled "Arctic Aboriginal Settlement Areas'.

Mean Ice Coverage

- A series of 10 Mean Ice Coverage maps for Canada's Arctic were digitized and converted to database polylines

ESEBase for FOXPRO

- A FOXPRO version of ESEBase functions related to borehole data query was developed that could run as a module within inFOcus. This permits extended, spatially-oriented queries on borehole databases.

Suggestions for further work

- inclusion of additional hard-copy map references
- inclusion of additional information relating to native land and jurisdictions which may effect access to sites and have implications for cost-shared programs
- the generation of an improved-resolution coastline and drainage basemap would aid in the interpretation of database information for small geographic areas
- the inclusion of a regional surficial sediment map

Additional information:

Appendix A: Application and Basemap Directory Structure
Appendix B: Atlas of Selected Maps
Appendix C: Installation Procedure for ESEBase for FOXPRO

NOGAP A4-19
DSS#
EOR

Report Title: Digitization of Beaufort Granular Resource Information - Final Report

Prepared by: Earth & Ocean Research Limited, Dartmouth, Nova Scotia

Date: December 8, 1988

Geographical Area: Canadian Beaufort Sea - Isserk and Erksak borrow regions

PURPOSE

This report describes the work undertaken to build a digital database of seismic and sidescan track information from Beaufort Sea. This includes methods used to compile digitize and convert the data into the DIAND geographic data management system format, as well as an outline of database content and organisation.

SUMMARY OF CONTENT

Data compilation - data sources - delivery mediums

Digitizing
- tools - SUPER-TECH workstation - hardware, software
- methods - map projections - map distortions - filenames
- conversion to AutoCAD format

Data Content - each track line was digitized to show the coverage of each line, with a line label, and start and end "fix" labels. Intermediate fixes were created to allow users to select only parts of track lines that may be of interest in a particular study.

File manipulation - index files - concatenated files - file organisation prior to conversion to DIAND format

Problems
- reconciling projections
- minimizing distortions, fix accuracy
- positional error for various map scales

Data Conversion
- outline of the procedures used to convert the digitized data to DIAND database format

DIAND format database structure and usage
- files types - data files, index files, text files
- file formats - description of filenames, content and file structures

- query types

Conclusions

- database includes all of the government track data up to 1986 - 355 lines covering 14104 line-km. (disk 1)
- all regional lines provided by ESSO, GULF and DOME - 581 lines, 12036 line-km. (disk 2, 3)
- site survey data from GULF and DOME
- all digitized data was plotted and compared to the source data to evaluate positional accuracy
- source information for EOR digitized databases
- digitized track inventory databases (disk 4)

Recommendations

- additional track data not included in the database could be added at minimal cost
- given the digitizing problems caused by distorted copies of some source maps, it is recommended that stable source maps be used in future

Additional information:

Appendix 1: The Beaufort Sea Granular Resource Database - digitized track inventory

Appendix II: The Beaufort Sea Granular Resource Database - list of digitized track databases correlated with the McElhanney catalogue

Appendix III: The SUPER-TECH workstation

NOGAP A4-19
DSS# 038ST.A7134-1-0039
EOR

Title: Updating of the Northern Granular Resources Information Mapping System - PROJECT REPORT

Prepared by: Earth & Ocean Research Limited, Dartmouth, Nova Scotia

Date: March 31, 1992

Geographical Area: This inFOcus application is based on granular resource information from the Yukon and eastern Northwest Territories, including the Beaufort Sea.

PURPOSE

This report describes work undertaken to upgrade the Northern Granular Resource Information Mapping System. The system has been developed around Earth & Oceans Research Ltd's (EOR) inFOcus geographic data management software, interfaced to the QUICKMap mapping engine. specific objectives were to:

- import the Yukon Shelf borrow study maps produced by EOR under separate contracts
- upgrade existing maps to eliminate deficiencies in the text display
- refine the presentation of data through enhanced legends and additional accreditation data
- provide borehole database management capability from within inFOcus
- import various borehole database applications to be accessible to inFOcus for general database inquiry and map display

SUMMARY OF CONTENT

Yukon Shelf borrow study maps

- consists of 18 geological maps constructed in AutoCAD and translated to QUICKMap format using the DXF2ESL utility
- problems with the translation procedure - recovery of lost attribute data
- processing efficiency - pre-conditioning of data vs re-digitising maps

Updating existing maps

- problems with pre -1992 versions of the DXF2ESL translator - text enlargement related to latitude, text orientation
- reconversion of existing data using a new, corrected translator
- improved legend display capability for inFOcus and QUICKMap applications
- problems with legend displays for basemaps - hatch scaling

Borehole database management system

- ESEBASE as a platform for handling existing borehole datasets
- extending existing inFOcus functions to include the ability to map and symbolise borehole locations
- development of a limited functionality, prototype version of ESEBASE intended as a standalone product, or as a module under inFOcus features:
- retains ESEBASE file and data structures to maintain compatibility with existing datasets
- startup dialog box for selection, addition, removal of existing databases
- view modes - browse or formatted
- query capability - not yet implemented
- browse - field dragging and sizing - database navigating
- multiple windows - synchronous updating
- proposed display and utility functions

Suggestions for further work

- expansion of granular resource database inventories
- preparation of additional base maps for significant sub-regions
- incorporation of existing Beaufort borrow prospects database identifying proven, probable and prospective deposits, into the inFOcus data management system
- quality control check of borehole database georeferencing
- consolidate and standardise the Beaufort borehole inventory so that regional-scope queries can be resolved

Additional information:

Appendix 1: ESE program specifications

Appendix 2: List of selected maps

Appendix 3: Directory structures and database files

NOGAP A4-20
DSS# A0632-7-5011/C1ST
EOR 88-03

Title: Synthesis and Interpretation of Bathymetric, Geophysical, Geological and Geotechnical Data: Isserk Borrow Block - South Central Beaufort Sea

Prepared by: Earth and Ocean Research Ltd., 22 Waddell Ave., Dartmouth, Nova Scotia, B3B 1K3

Date: 31 March 1988

Geographical Area: The Isserk Borrow Block is confined primarily to the Akpak Plateau of the South Central Beaufort Sea. It is a 400km^2 area the southern boundary of which lies approximately nine km to the north of Pullen Island. Study area co-ordinate boundaries are defined as follows:

- NW: 70°02'16"N, 134°28'30"W
- NE: 70°02'10"N, 134°04'53"W
- SW: 69°51'31"N, 134°28'47"W
- SE: 69°51'25"N, 134°05'22"W

PURPOSE

The purpose of this study was to establish the proven, probable, and prospective granular resources in the Isserk Borrow Block in the South Central Beaufort Sea, and to fit this information within the context of a geologic framework and model for the region.

METHODOLOGY

This study is based on data sets constructed from data collected during previous exploratory and research projects carried out by Gulf Canada Resources Ltd., Dome Petroleum Ltd., ESSO Resources Canada Ltd., and the Geological Survey of Canada. Various seismic techniques were used including boomer, microprofiler, high resolution single channel airgun and echo sounder. The available seismic data, however, was sparse and consequently of limited use. Borehole data was extracted from 99 records of borehole drilling within the Isserk Borrow Block. However, a very serious shortcoming of this data set is that very few of the boreholes lie directly on or near the profile tracks.

