50

INVESTIGATION OF SUBSURFACE CONDITIONS AT KING POINT, YUKON TERRITORY

VOLUME I

10-300

Submitted to:

Indian and Northern Affairs Canada

Submitted by:

M. J. O'Connor & Associates Ltd.

April, 1986

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1.0 INTRODUCTION

1.1 Authorization

The following report documents the findings of a geotechnical site investigation at King Point, Yukon Territory. Authorization to proceed with the study was received by telex from Mr. F. McLennan, Senior Science Procurement Officer, Supply and Services Canada, on 85/03/01. The contract document for Contract No. OST84-00494 was received on 85/03/18. Mr. D. L. Longlitz of Indian and Northern Affairs Canada (INAC) was named in the contract as the scientific authority for the project.

1.2 Background

Located at latitude 69°06'N and longitude 137°58'W on the Yukon coastal plain, the cliffed promontory of King Point rises approximately 50 m above adjacent MacKenzie Bay (Drawing No. 1.1). Immediately southeast of the King Point promontory a lagoon is enclosed by a coastal deposit of sand and gravel, forming a barrier bar across a former bay-mouth. The coastline to the northwest and southeast of King Point is comprised of ice-bonded soils which are susceptible to erosion and redeposition by arctic marine processes.

King Point was formerly an outpost for the Royal Canadian Mounted Police (RCMP). Remnants of the RCMP buildings are currently visible at the site (Plate No. 1.1). Because deep water occurs relatively close to the coastline and granular resource deposits occur in close proximity, King Point has, in the past, generated interest as a potential marine terminal and harbour for servicing offshore activities

Plate No. 1.1 Remnants of RCMP cabin at King Point related to hydrocarbon exploration and development in the Beaufort Sea. Recently a potential rock quarry site located approximately 12 km south of King Point has been identified as a possible source of aggregate for offshore construction in both the Canadian and the American sectors of the Beaufort Sea, and this has renewed industry interest in development of a harbour at King Point.

In view of the above, Indian and Northern Affairs Canada (INAC) has undertaken to acquire the necessary additional data to permit engineering assessment of the potential impacts of the proposed developments on both the coastal and onshore environments proximate to King Point. In so doing, INAC will be able to more effectively regulate and manage these resources so that the total impact on the environment is minimized.

1.3 Objectives of the Study

At the request of Mr. D. L. Longlitz of INAC, an engineering investigation of the general subsurface conditions near King Point was initiated. The main objective of the programme was to acquire the necessary information to permit engineering assessment of the potential impacts of the proposed developments on the offshore, coastal and onshore environments. Specific objectives in each area were as follows:

1. Offshore - 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.

2. Coastal - To evaluate the coastal regime, to identify the potential impacts of development on the existing coastal processes and any constraints to development.

3. Onshore - 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.

1.4 Scope of the Study

During the course of the study, M. J. O'Connor & Associates Ltd. were required to perform the following specific tasks:

1. Use existing information from the onshore and coastal areas including: logs of shot holes, boreholes, test pits, natural exposures, etc. to prepare a detailed geomorphic/geologic map on a photomosaic base of the area east of the Babbage River from longitude 137°45' to 138°15' and from latitude 68°55' to the coastline.

2. Synthesize existing onshore and coastal information regarding material types and potential aggregate sources (including the distribution of permafrost and ground ice) in the study area.

3. Drill, log and sample selected geomorphic terrain units in the vicinity of King Point, to assess the suitability of foundation conditions and the potential for granular resource development.

4. Drill, sample and log boreholes in the offshore and coastal areas at King Point retaining the samples for future laboratory testing.

5. Log and sample the offshore permafrost where encountered, noting in particular the presence of any excess ice.

6. Conduct laboratory and in situ testing as may be required to provide a preliminary geotechnical assessment of the strength and deformation behaviour of the offshore sediments.

7. Evaluate the coastal regime at King Point by assembling existing information on cliff substrates, beach substrates, nearshore substrates, coastal retreat rates, longshore transport directions and magnitudes, recent sea level changes, and oceanographic processes.

8. Construct a coastal sediment dynamics model to illustrate the probable evolution of the King Point shoreline over the previous 5000 to 10 000 years, incorporating not only coastal erosion information, but also estimates on ebb tidal delta size and subaqueous delta size of small nearby streams. Oceanographic data was to be used as appropriate.

9. Evaluate probable distributions and thicknesses of nearshore gravels using the sediment dynamics model.

1.5 Execution of the Study

Under the direction of M. J. O'Connor & Associates Ltd., a group of subcontractors provided specialized services related to execution of the study. The subcontractors and their respective responsibilities are listed in Table No. 1.1.

In addition to the above subcontractors and M. J. O'Connor & Associates Ltd. personnel, scientific personnel from the Department of Indian and Northern Affairs and the Geological Survey of Canada (Atlantic Geoscience Centre and Terrain Sciences Division) were on site during the investigation. Mr. D. L. Longlitz, the Scientific Authority for the contract, was present on behalf of Indian and Northern Affairs Canada. The Geological Survey of Canada (GSC) personnel participated in logging the boreholes, collecting samples, conducting in situ cone penetrometer tests and installing ground temperature instrumentation. GSC personnel also performed laboratory miniature vane tests and salinity measurements. Yukon Territory land-use inspection personnel were present for the onshore investigation to provide direction with respect to environmental protection considerations.

The site investigation was carried out between 85/03/21 and 85/03/29. Locations of all of the onshore, coastal and offshore boreholes and cone penetration tests are shown on Drawing No. 1.2. The test hole locations and depths are summarized in Table No. 1.2.

TABLE NO. 1.1

SUBCONTRACTORS

COMPANY	RESPONSIBILITY
Beaudril Ltd.	Ice profiling of the access route.
Beau-Tuk Marine Services Ltd.	Supply of cat-train camp, food, provisions, camp personnel and bear monitors.
Challenger Surveys & Services Ltd.	Location of survey control and surveying of borehole locations.
Dobrocky Seatech Ltd.	Review and analysis of coastal processes.
Foundex Explorations Ltd.	Provision and operation of the rotary drilling rig, equipment, soil sampling tools and the acoustic cone penetrometer system for the offshore investigation.
Midwest Drilling Ltd.	Provision and operation of a rotasonic drill rig and soil sampling equipment for the onshore and coastal investigations.
Terrain Analysis and Mapping Services Ltd.	Geomorphology study and terrain mapping.

TABLE NO. 1.2

TEST HOLE SUMMARY

Area	Test Hole No.	UTM Coordinates (Zone 8 CM 135°W) Northing	Easting	Below Seabed (m)	Type of Test Hole	Date
Offshore	F85-KM1	7669092	381335	26.0	M	85/03/24
	F85-KM2	7669364	381787	24.4	M	85/03/24
	F85-KF1	7669313	381811	20.1	F	85/03/22
	F85-KF2	7669015	382161	30.6	F	85/03/23
	F85-KF3	7669837	382845	0.1	CPT	85/03/24
	F85-KF4	7670498	383551	17.5	CPT	85/03/24
	F85-KF5	7670393	383141	11.4	CPT	85/03/24
	F85-KF6	7670031	383008	8.6	CPT	85/03/25
	F85-KF7	7670498	383551	15.1	F	85/03/25
	F85-KF8	7669449	382667	15.2	F	85/03/26
Coastal	F85-KM3	7668632	381521	13.8	M	85/03/24
	F85-KM4	7668126	381521	12.2	M	85/03/23
	F85-KM5	7667824	381703	9.8	M	85/03/23
	F85-KM6	7667567	381779	4.9	M	85/03/23
	F85-KM7	7667816	382085	7.9	M	85/03/23
	F85-KM8	7667975	381848	8.3	M	85/03/23
	F85-KM9	7668070	381954	7.9	M	85/03/23
	F85-KM10	7668193	382091	7.4	M	85/03/23
	F85-KM11	7668453	381814	11.0	M	85/03/23
	F85-KM12	7668392	381750	7.9	M	85/03/23
	F85-KM14	7668761	381593	9.7	M	85/03/22
	F85-KM15	7668724	381530	7.9	M	85/03/23
	F85-KM16	7668674	381484	7.4	M	85/03/23
	F85-KM17	7668295	381672	10.2	M	85/03/23
	F85-KF9	7667772	381631	26.5	CPT	85/03/26
	F85-KF10	7667769	381628	19.1	F	85/03/26
Onshore	F85-KM13	7668057	381221	25.0	M	85/03/22
	F85-KM18	7667441	382097	29.3	M	85/03/24
	F85-KM19	7669288	381879	20.1	M	85/03/24
	F85-KM20	7666768	381917	20.1	M	85/03/25
	F85-KM21	7666380	382460	29.3	M	85/03/25
	F85-KM22	7666559	381148	23.2	M	85/03/25
	F85-KM23	7666595	379632	26.2	M	85/03/25
	F85-KM24	7667869	378551	14.0	M	85/03/25
	F85-KM25	7667507	379991	29.3	M	85/03/26
	F85-KM26	7668635	380270	29.3	M	85/03/26
	F85-KM27	7669785	379714	20.1	M	85/03/26
	F85-KM28	7669785	378987	14.0	M	85/03/26
	F85-KM29	7667967	377332	20.1	M	85/03/26
	F85-KM30	7666233	377025	20.5	M	85/03/26
	F85-KM31	7669371	378496	29.3	M	85/03/26
	F85-KM32	7669813	377802	29.3	M	85/03/27
	F85-KM33	7670498	376800	11.0	M	85/03/27

* Letter symbols represent the following types of test hole:

M - Midwest Rotasonic Borehole

F - Foundex Rotary Borehole

CPT - Cone Penetration Test

2.0 REGIONAL CONDITIONS

2.1 Regional Geomorphology and Quaternary Geology

Most of the study area lies within the coastal fringe of the Yukon Coastal Plain (Rampton, 1982, Bostock, 1970). The coastal fringe is relatively low with elevations rarely exceeding 80 m. Local relief to 60 m is common. The southern end of the area rises gently to (near) 250 m elevation as it impinges on the mountains of the Yukon Coastal Plain. Unconsolidated Quaternary sediments are thick (generally more than 60 m) under the coastal fringe. Under the mountain fringe the Quaternary sediments are generally thinner and the surface topography commonly reflects the underlying bedrock topography. Locally, bedrock is exposed at the surface.

The thick sequence of unconsolidated Quaternary sediments of the coastal fringe overlies a gentle northward-sloping pediment, or erosion surface, that extends southward to the mountain fringe. The erosion surface was likely formed during the late to middle Tertiary (Rampton, 1982). Resistant bedrock stands out as knobs and ridges (or monadnocks) on the erosion surface.

Since the middle and late Quaternary the Yukon coastal plain has been the focus of perimarine sedimentation. Thick interbedded sequences of both marine and fresh-water fine grained sediments (clay, silt and fine sand) are exposed along the coast from west of Herschel Island to near Shingle Point. Peat layers representing terrestrial organic accumulation are common within the fresh-water fine grained sediments.

Wedges of sandy and gravelly sediment present within the fine grained sequence represent deltas and large alluvial-fans grading to sea level. The latter, which were probably deposited locally by an ancestral Babbage River, are particularly well exposed along the sea cliffs southwest of King Point. Plates No. 2.1 and 2.2 are photographs, obtained during the 1985 site investigation, of these cliff exposures.

According to Rampton (1982), there is no evidence to suggest that the surficial deposits and landforms along the Yukon Coastal Plain can be attributed to more than one glaciation of probable early Wisconsinan age. During this period, termed the Buckland Glaciation by Rampton (1982, p. 21), the ice front advanced from the northeast, overriding perimarine sediments in the King Point area and reaching its most advanced positon well west and south of King Point. A clay till was deposited over the perimarine sediments during this advance. During retreat from its most advanced position, the ice appears to have paused near the present coastline to the southeast of Kay Point (Rampton, 1982). This major stillstand, which has been termed the Sabine Phase of the Buckland Glaciation, resulted in the deposition of an apron of glaciofluvial sand and gravel south of the ice front. The meltwater which formed this apron discharged westward, paralleling the present course of Deep Creek, to Phillips Bay. During the Sabine Phase the ridge between Kay and King Points was formed by either ice thrusting or squeezing out of unconsolidated preglacial perimarine sediments from under the edge of the glacier (Mackay, 1959, Rampton, 1982). This process resulted in a variable thickness of till being deposited over contorted preglacial sediments.

Following final retreat of the glaciers from the Yukon coastal plain, water courses such as the Running River and the Blow River continued to be diverted westward toward Phillips Bay parallel to the Sabine Phase

Plate No. 2.1 Cliff Exposure of Coarse Grained Sediments

Plate No. 2.2   Cliff Exposure of Frozen Fine Grained Sediments ice front. These rivers flowed along the broad, terraced, glaciofluvial channel paralleling Deep Creek and its eastward extension. This flow pattern continued until at least 8500 years ago (Vincent, GSC, pers. comm. to V. N. Rampton, 1984). Shortly thereafter, coastal retreat resulted in the present lower courses of the Running and Blow Rivers being eroded. Incising and terracing of the Deep Creek valley has occurred subsequent to its abandonment by the Running and Blow Rivers.

During glaciation some of the ground is thought to have been unfrozen with the base of the glacier at its pressure melting point. Shortly after deglaciation, permafrost aggraded, with ground ice forming where groundwater was in plentiful supply at the base of the aggrading permafrost. Permafrost was probably absent below much of the alluvial channel presently occupied by Deep Creek (formerly the lower courses of the Running and Blow Rivers). Undoubtedly, permafrost aggraded rapidly following abandonment of this channel by the Running and Blow Rivers.

During the early Holocene, climatic warming led to thermokarst activity (Rampton, 1973, 1974). Once extensive areas of ground ice began to melt, the surrounding material was redistributed as retrogressive-thaw flow-slides formed around ponds, lakes, river banks, sea cliffs and along other slopes. Much of this thawed material was ultimately deposited in lake basins. Although it is presumed that the larger thermokarst lakes were, at one time, underlain by taliks, permafrost re-aggraded in the lake basins once they were either drained or infilled. Slight cooling during the late Holocene has led to a more stable landscape, albeit one marked by isolated active retrogressive-thaw flow-slides. Aggrading permafrost formed ground ice in the alluvial and colluvial deposits which have developed as a result of thermokarst activity (Mackay, 1972), while extensive ice wedge networks and polygonal ground have developed in all areas underlain by permafrost (Harry et al, 1985).

During the Late Wisconsinan and Early Holocene the sea level was lower than at present, allowing streams on the Yukon coastal plain to erode their stream valleys to depths well below modern sea level. The subsequent Holocene rise in sea level resulted in the drowning of small valleys like those immediately southeast of King Point, and also in-filling of the lower part of larger valleys by the modern streams, such as the Babbage River and Deep Creek.

The rise in sea level may also have contributed to active retreat of the coastline and the build-up of beaches and bars, the latter resulting from erosion of coarse materials from sea cliffs and the transport of these materials through long-shore drift. The coastal processes are discussed in greater detail in Section 7.0.

2.2 Regional Climate and Permafrost

Long, cold winters and short cool summers are characteristic of the arctic maritime climate on the Yukon coastal plain (Burns, 1973). The mean annual air temperature recorded at Shingle Point during the period 1957-1980 was -10.4°C (Harry et al, 1985). The entire onshore region near King Point is underlain by continuous permafrost, with the exception of major lakes and river channels. The thickness of the active layer ranges from less than 0.3 m in some fine grained sediments overlain by organic deposits, to 1-2 m in areas of sparsely vegetated sands and gravels (Rampton, 1982). The distribution of ground ice is highly variable, reflecting the wide range of geological and geomorphic environments, as well as the complex history of permafrost development. The occurrence of ice-bonded permafrost is widespread in the fine grained sediments of the area. Ground ice may be present as pore ice, reticulate ice-vein systems, segregated ice lenses and ice wedges, as well as thick tabular sheets of massive ice.

2.3 Physiography

The coastal cliff exposures, which are the major sources of materials for depositional features such as the King Point Barrier Bar, are composed of variable amounts of gravel, sand, mud and ice. Periglacial mass wasting processes in the form of retrogressive-thaw failures and block slump failures are common features of erosion along ice-rich cliff sections. Much of the volume of cliff material at King Point is actually ice, a fact which significantly affects the nature of cliff erosional processes. Gravity slope processes, such as gullying and talus cones are common along ice-poor cliff sections.

In the immediate vicinity of King Point, very high (50 m) cliffs with both old and modern cliff failure features are present. Some of the older failures have become re-activated. To the southeast, low (10 to 20 m) coastal cliffs display extensive, retrogressive thaw failure features with mudflow transport down the slope. Massive ground ice is usually present in the headwall of the thaw failures. A narrow sand and gravel beach fronts the base of the lower cliffs.

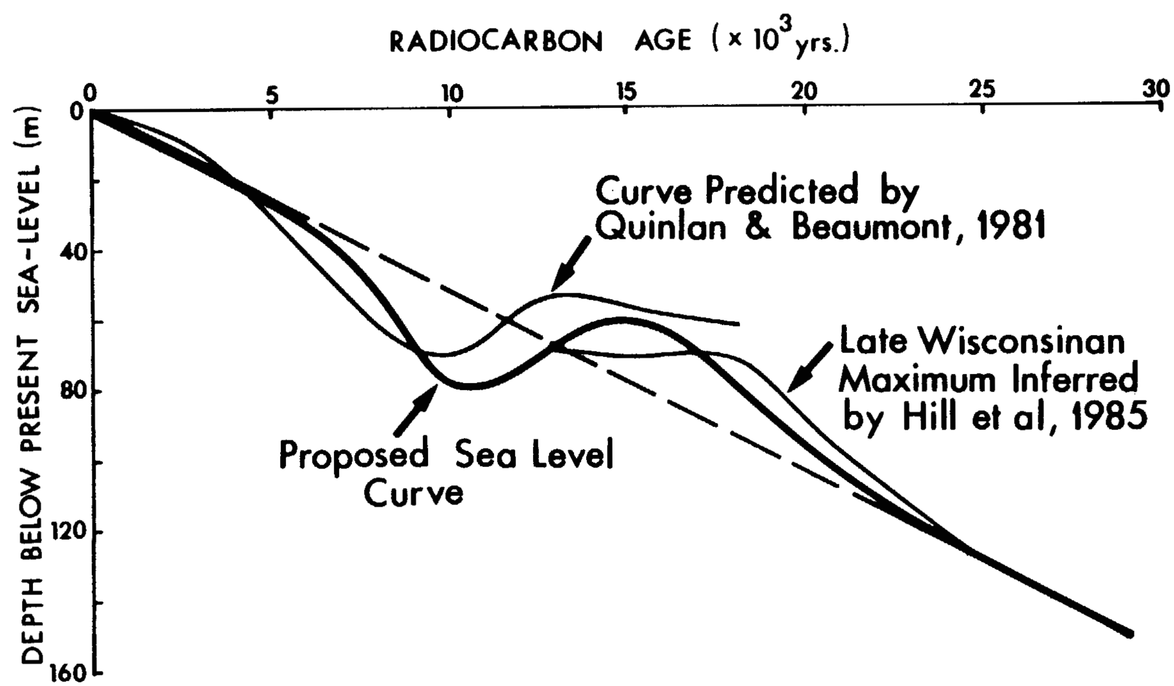
According to the sea level curves shown in Drawing No. 2.1, sea level has risen approximately 55 m over the last 15 000 years and presently may be rising as much as 10 mm/year. As a result of the increase in sea level, much of the coast is undergoing rapid erosion and the stream valleys are becoming submerged.

2.4 Bathymetry

Bathymetric data for the southern portion of Mackenzie Bay is shown in Drawing No. 2.2. The offshore bathymetry in this area reflects the seaward extension of the broad, shallow shelf, (<5 m deep) of the Mackenzie Delta from the southeast, the submarine extension of Kay Point to the northwest and the shoreward extension of the Mackenzie Trough from the north.

The nearshore bathymetric data presented in Drawing No. 2.2 shows the 20 m isobath located approximately 2400 m from shore at King Point. Inshore of this depth the contours are approximately parallel to the shoreline. Nearshore seabed slope angles are approximately 0.3° between the 10 m and 20 m depth contour and 0.1° between the 10 m depth and the shoreline. Sub-tidal beach slopes are not precisely known, but are probably steeper.

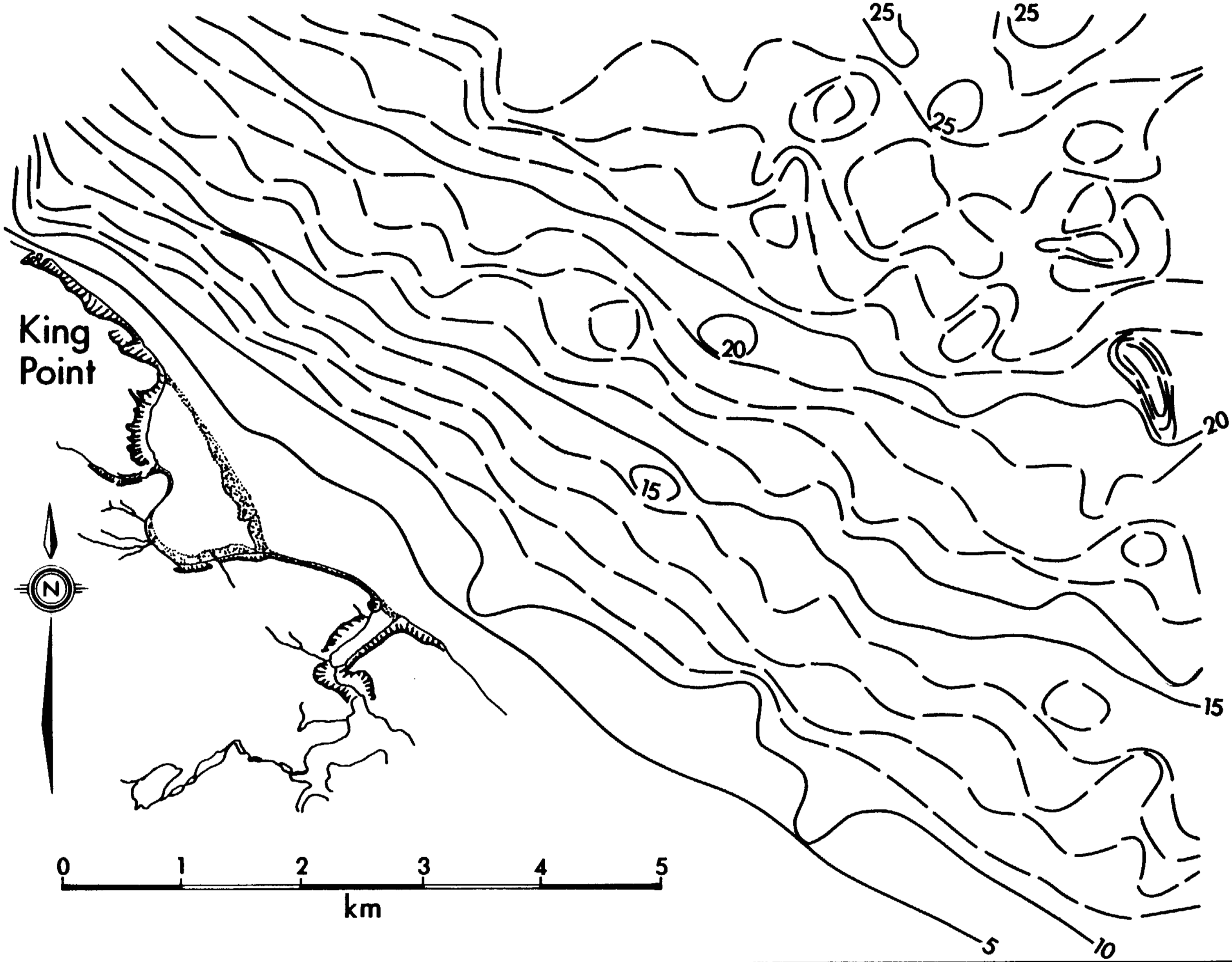
The only nearshore bathymetric anomalies in the area occur along the 10 m isobath where two 5 m deep trough features are oriented perpendicular to the shore. These features are located to the southeast of the King Point barrier and probably represent the seaward extension of two drowned valleys.



Proposed Sea Level Curve
(after M.J. O'Connor
& Associates Ltd., 1984)

M.J. O'CONNOR & ASSOCIATES LTD.

JOB No.:	10-300	**DATE:**	85/08/06
DRAWN BY:	MG	**DWG. No.:**	2.1



Nearshore Bathymetry (m) Along King Point Coastline (From Canadian Hydrographic Service Field Sheet WA10071)	**M.J. O'CONNOR & ASSOCIATES LTD.**

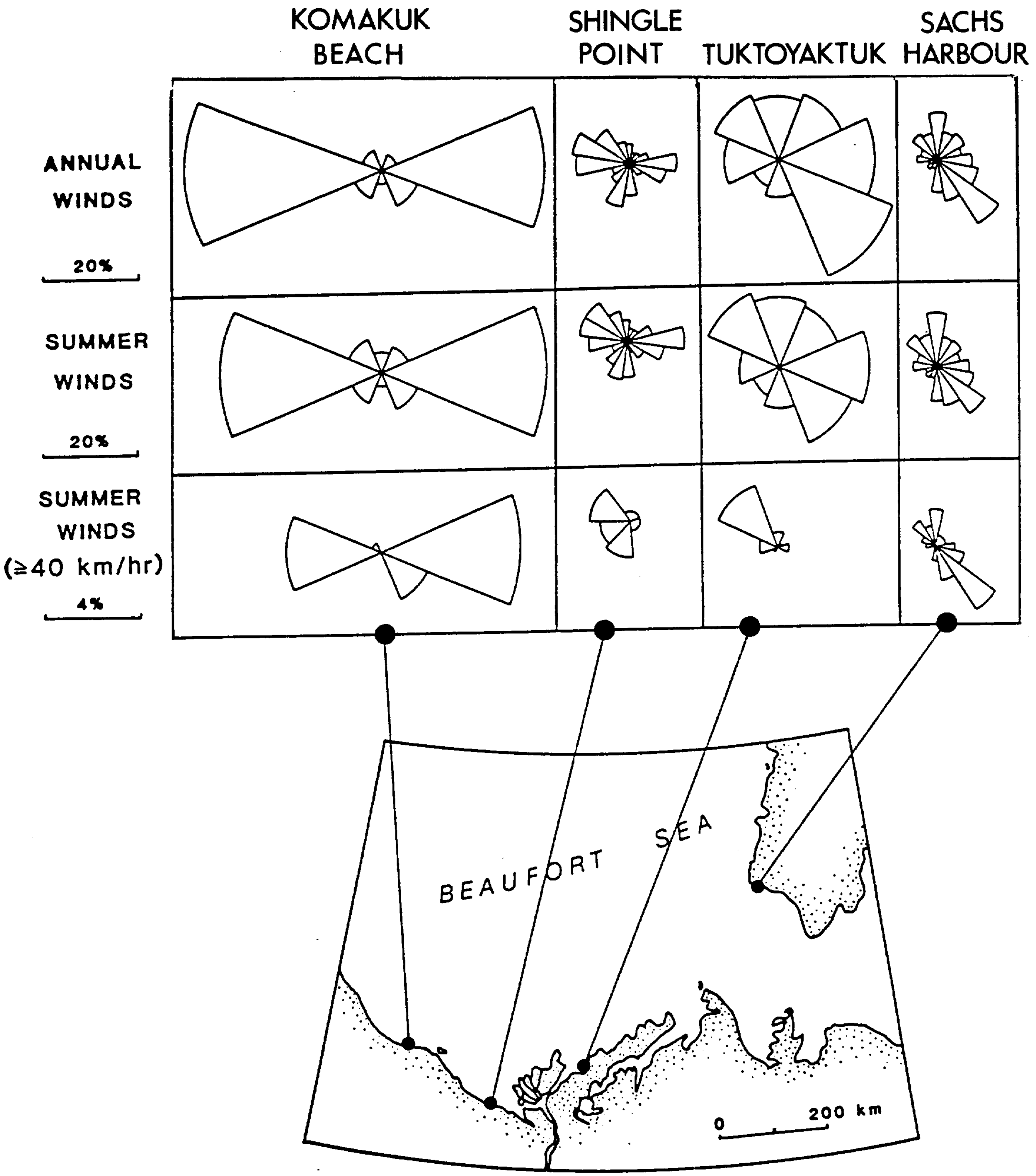
JOB No.:	10-300	**DATE:**	85/08/06
DRAWN BY:	MG	**DWG. No.:**	2.2

2.5 Hydrology

The hydrology of the Yukon coast rivers is not well documented; however, flow is known to occur only during the summer months and usually peaks in early June. Some of the larger rivers discharge as much as 100 000 to 200 000 tonnes of sediment per year (Harper et al, 1985). Most of the Yukon rivers discharge into lagoons where sediment is trapped until coastal erosion exposes the deposits at a later time. The Mackenzie River annually inputs approximately 15 000 000 tonnes of sediment to the Beaufort Sea, most of which is silt and clay. However, this only has limited influence on the area of study at King Point. Sediment loads from the local rivers do not contribute significantly to the local coastal sediment budget since there are no large rivers for 30 km in either direction.

