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MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES

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SURFICIAL GEOLOGY OF THE AREA AROUND ILLISARVIK RICHARDS ISLAND, NORTHWEST TERRITORIES

PREPARED FOR:

DEPARTMENT OF SUPPLY AND SERVICES

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ON BEHALF OF

GEOLOGICAL SURVEY OF CANADA

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ABSTRACT

Permafrost studies have been in progress at Illisarvik since 1978. Surficial geology mapping was undertaken to provide a geologic framework within which to interpret the results of the studies that are underway and proposed at this important experimental site.

Illisarvik is situated some 60 km west of Tuktoyaktuk, N.W.T. Physiographically, the study area comprises sections of both the Modern Delta and Pleistocene Coastlands (Tununuk and Kittigazuit Low Hills subdivisions). The stratigraphy of the former consists of a thick sequence of alluvial silt and fine sand, locally veneered by organics or recent marine deposits. Fine to medium sand, of marine-deltaic origin, occurs throughout the Pleistocene Coastlands. On ridges and uplands, it is overlain by diamicton (till and/or mudflow debris), in depressions by organics and recent lacustrine material.

With a mean annual ground temperature in the range -7° to -9°C, permafrost is continuous and in excess of 600 m thick in the Pleistocene Coastlands. It is discontinuous and thinner in the Modern Delta. Active layer thicknesses range from 30 cm to greater than 100 cm, depending on lithology and vegetation cover. Ground ice type and distribution are variable and often related to lithology, ranging from pore and vein ice, through ice wedges, to massive ground ice. Pingos are abundant in the Tununuk Low Hills.

Active geomorphic processes are associated with fluvial erosion and deposition, permafrost and ground ice, and marine processes. Permafrost-related activities include downslope movement by soil creep, ground ice formation and ice wedge growth, and pingo growth and decay. All contribute significantly to shaping of the present-day landscape in the area. Coastline change at Illisarvik has been significant, and is related to: retreat of coastal bluffs, erosion of tidal flats, and expansion of flats and spits. Erosion of tidal flats is apparently the dominant process; retreat rates of up to 50 m/yr are indicated locally.

Pleistocene marine-deltaic sand is the oldest unit exposed within the area. Together with the till that overlies it (laid down by a Laurentide ice-sheet that moved down the Mackenzie Valley and fanned out into the Beaufort Sea), the sand is beyond the range of radiocarbon dating. Both are considered, however, to be pre mid-Wisconsin in age. Since the ice sheet retreated (prior to 40 000 B.P.) periods of thermokarst activity (generally short) have led to landscape modification as massive ice thawed and the present hummocky topography developed. Since about 3600 B.P., the climate has deteriorated and thermokarst activity has been much reduced. Aside from continuing lake drainage, leading to pingo development, marine and alluvial erosion and deposition are now dominant in the Illisarvik area.

The terrain at Illisarvik is similar to that in areas of Richards Island where construction is considered in connection with onshore and offshore hydrocarbon development. Engineering concerns have been identified relating to the occurence of ice-rich and saline permafrost soils, the potential for flooding in low-lying areas, and the ongoing coastline changes.

1.0 INTRODUCTION

Multi-disciplinary studies of the growth of permafrost and its properties under full-scale natural field conditions have been on-going at the Illisarvik[1] experimental site, on the northwest coast of Richards Island, Northwest Territories (Figure 1), since 1978 when a lake that was on the verge of draining naturally was artificially breached. The background to, and rationale behind, these studies are discussed by Mackay (1980, 1981).

The prime objective of the present investigation was to map the distribution of landforms, surficial deposits and permafrost in an approximately 225 km^2 area around the Illisarvik site. The project, consisting of library research, airphoto interpretation and a field reconnaissance, was carried out during the second half of 1982. A program of field drilling was undertaken, in March, 1983, to complement the study; preliminary data have been incorporated, where appropriate, in this report.

It is intended that the study and its results should provide detailed background information on the nature, origin and distribution of surface and subsurface materials, including ground ice, in the area. These data will form a geological framework for understanding and interpreting the results of investigations that are in progress and proposed, by government and university researchers, at this important experimental site.

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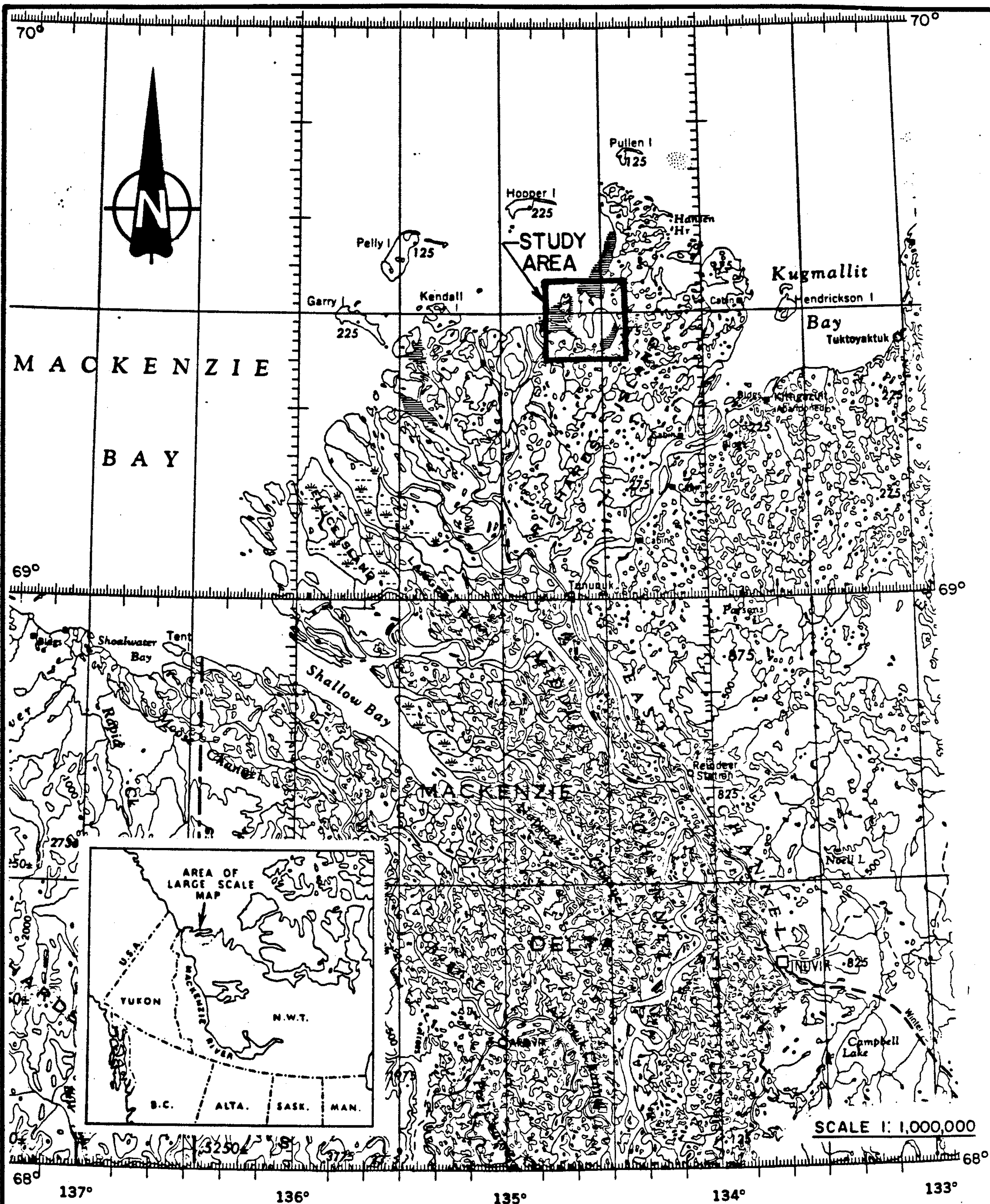
1 The name "Illisarvik" is an approximation of an Inuit word meaning "a place of learning". Its use is not yet officially approved.