SUMMARY OF FINDINGS

- The Isserk Borrow Block contains significant amounts of proven, probable and prospective granular resource materials. Two main deposits were identified consisting of fine to medium grained sand bodies that lie within a complex sequence of glacio-fluvial, fluvial, and transgressive marine type sediments that form a northwest-southeast trending ridge across the Akpat Plateau.

- The first deposit is a localized shallow sand body which lies in the central potion of the borrow block. An estimated 19 million m^3 of proven, 63 million m^3 of probable, and up to 80 million m^3 of prospective granular resource materials is indicated.

- The second deposit is a near surface exposure lying in the southeast quadrant of the borrow block. Its estimated 800 million m^3 of prospective granular resources is based on limited seismic information only, and requires considerable future ground truthing. Of this 800 million m^3 it is likely that only 100 to 300 million might actually be recoverable when permafrost bonding and resource quality are fully considered and delineated.

- Due to poor borehole coverage in the probable and prospective areas of both deposits, it is recommended that several boreholes be drilled on an interim basis in order to gain a better understanding of the variability and quality of granular resources in these areas.

- Due to the poor coverage and low quality of the geophysical data used in this study, it is recommended that the area be resurveyed covering both deposits.

- A geotechnical investigation should be carried out pending results of the recommended geophysical program. At least 60 boreholes are required to more accurately define the probable and prospective potential of the two deposits, and to clarify the nature and extent of the fine interlayer between the two sand bodies.

DATA

- Appendix 2: List of seismic data located and retrieved for use in this project

- Appendix 3: Issek borehole summaries and granular resource coding descriptions

- Table 1: Geologic model summary

- Table 3: Granular resource volume estimates

- Table 3A-2: List of boreholes within the borrow block

NOGAP A4-21
DSS# A0632-7-5011/01-ST
EBA 0101-94-11413

Title: Synthesis and Interpretation of Bathymetric, Geophysical, Geological and Geotechnical Data: Erksak Borrow Block - South Central Beaufort Sea

Prepared by: Earth and Ocean Research Ltd.

Date: July, 1994

Geographical Area: The Erksak borrow block is on the Tingmiark Plain of the Beaufort sea, with boundaries defined as:

NW corner:	70°18' 10" N 133°40' 15" W
N.E. corner:	70°17' 04" N 132°06' 15" W
S.E. corner:	69°50' 12" N 132°07' 57" W
S.W. corner:	69°51' 04" N 133°18' 33" W

PURPOSE

The objectives of the work were to summarize the physiographic and sedimentological conditions in one of the two principal portions of the near-shore Beaufort Sea where borrow resources may be recovered.

METHODOLOGY

Data for this interpretation were assembled from several sources, including:

- Geological Survey of Canada data archives
- Beaufort offshore operators (Gulf Canada Resources ltd, Dome Petroleum Ltd (currently AMOCO) and ESSO Resources Canada Ltd.
- Data assembled under NOGAP project A-15 (Compilation and Cataloguing Of Beaufort Bathymetric and High Resolution Shallow Geophysical Survey Data, 1988)
- Data assembled under NOGAP project A-22 (Beaufort Sea Geotechnical Database: Volume I, 1988)

SUMMARY OF FINDINGS

The area is near the Amauligak oil field, which has proven recoverable oil deposits, and comprises the raised, near-surface Tingmiark Plain, bounded to west and southeast by Kugmallit Trough and Niglik Channels. The surficial geology comprises three units deposited during and since the last glacial advance. Glacial outwash sands (Unit C) present the major source of borrow, but often these are overlain by finer-grained deposits, from the marine transgression (Unit B), and by marine clays (Unit A). The report summarizes data from seismic surveys, sea-bottom grab samples, and 122 geotechnical boreholes to delineate and estimate the resource available. The material must be

recovered by dredge, imposing constraints on the depth of useful material. Principal evaluation considerations for the deposits are the depth below sea level, mud cover, bonding as permafrost, and complexity of the stratigraphy. Seismic data are analyzed from records obtained by Geological Survey of Canada and Beaufort offshore operators [Gulf, Dome (Amoco), and Esso], to delineate the depth to Unit C, extent of permafrost, and the uniformity of the sediments.

Overall, 33 borrow sites are identified beneath a maximum overburden of 3 m. Reserves of 748 million m^3, are considered proven, with 7,414 million m^3 probably located at these sites. Over the entire block, however, up to 18,945 million m^3 of prospective resource may be recoverable with appropriate dredges. These deposits are spread over 997 km^2, but over a third of this area has <0.5 m overburden cover. The extent of permafrost detected by seismic methods is insufficient to raise concern over either potential difficulty in extracting ice-bonded sediments, or degradation of the resource by thawing following mining.

DATA

The report includes 22 figures showing:

- bathymetry, locations of study area; tracklines and positions for data;
- Relative sea level curve for southern Beaufort Sea (fig 2);
- Maps of surficial sediment cover and geological interpretation;
- Several sample plots from geophysical surveys;
- Granular resource prospects within the Erksak Borrow Block (fig 17);

The report includes 6 tables showing:

- Geological Model Summary (Table 1)
- Block names and abbreviations, Erksak Borrow Block (Table 2);
- Areas of Granular resource prospects, Erksak Borrow Block (Table 3);
- Proven granular resource (Table 4);
- Prospective granular resource volume estimates (Table 5);
- Probable granular resource estimate (Table 6);

Appendices:

- A: Listing of total seismic data coverage within the central Beaufort survey area
- B: Listing of seismic data located and retrieved for use in this project
- C: Erksak borehole summaries and granular resource coding descriptions

NOGAP A4-22
DSS # A0632-7-5014
EBA 0306-34413

Report Title: Beaufort Sea Geotechnical Database (Volume I)

Prepared by: EBA Engineering Consultants Limited, Alberta

Date: August, 1988

Geographical Area: Data is compiled from offshore borehole logs provided by the major petroleum companies operating in the Canadian Beaufort Sea. Additional data was provided by the Geological Survey of Canada (GSC). A significant portion of the database relates to the Isserk & Erksak borrow blocks located north of Richards Island and the Tuktoyaktuk Peninsula respectively.

Isserk borrow block - 69° 55'N, 134° 10' W
Erksak borrow block - 69° 55'N, 133° 00' W

PURPOSE

The purpose of the study was to compile, in standardized (ESELog) format, a database of existing borehole logs for boreholes completed in the Canadian Beaufort Sea between 1973 and 1987. The database was compiled on behalf of Indian and Northern Affairs Canada (INAC) and is intended for use in the evaluation of granular resources for construction materials.

SUMMARY OF CONTENT

The incorporates 1288 surficial sediment logs, the vast majority of which were provided by Dome Petroleum Ltd. (302), Esso Resources Canada Ltd. (816), and Gulf Resources Canada Ltd.(165). Existing borehole logs from some other Beaufort operators were not included in the database. Logs of shallow drop or gravity core samples and grab samples of bottom sediments were also excluded. A description of the database is provided, and procedures used in the conversion of source data to standardized ESEbase format are outlined. The major data elements included in each log are:

Borehole number
Reference to sea level
Sample type
Soil description
Soil classification data
Ground ice description
Sample temperature

A data dictionary and catalogue of field activities related to granular resource investigations was compiled to facilitate the retrieval of information from within various source reports, some of which cover extensive geographic areas.