2.6 Oceanography

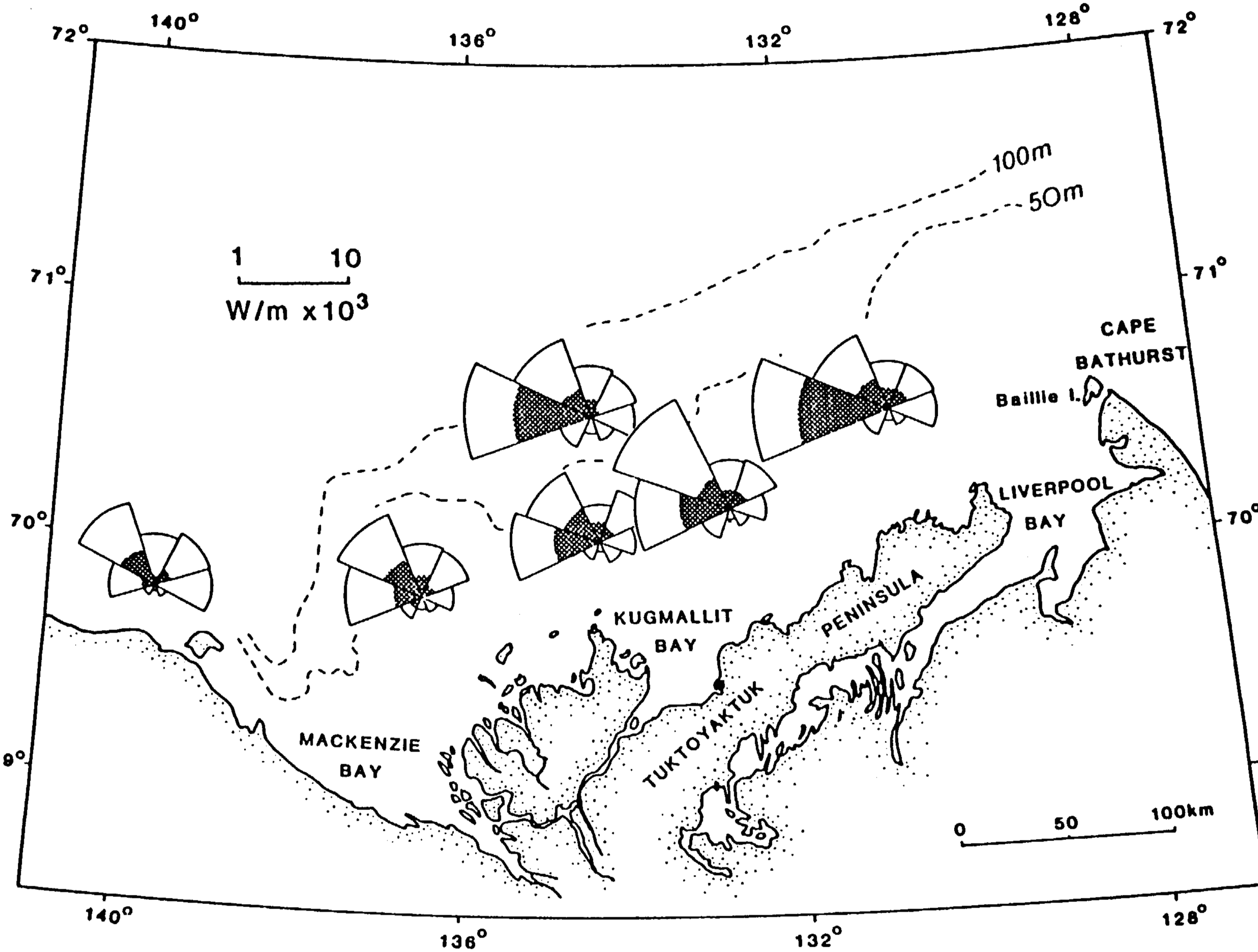
Low winter temperatures (mean for January at Tuktoyaktuk, N.W.T. is -27°C) result in the formation of sea ice for approximately 9 months of the year. In the open water season of the Beaufort Sea (July to September), prevailing winds tend to blow from both westerly and, to a lesser extent, easterly directions. There is a tendency, however, for stronger winds (exceeding 40 km/hr) to blow from the west to northwest in the vicinity and offshore of King Point (Drawing No. 2.3). Waves generated by the winds also exhibit a tendency for prevailing and predominant wave directions from the northwest (Drawing No. 2.4).



Beaufort Sea Wind Distribution (from Harper and Penland, 1982)

M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.:	10-300	DATE:	85/08/06
DRAWN BY:	DSL	DWG. No.:	2.3



Wave Power Roses Computed from Wave Climate Summaries (Baird and Hall, 1980) Shaded Roses Indicate Power Due to Waves Greater Than 2 m in height

M.J. O'CONNOR & ASSOCIATES LTD.			
JOB No.:	10-300	DATE:	85/08/06
DRAWN BY:	MG	DWG. No.:	2.4

Sea ice reforms annually in the Beaufort Sea and limits the open-water season to approximately 3 months. The dates of break-up and freeze-up in Mackenzie Bay are widely variable. The open water season usually begins in July, but is sometimes delayed by heavy ice until late August (Fisheries and Oceans Canada, 1981). The end dates of open water seasons recorded between 1970 and 1983 are summarized in Table 2.1 and are shown to range from early September to early November.

Wave activity is effectively confined to these open-water months and, as a result, the coastal processes are essentially dormant during the remaining 9 months. The presence of pack-ice offshore limits wave action even during the open-water months so that the Beaufort Sea is a comparatively low-wave energy environment.

In spite of the fact that waves are generated only during the open-water season, they remain the most significant modifying process of the Beaufort Sea coastal zone. Open-water characteristics are as follows:

1. Background waves that are less than 1 m in height account for less than 30% of the annual wave energy and occur 78% of the time;
2. Intermediate storm waves that are 1 m to 2 m in height account for less than 50% of the wave energy and occur 20% of the time; and
3. Severe storm waves that are greater than 2 m in height account for 20% of the annual wave energy and occur less than 2% of the time.

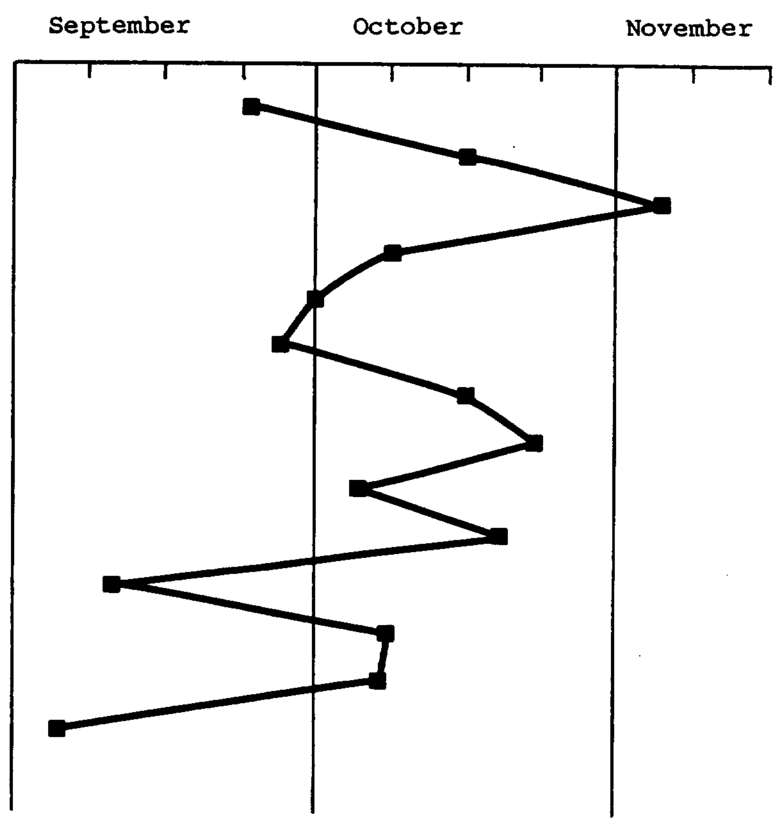
TABLE 2.1

VARIATION IN END OF OPEN WATER SEASON IN
SOUTHERN BEAUFORT SEA BETWEEN 1970 AND 1983

Data from Keith Philpott Consulting Ltd. (1985)

Year	Date
1970	Sept. 22
1971	Oct. 14
1972	Nov. 4
1973	Oct. 7
1974	Sept. 30
1975	Sept. 25
1976	Oct. 14
1977	Oct. 20
1978	Oct. 4
1979	Oct. 17
1980	Sept. 10
1981	Oct. 7
1982	Oct. 6
1983	Sept. 4
Mean	Oct. 5

Plot of Variation



Tidal currents are small in the Canadian Beaufort Sea (Fissel and Birch, 1984) and currents in the shallow coastal areas of the Beaufort Sea are assumed to be principally wave and wind-driven, although no measurements have been made in water depths of less than 7 m.

Astronomical tides are very small in the Canadian Beaufort Sea; tidal ranges for Tuktoyaktuk are 0.5 m for large tides and 0.3 m for small tides. Storm surges are significant and may be up to 1.5 m (Henry, 1975). A storm surge of slightly greater than 1.5 m would inundate most of the barrier bar at King Point (maximum crest elevation approximately 1.6 m). The presence of overwash channels on the backshore of the barrier bar is evidence of significant storm surge effects in the recent past.

2.7 Coastal Processes

There have been some local coastal observation studies conducted in the Canadian Beaufort Sea (MacKay, 1960, 1963a, 1963b). A larger-scale regional coastal reconnaissance study of the Yukon coast was conducted in the early 1970's (McDonald and Lewis, 1973; Lewis and Forbes, 1974), but only one multi-year process-oriented coastal study has been conducted in the Kay Point-Babbage River area (Forbes, 1981). Although the King Point area has been included in some of the local observational and regional reconnaissance studies, no detailed studies of coastal processes have been undertaken at King Point. In spite of the paucity of specific coastal studies at King Point, it is possible to deduce general coastal process information from some of the other major Beaufort Sea studies.

It is known, for instance, that the Beaufort Sea coast has experienced a rapid transgression in the past 10 000 years and there is abundant geomorphological evidence that the transgression is continuing at the present time (Forbes, 1980). Much of the coast appears to be undergoing spectacular annual retreat in the order of 0.5 m to 2 m per year.

As Plates No. 2.3 and 2.4 illustrate, erosional landforms are common. Coastal cliffs often exhibit unique mass-wasting processes such as retrogressive-thaw failures and block falls (MacKay, 1966; McDonald and Lewis, 1973; Lewis and Forbes, 1974).

Massive ice and excess pore ice are common in the coastal cliffs (Plate No. 2.5). These high ice contents mean that the actual volume of sediment eroded is greatly reduced, even when coastal retreat rates are rapid (MacKay, 1966, 1971, 1972).

Barrier islands and spits provide the principal coastal sediment sinks, and these features are typically comprised of gravelly sand (McDonald and Lewis, 1973; Lewis and Forbes, 1974). The smaller rivers off the Yukon coast do not directly contribute much sand and gravel to the coast; most is retained within the upper reaches of the river, and silt and clay comprise the main sediment components directly reaching the coast (McDonald and Lewis, 1973; Forbes, 1981). Sediment transport directions along the coast are primarily controlled by wave approach directions. A significant proportion of the wave energy, and hence sediment transport, occurs during episodic storm events (Harper and Penland, 1982).

Plate No. 2.3 Coastal Cliff Erosion Lanforms:
Block Falls Southeast of King Point

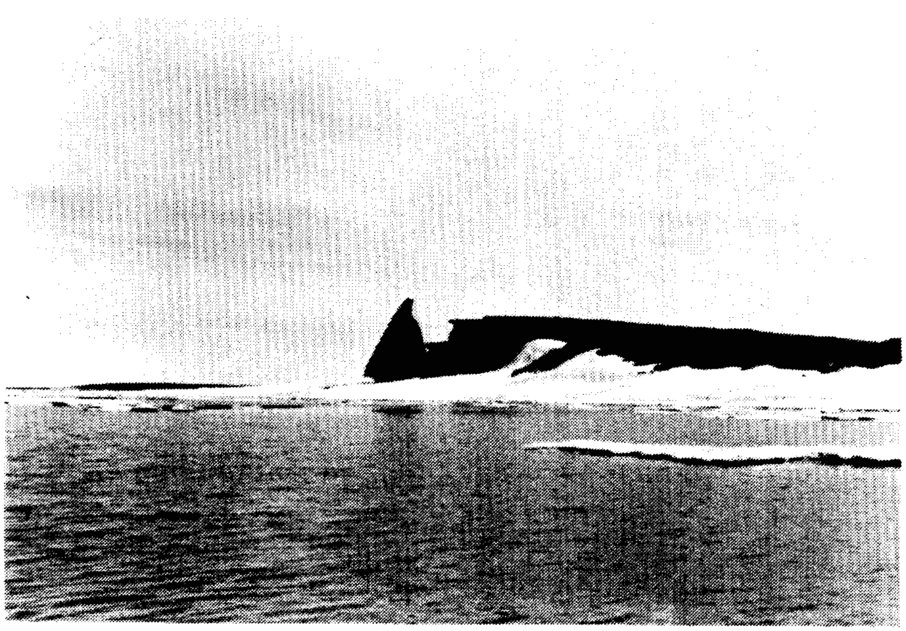


Plate No. 2.4 Block Fall

Plate No. 2.5 Vertically Inclined Segregated Ice in the Headwall of a Retrogressive Thaw Flow Side

3.0 SITE INVESTIGATION

3.1 Logistics

Two drilling rigs were utilized simultaneously at King Point to accomplish the objectives of both the onshore and offshore investigations. Continuous coring of the permafrost-affected soils at both the onshore and the coastal borehole locations was carried out using a rotasonic rig, owned and operated by Midwest Drilling Ltd. of Winnipeg, Manitoba. Geotechnical drilling and in situ testing in the offshore and coastal lagoon areas were accomplished using an HT-700 hydraulic top drive rotary drill, owned and operated by Foundex Explorations Ltd. of Surrey, British Columbia. The Midwest rotasonic rig was also used to provide continuous stratigraphic information at two offshore locations (F85KM1 and F85KM2). Both drilling rigs were mounted with weather-resistant enclosures on skis. Photographs of the two enclosed drilling rigs are presented in Plates No. 3.1 and 3.2.

The camp support required for scientific personnel and drilling crews at this remote location consisted of ski-mounted trailers with sleeping, wash-car and kitchen facilities (Plate No. 3.3). The camp and drill rigs were towed to the site with heavy construction equipment, including a D7 Caterpillar tractor and a Caterpillar 930 rubber-tired front end loader. This equipment was also used for plowing snow and moving the drill rigs between borehole locations at the site. The camp equipment and personnel were supplied by Beau-Tuk Marine Services Ltd. of Calgary, Alberta.

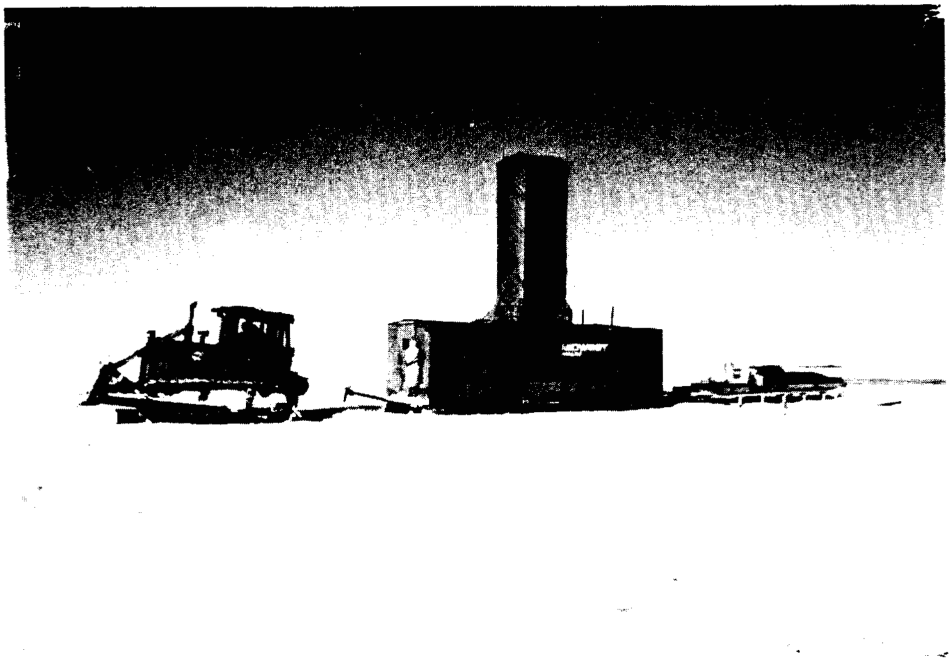


Plate No. 3.1 Midwest Rotasonic Drilling Rig in Tow
Behind D6 Cat

Plate No. 3.2 Foundex Rotary Drilling Rig

Mobilization of personnel and supplies from Inuvik, Northwest Territories to King Point, Yukon, was primarily via four-wheel drive vehicles along a temporary track plowed across the sea ice by BeauDril Ltd. of Calgary to support Gulf Canada Resources Ltd.'s operations near Herschel Island. Helicopter and fixed wing aircraft support were required on a limited basis for reconnaissance of the site, establishment of survey control and for transfers of personnel.

Native people equipped with rifles provided by the camp contractor, were employed to monitor wildlife movements, e.g. polar bears, wolverine, in the vicinity of the camp and the drill rigs on a 24 hour per day basis to ensure the safety of the drilling and scientific personnel (Plate No. 3.4).

3.2 Survey Control

The UTM coordinates of both the offshore and onshore borehole locations were established and recorded in the field by Challenger Surveys Ltd. of Edmonton, Alberta. Borehole locations were referenced to Government of Canada benchmarks in the vicinity of King Point using an electronic distance measuring (EDM) device and a Motorola Mini Ranger system. The measured borehole locations are presumed to be accurate to within ± 1 m. The Mini Ranger system was also used to locate the existing control stations. The locations and elevations of the control stations are summarized in Table 3.1.

The elevations of selected onshore and coastal boreholes relative to the sea ice surface were measured in the field (precision ± 5 mm) using the EDM survey equipment (Plate No. 3.5). Snowmobiles were used for transporation of the survey crew and equipment to the onshore borehole locations. Approximate elevations (± 2 m) of other onshore boreholes were obtained from a contour map of the area prepared by Gendron Lefebvre Inc. for Peter Kiewit Sons Co. Ltd. (Drawing No. H-1, Appendix H).

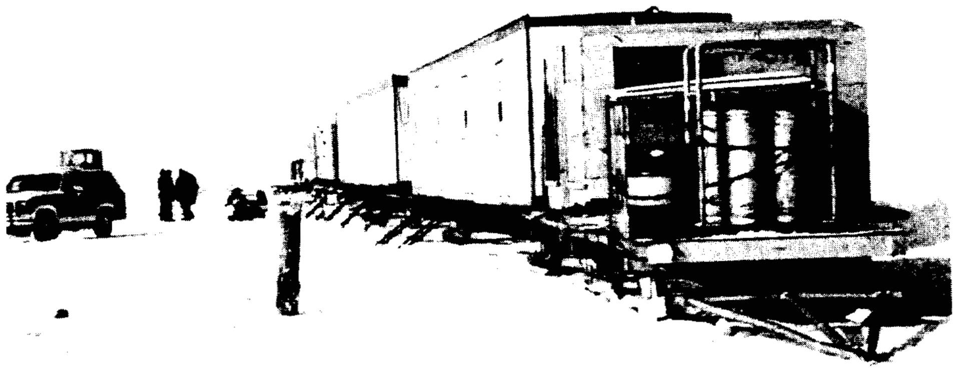


Plate No. 3.3   Cat-Train Camp

Plate No. 3.4   Bear Monitor

TABLE NO. 3.1

SURVEY CONTROL STATIONS

Station Name	Latitude	Longitude	Zone	UTM Coordinates Northing	Easting	Elevation (m)	Horiz. Adj.
SING A-55	69°-02'-13.528"	137°-41'-33.602"	8	7660677.9	392515.1	61.1	1979
PAT	68°-58'-48.676"	138°-00'-54.835"	7	7654878.7	619446.0	96.3	1979
KIN (1)	69°-06'-44.247"	138-00-06.954"	7	7669620.3	619258.1	N/A	1983
CLIFF A-23	69°-08'-08.817"	138°-07-43.840"	7	7671995.7	614090.3	75.7	1979

3.3 Drilling and Sampling Methods

A total of 43 test holes, including both boreholes and cone probes, were completed during the course of the investigation. All borehole numbers have the prefix F85K, signifying a Federal Government borehole drilled in 1985 at King Point. Those boreholes drilled using the Midwest rotasonic rig were numbered with the prefix F85KM, whereas those drilled with the Foundex rotary rig were prefixed by F85KF.

Stratigraphic information obtained from the boreholes is presented on the borehole logs in Appendix A.

3.3.1 Onshore and Coastal Boreholes

The onshore and coastal boreholes were drilled using the Midwest rotasonic rig. Hollow aluminum sonic drill pipe, nominally 100 mm internal diameter, was advanced into the subsurface under combined rotation, downward pressure and vibration. No drilling fluids were required with this drilling method. A continuous core sample of the subsoils was recovered in the annulus of the sonic drill pipe. The core sample was retained inside the drill pipe as it was being extracted from the borehole by a sealing valve located behind the drill head and/or by friction. After removal from the borehole, the core was either extruded into core trays by means of hydraulic pressure (pressurized water injected into the pipe) or was vibrated out under the influence of gravity. The former method of extrusion resulted in less disturbance of the core and was used wherever water was practically available.

3.3.2 Offshore Boreholes

All but two of the offshore boreholes were drilled using the Foundex rotary rig. An HW wireline drill casing, nominally 100 mm internal diameter, was advanced behind a rotating 125 mm drill bit while pumping drilling mud or sea water through the casing to remove cuttings and clear the bit. Drilling mud temperatures ranged from 0°C to +4°C. These temperatures were 2°C to 4°C warmer than the intake seawater temperatures because mud chilling equipment was not supplied with the rig.

Samples of the sub-seabed sediments were obtained from the offshore boreholes using wireline Shelby tube samplers. Thick-walled 65 mm O.D. tubes were used to obtain samples of coarse grained granular materials. Thin-walled tubes were used in the fine grained recent sediments. Triple tube diamond coring equipment (HQ3 and NQ3) was also available for obtaining core samples of ice-bonded permafrost but was not required during the programme.

3.4 Sample Handling and On-site Testing

3.4.1 Onshore and Coastal Samples

Core recovered from the rotasonic rig was placed on plastic core trays and transferred to a separate ski mounted lab trailer. The core was then examined and detailed stratigraphic logs were recorded. Some sections of the core were photographed. A photograph of core from borehole F85KM23 is shown in Plate No. 3.6. Core temperatures were measured using

Plate No. 3.5   Surveying with EDM

Plate No. 3.6   Rotasonic Core Samples
(note massive ice in core)

a thermistor probe to provide an indication of the thermal condition of the subsoils (frozen/unfrozen). Significant warming of the sonic core samples was observed when vibratory extrusion methods were used. The degree of thermal disturbance was reduced, however, when pressure extrusion methods were used. Representative samples from selected boreholes were sealed against moisture loss and retained for detailed laboratory analyses. Permafrost samples from the onshore boreholes were retained in a frozen condition during transportation to Inuvik to retard potential moisture loss. Selected samples of peat and organics were also wrapped in opaque foil for future amino-acid dating studies. Excess ice contents were measured in samples consisting of frozen ice-rich sediments.

3.4.2 Offshore Samples

A small portion of each of the Shelby tube samples obtained using the Foundex rig was extruded to permit on-site logging and testing. The remaining portions of these samples were sealed inside the Shelby tubes, packed in heavy insulated wooden boxes and stored at 4°C prior to shipping to Inuvik. The insulated boxes were stored and shipped in a vertical orientation to minimize possible sample disturbance.

On-site testing of the offshore samples performed in conjunction with the stratigraphic logging included measurement of:

1. soil temperature, using a hand-held thermistor probe;
2. bulk density, using a KM tube sampler (Plate No. 3.7);
3. undrained shear strength, using a Pilcon vane (Plate No. 3.8) and pocket penetrometer; and
4. excess ice content of ice rich samples.

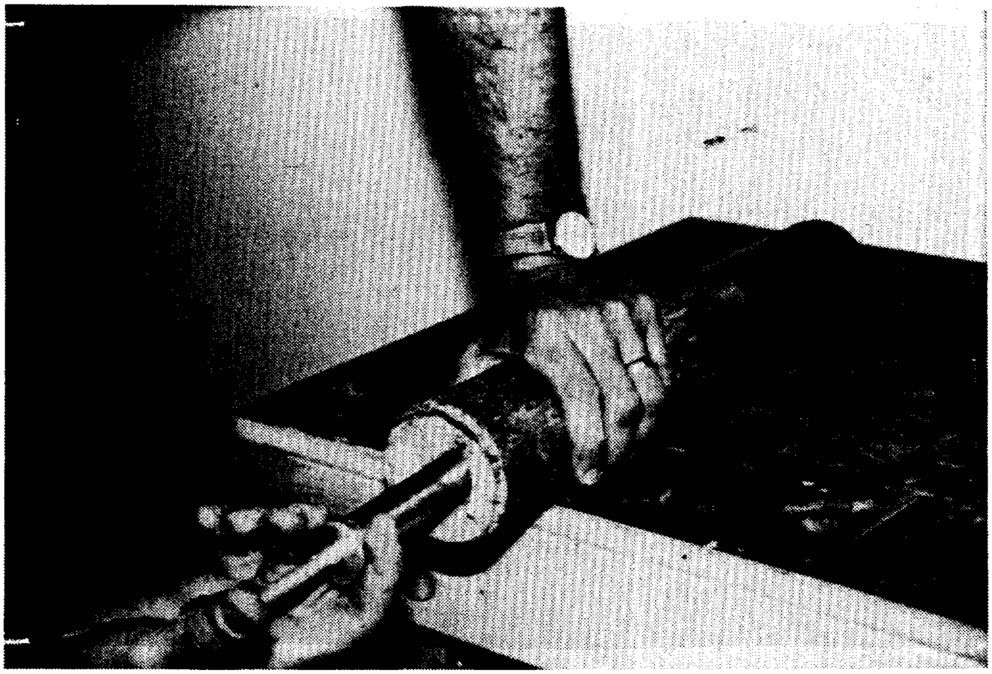


Plate No. 3.7   KM bulk density tube sampler

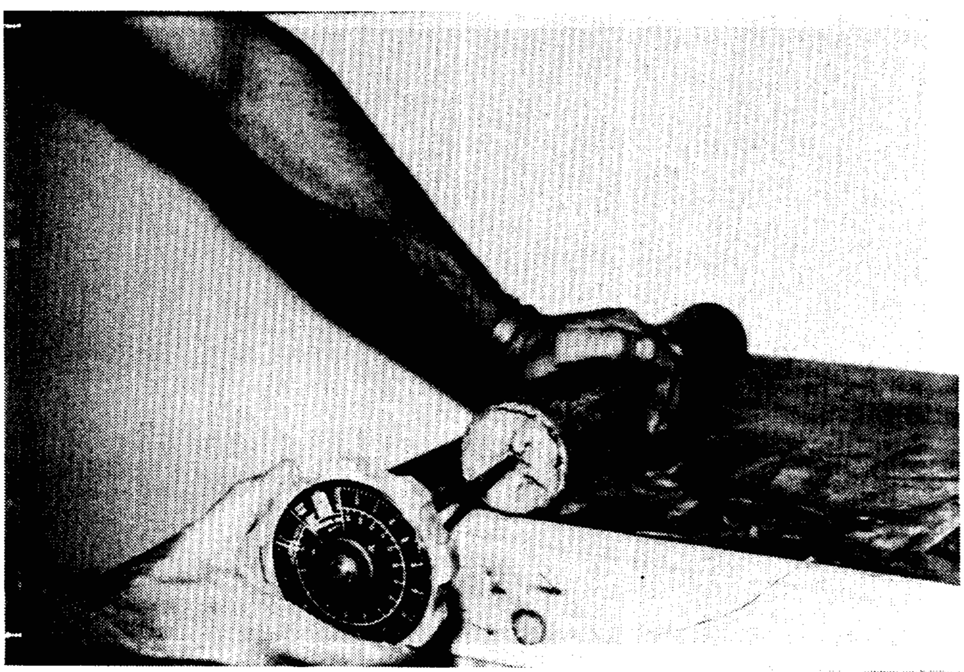


Plate No. 3.8   Pilcon vane testing

Soil samples were photographed after being completely extruded from the Shelby tubes, either on-site or in the laboratory (Plate No. 3.9).

3.5 In Situ Testing

In situ testing was carried out at several of the offshore and coastal borehole locations with a cone system which utilized acoustic transmission. This system consists of a 3 channel cone penetrometer outfitted with an acoustic transmitter which transfers cone data acoustically along the cone rods to a transducer mounted at the surface. The signal received at the surface is amplified and filtered by a surface control unit (signal conditioner). Data aquisition and recording were performed using a Hewlett Packard HP87 system interfaced with the signal conditioner. The equipment can simultaneously monitor cone point resistance and sleeve friction on the cone or porewater pressure behind the cone tip.

The cone penetration testing (CPT) was performed using the Foundex rotary rig. The cone penetrometer was pushed into the seabed by a 9 tonne hydraulic ram which could apply either downward or upward pressure to the drill head. A high viscosity/low friction drilling mud was pumped through the cone rod and ejected 1 m above the cone tip during the cone advancement to minimize skin friction between the cone rods and the seabed sediments, thereby increasing the maximum depth of penetration attainable.

The CPT data may be used to determine profiles of the geotechnical properties of marine sediments through the use of empirical correlations. Geotechnical properties such as undrained shear strength, soil sensitivity, overconsolidation ratio (OCR) and undrained Young's modulus (Eu) may be derived from the cone penetration test

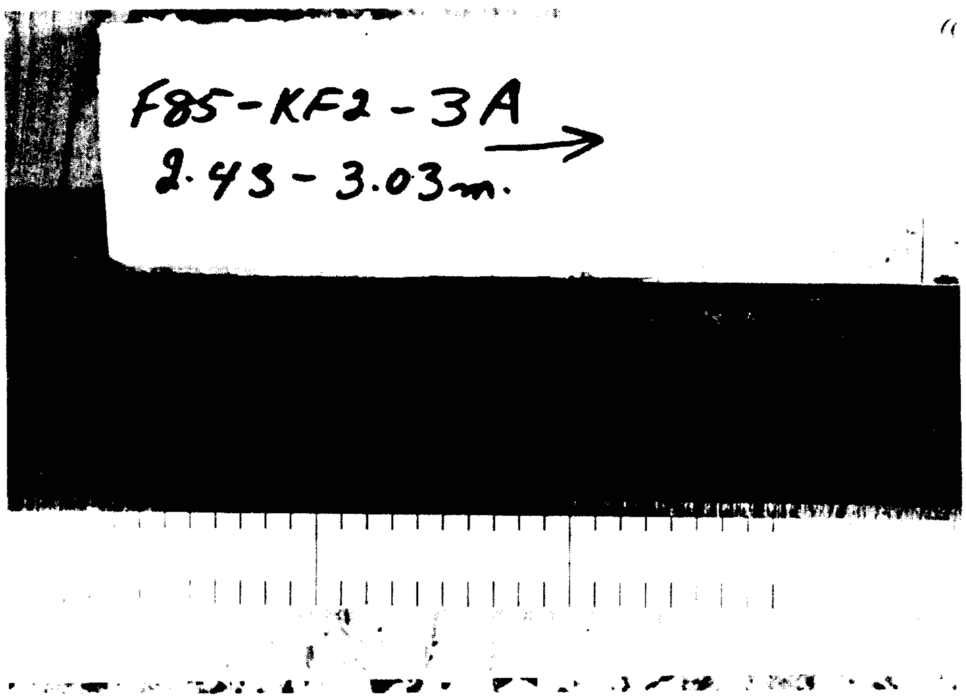


Plate No. 3.9   Extruded Shelby tube sample data (Robertson and Campanella, 1983). Pore pressure data obtained during a CPT probe may also be interpreted in conjunction with other stratigraphic information to provide an estimate of the general stress history of a soil deposit.