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LOCATION PLAN

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FIG. 1

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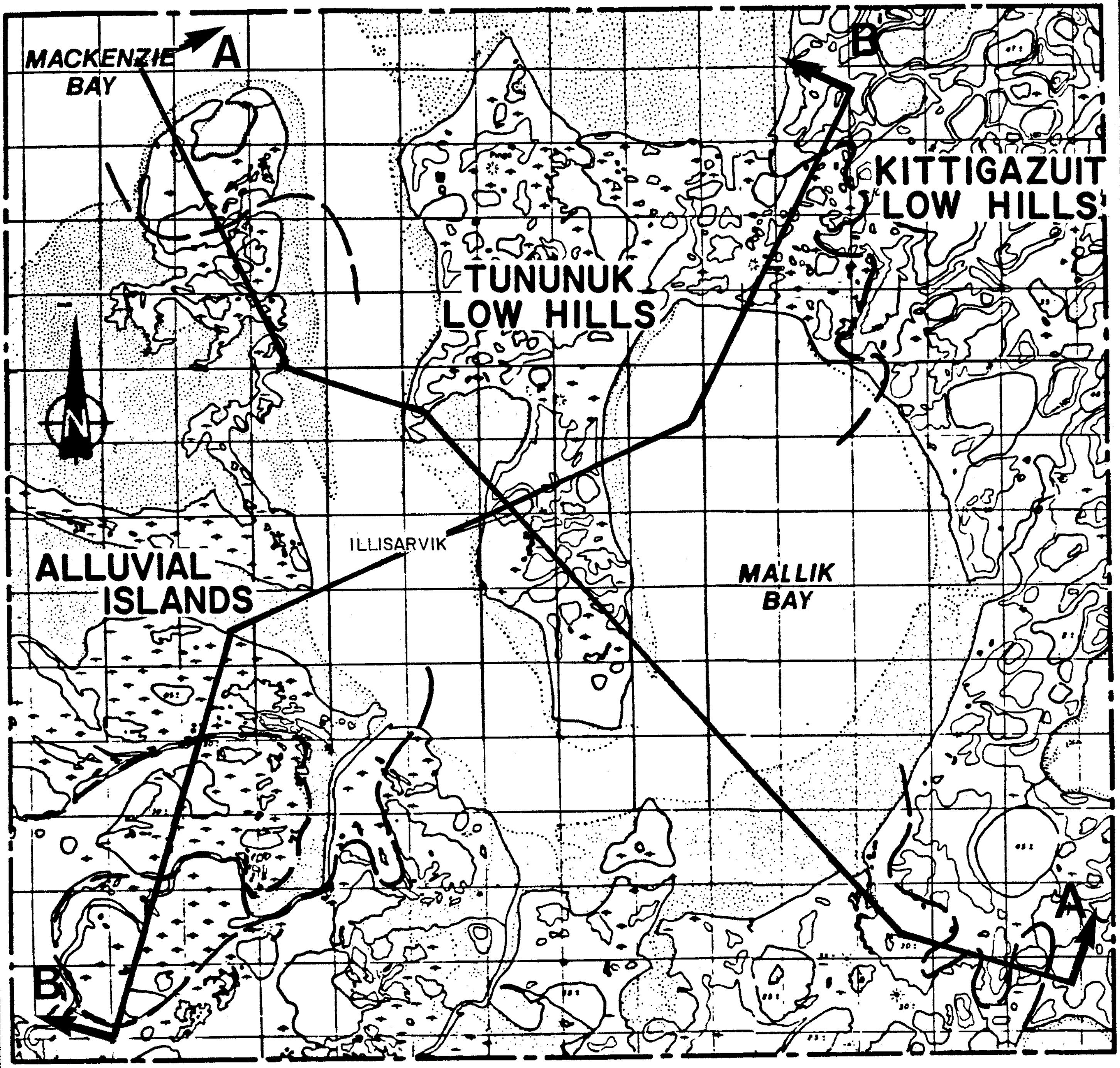
2.0 STUDY AREA

The study area comprises an area 15 km by 15 km (approximately 225 km^2), centred on the Illisarvik experimental site. It is located about 60 km west of Tuktoyaktuk, N.W.T. and some 120 km northwest of Inuvik, N.W.T. The location of the area of interest, defined on the north and south by latitudes 69^{o} 32.5'N and 69^{o} 25'N and on the east and west by longitudes 134^{o} 22.5'W and 134^{o} 45'W, is shown on Figure 1. About 22 percent of the total area (i.e. 51 km^2) consists of sea (Mallik and Mackenzie Bays), while lakes make up roughly 30 percent of the onshore section (Mackay, 1963: Figure 39).

2.1 PHYSIOGRAPHY

According to Bostock (1969), the entire Illisarvik area lies within the Mackenzie Delta physiographic division of the Arctic Coastal Plain. Relief and topography of the site are diverse, however, and, in general, more accurately reflected in the physiographic divisions and subdivisions of Mackay (1963). Thus, the southwestern section forms part of the Alluvial Islands subdivision of the (Modern) Mackenzie Delta, while the central and eastern parts respectively lie within the Tununuk Low Hills and Kittigazuit Low Hills, both subdivisions of the Pleistocene Coastlands (Mackay, 1963: Figure 37).

The physiography, relief and topography of the area around Illisarvik are shown on Figure 2. The Alluvial Islands comprise an area of flat terrain with very low relief, developed predominantly on deposits of alluvial and Holocene marine origin. Channels, lakes and thaw depressions are abundant; local relief is 1 m to 2 m maximum. The Tununuk and



LEGEND

- Study Area Boundary
- Physiographic Boundary
- A A' Geologic Section (Plate 2)

NOTE: Physiographic Subdivisions Modified After Mackay (1963)

1 0 1 2 3 Miles
1000 500 0 1000 2000 3000 4000 Metres
1000 500 0 1000 2000 3000 4000 Yards

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PHYSIOGRAPHY

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FIGURE 2

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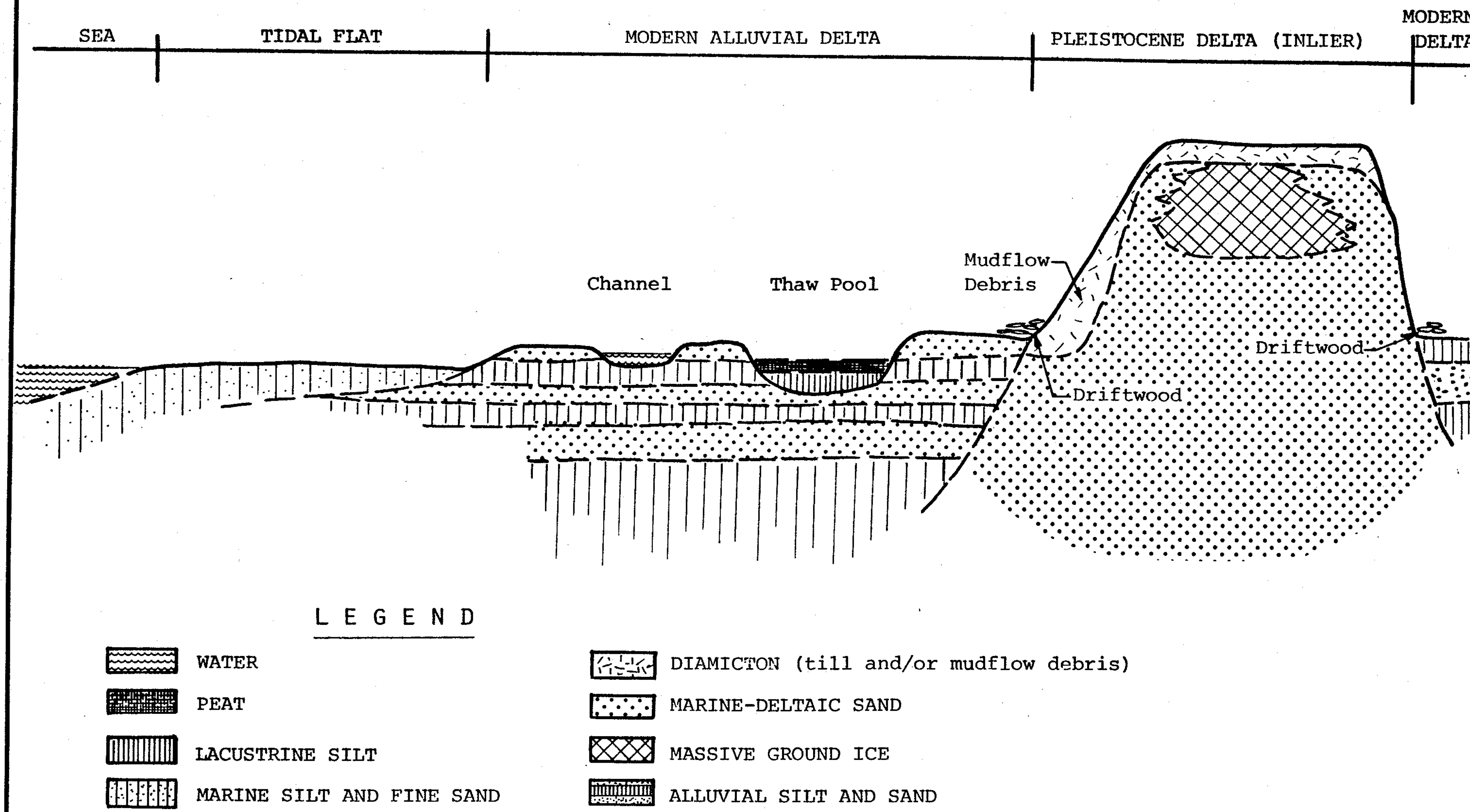
Kittigazuit Low Hills, on the other hand, are underlain by Pleistocene marine-deltaic sands, moraine and lacustrine deposits and exhibit considerably greater relief (locally in excess of 30 m). The terrain is hummocky to rolling and slopes range from less than 5 degrees, in thermokarst depressions, up to 30 to 40 degrees on eroding coastal bluffs. The two "Low Hills" subdivisions differ most significantly in that the Tununuk Low Hills are characterized by irregular terrain with "broad drained flats and drowned valleys", while the Kittigazuit Low Hills have "relatively deep lakes with smooth shorelines" (Mackay, 1963). Ground ice phenomena, notably pingos and ice wedge polygons, are abundant in drained lacustrine basins in the Tununuk Low Hills but are less widely distributed in the Kittigazuit Low Hills.

2.2 GENERAL GEOLOGY

Geological conditions within the three physiographic subdivisions are shown schematically on Figures 3 to 5. The sections illustrate the generalized distribution of landforms and surficial deposits in each area, and their relationships to each other. Landform characteristics are considered in detail in Section 3.0.