Deliverables were submitted in digital format (on floppy disk) and as bound paper copies, separate from the report. Because the Isserk and Erksak borrow blocks were of particular interest to INAC, data related to these regions have been compiled separately from those pertaining to the southern Beaufort Sea.

Deliverables:

a) Erksak and Isserk Borrow Blocks
   - diskette presentation of catalogue reports
   - diskette presentation of borehole logs
   - ESElogs for each area in separate printed volumes

b) Beaufort Sea Catalogue of Reports (excluding Erksak/Isserk)
   - diskette presentation of Beaufort Sea Geotechnical Reports

c) Beaufort Sea Borehole Log Database(excluding Erksak/Isserk)
   - diskette presentation of Beaufort Sea Borehole Logs
   - printout presentations (Volume I is the current report))
   Volume II - Logs from Gulf Canada Resources Inc. and INAC
   Volume III - Logs from Dome Petroleum Ltd. 1974-1980
   Volume IV - Logs from Dome Petroleum Ltd. 1981-1982
   Volume V - Logs from Esso Resources Canada Ltd. 1974
   Volume VI - Logs from Esso Resources Canada Ltd. 1975
   Volume VII - Logs from Esso Resources Canada Ltd. 1976
   Volume VIII - Logs from Esso Resources Canada Ltd. 1978-1985

d) Photocopies of assorted engineering and foundation logs in four unnumbered volumes.

Additional Information:

Table 1: Exploratory Block Names and Abbreviations
Table 2: Sample Types and Abbreviations (Isserk block database)
Figure 1: Location of Isserk and Erksak Borrow Blocks
Figure 2: Typical ESElog Borehole Log
Appendix A: Catalogue Data Dictionary and Selected Report Entries
Appendix B: Borehole Log Source Reports

Revision Reports:

EBA# 0305-34475 - Beaufort Sea Geotechnical and Surficial Sediment Database (1989)

EBA# 0306-34693 - Beaufort Sea Geotechnical and Geophysical Database (1991)

NOGAP A4-22
DSS # A7134-8-0055/01-ST
EBA 0305-34475

Report Title: Beaufort Sea Geotechnical and Surficial Sediment Database

Prepared by: EBA Engineering Consultants Limited, Alberta

Date: April, 1989

Geographical Area: Data is compiled from offshore borehole and corehole logs provided by the major petroleum companies operating in the Canadian Beaufort Sea. Additional data was provided by the Geological Survey of Canada (GSC). A significant portion of the database relates to the Isserk & Erksak borrow blocks located north of Richards Island and the Tuktoyaktuk Peninsula respectively.

Isserk borrow block - 69° 55'N, 134° 10' W
Erksak borrow block - 69° 55'N, 133° 00' W

PURPOSE

The purpose of the study was to expand a previously-compiled database (EBA Report 0306-34413) of 1288 existing borehole logs from the Canadian Beaufort Sea, to include 1051 surficial sediment corehole logs and 46 additional borehole logs completed between 1982 and 1988. The database (in standardized ESEbase format) was compiled on behalf of Indian and Northern Affairs Canada (INAC) and is intended for use in the evaluation of granular resources for construction materials.

SUMMARY OF CONTENT

The expansion of the Beaufort Sea Geotechnical and Surficial Sediment Database incorporates surficial sediment logs provided by Amoco (45), Esso (460), Gulf (405), and the GSC (91). A description of the database is provided, and procedures used in the conversion of source data to standardized ESEbase format are outlined. The major data elements included in each log are:

Borehole/corehole number
- Reference to sea level
- Sample type
- Soil description
- Soil classification data
- Ground ice description
- Sample temperature

The database was submitted in digital format (on floppy disk) and in bound paper copies (Volumes I-III), separate from this Report. As major areas of interest to INAC, logs related to the Isserk (103) and Erksak (137) borrow blocks have been compiled separately into Volume I of the printed logs.

Volume I - Surficial Sediment Logs for the Isserk and Erksak Regions of the Beaufort Sea; Gulf Canada Resources Ltd.

Volume II - Surficial Sediment Logs for the Beaufort Sea; Esso Resources Canada Ltd.

Volume III - Surficial Sediment and Borehole Logs for the Beaufort Sea; Amoco Canada Petroleum Ltd., Geological Survey of Canada, Gulf Canada Resources Ltd.

Additional Information:

Table 1: Exploratory Block Names and Abbreviations

Table 2: Sample Types and Abbreviations

Figure 1: Area Map of the Beaufort Sea

Figure 2: Typical ESEbase Borehole Log

Appendix A: Surficial Sediment Corehole Log Source Reports

Appendix B: Borehole Log Source Reports

Precedent Report:

EBA# 0306-34413 - Beaufort Sea Geotechnical Database (1988)

Revision Report:

EBA# 0306-34693 - Beaufort Sea Geotechnical and Geophysical Database (1991)

NOGAP A4-22
DSS # A7134-0-0037/01-ST
EBA 0306-34693

Report Title: Beaufort Sea Geotechnical and Geophysical Databases

Prepared by: EBA Engineering Consultants Limited, Alberta

Date: March, 1991

Geographical Area: Data is compiled from offshore borehole and corehole logs provided by the major petroleum companies operating in the Canadian Beaufort Sea. Additional data was provided by the Geological Survey of Canada (GSC). A significant portion of the database relates to the Isserk & Erksak borrow blocks located north of Richards Island and the Tuktoyaktuk Peninsula respectively.

Isserk borrow block - 69° 55'N, 134° 10' W
Erksak borrow block - 69° 55'N, 133° 00' W

PURPOSE

The purpose of the study was to continue the compilation of a standardized (ESEbase) format database of surficial sediment core and deep borehole data from the Canadian Beaufort Sea. A geotechnical report catalogue prepared in 1988 by McElhanney Geosurveys Ltd. has been expanded. The database was compiled on behalf of Indian and Northern Affairs Canada (INAC) and is intended for use in the evaluation of granular resources for construction materials

SUMMARY OF CONTENT

The Beaufort Sea Geotechnical and Surficial Sediment Database (1989) was expanded to incorporate 332 additional surficial sediment samples and 71 relatively deep borelole and corehole logs. These additional data were provided by Amoco Canada Resources Ltd., ESSO Resources Canada Ltd., Gulf Canada Resources Ltd., and the Geological Survey of Canada. A description of the database is provided, and procedures used in the conversion of source data to standardized ESEbase format are outlined. The major data elements included in each log are:

Study number
Borehole/corehole/surficial sediment sample number
Reference to sea level
Sample type
Soil description
Soil classification data
Ground ice description
Sample temperature

The source report catalogue compiled in 1988 has been expanded and updated to include report titles and job numbers.