Results of the cone penetration testing are presented in Appendix C and are discussed in Section 6.0.

3.6 Field Instrumentation

Thermistor strings were installed in 5 of the boreholes, 2 located offshore (F85KM2 and F85KF8) and 3 onshore (F85KM13, F85KM18 and F85KM23). The thermistors were installed in the open (uncased) boreholes and backfilled with the soil cuttings. The thermistors were provided and installed by the Terrain Sciences Division of the Geological Survey of Canada. String depths and initial temperature readings are summarized in Appendix D. The temperature readings were recorded at the time of installation and again within 1 to 6 days after installation (Plate No. 3.10).

Plate No. 3.10 Ground temperature measurements with thermistors

4.0 LABORATORY TESTING PROGRAMME

4.1 General

Soil samples from all of the boreholes were retained for laboratory analyses. The laboratory testing was carried out both at the Inuvik Scientific Resource Centre and subsequently in Calgary.

All of the laboratory classifications, moisture contents and excess ice contents were determined at Inuvik immediately following the site investigation. The offshore Shelby tube samples were all extruded with the exception of those samples from borehole F85KF4, which were retained by the Geological Survey of Canada (GSC) for future dating, triaxial compression and consolidation testing. The extruded tube samples were split longitudinally and visual classifications were recorded. One half of each sample was sealed and labelled for archiving at the Atlantic Geoscience Centre in Halifax, Nova Scotia. Supplementary tests were performed on remaining portions of each of these samples to determine moisture contents, salinities, bulk densities and undrained shear strengths (using a laboratory miniature vane).

Index testing to determine Atterberg limits (plasticity) and grain size characteristics of both the onshore and offshore samples were performed in Calgary. The disturbed soil samples are currently in storage in Calgary and Inuvik.

4.2 Testing Methods

4.2.1 Moisture Content

Natural water contents of the soils were determined according to testing procedures outlined in the American Society for Testing and Materials (ASTM) standard designation D2216.

4.2.2 Atterberg Limits

The liquid limits of fine grained soils were determined in accordance with ASTM test method D423, using the 3 point method. Plastic limits were determined for these same samples in accordance with ASTM test method D424. The Atterberg limits are plotted on the borehole logs in Appendix A and are summarized in Appendix B.

Other index parameters which are useful for soil classification (by the Unified Soil Classification System) and which may be derived from the Atterberg limits, natural moisture content and particle size data are:

1. Plasticity index;
2. Liquidity index; and
3. Activity.

Values of these index parameters are also summarized in Appendix B.

4.2.3 Particle Size Analyses

Soil particle size distributions were determined in accordance with the following test procedures:

1. ASTM D421 sieve analysis of coarse grained soils; and
2. ASTM D422 hydrometer analysis of soils with a significant percentage of particles less than 75 µm in diameter.

The coarse grained samples for sieve analyses were prepared in accordance with the procedures outlined in ASTM D2217. Hydrometer samples were pretreated with hydrogen peroxide to remove organic matter. The results of the grain size analyses are included in Appendix B.

4.2.4 Bulk Density and Dry Density

Bulk density was determined by measuring the mass of a known volume of relatively undisturbed cohesive soil. Dry density may be calculated if the natural moisture content of the material is measured. Densities are presented on the borehole logs in Appendix A and are also summarized in Appendix B.

4.2.5 Porewater Salinity

Porewater salinities of the samples from borehole F85KF4 were measured by GSC personnel. Porewater was extruded from thawed or unfrozen soil samples in a soil press and the porewater salinities were determined using a Goldberg refractometer.

4.2.6 Laboratory Miniature Vane

Miniature vane tests were conducted at the Inuvik Research Laboratory by GSC personnel to determine the undrained shear strengths of undisturbed samples. The unfrozen soil samples were either retained in the sampling tube or extruded into a split tube. The vane was inserted into the soil sample, then rotated at 50 degrees/minute. Rotation was continued until steady post-peak shearing resistance had been reached. A stress-strain curve and the post-peak shearing resistance may be generated from these test results in addition to the peak values of undrained shear strength reported here.

5.0 TERRAIN CONDITIONS OF THE KING POINT AREA

5.1 Terrain Analysis and Mapping

Evaluation of the terrain conditions in the vicinity of King Point involved:

1. Review of reports and information on the Quaternary, Tertiary and Cretaceous geology of the area. Reference is made to pertinent documents elsewhere in this report.

2. Compilation and synthesis of the stratigraphic information from boreholes drilled during the present investigation and previous investigations in the area. Information from previous studies included seismic shot hole logs from oil and gas exploration programmes conducted during the late 1960's, field observations along the coastal bluff and inland slope exposures, borrow investigation reports by Northern Engineering Services Company Limited (1976) and Klohn Leonoff Consultants Ltd. (1975) and gas pipeline route alignment and terrain data reported by Northern Engineering Services Company Limited (1975).

3. Production of an uncontrolled airphoto mosaic for the area at a scale of 1:25000 (Drawing No. H-2, Appendix H).

4. Development of a map delineating surficial terrain units in the area (Drawing No. H-2, Appendix H).

5. Definition and description of the geomorphology, drainage processes, stratigraphy, ground ice contents, and engineering properties of the various terrain units.

Stratigraphic information from the boreholes is presented on the borehole logs in Appendix A. Drawing No. H-2, Appendix H is an airphoto mosaic and overlay map of the area showing the terrain units.

The terrain units shown on Drawing No. H-2 are defined genetically in Table H-1 and are described in Table H-2, Appendix H. The terrain map was originally developed on the basis of airphoto interpretation augmented by existing data from other studies in the area. The distributions of the terrain units shown on the map were initially delineated on the airphoto mosaic and subsequently modified on the basis of ground observations and borehole information. In preparing Table H-2, the geomorphology, drainage and natural processes were interpreted using aerial photographs and ground-truthing observations near King Point. Interpretations were also based on field observations recorded in both published and unpublished sources. Descriptions of the stratigraphy, materials, permafrost and ground ice in Table H-2 are based primarily on the borehole data obtained during the present investigation and observations of the coastal exposures. Comments on the engineering properties are based on experience gained on geotechnical investigations, pipeline routing studies and aggregate searches in the Canadian Arctic and along the Yukon coast.

A summary of the terrain units in the study area is presented in Table 5.1. The surficial terrain units which cover significant portions of the map area include: organic blanket and veneer (O_B/O_V, approximately 25% of the map area); morainal deposits (M_M, 20%); alluvial terraces (A_T, 20%); lacustrine deposits (L_p, 12%), and colluvium (C_X/C_B, $\c{C}/C_V$, 15%). Although the glaciofluvial and perimarine deposits are also widespread they are only exposed at the surface at isolated locations. Surface waters including lakes, creeks and the King Point lagoon occupy approximately 8% of the total land-based map area.

5.2 Geomorphology and Drainage

Colluvium veneered (C_V) and blanketed (C_B) bedrock ridges, ice-thrust ridges composed of perimarine sediments (P_R) and rolling morainic (M_M) deposits are all elevated above the surrounding terrain and are commonly well drained. The bedrock ridge (R) south of Deep Creek stands well above the rest of the area. The rolling surfaces of the morainal deposits have occasional poorly drained depressions and swales within them.

Lacustrine plains (L_p) and alluvial terraces (A_T) and floodplains (A_p) are flat and commonly poorly drained, the exception being some higher, terraced lacustrine benches, which are moderately well drained. Organic deposits (O_B, O_V) have accumulated on the poorly drained portions of most lacustrine plains. Standing water on poorly drained

TABLE 5.1

SUMMARY OF TERRAIN UNITS

Map Unit Symbol	Genetic Origin	Typical Range of Thicknesses in Boreholes (m)	Approximate Areal Extent (% of Map Area)
A_A	Alluvial Apron		0.1 %
A_B	Thin Alluvial (fan)		0.1 %
A_F	Alluvial Fan	0.1 - 6.5	1 %
A_P	Active Alluvial Floodplain		1 %
A_T	Alluvial Terrace	0.1 - 9.5	20 %
Ç	Landslides		1 %
C_B	Colluvial Blanket	1.0 - 6.3	5 %
C_V	Colluvial Veneer	0 - 1.5	1 %
C_X	Colluvial Complex Formed on Steep Slopes	0.2 - 3.0	8 %
G_A	Glacial Fluvial Apron	1.8 M - 14.0+	1 %
G_H	Glacial Fluvial Deposit Hummocky		0.1 %
G_M	Glacial Fluvial Deposit Rolling		0.1 %
G_R	Glacial Fluvial Deposit Ridged		0.1 %
G_T	Glacial Fluvial Terrace	0.7 - 8.7	2 %
L_B	Lacustrine Blanket		0.1 %
L_P	Lacustrine Plain	0.5 - 10.0	5 %
M_M	Morainal Deposits: Rolling	0.3 - 11.2	20 %
O_B	Organic Blanket		19 %
O_V	Organic Veneer		6 %
P_M	Perimarine Deposits: Rolling		1 %
P_R	Perimarine Deposits: Ridges Underlain by Steeply Dipping Gravels		0.2 %
R	Rock: Mainly Sandstone		0.1 %
W_R	Marine Deposit: Beach Ridges	0 - 6.5	0.1 %
	Surface Waters (Lakes and Creeks)		8 %

areas is common as tundra ponds and in the centre of low-centred polygons or, less commonly, in the trenches of high-centred polygons. Table 5.1

All landforms near eroded scarps, whether lacustrine, alluvial or glaciofluvial, tend to be relatively free of organic materials and well drained. This is also true of the colluvium-covered slopes forming the scarps.

5.3 Materials and Stratigraphy

Most deposits in the King Point area are fine grained since the till has been largely derived from glacier ice incorporating fine grained perimarine (mainly marine) clay and silt into its base. The alluvium and colluvium are mainly derived from erosion of the till and also in the case of the alluvium, erosion of shaly bedrock. Colluvium and alluvium in low lying areas commonly contain organics due to the effects of periglacial processes on their formation.

Coarse sand and gravel are the primary components of the glaciofluvial deposits and the marine beaches and bars. Silty beds are common in each type of deposit. Sand and gravel also form large wedges within the perimarine sequence. One such gravel wedge, which has been highly contorted, is exposed on the seaward side of the ice-thrust ridge west of King Point. Other wedges of perimarine sand and gravel were noted in shot holes drilled by oil companies and in test holes drilled during this investigation.

Coarse rubbly colluvium covers the sandstone ridge at the south edge of the area.

The common stratigraphic sequences underlying the various landforms within the area are as follows:

1. Under lacustrine plains (L_P)

    0 - 4 m of peat
    2 - 8 m of lacustrine silts
    1 - 10 m of till
    > 20 m of perimarine sediments; generally clay or silt, less commonly gravel and sand;

    See, for example, the borehole logs for F85KM19, KM20, KM21 and KM22 in Appendix A.

2. Under rolling morainal deposits (M_M)

    0.3 - 8 m of a complex of peat, pond silts, alluvium or colluvium
    2 - 10 m of till
    5 - 10+m of massive ice
    > 20 m of perimarine sediments; generally comprised of silt and clay.

    See, for example, the borehole logs for F85KM26 and KM30 in Appendix A.

3. Under glaciofluvial aprons (G_A)

0 - 8 m of organic silt and peat

5 - 20 m of gravel and sand

5 - 10+m of massive ice

0 - 5 m of till

> 10 m of perimarine sediments (generally comprised on silt and clay).

See the borehole logs for F85KM27, KM28 and KM31.

Areas of highly contorted perimarine sediments may have only a thin cover of till or silty colluvium.

5.4 Ground Ice

The expected distribution of ground ice and the ice contents for the various terrain units are given in Table H-1, Appendix H. Ice contents are generally high in the surficial complex of organic peat, alluvial and colluvial materials which comprise the upper 2 m to 3 m of sediment. Ground ice contents of the underlying materials are usually closely related to the particle size characteristics of the generic materials and the availability of groundwater during freezing. Following is a summary of the general distributions of ground ice in the various terrain units and discussions of their significance.

Ice contents are generally low to moderate within the glaciofluvial sediments. Less than 30% interstitial ice in sands and gravels is generally representative of ice filling the pore spaces, whereas thawed water contents greater than about 30% indicate that the material contains excess ice since the natural porosity of surficial sand deposits is typically about 30%. Glaciofluvial deposits, particularly the glaciofluvial aprons, contain considerable thicknesses of massive ice (up to 13 m) at the base of the glaciofluvial sediments (see boreholes F85KM27, 28, 31, 32). It is believed that the large lakes within the glaciofluvial aprons are a result of natural thermokarst development resulting from the thawing of massive ice at the bases of these deposits. Many of the lakes do not freeze to the bottom in winter and hence taliks occur beneath them.

Morainal deposits contain much excess ice (see boreholes F85KM23, 26, 30, 33). The ice occurs mainly as ice lenses and beds. Massive ice beds are common under most uplands underlain by morainal deposits; the 8 m thick bed of massive ice intersected in borehole F84KM23 is typical. This subsurface massive ice has led to the development of many retrogressive-thaw flow-slides and thermokarst depressions in this unit. In many cases the presence of massive ice, or icy sediments, can be predicted on the airphotos by identifying landslides (retrogressive-thaw flow-slides) and thermokarst features.

Alluvial deposits have variable ice contents, but high ice contents are common, especially in the upper 2 m to 3 m (see boreholes F85KM24, 25 and 33).

Lacustrine deposits commonly contain moderate to very high ice contents (F85KM19, 20, 21, 22) and are susceptible to thermal disturbance. This is apparent along old seismic lines, which show the greatest subsidence where they cross the lacustrine units. Because the lacustrine deposits are relatively thin and the underlying units are generally ice-poor, there is little chance for massive subsidence and thermokarst development. Elevated lacustrine bench deposits such as those exposed in the retrogressive-thaw flow-slide 3.5 km southeast of King Point, are often underlain by massive ice, and are therefore an exception to the above observations.

Ice contents in the colluvial materials are typically high (see BH's F85KM18, 23, 25, 27, 28, 31, 32) due to the aggradation of permafrost as the colluvium accumulates.

Organic deposits have high to very high ice contents (see BH's F85KM21, 26, 29). Over most of the study area, the surficial organic deposits are relatively thin but provide important thermal insulation for the underlying frozen materials.

The perimarine deposits (see BH's F85KM19, 25, 26) and the bedrock noted in borehole B1024, drilled by Canadian Arctic Gas Pipelines Ltd. in 1975 (Northern Engineering Services Company Limited, 1976), and borehole N75-117A-B1-1, drilled by R. M. Hardy & Associates Ltd. in 1976 (R.M. Hardy & Associates Ltd. and Terrain Analysis and Mapping Services Ltd., 1977), typically have very low ground ice contents. Accordingly, there is limited potential for significant thaw subsidence of these units.

In summary, the upper 2 m to 3 m of sediments in most of the terrain units are ice rich, in part because of the ubiquitous occurrence of ice wedges (Harry et al, 1985) and due to the occurrence of surficial organic peat. Below this depth ice contents are generally low although isolated ice lenses may occur. An increasing frequency of ice lenses with depth is common in many glaciofluvial deposits. Massive ice is generally located under glaciofluvial deposits, most morainic highlands, and some lacustrine benches which are raised above the surrounding terrain.

Taliks may exist under some lacustrine and alluvial landforms, but taliks which completely penetrate the permafrost probably occur only under very large lakes and the Babbage River. No recently abandoned lake basins or streams are apparent in the area. The base of the permafrost probably rises under most large lacustrine plains and under the relatively large channel now occupied by Deep Creek.

5.5 Natural Processes

Thermokarst features are prominent in the King Point area and are associated primarily with the glaciofluvial and morainal landforms. Thermokarst development involves thawing of ice-rich material and subsidence of the overlying deposits to form a depression. The depression may then continue to expand due to lateral thawing through its banks and possibly due to the development of retrogressive-thaw flow-slides. Colluvial materials are deposited on the floor of the depressions as a result of this process. The banks eventually stabilize when covered by sufficient colluvial material to insulate the underlying ice-rich materials from further thawing. If drained, the floor of the basin eventually refreezes (producing some heave), ice wedges form and organic cover begins to accumulate. Many ponds and closed, or partially closed, depressions in morainal units were formed by this process; the depressions are typically 0.25-0.5 km diameter and the floors are 20 m below the surrounding hill top. Much larger lacustrine plains have formed by the coalescence of smaller depressions. Within the lacustrine plains are monadnodes, which are the remnants of the original morainal surface still underlain by massive ice.

Retrogressive-thaw flow-slides are common on scarps and slopes underlain by icy sediments or massive ice. These slides are caused by melting of the ice-rich sediments underlying the slopes resulting in the downslope movement of the melting materials. These materials form a viscous mixture that flows downslope on a low gradient until it is dewatered to the point where it becomes relatively stable. Scarps are common features of many of the flow slides which are presently active in ice-rich morainal materials. Some flow-slides are also occurring along the edge of the glaciofluvial apron west of King Point where massive ice has been exposed. Landslides are common along the coast where they are activated in part by coastal erosion.

Other mass wasting processes, such as soil creep and, to a lesser extent, solifluction, are active on some surfaces. Active gullying on steep scarps is occurring mostly along the coast northwest of King Point. Material eroded from these gullies is eventually removed from the scarp bases by wave action.

Alluvial erosion and deposition is presently active along both the Babbage River and Deep Creek, as well as their tributaries. Erosion on meanders has produced many small scarps along the river courses. Deposition, mainly of silt and fine sand, occurs on low lying areas adjacent to the streams.

Wind erosion of mineral soils in the study area is not active, but wind erosion of organic deposits may be active on sparsely vegetated slopes, particularly during the winter months.

Wave erosion and long-shore transportation of beach materials are active along the coast. Wave erosion is responsible for the formation of the steep coastal scarp and reactivation of landslides. Comparison of aerial photographs over a period of 20 years and the observations and photographs recorded over the years in personal field notes (particularly those of MacKay, 1959, 1963) indicate that erosion has caused significant alteration of the coastline configuration. MacKay (1963) estimates coastal erosion of several metres per year inland at King Point. McDonald and Lewis (1973) showed that coastal retreat was most rapid in areas where fine grained deposits formed the coastal cliffs, especially if they contained high ice contents or if massive ice was present. However, long-shore transport of coarse grained materials has extended the spit to form a barrier bar across the lagoon at King Point indicating that coarse grained sand and gravel are also being eroded. Aerial photography between 54/08/22 and 70/08/18 documents the closure of the lagoon by extension of the spit by 450 m (28 m/a) and areal enlargement of the spit by approximately 58 000 m^2 (3600 m^2/a).

6.0 SUBSURFACE CONDITIONS

6.1 Test Hole Locations

A total of 43 test holes, including both borings and cone penetration probes, were completed during the course of the study. The locations of all the test holes are shown on Drawing No. H-3, Appendix H. Stratigraphic information and geotechnical data obtained during the investigation are summarized on the borehole logs in Appendix A. Logs for the offshore boreholes are included in Appendix A-1, the coastal borehole logs are included in Appendix A-2 and logs for the onshore boreholes are presented in Appendix A-3. Laboratory testing data are presented in Appendix B and results of the cone penetration tests are presented in Appendix C.

6.2 Ground Temperatures

6.2.1 Offshore

Ground temperatures were measured using thermistor cables installed in 2 of the offshore boreholes (F85KM2 and F85KF8). The thermistor data are recorded in Appendix D and on the borehole logs in Appendix A-1. These thermistor cables which were installed through the ice in the open boreholes were later destroyed by shifting ice. The minimum temperatures of the frozen offshore sediments measured with the thermistors ranged from -1.5°C to -1.7°C. However, since these temperatures were measured only 1 to 2 days after installation of the thermistors, they are not considered to be representative of the in situ equilibrium temperatures. Lower temperatures ranging from -2°C to -3°C were, in fact, measured in some of the undisturbed tube samples from the offshore boreholes using hand-held digital thermometers. These sample temperatures are also recorded on the borehole logs in Appendix A-1 and on the summary sheets in Appendix B. Although the offshore thermistor installations were destroyed by moving ice, the data were useful in the present study for confirming the presence of subsea permafrost in the coarser sediments.

6.2.2 Onshore

Thermistor cables were installed in open boreholes at 3 onshore locations (F85KM13, 18 and 23). Ground temperatures measured 2 to 6 days after drilling and installation are recorded in Appendix D and on the logs in Appendix A-3. The minimum temperatures recorded in the onshore sediments ranged from -10°C to -13°C. The temperatures of core samples from the onshore boreholes measured using hand-held digital thermometers were warmer than those recorded with the thermistors. These sample temperature data which are recorded on the summary sheets in Appendix B are not considered to be representative of in situ temperatures because of thermal disturbance during drilling and core sample extrusion.

Based on the limited amount of good quality data it is evident that the onshore ground temperatures at King Point are considerably colder than those of the subsea permafrost in the offshore. Additional data are required to characterize more definitively the ground thermal regimes in both the onshore and coastal areas.

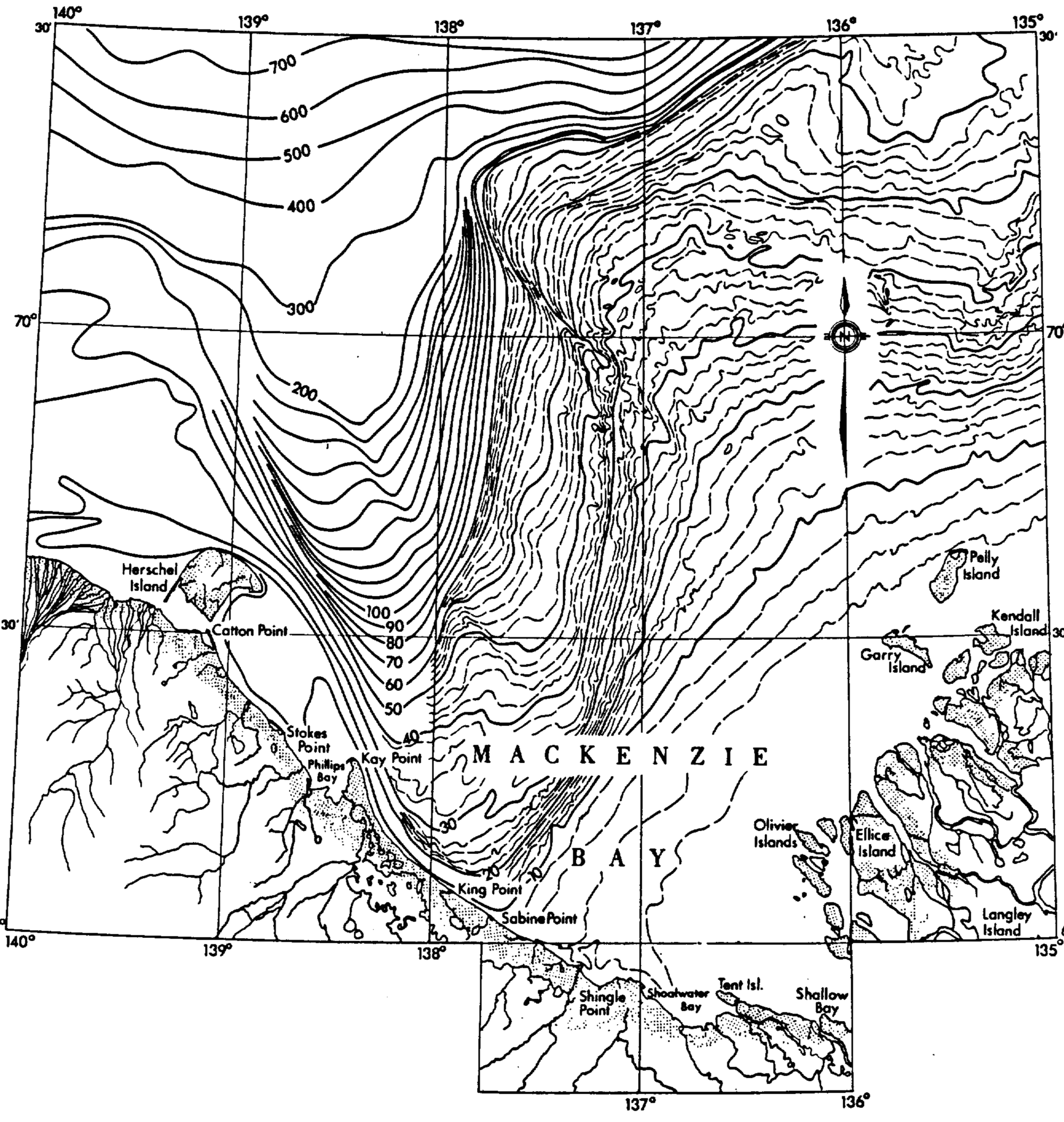
6.3 Offshore Sediments

6.3.1 Surficial Geology and Stratigraphy

As Drawing No. 6.1 demonstrates, King Point is located near the western margin of the major physiographic province known as the Mackenzie Trough. Immediately offshore, from the coastline to about 3 km offshore, the seabed slopes northeastward at an average gradient of approximately 0.5% to 0.6%, but thereafter the principal gradient turns northward and becomes more gentle for some distance.

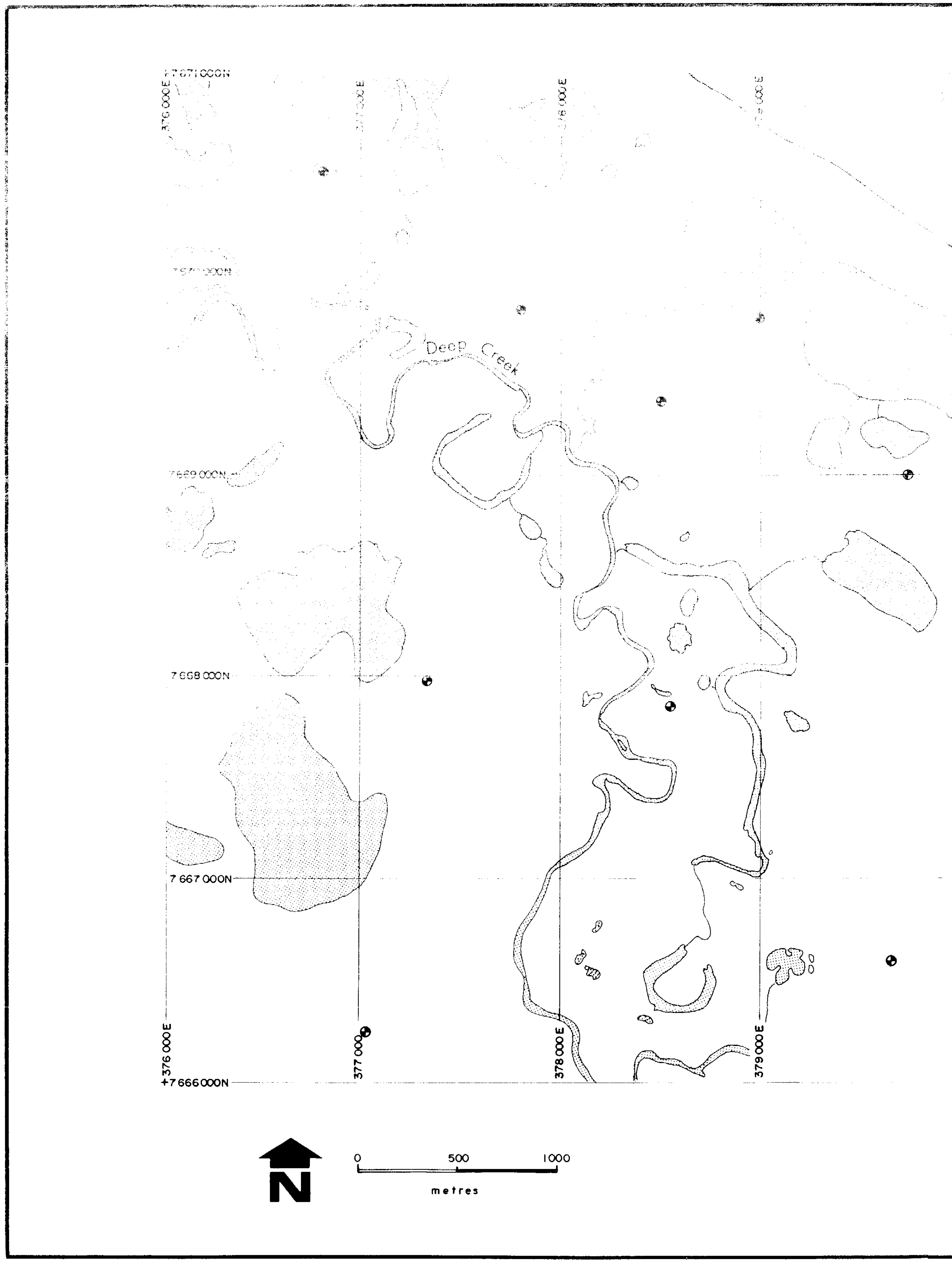
According to the cone penetration test data and geotechnical borehole information from the offshore, the surficial marine geology is comprised of 2 principal stratigraphic units: a recent marine sequence of silty clays and an older, much stiffer sequence equivalent to the deposits of the Yukon coastal plain which was eroded during the most recent marine transgression. The former represents Unit A in the general geologic model of the Beaufort Sea Continental Shelf proposed by O'Connor (1980), while the latter is similar to (though not necessarily the same age as) the pre-transgression Unit C sediments in the other physiographic provinces to the east. This area experienced erosion during marine transgression. The surface between the 2 units is a major unconformity recognized along much of the coast west of the Mackenzie Trough. A map of the surficial geology of the offshore and coastal areas which was developed from the test hole information obtained during this study is presented on Drawing No. 6.2.