The Alluvial Islands of the Modern Delta are underlain by a thick, interbedded, sequence of silts, clayey silts and fine sands (Figure 3). These sediments, deposition of which is continuing, are frequently organic-rich, especially in the upper part, and are in excess of 60 m thick (Kerfoot, 1975). Other surficial deposits, that occur to a more limited extent in the Illisarvik area, include recent (Holocene) marine silts and fine sands, shallow organic-rich silts and clays that have accumulated in thaw pools, and organic deposits. Inliers of



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GENERALISED GEOLOGY
ALLUVIAL ISLANDS

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Figure 3

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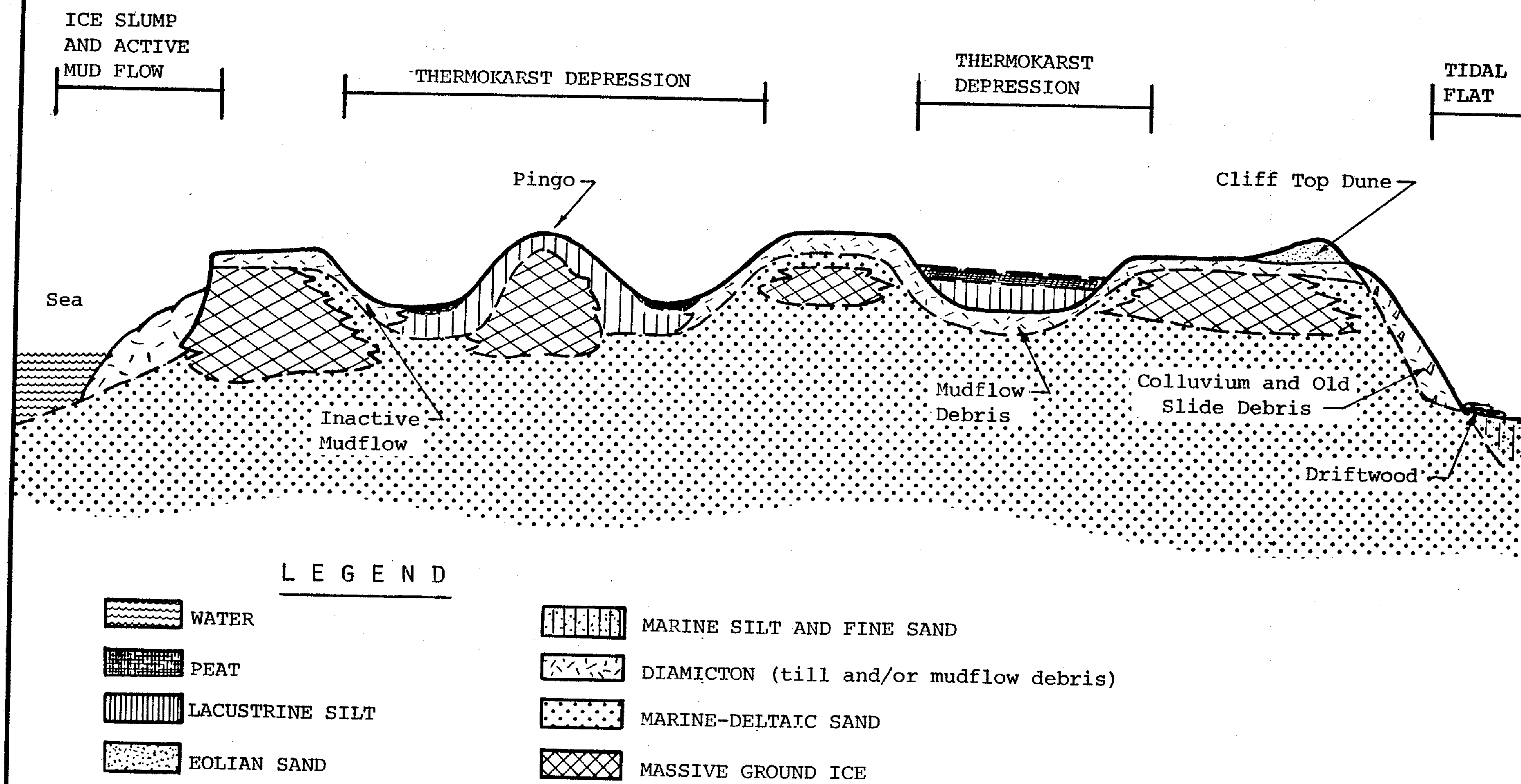
Pleistocene deltaic material (i.e. till and diamicton-veneered marine sand) are present locally (Figure 3).

Fine to medium deltaic sands, of marine origin and Pleistocene age, occur throughout the Tununuk Low Hills (Figure 4). Field drilling indicates that the sands are in excess of 80 m thick at the Illisarvik site (Hunter et al., 1981: Figure 4), and overlain by more recent materials, the character of which reflects the influence of thermokarst processes, and lake breaching and drainage. Beneath ridges and uplands (that have not been influenced by thermokarst processes), the sand is overlain by a stony clay diamicton, consisting of till and/or mudflow debris. The intervening thermokarst depressions are infilled by organic-rich lacustrine silt, fine sand and peat. In some locations, the lake deposits are underlain and separated from the sand by stony clay material, consisting of slump and mudflow debris (diamicton). High and low centre polygons are abundant in recent lake basins. In some instances, pingo growth has occured also. Along eroding coastal bluffs, developed in till-veneered sand, ice slumps (retrogressive-thaw flow slides), associated with melting of segregated ground ice, are locally abundant. Surficial deposits with a more limited distribution in the Tununuk Low Hills include: eolian sand, which forms cliff-top dunes, and marine silt, sand and minor gravel, forming beaches and spits, tidal flats and intertidal lagoon deposits.

The Pleistocene marine-deltaic sand is also present throughout the Kittigazuit Low Hills. Generalized geological conditions are shown on Figure 5. In some areas, the till/diamicton veneer is discontinuous, being absent or consisting only of a thin gravel lag deposit; in others it is present. Evidence of thermokarst is widespread; drained lacustrine basins, with



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TUNUNUK LOW HILLS

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Figure 4

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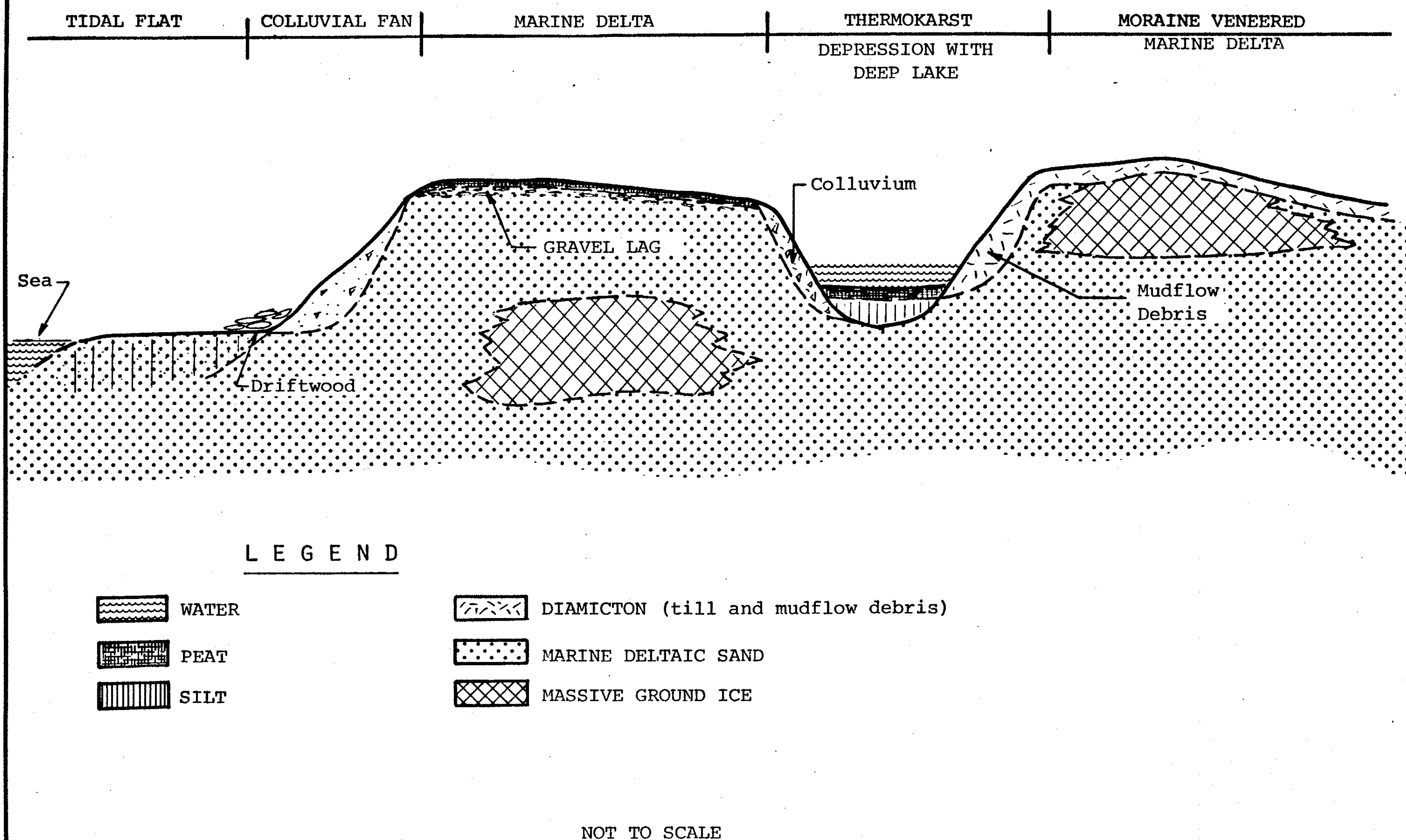

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GENERALISED GEOLOGY
KITTIGAZUIT LOW HILLS

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Figure 5

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associated pingos and extensive polygon development, are sparsely distributed, however. Rather, the ridge areas (which exhibit a faint southwest-northeast trend, due to glacial action), are separated from each other by "deep lakes, with smooth shore lines" (Mackay, 1963).

2.3 PERMAFROST

The "Permafrost Map of Canada" (Brown, 1967) indicates that the area around Illisarvik (with a mean annual ground temperature of -7°C to -9°C) is situated within the continuous permafrost zone. For the most part, this assessment is valid; in the alluvial islands, however, the thermal influence of the Mackenzie River and ever-changing configuration of its delta are such that talik zones are extensively developed, permafrost is aggrading and perennially frozen ground may be locally discontinuous (beneath major channels). In this sense, the Modern Delta may be considered a northward extension of the discontinuous permafrost zone (Smith and Hwang, 1973).

Data on permafrost thicknesses and characteristics have been published by Taylor and Judge (1976) and Judge *et al*. (1981) for a number of sites in the general vicinity of Illisarvik, and summarized graphically by Mackay (1979: Figure 6). Measured permafrost thicknesses at sites in the alluvial islands (at Niglintgak and Taglu) range from 140 m to greater than 620 m (in a Pleistocene Delta inlier) (Judge *et al*., 1981). Permafrost thicknesses of greater than 381 m and greater than 280 m are reported for two sites, located away from water bodies, to the south and east of Illisarvik (Taylor and Judge, 1976). Depth of permafrost at the Mallik A-06 well site, situated along the southern boundary of the study area, is greater than 250 m (Judge et al., 1981). Pre-drainage permafrost conditions at Illisarvik were investigated by Judge et al., (1980). A talik zone, up to 32 m thick, was present beneath the lake and the permafrost table dipped steeply around its margins.

