Potential Granular Resources and Their Geological Constraints Northern Richards Island (Part of NOGAP Project A4)

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EXECUTIVE SUMMARY

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

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

Outwash in the eastern part of the study area may provide some graded sand and minor gravel, but require further investigation concerning the quality of material and the presence of massive ice. Glaciofluvial valley trains and terraces and marine terrace south of Summer Island contain much sand, some pebbly and some with layers of woody detritus. The only located source of well graded gravel is found in a glaciofluvial valley train there and its quality and extent should be further investigated. Exploitation of these deposits is limited by drainage and an icy silt and peat cover.

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

1.0 Introduction

1.1 Regional Geotechnical Requirements

The offshore oil and gas reserves in the Beaufort Sea are fairly well defined along with the proposed facilities needed to transport the resources to staging areas and markets. Although the exact siting of the pipelines and the timing of developments are unknown, the transportation corridors from offshore reserves to inland staging areas are well-known. Both oil and gas transportation corridors have targeted North Point, Richards Island as the landing zone where the pipelines will begin their overland transport of hydrocarbons. North Point's northern coastal locality and peninsular geography combine to create an environment that will require site specific engineering designs to limit geomorphic changes to the peninsula. These engineering designs commonly utilize local granular resources in the implementation of mitigative measures.

Previous reports and studies have provided general information on geotechnical factors and the surficial geology and active geomorphological processes in the area. The information, however, is inadequate to manage the anticipated demands for granular material in the area that would result from future offshore hydrocarbon developments. Thus this project is being undertaken to provide an initial assessment of the potential granular resources and conditions on North Point, Richards Island, in the anticipated landing zone of offshore pipeline corridors. The study delineates and characterizes potential granular materials, provides an understanding of the surficial sediments inland from the coast, and compiles data from known boreholes drilled in the area. The report also identifies sensitive terrain, permafrost conditions, ground ice conditions, and other geological constraints which are likely to limit or prohibit development of potential granular deposits.

1.2 Geographic Setting

The study area, northern Richards Island, is located just east of the Mackenzie Delta in the Northwest Territories (Figure 1). It lies 40 km west of Tuktoyaktuk and 100 km north of Inuvik.

Richards Island forms part of the Tuktoyaktuk Coastlands (Rampton 1988), an area of thick Quaternary sediments having low relief, rarely rising over 60 metres above sea level. Most of the investigated area lies within Rampton's Kittigazuit Low Hills. They are "characterized by deeply inset lakes with moderately step slopes on adjacent well drained ridges. Thin surface tills cap thick, brown fine grained sands, which form most tills and ridges. The areas of lakes and ridges have a strong northeast trend". (Rampton 1988, p.11).

Northern Richards Island, excluding taliks under large lakes and marine embayment's, is underlain by between 600 and 750 metres of permafrost and is characterized by mean annual ground surface temperatures of -8° to -9°C (Dallimore 1992).

The Richards Island is characterized by an arctic coastal climate with long cold winters, October through April, and short cool summers. Precipitation is low, being concentrated during the summer and early fall. Snow, which falls mainly in October, is redistributed and compacted by wind. Winds are strong during the fall and winter.

Meaningful thaw only occurs during June, July and August. This limits the active layer to an average of about 0.3 metres in depth, but up to 1 metres in well drained sands with broken vegetation cover. Although precipitation is minimal, the cool summer temperatures and shallow active layer maintain a moist active layer in well drained areas, and a saturated active layer in imperfectly drained areas.

The investigated area is covered by low arctic tundra. Well drained areas have a broken tundra cover dominated by Dryas, heaths and low prostrate willow. Sedges are common in poorly drained areas. Cottongrass tussocks cover large parts of imperfectly drained terrain. Shrub birch becomes common toward the south edge of the study area.

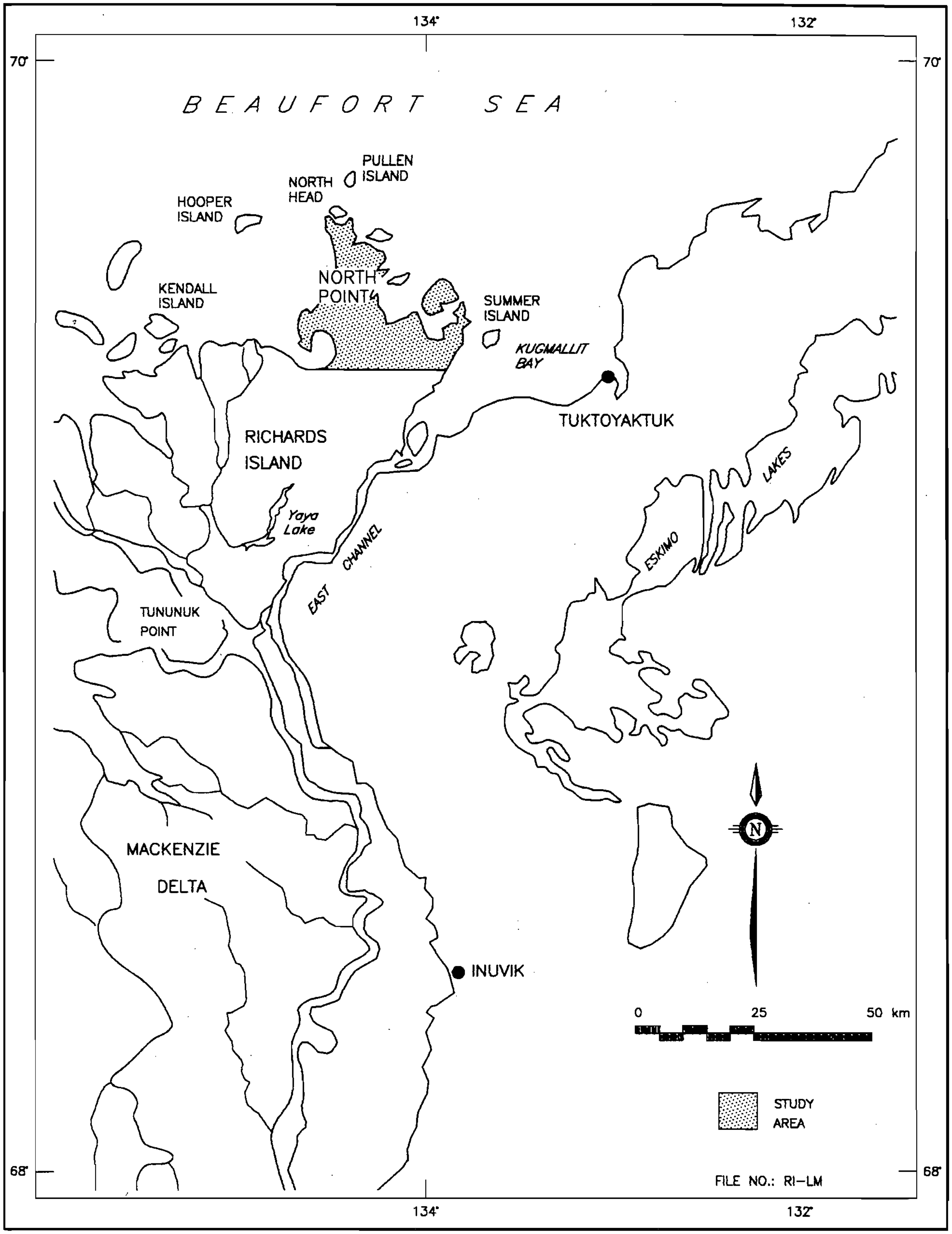


Figure 1. Location Map

1.3 Methodology

The project was completed in three phases. Data compilation and literature review was mainly completed prior to a field reconnaissance, whereas air photo interpretation and final assessments were completed following the field reconnaissance.

1.3.1 Data Compilation and Literature Review

Data compilation involved retrieving and reviewing IOL shot hole log compilations in the files of the Geological Survey of Canada (Appendices I and II). These records have to be evaluated subjectively as each hole is not systematically logged and carefully evaluated in the course of the seismic surveys. However, an interpretation can be made of the general thickness and nature of the surficial materials.

Description field notes of exposures from the files of Scott Dallimore, Geological Survey of Canada, and from the files of Terrain Analysis and Mapping Services Ltd (Appendix III) were reviewed and plotted as necessary to detect patterns in materials and ground ice associations.

Granular studies related in part to Richards Island by Ripley, Klohn and Leonoff International Ltd (1972), EBA Engineering Consultants Ltd (1975, 1986), Terrain Analysis & Mapping Services Ltd (1976), BBT Geotechnical Consultants Ltd, GVM Geological Consultants Ltd and Terrain Analysis & Mapping Services Ltd (1983) were reviewed as a guide to this investigation, although most of these investigations concerned granular deposits on southern Richards Island. The similarity in materials and ground ice distributions are considered useful as guides to northern Richards Island, although many of the deposits on southern Richards Island are more clearly glaciofluvial in origin. Scientific reports and maps by Dallimore (1991, 1992), Kurfurst and Dallimore (1991), Rampton (1979, 1988), and a technical report by D.F. Dickens Associates Ltd and Terrain Analysis & Mapping Services Ltd (1993) were utilized to determine the distribution of different surficial materials, the distribution of ground ice, and the nature of coastal retreat and other geologic processes in the area.

1.3.2 Field Reconnaissance & Air Photo Interpretation

Prior to field reconnaissance, a review of the air photos was conducted to plan traverses in order that sites having potential as aggregate sources would be reconnoitred. Compiled data from all sources was also used as a guide. S. Traynor of DIAND obtained all land use permits required for the field investigations.

During the field reconnaissance in mid-August, helicopter traverses (helicopter based at PCSP, Tuktoyaktuk) were flown in order to delineate potential aggregate sources from the air and to effect landings on sites in order to test pit selected sources. Ground investigations by V. Rampton of Terrain Analysis & Mapping Services Ltd. and S. Traynor of DIAND included test pitting areas showing the highest potential for aggregate and examining drainage patterns and materials in surrounding areas to delineate the edge of the area that might be easily exploited. Some time was spent examining retrogressive thaw slumps and coastal exposures to determine the nature of material and ground ice distributions associated with these features.

Subsequent to field work, an air photo interpretation of the surficial geology of the total area was completed in order to define potential sources of granular materials and restrictions to their exploration. It was necessary to map the complete landscape in order to access the potential of granular sources because some of the major identified sources were unconventional and had a unique nature and distribution.

1.3.3 Final Assessments

Surficial geology maps, a final assessment of potential sources of granular material and possible restrictions on their exploitation was completed based on the results of the earlier investigation. Requirements for future investigations to confirm the above were also determined. A preliminary report was submitted to S. Traynor and R Gowan of DIAND for review. Based on the review, they suggested modifications that were integrated into this report.

1.4 Acknowledgements

We would like to thank S. Dallimore of the GSC and S. Traynor and R. Gowan of DIAND for their assistance in completing this project. Mr. Dallimore provided his field notes and shot hole log compilations from the study area for our review. Mr. Traynor and Mr. Gowan provided copies of numerous granular material investigations from Richards Islands for our review. Mr. Traynor also obtained all required land use permits, made arrangements for lodging and helicopter support from PCSP at Tuktoyaktuk and assisted with the field reconnaissance.

Discussions with Dallimore concerning his knowledge of the distribution of surficial materials, permafrost and ground ice were helpful in location of granular materials and evaluation of restrictions to their extraction. Discussions with Traynor and Gowan concerning their knowledge of granular materials in surrounding areas and their requirements within the study area were critical to completion of the project.

2.0 Surficial Geology

2.1 Geologic History and Stratigraphy

Richards Island is underlain by a number of Middle to Late Quaternary stratigraphic units. Based on a section at the south edge of Summer Island and sections at Kendall Island (Figure 1), the sequence shown in Figure 2 was established (Rampton 1988). This sequence has been confirmed during geotechnical investigations by the Geological Survey of Canada (Dallimore 1991), and Kurfurst and Dallimore (1991).

A series of marine sands with interbeds of silty clay, deposited in a fluctuating shallow sea, form the oldest sediment in this sequence. These sediments are known as the Kendall Sediments and are probably not exposed or at the near-surface on North Point. The exception being within the highly deformed sequences at Summer Island where Kendall Sediments may be elevated through ice thrust.

Following deposition of the Kendall Sediments, the area was submerged further and marine clay was deposited. This clay, known as the Hooper Clay, has only been noted on northern Richards Island in the deformed sequence at Summer Island. This clay was generally absent from the base of the shot hole logs on northern Richards Island (Rampton 1988; also Appendices I and II), but has been noted in a hole drilled by the Geological Survey of Canada near North Head (Dallimore 1991; hole 1A, Appendix III) and offshore drill holes (Dallimore 1991, Kurfurst and Dallimore 1991).