The recent marine sequence is most clearly seen at locations F85KF4, KF5, KF6 and KF7 shown in cross-section Drawing No. 6.3. CPT testing provided excellent definition of the



Contour Elevations in metres

Bathymetry (m)	M.J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-300	**DATE:** 85/08/06
	DRAWN BY: MG	**DWG. No.:** 6.1



Deep Creek
7 669 000N
7 668 000N
7 667 000N
7 666 000N
376 000 E
377 000
378 000 E
379 000 E
0
500
1000
metres
N

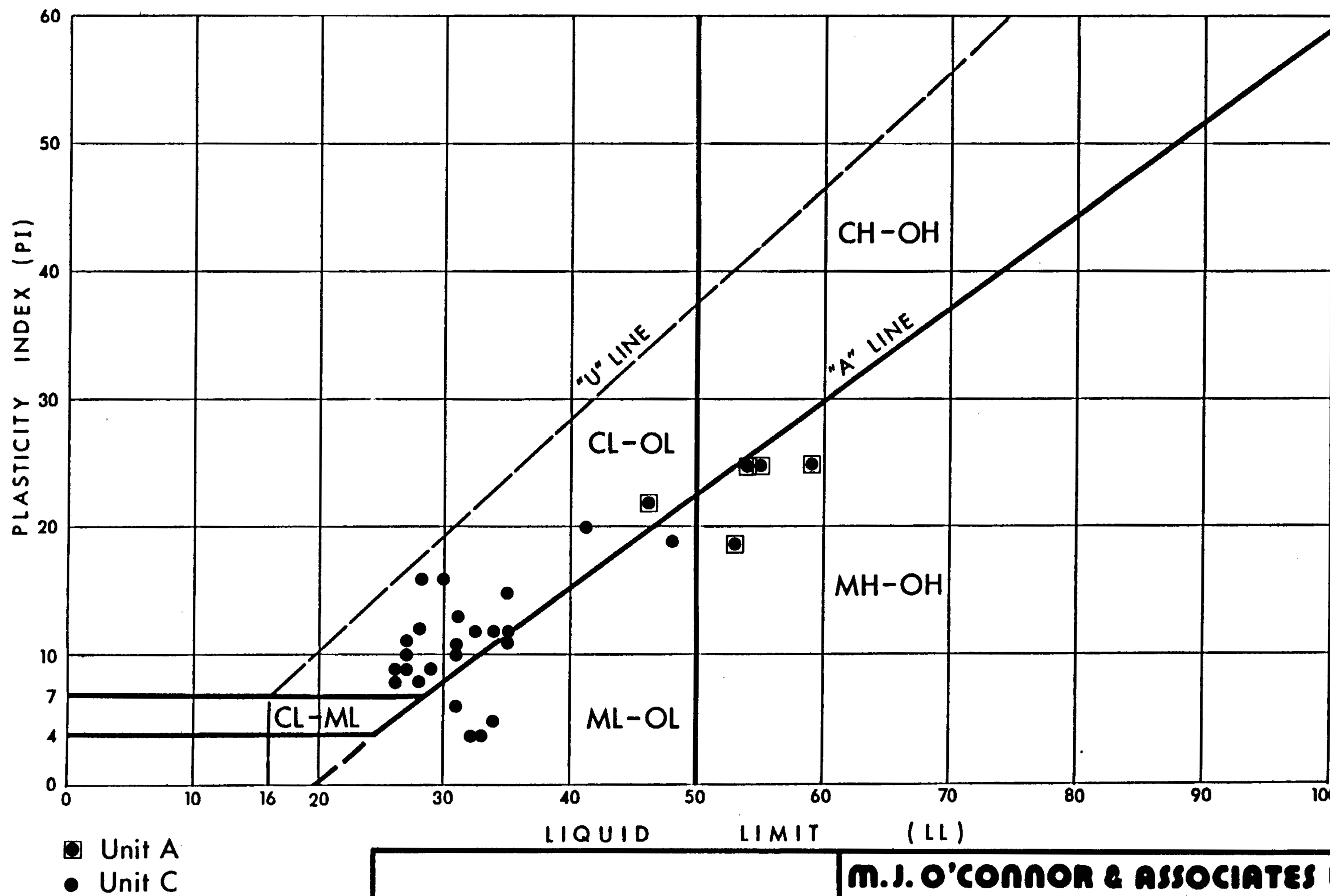
[redacted]

stratigraphic changes within the recent surficial marine sediments, but the cone could not penetrate the underlying older coastal sediments. In boreholes F85KF1, KF2, KM2 and KF3, located within 1.7 km of the shoreline, these older coastal sediments outcrop directly at the seabed. The edge of this outcrop occurs close to, but seaward of borehole F85KF3, near the 17 m isobath. This is about the same edge of outcrop depth previously observed near Herschel Basin (M.J. O'Connor & Associates Ltd., 1984).

As noted above, the recent marine sequence near King Point consists entirely of soft clays with a trace to some silt. According to laboratory test data shown on the log for borehole F85KF7, this clay appears to be high plastic with some organic layers. The underlying older sequence is comprised mainly of low plastic silty clays and clayey silts, but sand and gravel layers are also common, both near the surface (see BH's F85KM1, KF2, KF8) and also at depth (see BH's F85KM1, KF8).

6.3.2 Geotechnical Properties

A range of geotechnical properties of the marine sediments were measured in order to classify the materials and to provide a basis for preliminary design and assessment of the feasibility of proposed developments in the offshore and coastal areas. All of the laboratory data for the offshore boreholes are presented in Appendix C. Plasticity data for the offshore sediments have been summarized in Drawing No. 6.4. The fine grained recent (Unit A) sediments generally classify as high plastic silts and organic silts, while the older (Unit C) sediments are generally low plastic clays and silts.



Atterberg Limits - Offshore

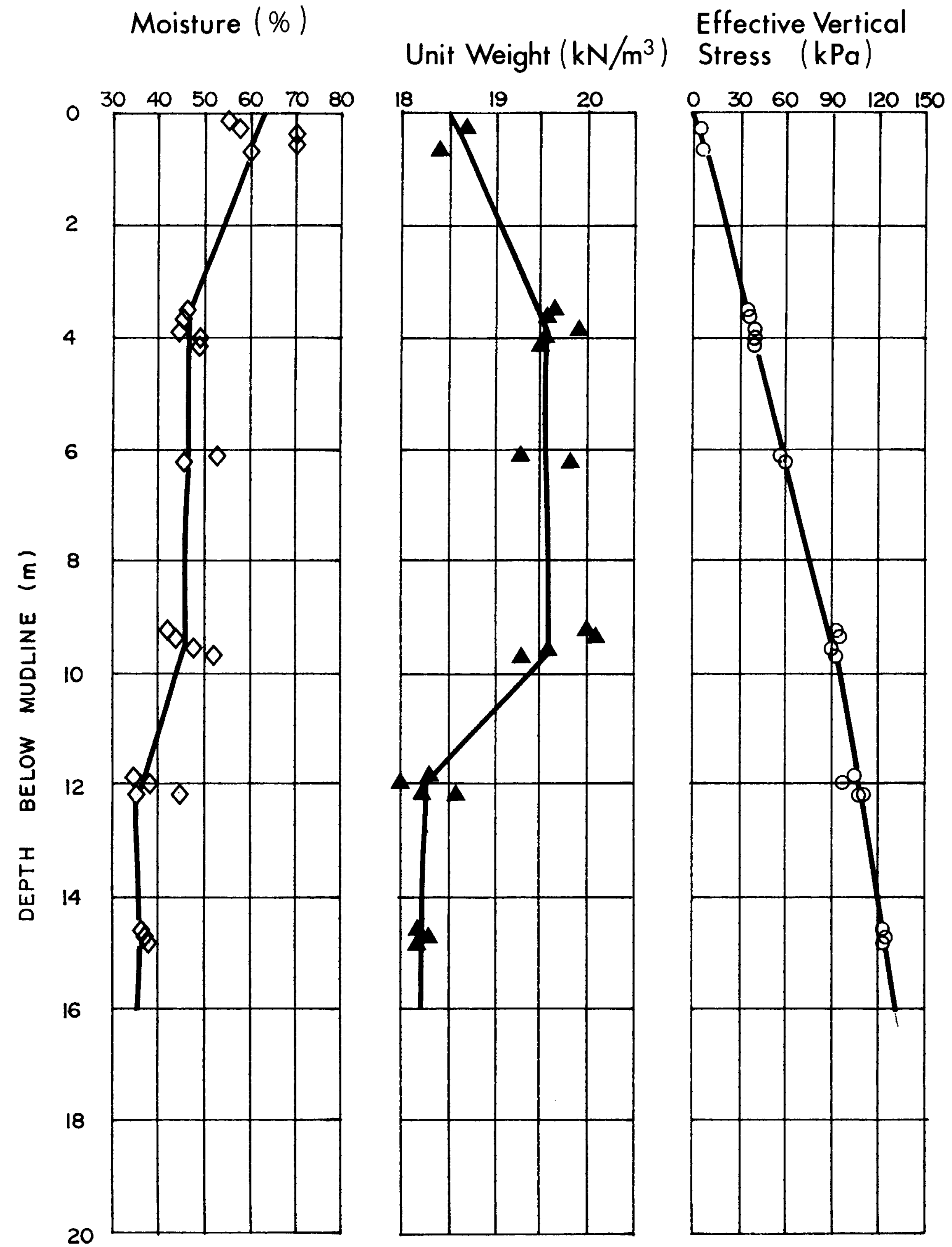
M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.: 10-300	DATE: 85/08/06
DRAWN BY: MG	DWG. No.: 6.4

The measured moisture contents of the fine grained offshore sediments were typically between about 15% and 25%, however, moisture contents ranging from 30% to 60% were also measured in ice-rich sediments and soils containing organic peat. Although Atterberg limits were not determined for the ice-rich and organic soils, some of these materials appear to have moisture contents which may exceed the liquid limit. The natural moisture contents of those offshore samples which were analyzed were lower than the liquid limit and, in some cases, were below the plastic limit.

The measured bulk unit weights of the recent soft sediments and organic materials ranged from 16 to 20 kN/m^3, whereas those of the stiffer, pre-unconformity materials were generally between about 20 and 21.5 kN/m^3.

Undrained shear strengths of the offshore sediments were measured using 3 different methods: acoustic cone penetration testing, the Pilcon vane and the miniature laboratory vane. The vane strength data from borehole F85KF7 and the CPT data from test hole F85KF4 (adjacent to F85KF7) are plotted with depth on Drawing No. 6.5. Profiles of other properties including moisture content, bulk unit weight and salinity for the recent marine sediments from borehole F85KF7 are also plotted on Drawing No. 6.5. There is some variability in the moisture and unit weight data with depth, however salinity and undrained strength generally increase with depth in these recent sediments. The data on the drawing indicate that the vane strengths compare reasonably well with the CPT strength profile calculated using a cone factor (N_k) of 11. However, vane strengths of undisturbed samples taken over the depth interval 11.9 to 12.3 m, in particular, varied widely from 5 kPa to 95 kPa. This wide variation in strength is believed to reflect the laminated structure over this depth interval.



NOTE: No CPT data obtained from 2.8m to 4.4m depth because cone penetrated sediments under the weight of the rods alone.

The sensitivity[1] (S_t) of the recent offshore sediments was estimated based on CPT friction ratios (FR). Using the empirical correlation presented by Robertson and Campanella (1983)[2], S_t values were found to range from about 1 to 8 and had a mean value of about 4. According to the classification system shown in Table 6.1, the recent fine grained sediments are slightly sensitive to very sensitive, indicating that only moderate reductions in undrained shear strength may result due to disturbance and remoulding of the sediments.

Ratios of undrained strength (based on vane tests) to effective vertical stress are plotted against plasticity index for the offshore sediments in Drawing No. 6.6. The Cu/σ_v' ratios derived from the CPT data at F85KF4 are also plotted on Drawing No. 6.6 against plasticity indices (I_p) for samples obtained from the adjacent borehole F85KF7. An empirical correlation between Cu/σ_v' and I_p for normally consolidated soils presented by Skempton (1957) is plotted on the same drawing for comparison.

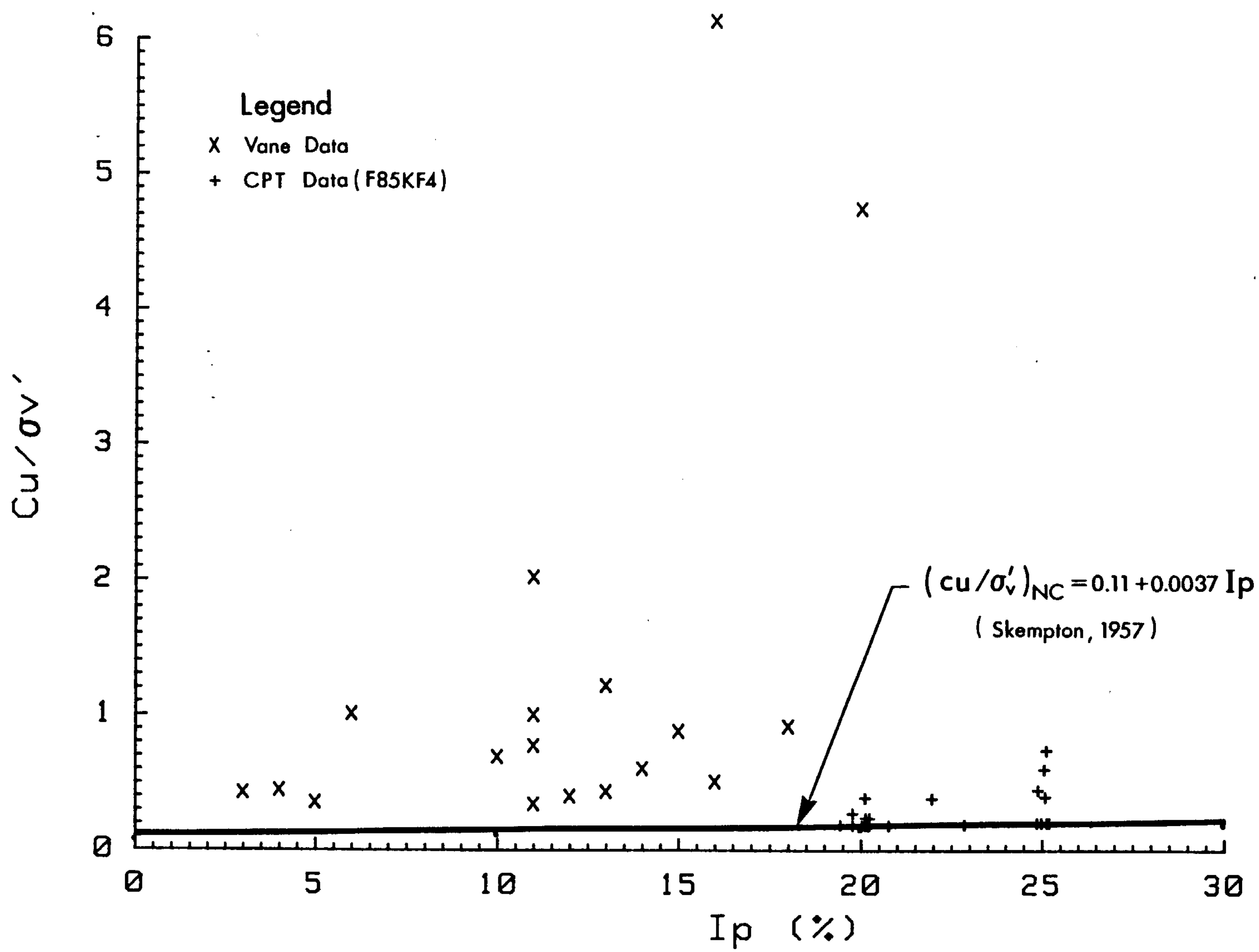
It is readily apparent that the CPT data from the recent sediments (Unit A) all fall close to or slightly above Skempton's empirical relationship, confirming that the recent sediments are normally or just very slightly overconsolidated. The vane data, on the other hand, exhibit considerably more scatter and significantly higher values. It is presently uncertain whether these higher values are the result of using a different method (the vane) for determining the undrained shear strengths, or whether such values actually arise because the older sediments tested at some locations using the vane are more highly overconsolidated than the recent sediments. In any case, both sets of data fall within the range noted previously by other investigations in the Beaufort Sea.

1. Sensitivity is defined as the ratio of undisturbed to remoulded strength.
2. $S_t = 10/FR\%$

TABLE NO. 6.1

CLASSIFICATION OF SENSITIVITY VALUES
(From Rosenqvist, 1953)

	S_t
Insensitive	about 1.0
Slightly sensitive clays	1 - 2
Medium sensitive clays	2 - 4
Very sensitive clays	4 - 8
Slightly quick clays	8 - 16
Medium quick clays	16 - 32
Very quick clays	32 - 64
Extra quick clays	> 64



Ratio of Undrained Strength to Effective Vertical Stress vs. Plasticity Index for the Offshore Sediments	**M. J. O'CONNOR & ASSOCIATES LTD.**	
	JOB No.: 10-300	**DATE:** 85/08/06
	DRAWN BY: MG	**DWG. No.:** 6.6

Overconsolidation ratios* (OCR) were estimated based on the CPT data from test hole F85KF4 and the plasticity data from borehole F85KF7 using the empirical correlations outlined by Schmertmann (1978). Estimated OCR values are plotted with depth on Drawing No. 6.5 and are summarized in Table C-1, Appendix C. The estimated OCR values for these recent sediments range from 1 to 5, with a mean of about 2. The sediments exhibit slightly more apparent overconsolidation within the depth interval 0 to 11 m below seabed than in the interval from 11 to 17 m. Stiff to hard sediments encountered at 17.5 m may either be ice-bonded or heavily overconsolidated.

6.4 Coastal Sediments

6.4.1 Surficial Geology and Stratigraphy

Fifteen (15) coastal boreholes were drilled and 1 CPT was conducted to investigate subsurface conditions along the barrier bar and under the coastal lagoon at King Point. Stratigraphic cross sections through the barrier bar and lagoon are presented in Drawings No. 6.7 to 6.10, inclusive.

Boreholes drilled along the crest and flanks of the barrier bar indicate that the bar is comprised of gravel and sand overlying fine grained materials (including silt, clay and peat). The sediments comprising the barrier bar and beaches represent Unit B in the general geologic model of the Beaufort Sea Continental Shelf proposed by O'Connor (1980).

* Overconsolidation ratio is defined as the ratio of maximum past effective vertical stress to the present effective vertical stress.

A north-south stratigraphic cross section through the lagoon boreholes is presented in Drawing No. 6.11. Although the origin of the sediments at the base of the lagoon are presently not well defined, it appears that the lagoon may have formed initially as two separate depressions which were eventually interconnected as the intermediate causeway of land was breached. Dating of the sublagoonal sediments may provide insight into the morphology of the lagoon. For example, it may be possible to establish whether or not the two depressions formed simultaneously and the approximate time since marine transgression of each of the depressions occurred. This information has a bearing on existing subsurface conditions and on estimated historical rates of sediment transport and deposition.

Very soft to soft clayey silts were encountered to a depth of 7 m below the mudline at the south end of the lagoon in test hole F85KF9 and borehole F85KF10. The thickness of soft silt in the nearby borehole F85KM5 was 4.1 m. However, only 1.5 m of soft clay was noted below the mudline in borehole F85KM3, located in the north sector of the lagoon, and no soft sediments were encountered in borehole F85KM4, located in the central area between the depressions.

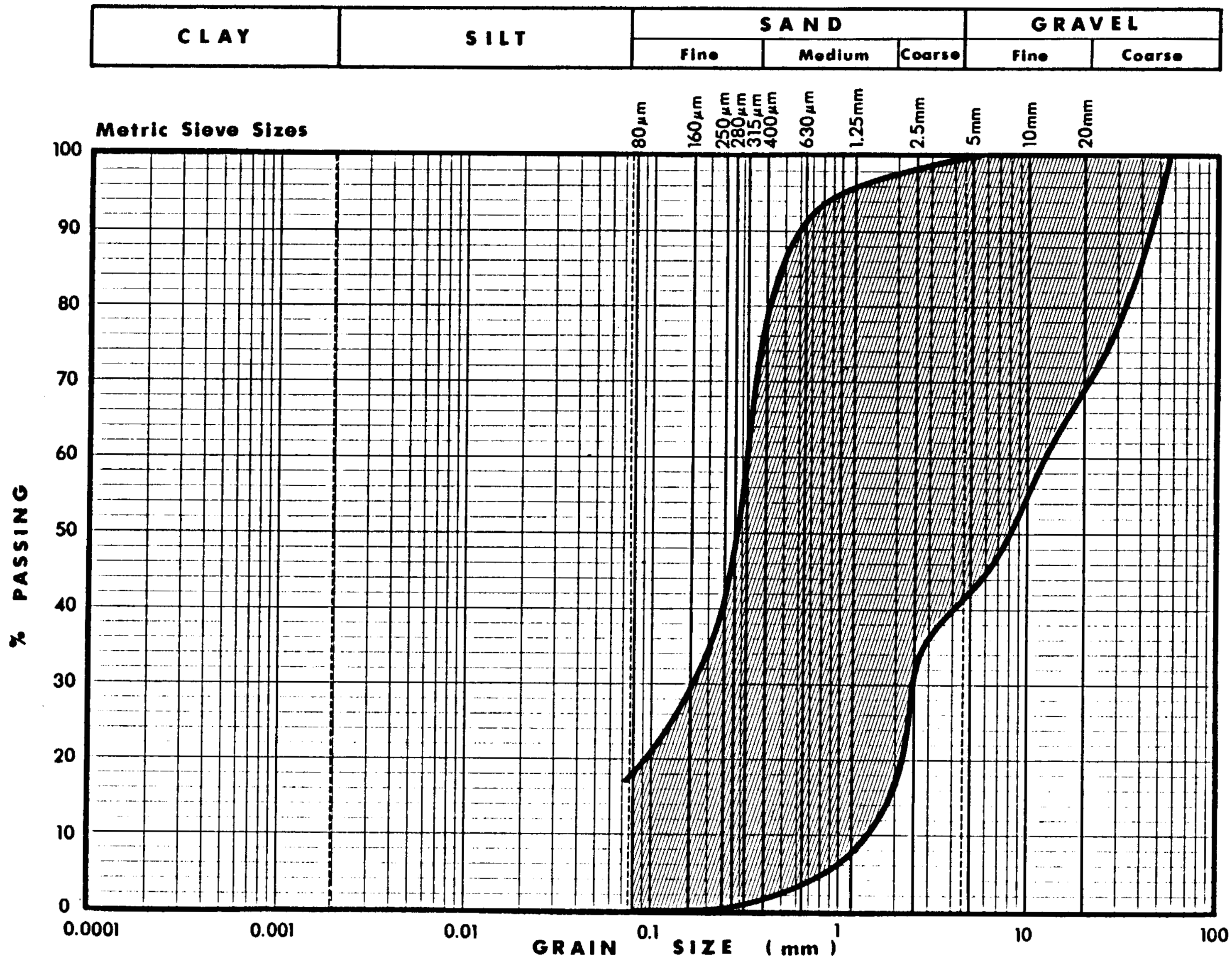
6.4.2 Geotechnical Properties

The grain size distributions presented in Appendix C indicate that gravel and sand materials comprising the barrier bar are generally poorly graded (well sorted). Fines content is generally greater in the sands than in the gravels and apparently increases with depth. The range of grain size distributions for gravel and sand samples from boreholes which penetrated the barrier bar is illustrated in the grain size envelope presented in Drawing No. 6.12. The estimated quantity of gravel and sand in the barrier bar is approximately 2 000 000 m^3 based on the cross-sections presented in Drawings No. 6.7 to 6.10, inclusive. Additional granular materials which have accumulated on the beach to the southeast of the barrier bar are not included in the above estimated quantity.

Plasticity data for fine grained sediments encountered in the coastal boreholes are presented in Drawing No. 6.13. The fine grained sediments include low plastic silts, clays and organic peat.

Although the samples in many of the coastal holes were thermally disturbed during vibratory extrusion, ice-bonded frozen soils (both coarse and fine grained) were encountered in some of the coastal boreholes, as noted on the logs in Appendix A-2. Massive ground ice was not identified in any of the coastal boreholes. The distribution of ground ice in the coastal sediments is poorly defined because of sampling disturbance. Additional in situ thermistor data in the vicinity of the coastal lagoon would be useful for defining the transitions of ground temperatures between the onshore, coastal and offshore areas.

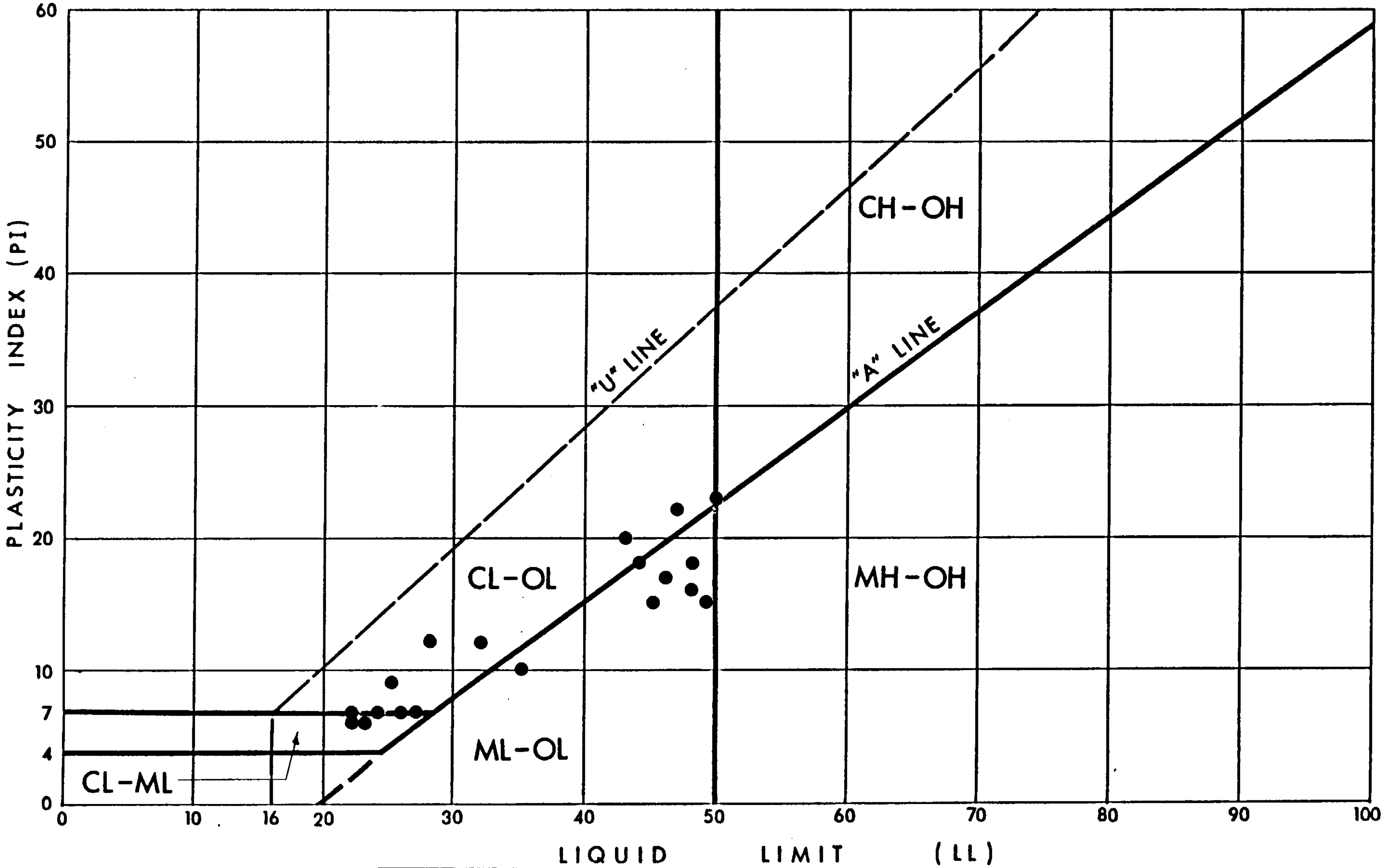
Moisture contents of the fine grained coastal sediments (in the thawed state) ranged from about 5% to 80%. The higher moisture contents, exceeding about 50%, typically occur either in organic or ice-rich sediments. The natural moisture contents exceeded the liquid limits of several of the coastal sediment samples analyzed, e.g. in boreholes F85KM7, KM8, KM10 and KM11.



Grain Size Envelope for Granular Materials in the King Point Barrier Bar
(Based on 25 samples)

M.J. O'CONNOR & ASSOCIATES LTD.

JOB No.:	10-300	**DATE:**	85/09/24
DRAWN BY:	MG	**DWG. No.:**	6.12



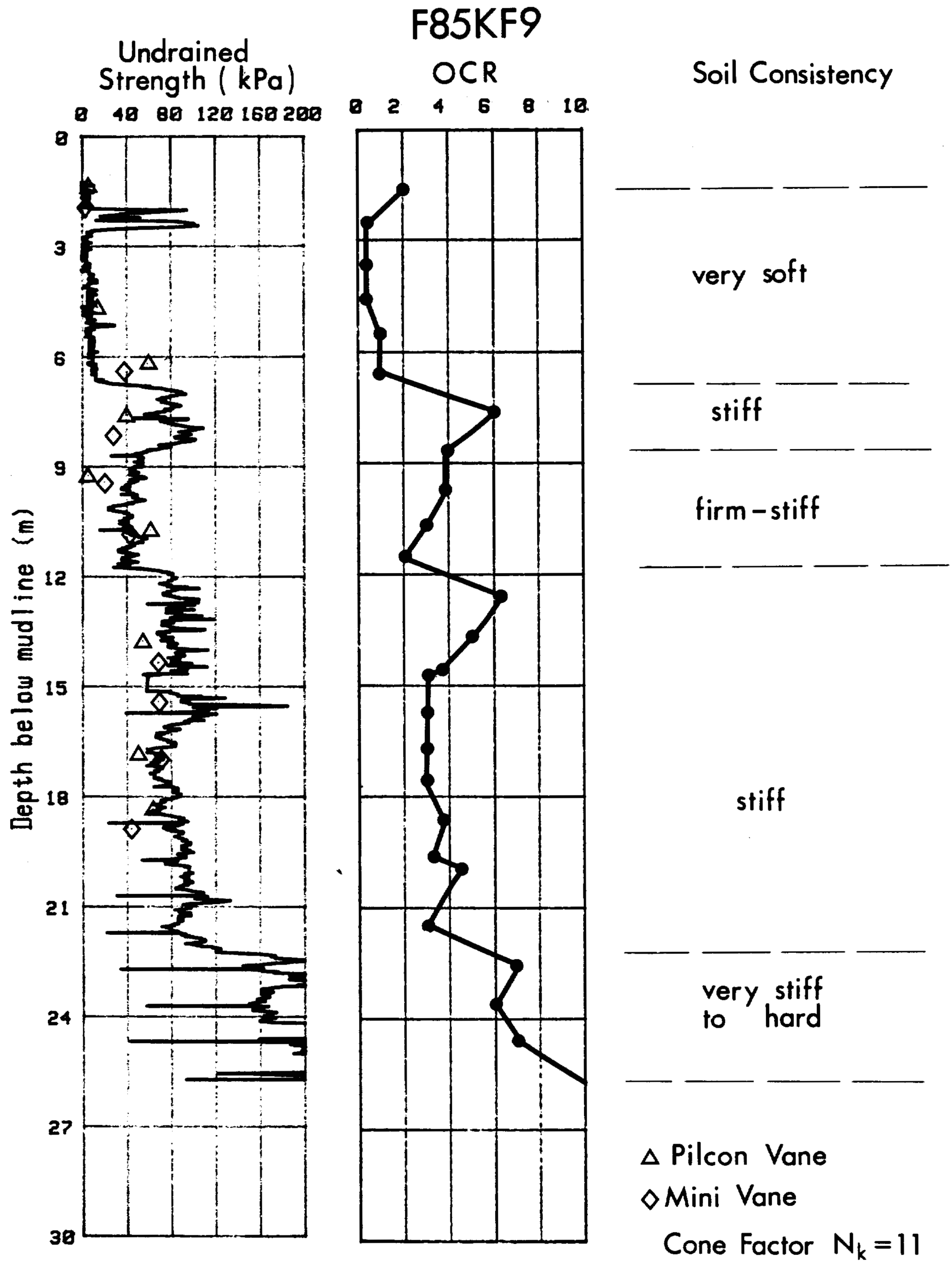
Atterberg Limits - Coastal

M.J. O'CONNOR & ASSOCIATES LTD.	
JOB No.: 10-300	DATE: 85/08/06
DRAWN BY: MG	DWG. No.: 6.13

Undrained shear strengths were measured at only two of the coastal borehole locations in the lagoon. Vane tests were performed on undisturbed fine grained soil samples from borehole F85KF10 and a CPT was performed in test hole F85KF9, both located in the southern sector of the lagoon.