Site-specific information is not available on the distribution of sub-sea permafrost in the vicinity of Illisarvik. However, experience in adjacent areas of the offshore Beaufort Sea would strongly indicate that frozen ground is present beneath at least parts of both the Mallik and Mackenzie Bay sections of the study area.

Ground ice, in a wide variety of forms, occurs throughout the area of interest. Segregated (massive) ice, wedge ice, reticulate vein ice and lenses, and pingo ice are the main types (Mackay, 1972). To a great extent, ground ice type in a particular area is dependent on subsurface soil type. Relationships between landforms, surficial deposits and characteristic ground ice types are summarized on Table I, and described in detail in Section 3.0.

2.4 DRAINAGE

As described previously, the alluvial islands are an area of very low relief, frequently inundated by both the sea and the Mackenzie River. Overall, surface drainage is poor, and channels, lakes and thaw ponds are abundant.

Drainage of the Pleistocene Coastlands is more variable, reflecting changes in relief and near-surface materials. In general, the ridges and uplands, underlain by Pleistocene sands and till, have good surface drainage, while the intervening thermokarst depressions are poorly drained and commonly include extensive areas of standing water. An integrated system of creeks and streams, connecting the various lakes, has developed in parts of the Kittigazuit Low Hills but is absent elsewhere.

2.5 CLIMATE

The climate of Illisarvik is likely similar to that of Tuktoyaktuk, the closest station (60 km to the east) for which long-term data are available. Both sites have an arctic climate, characterized by long cold winters and cool summers. At Tuktoyaktuk, the mean annual daily temperature is -10.6°C, with extreme minimum and maximum values (for 10 to 14 years of record) of -50°C and 30°C (Environment Canada, 1972a). Precipitation is low, and fog common, especially in the fall (Mackay, 1963). Winds from the northwest and east are prevalent, with a mean wind speed of about 9.75 km/hr throughout the year (Environment Canada, 1972b).

2.6 VEGETATION

Vegetation communities of the Mackenzie Delta region have been described by Lambert (1972).

In the alluvial islands:

> "*Menyanthes trifoliata* is present in many of the pools of standing water, while the lake shores and extensive depressions are dominated by such species as *Hippuris vulgaris*, *Arctophila fulva*, *Carex aquatilis*, *Juncus arcticus* and *Dupontia Fisherii*. In better-drained areas, the ground surface is generally hummocky and supports a community type dominated by low, scattered *Salix Richardsonii*, *S. glauca*, *Equisetum arvense*, *Pedicularis sudetica* and *Carex aquatilis*."

Higher, better drained, areas in the Tununuk and Kittigazuit Low Hills, are dominated by:

> "Betula glandulosa, Salix glauca, Dryas integrifolia, Vaccinium uliginosum, V. vitis-idaea, mosses and lichens.
>
> "Tussock communities (Eriophorum vaginatum) occupy poorly-drained areas on the gentler, lower slopes and flat lowlands, while areas of impeded drainage characteristically have a sedge meadow community, dominated by mosses (Drepanocladus and Sphagnum), sedges (Carex rariflora) and cotton grass Eriophorum scheuchzeri).
>
> "Saline flats that occur in protected areas along the coast are subject to flooding at high tide. Four different community types are associated with the flats: (1) Dupontia Fisherii and Carex maritima on saturated soils; (2) Puccinellia phryganodes; (3) Carex salina; (4) Salix arctica and Potentilla Egedii on the drier flats. Hippuris vulgaris and Arctophila fulva are also present in many of the pools.
>
> "Driftwood scattered along the coast offers protection to many plants including Saxifraga cernua, Artemisia tilesii, Matricaria ambigua and Rumex arcticus." (Lambert, 1972).

3.0 SURFICIAL DEPOSITS

A map and sections showing the distribution of surficial deposits in the area around Illisarvik are presented in Appendix "C". Landform characteristics are described in the sections that follow, and summarized on Table I. Discussion is in chronological order, from oldest to youngest.

3.1 PLEISTOCENE MARINE DEPOSITS

Horizontally bedded fine to medium sand, generally brown in colour and interpreted to be of marine-deltaic origin, underlies the entire Pleistocene Coastlands section of the Illisarvik area. The sand is overlain on most ridges and upland areas by stony clay diamicton and in depressions by other more recent deposits (predominantly of lacustrine and organic origin). In some coastal bluff exposures along the east side of Mallik Bay the stony clay was not observed; a gravel lag remains locally, however, suggesting the till may have been removed by glaciofluvial or fluvial erosion. Since exposures away from the coastline are sparse, the detailed distribution of Pleistocene marine deposits has been delineated, on the Surficial Geology Map (Plate 1) by means of airphoto interpretation. Gently rolling to hummocky topography is characteristic of the Pleistocene marine areas, with a local relief of 20 m to 30 m and slopes ranging up to 30 to 40 degrees (on eroding bluffs).

The maximum sand thickness observed in the field was greater than 17 m, on a bluff along the east side of Mallik Bay (Photo 4, Appendix "B"); however, a borehole recently drilled close to the Illisarvik experimental site encountered over 90 m of sand. Locally, the brown sand is underlain by a finer