Following deposition of the Hooper clay, sea level fell and sand was deposited on a broad alluvial plain by braided streams. The sand, known as the Kidluit Formation, is generally gray, medium to fine-grained and planar to cross-bedded. It can contain mats of organic detritus and coal fragments and isolated pebbly beds. The Kidluit Formation has been noted in the ice thrust sediments of Summer Island and adjacent areas. At one section on the south side of Summer Island it was noted to be 11 metres thick. Although it is exposed near or at the surface in areas of ice thrust sediments, it does not appear to be near the surface throughout the remainder of northern Richards Island. In a hole drilled by the

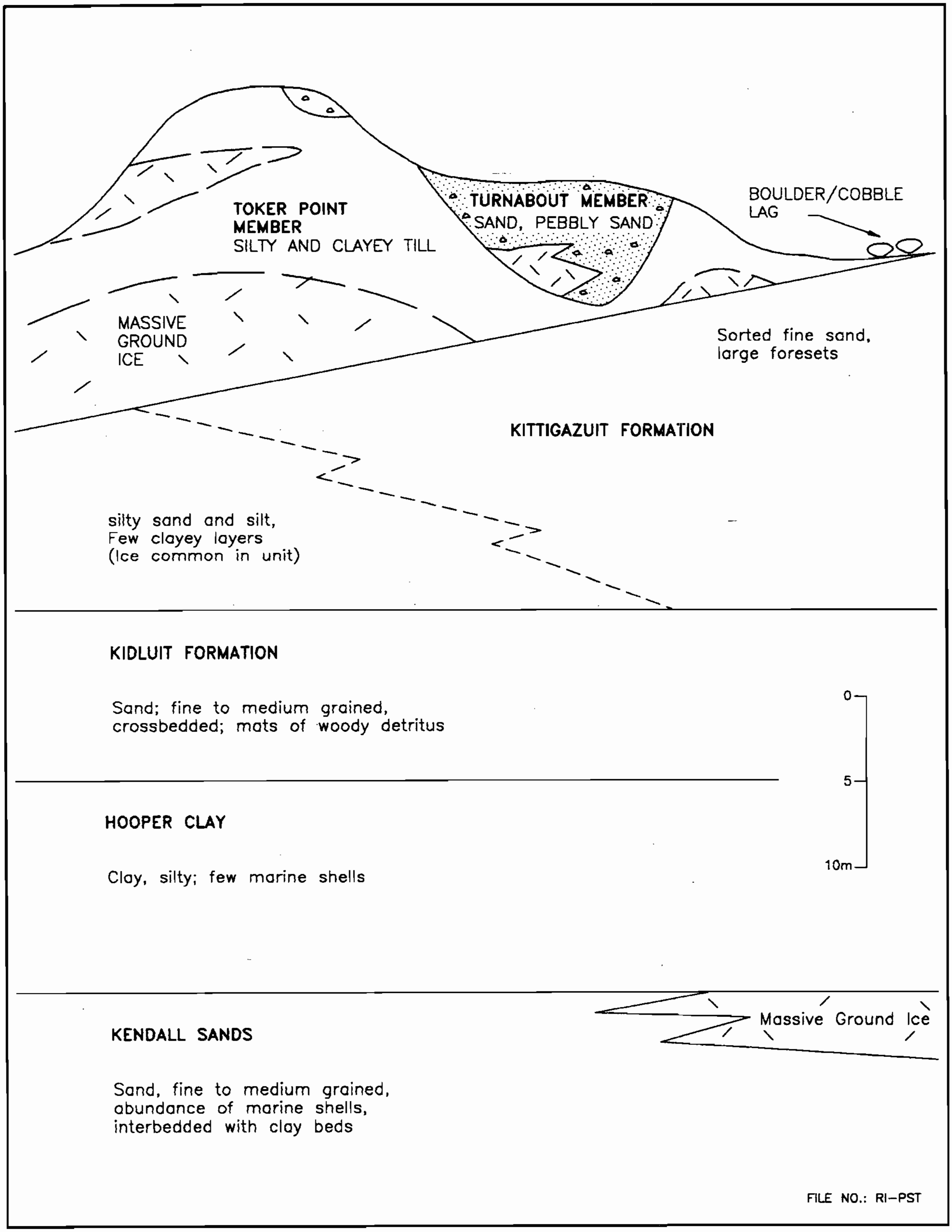


Figure 2. Schematic Representation of Pleistocene Stratigraphy on Richards Island, (after Rampton 1988).

Geological Survey of Canada (Dallimore 1991) just west of the Reindeer Islands near sea level (hole 1A, Appendix III), it lies at a depth of 27m.

Immediately overlying the Kidluit Formation, are brown sands and silts of the Kittigazuit Formation (Figure 3). On North Head these fine-grained brown sands are often characterized by foreset beds up to 12 metres thick. However at the eastern end of Liverpool Bay, at the base of sections along southwestern Liverpool Bay, in deformed sections on Hooper Island and locally at North Head, the sands are silty and are horizontally bedded. At North Head they were noted to contain thin clayey lenses with marine shells. In fresh exposures they may be gray, but rapidly turn brown upon exposure. This is the result of rapid oxidation upon exposure to air of unstable iron sulphide compounds or fine organic detritus within the sands deposited in a reducing marine environment (Rampton 1988). The large scale foresets are probably the result of wind reworking the sandy facies (Dallimore et al, 1993) and their redeposition in form of a large dune field. Alternately, they may represent rapid deltaic deposition into a cold sea (Rampton 1988). The Kittigazuit Formation sands generally are over 20m in thickness where well exposed. Geotechnical investigations (Kurfurst and Dallimore 1991, Dallimore 1991) also confirm that this is commonly a minimum thickness.

Following deposition of the Kittigazuit Formation, the area was glaciated, probably during the Early Wisconsinan. The glacier ice that affected Richards Island significantly modified the preglacial landscape. Pressure and temperatures conditions under the base of the glacier, in combination with a variety of subglacial sediments, resulted in the glacier sculpting a fluted surface on the southwestern part of North Point and the ice thrusting of sediment from Mason Bay and "Summer Bay" (this name is used for convenience and is not being proposed formally) to form the southern part of Summer Island and adjacent ice-thrust blocks. On hydrographic charts, a depression of over 24 metres is present in southern Mason Bay (Canadian Hydrographic Services 1967), and undoubtedly a similar depression is present in "Summer Bay". Folds and faults are common in exposures around ice-thrust blocks. Evidence of deformation caused by glacier ice thrusting is also present at North Head (Figure 4) and at a locality south of Mason Bay where Kittigazuit sands appear to overlie till (93RI-11; Figure 5).

Figure 3.
Kittigazuit Formation at 93RI-1. (Note uniform bedding of Foresets)

Figure 4. Deformed Kittigazuit Formation at North Head (93RI-19)
Silty sand is brown and silt is gray.

Till, known as the Toker Point Member (Rampton 1988), was deposited over much of the landscape during glaciation, although it is relatively thin on ice-thrust blocks and other ridges on the east side of North Point. However, even there till is present in significant thicknesses in some places. Eskers and kames were also deposited during glaciation and are present throughout areas covered by the Toker Point Member. These glaciofluvial features have been termed the Turnabout Member (Rampton 1988). During the late phases of glaciation, proglacial valley trains and glaciofluvial terraces were deposited south of "Summer Bay" and adjacent Kugmallit Bay. These features graded to a sea (with a relative level well above present sea level) that was developing coastal escarpments through wave erosion around Corral Bay and to the north at the time.

In the later phases of glaciation and subsequent to deglaciation segregated ground ice formed where temperature conditions were amenable to an aggrading frost table (Rampton 1988). Generally, relatively impermeable fine-grained sediments overlying permeable sediments containing water under high hydrostatic pressure led to the formation of ground ice. Typically this segregated ice formed as thick extensive ice sheets (massive ice) at the base of the Toker Point till (Figure 5), under the Hooper clay (Figure 2) and in the siltier facies of the Kittigazuit sands (Figure 6). Massive ice is also present in glaciofluvial sediments. Some of this ice could be buried glacier ice rather than segregated ice (Dallimore and Wolfe 1988, Gowan and Dallimore 1990).

Following the Wisconsian, climate warming induced thickening of active layers and thermokarst. The thermokarst proceeded largely through retrogressive thaw slumps, a process still actively occurring (Figure 5). Massive melting of ground ice resulted in the formation of thermokarst lakes, which in turn were filled in by sediments from retrogressive thaw slumps around their edges. Drainage of these basins, generally prompted by thaw and thermokarst at their outlets has resulted in peat accumulation in the poorly drained environment within the basins.

Figure 5.
Massive ice and icy sediment thawing at the base of till in an active retrogressive thaw flow at 93RI-11

Figure 6.
Frozen Kittigazuit Formation silts with massive ice at North Head.

A gravity survey across thermokarst depressions and ice-cored hills on southern Richards Island indicate that the relief there is simply due to the thawing of ground ice (Rampton and Walcott 1974). However this model cannot be simply extrapolated to northern Richards Island because of the effect upon the landscape of glacial ice thrusting and fluting.

2.2 Surficial Units

In order to understand the distribution of potential areas for granular materials and the restrictions upon their extraction, a detailed map of the surficial materials of northern Richards Island was undertaken (Figure 7). Table 1 and the following text is a brief description of the delineated surficial units.

2.2.1 Alluvium (A and F; Figure 7)

Alluvial deposits are present along most small streams, but they are generally too narrow to map at the scale of Figure 7. In addition, they often are flanked by lacustrine deposits having similar sediments, drainage and ice contents (Table 1.) They have not been separately delineated in some instances for this reason. The floodplain portion of these units may be subject to periodic flooding. In addition those parts near sea level may be subject to flooding during high tides and storm surges. Alluvial floodplains are prograding into drowned valleys. The materials within alluvial deposits, their thickness, ice contents and drainage are described in Table 1.

The few fans mapped on northern Richards Island (Figure 7) form coalescing deposits adjacent to escarpments bordering glacial meltwater or wave cut and steepened escarpments. These fans are composed primarily of materials forming the adjacent escarpments. Parts of the fans may be colluvial in origin resulting from slumping of materials from the escarpments. Slow aggradation on the fan surfaces and continuous seepage across them has resulted in these features containing peaty layers and having high ice contents (Table 1), even though their surfaces are characterized by continuous slopes, albeit gentle.

TABLE 1. DESCRIPTION OF TERRAIN UNITS (after Rampton 1979)

SYMBOL	NAME	MATERIALS AND THICKNESS	PERMAFROST DISTRIBUTION AND ICE CONTENTS	GEOMORPHOLOGY AND DRAINAGE
A	Alluvial Deposits	Silt, fine sand, and clayey silt, commonly organic; generally more than 6m thick. Thin local accumulations of peat present.	Irregular distribution of permafrost; medium ice contents in frozen sediment due to presence of ice lenses.	Flat floodplains and low terraces near sea or stream level; thaw pools, lakes, and marshy areas common; low surfaces occasionally inundated.
F	Fans	Sand with interbeds of silt and peaty lenses; unit may exceed 10m thickness, thins to nil at apex and distal margins of fans.	Continuous permafrost; ice contents variable, but generally medium.	Coalescing fans flank uplands on glaciofluvial and marine terraces. Surfaces imperfectly drained due to seepage across fans.
L, L_w	Lacustrine Deposits	Interbedded silt, clayey silt, and silty sand with peaty layers; predominantly silty sand and sand in areas of outwash and Kittigazuit sands; generally 1.5-8m thick.	Rare isolated taliks present within continuous permafrost; ice contents generally low to medium in sandy sediments and medium to high in silty and clayey sediments due to presence of ice lenses; massive ice under pingos and domes.	Flat to gently sloping; in places benches are separated by small scarps. Surface commonly marshy with many thaw pools. Pingos and small domes, both inactive and presently forming, within unit. Lw are areas frequently inundated by marine water.
W_r	Beaches, spits and bars.	Sand predominantly; sandy gravel less common; 0.5-3m thick.	Irregular distribution of thin permafrost; low ice contents in frozen sediment.	Low broad ridges rising up to 3m a.s.l.
W_t, P/W_t	Marine plain and terrace	Sand with few pebbly beds; local veneer of fine sand and silt and patches of thin peat on surface; where surface peat thickens consistently to over 0.5m, it is mapped as P/Wt. Generally 3-10m thick.	Continuous permafrost; ice contents generally low except medium to high in silt and peat.	Flat plain with little relief due to terracing and thermokarst basins; drainage moderately good to good, but imperfect to poor on extensive broad flat areas.

Table 1. Continued

Gt, P/Gt	Glaciofluvial valley train and terrace	Silty sand and sand with few interbeds of sand and gravel; local veneer of fine sand and silt and surface patches of thin peats; where surface peat thickens consistently to over 0.5m it is mapped as P/Gt.	Continuous permafrost; ice contents of sand generally low, but silt has high ice content. Ice wedges abundant, especially in peat covered areas.	Flat plain with some relief due to terracing, inset channels, and thermokarst basins; drainage moderately good to good, but imperfect to poor in channel traces and on extensive broad flat areas where ice-thaw pools are common.
G	Outwash	Sand with few pebbly beds; generally 5-20m thick. Local veneer of fine sand and silt and patches of thin peat on surface. Depressions contain 2-5m of sandy lacustrine sediment and peat.	Rare taliks in depressions within continuous permafrost; ice contents in near-surface outwash low, but massive ice may be present at depths of 7-70m.	Rolling to hummocky surface with local relief to 20m; on Summer Island summits of hills are generally flat and accordant; well drained.
Tv	Till veneer	Clayey diamicton or poorly sorted gravel over sandy or silty Kittigazuit Formation. Diamicton variable in thickness, generally 1-3m but thinner in areas. Sands generally 10 to 30m thick. Depressions contain 2-8m of lacustrine sediment and peat.	Rare taliks in depressions within continuous permafrost; ice contents of diamicton low to medium due to presence of ice lenses; near-surface sands have low ice contents, but massive ice may be present at base of till and at depths of 7-70m.	Hummocky to rolling with local relief between 10 and 40m; hills and slopes moderately well drained, depressions imperfectly drained. inactive retrogressive thaw slumps on slopes where till is thick, active slumps on recently steepened slopes. Cliff-top dunes and blowouts common along eroding coast lines where till is thin.
Tb	Till blanket	Clayey diamiction over sandy Kittigazuit Formation. Diamicton variable in thickness, generally 1 to 5m thick, but may be thicker over extensive areas.	Rare taliks in depressions within continuous permafrost; ice content of diamiction low to medium due to presence of ice lenses; massive ice common at base of till and at depths of 7-70m.	Hummocky to rolling with local relief between 10 and 40m, hills and slopes moderately well drained, depressions imperfectly drained. Inactive and active retrogressive thaw slumps on hill slopes.