Deliverables

a) Report catalogue databases on floppy disk
- geotechnical
- geophysical
- hydrographic

b) ESEbase database on floppy disk and bound paper copy
- borehole logs
- corehole logs
- surficial sediment logs

c) Final Report (current volume)

d) Revised data handling routines, source code and documentation (under separate cover)

Additional Information:
Table 1: Exploration Block Names and Abbreviations
Table 2: Sample Types and Abbreviations
Figure 1: Area Map of the Beaufort Sea
Figure 2: Typical ESEbase Borehole Log
Appendix A: Surficial Sediment Corehole Log Source Reports
Appendix B: Report Catalogue Entries
Appendix C: Borehole/Corehole/Surficial Sediment Log Source Reports
Appendix D: Additional References

Precedent Report:
EBA# 0306-34413 - Beaufort Sea Geotechnical Database (1988)
Subsequent Report:
EBA# 0306-34693 - Beaufort Sea Geotechnical and Geophysical Database (1991)

NOGAP A4-24
DSS# A7134-3-0046/01-ST

Title: Review of Granular Resource Potential: South-Central Beaufort Sea with Identification of Field Investigation Targets

Prepared by: Lewis Geophysical Consulting, 376 Prospect Bay Rd., P.O. Box 4093, RR#4, Armdale, N.S., B3L 4J4

Date: 31 March 1994

Geographical Area: The study area lies within the Southern "Alpak Plateau" physiographic area of the south-central Beaufort Sea. The study area of some 2000 square kilometers lies just north of North Point on Richards Island in the Mackenzie Delta of the Northwest Territories at 70° north latitude, 134° 30' west longitude.

PURPOSE

The purpose of this study was

- to tentatively define a number of new possible granular resource targets.
- to outline both geophysical survey programs and borehole drilling site programs that would help to more fully define the lateral extent and resource qualities of these targets.

METHODOLOGY

The study is based on a review of data gleaned from reports published prior to 1993 on the geology and granular resources associated with the South Central Beaufort Sea. The data can be divided into three broad categories as follows:

- **Geophysical Survey Data.** These data were generated using the high resolution IKB Seistec boomer profiling system along with a 3.5/7.0 kHz profiler.
- **Bathymetric Data.** Bathymetric data was obtained from a new (1986-1988) bathymetric survey of the region using ARGO positioning with 100-150m line spacing.
- **Borehole and Sample Data.** This class of data was extracted from the ESEBASE borehole data set which consists of 2935 borehole and core samples extracted from within the entire Beaufort Sea region.

SUMMARY OF FINDINGS

- A total of one known and 19 possible granular resource targets have been identified.

- 45 proposed borehole sites were selected for exploratory drilling inside the 12m depth contour.

- A further geophysical survey was proposed consisting of 521 line km of survey.

- This study was unable to re-define the current understanding of the shallow seismo-stratigraphy within the southern Akpak Plateau-Isserk area.

DATA

- Tabular borehole summaries by individual map sheet.

- Standard seismic records with verbal interpretive notes.

- Standard borehole logs.

- Bathymetric target maps for proposed new exploration program.

NOGAP A4-24D
DSS#
C-CORE

Title: Inversion of Electrical Resistivity Data to Identify Granular Resources in Arctic Waters

Prepared by: Centre for Cold Ocean Resources Engineering (C-CORE)
(Scott, English and Smyth)

Date: March 1994

Geographical Area: The results are intended for use in Beaufort Sea coastal waters.

PURPOSE

This study was undertaken to find the best algorithmic approach to real time inversion of marine resistivity data, using the Micro-WIP system shown to be feasible in a previous NOGAP report (Real Time Marine Resistivity System, Hardy BBT Ltd. , March 1987)

METHODOLOGY

The analysis considers one dimensional cases only, and considers resistivity only (i.e. Induced polarization effects are not examined: see previous report by Hardy BBT) Analysis of inversion techniques was based on the following:

- Model inversion involves using apparent resistivity data to determine the thickness and resistivity of distinct earth layers. Five models of inversion were available for comparison, although one (ResixIP) could not be integrated into a real time measurement system. This model was used as a bench mark for comparison, since it is the standard package in use at C-CORE. A second model (Zohdy 1990, USGS) was developed to handle a dipole geometry not suitable for the current application. The three remaining inversion routines were:

  Inversion with ridge regression (Davis): Model parameters are determined via non-linear least squares regression fit of model parameters to field data.

  Monte Carlo inversion (Hardy): Starting from initial estimates of model parameters, a forward model is calculated and the error in fitting to field data is established. Each parameter is varied in turn by a fixed percentage, fitting errors are calculated, and the process repeated. When large data sets are examined, this approach is computationally more intensive than regression.

  Direct Calculation (Basokur): Sample values of the resistivity transform function are first obtained from the from the sample values of the measured apparent resistivity data. Model parameters are then calculated from the resistivity transform.

- "To appraise the performance of the various inversion schemes, data from three sources have been used. The first tests were carried out on apparent resistivity

data sets from the 1991 Beaufort Sea survey. Subsequent comparisons were made on the set collected on three lines in the mouth of Passamaquoddy Bay in the Bay of Fundy. Finally, data sets collected in Conception bay with both dipole and logarithmic arrays were processed. However, most of the appraisal effort was expended on the Beaufort Sea data sets. In addition to running inversions, tests were made on the effect of inverting with fixed layer thicknesses, and on the influence of using different starting models on the ultimate fit. " (report p. 22)

SUMMARY OF FINDINGS

■ The parameter estimates are subject to errors due to lateral variation in sub-bottom resistivities, to departures from straightness in the dipole streamer, and to the problem of equivalence of alternate models. The potential for the first two problems was minimized during testing. Equivalence makes it impossible to decide between different models when layers are thin in comparison to the depth to their tops. In these situations, independent control on layer thickness (e.g. borehole data or seismic data) is necessary in order to separate the combined effects of layer thickness and layer resistivity.

■ Inversion results can be sensitive to initial parameter estimates, especially where marked differences in parameter values occur in the course of a survey. This is due in large part to the use of parameters estimated from the previous sounding as the starting point for the inversion process. During running inversion, the Davis routine appears to be most sensitive to initial model parameters, while Hardy and Basokur produce large errors primarily in the region surrounding abrupt changes in profile.

■ Running inversions with fixed layer thicknesses permits the definition of a resistivity versus depth function. While this technique is promising, fitting alternate layer thickness models is too time intensive to permit its use on a routine basis with the existing system.

■The Basokur routine, while fastest of those examined, was the least reliable for real time inversion using the existing equipment. It uses the shape of the apparent resistivity /depth curve to calculate parameters, and works best with many more dipoles than model parameters to be determined. It would be useful only if more dipoles can be measured with the MICRO-WIP.

■In future, it appears likely that the running inversions would be carried out by either Hardy or Davis, and ResixIP would be used to check solutions, or to do forward modelling. (Report, p 64). Program modifications carried out in the execution of the project provides the capability to rerun data with alternate routines or to alter the initial model when the fitting error deteriorates.

■With existing equipment, use of a logarithmic dipole array with 6 channels, with

real time inversion by the Hardy routine.

■Recommended future modifications include an increase in the number of dipoles, and possible use of a bottom towed streamer. Both would require additional engineering and program development.

■ Addition information from acoustical soundings remains important in reducing uncertainties associated with inversion.

DATA

■Appendix A
- Figures
- Beaufort Sea Running Inversion Printouts
- Conception Bay Printouts
- Tests of starting models

■Appendix B
- Inversion results with ResixIP

NOGAP A4-26A
DSS#

Title: Granular Resource Requirements For Proposed Mackenzie Valley Pipelines: Technical Papers and Workshop Proceedings

Prepared by: Stanley Associates Engineering Ltd.

Date: June 1993

Geographical Area: Presentations relate to development in the entire Mackenzie valley transportation corridor, including the Mackenzie Valley, Mackenzie Delta, and South Slave regions.