TABLE I

LANDFORM CHARACTERISTICS

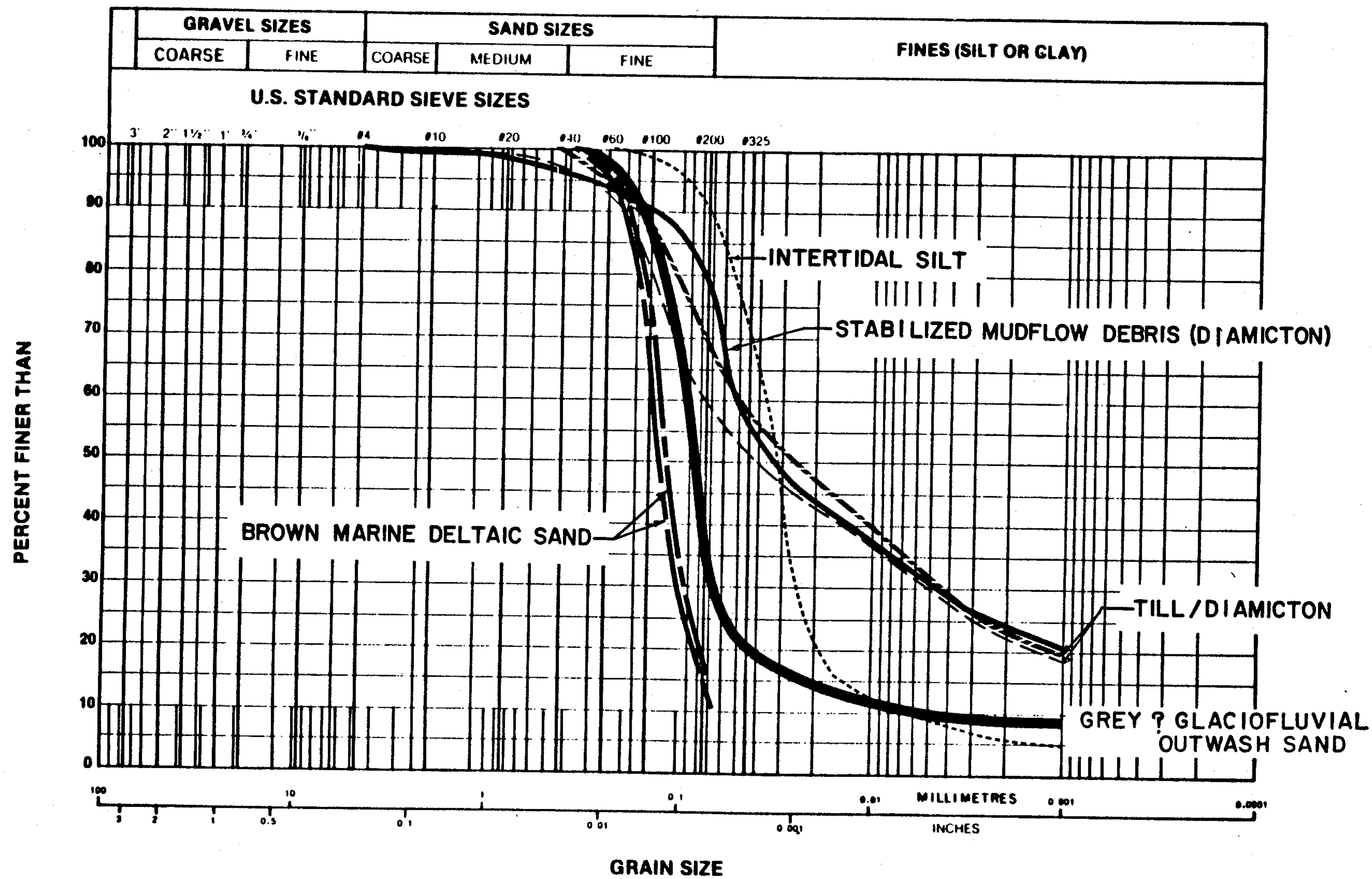
ORIGIN	SYMBOL	DESCRIPTION	SUBSURFACE STRATIGRAPHY	RELIEF AND DRAINAGE	PERMAFROST AND GROUND ICE	ENGINEERING CONSIDERATIONS
ORGANIC	Op	Organic Bog	Peat, generally from 1 to 3 m thick; underlain by lacustrine organic silt and till or diamicton.	Flat; poorly drained, with standing water in thaw pools; low and high centre polygons.	Continuous permafrost; active layer: 15 cm to 20 cm; high ice content, mainly as wedges, reticulate veins and lenses.	Potential for thaw settlement following disturbance.
HOLOCENE MARINE	aMr	Beaches and Spits	Fine to medium sand and fine gravel, up to 1.5 to 2 m thick, over fine sand and silt.	Ridges, 1.5 m to 2 m high with gentle side slopes; well drained.	Sporadically distributed thin permafrost in ridges; active layer, where frozen: 80 cm to >1 m; low ice content permafrost.	Potential source of borrow materials. Saline pore fluid may cause freezing point depression, and should be considered in gravel pad design.
HOLOCENE MARINE	fMp	Tidal Flats	Interbedded silt, clayey silt and fine sand, locally organic-rich.	Flat, with shallow channels and thaw pools; poorly drained; frequently inundated by sea water.	Continuous permafrost, with shallow talik zones beneath major channels; active layer 40 cm to 50 cm; medium to high ice content, generally as lenses, reticulate veins and wedges.	Potential for thaw settlement following disturbance; saline soils may create problems for foundation design; construction grades should be above storm surge levels.
HOLOCENE MARINE	$\frac{fMv}{Lp}$	Intertidal Lagoon	Interbedded silt, clayey silt and fine sand, locally organic-rich; forms veneer, 1 m to 2 m thick, over lacustrine silt and clay.	Flat, with shallow channels; poorly drained with areas of standing water; occasionally to frequently inundated by sea water.	Continuous permafrost, with talik zones beneath channels and areas of deep standing water; active layer: 30 cm; to 40 cm; medium to high ice content, as lenses, reticulate veins and wedges.	
ALLUVIAL	fAp	Alluvial Floodplain	Stratified fine sand and silt, with organic inclusions; probably 2 m to 5 m thick and overlying diamicton or sand.	Flat, with channels, cut-offs and pools; poorly drained, with areas of standing water; infrequently inundated by sea water.	Continuous permafrost, with talik zones beneath active channels, aggrading permafrost elsewhere; active layer: 40 cm to 50 cm; lens and vein ice are dominant, in medium ice content permafrost.	Potential for thaw settlement; construction grades should be above storm surge levels; saline soils may create foundation design problems, in areas subject to frequent inundation.
ALLUVIAL	fAd	Alluvial (Modern) Delta	Stratified silt, and fine sand and clay, frequently organic; greater than 20 m thick.	Flat, with frequent channels, cut-offs, lakes and thaw pools; abundant low centre polygons; subject to relatively frequent inundation by river and sea water.	Complex distribution of permafrost and talik zones reflecting changing hydrologic conditions; active layer in permafrost 40 cm to 50 cm; medium ice content in frozen ground, generally as lenses and wedges.	
ALLUVIAL	fAt-T	Alluvial Terrace, thermokarst modified	Stratified silt, and fine sand and clay, frequently organic; greater than 20 m thick.	Flat, with gentle frontal scarp; poorly drained, with channels, cut-offs and thaw pools; low centre polygons; infrequently inundated by river and sea water.	Continuous permafrost, shallow taliks beneath channels and cut-offs; active layer: 40 cm to 50 cm; medium ice content in lenses and wedges.	Potential for thaw settlement; construction grades should be above storm surge levels.
LACUSTRINE	fLp-T	Lacustrine Plains and Basins, thermokarst modified	Interbedded silt and clay, minor fine sand, frequently organic-rich; 2 m to 5 m thick; generally underlain by diamicton (stony clay).	Flat (gentle to steep slopes on pingos); abundant polygons, both high and low centre; poorly drained, with thermokarst thaw pools.	Continuous permafrost, with talik zones beneath thaw pools and recently drained basins; active layer: 25 cm to 40 cm; medium to high ice content wedge and reticulate vein ice are main types, massive ice in pingos.	Potential for thaw settlement, especially in areas underlain by high ice content soils or wedge ice. Potential for frost heave in refreezing talik areas in the long-term.
MORAINAL	$\frac{dMv}{Md}$-T	Moraine-Veneered Marine (Pleistocene) Delta, thermokarst modified	Stony clay diamicton (till or mudflow debris); up to 2.5 m thick; overlying fine sand; peat and organic silt, up to 2 m thick in thermokarst depressions; shallow peat veneer.	Hummocky to rolling, with local relief of 20 m to 30 m; well drained, except for poorly drained thermokarst depressions.	Continuous permafrost, with infrequent talik zones beneath thermokarst depressions; active layer: 50 cm to 70 cm; low to medium ice content in diamicton and sand, massive ice at boundary between two units, occasional active and inactive ice slumps.	Potential for thaw settlement, with development of ice slumps, following disturbance, structures should be constructed so as to protect permafrost and prevent active layer thickening, i.e. using ventilated gravel pads, piles etc.
PLEISTOCENE MARINE	sMd-T	Marine (Pleistocene) Delta, thermokarst modified	Fine, locally silty, sand, with occasional wood and lenses of clay and silt; greater than 15 m thick; shallow peat veneer.	Hummocky to rolling, with local relief of 20 m to 30 m; well-drained, except for poorly drained thermokarst depressions.	Continuous permafrost, with infrequent talik zones, beneath deep lakes in thermokarst depressions; active layer: 80 cm to 100 cm; low ice content in sand.	

sand that is characteristically grey-brown in colour. In terms of grain size characteristics, the brown sand is uniform and clean: between 84 and 88 percent consists of fine sand, the remaining 12 to 16 percent of silt and clay (Figure 6). The lower grey sand, where exposed, is finer grained overall and dirtier; for one sample, its composition was 62 percent fine sand, 29 percent silt, and 9 percent clay. The brown sand contains occasional lenses of silt and clay, wood fragments and, in other areas, rare terrestrial vertebrate remains (Fyles, 1967). On this basis, it is interpreted as being of marine-deltaic origin. The lower grey sand is everywhere poorly exposed. If correlative with the grey sand described by Fyles et al. (1972) from Richards Island, it may be of glaciofluvial outwash origin.

Perennially frozen ground continuously underlies the areas of Pleistocene marine sand, with talik zones occurring beneath the deeper lakes. Active layer development ranges from about 80 cm to greater than 100 cm. In general, the ice content of the marine sand is low; where it is veneered by diamicton, however, massive segregated ground ice is prevalent (Mackay, 1966). Massive ice bodies may also occur at greater depth within the sand stratum (Rampton and Mackay, 1971); no such occurrences have been reported to date during drilling at Illisarvik (Hunter et al., 1981).

3.2 MORAINAL DEPOSITS

Stony clay diamicton, consisting of till and mudflow debris, forms a relatively continuous, 2 m to 2.5 m thick, veneer over the Pleistocene marine sand throughout the Tununuk and Kittigazuit Low Hills (Photo 1). As described above, the stony clay is locally either absent or has been eroded away,



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GRAIN SIZE CURVES

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FIGURE 6

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leaving a gravel lag. Exposures of the diamicton, often consisting of a relatively structureless upper part (interpreted as fossil mudflow material) and a characteristically highly jointed and fractured lower till (Photo 2), are abundant in the area around Illisarvik. A typical section is shown on Photo 1. In most instances, exposures of till are associated with active or inactive ice slumps (retrogressive-thaw flow slides). In such locations, the diamicton is visible in both the headscarps of active features and mudflow deposits at the toe (Photo 9). The topography of the moraine-veneered Pleistocene marine sand areas is rolling to hummocky. Local relief is in the order of 30 m and slopes of up to 35 degrees are characteristic.

Observed thicknesses of the stony clay diamicton in the Illisarvik area range from 0.5 m to 2.5 m, without a great deal of variation across the area. In general, the unit has a sharp contact with the underlying Pleistocene sand and a gradational one with the peat or lacustrine deposits that often overlie it (Photo 1). Three grain size analyses, shown on Figure 6, indicate that the composition of the diamicton is relatively uniform: 22 to 41 percent sand (mostly in the fine fraction), 37 to 59 percent silt and 19 to 22 percent clay. There is little difference, in terms of grain size, between samples of till and mudflow debris (Figure 6). Where observed in the field, however, the material identified as till frequently has a characteristic very prominent jointing and fracturing (shown on Photo 2 and perhaps related, in part, to melting-out of reticulate ice veins). The mudflow material is generally relatively structureless and exhibits evidence of plastic flow. Gravel size fragments are sparsely distributed in the till throughout the area, while boulders are prevalent at the north end of Mallik Bay. Where present, granitic lithologies, volcanics and quartzites predominate, indicating a Laurentide (i.e. Continental) rather than Cordilleran provenance.

The morainal areas are underlain by continuous permafrost, with talik zones existing only below the deeper lakes in the thermokarst depressions. Typically, the active layer is 50 cm to 60 cm thick. Excess ice content ranges from low in the mudflow material to medium in till, with reticulate vein and lens ice the dominant types. Of greater significance, is the frequent occurrence, at the boundary of the till/diamicton and underlying sand, of tabular bodies of massive ground ice (Mackay, 1972; Rampton and Mackay, 1971). Such ice masses probably underlie a large part of the Illisarvik area and in the past, upon melting, have given rise to the characteristic hummocky to rolling relief of the morainal areas (Rampton, 1972). In addition, coastal erosion and disturbance of such areas at the present time leads to the development of ice-slumps or retrogressive-thaw flow slides (Mackay, 1966). The distribution of these slumps, both active and inactive, is shown on the "Surficial Geology Map" (Plate 1).

3.3 ALLUVIAL DEPOSITS

Two types of alluvial deposits have been mapped. Deltaic and terrace sediments have been deposited in the "alluvial islands" by the Mackenzie River, and floodplain deposits occur along Burnt Creek, a small stream draining northwestwards from Umiak Lake into Mallik Bay (Plate 1).