Table 1. Continued

T	Till modified by thermokarst	Clayey diamicton containing pockets of sorted silty and clayey material; diamicton is 5-15m thick; depressions contain 2-8m of lacustrine sediment and peat.	Rare taliks in depressions within continuous permafrost; ice contents of diamicton low to medium due to presence of ice lenses (generally having reticulate pattern); massive ice common at base of till and at depths of 7-70m especially under hills and ridges.	Hummocky to rolling with local relief between 10 and 40m. Few hills show an "involuted" pattern of ridges with 1-4m relief. Slopes moderately well drained, hill crests imperfectly to moderately well drained; depressions poorly drained. Inactive and active retrogressive thaw slumps on hill slopes.
S	Kittigazuit Formation	Sorted fine sand; generally 10 to 30m thick. Patches of thin till and peat, (<0.5m) may be present on flat surfaces.	Continuous permafrost; ice contents generally low, although massive ice may be present in underlying formations.	Ridges standing 10 to 30m above surrounding landscape. Well drained. Ridges actively eroding along coast.
SI	Ice-thrust Kittigazuit Formation (also Kidluit Formation ?)	Sorted fine sand; includes some medium sand, occasionally with pebbly lenses and abundant woody detritus layers. Patches of thin till, silt and peat, 0.5 to 3m thick may be present in depressions.	Rare taliks in depressions within continuous permafrost; ice contents of sand generally low; thin silt and till low to medium. Massive ice may be present within ice thrust blocks.	Broad ridges standing 20 to 40m above surrounding landscapes. Swales and valleys give 5-20m of local relief. Generally well drained, actively eroding along coast.

2.2.2 Lacustrine Deposits (L,Lw; Figure 7)

Lacustrine deposits lie in basins that were initially formed by thermokarst. The distribution of the lacustrine deposits indicates that the large thermokarst depressions have formed in areas primarily underlain by till and glaciofluvial and marine plains and terraces. The basins and deposits in areas of sandy sediments are respectively shallower and thinner than those in areas of till; this is related to ground ice contents and massive ice distribution within the surficial units within which the thermokarst developed.

Lacustrine deposits are commonly marked by multiple benches (Table 1) that relate to continuing changes in lake levels. Permafrost develops in emerging areas and the build-up of ice lenses in the sediments as the permafrost aggrades leads to these areas standing as benches above lower levels. The lower levels have drained at a latter date and permafrost aggradation and the related ice lenses are thinner. The total amount of ground ice under any lacustrine bench within a basin is related to the relative elevation of the bench.

Lacustrine deposits in basins breached and periodically inundated by marine water commonly have a discontinuous cover of driftwood. The driftwood is concentrated at the elevation of storm surges and high tides. Marine inundation leads to changes in the active layers water chemistry and deterioration of the former vegetation cover. This in turn affects the stability of the near-surface peat and the ground surface.

2.2.3 Marine beaches, Bars and Spits (Wr; Figure 7)

These features are commonly sandy around North Point because of the large amount of sand, namely the Kittigazuit sands, being eroded by wave activity during coastal retreat. Where gravel is present in these features, e.g. in the spit at the east end of North Head, it is the result of headlands containing till being eroded and retreating landward over long distances. The coarser clasts are continuously moved in a landward direction as the spit migrates in that direction.

2.2.4 Glaciofluvial & Marine Plains & Terraces (Gt, Wt, P/Gt, P/Wt; Figure 7)

These features are only evident on the eastern part of northern Richards Island, where it appears that a valley train originating to the south of "Summer Bay" and a plain or terrace originating near the apex of Kugmallit Bay graded to a sea level of between 6 and 8 metres above present sea level. What portion of this terrace was deposited in shallow marine waters or was re-worked by marine waters is difficult to determine, but the terraces around Corral Bay and southeast of Summer Island do not appear part of a valley train, but rather to erosion of sandy cliffs by a former sea and re-deposition of the sand in the terraces.

In spite of their sandy nature, these features are commonly poorly drained because of their flatness (Table 1). This has lead to accumulation of organic deposits on their surface and a further deterioration of the drainage. Only near scarps has good drainage been maintained and is their surface relatively free of organic cover.

2.2.5 Outwash (G; Figure 7)

Two areas of possible outwash have been mapped : (1) on Summer Island and (2) south of Kidluit Bay above a glaciofluvial terrace. On Summer Island, a flat plateau marked by thermokarst lakes and large well developed polygons on its upper surface is present. Both of these characteristics are common to ice-cored outwash plains. However no observations were made in this area to confirm this possibility.

South of Kidluit Bay, ridges adjacent to a lower glaciofluvial terrace appear to be superimposed upon the landscape. As such they might be glaciofluvial rather than bare Kittigazuit sand ridges or ice-thrust features.

2.2.6 Till (T, Tb, Tv; Figure 7)

With exception of ice-thrust features and bare Kittigazuit sand ridges, till covers much of the upland areas. It would appear to be thickest in the south part of the study area where it generally ranges between 6 and 15 metres in most shot hole logs, but varies between

3 and 24 metres (Appendix I and II). Some of this thickness may be accounted for by segregated and massive ice as retrogressive thaw slumps are common.

Till is still present in some thickness on North Head. Indeed, the GSC recorded 28 metres of till, 7km south of North Head (Dallimore 1991). One shot hole southwest of Wallace Bay showed 29 metres of till; others commonly showed 6 to 15 metres of till (Appendix II). However, when looking at exposures along the coast one commonly sees only 1 to 2 metres of till. This suggests a great variability of till thickness in areas mapped as Tb and Tv than in areas mapped as T (Figure 7). In the Tv area the till can be very thin, commonly thinning to a negligible thickness or being absent.

Slopes covered by till are often marked by active or inactive retrogressive thaw slumps, depending on slope and disturbance.

2.2.7 Kittigazuit Formation (S, Sl; Figure 7)

The Kittigazuit Formation, where mapped, consists primarily of fine sorted sand (Figure 8). Pebbles and cobbles and rarely boulders may veneer its surface, but they are thought to relate to glacial deposition.

In exposures, the Kittigazuit is primarily a well sorted brown fine-grained sand (Figure 9). Only toward North Head does it contain significant silt and silty sand. Characteristically, it shows large scale foresets. It is barren of pebbly beds and major organics beds, except possibly at site 93RI-18 (Figure 9). Here woody detritus and pebbly beds are present in gray and brown sands representative of a floodplain environment. Possibly the sediments noted at 93RI-18 are inland facies of the Kittigazuit Formation as large-scale foresets are absent from here south to Tununuk Point (Rampton 1988).

The Kittigazuit Formation is commonly at surface on Hadwen Island and the eastern part of North Head. Its surface is well drained and stable, commonly with a broken vegetation cover (Figure 10).

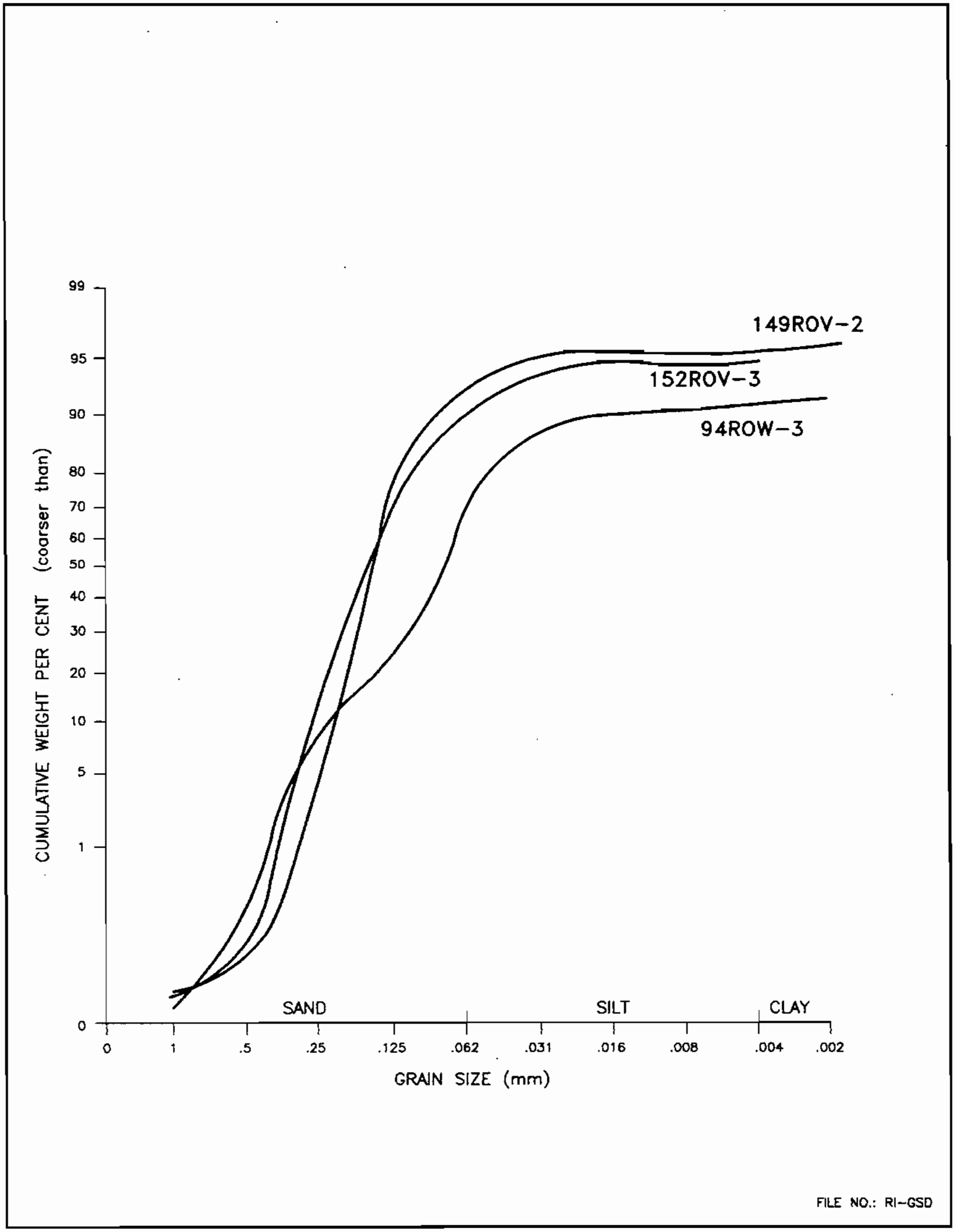
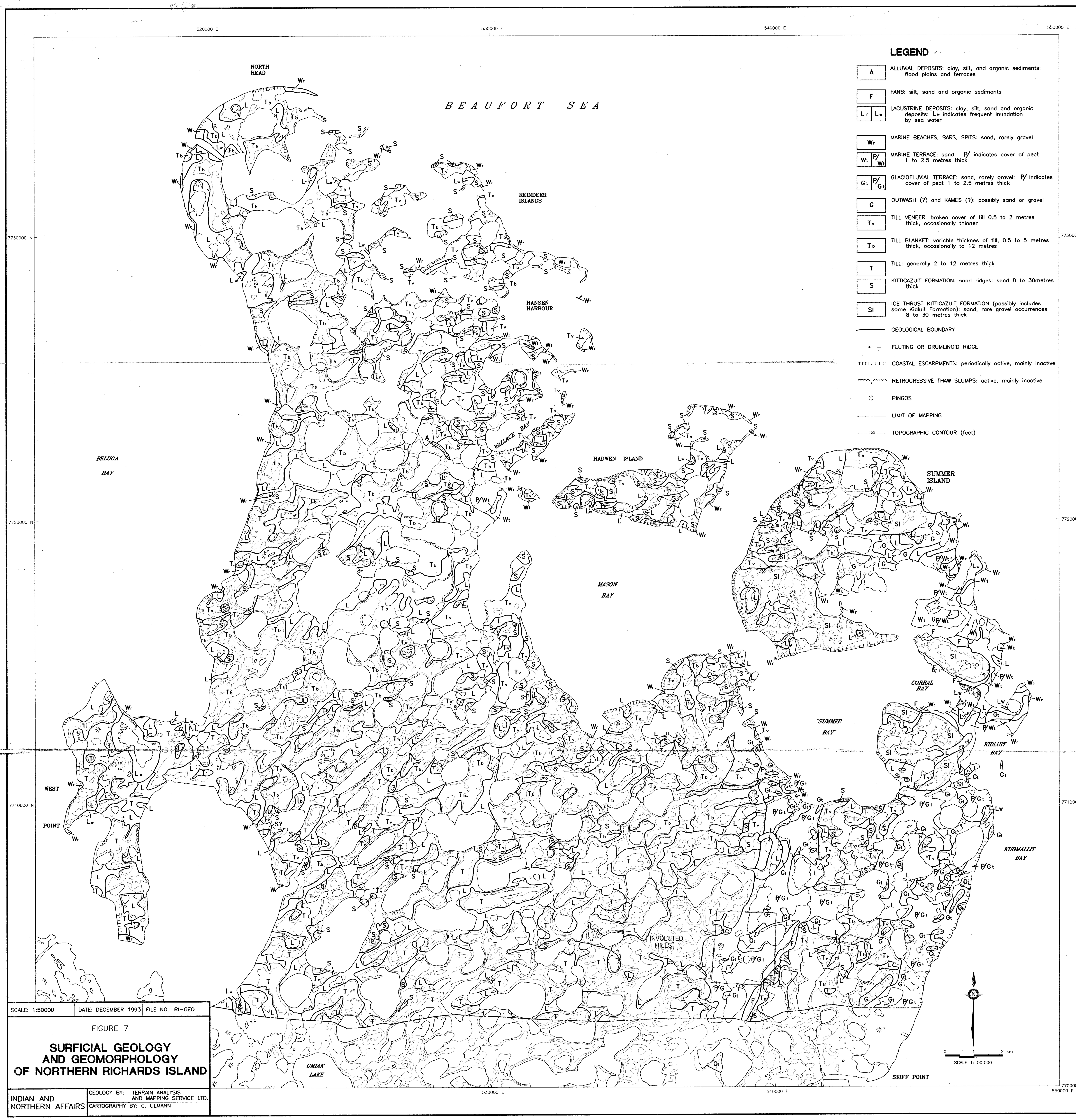


Figure 8. Logarithmic-Probability Graph of Grain-Size Distribution for Typical Kittigazuit Formation Sands (from Rampton 1988).