PURPOSE

This workshop was convened to summarize previously completed borrow resource inventory studies, identify any new granular resource requirements or development constraints in the Mackenzie Valley and Delta regions, and identify any future research requirements or outstanding granular resource management issues.

SUMMARY OF CONTENT

The Proceedings records 23 papers presented at a workshop, held in Yellowknife during February 1993, to discuss aspects of granular resource management during potential industrial development in the Mackenzie Valley. The papers summarize activities conducted during NOGAP project 4A which contribute to a full assessment of potential and proven gravel resources, possible future demands on such resources, and social and environmental considerations regarding development of the deposits. Nine of the papers concern the inventory of gravel resources that have been delineated during the project. Six papers concern environmental and cultural considerations in borrow pit development resources, especially the influence of land claims agreements on resource management. The workshop proceedings provide an effective summary of the state of granular resource knowledge in the region.

- Presentations:

- Sources of Information on Granular resources:
  - -Surficial Geology Mapping of the Mackenzie Transportation Corridor
  - - DIAND Northern Granular Resources Inventory Program
  - - Borrow Resources in Bibliographic Databases

- Regional Borrow Deposit Inventories:
  - South Slave Region
  - Upper Mackenzie Valley
  - Lower Mackenzie Valley
  - The Feasibility of Developing Granular Resources from the Bed of the Mackenzie River
  - Mackenzie Delta Region

- Typical Borrow Materials Usage:
  - Typical Northern Transportation Borrow Requirements
  - Typical Northern Community Borrow Requirements
  - Norman Wells Pipeline Borrow Materials Usage
  - Historical Borrow Demand Forecasts: Mackenzie Valley Corridor

- Potential Industrial Demands:
  - Granular Resource Requirements For Potential Hydrocarbon Development In The Western NWT

- Discussion Panels:

- Industrial Borrow Demand Issues:
  - Inuvialuit Petroleum Corporation Borrow Demand Issues
  - Gas Pipeline Borrow Demand Issues
  - Oil Pipeline Borrow Demand Issues

- Potential Constraints to Borrow Development:
  - Potential Environmental Impacts: Biophysical
  - Potential Environmental Impacts: Fisheries
  - Potential Cultural Impacts: Heritage and Archaeological Sites

- Land Claims and Borrow Supply: Aboriginal Perspective:
  - The Inuvialuit Land Administration and Borrow Resource Management Issues
  - Gwich'in Land Claim and Borrow Resource Issues
  - Sahtu Land Claim and Borrow Resource Issues

NOGAP A4-26B
DSS # 038ST.A7134-0-0037
EBA 0306-34786

Report Title: Proceedings of the Beaufort Sea Granular Resources Workshop

Prepared by: EBA Engineering Consultants Limited, Alberta

Date: December, 1993

Geographical Area : Discussion is focussed on the Canadian Beaufort Sea borrow sites:

- Western Beaufort (Yukon Continental Shelf);
- Hershel Island;
- Issigak deposit;
- Isserk borrow block
- Erksak borrow block
- Southwest coast of Banks Island

PURPOSE

The purpose of the workshop was to "bring together those who have been part of Beaufort exploration activities and those who may be future participants. This workshop was intended to provide a forum to review the existing information and to identify future research and study requirements. " (Preface, p. 2)

SUMMARY OF CONTENT

This report contains text versions of workshop presentations on regional studies and research undertaken as part of Beaufort-related tasks for NOGAP project A4, invited presentations from partners contributing to and interested in Beaufort sea granular resource delineation and utilization. This is followed by the edited transcript of a round-table discussion of the state of knowledge and identification of the future research required for particular regions and for particular techniques.

■Individual Workshop Presentations:

■Summary Reports on Regional Studies:
(as itemized in "geographical area" above)

■Reports on NOGAP R & D Studies:
Northern Granular Resources Mapping Information System
Geotechnical and Geophysical Databases
Real-Time interpretation of Marine Resistivity

- Invited Presentations:
  - Canadian Hydrographic Services - Beaufort Sea Activities
  - Geological Constraints to Off-Shore Granular Resource Assessment in the Canadian Beaufort
  - Arctic Offshore Exploration Structures: A Geotechnical Perspective

- Round Table Discussion:
  - NOGAP Regional Studies
  - Technology and Techniques
  - Priorities for Future Work

- Editor's Summary of Recommendations.

  - NOGAP Study areas: recommendations are given for each of the study areas, although the Amauligak area is identified as having highest priority because it is likely to be developed first.

  - Geological Objectives: offshore and onshore geology need to be reconciled, since gravel deposits may have been overlooked because of model discrepancies. The first priority for granular resources exploration should be in the Amauligak/Issigak/North Head triangle.

  - Data Archives: A thorough search for seismic data should undertaken to retrieve valuable data, identify lost and destroyed records and establish, an archive.

  - Data Base/GIS: A number of specific recommendations are made about improvements to Data Base/GIS utility, but it is recommended that NOGAP funding should be reserved only for developments relating directly to granular resource applications.

  - New Technology: significant advances in GPS, data acquisition, heave compensation, etc. hold the potential to significantly improve survey techniques. It is recommended that field trials be held in the Fraser Delta area to perfect suites of geophysical equipment, bathymetric techniques and sampling tools before taking then to the Beaufort Sea.

NOGAP A4-26C
DSS #

Report Title: Granular Resource Requirements for Potential Hydrocarbon Developments in the Western Region of NWT

Prepared by: North of 60 Engineering Limited, Alberta

Date: March, 1993

Geographical Area : Hydrocarbon developments are limited to the Beaufort sea/ Lower Mackenzie valley. Granular resource implications of some scenarios extend down the Mackenzie valley and into Alberta.

PURPOSE

This report summarizes several potential hydrocarbon development scenarios which have potential to be economic under current price outlooks, and examines the granular resource implications of each.

METHODOLOGY

Four potential development scenarios were considered:
- development of a small onshore oil or gas field for local energy demands;
- seasonal production from the Amauligak reservoir;
- a generic 200 million barrel onshore oilfield;
- processing of onshore gas for sale to southern markets;

Timing of these scenarios was "phased to reflect the ongoing level of exploration, the time frame required to develop a particular scenario, and the current economic outlook. Using existing experience, computer models and input from industry contacts, the types and quantities and timing of granular resources requirements were determined fore each of the scenarios identified above.

SUMMARY OF FINDINGS

- Current granular resource requirements for the oil and gas industry are modest. The conventional wisdom is that offshore oil extraction is not likely until more reserves are discovered.

- An earlier study by the current author indicated that small scale oil development using either tankers or an extension to the Norman Wells pipeline could be

NOGAP A4-27
DSS# A7134-3-048/01-ST
EBA 0101-11413

Title: Granular Resource Investigation, Source 222, Dempster Highway #8, km 222, Caribou creek, NWT (**Draft**)

Prepared by: EBA Engineering Consultants Ltd., Edmonton, Alta.

Date: May, 1994

Geographical Area: The study area is located approximately 50 km south of Inuvik, NWT, adjacent to km 222 of the Dempster Highway immediately north of Caribou Creek at 68°05.4'N latitude and 239°29.2'W longitude. The site consists of two adjacent hills that were believed to contain large volumes of well-drained sand.