The Mackenzie River sediments consist of silts and fine sands that are frequently organic-rich. Greater than 60 m thick (Kerfoot, 1975), they give rise to a surficially poorly drained area of low relief (the "Alluvial Islands" of Mackay). Permafrost conditions are complex, due to the ever-changing hydrologic regime of the delta. The terraces and inactive areas of the delta have relatively continuous permafrost except for the occasional talik zone that may penetrate the frozen ground beneath the larger lakes and channels; permafrost thicknesses may be greater than 100 m (Taylor and Judge, 1976). On the other hand, in the active sections of the delta, permafrost is thin (less than 20 m thick) and actively aggrading. Talik zones are extensive.

The Burnt Creek floodplain is flat, with abundant channels, cut-offs and thaw pools; surface drainage is poor. Near-surface sediments are organic-rich silts and fine sands, probably a maximum of 5 m thick. Permafrost is likely continuous, with a shallow talik beneath the active creek channel. The active layer is 40 cm to 50 cm deep.

3.4 LACUSTRINE DEPOSITS

Thermokarst depressions, infilled with fine-grained lacustrine material, are abundant in the Pleistocene Coastland areas (Plate 1). Flat to depressional terrain, generally with high and low centre polygons, and sometimes a pingo, is characteristic. Such areas are underlain by 2 m to 5 m of interbedded organic silt, clay and fine sand, generally with a peat veneer. Surface drainage is poor, with abundant areas of standing water in thaw pools.

Interbedded organic silts and fine sands up to 3 m thick were observed in eroding coastal sections within the area. Freshwater shells (gastropods) are present at some locations. Up to 5 m of "organics" was encountered in boreholes put down at the Illisarvik site (Hunter et al., 1981: Figure 4).

Permafrost is continuous beneath most lacustrine plains and basins, with an active layer in the range: 25 cm to 40 cm. Where a deep lake is present or lake drainage has recently taken place, a talik zone may be present; an example is Illisarvik itself, where a talik zone in excess of 30 m deep was present prior to drainage (Judge et al., 1980). In general, the frozen lacustrine sediments are ice-rich. Ground ice occurs most abundantly in the form of wedges but also as lenses and reticulate veins. Pingos are found almost exclusively in the lacustrine basin areas of the Tununuk Low Hills (Mackay, 1979).

3.5 COLLUVIAL DEPOSITS

As a result of solifluction and soil creep, most slopes in the area are veneered by colluvium. These deposits have not been mapped separately, since in almost all instances they do not exceed 50 cm to 60 cm in thickness (becoming thicker towards the toe of the slope).

A more significant and widely distributed form of colluvial deposit is the active or inactive mudflow, associated with the development of ice slumps or retrogressive-thaw flow slides (Photos 8 to 10). The distribution of ice slumps and mudflows is shown on Plate 1 ("Surficial Geology Map"). They occur in morainal areas, where coastal bluffs are subject to continuing erosion by the sea, and also along lake shores. The mudflow material is usually 2 m to 3 m thick maximum and has a similar composition to the parent clay till (i.e about 25 percent fine sand, 55 percent silt and 20 percent clay, Figure 6). Excess ice content of the mudflow debris is generally low (Mackay, 1966).

A third type of colluvial deposit is illustrated on Photo 4. Colluvial fans occur along the base of a high Pleistocene marine sand bluff that borders the east side of Mallik Bay. Individual fans are about 8 m high, 1 m wide at the top and 4 m to 5 m wide at the bottom, where they tend to coalesce. An erosional notch at the toe of the slope shows that the fan material is up to 2 m thick (Photo 4). Ice content of the fan material is probably very low.

3.6 EOLIAN DEPOSITS

Significant thicknesses of wind-blown silt and sand are rare in the area around Illisarvik. In fact, with the exception of a small dune, 2 m to 3 m high, on the top of a bluff approximately 1100 m east of Illisarvik (Plate 1), constructional eolian landforms (i.e. dunes, blankets, etc.) were not observed. In a number of exposures, fine sand and silt are associated with recent lacustrine sediments; these are identified as being of eolian origin. The eolian deposits consist of silts and very fine sands and are brown in colour with a very low ice content.

3.7 HOLOCENE MARINE DEPOSITS

Recent marine sediments comprise coarse grained beaches and spits (Photo 3) and fine grained tidal flats and intertidal lagoons (Photo 7). The main types of deposit are addressed below.

Sandy to gravelly beach deposits, 5 m to 10 m wide and 1 m to 1.5 m thick, occur throughout the Pleistocene Coastlands, often in association with small lagoons (Photo 3). Their composition at any given location is frequently related to that of the eroding bluffs in the vicinity. Thus, where moraine-veneered bluffs are being eroded, gravelly beach material predominates; where sand bluffs are present, the beaches tend to be sandy. While the sediments underlying the beach and spit deposits are generally frozen, permafrost in the beach or spit itself may be discontinuous; where frozen, ice content is low.

The tidal and intertidal deposits are of similar composition, consisting of organic-rich silts and fine sands. They differ in that the tidal flat sediments are probably greater than 5 m thick and frequently inundated by the sea, whereas the intertidal sediments are thin (1 m to 2 m maximum) and underlain by lake sediments (the lake bottom material prior to inundation). In both instances, permafrost is continuous, wih minor development of talik zones beneath channels and areas of standing water. Excess ice content is high, with abundant ice wedges.

3.8 ORGANIC DEPOSITS

Peat occurs as a veneer, usually from 0.5 m to 1 m thick, over most surficial materials in the area. Accumulations greater than about 1 m thick are present in a number of thermokarst depressions and have been mapped separately on the "Surficial Geology Map" (Plate 1). Flat terrain, with poor surface drainage and slopes of 5 degrees or less, is characteristic.

Observed peat thicknesses in the Illisarvik area range up to 2 m to 3 m maximum. Such areas are continuously frozen, with a very shallow active layer, less than 30 cm thick, and high excess ice content. Ground ice occurs predominantly as ice wedges, in association with abundant high and low centre polygons (Photos 5 and 6). Lens and vein ice is also commonly present. In the mapped organic areas, the peat frequently grades downwards into the underlying lacustrine silts.

4.0 DYNAMIC PROCESSES

Three main types of geomorphic processes are active in the area around Illisarvik. Fluvial processes, those associated with permafrost and ground ice, and marine processes are addressed in the sections that follow.

4.1 FLUVIAL PROCESSES

Fluvial erosion and deposition are most important in the southwestern ("alluvial islands") section, associated with the Swan and other minor channels of the Mackenzie Delta. Both processes occur rapidly during the spring break-up period, decreasing in importance as river levels fall through the summer. The significance of such fluvial processes in the Delta is reflected in the ever-changing configuration of the channels and complex distribution of permafrost and unfrozen ground in the area.

Due to the general sparsity of streams and creeks in the Pleistocene Coastlands, fluvial processes are of relatively little significance. Alluvial floodplain deposits have been laid down along Burnt Creek, a small stream in the southern part of the study area that drains Umiak Lake into Mallik Bay.

4.2 PERMAFROST-RELATED PROCESSES

These include: downslope movement by soil creep, solifluction and mass-movement, ground ice formation, ice wedge growth, patterned ground development and pingo growth and decay. All contribute, to a greater or lesser degree, to the shaping of the present-day landscape in the area around Illisarvik.

As described previously, colluvium veneers most slopes in the area. It comprises a layer, 0.5 m to 2 m thick (generally thicker at the toe of the slope), formed by soil creep and solifluction processes. Locally, mass movements, notably ice slumps and associated mudflows, also contribute. In most areas, the overall impact of such processes is to lead to a general "smoothing out" of irregularities in the terrain. Excepting the mudflows, the operation of these processes rarely has a topographic expression; solifluction lobes were not observed in the study area.

Tundra polygons are abundant in the Illisarvik area, apparently occurring in all types of surficial material (though sometimes masked by soil creep and solifluction). As described by Mackay (1963), polygons develop in association with ice wedge formation. There is a natural progression from large-diameter, low-centre polygons, with accumulation of organics and improving surface drainage, to smaller-diameter, high-centre polygons. Low-centre polygons, generally 10 m to 15 m in diameter (Photo 6), develop in deposits of organic, lacustrine and Holocene marine origin, as well as in alluvial sediments of the Modern Delta. High-centre polygons are often only 3 m to 5 m in diameter and occur most frequently in the better drained lake basins. They are also found in the morainal and (less frequently) Pleistocene Delta areas (Photo 5). A less widely distributed form of patterned ground is the non-sorted circle (or frost boil), which occurs in the moraine and Pleistocene marine-deltaic areas.

The "Surficial Geology Map" (Plate 1) shows a total of 29 pingos (out of the greater than 1400 identified by Mackay (1963, 1979) in the Mackenzie Delta region as a whole). These have been mapped in the Tununuk Low Hills portion of the area only, and apparently occur very infrequently in the Kittigazuit Low Hills (Mackay, 1979: Figure 3). The generally conical, ice-cored, mounds range in height from 1 m to 2 m up to greater than 15 m, with some over 300 m in diameter. In all instances, pingo development has apparently occurred in poorly drained lake basins, previously breached and now partially or completely drained. Locally, the pingo site is subject to marine inundation so that the pingo either rises above an expanse of intertidal deposits (underlain at shallow depth by lacustrine sediments) or is surrounded by driftwood (Photo 11). Comparison of airphoto coverage dated 1950 and 1972 disclosed no evidence of active pingo growth or decay over this period. Two pingos in the southwest part of the area have a "collapsed" appearance, however, with flatter than usual side slopes and prominent gullying and erosion.

4.3 MARINE PROCESSES

Changes in the coastline of the area around Illisarvik during the period from 1950 to 1972 are shown on Figure 7. Comparison of airphotos dating from 1950 (when coverage initially became available) and 1972 (the most recently available), indicates that three types of coastline modification, due to active marine processes, have been significant:

i) Retreat of coastal bluffs.