Figure 9. Sands and pebbly gravel at 93RI-18

Figure 10.
Photograph of sand ridge. Note pebbles and cobbles throughout broken vegetation in stabilized blow-out. Also impression of gentle southward dip (photo left) of surface strata. Figure in centre for scale.



SCALE: 1:50000	DATE: DECEMBER 1993	FILE NO.: RI-GEO

FIGURE 7

SURFICIAL GEOLOGY AND GEOMORPHOLOGY OF NORTHERN RICHARDS ISLAND

INDIAN AND NORTHERN AFFAIRS	GEOLOGY BY: TERRAIN ANALYSIS AND MAPPING SERVICE LTD. CARTOGRAPHY BY: C. ULMANN

FIGURE 11

GENERAL DISTRIBUTION OF SURFICIAL UNITS AND FEATURES ON NORTHERN RICHARDS ISLAND

The Kittigazuit Formation appears on the surface of most of the ice- thrust blocks on Summer Island and around Corral Bay (Figure 11). Gray sand of the Kidluit Formation has been observed in some exposures. However, the Kidluit Formation is also a medium to fine-grained sand and rarely contains pebbly layers in this area. Due to deformation it may form the surface of parts of some ice-thrust blocks. The ice-thrust blocks were not examined in detail during this study because they are east of the general area of concern.

The surface of the ice-thrust blocks consist of ridges or knobs of well-drained bare sand separated by vegetated depressions.

2.3 Pattern and Origin of Units Having Potential Granular Materials

The detailed map of the surficial geology and geomorphology of the study area (Figure 7), indicates a distribution pattern of surficial units and landforms as illustrated in Figure 11. This pattern of surficial units and features suggests a more complex landscape than Rampton's (1988) description of the Kittigazuit Low Hills. Northeast trending ridges and lakes are confined to the southwest corner of the study area. Lakes and hills throughout the remainder of the area are more irregularly oriented and shaped. Broad glaciofluvial and marine terraces are commonly poorly drained, whereas ice-thrust blocks stand up as unique well drained landforms.

Ice-thrust features are confined to Summer Island and around Corral Bay. These units were probably squeezed out from under the edges of a glacier rather than incorporated into the bed of a glacier and thrust upward at its margin. The lack of till cover on them points to this mode of origin.

A zone of till veneer and sand ridges lies between Summer Island and areas covered by thick till to the west. What is the rational behind this distribution of these ridges?. Although relief on parts of southern Richards Island can be attributed to the presence or absence of ground ice (Rampton and Walcott 1974; Rampton 1988), local exposures suggest that this is not the case here (simple gravity profiling could easily prove or disprove this possibility).

The general thinning of till might be due to removal of till from the ridge crests by a mass wastage process involving retrogressive thaw slumps moving till downslope and off of the sand (Figure 12). Thus the sand is exposed in a manner similar to terrace-edge preglacial gravels along the Yukon Coastal Plain (R.M. Hardy and Associates Ltd and Terrain Analysis and Mapping Services Ltd. 1976). A till veneer on some of the ridges suggests that this process might partly explain the thinness or absence of till on some ridges.

Ice thrusting at a scale smaller that involved in the formation of Summer Island is another possibility, given the deformation at Summer Island and North Head (Figure 4). The lack of deformation structures in exposures of Kittigazuit sands in the area suggests that this is not the origin of most sand ridges. However the presence of brown sand over till in an exposure south of "Summer Bay" (93RI-11; Figure 11) suggests that some sand ridges, especially those close to Summer Island, may in part owe their topographic position to ice thrusting.

Another possible origin of sand ridges is due to subglacial processes. The subglacial environment was such that the Kittigazuit Formation was being fluted either directly by the glacier or by subglacial meltwater in the western part of the study area where till was subsequently deposited (Figure 11). Toward Summer Island the glacier paused because of changing subglacial conditions and the ice thrust blocks were formed. In the intermediate area, subglacial conditions including meltwater flow resulted in the subglacial ridges remaining free of till or being covered by a very thin cover of till.

Glaciofluvial valley trains and terraces originate south of the area and may relate to glacial meltwater systems originating at Yaya Lake, and along the East Channel and the east side of Kugmallit Bay (Figure 1). The northern extent of these terrace systems may be marine in origin or may be reworked by wave action.

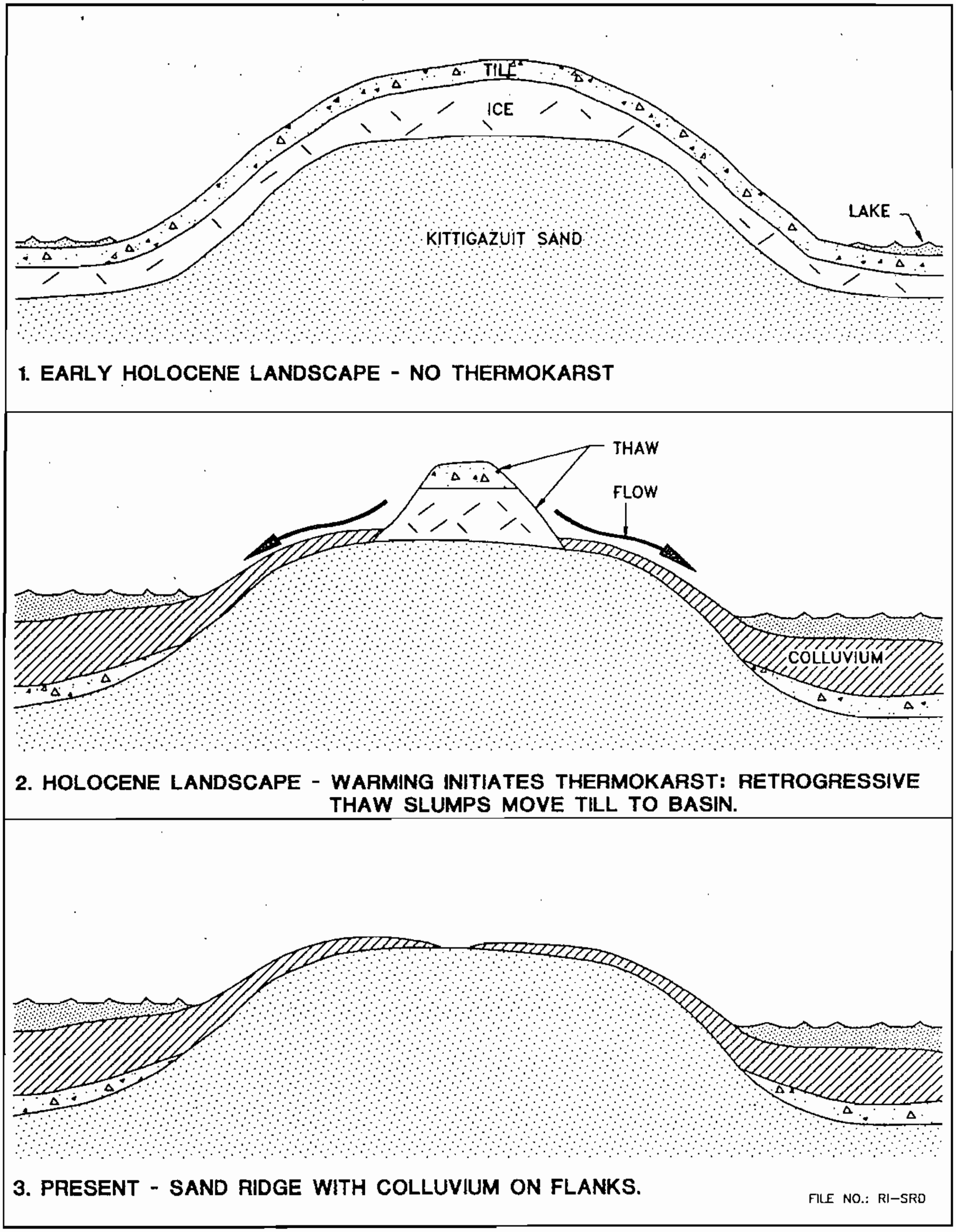


Figure 12. Simplified Schematic Sketches of Sand Ridge Development Through Removal of Till and Segregated Massive Ice From Crest

2.4 Mass Wastage and Coastal Retreat

Mass wastage in this area is primarily related to the melting of frozen ground, specifically ground ice, and the erosion of cliffs by marine wave action.

Ground ice appears to be common within and at the base of till (Figure 5). This leads to the development of retrogressive thaw slumps where the slopes or base of slopes underlain by this ground ice are disturbed. These flows are common: Dallimore (1992) documented over 100 active flows on Richards Island in 1985. Other forms of ground ice such as pore ice, wedge ice and thin lenses and veins of segregated ice do not seem to always lead to retrogressive thaw slumps.

In areas of active coastal erosion, massive ice in Kittigazuit silts (Figure 6) or where exposed under Hooper clay can facilitate retreat if the ice is exposed to thaw. Melting of pore ice and ice veinlets also leads to instability and slumping of coastal bluffs under attack by waves. Exposed headlands, such as North Head, can retreat as much as 3.2 metres per year. Scarps in sheltered bays may only retreat sporadically.

3.0 Granular Sources and Development Restrictions

Six geologic features have been identified that are possible sources of granular material (Figure 13 and Table 2):

(1) Beaches, bars and spits;
(2) Coastal escarpment;
(3) Outwash;
(4) Marine and Glaciofluvial terraces;
(5) Ice-thrust blocks; and
(6) Sand ridges.

All are sources of sand. One isolated occurrence of well graded gravel has been identified although a few other possibilities exist. Thin gravel beds are present in the marine and glaciofluvial terraces.

Resource areas have been established on Figure 13 because of local differences in the nature and pattern of geologic features and their geographic distribution.

3.1 Beaches, Bars and Spits

Beaches, bars and spits flank all coastal exposures (Figure 7), but are generally of limited extent and are subject to frequent inundation by high tides, especially storm surges. One of the largest spits extends off the east end of North Head where gravel has been noted on the spit. There is not good data on the thickness of these sources, but their geomorphology precludes extensive volumes. Removal of material from the spits would facilitate coastal retreat and modify coastal environments including biological conditions. Thus these sources probably have limited or negligible availability.

TABLE 2. SOURCES OF GRANULAR MATERIAL

Unit	Materials	Distribution	Constraints
Wr - Beaches, Bars and Spits	Mainly sand; some sandy gravel	Along coastline	Thin; inundated frequently; removal will increase coastal retreat; biological constraints?
Coastal Bluffs	Sand	Adjacent west coast	Organic and till contamination; ice and clay possible in stratigraphy behind colluvium.
G - Outwash	Sand; some gravel ?	Summer Island and along east edge of study area.	Subsurface massive ice?.
Wt, Gt, P/Wt, P/Gt - Marine and glaciofluvial terraces	Mainly sand; pebbly layers; some woody detritus; locally well graded gravel at 93RI-17	South of "Summer Bay" and adjacent to Kugmallit Bay	Well drained areas only present near scarps; poor drainage; peat cover.
SI - Ice-thrust Blocks	Sand; some gravel patches?	Summer Island and around Corral Bay	Irregular subsurface distribution of clay, till and massive ice beds?
S - Sand Ridges	Sorted fine sand	Concentrated on Hadwen Island and east side Richards Island	Possible near-surface clay and/or massive ice.

3.2 Coastal Escarpments

Along the coast numerous escarpments are present that are developed in sand, mainly of the Kittigazuit Formation (Figures 3 and 7). These sands are present in the escarpment even where the upland is capped by till.

Along actively eroding coastlines such as the north coast of Hadwen Island (93RI-1 and 2, Figure 11), material would have to be removed from a frozen escarpment and transported onto the upland surface for thaw and drainage. There would be little opportunity for natural thawing in the escarpments as thawed material would tend to be eroded by wave action at the base of the escarpment. In addition removal of this material would lead to some acceleration of coastal retreat. The possibility does exist for this type of successful extraction in protected inlets or bays, e.g.. Wallace Bay.