PURPOSE

The purpose of this study was to delineate the potential borrow material for use as a blend sand.

METHODOLOGY

The field investigation consisted of drilling five boreholes which were sampled to a maximum penetration of 8.4 meters.

Laboratory analysis was conducted to determine natural moisture content and grain size distribution.

SUMMARY OF FINDINGS

The subsurface material at the site generally consists of glacial sand and silt till. Natural moisture conditions were observed to be generally moist to wet. Excess ground ice was encountered within the permafrost, thus the moisture condition upon thawing is expected to be wet to saturated with some free water produced.

Indian and Northern Affairs Canada (INAC) will need to determine the economics of developing the deposit based on the recovered subsurface information and on giving consideration to the economics associated with this deposit's distance from Inuvik as compared with a possible crushed quarried rock alternative.

General comments and recommendations are provided with regard to pit development, material processing, and pit restoration considerations in the event that INAC should

decide to develop the source.

DATA

- Five borehole logs (tabular) - Appendix A
- Laboratory test summary (tabular) - Appendix B
- Sixteen grain size distribution curves (graphical) - Appendix B

economically attractive without additional reserves if technology advances could lower costs.

- "A number of development scenarios have been identified that are potentially viable given technology and fiscal uplift. Granular resource requirements for these development scenarios are significant (13.76 million m^3), but lower than historical estimates for larger development scenarios.

- Onshore oil development is estimated to require 2 million cubic metres while onshore gas developments is estimated to require 8.5 million cubic metres.

- Timing of granular resource requirements will depend on the actual timing of development.

DATA

NOGAP A4-27
DSS# A7134-3-0048/01-ST
EBA 0101-94-11413

Title: Granular Resource Investigation Northern Richards Island, NWT : Geophysical Program(**Draft**)

Prepared by: EBA Engineering Consultants Ltd., Edmonton, Alta

Date: July, 1994

Geographical Area: The study area is the northern portion of Richards Island, NWT, at 69°35'N latitude and 135°15'W longitude.

PURPOSE

This study presents the results of geophysical work undertaken as part of a larger project: it comprises Volume 2 of a study to provide preliminary information regarding the feasibility of exploiting sand deposits in this area to meet the expected demand for onshore granular resources associated with Mackenzie Delta oil and gas production.

METHODOLOGY

Ground Probing Rada (GPR) and electromagnetic conductivity measurements were taken at 4 sites in the area of investigation. Three "resource targets" were identified through literature review and air photo interpretation. The field investigation comprised eight sampled boreholes to a maximum penetration of 11.1 meters. Seven of these holes were drilled on the two "Sand Ridges" resource targets, and the eighth hole was drilled on the "Glaciofluvial Terraces" resource target.

The laboratory testing consisted of moisture content determination and grain size distribution analysis.

SUMMARY OF FINDINGS

The soil encountered on the sand ridges generally consists of poorly sorted sand with a highly variable fines content. Below the depth of seasonal thaw (active layer), the moisture content was determined to be greater than 20 percent, which will require careful planning consideration be given to extraction methodology and pit drainage requirements.

Only one borehole was drilled on the glaciofluvial terraces due to inclement weather

encountered while on location and associated time constraints. Due to the limited investigation at the discontinuous glaciofluvial terraces, further investigation is recommended.

DATA

- Eight borehole logs (tabular) - Appendix B
- Laboratory test summary (tabular) - Appendix C
- Twenty-one grain size distribution curves (graphical) - Appendix C

NOGAP A4-27
DSS# A7134-3-0048/01-ST
EBA 0101-11413

Title: Granular Resource Investigation Northern Richards Island, NWT (**Draft**)

Prepared by: EBA Engineering Consultants Ltd., Edmonton, Alta

Date: July, 1994

Geographical Area: The study area is the northern portion of Richards Island, NWT, at 69°35'N latitude and 135°15'W longitude.

PURPOSE

The purpose of this study was to provide preliminary information regarding the feasibility of exploiting sand deposits in this area to meet the expected demand for onshore granular resources associated with Mackenzie Delta oil and gas production.

METHODOLOGY

Three "resource targets" were identified through literature review and air photo interpretation. The field investigation comprised eight sampled boreholes to a maximum penetration of 11.1 meters. Seven of these holes were drilled on the two "Sand Ridges" resource targets, and the eighth hole was drilled on the "Glaciofluvial Terraces" resource target.

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Only one borehole was drilled on the glaciofluvial terraces due to inclement weather encountered while on location and associated time constraints. Due to the limited investigation at the discontinuous glaciofluvial terraces, further investigation is recommended.

DATA

- Eight borehole logs (tabular) - Appendix B
- Laboratory test summary (tabular) - Appendix C
- Twenty-one grain size distribution curves (graphical) - Appendix C

NOGAP A4-27
DSS# A7134-3-0048/01-ST
EBA 0101-94-11413

Title: Geotechnical/Geological Investigation of Selected Granular Resource Prospects Beaufort Sea (**Draft**)

Prepared by: EBA Engineering Consultants Ltd., Edmonton, Alberta

Date: February, 1995

Geographical Area: The study area is a 350 km^2 block of shallow sea bottom within the south-central region of the Beaufort Sea, just north of Richards Island. The centre of the study area is at 69° 45'N latitude and 135° 15'W longitude.

PURPOSE

The purpose of the study was to obtain geotechnical data for use in ground truthing geophysical interpretations and in evaluating the suitability of the derived geological models for prospective granular resource sites.

METHODOLOGY

The field investigation comprised 19 sampled boreholes to maximum penetration of 14.5 meters in shallow water with a maximum depth of 9.3 meters. The laboratory testing program included moisture content determination, Atterberg limits, particle size distribution, and porewater salinity determinations.

SUMMARY OF FINDINGS

A simplified stratigraphic description of the area would include a clay unit, however this unit was not encountered at three of the borehole locations. This material is described as low plastic, thinly laminated, and thinly interbedded with silt or silty fine-grained sand. This surficial layer was less than 1.5 m thick in all but one of the boreholes in which it was encountered.

An underlying sand unit was observed to be fine-grained containing varying contents of both silt and clay. Thin interbeds of silt and clay were observed within the sand unit. The presence of disseminated organics and shell fragments was noted in several samples.

Porewater salinities range between 20 and 40 ppt resulting in a freezing point depression that averages at least 1.5°C.

Visible ice and/or well-bonded soil was encountered in samples obtained from within the

sand unit in four of the boreholes.

DATA

- Standard borehole logs - Appendix B
- Laboratory Test summary (tabular) - Appendix C
- Particle size distribution (graphical and tabular) - Appendix D

NOGAP A4-28
DSS#
EOR

Title: Environmental Constraints Analysis for Granular Resource Development in the Beaufort Sea - A New Methodology using Low Cost Raster GIS

Prepared by: Earth & Ocean Research Limited, Dartmouth, Nova Scotia

Date: March, 1993

Geographical Area: Canadian Beaufort Sea, Beaufort coastal areas

PURPOSE

This study investigates the applicability and suitability of low-cost, raster GIS (IDRISI) to carry out environmental constraints analysis in support of granular resource development in marine environments. The pilot study develops and demonstrates a methodology that can be used to evaluate and incorporate different constraints that might be subject to changing conditions. Accompanying the report is a companion dataset (on 2 floppy disks) consisting of 82 digital maps.