The vane data are plotted on the borehole logs in Appendix A and the CPT data are presented in Appendix C. Undrained shear strengths measured by vane testing of undisturbed samples from borehole F85KF10 and cone penetrometer results from test hole F85KF9 (assuming a cone factor, N_K of 11) are plotted with depth on Drawing No. 6.14. Some of the vane strengths are lower than the comparable cone strengths, suggesting that a cone factor greater than 11, e.g. $N_K = 14$, may be more appropriate for some of the sediments underlying the lagoon.

The soil consistencies and OCR values shown on Drawing No. 6.14 indicate that the stress histories of the soil strata under the lagoon vary considerably. Very soft, compressible silt is present in the upper 7 m. The clay materials between 7 m and 22 m have consistencies ranging from firm to very stiff. Below 22 m depth the sediments are very stiff to hard. Overconsolidation ratios estimated on the basis of CPT data from test hole F85KF9 are less than 1 in the upper 7 m of sediment, but range from 2 to 6 in the underlying firm to stiff materials and continue to increase further to greater than 10 in the very stiff to hard strata at depth. These OCR values indicate that the shallow lagoonal sediments in the upper 7 m are slightly underconsolidated or normally consolidated while the



Comparison of CPT Strength Measurements in F85KF9 with Vane Strength Measurements in F85KF10	**M.J. O'CONNOR & ASSOCIATES LTD.**
JOB No.: 10-300	**DATE:** 85/08/06
DRAWN BY: MG	**DWG. No.:** 6.14

sediments below 7 m depth are overconsolidated. It is not presently known whether the high OCR values obtained at depth are indicative of a hard stratum or ice-bonded permafrost.

The average sensitivity (estimated on the basis of CPT friction ratios) of the very soft to soft sediments within the upper 7 m of borehole F85KF9 was approximately 2, indicating slight sensitivity (Rosenqvist, 1953). The average sensitivity of the underlying firm to stiff sediments was about 4, indicating medium to very sensitive soils. These sensitivity values indicate that the potential loss of strength of the sublagoonal sediments upon remoulding is only moderate to low.

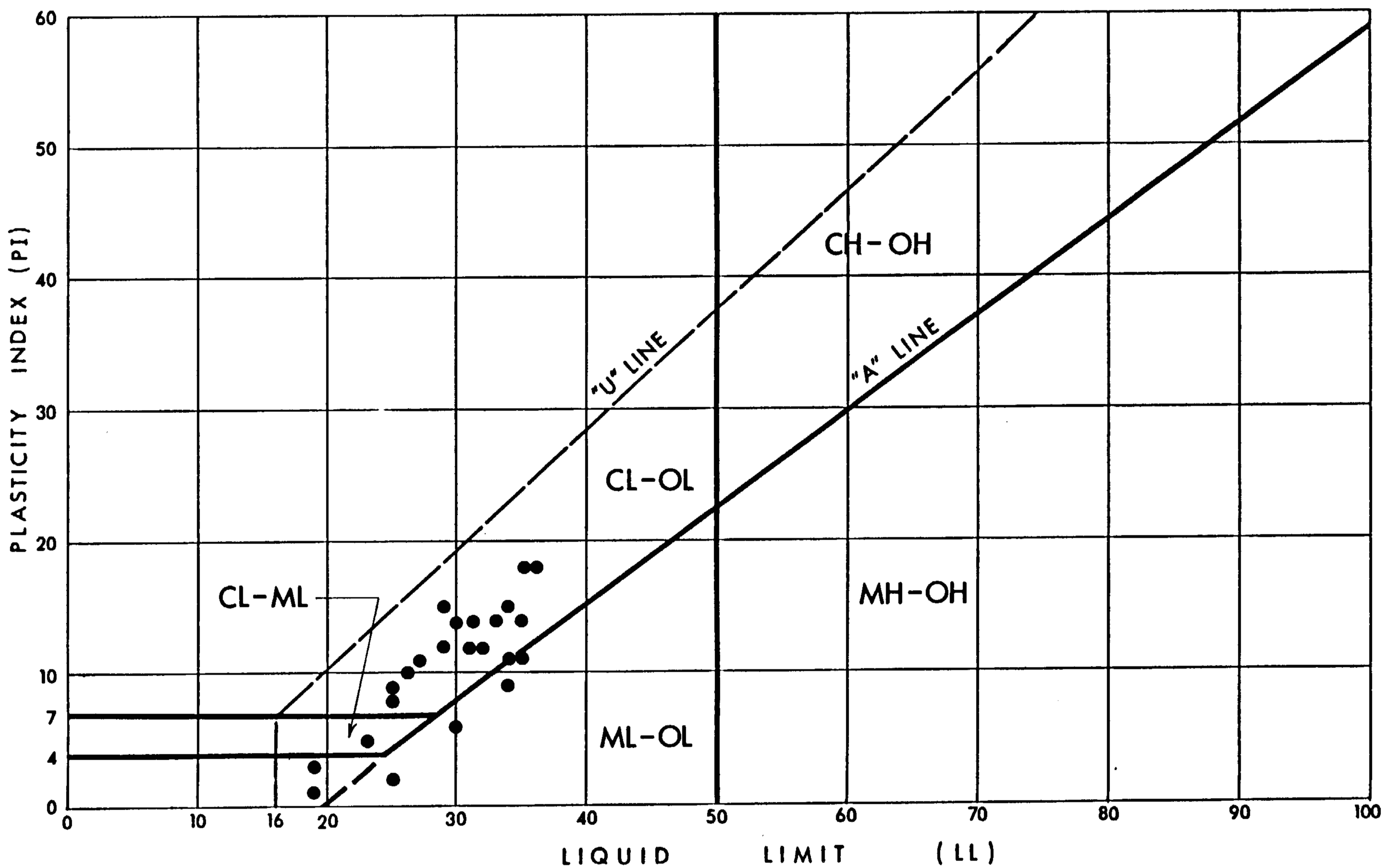
6.5 Onshore Sediments

Seventeen (17) onshore boreholes were drilled over an area of approximately 26 km^2 in the area south and west of King Point. The locations of the onshore boreholes are shown on Drawing No. H-3, Appendix H.

As described previously in Section 5.0, these boreholes were drilled into a number of different terrain units. While the stratigraphic conditions encountered in the onshore boreholes are therefore highly variable (see the detailed logs in Appendix A-3), most (over 80%) of the sediments encountered were silts and clays.

6.5.1 Index Properties

Plasticity data for the onshore fine grained sediments which are summarized in Drawing No. 6.15 indicate that these materials are generally classified as low plastic silts and clays.



Atterberg Limits - Onshore

M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.: 10-300	**DATE:** 85/08/06
DRAWN BY: MG	**DWG. No.:** 6.15

Natural moisture contents measured after thawing of the onshore samples are plotted with depth on the borehole logs and are listed in Appendix B. The natural moisture contents are generally below the liquid limit except in ice-rich sediments and organic peat.

The strength and compressibility of the onshore sediments were not measured during this study. Both are principally dependent on ice content and temperature for ice-rich permafrost. Core samples obtained using the Midwest rotasonic rig were thermally disturbed and therefore not suitable for compression testing.

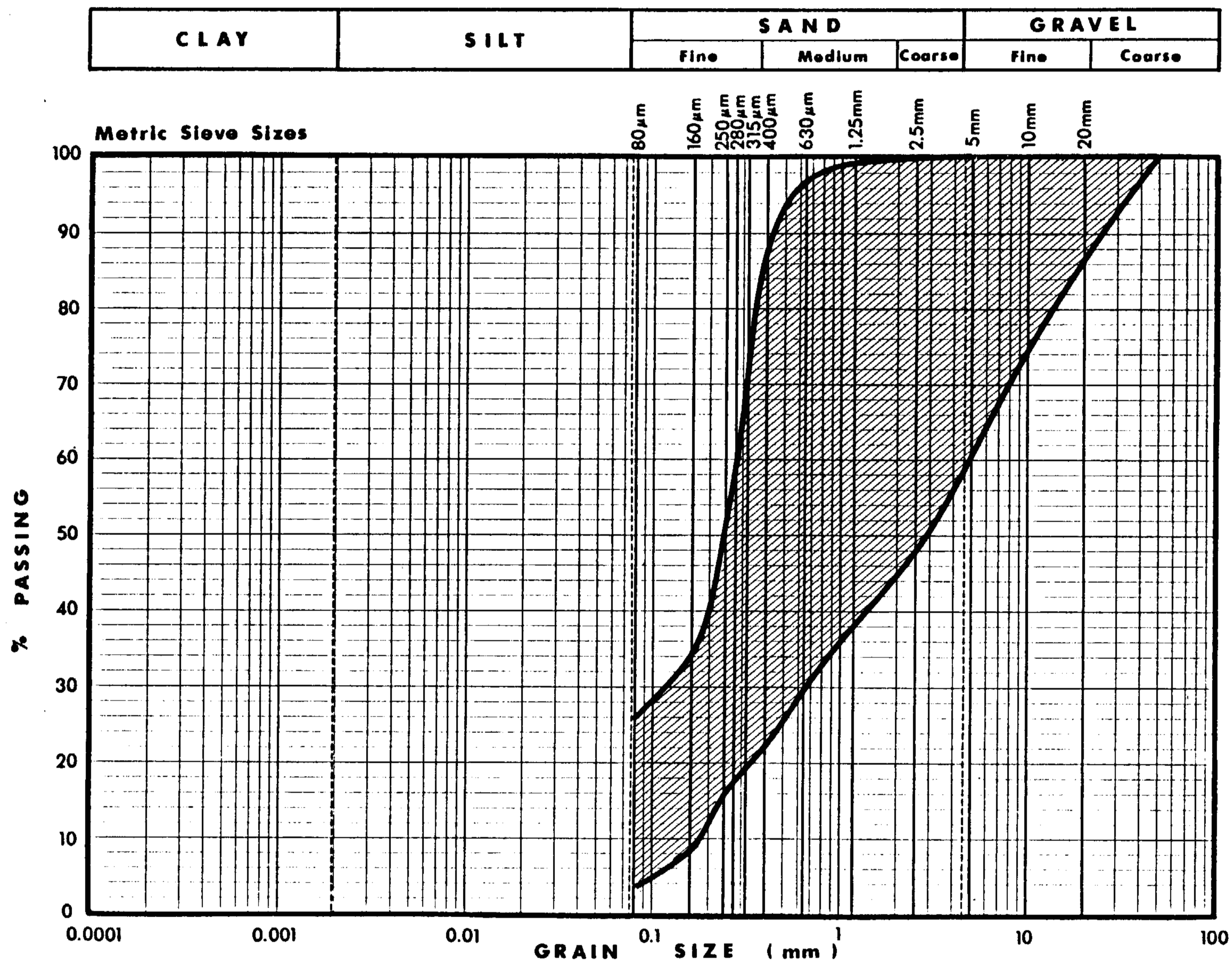
6.5.2 Onshore Granular Resources

In spite of the predominance of fine grained sediments in the study area, coarse grained materials are also common. Sand and gravel were identified in 13 of the onshore boreholes (F85KM18, 20, 21, 22, 24, 25, 26, 27, 28, 29, 31, 32 and 33). Unfortunately, most of the sand and gravel occurs in beds of only 1 to 3 m thickness, often interbedded with silty or clayey materials. Gravels of perimarine origin usually contain relatively high fines contents (greater than 15% silt and clay sized particles). Moreover, much of the gravel is buried at appreciable depths ranging from about 10 to 25 m under ice-rich fine grained sediments. Alluvial sands found in boreholes F85KM24 and 33 are buried at depths of only 6 m and 1 m respectively, but these layers are generally silty and are interbedded with ice-rich material. For these reasons many of the sand and gravel deposits near King Point are not readily exploitable for engineering grade materials.

Deposits of glaciofluvial sands and gravels identified in boreholes F85KM28, 31 and 32 are more readily exploitable, because they are usually cleaner (less than 15% fines), much thicker, and occur relatively close to the ground surface. Like all the onshore granular materials, however, these deposits are well ice-bonded, and therefore would require gradual development over several seasons or blasting of the frozen gravels if exploitation is to proceed. Grain size distributions for some of the gravel and sand samples obtained from the boreholes are presented in Appendix B. An envelope of the measured grain size distributions for the glaciofluvial materials in boreholes F85KM28, 31 and 32 is presented in Drawing No. 6.16.

6.5.3 Seasonal Thawing

Because the present programme was conducted during the winter months, it was difficult to determine the thickness of the active layer at King Point. Generally, fine grained soils along the Yukon coastal plain which are covered by peat and moss have active layers less than 300 mm in thickness. Coarser grained gravels or sands with broken vegetative cover may have active layers with thicknesses of 1.0 to 1.2 m (Rampton, 1982). Moss and organic peat were present at the ground surface at all of the onshore borehole locations hence it is likely that the active layer thickness is less than 300 mm over much of the area. Surficial peat thicknesses encountered in the boreholes ranged from about 100 mm (organic veneer) to several metres (organic peat blanket).



Grain Size Envelope For Glaciofluvial Materials (Based on 17 samples)	**M. J. O'CONNOR & ASSOCIATES LTD.**		
	JOB No.: 10-300	**DATE:** 85/10/25	
	DRAWN BY: MG	**DWG. No.:** 6.16	

6.5.4 Ground Ice

The occurrence of massive ground ice presents the most significant geotechnical constraint to possible onshore site development because the potential for thaw subsidence and mass wasting increases significantly if the existing thermal equilibrium of the ground is altered. The terrain units and approximate thicknesses of massive ground ice encountered in each of the onshore boreholes are summarized in Table 6.2. The greatest ground ice thicknesses were observed under the glaciofluvial aprons (see BH's F85KM31 and 32) and glacial moraine deposits (see BH's F85KM21, 23 and KM30). As the detailed ground ice descriptions presented on the borehole logs in Appendix A-3 demonstrate, massive ice and very ice rich strata were identified in all but one of the onshore holes (BHF85KM13) and excess ground ice was noted in all of the boreholes. The thicknesses of massive ice noted in Table 6.2 are significant, ranging from less than 1 m to greater than 14 m. It is noteworthy that the full depth of massive ice was not completely penetrated in two of the boreholes (F85KM31 and F85KM32).

TABLE NO. 6.2

SUMMARY OF TERRAIN TYPES AND GROUND ICE DISTRIBUTION IN THE ONSHORE BOREHOLES

Borehole	Terrain Units	Total Thickness of Massive Ground Ice (m)
F85 KM13	Colluvium, alluvial fan and marine (beach ridge) deposits over glacial moraine ($mC_B/A_F/W_R/M_M$)	0.0
F85 KM18	Colluvium over perimarine gravel (C_X/gP)	0.5
F85 KM19	Lacustrine plain deposit over glacial till and perimarine silt (L_P/M_M/mP)	2.4
F85 KM20	Lacustrine plain over glacial till and perimarine deposits (L_P/M_M/msgP)	1.5
F85 KM21	Lacustrine plain over glacial till and perimarine deposits (L_P/M_M/msgP)	5.5
F85 KM22	Organic peat blanket over lacustrine plain, glacial moraine and perimarine deposits ($O_B/L_P/M_M$)	1.5
F85 KM23	Colluvium over glacial moraine (C_X/M_M)	10.0
F85 KM24	Alluvial terrace over glacial moraine (A_T/M_M)	0.8
F85 KM25	Colluvial complex and alluvial fan over glacial moraine and perimarine deposits ($C_X/A_F/M_M$/P)	2.5
F85 KM26	Organic peat blanket over glacial till and perimarine deposits (O_B/M_M/P)	0.9
F85 KM27	Organic peat blanket over glaciofluvial sand, glacial till and perimarine deposits (O_B/G/M/P)	1.0
F85 KM28	Peaty colluvial blanket over glaciofluvial apron (C_B/G_A)	1.6
F85 KM29	Alluvial terrace over glacial till and perimarine deposits (A_T/M_M/P)	0.5
F85 KM30	Glacial moraine over perimarine sediments (M_M/P)	5.8
F85 KM31	Peaty colluvial blanket over glaciofluvial apron (C_B/G_A)	>14.0
F85 KM32	Peat over silty colluvium over glaciofluvial apron ($O_V/C_B/G_A$)	>10.0
F85 KM33	Alluvial terrace over glacial moraine (A_T/M_M)	1.0

7.0 COASTAL PROCESSES AT KING POINT

7.1 Coastal Morphology and Sediments

A description of the existing coastal morphology of the King Point area provides considerable insight into present-day coastal processes, especially in terms of sediment supply, sediment transport paths and coastal instability. The presence of coastal cliffs indicates a net coastal sediment deficit and suggests that the coast is in a state of dynamic disequilibrium as a result of changing environmental processes. The eroded materials which are derived from the predominantly fine grained, ice-rich sediments comprising the coastal cliffs, are mainly transported offshore, although lesser amounts of sand and gravel are also eroded from the cliffs and deposited on the beach. Barrier islands and spits provide an index of net transport directions and, as such, indicate where potential sediment sinks exist. These examples illustrate the utility of inferring coastal process elements from coastal morphology.

Coastal morphology also provides an excellent indication of coastal stability and may be used to estimate coastal sediment budgets or establish risks associated with engineering proposals provided that changes in coastal morphology can be documented over time from shore or aerial photographic surveys. In this respect, aerial photography of King Point for three successive times (1954 and 1970 vertical aerial photography, and 1984 oblique colour video photography) can be used to estimate coastal morphologic processes.

In the King Point area, the coastline can be divided into the 6 major coastal morphology segments, which are listed in Table No. 7.1 and shown in Drawing No. 7.1.

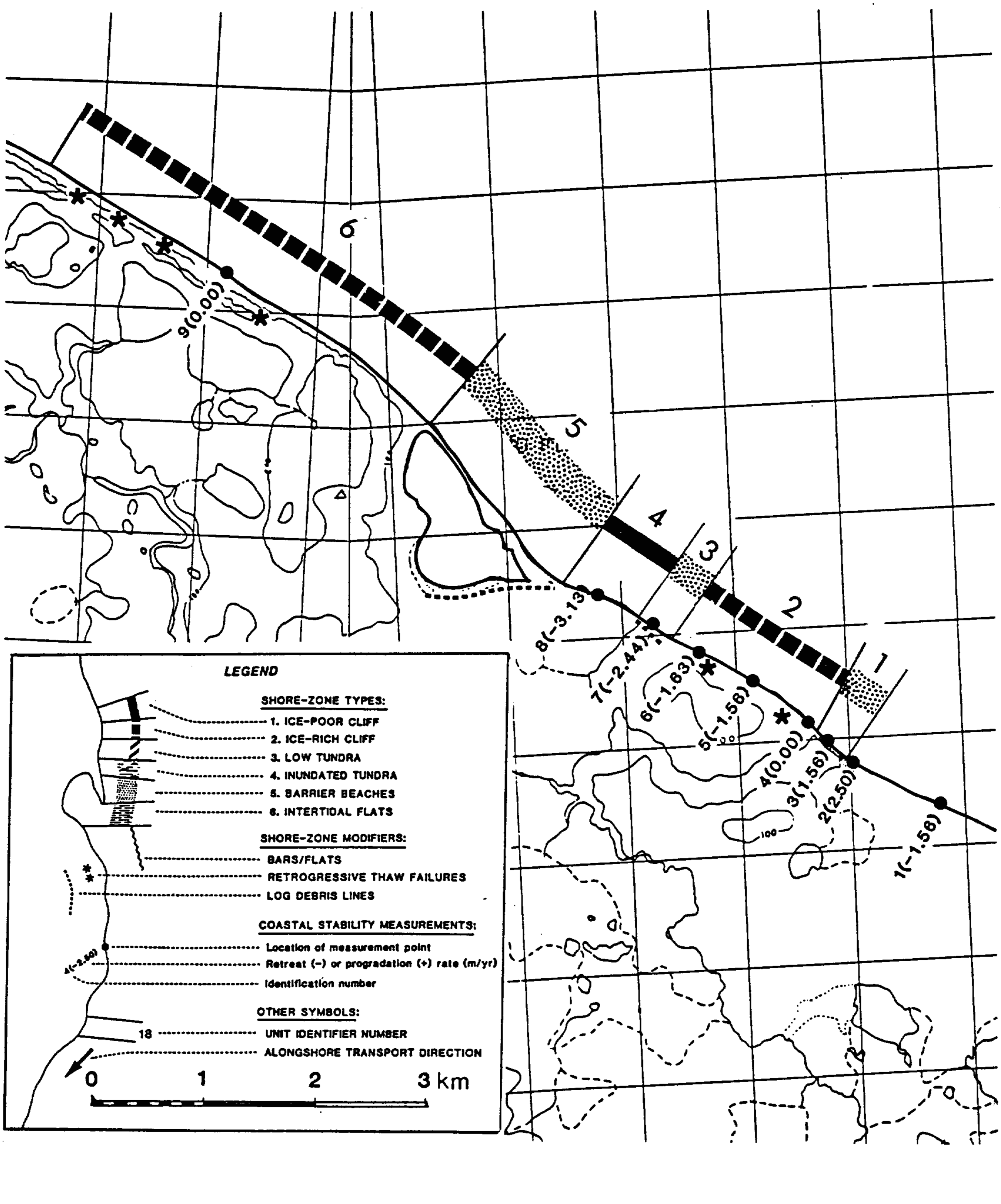
Grain size data reported by R.M. Hardy and Associates (1977) for cliff and beach samples are presented in Table No. 7.2. According to the grain size data in Table No. 7.2, it may be inferred that sand-sized particles eroded from the cliffs are transported readily to the barrier beach while some of the gravel, silt and clay particles are excluded from the sediment load arriving at the beach. However, the grain size data for barrier bar samples obtained during this investigation which are summarized in Table No. 7.3 , indicate that materials with higher proportions of fines and/or gravel than suggested by the more selective data in Table No. 7.2 are also present in the barrier bar. Nevertheless, the barrier bar sediments are primarily coarser grained sands and gravels with limited fines contents.

The cliff sediments exposed to the northwest of King Point are primarily fine grained sediments of perimarine origin although a glaciofluvial apron deposit comprised mainly of sand and gravel is also exposed over a limited distance (see Drawing No. H-2, Appendix H). Gravels and sands within the perimarine deposits generally occur in beds of only 1 to 3 m thickness and contain relatively high fines contents (greater than 15%). Based on the present data it appears that coarse grained sands and gravels derived from coastal erosion processes are being deposited on the King Point barrier beach while fine grained sediments are probably being transported offshore.

TABLE NO. 7.1

DEFINITION OF COASTAL MORPHOLOGY SEGMENTS
IN THE KING POINT AREA

Segment	Feature	Linear Extent	Description
1	Barrier Bar 1 (3 km east)	0.6 km	Gravel/sand/driftwood barrier bar (50 m to 100 m width) across mouth of drowned valley enclosing a lagoon. Bar breached by open channel in July, 1984 video survey.
2	Low Coastal Cliff	1.7 km	Extensive retrogressive thaw failure with mudflow transport. Massive ground ice in headwall of failure. Narrow gravel/sand beach.
3	Barrier Bar 2 (1 km east)	0.2 km	Gravel/sand/driftwood barrier bar (50 m width) across mouth of lagoon.
4	Low Coastal Cliff	1.0 km	Ice rich and fine sediment cliff section. Very narrow gravel/sand beach.
5	King Point Barrier Bar	1.9 km	
	5.1 Proximal Neck	(0.6 km)	Narrow (<50 m), transgressive barrier section.
	5.2 Re-curved Ridges	(0.6 km)	Multiple, re-curved spit ridges on backshore, broken by overwash channel, fronted by parallel beach ridges on foreshore.
	5.3 Distal Segment	(0.7 km)	Post-early 1950's channel fill, with post 1970 prograded, parallel to curving beach ridges (width 100 m to 200 m).
	5.4 Lagoon Beach	(---)	Pre-early 1950's sediment deposition before inlet channel closure. Generally 50 - 100 m width.
6	High Coastal Cliff	> 3 km	Cliffs up to 50 m above sea level. Composed of early Wisconsin ice-thrust sediments. Old, stabilized sections and re-activated, retrogressive slump failure sections. Narrow gravel/sand beach to 10 m width at base.



Coastal Morphology Segments in the Vicinity of King Point (Harper et al, 1985)	**M. J. O'CONNOR & ASSOCIATES LTD.** **JOB No.:** 10-300 **DATE:** 85/08/06 **DRAWN BY:** DSL **DWG. No.:** 7.1

TABLE NO. 7.2

RELATIVE CHANGES IN SEDIMENT SIZE CLASSES BETWEEN CLIFF SAMPLES (SEDIMENT SOURCE) AND BARRIER BEACH SAMPLES (SEDIMENT SINK)

Sediment Size Class		Cliff Samples (% wt.)	Barrier Beach Samples (% wt.)	Relative Change (% wt.)
Gravel	- Coarse	38	13	-25
	- Fine	31	29	- 2
Sand	- Coarse	6	5	- 1
	- Medium	9	37	+28
	- Fine	12	6	- 6
Fines		4	0	- 4

NOTES:

1. Data from R.M. Hardy and Associates Ltd. (1977). See Appendix 1 for original sample data. Note that only 2 cliff samples and 2 barrier beach samples were analyzed.

2. Cliff samples are only representative of 20 - 30% of the cliff face with the majority of cliff being fine sediments.

TABLE NO. 7.3

GRAIN SIZE DATA SUMMARY

1985 BARRIER BEACH SAMPLES

BOREHOLE	SAMPLING Depth (m)	GRAVEL (%)	SAND (%)	SILT/CLAY (%)
F85KM7	3.0	54.0	29.8	16.2
F85KM9	3.3	41.3	54.3	4.4
F85KM12	0.5	37.4	57.0	5.6
	1.0	26.1	63.6	10.3
	1.6	38.2	56.7	5.1
	1.9	58.0	31.6	10.4
	2.2	50.2	37.4	12.4
	5.0	3.0	88.2	8.8
	6.0	45.6	51.0	3.4
F85KM15	5.0	32.9	66.4	0.7
AVERAGE		38.7%	53.6%	7.7

7.2 Coastal Erosion and Deposition

In the longer term, the entire length of the Yukon coastal plain is undergoing erosion as a result of the coastal transgression. In the shorter term, however, sections of the coast are eroding at variable rates with some sections exhibiting coastal deposition and progradation. A summary of all the available historical data regarding coastal changes in the vicinity of King Point are presented in Table No. 7.4.

Rates of coastal erosion and deposition for the King Point area have been determined from historical accounts and more reliable comparisons of vertical air photographs. The location of the grave marker of G. Wiik (shown in Plate No. 7.1) and its proximity to the coastal cliff with time were used by McDonald and Lewis (1973) to estimate the rate of coastal erosion, but since the grave marker was moved, this estimate is considered less reliable than the more recent aerial survey results. Rates of coastal change for the period 1954 to 1970 are shown for the various coastal morphology segments in Drawing No. 7.1. In addition, over this period the King Point spit had grown southeastward approximately 400 m and formed a barrier bar completely enclosing the lagoon. From a review of the 1984 aerial video survey it is also apparent that there has been seaward progradation of the southeast end of the barrier bar in the order of 100 m since 1970.

On a larger scale, the coastal cliffs within 20 km in either direction from King Point are eroding at an average rate of approximately 0.6 m/a; however, in the period 1954 to 1970, the coastal cliffs to

TABLE NO. 7.4

SUMMARY OF HISTORICAL DATA OF VARIOUS TYPES ON COASTAL CHANGES IN THE VICINITY OF KING POINT

Date	Source	Description
1905 - 1906	Amundsen (1908)	Roald Amundsen with the crew of the Gjoa wintered at King Point. The boat was frozen in by September 9, 1905, seaward from the sandspit in about 3 m of water.
1906 - 1957	McDonald and Lewis (1973)	An historical and somewhat unreliable account of coastal retreat at King Point based upon the location of the grave marker of G. Wiik (Plate No. 7.1) with respect to the coastal cliff. A rigorous interpretation confirms a maximum of 10 m of coastal retreat between 1906 and 1957.
1954	Vertical airphoto (EMR)	The photo shows the spit beach with a channel opening of approximately 400 m. An extensive beach is also present in the south side of the lagoon.
1957	MacKay (1960)	Photographs taken in 1905-1906 (Amundsen, 1908) compared with the present coast (1957), show that the sandspit has been driven landwards (southeast) some 15 to 30 metres. In 1957, depths within the lagoon and the wide channel reached a maximum of 3 to 3.5 metres.
1968	Fisheries and Oceans Canada (1981)	The survey ship Richardson reported that the lagoon was closed and the sand bar across it had built up to a height of about 1 m.
1970	Vertical airphoto (EMR)	The photo shows the entrance channel closed with a barrier bar width of approximately 100 m at the location of the former channel.
1954 - 1970	McDonald and Lewis	Based on airphoto comparisons and a ground survey in 1972 they (1973) concluded: (1) a bay-mouth bar about 100 m wide and composed of sandy pebble gravel had grown (south) eastward 425 m to completely enclose the lagoon; (2) the coastal cliff for 5 km west of King Point showed no measureable change; and (3) between King Point and Sabine Point the coast has straightened by coastal retreat and the local progradation of bay-mouth bars and mainland beaches.
1984	Oblique Aerial Colour Video Survey (GSC)	The most apparent change is the progradation deposit of beach ridges at the southeast end of the barrier bar.