Along the west coast of North Head there are some high (30 metres plus) stable bluffs (Resource Area 2, Figures 13 and 14) that seem to be composed of sand. The problem with these sources is that other materials may be mixed in with the sand in the colluvium and slump blocks partly constituting them. Till does cap these bluffs and till and organic materials could be present. Because the bluffs are high, clayey, silty or icy substrata could be present well above the base of the escarpments behind the sandy colluvium. A bowl like feature observed at 93RI-9 (Figure 11) may owe its origin to thaw of a former massive ice body in the sedimentary sequence above sea level. If the sandy colluvium is extracted and clayey or icy beds, rather than just Kittigazuit sands, are exposed above sea level, this would lead to problems during continued exploitation.

3.3 Outwash

Possible outwash has been mapped in two areas (Resource Areas 3A and 3B; Figure 13). Regardless of the origin of these features, they are both undoubtedly composed of sand and/or minor amounts of gravel.

The outwash on Summer Island (Resource Area 3A) has similar air photo characteristics to areas of sandy outwash identified to the northeast of Tuktoyaktuk, namely

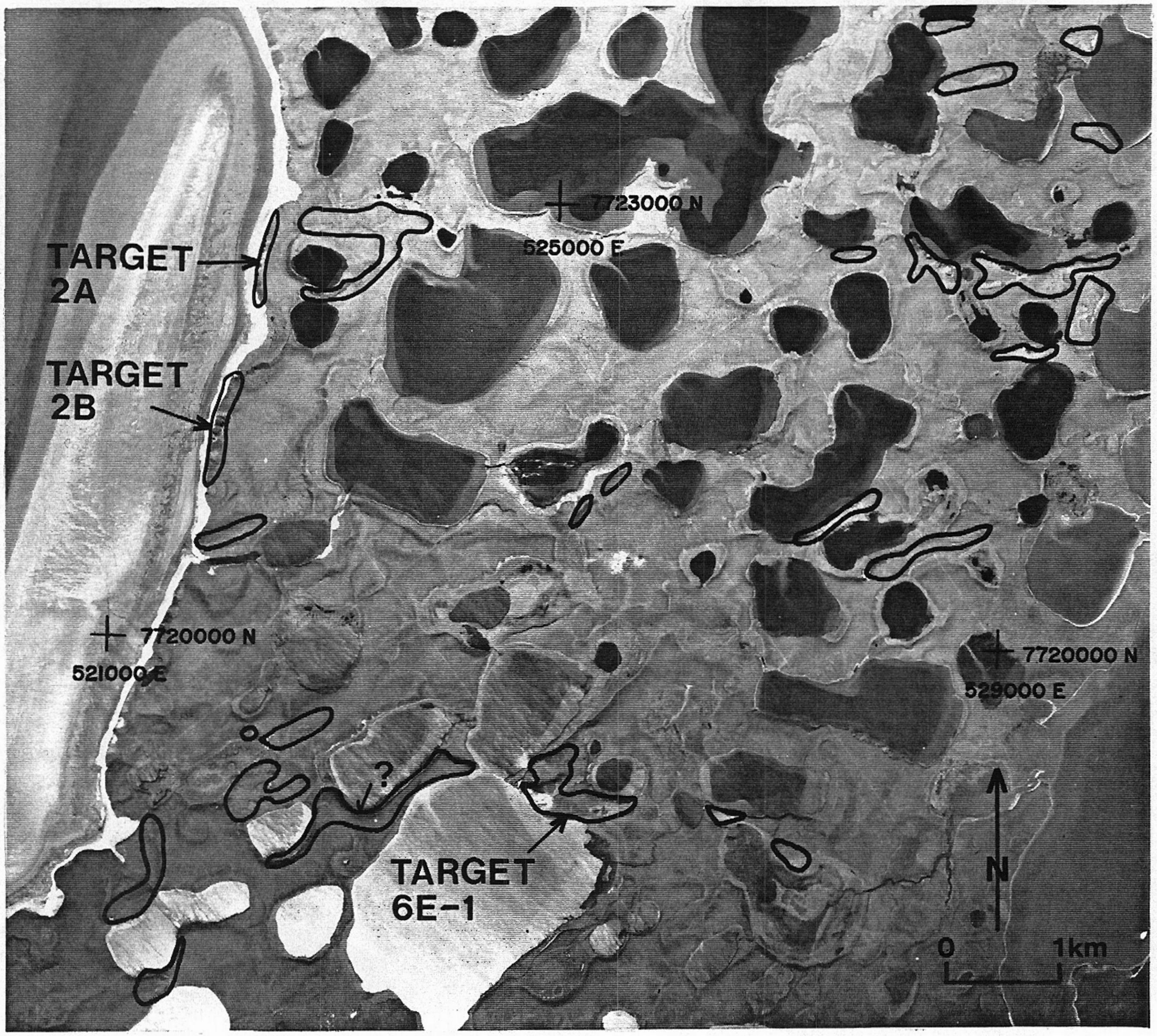


Figure 14. Air Photo A22974-84 (EMR) Showing Targets 2A, 2B and 6E-1 and Other Mapped Sand Ridges (S).

large ice-wedge polygons on its surface. In addition it appears flat and marked by thermokarst lakes similar to those southeast of Inuvik at the head of Eskimo Lakes (Rampton and Walcott 1974). Gravity indicated that this outwash was underlain by massive ice and the same conditions may be present on Summer Island.

The outwash at the southeast edge of the map area (Resource Area 3B, Figure 13; Target 3B, Figure 15) all appear to be mounds of sand and gravel superimposed on the landscape. They were probably deposited just prior to initiation of the glaciofluvial terraces at that locality. At site 93RI-16 (Figure 11), the active layer was over a metre thick in late August 1993, and fine-medium sand was noted to contain pebbles to a depth of at least 0.9 metres. There is no evidence relating to the absence or presence of buried ice in the outwash here.

3.4 Marine and Glaciofluvial Terraces

Adjacent to Kugmallit Bay (Resource Area 4A; Figure 13) and south of "Summer Bay" (Resource Area 4B; Figure 13) glaciofluvial terraces are present that appear to grade to a marine terrace in the vicinity of Corral Bay and Kidluit Bay (also part of Resource Area 4A). These terraces are composed primarily of sand with thin gravel layers (noted at 93RI-15; Figure 11) and thin beds of woody detritus (noted at 93RI-20; Figure 11). These terraces have been mapped as sand previously by Rampton (1979). However at target 4B-1 (Figures 13 and 15), at least 1 metre of graded sandy gravel tops a 5 metre scarp (93RI-17; Figure 11). Gravel may be more extensive in the vicinity of this locality.

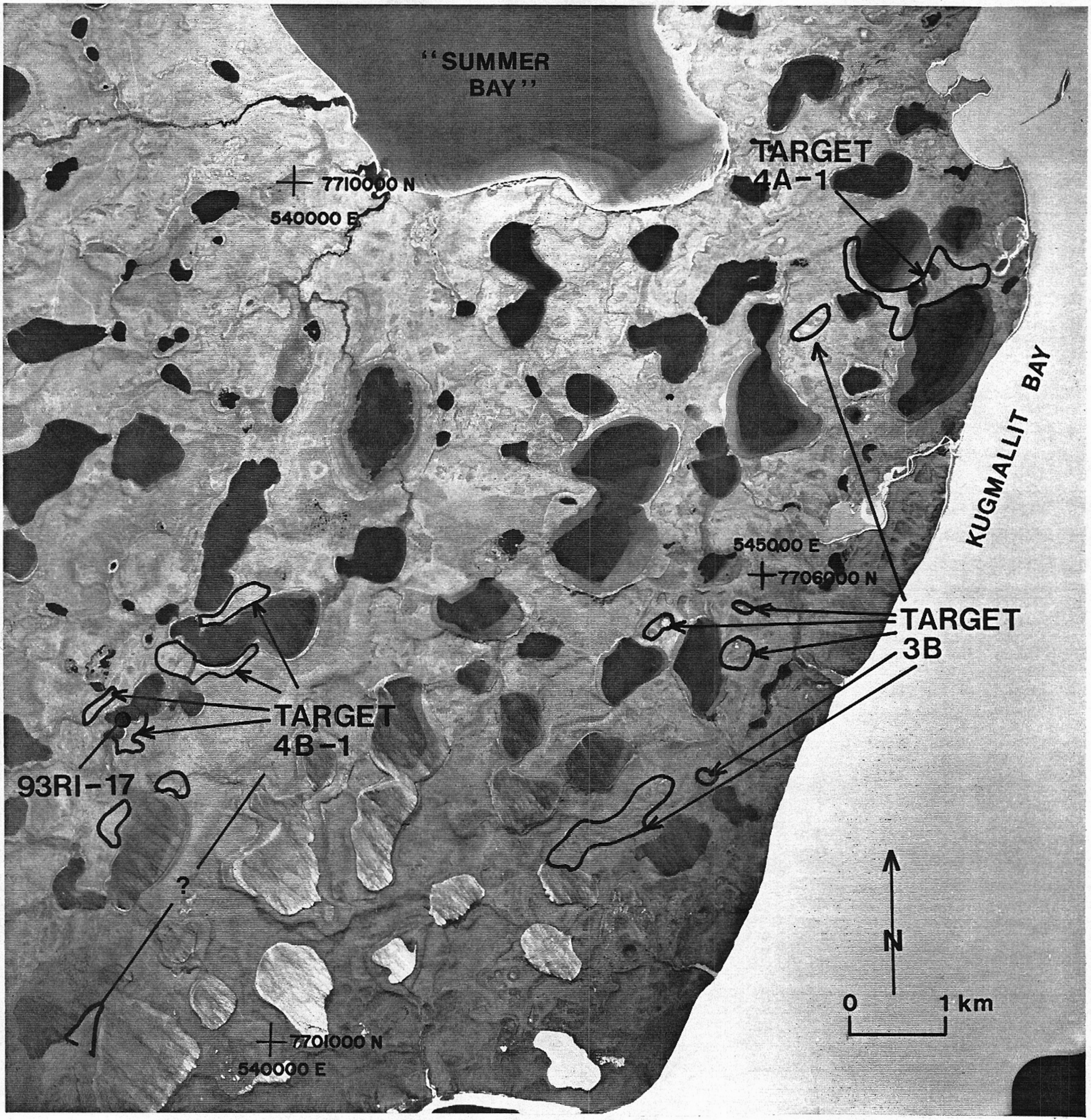


Figure 15. Air Photo A22974-40 (EMR) Showing Targets 3B, 4A-1 and 4B-1

Extraction of sand (and gravel) from identified potential sources (cf. Figures 13 and 15), will be limited by poor drainage and peat cover. Only near escarpments cut into the terraces are there areas where the surface of the sand is well drained and free of peat cover. Large areas in the northern part of Resource Area 4A are relatively bare of peat (Figure 13), but only 3 to 4 metres of material stands above sea level.

3.5 Ice-thrust Blocks

Ice-thrust blocks are evident around Corral Bay (Resource Area 5A; Figure 13) and on Summer Island (Resource Area 5B; Figure 13). Much of the surface of these features consists of sand with a cap of pebbles, cobbles and boulders. Because of their locations, these features were not investigated in detail. Field notes provided by the Geological Survey of Canada (Appendix III) describing exposures around the edge of the features indicate that the upper surfaces of the ice-thrust blocks generally consist of Kittigazuit Formation. Kidluit Formation may form the upper part of these blocks at some locations. Field notes suggest that this is the case at one locality on the north side of Corral Bay.

Bare areas of sand are common on the surface of the ice-thrust blocks (Figure 16), especially on knobs and ridges standing above the general level of the blocks. This is especially evident on those to the north of Corral Bay and on Summer Island. Swales (obvious on Target 5A-1) appear to be covered with peat and possibly silty material. However, even in the swales the drainage appears to be relatively good, suggesting that the peat and silt is very thin.

Because of the deformation involved in the formation of these features, the possibility of Hooper clay or massive ice at surface cannot be dismissed. Both have been relatively elevated in an exposure on the south edge of Summer Island (cf. Table 3.). These factors could lead to complications in extraction of aggregate.