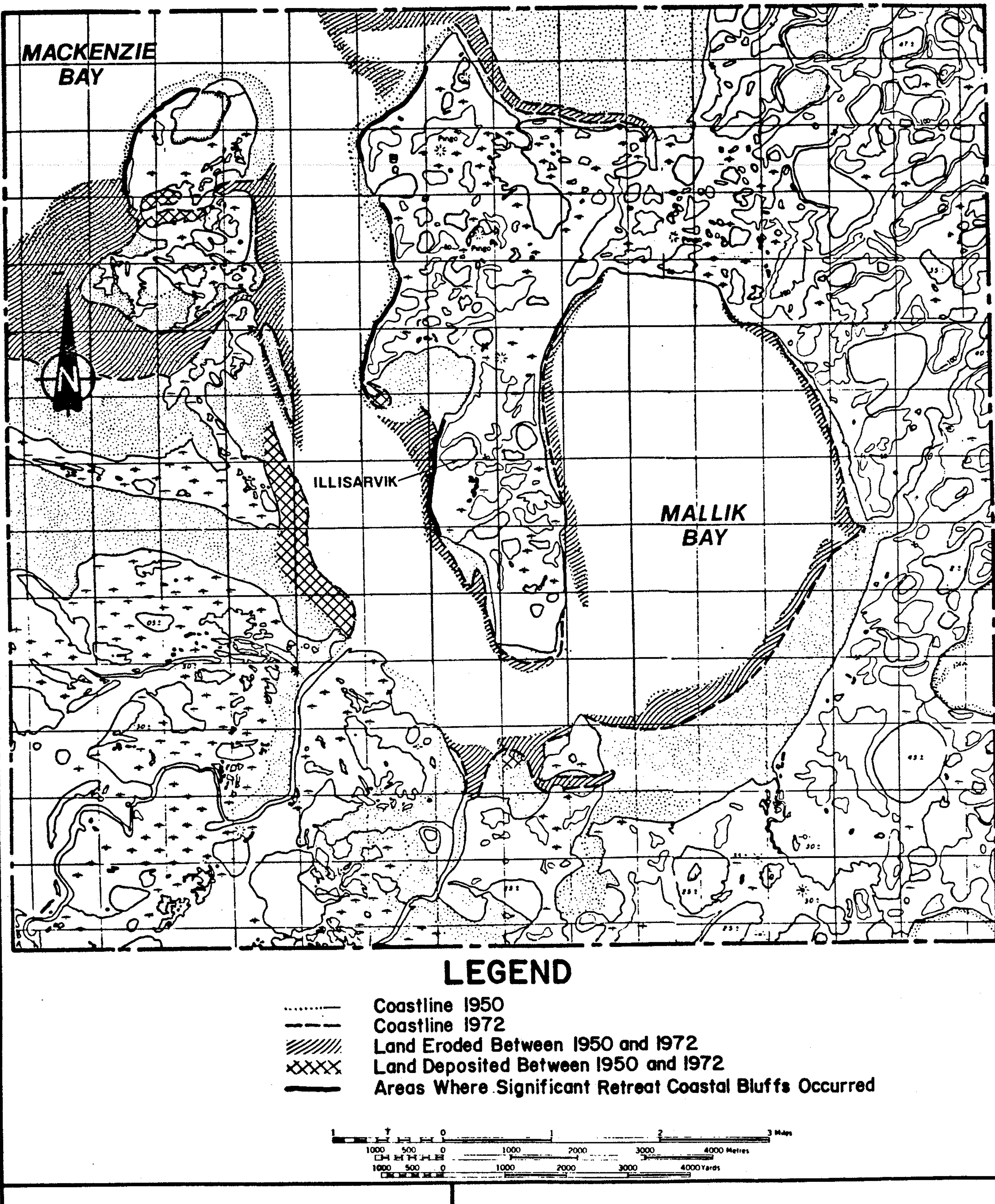
ii) Erosion of tidal flats.

iii) Expansion of tidal flats and spits as a result of marine deposition.

A related process is natural breaching and drainage of lakes near to the coastline.

Major areas of present-day coastal bluff erosion and retreat are indicated on the "Surficial Geology Map" (Plate 1); areas where significant retreat occurred between 1950 and 1972 are shown on Figure 7. Erosion has been important within west and northwest-facing coastal segments, especially where the bluff stratigraphy includes diamicton-veneered Pleistocene marine sands and associated massive (segregated) ground ice. The airphoto review suggests that the bluffs in these areas retreated, over the 22 years from 1950 to 1972, by up to 25 m approximately. On an annual basis, rates of 1 m/yr to 1.5 m/yr are indicated. It should be borne in mind, however, that coastal retreat likely took place most importantly during major storms (such as that of 1970), i.e. on a episodic rather than continuing, year-round, basis.

Erosion of tidal flats is apparently the dominant marine process, in terms of area affected and volume of material moved (Figure 7). All the tidal flat areas that were present in 1950 had undergone significant erosion and removal of sediment by 1972. As shown on Figure 7, areas where the process was most important were the west, south and east sides of Mallik Bay and the northwest corner of the area. Comparison of the airphotos suggests that a strip from 150 m to 500 m wide (averaging 200 m to 250 m) was eroded from the tidal flats around Mallik Bay; in the northwest corner of the study area, the figure is closer to 1000 m. Again, bearing in mind that erosion likely occurs in an episodic fashion, at



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COASTLINE CHANGES (1950 - 1972)

CGI0039

FIGURE 7

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least to some extent (i.e. related to the incidence of major storms), average coastal retreat rates, for the period 1950 to 1972, of about 10 m/year and close to 50 m/year, are indicated for Mallik Bay and the more exposed northwest area, respectively.

Expansion of the tidal flat areas, by marine deposition, is a process of lesser importance. During the period 1950 to 1972, sediment deposition was significant in only one area: along the southwest side of the inlet channel to Mallik Bay (Figure 7). In addition, deposition and tidal flat growth occurred in one small area at the south end of Mallik Bay and in the northwest corner of the area. On the west side of the inlet channel, a strip of sediment some 500 m wide accumulated between 1950 and 1972 (an annual rate of almost 20 m/yr).

As noted by Mackay (1981), some 30 lakes have drained naturally in the Richards Island - Tuktoyaktuk Peninsula region since 1950, for a drainage rate of about one lake per year. A review of airphoto coverage for the Illisarvik area failed to disclose the existence of such a lake, or a lake (other than Illisarvik) that was on the verge of draining naturally.

5.0 QUATERNARY GEOLOGIC HISTORY

Two geologic sections showing the distribution of surficial deposits with depth are presented on Plate 2 (Appendix "C"). The inferred sequence of recent (Quaternary) geologic events is outlined below, based on observed field relationships and radiocarbon dates obtained by others. Emphasis is placed throughout on the Pleistocene Coastland area, since the availability of similar data concerning the Modern Delta areas is limited.

A fine grained silty grey-brown sand, that locally underlies the more widespread fine to medium brown sand, is the oldest unit exposed in the Illisarvik area. No data are available as to its precise age; however, the sand is obviously older than the overlying brown sand and till, both of which are pre mid-Wisconsin (i.e. beyond the range of radiocarbon dating). The basal sand is poorly exposed and evidence as to its mode of deposition was not observed; however, it may be correlative with a grey sand from Richards Island that Fyles et al. (1972) suggest is of glaciofluvial outwash origin.

The brown sand, fine to medium grained, with wood, silt and clay inclusions and (rarely) terrestrial vertebrate remains (Mackay, 1963; Fyles, 1967), is widespread in the Illisarvik area. It has characteristic thick foreset beds, the presence of which indicates that it was laid down along an active marine delta front in 15 m to 30 m of water (Mackay, 1963). Again, age relationships are uncertain, other than that the unit is younger than the grey sand and predates the till.

Following deposition of the marine-deltaic sands, sea levels fell, the study area emerged as dry land and, probably in response to the deteriorating climate associated with the approaching ice sheet, permafrost development and ground ice growth commenced. The ice sheet approached from the south, "moving down the lower Mackenize Valley and then fanning out into the Beaufort Sea" (Mackay et al., 1972). The presence of occasional flutings and alignment of major lakes within the Kittigazuit Low Hills suggests the ice movement within the study area was dominantly from southwest to northeast. As described by Mackay et al. (1972), the frozen sediments were overridden, in some areas (though apparently not in the immediate vicinity of Illisarvik) the deposits were deformed, and a stony clay till was deposited. While still beyond the range of C^{14} dating (i.e. greater than 40 000 years B.P.), the till has a relatively fresh apearance, lacks weathering surfaces and is not overlain by interglacial deposits. On this basis, it is considered to be post-Sangamon Interglacial and is assigned an early Wisconsin age (Rampton, 1972; Rampton and Bouchard, 1975).

Deposition of the till was followed by a long period of relative stability in the landscape, that was punctuated by short periods of thermokarst activity related to temporarily warmer climatic conditions. Radiocarbon dates of 22 400 $\pm$ 240 B.P., 17 800 $\pm$ 250 B.P. and 14 130 $\pm$ 440 B.P. are presented by Mackay et al. (1972) for sediments deposited under such conditions.

A more general and significant amelioration in climate began approximately 11 500 B.P. (Ritchie and Hare, 1971), lasting until about 3 600 B.P. During this period, the landscape was extensively modified by thermokarst as bodies of massive ice thawed and the present-day hummocky topography developed. As well, the accumulation of peat deposits took place. A number of radiocarbon dates, on material from the base of thermokarst depressions, confirm this (Rampton, 1972).

Since 3 600 B.P. the climate has deteriorated, such that the level of thermokarst activity is much reduced (Ritchie and Hare, 1971). To a large extent, ice slumps and mudflows have stabilized (except where subject to toe erosion by the sea or lakes). Under these conditions, erosion of lake outlets has been the dominant process, leading to lake drainage, permafrost aggradation and pingo formation (Rampton and Bouchard, 1975). Radiocarbon dates for samples collected during the Illisarvik drainage program are: 9 535 ± 220 B.P and 8 880 ± 320 B.P for peat clods within stony clay mudflow debris, deposited during a period of thermokarst activity, 915 ± 140 B.P. for lake silt which overlies the diamicton (mudflow material), and 960 ± 125 B.P. for peat in an ice wedge pseudomorph (Mackay, 1980).