Plate No. 7.1 Grave Marker of G. Wiik (1905) at King Point

5 km northwest of King Point showed no measureable change. The cliffs are generally high (30 m to 50 m) and are fronted by a 15 to 20 m wide beach.

7.3 Sediment Sources and Sinks

An assessment of coastal processes at King Point was conducted by reviewing possible sediment sources and sinks within the coastal system. Because of the limited data base for the area it was not considered feasible to derive an exact quantitative coastal sediment budget.

Within the extent of coast bounded by Kay Point to the northwest and the Shingle Point spit to the southeast, coastal erosion of unconsolidated terrestrial sediments is considered to be the dominant source of sediment to the coastal zone. No large rivers enter the coast between Kay Point and the Shingle Point spit. Beyond these features, sediments from large rivers are transported away from, rather than toward, King Point. The small streams which enter the coast in the vicinity of King Point are considered to be insignificant sediment sources. Likewise, shallow marine sediments in the nearshore apparently do not contribute significant amounts of sediment to the coastal sediment load.

An estimate of the annual contribution of sediments from cliff erosion to 10 km either side of King Point was derived from the average erosion rate of 0.6 m/a, the average cliff height (20 m) and the total distance along the coast (20 km). The product of these yields 240 000 m^3/a, of which approximately 10% to 50% may be excess ice, thereby reducing the net amount of sediment to as little as 120 000 m^3/a. Of this amount, it is only the sand and gravel size fractions (estimated to be approximately 10% to 30% or 12 000 to 40 000 m^3/a) which will remain in the coastal system, the silt and clay size fractions being suspended and transported to shelf depths and beyond.

The significant sinks for eroded cliff sand and gravel sediments include coastal deposits and submarine deposits as a result of ongoing transgression. The coastal deposits include beaches, spits, barrier bars and lagoon fill resulting from overwash processes. The coastal beaches along the base of cliffs to the northwest and southeast of King Point vary from non-existent up to 10m to 30 m in width. The only 3 barrier bar features are those shown in Drawing No. 7.1, which also enclose lagoons. Ultimately, with prolonged coastal transgression, coastal sand and gravel deposits must either be retained as a transgressive coastal deposit or "smeared" as a lag deposit over the nearshore unconformity that results from the transgression.

7.4 Evolution Model of King Point Barrier Bar

Coastal features in the vicinity of King Point consist primarily of the adjacent cliffs, the barrier bar and the lagoon. These have evolved under the influence of a variety of controlling factors, including:

1. The initial coastal plain morphology, sediments and distribution of ice.
2. A gradual sea level rise, Holocene transgression and resultant coastal erosion.
3. Coastal sediment transport processes influenced by waves and currents.

The primary, or initial, origin of King Point is due to a topographic high of deformed (preglacial) perimarine deposits. Conversely, to the southeast, a relative topographic depression contains the barrier bar and lagoon. Although there are several possible origins for King

Point, it appears that the topographic depression was probably created as the result of one or two thermokarst lakes being breached by the coastal transgression. There is no topographic or bathymetric evidence to indicate that the lagoon has formed as a result of the submergence of a pre-existing valley, however some downwasting appears to have occurred on the landward side of the former lake depressions.

Once a local indentation had been created in the coastline, a discontinuity in longshore sediment transport was also created which resulted in a locus for sediment deposition. Initially, this appears to have occurred both as the formation of a spit extending southeast from King Point and as the formation of a beach in the south lagoon embayment (based on the 1954 air photograph). Thus, the locus of deposition for sediment transported from the northwest was the spit while the locus of deposition for sediment transported from the southeast was the lagoon beach. The spit continued to advance southeastward as indicated by the re-curved spit ridges in the middle and distal sections. At the same time, continued coastal transgression eroded most of the proximal portion of the spit, leaving a relatively narrow beach ridge deposit.

Eventually, the southeastward migration of the spit and the migration of the lagoon beach to the inlet mouth combined to close off the channel. The exact time of this event is not known, but it probably occurred in the mid 1960's. Since then, the greatest amount of sediment accumulation has occurred as prograded beach ridges along the southeast section of the barrier bar. This has modified the local shoreline configuration from concave seaward to almost straight.

In the near future (10 to 20 years) it is likely that continued coastal progradation will take place in the southeast section of the barrier bar, although the locus of sediment deposition may change or migrate as the local shoreline orientation changes.

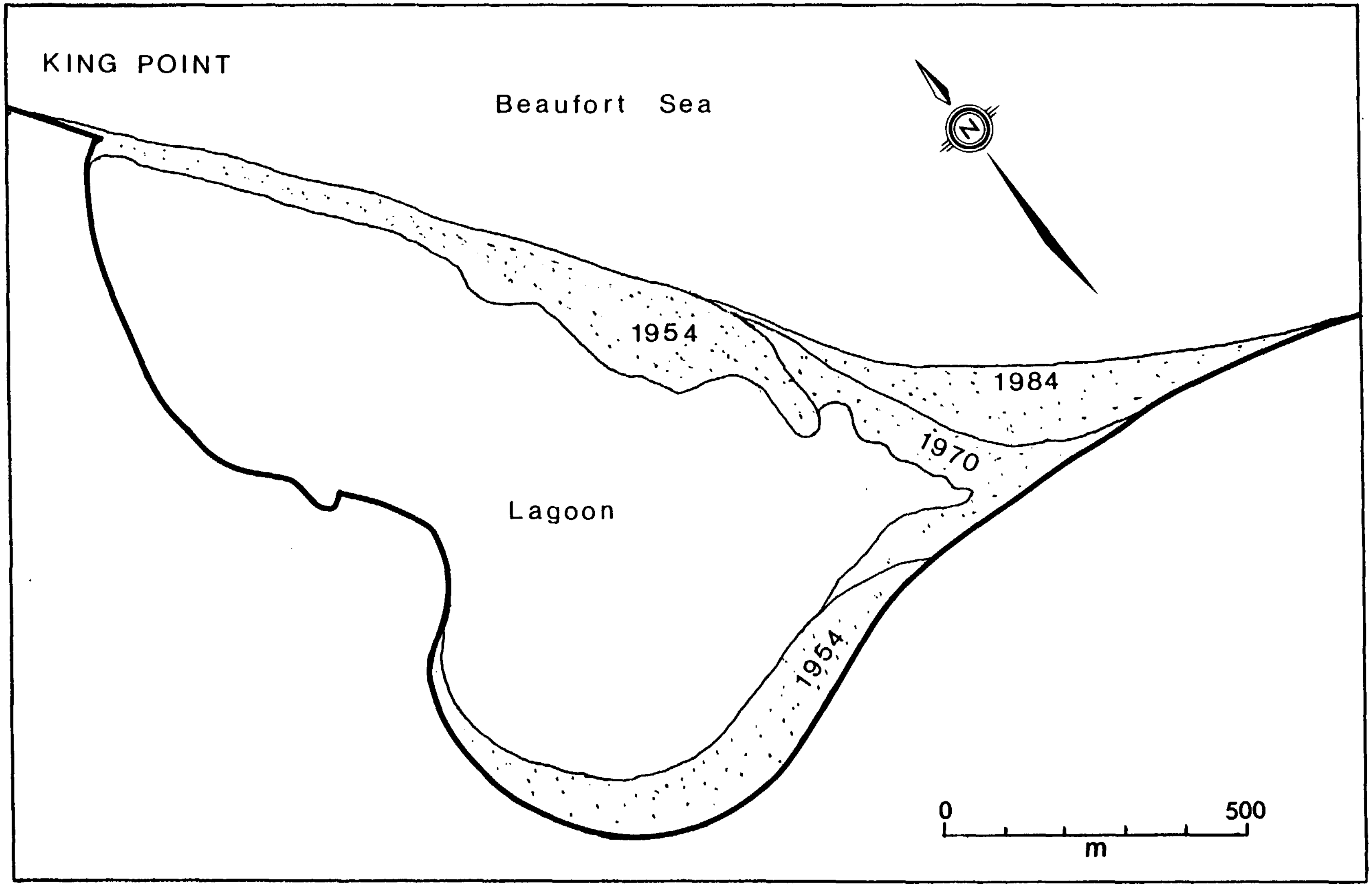
7.5 Modern Longshore Sediment Transport

For the King Point area the rates and directions of modern longshore sediment transport can be derived using two approaches:

1. The first approach consists of measuring shoreline changes between the 1954 and 1970 vertical air photographs and the 1984 aerial video survey. When these plan measurements are combined with elevation, borehole and bathymetric data, the volumetric accumulation of sediment can be estimated.
2. The second approach is the numerical estimation of sediment transport using hindcast wind and wave data, wave refraction analysis and longshore sediment transport models.

The latter approach has recently been applied to the King Point area in a study by Keith Philpott Consulting Ltd. (KPCL in 1985). This study included a beach plan evolution model for 2 conditions, with and without an engineering structure.

The areas of coastal sediment accumulation for the various periods (1954, 1970, 1984) are shown on Drawing No. 7.2. When combined with borehole data of barrier bar and nearshore deposit sediment thicknesses (see Appendix F) and shoreline feature elevations, it has been possible to compute volumes of coastal sediment accumulation (Table No. 7.5).



Coastal Sediment Accumulation Near King Point as Measured from Vertical Air Photographs (1954, 1970) and Oblique Aerial Video Camera Survey (1984)

M.J. O'CONNOR & ASSOCIATES LTD.	
JOB No.: 10-300	DATE: 85/08/06
DRAWN BY: DSL	DWG. No.: 7.2

TABLE NO. 7.5

VOLUME ACCUMULATION OF COASTAL SEDIMENTS AT KING POINT

Period	Volume Accumulation (m^3)	Average Accumulation Rate (m^3/a)
At 1954	1 500 000 to 2 500 000	Unknown
1954 - 1970	300 000 to 700 000	20 000 to 40 000
1970 - 1984	200 000 to 300 000	15 000 to 20 000

The total volume accumulation prior to 1954 (1 500 000 to 2 500 000 m^3) appears to be comprised of approximately 75% spit deposits and 25% lagoon beach and bay mouth deposits. The fact that the spit was being extended toward the southeast suggests that 75% of the sediments were probably derived from the northwest. Furthermore, the fact that the proximal end of the spit displayed the effects of transgression, would seem to amplify the relative amount of sediment supplied from the northwest. In this respect, it is thought that the lagoon beach sediments, once deposited by longshore transport from the southeast, were trapped and not recycled out through the entrance channel. It is also thought that the amount of sediment bypassing the channel was very limited.

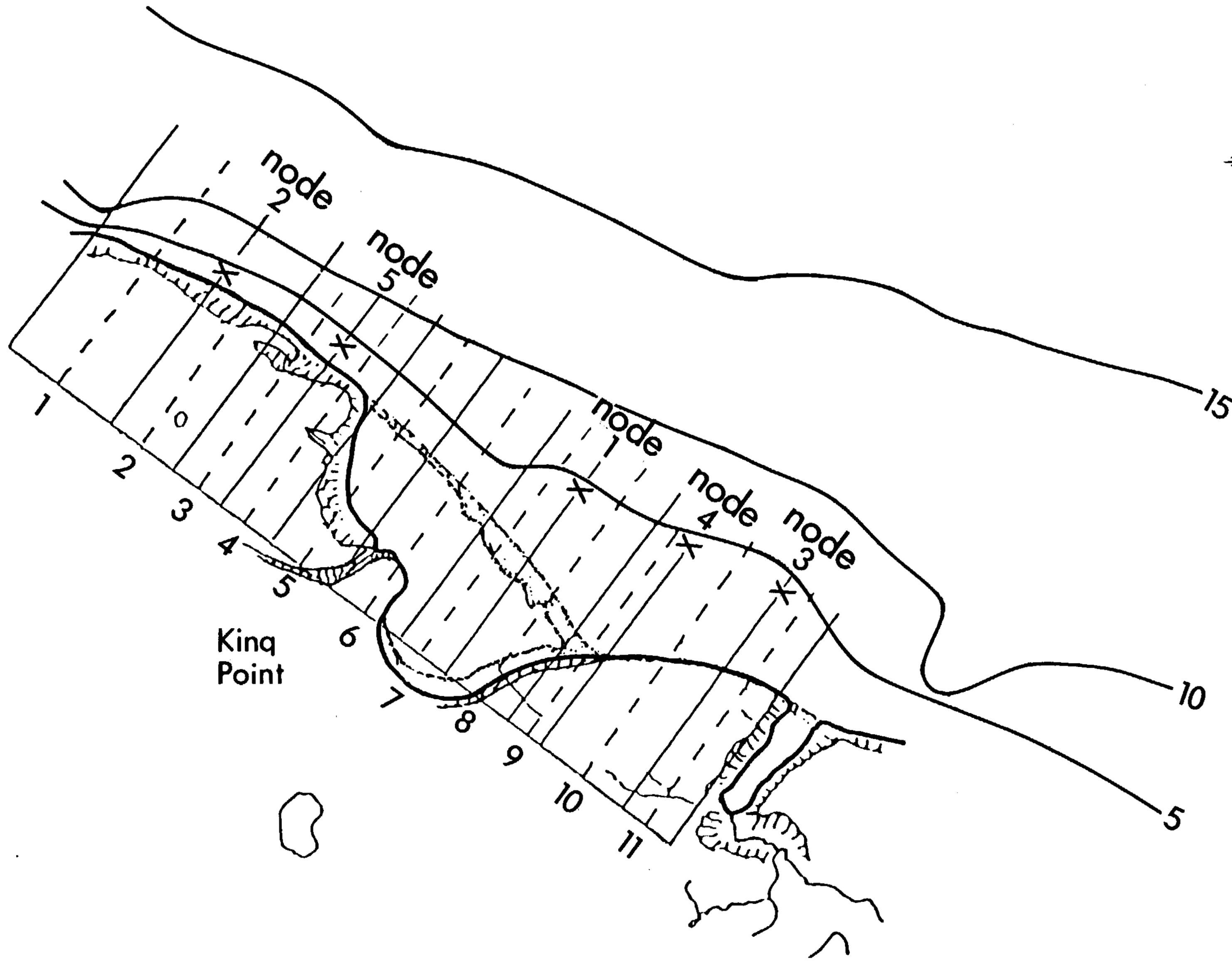
A preliminary estimate of sediment accumulation derived from the comparison of air photographs for the period 1954 to 1970 indicates that approximately 300 000 to 700 000 m^3 of sediment accumulated at the southeast end of the barrier bar. This has resulted in an average annual rate of accumulation of 20 000 to 40 000 m^3/a. This can be considered to be the total or gross quantity of sediment transport if this sediment accumulated from both directional sources (northwest and southeast) and if the inlet was 100% efficient in trapping sediment and did not allow any sediment bypassing. The total quantity does not indicate the relative amounts of transport from the northwest or southeast.

Finally, volume accumulation from 1970 to 1984 indicates an accumulation rate of 15 000 to 20 000 m^3/a. Since the inlet of the bay mouth was closed for this period, sediment transport could now continue along the coast in both directions, thereby reducing the local apparent accumulation of sediment at this section of the shoreline.

Thus, the lower measured accumulation rates between 1970 - 1984, than between 1954 - 1970, would also seem likely to occur in principle.

In summary, a total or gross sediment transport rate of 20 000 to 40 000 m^3/a seems representative of the southeast section of the King Point barrier bar, with an historical indication (to 1954) of 75% of the transport from the northwest and 25% from the southeast. Because of the changing shoreline angle at King Point and to the southeast (past the barrier bar), it is also likely that the percentages of northwest and southeast directed transport vary locally along the coast.

A numerical estimation of sediment transport and beach plan change was conducted for the King Point site as part of a recent coastal sediment transport modelling study in the Beaufort Sea (KPCL, 1985). The study compiled available wind and open water data for the period 1970 to 1983 to derived time series predictions of wave height, period and directional statistics for offshore, deep water locations. Wave refraction analyses were then performed using a nearshore bathymetric grid to transform the deep water wave climate data to an inshore wave climate at the coastal site of interest. Computation of potential longshore sediment transport rates were then performed using a dozen separate longshore sediment transport models. "Best estimates" were determined from the results of all of the models. A beach plan evolution model was also conducted for King Point for the period 1970 to 1983. A total of 11 beach sections were delineated (Drawing No. 7.3) and longshore drift rates, beach section volume changes and beach shoreline position changes were determined. Beach plan evolution was also considered to evaluate the effect of a hypothetical structure at the boundary between beach sections 4 and 5 (Drawing No. 7.3).



Baseline Location and
Sector Definition for
Beach Plan Evolution
Model (KPCL, 1985)

M. J. O'CONNOR & ASSOCIATES LTD.

JOB No.: 10-300	DATE: 85/08/06
DRAWN BY: DSL	DWG. No.: 7.3

The relevant results of the numerical model estimates of sediment transport are contained in Appendix F. Before examining these results, it is appropriate to review some of the limitations and simplifying assumptions required to operate the model, since sediment transport modelling is at best an approximation of real physical conditions.

1. All sediment transport models determine the potential or maximum longshore transport rate which is only realized when there is an unlimited supply of sand. At King Point, the potential transport rate is probably not realized because of mixtures of gravel, sand, silt and clay with the additional influence of frozen beach materials.

2. Related to 1, in the beach plan evolution model there is an underlying assumption that all of the material eroded from the active beach face is transported as littoral material and that possible offshore loss of fine material is neglected. At King Point, eroding cliff faces contain substantial fine material and high ice contents which do not become part of beach sediments in transport.

3. Waves are refracted to a depth of 4 m using available bathymetric data. Inshore of the 4 m depth, waves are refracted to the breakpoint using plane beach refraction, assuming the contours are locally parallel to the shoreline. However, it is known that the bathymetry inshore of 4 m is not everywhere parallel to the shoreline.

4. Longshore currents are assumed to be generated only by the oblique approach of breaking waves without any consideration of wind generated currents within the coastal zone. Wind generated coastal currents can contribute significantly to longshore current speeds.

5. For the beach plan evolution model with the condition of a structure, the structure is only considered to create no transport across the boundary of the adjacent beach cells with no provision in the model for local effects of the structure. Realistic local effects would include wave diffraction, refraction, and sheltering, all of which would result in substantial modifications in the volume of erosion/deposition estimated by the model results.

The detailed results of the numerical model estimates of longshore sediment transport are presented in Appendix F. These results can be generalized to provide the following main conclusions:

1. The potential longshore transport along the coast at King Point reaches a maximum gross potential rate of approximately 200 000 m^3/a. Numerical predictions suggest that the 14 year average rate of sediment accummulation is approximately 2 to 4 times the measured rate shown in Table No. 7.5.

2. From year to year there may be more than an order of magnitude variation in the rate of longshore sediment transport.

3. From year to year there may be significant reversals in the direction of net sediment transport.

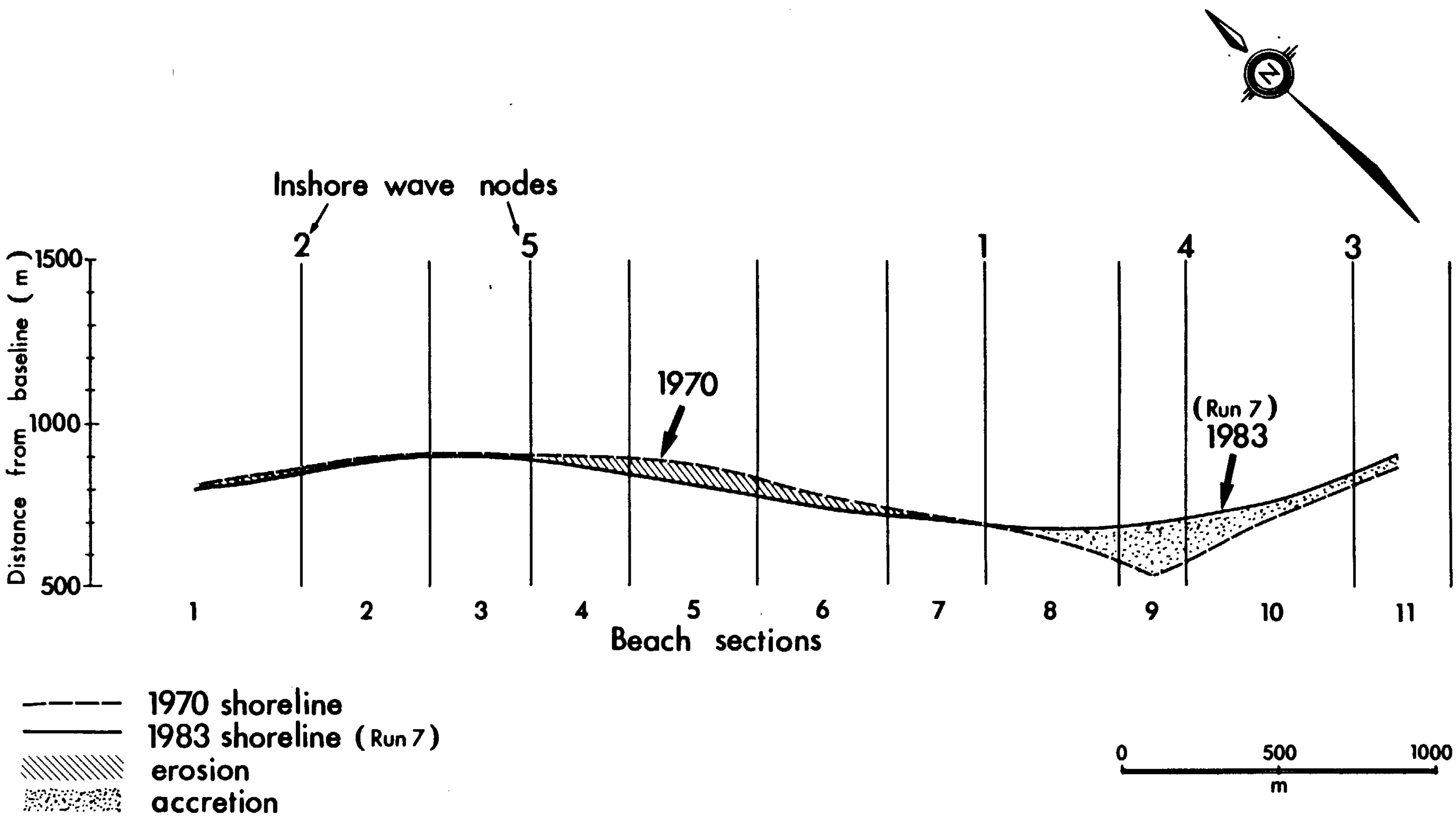
4. Longshore sediment transport predicted for the beach sections shown in Drawing No. 7.3 indicates that the directions and rates of

transport are not uniform along the King Point coastline. There is a zone of divergence of longshore sediment transport near the northwest end of the barrier bar and a zone of convergence of transport at the southeast end of the barrier bar.

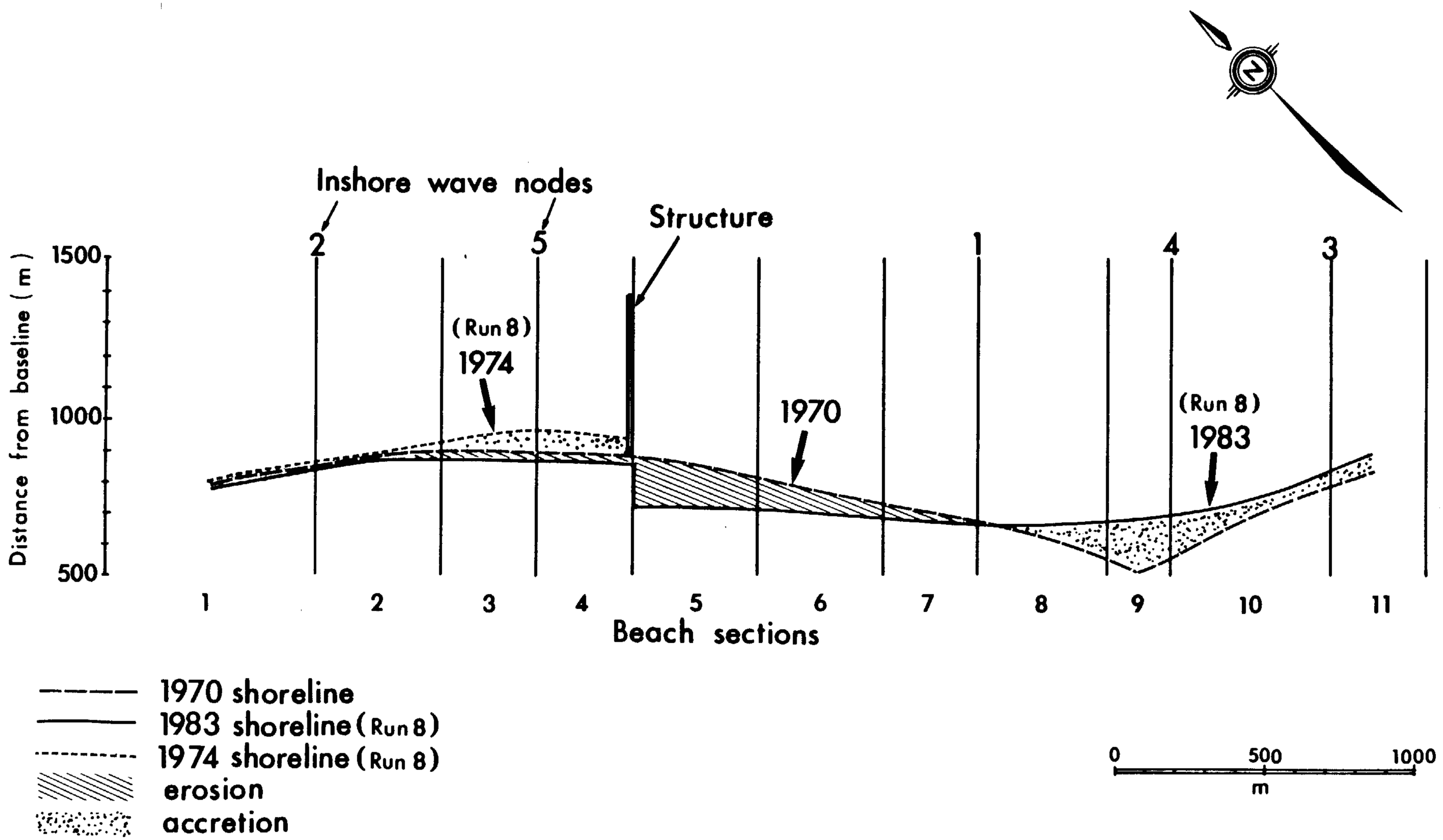
5. The results for the beach plan evolution model (see Drawing No. 7.4) conducted without a structure for the period 1970 to 1983 show erosion of the shoreline by 40 to 50 m near the northwest end of the barrier bar and deposition or progradation of 100 to 150 m on the southeast end of the barrier bar. This is similar to the measured depositional advance between 1970 and 1984 determined using aerial photographs (see Drawing No. 7.2). However, the model predicted much higher rates of erosion than the average measured rate 0.6 m/a.

6. The results for the beach plan evolution model conducted with a structure in place for the period 1970 to 1983 are presented in Drawing No. 7.5. On the northwest side of the structure, the shoreline position initially prograded to +80 m between 1970 and 1974 and then receded to -40 m from the original shoreline by 1983. On the southeast side of the structure, the shoreline position receded as much as 130 m. The predicted total accretion of sediment on the lagoon beach southeast of King Point is similar with or without the structure.

7. Although the predicted rates of longshore transport and erosion/deposition volumes are greater than those measured from actual coastal changes on air photos, the pattern of erosion/deposition is considered to be representative of the real physical system. This is substantiated by the actual accumulation of sediment at the southeast end of the barrier bar as predicted by the beach plan model for the period 1970 to 1983 (Drawing No. 7.2).



Beach Plan Evolution at King Point (1970-1983) without Structure	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-300	DATE: 85/06
	DRAWN BY: MG	DWG. No.: 7.4



Beach Plan Evolution at King Point with Structure (1970-1983)	M. J. O'CONNOR & ASSOCIATES LTD.	
	JOB No.: 10-300	DATE: 85/06
	DRAWN BY: MG	DWG. No.: 7.5

8.0 IMPACT OF PROPOSED DEVELOPMENT AT KING POINT

Future development of the King Point area must consider not only the natural environmental and physical constraints imposed by the terrestrial, coastal and marine conditions which presently exist in the area, but also how these existing conditions may be impacted by any proposed development scenario.

Several development concepts have already been proposed for King Point. Detailed engineering studies have not yet been conducted to support the proposed conceptual designs. Such studies have, however, been conducted at Stokes Point on the Yukon Coast and at McKinley Bay on the Tuktoyaktuk Peninsula, as well as at Prudhoe Bay in the Alaskan Beaufort Sea. Information obtained in these other areas has been helpful in evaluating the requirements for impact assessment in the King Point area.

8.1 Proposed Harbour and Onshore Developments

A total of 6 proposed harbour and onshore development schemes were available for review during this study:

1. Peter Kiewit Sons Co. Ltd., Phase I
2. Peter Kiewit Sons Co. Ltd., Phase II
3. Dome Petroleum Ltd., Short-term Use
4. Dome Petroleum Ltd., Long-term Development
5. Monenco, Phase I
6. Monenco, Phase II

These proposed development schemes are conceptual only and do not include design considerations developed on the basis of site specific investigations.

Drawings of the proposed development concepts are included in Appendix G. Test hole locations from the present study are plotted on the drawings in Appendix G for reference. These test hole locations were selected primarily on the basis of geological considerations rather than to provide specific information required for engineering design.

8.1.1 Peter Kiewit Sons co. Ltd., Phase I

The Phase I Kiewit proposal is intended primarily to support a rock quarrying operation. The harbour development therefore has been designed to provide facilities for bulk carrier vessel loading and a shore pad for the temporary storage of quarry products (armour stone and gravel). The proposed harbour facility consists of both a wide channel dredged to 13 m depth and extending toward shore as far as the existing 8 or 9 m depth contour, and a rock berm storage pad built on the northwest end of the barrier bar with a rock berm extension to a depth of 8 m. An access road to the site from the southeast has been sited on the existing barrier bar with additional rock berm protection beside the road.