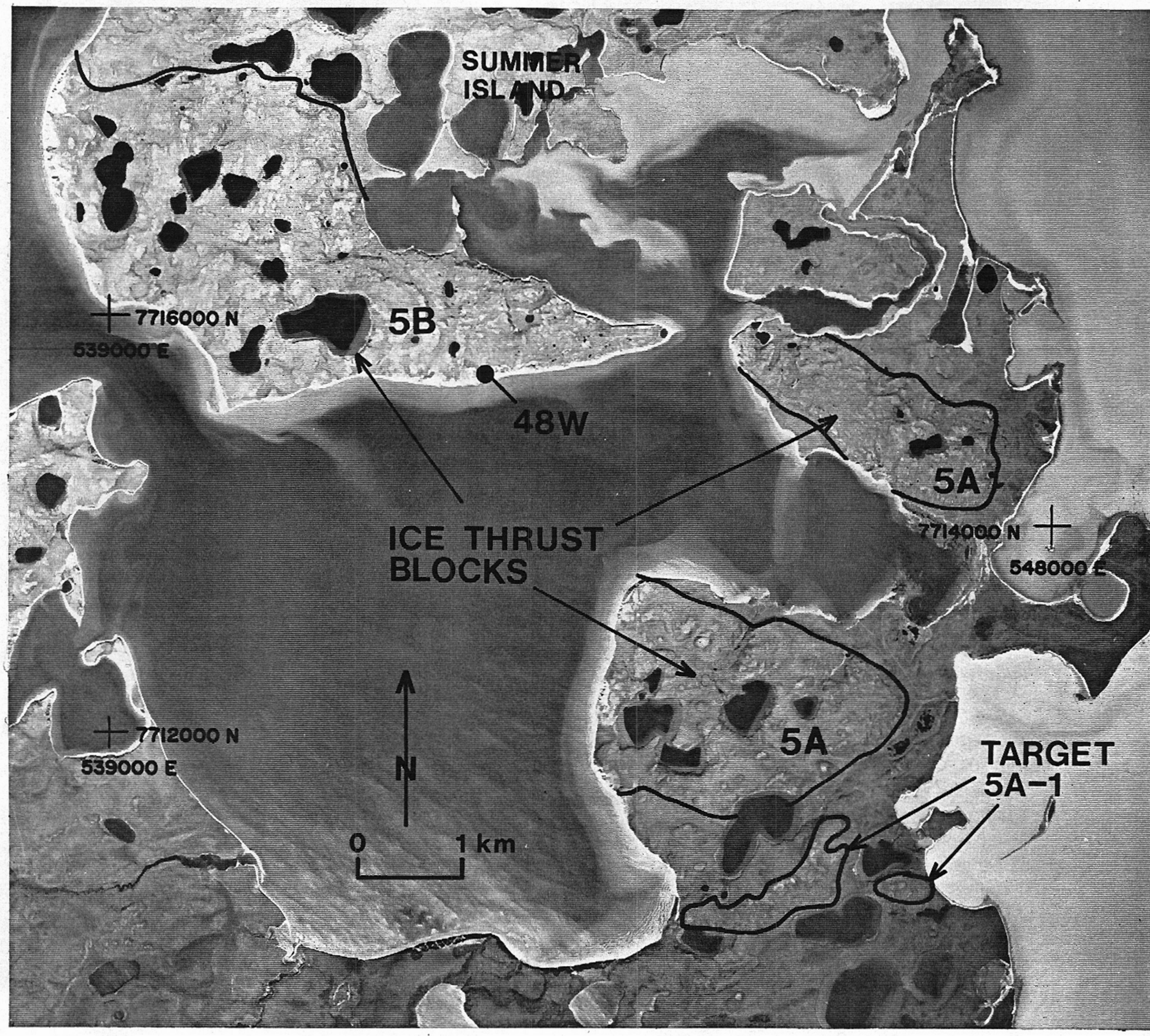


Figure 16. Air Photo A22974-72 (EMR) Showing Target 5A-1 and Associated Ice Thrust Blocks (Resource Areas 5A and 5B).

TABLE 3.

Stratigraphy at site on Southern Summer Island (48W on Figure 16 : from Rampton 1988)

Thickness	Material (unit)
2.4m	Sand, fine grained, light greyish brown; many rootlets and peaty layers (Holocene cliff-top dune)
0.2m	Gravel, sandy (lag from glaciofluvial deposit?)
1.5m	Sand, fine grained, olive brown; silty beds near base; thinly bedded (Kittigazuit Formation)
11m	Sand, medium grained, light greyish brown; stratified; contains logs, some marine shell fragments and freshwater shells and mats of woody detritus (Kidluit Formation)
14m	Clay, silty, light brown; banded; contains fragments of iron-stained wood and shells (some hinged); driftwood mat with many marine shells near base (Hooper clay)
9m	Covered to sea level; laterally foliated massive ice with clayey and sandy bands present (Kendall sediments)

3.6 Sand Ridges

Sand ridges offer the largest potential for granular materials at appropriate locations down the axis of northern Richards Island (Figure 13). At locations where their surface has been examined, e.g. 93RI-1,3,4,5,7,10,12 and 18. (Figures 11 and 13) the upper part of these ridges tend to be composed of brown well sorted fine sand. Pebbles and cobbles may infrequently be present in the upper 0.3 to 0.5 metres. A broken cover of 0.1 to 0.3 metres of moss, silty sand and involuted thin organic layers is characteristic of these surfaces. Away from the ridge tops the vegetation cover increases and the silty organic layers thicken. It is difficult to determine how quickly till and clayey, silty lacustrine deposits thicken on the flanks of these ridges. Scattered observations have noted the presence of these materials in adjacent low areas.

On air photos, portions of these sand ridges, particularly where they are marked by broken vegetation, show as distinct light-toned features. This is particularly true in the areas characterized by 'Sand Ridges and Till Veneer over Kittigazuit Sands' (Figure 11). Typical are Targets 6C-1, 6C-2, 6D-1 AND 6E-1 (Figures 14, 17 and 18).

Sand ridges are abundant and clearly defined on Summer Island (Resource Area 6A), Hadwen Island (Resource Area 6B), areas adjacent to Hansen Harbour (Resource Area 6C) and areas west and south of Mason Bay (Resource Area 6D). Sand ridges on Summer Island (Resource Area 6A) were not examined in the field because of their easterly location. Numerous observations have been made along the coast of Hadwen Island (93R-1, 2; Figure 11 and Appendix III) and confirm the presence of thick sands in coastal exposures there. In Resource Areas 6C and 6D, 10 to 15 metres of brown sand (Kittigazuit Formation) have been noted in numerous coastal exposures (Appendix III). In one hole drilled by the GSC, 35 m of gray and brown sand were recorded (Dallimore 1991; see also Appendix III).

Sand ridges are less common in Resource Areas 6E and 6F (Figure 13) than in areas 6A through 6D. Sand ridges are also less easily distinguished on air photos in Resource Areas 6E and 6F. Till is generally thicker in Resource Areas 6E and 6F than in areas 6A through 6D and suggests some common cause between till thickness and frequency of sand ridges.

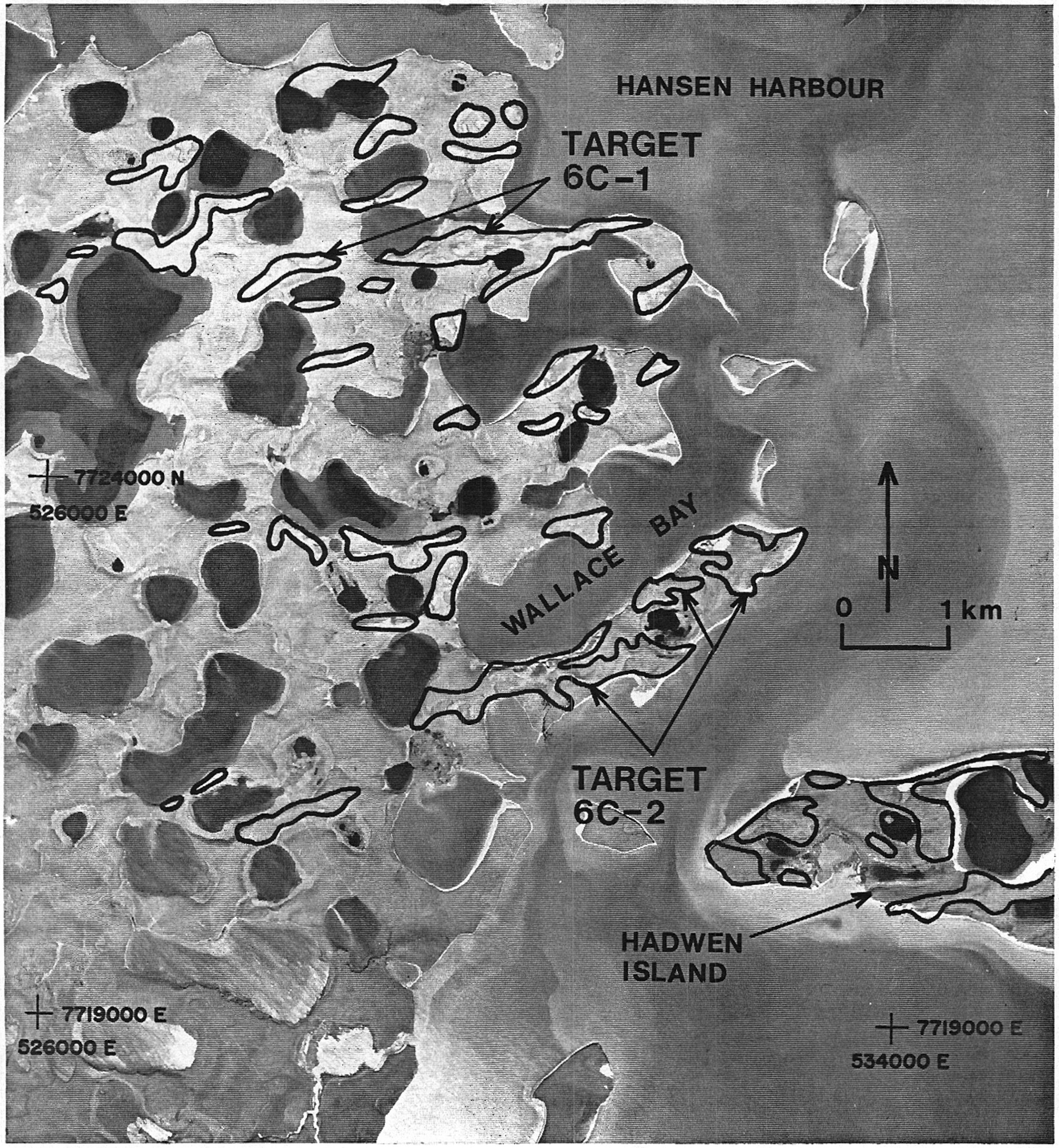


Figure 17. Air Photo A22974-82 (EMR) Showing Targets 6C-1 and 6C-2 and Other Mapped Sand Ridges (S).

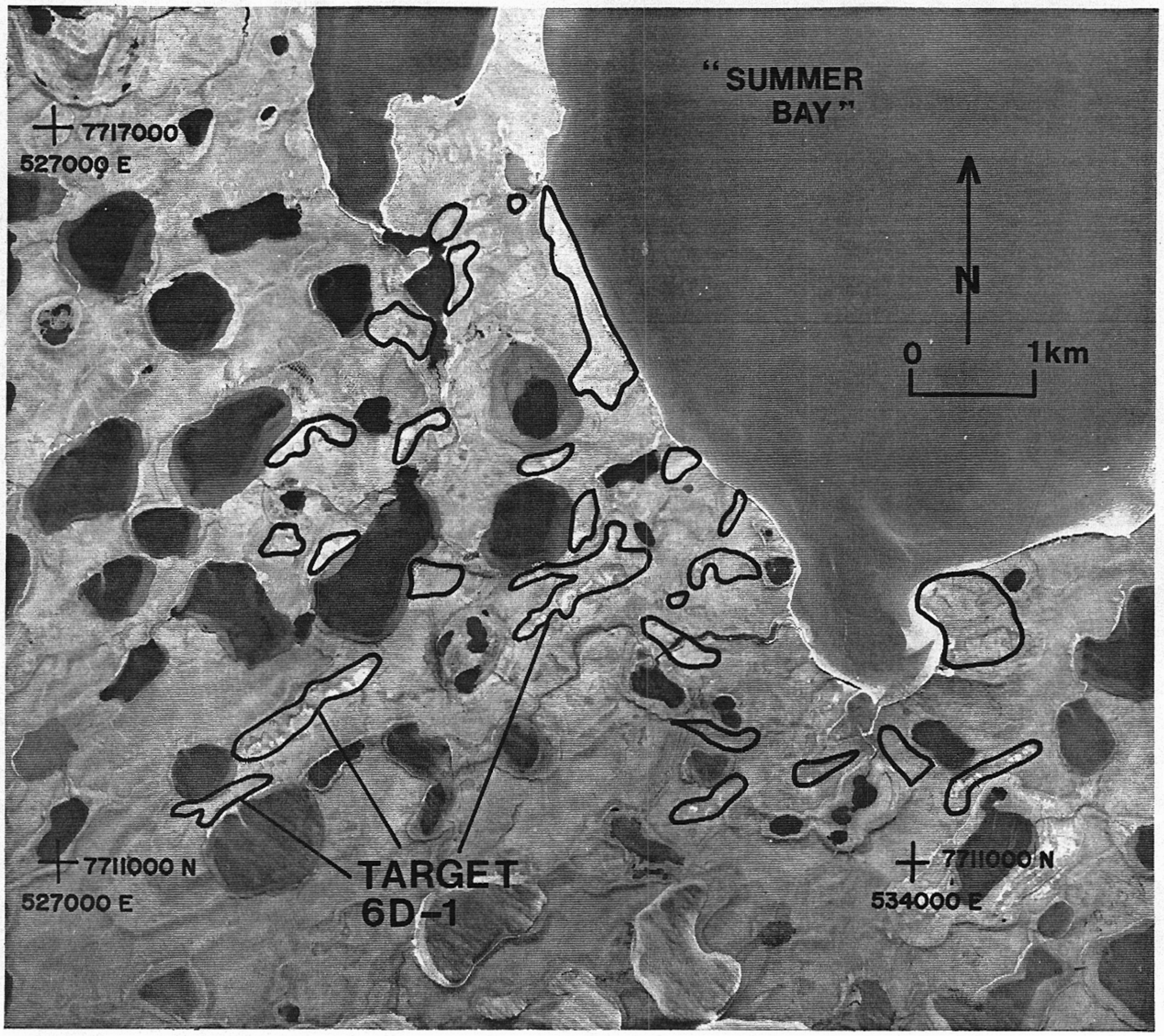


Figure 18. Air Photo A22974-70 (EMR) Showing Target 6D-1 and Other Mapped Sand Ridges (S).