Aside from continuing drainage of lakes, leading to pingo development, marine and alluvial erosion and depositional processes are dominant in the Illisarvik area at the present time.

6.0 ENGINEERING CONSIDERATIONS

The terrain in parts of the Illisarvik area is similar to that in both the Taglu and Niglintgak hydrocarbon discovery areas and other parts of northern Richards Island being considered for facilities construction, relative to off-shore Beaufort Sea development. Four areas of concern, from an engineering point of view, that have been identified during this study at Illisarvik may be emphasized.

6.1 ICE-RICH SOILS

The prime concern, from a foundation engineering standpoint, relates to the widespread occurrence of ice-rich soils. Organic and lacustrine basin areas are particularly susceptible in this respect; however, morainal and Pleistocene deltaic terrain (often underlain by massive ground ice) may also be affected. As described previously, terrain disturbance in such areas may lead to permafrost degradation, extensive thaw settlement, thickening of the active layer, and development of ice slumps. These are all problems that must be avoided in engineering design and construction. Procedures to mitigate such problems, involving construction on insulated gravel pads, are now well-established; details are provided by Johnston (1981). In addition, frost heaving may be a long-term consideration in talik areas.

6.2 SALINE SOILS

In the event development is considered in areas subject to frequent marine inundation, such as low areas of the Delta and intertidal lagoon areas, the potential for problems in foundation design due to saline soils should be recognized.

The presence of brine may lower the freezing point and strength of a soil, in terms of engineering design.

6.3 FLOOD LEVELS

The widespread distribution of driftwood in the Illisarvik area indicates that extensive areas, away from the immediate vicinity of the coastline, may be subject to flooding, either during spring break-up or storm surges. The alluvial delta, floodplain areas and intertidal lagoons, seem to be especially susceptible. Construction planned for such areas should take into account the potential for flooding (e.g. by raising design grade above likely flood elevations, etc.).

6.4 COASTLINE CHANGES

Areas of major coastline change are identified in Section 4.3. While it is unlikely that major construction in tidal flat areas would be considered, development close to eroding coastal bluffs may be anticipated. In this event, the potential for continued "coastal retreat" over the design life of a project should be recognized and structures located and designed accordingly.

Respectfully submitted,

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APPENDIX "A"

SELECTED OBSERVATION POINTS

APPENDIX "A"

SELECTED OBSERVATION POINTS

(Locations indicated on Sections A-A' and B-B', on Plate 2 in Appendix "C").

OP-1 Exposure in head-scarp of retrogressive-thaw flow slide (Photo 8, UTM 511800E 7713100N):

0 - 120 cm	Clay (till or diamicton), silty, trace gravel, to 1 to 2 cm, grey.
120 - 230 cm	Sand, fine to medium, clean, light brown, high ice content.
230 - 350 cm +	Massive ice, horizontally laminated.

OP-2 Exposure in toe area of inactive slump (UTM 515000E 7709500N):

0 to 150 cm + Stony clay (diamicton or till)

Bottom of exposure obscured by slump debris.

OP-3 Exposure in eroding bluff on north side of outlet from Illisarvik (UTM 515000E 7709500N):

0 - 55 cm	Peat, fine fibrous, dark brown.
55 - 95 cm	Clay, silty, blue-grey, laminated (lacustrine).
95 - 185 cm	Sand, fine, very silty, trace clay and gravel, brown with grey laminations.
185 - 350 cm +	Sand, fine to medium, grey, trace of silt and clay.

OP-4 Exposure at edge of inactive slump shows following section through centre of high centre polygon (UTM 517900E 7706600N):

0 - 30 cm	Peat, fine fibrous, brown.
30 - 70 cm	Silt, grey, loose, minor marl (lacustrine).
70 - 160 cm	Silt and fine sand, interbedded, brown (eolian or lacustrine).
160 - 300 cm +	Clay (till or diamicton) silty, some fine gravel and boulders (to 100 cm Ø), prominently jointed and fractured, dark grey.

OP-5 Exposure in headscarp of active retrogressive thaw-flow slide (UTM 517700E 7708800N):

0 - 100 cm	Peat, fine fibrous, brown.
100 - 150 cm +	Massive ice, horizontally laminated, stony clay inclusions in upper part.

Toe of exposure comprises active mudflow, extending 5 m to 6 m downslope to sea.

OP-6 Exposure through eroding high centre polygon (UTM 519400E 7710800N):

0 - 110 cm	Peat, fine fibrous, brown.
110 - 260 cm +	Silt, organic, very peaty, horizontally laminated, freshwater shells (gastropods) scattered throughout.

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APPENDIX "B"

PHOTOGRAPHS

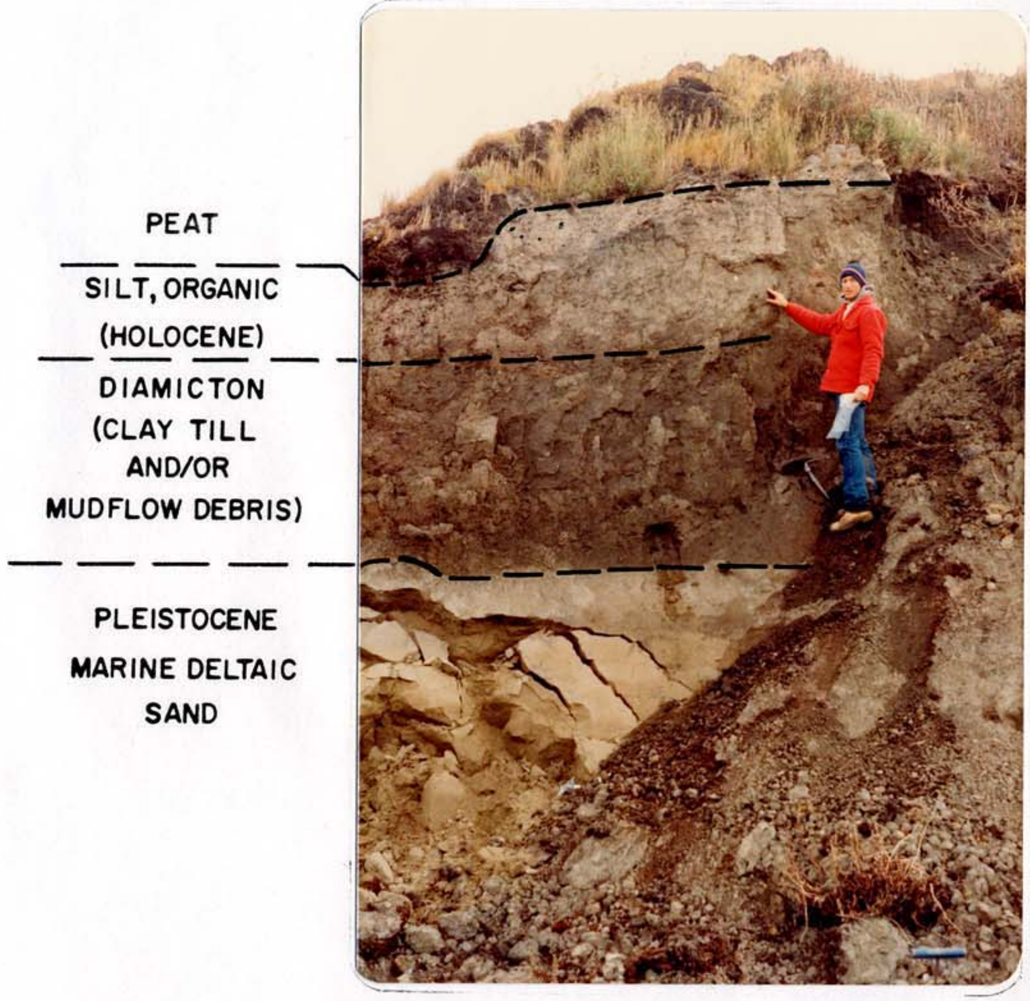

PHOTO 1: Section in coastal bluff, east side of Mallik Bay inlet channel, approximately 5 km northwest of Illisarvik, showing typical stratigraphic sequence in the area. (UTM 515100E 7712900N)

PHOTO 2: Coastal bluff section, approximately 2.75 km north of Illisarvik, showing insitu till with characteristic joints and fractures (UTM 518100E 7710400N)

PHOTO 3: Sand beach spit, with lagoon on landward side, approximately 2.5 km southeast of Illisarvik (UTM 517800E 7705400N).

PHOTO 4: Pleistocene marine sand exposed in 17 m high bluff along Mallik Bay coastline, 6 km east of Illisarvik. Note: thin peat veneer overlying sand, apparent absence of till (a gravel lag is present), and colluvial fans along toe (UTM 521800E 7709000N).

PHOTO 5: High centre polygons, approximately 900 m east of Illisarvik (UTM 517600E 7708000N).

PHOTO 6: Low centre polygons (with high centre polygons on pingo), approximately 5.5 km south of Illisarvik (UTM 7701200N).

PHOTO 7: Area of recent (Holocene) marine tidal and intertidal deposits (silt and fine sand) in western part of area (approximately 3.5 km west of Illisarvik, UTM 513300E 7709600N).

PHOTO 8: Retrogressive thaw-flow slide in area of diamicton-veneered Pleistocene marine sand, 6.5 km northwest of Illisarvik. Note: development of massive ice at boundary between diamicton and sand (UTM 511800E 7713100N).

PHOTO 9: Ice slump, 1.2 km east of Illisarvik along west coastline of Mallik Bay. Note: mudflow at toe of slump, which is being eroded by sea (UTM 517900E 7709000N).

PHOTO 10: Close-up of ice slump shown on Figure 9. Massive ice extends from the base of 50 cm thick surficial peat horizon (UTM 517900E 7709000N).

PHOTO 11: Extensive area of driftwood surrounding 10 m to 12 m high pingo on north side of Burnt Creek, approximately 7.5 km southeast of Illisarvik (UTM 521500E 7702400N).

APPENDIX "C"

MAP AND SECTIONS

see file:
of_0941-2_sections.pdf

see file:
of_0941-2_map.pdf