8.1.2 Peter Kiewit Sons Co. Ltd., Phase II

In the proposed second phase the original Phase I development is significantly extended to provide multi-user port facilities on a year round basis. The Phase II harbour includes an offshore breakwater parallel to the shoreline, 2 right-angled jetties enclosing a large basin dredged to a depth of 7 to 13 m and the complete filling-in of the existing lagoon.

8.1.3 Dome Petroleum Ltd., Short-term Use

The development proposed by Dome Petroleum includes a 4 ha camp, STOL airstrip, gravel mining areas and access roads. The proposed harbour development consists of a 800 m long causeway or breakwater placed approximately perpendicular to shore and extending to a depth of 10 m. The causeway is shown as being attached to the King Point shoreline immediately west of the northwest end of the barrier bar. The causeway is oriented to shelter vessels from north to northwest waves. The existing barrier bar is shown as unaltered in this proposal.

8.1.4 Dome Petroleum Ltd., Long-term Development

This expanded proposal includes a 2100 m airstrip, 16 ha camp, and extended access roads to facilitate both gravel mining and rock quarrying operations. The proposed harbour development consists of a causeway extending 2200 m offshore into depths of approximately 20 m and an additional offshore breakwater oriented to shelter vessels from waves from the north-northeast to easterly directions. The barrier bar is also cut through at its northwest end to allow access to a shallow draft mooring basin within the existing lagoon.

8.1.5 Monenco, Phase I

This development scheme proposes to utilize the King Point lagoon as a harbour. The proposed harbour development includes a dredged channel extending perpendicular to the shoreline from the 20 m depth contour which cuts across the existing barrier bar into the lagoon. The channel is to be dredged to a depth of 13 m(?). It is not clear at the present time whether or not the dredged channel has protective berms along its sides. For the present study, it was assumed that there are no berms and that the only modification of the seafloor is a dredged channel.

The proposed onshore development includes administration, warehousing, maintenance and support facilities with a heliport and STOL airstrip. An access road is planned from the harbour to the airstrip, a distance of approximately 3.5 km onshore.

8.1.6 Monenco, Phase II

This proposal includes a large scale airport, townsite and harbour development. The proposed harbour development includes the dredged channel of Phase I and two large "dog leg" jetties or breakwaters which are attached to the shore and extend offshore to terminate in water depths between 10 and 15 m. It is assumed that the two jetties are primarily designed to shelter the harbour from Beaufort Sea wave activity, although there is a relatively large opening remaining between the ends of the two jetties. The jetties may also be intended to trap sand and gravel beach sediment on each side of the harbour and reduce channel maintenance dredging costs.

8.2 Considerations Related to Coastal and Offshore Development

8.2.1 Impact of Coastal Processes on Harbour Developments

Harbour siting facilities at King Point may be designed only after the impact of both marine and coastal processes on the development have been carefully evaluated. Although the paucity of coastal information at King Point presently precludes the detailed assessment of any site specific conditions, it is possible to make some general statements regarding the potential impacts to be considered.

Waves, currents, sea ice floes and storm surges are but some of the marine parameters to be evaluated in more detail before development proceeds. From a coastal process viewpoint, chronic erosion of the unconsolidated cliff sediments must remain a major consideration for any long-term development of the area. The numerical analyses suggest that erosion rates may be significantly accelerated adjacent to jetties constructed perpendicular to the shoreline.

Harbour development must also take into account the potential impact of longshore sediment transport which may result in accumulation of material at the jetties, in dredged channels, and in harbour basins. This is particularly important for those scenarios which include the construction of a dredged channel into the King Point lagoon as part of the initial phase. Longshore sediment transport is so substantial that it may not be feasible to satisfactorily maintain such a channel without the benefit of protective jetties.

Dredged channels which extend offshore beyond the 17 m isobath will likely require ongoing maintenance as they may be infilled with fine-grained sediments originating from the MacKenzie Delta. At present, the geological evidence suggests that erosion/accumulation rates vary directly with distance from the shoreline. It is doubtful, however, whether these same relationships will be maintained once development is initiated. It is not possible, therefore, to predict either the optimum orientation or location for channel dredging without first conducting more detailed modelling using site specific coastal parameters.

Development scenarios which propose to use the barrier bar of the King Point lagoon for access should take into account the effects of grounded nearshore ice, ice ridging and ice push on the adjacent beaches. In addition, consideration should be given to the impact of erosion/deposition on the barrier bar itself caused by overwash channels arising during storm surges. Such erosion may reduce the serviceability of access roads constructed on the barrier bar.

8.2.2 Impact of Harbour Developments on Coastal Processes

The impact of harbour developments on the coastal processes themselves must also be considered prior to construction. While detailed coastal studies have not been conducted during the present investigation, it is again possible to make some general statements based on the range of engineering structures noted in the proposed development scenarios.

The most significant effect of any harbour development on coastal processes is envisaged to be the modification of the longshore sediment transport regime, resulting in concomitant alteration of the existing sites of sediment erosion and deposition. The construction of harbour jetties, causeways or breakwaters, for example, will form partial or total barriers to the longshore transport of sediment which now occurs from both the northwest and southeast directions. Beach sediment may initially be trapped at the base of engineering structures, gradually accumulating wide curved beaches on the outside of the harbour jetties. Conversely, one side of the harbour structures may become starved of the natural transport of sediment and hence may become a site of erosion. Sediment will also tend to accumulate in unprotected dredged channels and mooring basins. Exactly where these sites of erosion and deposition will occur, and to what extent this impact will develop, will vary with the various harbour plan configurations. The effects can be mitigated through alteration of the design of the engineering structures or operational maintenance procedures (for example, beach sediment bypassing, beach feeding, or beach sediment extraction), but it is clear that substantial additional work is necessary to understand the present coastal regime in more detail, before such design measures can be proposed.

Construction of access roads on the barrier bar and the proposed infilling of the lagoon are not expected to have any significant impact on the coastal processes.

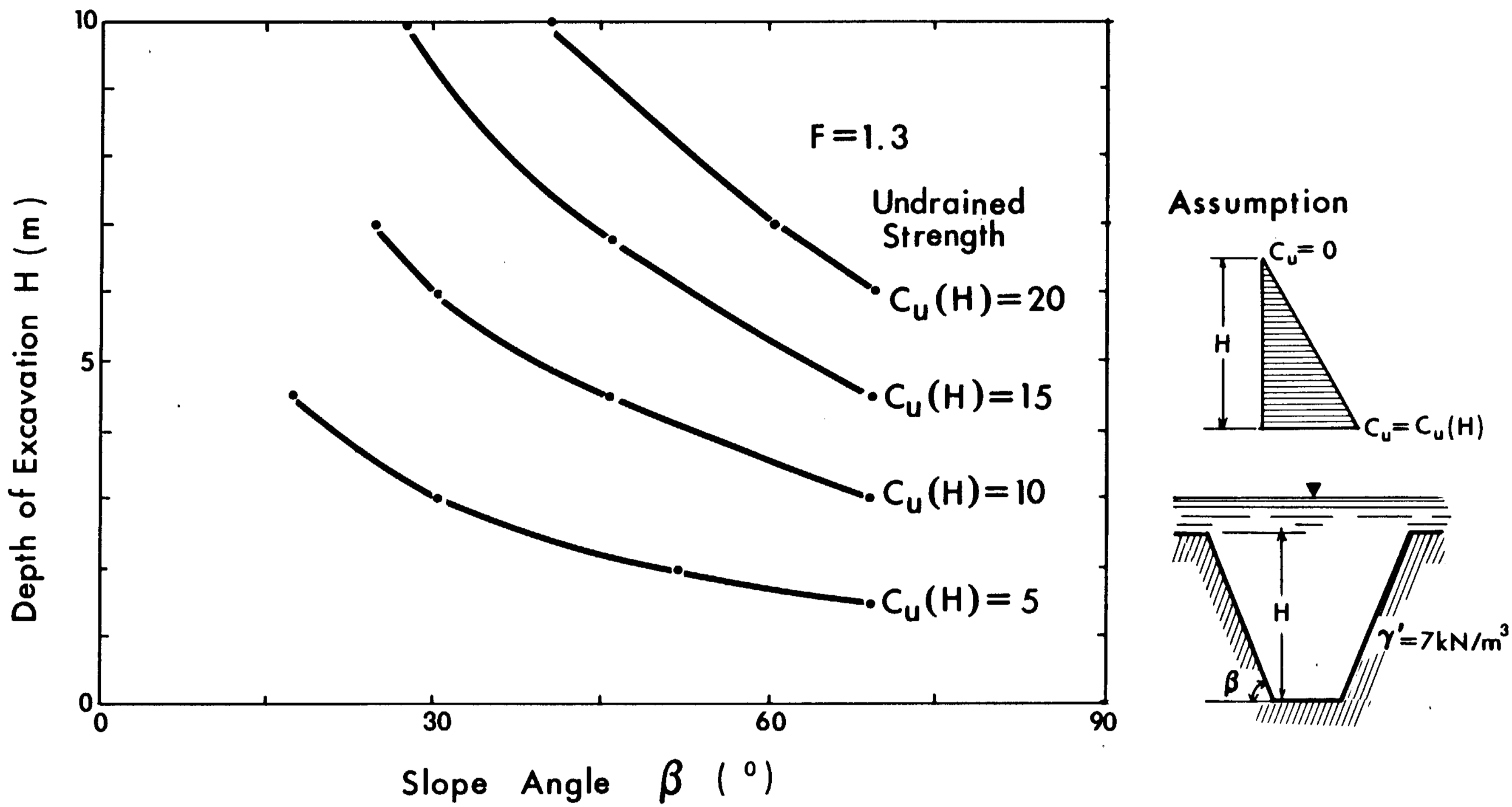
8.2.3 Dredging Conditions

Nearshore dredging operations at King Point may expect to encounter pre-Holocene (Unit C) sediments having firm to very stiff consistencies both at the seabed and at depth within approximately 1.7 km from shore (to about the 17 m water depth). As described in Section 6.3, the sediments are mainly fine grained silts and clays, but coarse grained sands and gravels are also present at locations noted on the borehole logs. Ice-bonded sediments may be encountered within the anticipated dredging depths, particularly close to shore. These may impede dredging rates. Very soft to soft sediments were only identified in boreholes located beyond the 17 m isobath. These latter surficial sediments exhibit such low undrained shear strengths that slope stability considerations may form an important part of any deep water dredging programme.

Although only limited strength information was obtained for the offshore sediments, results of theoretical slope stability analyses for a range of soil strengths are presented below to permit preliminary assessment of possible dredging requirements for channels and mooring basins at King Point.

The short-term and long-term stability of submarine trench slopes for varying soil strengths are presented in Drawings No. 8.1 and 8.2, respectively. Although the conditions assumed for these analyses are of necessity idealized, the results indicate that stable slope angles for long-term (drained) conditions are shallower and therefore more critical than those for short-term (undrained) conditions.

The theoretical short-term stability of temporary excavations in sediments whose undrained strength profiles increase linearly with depth depends both on the slope angle and the depth of excavation as indicated in Drawing No. 8.1. Under such assumptions, Drawing No. 8.1 demonstrates that trenches may be dredged to a minimum depth of 4.5 m even in sediments where the undrained shear strength does not exceed 5 kPa, but the stable slope angles then become quite flat. Steeper temporary slopes may be excavated in soils with slightly higher



Short-Term Stability of Submerged Trench Slopes in Cohesive Sediments	M. J. O'CONNOR & ASSOCIATES LTD.	
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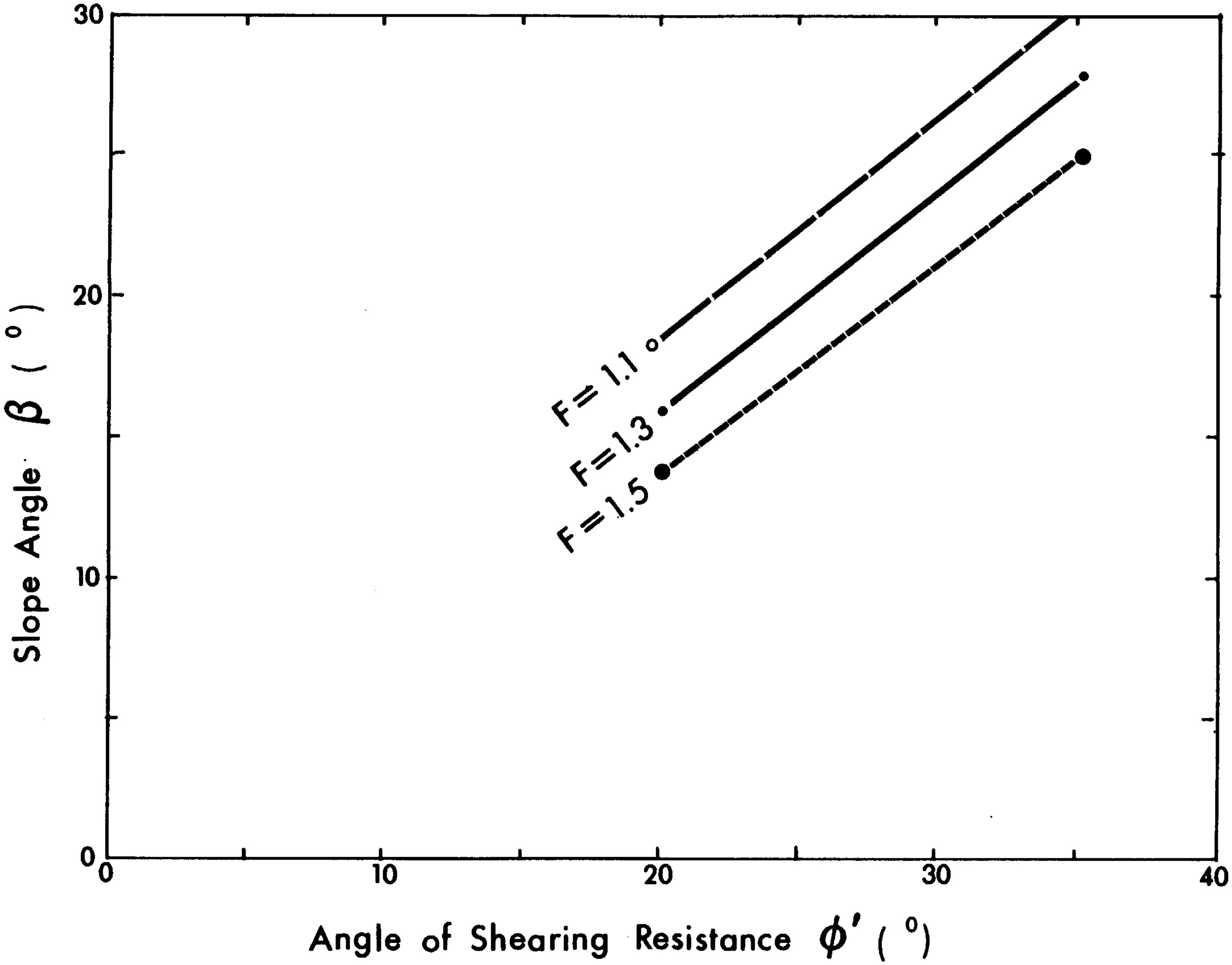

Frictional Stability of
Submerged Trench Slopes

M. J. O'CONNOR & ASSOCIATES LTD.

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strengths: e.g. a 4.5 m deep cut has a factor of safety (F) of 1.3 against failure at a slope of 45° if $c_u(H)$ = 10 kPa, while 70° slopes are stable for the same trench depth if $c_u(H)$ = 15 kPa.

For permanent submerged cut slopes in cohesive or cohesionless materials (under fully drained conditions), slope stability depends on the frictional shearing resistance of the soil, but is independent of the depth of excavation. Drawing No. 8.2 shows the variation of stable slope angles with the angle of shearing resistance for factors of safety ranging from 1.1 to 1.5. For soils with $c' = 0$ and $\phi' = 25°$, a permanent slope angle of 20° has a factor of safety of 1.3.

8.2.4 Offshore and Coastal Foundation Conditions

Foundation conditions are generally considered to be suitable for marine structures located within about 1.7 km of the coastline and founded on firm to very stiff Unit C sediments. Soft, recent marine (Unit A) sediments which blanket the older Unit C materials further offshore are not considered to be competent foundation materials since they are highly compressible and have relatively low shear strengths. The thickness of the Unit A sediments generally increases with distance from the shoreline. Recent depositional sediments nearshore (within about 100 m) comprising the beaches and barrier bar (Unit B sediments) are mainly coarse grained materials in a loose to compact state. Because the Unit B materials are generally loose and well sorted (poorly graded), they probably will not support major structures or heavy traffic loading, but should provide adequate support for earth fill berms and light traffic loading. The thermal interaction of coastal and offshore structures with the permafrost-affected sediments which presently exist near the seabed must be considered during detailed engineering design since thaw-weakening may result if the subsea permafrost is degraded. Although massive ice was not encountered in either the coastal or offshore test holes, ice-bonded sediments, some containing visible ice, were present.

Unfrozen, compressible sediments which are present at the base of the King Point lagoon are not competent foundation materials. The thickness of these relatively soft sub-lagoonal sediments is variable, but generally appears to be greater in the southern part of the lagoon than in the northern sector.

8.2.5 Lagoon Backfill

Infilling of the King Point lagoon with dredged fill and quarried rock has been proposed to provide a level pad and working area for stockpiling aggregate. Based on the results of this study, it is anticipated that infilling of the lagoon may cause significant consolidation of the unfrozen, fine grained sediments, both during and after fill placement. The magnitude of consolidation settlement is expected to be greater in the southern sector of the lagoon (near borehole F85KF10) than in the northern sector in the vicinity of borehole F85KM3 due to the greater thickness of soft sediments in the former area. Time-dependent settlement of these sediments may introduce a requirement for on-going maintenance of the area, including filling and regrading.

Infilling of the lagoon is expected to alter the thermal regime in the underlying materials resulting in potential aggradation of permafrost into the sub-lagoonal sediments and eventually into the lagoon backfill. Although freezing may reduce the compressibility of these sediments, frost heave would also be expected to cause significant differential surface deformations, resulting in on-going maintenance requirements for surface facilities in the area.

8.2.6 Lagoon Dredging

The Monenco development scheme which proposes to utilize the lagoon as a harbour would require excavation of a channel through the barrier bar and dredging of the sub-lagoonal sediments. While it is apparent that dredging the lagoon will alter both the salinity of the lagoonal waters and the thermal regime in the underlying sediments, the impact of these changes is not clear at the present time. Further investigation and mathematical modelling studies should be conducted to investigate the impact of specific dredging limits on the stability of the adjacent terrain.

8.3 Engineering Considerations Related to Onshore Development

The proposed development schemes involve the construction of roads, an airstrip, housing, warehouses, shop structures and other related onshore support facilities for both quarrying and marine operations.

Construction of such facilities will require the exploitation of local aggregate sources. The Kiewit Phase II proposal includes infilling of the existing lagoon with dredged materials and quarried rock. The location and detailed design of all onshore facilities for any such development must include careful consideration of site stratigraphy, the ground thermal regime, the distribution of ground ice and the implications of thaw-induced subsidence or slope movements as well as ground surface conditions.

Engineering considerations related to onshore development are outlined in the following subsections.

8.3.1 General

The results of the present subsurface investigation, in conjunction with airphoto interpretation and information derived from previous studies, provide an overview of the nature and distribution of the terrain units within the study area. A total of 9 generic units were identified within the onshore study area. As Table No. H-1 demonstrates, these 9 units were further subdivided on the basis of geomorphology, stratigraphy, material types, ground ice, natural processes and engineering properties into 23 terrain units. Natural hazards and general engineering properties of each of the terrain units are summarized in Table No. H-1.

Several characteristics of the various terrain units near King Point are of interest with respect to future engineering and site development considerations. Of particular importance are the following:

1. Permafrost is ubiquitous in the onshore area. The limited amount of reliable thermal data indicates that onshore permafrost temperatures within the upper 20 m of the ground surface range from about -13°C to -8°C.

2. Near surface, ice-rich materials occur in most areas. Ice wedges, some of which are active, are common. Those units that are poorly drained, such as the organic, lacustrine and alluvial deposits, are most prone to shallow thaw subsidence when their surfaces are disturbed, although significant subsidence may also occur due to melting of well drained ice-rich materials.

3. Massive segregated ice occurs principally at depth within the morainal and glaciofluvial units. The presence of large thermokarst depressions indicates that these units are susceptible to thaw subsidence if thermally disturbed.

4. Taliks penetrating the permafrost probably occur under the Babbage River and very large lakes in the area. The base of the permafrost is believed to rise under the larger lacustrine plains and the present-day Deep Creek channel.

5. Retrogressive-thaw flow-slides, both active and inactive, occur on scarps and steep slopes in ice-rich materials which have exposed cores of massive ice or ice-rich sediments, particularly along Deep Creek and along the coast.

6. The best potential sources of granular material are the glaciofluvial deposits. The glaciofluvial apron west of King Point, in particular, is a potential source of aggregate. Some fine-grained ice-rich material will necessarily have to be removed from these deposits to facilitate their exploitation.

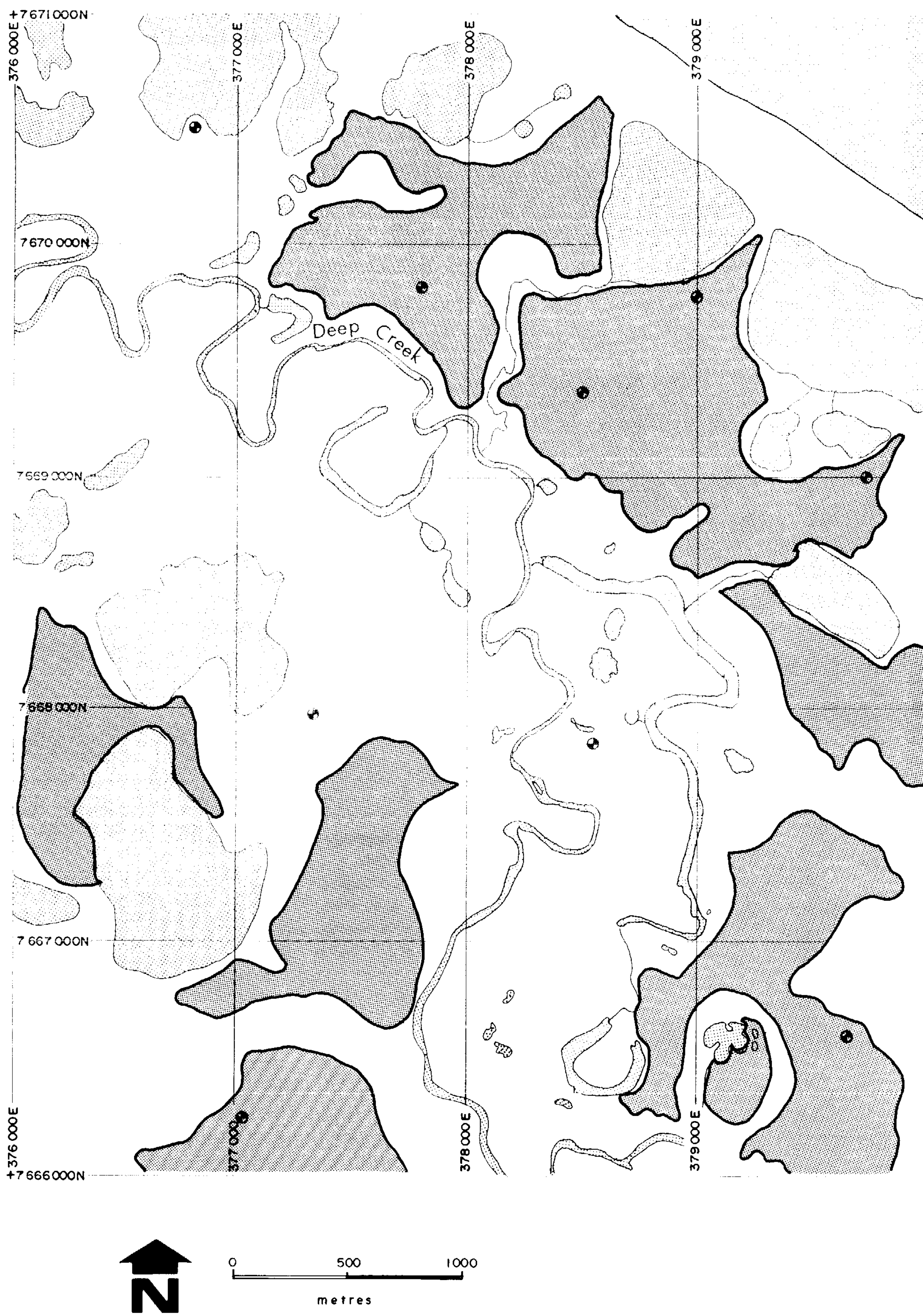
7. The perimarine and rock units have low ground ice contents and are relatively stable with respect to thaw settlement. Massive ground ice within the glaciofluvial and morainal deposits may become unstable if thawed. Surficial deposits comprised of organic, colluvial, alluvial and lacustrine sediments are generally ice-rich, poorly drained and compressible when thawed.

Detailed information on subgrade conditions and terrain types is of particular importance when selecting locations for structures, airstrips and road alignments. Although detailed engineering information was not collected during the present study, the preliminary engineering and geological information that was obtained demonstrates clearly that some terrain units should be avoided, whereas construction may proceed in others provided that the design includes appropriate measures to mitigate the envisaged environmental and physical constraints. Potential problem areas are identified in the following sections.

8.3.2 Engineering Constraints to Development

Areas where constraints to site development are believed to exist are delineated on Drawings No. 8.3 to 8.5, inclusive. The major constraints which arise both from unstable foundation conditions and natural hazards include:

1. near-surface ice-rich sediments;
2. massive ground ice;
3. taliks;
4. thaw-unstable slopes; and
5. poor surface drainage.



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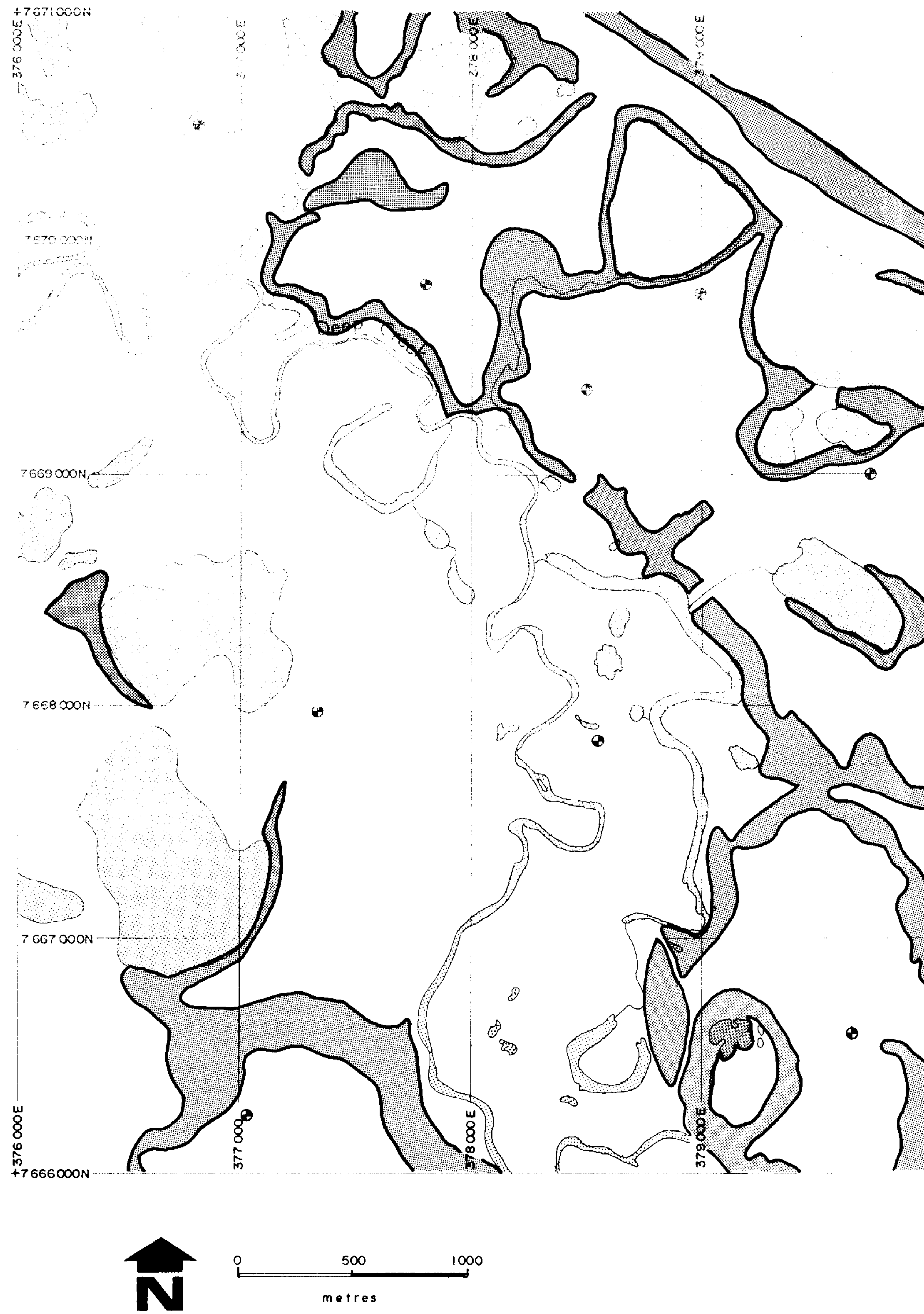

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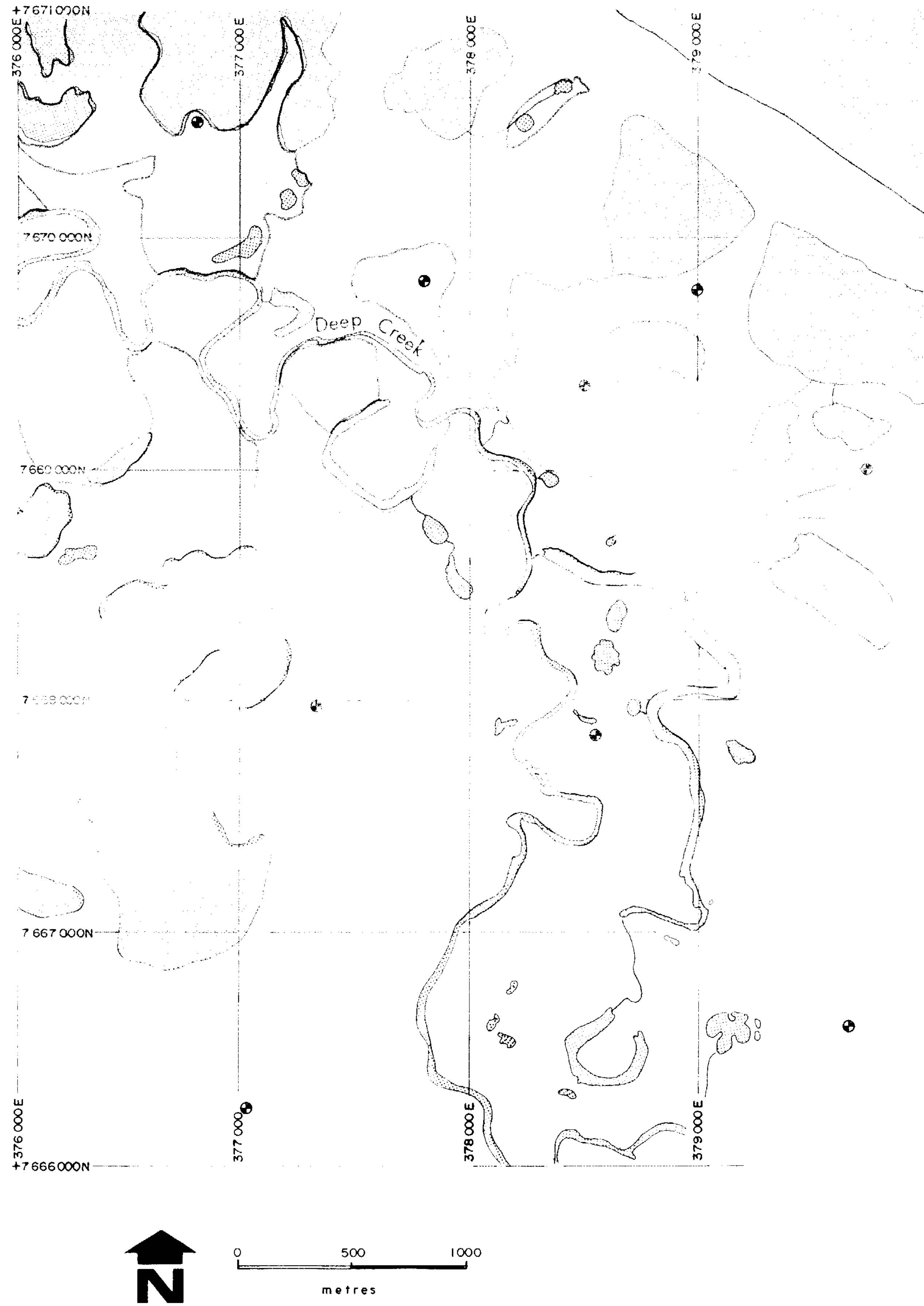

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The terrain units in which these constraints are prevalent were described in Section 5.0 and are summarized below.