If the sand ridges are simply the remnant of eroded Kittigazuit Formation, either through simple glacial processes or a combination of glacial processes and mass wastage, one can assume that thickness of 20 to 30 metres of Kittigazuit sands with low ice contents underlies these ridges. Drill hole data and exposures in ice-thrust blocks south of Corral Bay (Appendix III) suggest that the thickness of the Kittigazuit sands exceeds 20 metres. In addition, Kidluit Formation sands with low ice contents directly underlie the Kittigazuit Sands (Figure 2). Both the Kittigazuit sands and Kidluit Formation have low ice contents. If however, deformation is involved in the formation of sand ridges, massive ice and the Hooper clay may be present locally at shallow depths and inhibit exploitation of the sands.

The sand ridges are generally well drained with negligible peat cover. If their ground ice content is minimal and no clay beds are present at shallow depths, there will be few constraints to their exploitation.

4.0 Constraints to Extraction

4.1 Source Constraints

Constraints have been discussed for each type of sources in section 3.0 (see also Table 2). To summarize, marine beaches, spits and bars are relatively small, subject to frequent flooding and their exploitation may negatively affect coastal processes and local land uses. Coastal escarpments require innovative exploitation to avoid erosion of material by wave action during extraction. Their exploitation may also negatively affect coastal processes: the exception being stable coastal bluffs on the western side of North Point (Resource Areas 2A and 2B) - however the possibility of massive ice or clayey sediments in the back of the cliffs could prevent continuous exploitation.

Outwash on Summer Island (Resource Areas 3A) may contain buried massive ice. In addition these deposits are geographically isolated. Outwash west of Kugmallit Bay (Resource Area 3B) may also be underlain by ground ice.

Marine and glaciofluvial terraces (Resource Areas 4A and 4B) are characterized by broad areas of poor drainage and peat cover except near the upper edges of scarps incised into them. Drainage may also limit depths of extraction because of their low elevation relative to adjacent water bodies. Drainage will have to be also addressed during exploitation of these features in order that ponding on adjacent areas does not lead to the thaw of ice-rich peat and silty deposits and unwanted thermokarst there. Thermokarst may also be a problem if some sort of road access is required during the thaw season.

Ice-thrust blocks (Resource Areas 5A and 5B) and sand ridges (Resource Areas 6A through 6F) are well drained and appear free of a cover of icy sediments. Clayey beds and massive ice or masses of icy sediments may be present near their upper surface where ice-thrusting is involved in their origin, although few surface observations suggest that this is the case. However, each potential extraction site could have a unique stratigraphy if ice thrusting was involved, certainly for the ice-thrust blocks and possibly for the sand ridges that have an ice-thrust origin. Because of this, drilling will be required at sites proposed for extraction to determine if ice or clay are present. The presence of near-surface massive ice or clay will inhibit exploitation.

The presence of massive ice or icy sediments will restrict extraction because of the difficulty of selectively removing the ice and because its thaw will lead to thermokarst and ponding. Unless pit development is carefully planned, thermokarst and ponding can restrict further exploitation of a deposit.

All sands can be expected to be bonded by ice, even where massive ice or ice lensing is absent, as most freshly eroded coastal exposures show bonded sands. Pit development may require ripping and blasting or stripping of surfaces to maximize thaw and extraction for stock piling over the thaw season.

4.2 Access Constraints

Access during the winter will primarily be affected by snow thicknesses. This will be especially true where sand ridges away from the coast in Resource Areas 6C through 6E are utilized. The hilly topography in these areas can lead to thick snow drifts forming in depressions. Scouting of access routes will be necessary to avoid thick snow drifts. Snow ploughing or removal will be required where thick drifts cannot be avoided.

Access during the thaw season will be severely limited. Access routes near coasts will have to take note of coastal retreat, which has been recorded as high as 3.2 metres per year at North Head (sheltered areas however experience negligible retreat; D.F. Dickens Associates Ltd and Terrain Analysis and Mapping Services Ltd, 1993). Access in other areas will be affected by drainage and susceptibility to mass wastage, primarily the initiation of retrogressive thaw slumps. Areas of poor drainage such as alluvial deposits, lacustrine deposits and areas of marine and glaciofluvial terraces having a peat cover are difficult for vehicles to cross when the active layer is thawed, saturated and lacking in bearing capacity. In addition, vehicle traffic generally disrupts the surface and drainage. This leads to thawing of near-surface icy sediments, which commonly underlay the active layer, and thermokarst subsidence and erosion. Retrogressive thaw slumps cannot be traversed by most vehicles during active thaw and retreat. During the thaw season, access routes across slopes underlain by till, especially those underlain by thick till (Tb, T on Figure 7) where massive ice and icy sediments are common at depth, would have to be planned to avoid rutting or any suppression of the active layer that might cause thaw of the ice and initiation of retrogressive thaw slumps.

5.0 Recommendations

Further investigations may depend on the locations where granular material is required and the type of granular material needed. The following recommendations for further investigations are given with the understanding that DIAND requires a general knowledge of the location, geometry, quantity and quality of potential sources of granular materials and the possible restriction to their exploitation. The recommendations are listed in a general order of priority.

(1) The geometry of sand ridges and their internal stratigraphy should be investigated at a number of strategically located sites in each resource area (Table 4) to determine the quantity of sand available and to delineate any clay or icy units, which might be present. Drilling should be planned to determine their origin so that results could be easily extrapolated from deposit to deposit. To meet this objective, drilling should be done on 50 to 100 metre centres (similar to that completed by EBA Engineering Consultants Ltd (1975) at Yaya Lake) in selected areas in order that the geometry of the granular deposits and their relationship to other materials can be properly determined. The drilling could be supplemented by ground penetrating radar, which has been used with some success in the area to delineate granular materials and massive ice (Dallimore and Wolfe 1988, Dallimore and Davis 1992).

Experts on subglacial processes and meltwater activity, such as Dr. D. Sharpe, of the Geological Survey of Canada, might be consulted on their origin. The geometry of the granular materials and the possibility of massive ice and/or clay within them can be more easily postulated if their origin is known.

In Resource Area 6C two targets for future investigation have been identified, Targets 6C-1 and 6C-2 (Figures 13 and 17), either of which are typical of sand ridges in this area. Both were easily identified on air photos, are extensive in area, are relatively continuous and have east-west orientations. In addition, drilling can be supplemented by observations along coastal exposures as their edges are being eroded and exposed through coastal erosion. Ten metres of brown sand (Kittigazuit Formation) was noted at one coastal exposure at the east end of Target 6C-1 by Dallimore (Appendix III).

TABLE 4. Resource Areas and Recommended Targets for Future Investigations (See Figure 13 for Locations)

Resource Area	Targets
1	None
2	2A and 2B
3A	None
3B	3B
4A	4A-1
4B	4B-1
5A	5A-1
5B	None
6A	None
6B	None
6C	6C-1, 6C-2
6D	6D-1
6E	6E-1
6F	None

Target 6D-1 in Resource Area 6D (Figures 13 and 18) is recommended for future investigations. It is clearly discernable on air photos, is extensive in area and extends to near the central axis of northern Richards Island. Its surface as shown by Figure 10 is well drained and consists of a sand with a veneer of cobbles and pebbles.

Sand ridges are not as abundant in Resource Area 6E as in Resource Areas 6C and 6D. They are also not as easily delineated on air photos or on the ground. However, because the axis of northern Richards Island lies within Resource Area 6E, a target has been selected for future investigation. Target 6E-1 (Figures 13 and 14) appears typical of the resource area and to have as good a potential as a source for granular materials as any other sand ridge in Resource Area 6E.

No drilling is recommended in Resource Areas 6A and 6B because of their island locations. No further investigations are recommended in Resource Area 6F because of its easterly locations and the availability of granular materials from other sources in this area.

Before drilling of targets, aerial photography of the A 23757 series from EMR should be purchased and enlarged to aid planning (their definition is better than the air photos used for this project). Following field investigations to confirm the extent and volume of granular materials in targets suggested for investigation, it would be useful to have aerial photography, possibly colour, flown at a scale of 1:10000 or 1:20000 to further delineate targets (colour photography proved useful in mapping of the Yaya Lake Complex; Terrain Analysis and Mapping Services 1976).

(2) To establish gravel reserves in the study area, further detailed ground investigations of target 4B-1 (Figures 13 and 15), which includes a site (93RI-17; Figure 11) where gravel was noted during this investigation, are recommended. This area was not investigated in detail during this study because of its easterly location. Aerial and ground reconnaissance of target 4B-1 and two to three kilometres to its north within Resource

Area 4B might reveal other areas underlain by gravel. During this search, test pitting and cleaning of scarps should be undertaken to sample and determine material quality. The extent of areas relatively free of peat and silt cover and the thickness of these sediments in adjacent areas could be determined. If the gravel is of good enough quality to warrant stripping of icy peat and surface cover, drilling could be undertaken to determine the thickness of gravel and overburden and their ice contents. Other targets (e.g. Target 3B on Figures 13 and 15) should be detailed in conjunction with this investigation.

(3) The surfaces and related exposures of outwash, especially those easily assessable such as Target 3B (Figures 13 and 15), and ice-thrust blocks, e.g. Target 5A-1 (Figures 13 and 15) should be examined by more detailed aerial and ground reconnaissance to determine the possible availability of graded sands, pebbly sands or sandy gravels that might be present within or near the surface of these units. Prior to exploitation of Target 3B drilling will be required to determine thicknesses, qualities, ice contents and the location of massive ice (if present). Similar investigations would be required of the outwash on Summer Island (Resource Area 3A; Figure 13), if it were utilized. Prior to utilization of Target 5A-1, or any materials from the ice-thrust blocks, drilling would probably be required to determine if any near-surface clayey or icy beds were present in the area to be exploited.

(4) A more thorough investigation of Targets 2A and 2B (Figures 13 and 14) through drilling at the crest of the bluffs and or any benches on the bluffs is recommended to determine (a) the stratigraphy of the sequence backing the bluff and (b) the nature of the slumped and colluviated materials in the bluffs. This drilling should determine if clayey or icy beds are present that would inhibit extraction. Extensive test pitting on the bluffs could determine the quality of the slumped materials and the extent to which slumped organic sediments or till have been incorporated into them.

(5) If significant quantities of sand and pebbly sand are required at the eastern edge of Richards Island, the sands in Resource Area 4A offer potential, but will require further investigation. Target 4A-1 (Figure 15) is one of the largest areas in Resource Area 4A south of Kidluit Bay that appears to be free of a peat cover. It is recommended for further investigations because of its location and size. Investigations similar to those recommended for Target 4B-1 would be necessary.

6.0 Conclusions

Numerous potential sources of well sorted fine sand exist on northern Richards Island, especially on its eastern part. Those having the largest volumes are the sand ridges and ice-thrust blocks (Figure 13). Extraction of sand may only be inhibited if clayey or icy beds have been thrust to near-surface locations by deformation during glaciation. On some ice-thrust blocks medium to course graded sand may be present near the surface.

Other sources of sand (minor gravel) along the coast such as beaches, bars and spits and coastal escarpments are inhibited by coastal flooding and erosion during high tides and the affects that their exploitation may have on coastal retreat. High stable coastal bluffs may provide sand on the western edge of northern Richards Island, if organics and till layers are not present in the slumped materials. However clayey beds and massive ice near the base of the original escarpment might inhibit continuous exploitation.

Abundant reserves of sand, some of it possibly graded, parts of it containing lenses of woody detritus and coal fragments, are present in the marine and glaciofluvial terraces of eastern Richards Island (Figure 13). Development of much of the surface area is hindered by poor drainage and a cover of icy sediments and peat. Within the glaciofluvial valley train south of "Summer Bay" the only presently known source of well graded gravel has been located in Target 4B-1 (Figures 13 and 15). The extent of extractable gravel may be limited by peaty cover, but further investigation might detail more exploitable gravel in the area.

Outwash has been possibly identified in two locations (Figure 13.). This unit offers the potential for graded sand and minor sandy gravel. Massive ice may also be present at shallow depths in these deposits.

Further investigations including drilling, geophysics and acquisition of colour aerial photography are recommended to determine the geometry and origin of representative sand ridges and constraints to their exploitation. Aerial and ground reconnaissance and sampling of glaciofluvial valley trains near Target 4B-1 (Figures 13 and 15) are recommended to locate, determine quality and ease of exploitation of gravel in this vicinity. Surface assessment of outwash and ice-thrust blocks are also recommended to determine if graded sands or gravel are present in these sources. Some further investigation of high stable coastal bluffs are needed to determine the presence or absence of contaminating organics or till in the slumped materials and/or icy and clayey sediments in materials behind them. Priority of investigations might be determined by the location of requirements for granular material.

Respectively submitted

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7.0 References

BBT Geotechnical Consultants Ltd., GVM Geological Consultants Ltd and Terrain Analysis and Mapping Services Ltd.
1983: Granular Materials Evaluations. Deposits 168 and 211, Tuktoyaktuk area, N.W.T. Report for IAND.

Canadian Hydrographic Services
1967: Kugmallit Bay and approaches; Hydrographic Chart 7604.