SUMMARY OF WORK

Introduction

- summary of activities related to granular resource extraction and their importance in the Beaufort region
- environmental issues related to granular resource extraction and utilization
- outline of 3 test applications of the analysis methodology
- instructions for viewing the digital map dataset

Test 1 - A Method for Evaluating the Direct Impact of Marine Dredging on the Benthic Environment in the Beaufort Sea

Background - potential impacts of dredging on elements of the benthic environment
- biological effects on the benthic community
- impact on benthic habitat
- impact analysis and the planning process
- incorporating IDRISI into the DIAND database analysis system

The Physiography of the Erksak Borrow Site
- study area test site location
- use of bathymetric data in environmental investigations of benthic communities
- detailed, step-by-step explanation of the methodology for creating raster data layers of regional bathymetry within IDRISI

Direct Impact of Dredging on Total Benthic Biomass
- dredging activities and borrow requirements assumed for the hypothetical development scenario
- ecological impact of the removal of organic overburden
- locations of borrow deposits, organic-rich sediments (Erksak)

Raster GIS Analysis
- prepare orthographic images depicting the physiography before and after dredging
- determine the loss of total organic carbon from the excavation
- 3-D image construction - outline of the IDRISI functions used in creation of a Digital Elevation Model (DEM)
- calculation of excavation volumes and total organic carbon

Test 2 - Optimizing the Selection of Pipeline Corridors in Environmentally Sensitive Areas in the Beaufort Sea

Background
- development of oil and gas fields in the Beaufort Sea
- the Environmental Atlas for Beaufort Sea Oil Spill Response
- categories of environmental sensitivity -Human Use, Biology, Shore Zone, Marine Oil Residence
- implications of mapping environmental sensitivities
- environmental risk or vulnerability vs distance from an oil spill
- objective - selection of a pipeline route between two locations that minimizes the exposure of sensitive areas to pipeline construction and operational activities

Analytical Approach
- applying proximity analysis to determine the risk to environmentally sensitive shorelines
- outline of the raster analysis procedure used within IDRISI
    - cost/friction analysis
    - pathway analysis
- analyzing alternative scenarios

Test 3 - Planning for Environmental Conditions that Impact Borrow Deposit Surveying and Dredging Operations

Background
- factors affecting the surveying recovery of granular deposits in the Beaufort Sea
- data sources - bathymetry, sea ice

Beaufort Regional Bathymetry
- DEMs as a visualization tool, vertical exaggeration
- extracting information from a DEM

- depth profiles
- histograms
- map algebra
- correlation to water depth, other variables

Planning Survey Work For Different Environmental Conditions

- implications of sea ice for survey and dredging operations
- difficulties in interpreting contour representations of sea ice data
- portraying frequency of ice occurrence as a digital data surface
- analysis of open water accessibility vs distance from land
- time series analysis capability within IDRISI

Conclusions

IDRISI GIS is a capable and cost-effective tool for application to environmental constraint analysis, with standard GIS functionality being well-represented. Given its additional capacity for time-series display and analysis, together with its considerable capacity for satellite image processing and statistical analysis, IDRISI is the least expensive commercially-available GIS at its performance level. However, IDRISI has relatively large data storage requirements, and is inadequately documented, with the result that it is difficult to learn how to use the system.

NOGAP A4-30
DSS # 038ST.A7134-2-0039
K-C PA 2695 04 01

Report Title: Granular Resource Potential, Beaufort Sea Artificial Islands

Prepared by: Klohn - Crippen Consultants Limited, Alberta

Date: March 31, 1995

Geographical Area : Canadian Beaufort Sea artificial islands and berms with boundaries defined as:

N.W. corner:	70°30'N latitude and 137°W longitude.
S.E. corner:	69°N latitude and 131°W longitude.

PURPOSE

The purpose of this study was to:

- provide a summary of the location, type, quantity and quality of granular materials in the study area.

- provide selected examples of island erosion and sediment transport rates, to illustrate the importance of material type, water depth range, and environmental conditions on the potential change in the resource potential of the artificial islands with time.

- provide an evaluation of the constraints to possible utilization of these granular materials for future development in the Beaufort Sea.

- prepare digitized information (including bathymetry) for use with the inFOcus database/mapping system.

SUMMARY OF CONTENT

Beaufort Sea artificial island construction began in 1973 in shallow (< 5 m) nearshore water. Through the 70's and 80's, development moved to deeper water as experience increased. The deepest island is in 19 m water. The resource potential and erosion characteristics of 37 artificial islands are examined in this report.

Erosion / failure problems with individual islands are discussed. Failures occurred as a result of :

- excess pore water pressure at time of placement
- wave induced liquefaction
- storm erosion
- ice-induced cyclic mobility
- large scale liquefaction failure in loose sand fill

The principal processes responsible for island erosion are:

- extreme storm events
- winds and near bottom currents
- ice scouring
- sediment scouring

In general, the environmental conditions responsible for erosion become increasingly severe with increasing water depth/ distance offshore. Islands submerge and migrate with time: The rate of submergence is most rapid in the first 2-3 years after abandonment, and is faster for islands in deeper water. Islands migrate in the direction of summer storm tracks. Islands stabilize as they submerge, and sediment loss decreases.

The resource potential of the islands is summarized as:

- 200,000 m^3 gravel fill from onshore borrow pits (4 islands)
- 4,000,000 m^3 coarse sand from Ukalerk/Issigak deposits (3 Islands)
- 7,000,000 m^3 Ukalerk sand (8 islands)
- 14,000000 m^3 fine sand is recoverable from the remaining islands.

Constraints to the development of the granular resources available in the artificial islands are:

- Environmental conditions
  - extended periods (Typically 9 months) with ice cover.
  - persistence of grounded rubble around islands
  - storms
- Water Depth
  - technologies used in the past were limited to operation in water between 8 and 40 metres deep.
- Drilling debris remaining on the island surface.
  - depending on island type
- Contaminants spilled on island surface migrating into borrow materials
  - depending on island type

DATA

Figures

Location plan
Schematic Representation of Island Types
Summary of In-situ Gradation for Borrow Sources
Wave induced Excess Pore Pressure
Approximate Fill Quantities at Gravel and Sand Islands
Approximate Fill Quantities at Ukalerk Type Sand Islands
Ice Ridging

Rubble formation Sequence
Example of Rubble Formation around Issungnak Island
Rubble Formation for the CRI At Amerk 0-09
Rubble Formation on a Natural Shoal
Distribution of Ridge Grounding and Scours on the Natural Shoal
Typical Significant Wave Height Exceedance Distribution for the Beaufort Sea
Extreme Value Current Speed for the Amauligak Location
Wave and Current Data used in the Gulf Canada Storm Assessment Study.
Amauligak Location Extreme Storm Profiles
Island Sediment Transport Summary
Island Sediment Transport Pattern and Volume Loss Summary

Appendix I

INFOCUS/QUICKMAP/FOXPRO2 Database

Appendix II

ITIYOK I-27 Example of Database

Volume 2: Island Inventory

This contains a hard copy summary of information entered into the database. Section 1 provides an introduction to the project. Section 2 presents the database and discusses the use of FoxPro2 and Infocus/Quickmap. Section 3 summarizes the availability of granular resources in the artificial islands. Separate sections are then provided in Appendix I for each of the 37 artificial islands summarizing available information.