Subsidence due to surficial terrain disturbance may occur in units containing near-surface ice-rich sediments, namely the colluvial, alluvial, organic (peat) and particularly the lacustrine deposits, where surface drainage is poor.

Ice-rich materials and massive ice occur at depth within the morainal and glaciofluvial deposits. Areas where these deposits are present in the study area are delineated on Drawing No. 8.3. Induced thawing of massive ice may result in much greater subsidence than that of the near surface ice-rich sediments, but more significant terrain disturbance may be required to activate thaw subsidence in these materials. These units are most vulnerable to thaw degradation along natural and cut slopes where massive ice and ice-rich sediments may be exposed or may only be capped by a thin cover of soil. Removal of this protective soil cover may initiate thawing and instability.

Taliks under the major lakes in the area (as well as the King Point lagoon) may include soft or weak sediments which provide poor foundation support. Drainage or backfilling of these lakes will result in aggradation of the permafrost along with potential frost heave and uplift of surface facilities.

Retrogressive-thaw flow-slides and other landslides are most prominent in the morainal units, but also occur to a lesser degree in the glaciofluvial and perimarine units adjacent to the coast. Most other terrain units are not particularly susceptible to mass wasting because the scarps or steep slopes developed on these other units are not underlain by massive ice. The occurrence of retrogressive-thaw flow-slides is limited in the glaciofluvial materials because the gravel cover is well drained and relatively stable even when thawed. Disturbance of these slopes may, however, activate retrogressive-thaw flow-slides if significant volumes of ground ice are present. Similarly, any scarp covered by colluvium may be ice-rich and prone to the development of retrogressive-thaw flow-slides, especially if it is underlain by massive ice. On long slopes underlain by morainal or colluvial deposits, superficial failure and sediment flow may occur if the ice-rich near-surface materials are thawed. Potentially unstable slopes in the study area are shown on Drawing No. 8.4.

Wet areas which have been delineated on Drawing No. 8.5 and on the terrain map (Drawing No. H-2) are considered to be poor prospects for site development because of inadequate drainage, as evidenced by the abundance of standing surface water. This water may flow along ice wedges if thawing of the wedges is initiated and a polygonal system of gullies may then develop. In many areas, it may be possible to improve the surface drainage conditions in conjunction with the development.

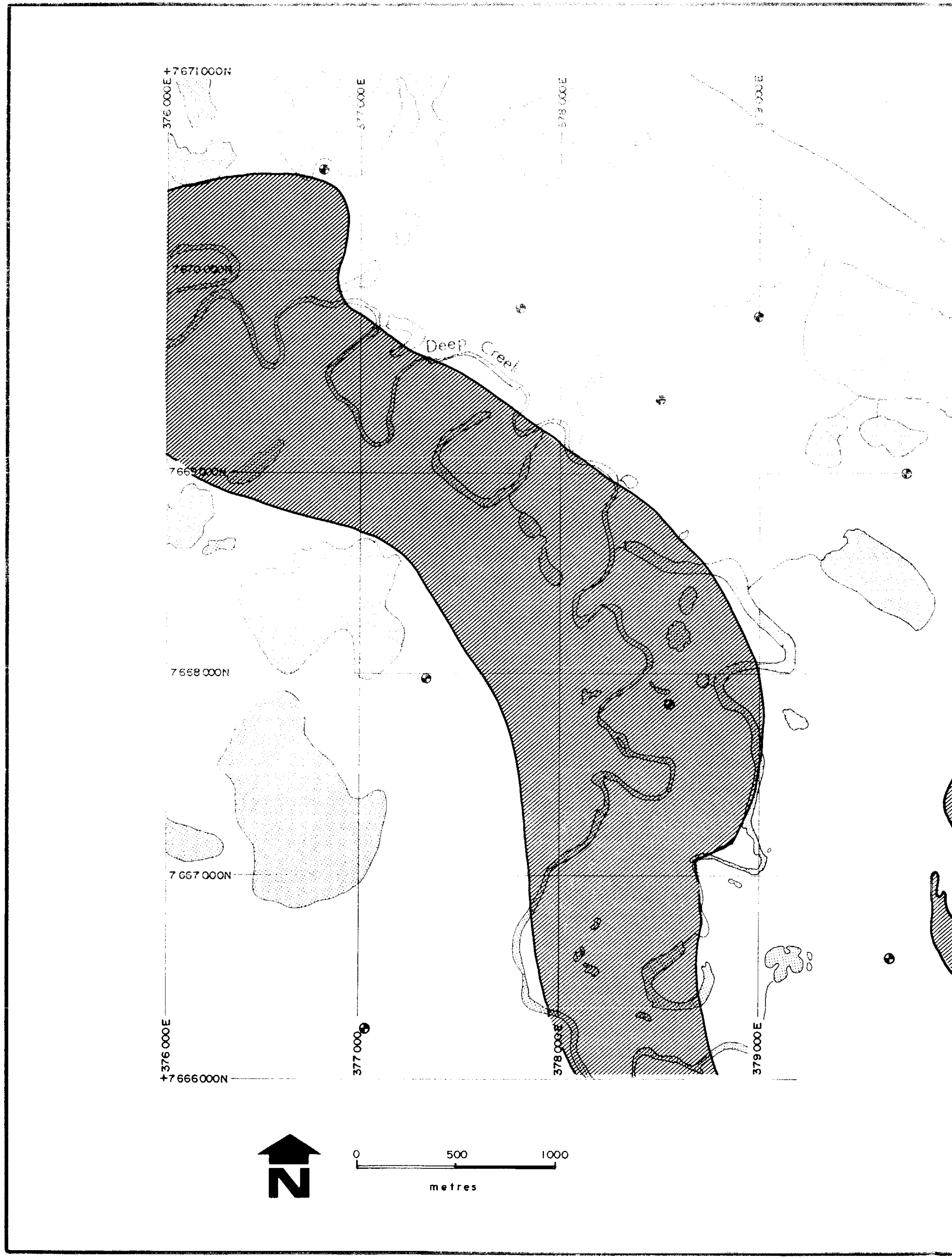
In general, the units least susceptible to thaw induced weakening and settlement are the perimarine and rock deposits. Notwithstanding the presence of near-surface ice-rich sediments overlying the lacustrine deposits, the geotechnical constraints to development in these areas are considered to be minimal provided that measures are implemented to limit surface disturbance. The onshore areas with minimal geotechnical constraints to development are shown on Drawing No. 8.6.

Development within the Deep Creek Valley, indicated on Drawing No. 8.6 as an area where minimal geotechnical constraints exist, would of course be contingent upon detailed evaluation of arctic hydrology considerations such as flood hazards, talik distribution and potential icings.

8.3.3 Foundation Conditions

It is important that the site development proceed in accordance with well planned construction procedures designed to minimize surface disturbance because of the widespread distribution of ice-rich surficial sediments. Engineered fills for roadways, airstrips and building pads should be designed to limit potential thawing of the natural subgrade materials based on consideration of long-term thermal interaction between the surface facilities and subgrade. Pile foundations are generally preferrable to other types of foundation support in most areas.

Major structures and surface facilities should generally not be located in areas underlain by massive ice. Similarly, road-cuts should not be excavated through terrain units containing massive ice or ice-rich sediments. Where such construction activities are deemed unavoidable, specially designed mitigative measures such as insulation and slope protection will be required. Such measures may have significant cost impacts on the development.



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Drainage and/or backfilling of lakes should be avoided or should only be carried out subject to recognition that the resulting alteration of the ground thermal regime may cause permafrost aggradation into the lake bed sediments and possible frost heave effects.

8.3.4 Natural Hazards

The locations selected for surface facilities and structures should generally avoid steep natural slopes in areas prone to thaw induced instability. If access road alignments unavoidably intersect such areas, special precautions must be implemented to limit possible surface disturbance and thawing. Facilities located adjacent to active retrogressive-thaw flow-slides along the coast must be set back from the slope to areas which will not be affected by the landslide activity during their required operating lives.

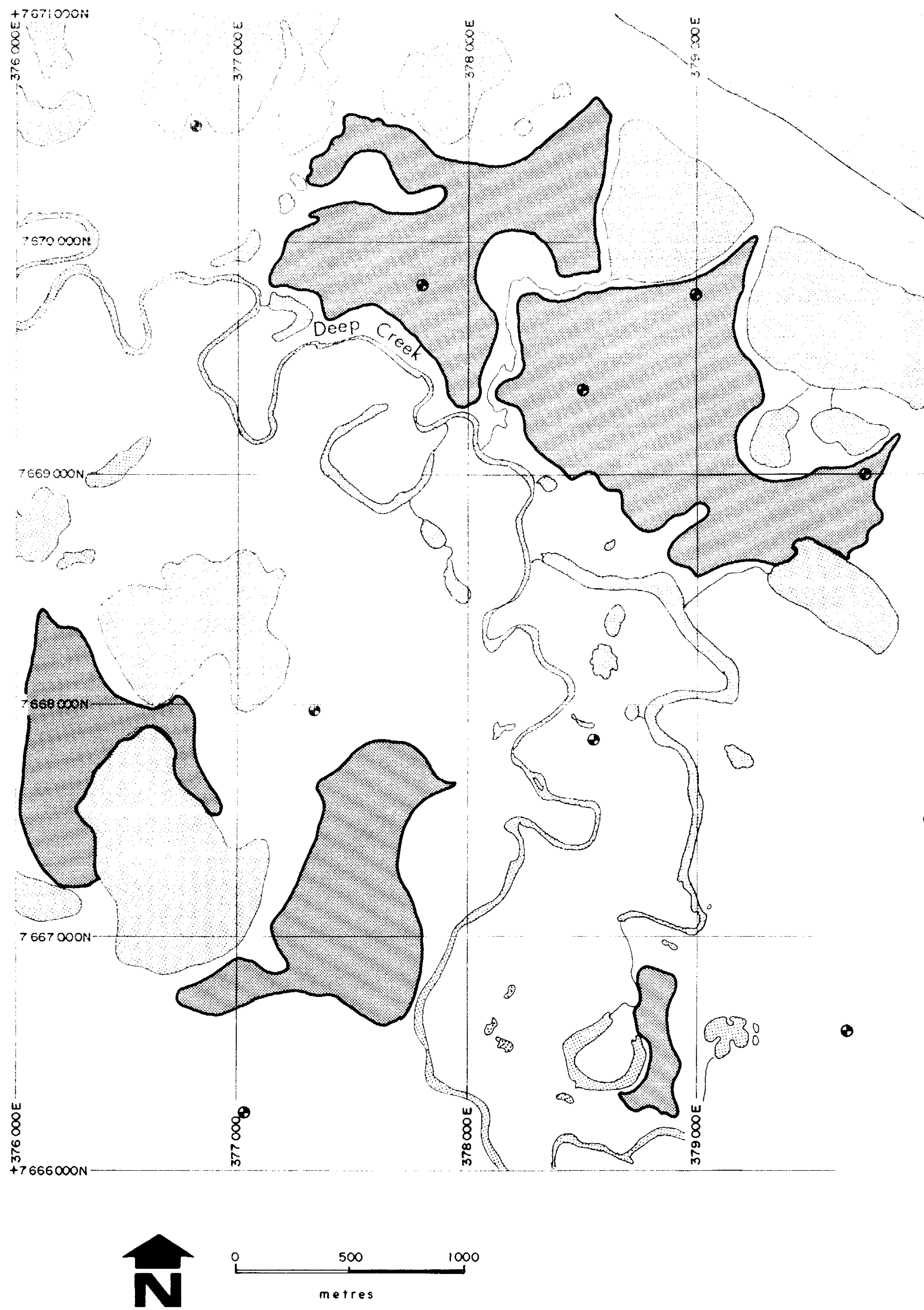
Development in areas where surface drainage is poor should be avoided if possible because the surficial sediments in these areas are usually ice-rich and susceptible to thaw subsidence. Wet areas are particularly susceptible to thaw degradation if the protective cover is disturbed. Development in these areas is feasible only if specific design features and construction procedures are implemented to minimize potential disturbance.

8.3.5 Prospective Granular Resource Deposits

Several prospective sources of granular materials have been identified within the onshore study area during previous investigations. Several other granular deposits (alluvial terraces, floodplains, fans) are generally considered to be unsuitable for exploitation because of their small size or poor quality.

The large glaciofluvial deposits appear to be the best potential sources of sand and gravel within the area. These prospects are delineated on Drawing No. 8.7. It has been estimated that the glaciofluvial apron located due west of King Point (near borehole F85KM31) contains approximately 4 500 000 m^3 of accessible sand and gravel (Deposit No. Y70, R. M. Hardy & Associates Ltd., 1977). Samples taken from test pits excavated in the active layer of this glaciofluvial deposit were classified as well graded to poorly graded gravels. Boreholes through this same deposit (BH F85KM27, 28, 31 and 32) intersected stratified glaciofluvial material consisting of 2 to 9 m of silty gravel overlying 0 to 5 m of silty, well graded sand, and 2 to 6 m of well graded sand and gravel which contained occasional silt beds. Exploitation of these deposits would necessitate the removal of several metres of ice-rich surface materials (2 to 14 m) and may be expected to cause thawing of the underlying massive ice.

Glaciofluvial deposits in terraces generally contain too much fine grained silt to be utilized as aggregate according to a report prepared by Klohn Leonoff Consultants Ltd. (1975) for Esso Canada Resources Ltd. Nevertheless, materials from these deposits may be suitable for some purposes such as road sub-base fill, building pads and general fill. It is estimated that approximately 2 000 000 m^3 of such granular materials may be available in glaciofluvial terrace deposits shown to the southwest of Deep Creek on Drawing No. 8.7 and on Drawing No. H-2 in Appendix H.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A stratum of well graded gravel and sand 8.7 m in thickness was encountered in a terraced glaciofluvial deposit, located near the southwest boundary of the area, during the study conducted by R. M. Hardy & Associates Ltd.(1977) (hole N75-117D-B13-A). This deposit contains an estimated volume of 1 000 000 m^3. Ice-rich material underlies this deposit. Small areas of glaciofluvial materials denoted as GH or GR on Drawing No. H-2 may also provide easily accessible local sources of aggregate, although the available volumes of material in these deposits may be very limited.

A deposit of sandstone debris overlain by colluvial veneer in the southern part of the area (hole N75-117A-B1-1 on Drawing No. H-2) may be suitable for general fill and building pads, according to R. M. Hardy & Associates Ltd. (1977). The estimated volume of material which is accessible without blasting in this area is 1 000 000 m^3.

Marine beach deposits contain fair to good quality granular aggregate materials. R. M. Hardy & Associates Ltd. (1977) tested samples of material from the King Point barrier bar (Deposit Y72) for suitability as concrete aggregate and found it to be of fair quality. The total estimated volume of granular material comprising the beaches and barrier bar within the map area is 4 000 000 m^3. Removal of the beach materials fronting the coastal cliffs may not be acceptable because of the potential for accelerated coastal retreat. Restoration of the barrier bar with time by natural long shore transport is conceivable, however, random removal of this material might also significantly affect the present rate and pattern of coastal erosion.

A deposit of preglacial gravels and sands along the coastal escarpment immediately northwest of King Point which was designated as Deposit Y71 by R. M. Hardy & Associates Ltd. (1977) contains approximately 1 500 000 m^3 of granular material. It may be difficult to segregate clean sands and gravels during excavation because of the stratified nature of this deposit. Mitigative measures would also be required to minimize the effects of accelerated coastal erosion following removal of this material.

Some ridges of sand and gravel occur within the perimarine units. Although the quality of these materials is probably suitable for general site development purposes, the lateral extent of these deposits is limited because of their steep inclinations. Furthermore, they are generally covered by appreciable depths of organic and fine grained materials (for example see the logs of boreholes F85KM21 and KMF8526). Exploitation of these perimarine materials may, therefore, not be practical.

In summary, there appear to be substantial volumes of granular resources which are suitable for the envisaged site development of King Point. Although the deposits which have been identified contain more than 14 000 000 m^3 of granular materials, exploitation of some of these resources may not be practically feasible. Present projections indicate that only about 50% of this total volume may ultimately be available for exploitation. The glaciofluvial apron deposits are considered to be the most readily accessible sources of suitable quality granular materials.

8.4 Summary

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 based on the results of the present study. Although a number of environmental and physical constraints to development have been identified, it is recognized that the potentially adverse effects of development can be mitigated by implementing the appropriate site selection and engineering design procedures.

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

1. Erosion of unconsolidated cliff sediments.
2. Accumulation of sediment adjacent to structures, in dredged channels and mooring basins.
3. Nearshore ice conditions.
4. Dredgability of stiff and/or ice-bonded sediments.
5. Stability of submarine trench slopes.
6. Offshore and coastal foundation conditions.
7. Impact of backfilling the coastal lagoon.
8. Impact of dredging lagoonal sediments and breaching the barrier bar.

Following are the major factors identified during the present study which may constrain onshore development:

1. Potential instability of foundations due to:

   a) thermal degradation of near-surface ice-rich sediments or massive ground ice;

   b) permafrost aggradation into drained or infilled lake basins.

2. Natural hazards such as:

   a) landslides (thaw-unstable slopes); and

   b) poor surface drainage.

3. The accessibility of granular resources for development.

9.0 SUMMARY AND CONCLUSIONS

9.1 Offshore Geotechnical Studies

9.1.1 Gravel, sand, silt and clay materials were encountered at the seabed in geotechnical boreholes drilled to a distance of approximately 1.7 km from the coastline. All sediments appear to have dense or firm to very stiff consistencies, and are believed to represent materials exposed by coastal erosion during the most recent marine transgression (Unit C). Further offshore this older stratigraphic unit has been blanketed by very soft to soft, recent marine, high plastic clay (Unit A).

9.1.2 Relatively slow dredging rates may be anticipated when excavating channels or deepening harbours founded in the older, stiffer sediments or in ice-bonded sediments. Slope stability considerations may form an important part of the dredging process for excavations founded in the soft recent marine sediments further offshore.

9.1.3 Although massive ice was not encountered in either the offshore boreholes or the coastal boreholes, some of the shallow nearshore sediments and sediments underlying the barrier bar are known to be ice-bonded and contain visible ice. The in situ strength of the nearshore sediments may be due, in part, to the presence of this ice-bonding. Degradation of the subsea permafrost may therefore be expected to result in some thaw weakening of these materials.

9.1.4 Thus, while existing foundation conditions are generally believed to be suitable for marine structures placed within 1.7 km of the coastline, engineering design must consider the thermal interaction of the structures with the permafrost-affected sediments which presently exist at or near the seabed.

9.2 Coastal Studies

9.2.1 Unfrozen, compressible sediments were identified at the base of the King Point lagoon in boreholes drilled during the present investigation. It is apparent that infilling of the lagoon may result in significant consolidation of these sediments and also time-dependent settlement of the fill. It is also anticipated that backfilling of the lagoon may result in aggradation of permafrost into the sub-lagoonal sediments and the backfill. While freezing of the soft sediments may reduce their compressibility, it may also cause frost heave and uplift of surface facilities supported on the backfill. Further investigation and analyses are required to determine whether dredging in the lagoon will have a significant effect on the thermal regime and stability of the sub-lagoonal sediments.

9.2.2 The limited drilling conducted in the lagoon has demonstrated that soil conditions are somewhat different in the north half than they are in the south half. It is postulated that the present lagoon may have formed when 2 adjacent thaw depressions were interconnected. The sequence of formation of these thaw depressions and the subsequent marine transgression has a bearing on existing subsurface conditions and on the estimated historical rates of sediment transport and deposition. More detailed drilling and sediment dating studies must be carried out before the morphology of the lagoon is known in sufficient engineering detail for development purposes.

9.2.3 Coastal processes along the Yukon coast of the Beaufort Sea and in the vicinity of King Point are characterized by common erosional cliffed coastal sections with unique mass-wasting processes. This mass wasting has resulted in ongoing seasonal coastal erosion. The rate of erosion at individual sites is highly variable[1], but averages approximately 0.6 m/a in the study area. The impact of coastal structures on the processes must be considered during the design and layout of harbour developments.

9.2.4 Coastal processes of sediment erosion, transport and deposition in the vicinity of King Point all display a high amount of variability from year to year. Longshore sediment transport at King Point occurs in both directions, with a gross average amount of 20 000 to 40 000 m^3/a. The dominant source of beach and barrier bar sediments is coastal cliff erosion with insignificant amounts of sediment derived from river sources. The locus of deposition of sediment at King Point has moved southeastward with the rapid evolution of the former King Point spit into a barrier bar.

9.2.5 It is anticipated that the impact of coastal processes on harbour development at King Point will be significant. This impact will primarily take the form of a local alteration in longshore sediment transport rates which will in turn create sites of erosion and deposition. The effects of these changes can be mitigated by incorporating appropriate design features in the engineering structures and by implementing suitable operational maintenance procedures.

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1. The average rate of retreat of thaw flow slides measured in the the vicinity of King Point is about 5 to 6 m/a from 1954 to 1985 (personal communication with S.R. Dallimore, 1985).

9.2.6 It is also anticipated that the proposed harbour developments will cause substantial accumulation of sediments in harbour basins or channels which have been artificially deepened by dredging. These areas will require ongoing maintenance.

9.2.7 Instability of the ice-rich cliffs along the King Point shoreline must be considered a significant environmental constraint to coastal harbour developments. Other marine environmental constraints include sea ice flows, exposure to waves and storm surges.

9.2.8 The available coastal process data in the vicinity of King Point is presently very limited. Substantial additional coastal information will have to be obtained before a more detailed assessment of the potential impact of harbour developments can be made.

9.3 Onshore Geotechnical Studies

9.3.1 More than 80% of the onshore strata encountered in the boreholes consist of silt and clay sized materials, however, sand, gravel, peat and massive ice also occur in lesser amounts at most locations examined. The resulting stratigraphy is commonly very complex.

9.3.2 The onshore area at King Point is underlain by continuous permafrost. Taliks penetrating the permafrost only occur under major lakes and rivers. The base of the permafrost is believed to rise beneath the large lacustrine plains and the channel occupied by Deep Creek.

9.3.3 Organic peat and mosses covering the ground surface provide insulation, thereby limiting the depth of the active layer. Disturbance of the organic cover is known to significantly increase the depth of seasonal thawing.

9.3.4 The near-surface organic materials and fine grained soils in the onshore area are generally ice-rich and very compressible when thawed.

9.3.5 Ice wedges, some of which are active, are common in the near surface, ice-rich sediments. The poorly drained alluvial, lacustrine and organic deposits are prone to shallow thaw subsidence when disturbed.

9.3.6 Massive ice occurs at depth mainly within the morainal and glaciofluvial units. Large thermokarst depressions indicate that these units are susceptible to considerable thaw settlement and instability if thermally disturbed.

9.3.7 Retrogressive-thaw flow-slides occur on scarps and steep slopes in ice-rich materials. These are most active in deposits which have cores of massive ice which are exposed to convective heat transfer by air or water. Active erosion of the cliffs along the shoreline near King Point has been accelerated by seasonal thawing.

9.3.8 Glaciofluvial deposits are potentially the best sources of granular materials. The glaciofluvial apron west of King Point, in particular, contains a significant quantity of mineable sand and gravel. Some ice-rich materials will necessarily have to be stripped and handled to permit exploitation of this aggregate source. Mitigative measures will be necessary to control or minimize thaw of the underlying massive ice.

9.3.9 The perimarine deposits and rock units have low ice contents and are relatively stable with respect to thaw settlement, although some thaw weakening and settlement may occur if the materials which mantle their surfaces are removed or disturbed. Massive ground ice which is present in the glaciofluvial and morainal deposits may become unstable if thawed, although relatively deep thermal disturbance is generally required to initiate thaw in these units. The near-surface organic, colluvial, alluvial and lacustrine deposits are generally ice-rich, poorly drained and compressible when thawed.

9.3.10 Although some forms of constraint to development have been identified in most of the onshore areas, it is recognized that the potentially adverse affects can generally be mitigated by implementing appropriate site selection and engineering design procedures. Some of the important impacts and constraints described in section 8.0 should be addressed in future detailed engineering studies.

10.0 RECOMMENDATIONS

The subsurface information obtained during this investigation is appropriate for preliminary planning and design purposes, but specific geotechnical and coastal engineering data will be required for the detailed design and ultimate development of any harbour and onshore facilities at King Point. Following are areas of concern which will require additional investigation prior to undertaking detailed design of such facilities.

1. Drilling of geotechnical boreholes and determination of foundation design parameters at specific structure locations (both onshore and offshore).

2. Evaluation of the consolidation characteristics of the lagoon sediments, if backfilling of the lagoon is proposed.

3. More extensive definition of the subsurface thermal regime and terrain sensitivity in both the onshore and coastal areas.

4. Evaluation of the impact of dredging the lagoon as it may affect both the thermal regime and the stability of the sub-lagoonal sediments.

5. Drilling of additional test holes in the lagoon and dating of the sub-lagoonal sediments to provide a better understanding of the lagoon morphology as it relates to existing subsurface conditions.

6. Investigation to prove the quantity and quality of granular materials which are accessible for the proposed development, including materials for road and airstrip construction as well as aggregates for Portland cement concrete and asphaltic concrete.

7. Development of a mining strategy for the required granular materials which minimizes and controls environmental disturbance of the tundra.

8. A detailed construction plan outlining proposed haulage routes from selected granular borrow source locations and the sequence of route construction operations. Ground-truthing and investigation of subsurface conditions for the selected alignments of inland routes will also be required, particularly in areas which have not previously been investigated in detail, e.g. to the quarry.

9. Initiation of a field measurement program designed to provide site-specific data on the coastal processes at King Point. This program should include: (i) collection of directional wave data which can be used to calibrate previous wind and wave hindcast predictions; (ii) annual documentation of the barrier bar evolution using both air and ground surveys to provide detailed sediment transport rates and directions; and (iii) observation and measurement of winds, waves, currents and beach process responses at the site to enable improvement of the coastal sediment transport model predictions.

11.0 CLOSURE

The foregoing report has been prepared in accordance with generally accepted principles of engineering, geology and geophysics in order to provide Indian and Northern Affairs Canada with an assessment of subsurface conditions and the potential impacts of proposed development at King Point. Conclusions and recommendations have been formulated on the basis of the available data and only address general considerations related to the proposed conceptual development schemes. Additional detailed studies are required before final design or construction of specific harbour development facilities can proceed.

Respectfully submitted,

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12.0 ACKNOWLEDGEMENTS

M. J. O'Connor & Associates Ltd. wish to acknowledge the close cooperation and assistance provided by both GSC and INAC personnel during the course of the field investigation. In particular, Dr. Phil Hill and Ms. Kate Moran of the GSC Atlantic Geoscience Centre, and Dr. Julie Brigham from the University of Alberta, assisted with sampling and logging of the boreholes and acoustic cone testing. Mr. Scott Dallimore of the GSC Terrain Sciences Division in Ottawa also assisted with the logging and sampling activities and installed thermistor cables in 5 of the open boreholes. Dr. Anders Elverhoi of the Norwegian Polar Research Institute was present during the initial phases of the investigation and assisted with the sampling and logging activities during this period. Mr. Bob Harmes and Mr. Harold Christian of the GSC Atlantic Geoscience Centre performed laboratory miniature vane tests and salinity tests, and assisted in archiving the offshore sediment samples. Mr. Neil Wortley of INAC provided direction with respect to land use regulations during the course of the onshore investigation. M. J. O'Connor & Associates Ltd. would like to thank Mr. D. L. Longlitz and Mr. R. Gowan of INAC for their guidance both in the field and during preparation of this report. Useful critical comments were also provided by Mr. S. Dallimore (GSC), Dr. P. Hill (GSC), and Ms. K. Moran (GSC) during preparation of the final document. M. J. O'Connor & Associates Ltd. also wish to acknowledge the assistance of Mr. M. Jeffries of Gulf Canada Resources Inc. with the computer analyses and plotting of the CPT data.

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