Dallimore, S.R.
1991: Geological, Geotechnical and Geophysical Studies along an Onshore-Offshore Transect of the Beaufort Shelf; Geological Survey of Canada, Open File Report 2408.

1992: Engineering Geology of the Richards Island Area, N.W.T.; Reprint Volume of the 45th Canadian Geotechnical Conference, Paper No. 13. to 13-9.

Dallimore, S.R., and Davis J.L.
1992: Ground penetrating radar investigations of massive ice; Geological Survey of Canada, Paper 90-4, pp. 41-48.

Dallimore, S.R., and Wolfe, S.A.
1988: Massive Ground Ice Associated with Glaciofluvial Sediments, Richards Island, N.W.T. Canada; Proceedings, 5th International Conference on Permafrost, Trondheim, Norway, 1988, pp. 132-138.

Dallimore, S.R., Vincent, J-S., and Matthews, J.V.,Jr.
1993: Depositional Conditions of Late Pleistocene Kidluit Formation and Kittigazuit Sands from the Tuktoyaktuk Coastlands Area, N.W.T.; Geological Survey of Canada, Unpublished Manuscript.

D.F. Dickens Associates Ltd and Terrain Analysis and Mapping Services Ltd.
1993: Beaufort Sea Oily Waste Disposal Sites; Report for Environment Canada.

EBA Engineering Consultants Ltd

1975: Ya-Ya Granular Resource Study; Report for Arctic Petroleum Operators Association.

1986: Granular Resource Evaluation Richards Island, N.W.T.; Report for IAND.

Gowan, R.J., and Dallimore, S.R.

1990: Ground Ice Associated with Granular Deposits in the Tuktoyaktuk Coastland Area, N.W.T.; Proceedings of the Fifth Canadian Permafrost Conference, pp. 283-290.

Kurfurst, P.J., and Dallimore, S.R.

1991: Engineering Geology of Nearshore Areas off Richards Island, N.W.T.; A Comparison of Stable and Actively Eroding Shorelines; Canadian Geotechnical Journal, Vol. 28, pp. 179-188.

Rampton, V.N.

1979: Surficial Geology, Mackenzie Delta, District of Mackenzie; Geological Survey of Canada, Map 32-1979.

1988: Quaternary Geology of the Tuktoyaktuk Coastlands, N.W.T.; Geological Survey of Canada, Memoir 423.

Rampton, V.N., and Walcott, R.I.

1974: Gravity Profiles Across Ice-Cored Topography; Canadian Journal of Earth Sciences; Vol. 11, pp.110-122.

Ripley, Klohn and Leonoff International Ltd

1972: Granular Materials Inventory: Zone II; Report for IAND.

R.M. Hardy and Associates Ltd. and Terrain Analysis and Mapping Services Ltd

1976: Granular Materials Inventory, Yukon Coastal Plain and Adjacent Areas; Report for IAND.

Terrain Analysis and Mapping Services Ltd.

1976: Ya-Ya Lake Esker Complex: Site Development and Restoration Plan; Report for IAND.

Appendix I

Shot hole stratigraphy : IOL 1970 and 1971 lines

APPENDIX I

SHOT HOLE STRATIGRAPHY: IOL 1970 AND 1971 LINES ON NORTHERN RICHARDS ISLAND

SCALE: 1:50000 | DATE: DECEMBER 1993 | FILE NO.: RI-AP1

LEGEND

- • DRILL HOLE LOCATION
- c CLAY
- m SILT
- s SAND
- b BOULDERS
- p PEAT
- i ICE
- w WATER

0.3 p / 15 i / 37 s — INDICATES 0.3 METRES OF PEAT OVER 14.2 METRES OF ICE OVER 12 METRES OF SAND

NOTE: ALL FIGURES ARE IN METRES AND GIVE DEPTH TO BASE OF INDICATED MATERIAL OR DRILL HOLE.

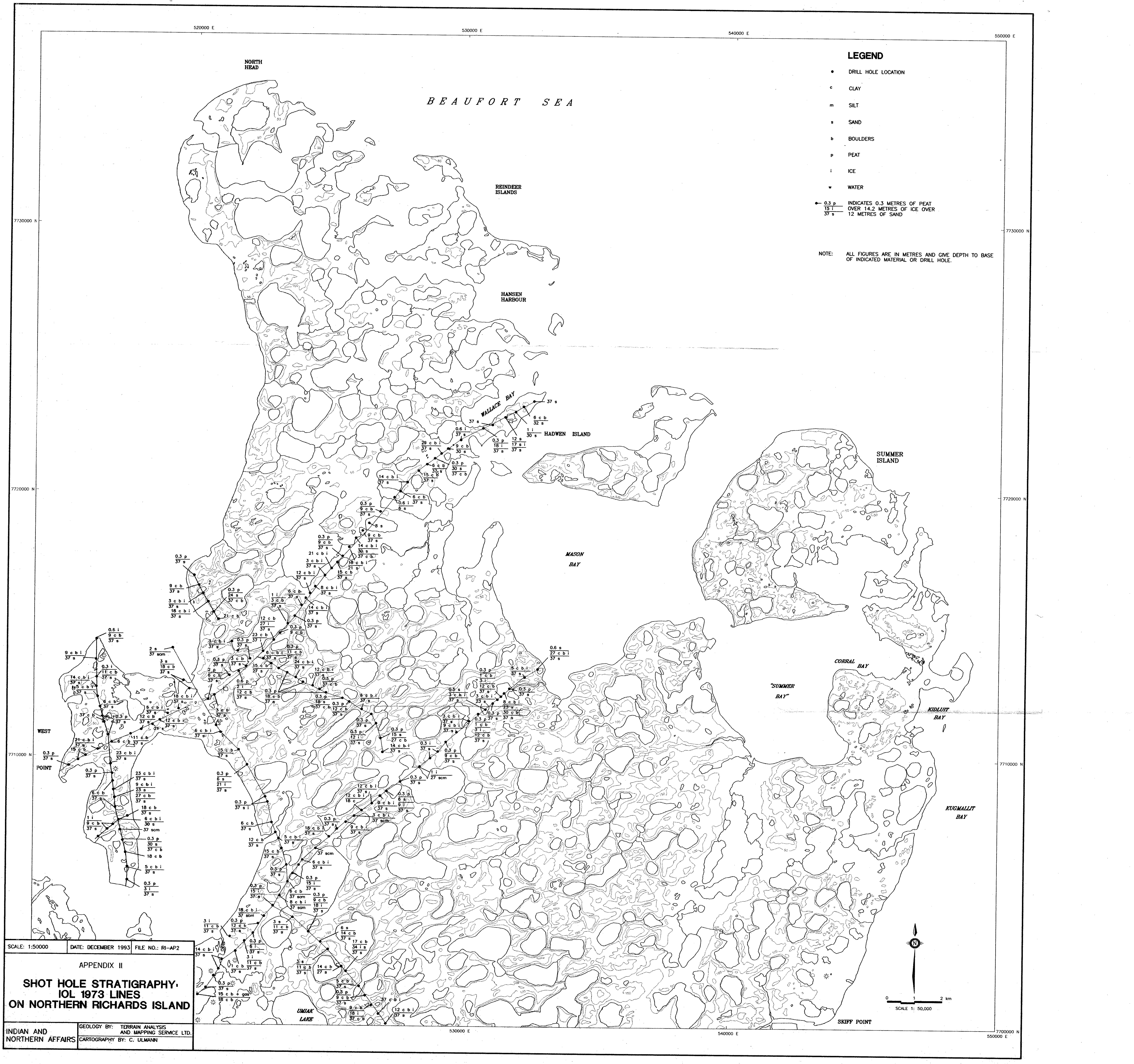
INDIAN AND NORTHERN AFFAIRS

GEOLOGY BY: TERRAIN ANALYSIS AND MAPPING SERVICE LTD.

CARTOGRAPHY BY: C. ULMANN

Appendix II

Shot hole stratigraphy : IOL 1973 lines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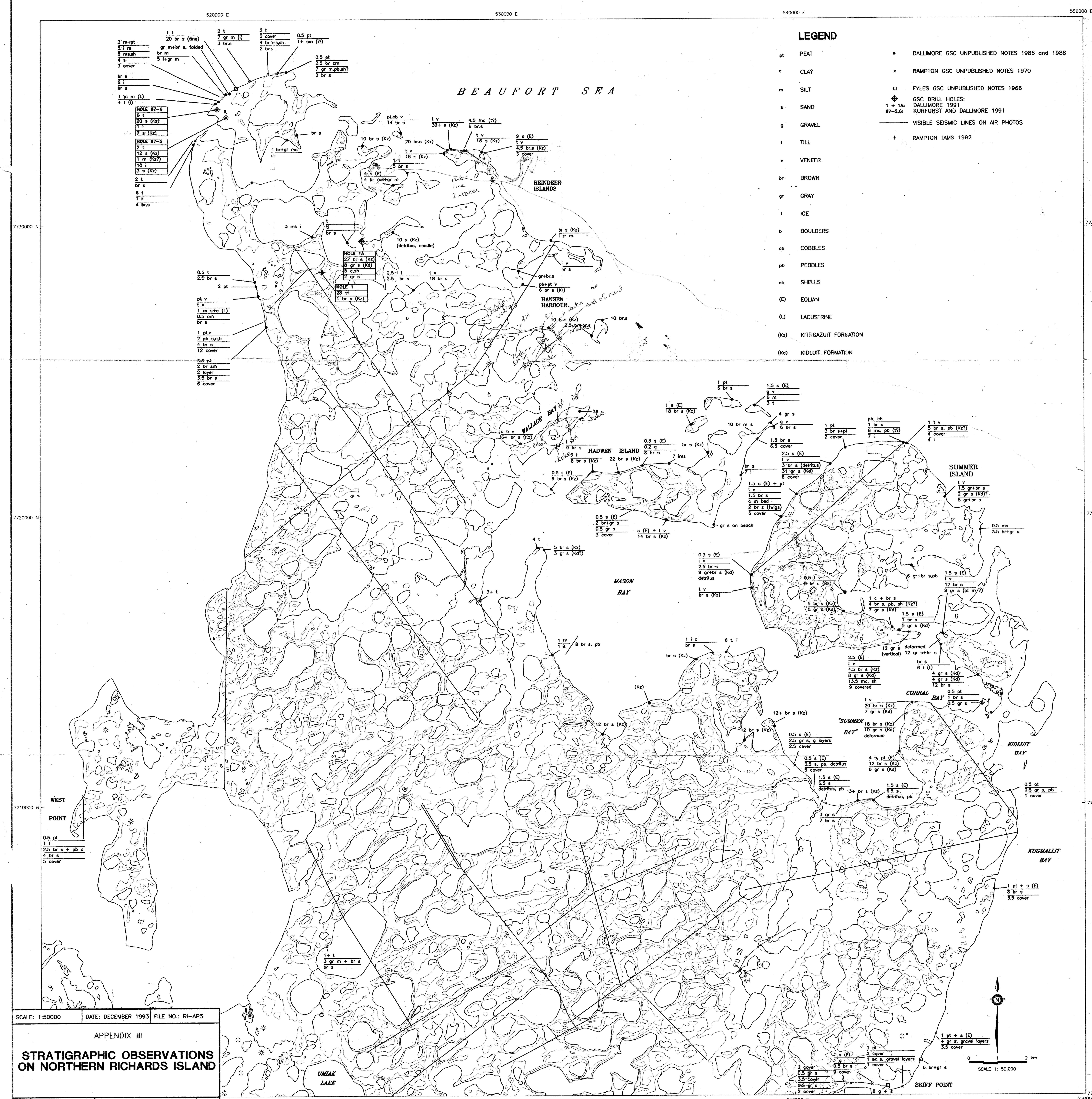
APPENDIX II
SHOT HOLE STRATIGRAPHY: IOL 1973 LINES ON NORTHERN RICHARDS ISLAND
INDIAN AND NORTHERN AFFAIRS
GEOLOGY BY: TERRAIN ANALYSIS AND MAPPING SERVICE LTD.
CARTOGRAPHY BY: C. ULMANN
LEGEND
DRILL HOLE LOCATION
c CLAY
m SILT
s SAND
b BOULDERS
p PEAT
i ICE
w WATER
0.3 p / 15 i / 37 s INDICATES 0.3 METRES OF PEAT OVER 14.2 METRES OF ICE OVER 12 METRES OF SAND
NOTE: ALL FIGURES ARE IN METRES AND GIVE DEPTH TO BASE OF INDICATED MATERIAL OR DRILL HOLE.
BEAUFORT SEA
NORTH HEAD
REINDEER ISLANDS
HANSEN HARBOUR
WALLACE BAY
HADWEN ISLAND
SUMMER ISLAND
MASON BAY
"SUMMER BAY"
CORRAL BAY
KIDLUIT BAY
KUGMALLIT BAY
WEST POINT
UMIAK LAKE
SKIFF POINT
520000 E
530000 E
540000 E
550000 E
7730000 N
7720000 N
7710000 N
7700000 N
0 1 2 km
SCALE 1: 50,000

Appendix III

Stratigraphic Observations on Northern Richards Island



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APPENDIX III

STRATIGRAPHIC OBSERVATIONS ON NORTHERN RICHARDS ISLAND

INDIAN AND NORTHERN AFFAIRS	GEOLOGY BY: TERRAIN ANALYSIS AND MAPPING SERVICE LTD.
	CARTOGRAPHY BY: C. ULMANN