Volume 3: Sediment Transport at Artificial Islands Sites, Canadian Beaufort Sea.

A Study of selected Islands over time was used to determine potential changes to the resource potential of the old artificial islands.

NOGAP A4-31
DSS#

Title: Potential Granular Resources and Their Geological Constraints Northern Richards Island

Prepared by: Terrain Analysis and Mapping Services Ltd, 2161 Westhunt Drive, Box 158, Carp, Ontario

Date: December, 1993

Geographical Area: The study area is North Point, Richards Island, NWT (69°30' north latitude and 134°10' west longitude). It comprises approximately 375 km^2 of the northern tip of the island lying some 50 km west of Tuktoyaktuk.

PURPOSE

The purpose of this study was to provide an initial assessment of the potential granular resources and conditions on North Point in the anticipated landing zone of offshore pipeline corridors.

METHODOLOGY

The literature review included data retrieval of IOL shot hole log compilations in the files of the Geological Survey of Canada. This was followed by field (helicopter) reconnaissance, air photo interpretation and mapping.

SUMMARY OF FINDINGS

Much of northern Richards Island is a complex of lacustrine deposits, till-covered uplands and sand ridges sculpted by glaciation and thermokarst. Ice thrust blocks were formed and outwash was also deposited during glaciation along the eastern part of North Point, i.e. on Summer Island and south of Corral Bay. During deglaciation, major glaciofluvial valley trains and terraces and marine terraces were formed in the same area. A rising sea level and coastal retreat has resulted in constant erosion of coastal bluffs and the formation of many sandy marine beaches, bars and spits. (report, p.1)

Sand ridges can provide a significant supply of fine-grained sorted sand along the east side of North Point. The surfaces of ice-thrust blocks also appear to be mainly composed of sand. Both types of sources will require drilling to determine the presence or absence of clayey or icy beds within them that might limit exploitation.

Outwash in the eastern part of the study area may provide some graded sand and minor gravel, but requires further investigation concerning the quality of materials and the presence of massive ice. Glaciofluvial valley trains and terraces and a marine terrace

south of Summer Island contain much sand, some of which is pebbly and some of which contains layers of woody detritus. The only located source of well-graded gravel is found in a glaciofluvial valley train there and its quality and extent should be further investigated. Exploitation of these deposits is limited by drainage, icy silt and peat cover.

Marine beaches, bars, and spits contain sand and minor gravel, but their exploitation will be limited by coastal processes. Sand extraction in coastal escarpments is also limited by coastal processes. Sand may be available in stable coastal bluffs on the west side of North Point, but investigations will be needed to determine its purity and exploitability.

DATA

- Description of terrain units - Table 1, p.16.
- General Distribution of Surficial Units and Features on Northern Richards Island. - Figure 11, p. 25.
- Potential sources of granular material, Northern Richards Island. - Figure 13, p. 30.
- Sources of granular material - Table 2, p.31.
- Stratigraphy at site on southern Summer Island - Table 3, p.38.
- Resource areas and recommended targets for future investigation - Table 4, p. 46.
- Shot hole stratigraphy Appendix I-III.

NOGAP A4-31
DSS#

Title: Potential Granular Deposits and Terrain Analysis of Selected Areas on the Cameron Hills, Northwest Territories

Prepared by: J.D. Mollard and Associates Limited, 810 Avord Tower, 2002 Victoria Avenue, Regina Saskatchewan, S4P 0R7

Date: March, 1994

Geographical Area: The study area is located on the Cameron Hills Upland in the Northwest territories, north of the NWT/Alberta boundary. It extends from 60° 00′ to 60° 14′ N latitude and from 117° 11′ to 117° 45′ W longitude.

PURPOSE

- To interpret aerial photographs to identify potential granular sources and clay deposits.

- To prepare photomosaics of the study areas to include outlines of identified granular material prospects.

- To provide estimates of potential volumes of the identified granular material prospects.

- To map drainage patterns in the study areas along with a complete interpretation of geographic features (terrain units) in the study areas.

METHODOLOGY

Air photo interpretation based on stereo viewing.

SUMMARY OF FINDINGS

- Terrain types and distribution on the Cameron Hills Upland are complex. Altogether, 19 significantly different terrain units were identified.

- There is much more ice-rich permafrost in peat bogs than anticipated. It is significant in terms of route and wellsite access as well as road and pipeline location, construction and maintenance.

- There is little or no infiltration into the ground in the permafrost-affected areas. This is likely to present a problem in road design and drainage control.

- Promising clay borrow sources occur on hill and ridge tops and on south-facing sunny slopes covered with deciduous trees in numerous locations.

- In general, granular material prospects are scarce and difficult to identify with confidence on air photos. A total of 87 prospects were mapped, but 32 of these are questionable.

DATA

- Figure 1: Regional bedrock geology map.
- Figure 2: Regional surficial geology map.
- Figure 3: Regional vegetation map.
- Figure 4: Permafrost zones of North America (map).
- Figure 5: Schematics of permafrost situations on Cameron Hills Upland.
- Figure 6: Schematic of ice-rich permafrost in alluvial and slopewash silty and clayey soils over till on Cameron Hills Upland.
- Figure 7: Key map showing location of better granular material prospects.
- Figures 8-13: Air photo overlays of granular material prospects.
- Tables 1 and 2: Granular material volume estimates.

NOGAP A4-32
DSS#

Title: Compilation Inventory of Granular Resources Information Within Cameron Hills Area

Prepared by: J.D. Mollard and Associates Limited, 810 Avord Tower, 2002 Victoria Avenue, Regina Saskatchewan, S4P 0R7

Date: October, 1993

Geographical Area: The study area consists of the northwest corner of the Province of Alberta and contiguous areas in the Northwest Territories. It extends from 58° to 61°N latitude and from 118° to 122°W longitude.

PURPOSE

- To review previous aerial photographic studies and associated reports of the two study areas.

- To identify potential granular resource materials from the information sources researched.

- To transfer onto 1:250,000 maps data on granular prospects or deposit locations taken from existing maps and/or air photo reports.

- Provide a table or deposit summary including information on the landform, potential volume of granular material, and an indication of geological constraints.

- Provide a brief report on each of the study areas.

METHODOLOGY

The study was based on air photos, existing maps and literature reviews. The air photo study was conducted without the aid of stereoscopic viewing. Three categories of prospect size were used:

- Small - tens of thousands to hundreds of thousands of cubic meters.

- Medium - hundreds of thousands to millions of cubic meters.

- Large - millions to tens of millions of cubic meters.

SUMMARY OF FINDINGS

- No attempt was made to differentiate between granular resource *"prospects"* (unproven by testing) and *"deposits"* (proven by testing).

- Many of the prospect landforms in the study area are complex (more than one landform present in the same prospect).

- Due to the lack of stereoscopic viewing of air photos, landforms associated with the granular locations were predicted from past experience in the study area.

- No precise data are available on permafrost conditions on the prospects.

DATA

- Tables 1-5: summary of granular deposits by NTS sheet including an indication of landforms, surface topography, and deposit size category for each prospect.

- Figure 1: key map showing study area and NTS sheets.

- Figures 2-6: individual study area maps, each with a repeat of the relevant summary of granular deposits (Tables 1-5).