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PAPER 71-21

MASSIVE ICE AND ICY SEDIMENTS THROUGHOUT THE TUKTOYAKTUK PENINSULA, RICHARDS ISLAND, AND NEARBY AREAS, DISTRICT OF MACKENZIE

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by V.N. Rampton and J. Ross Mackay

The captions for Figures 3 and 4 should read as follows:

Figure 3. Percentage of shot holes that encountered massive ice at given depths based on the number of holes that did encounter massive ice at any depth.

Figure 4. Percentage of shot holes that encountered icy sediments at given depths based on the number of holes that did encounter icy sediments at any depth.

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* Photographs by J. Ross Mackay. Prints not available from Geological Survey of Canada.

ABSTRACT

Massive bodies of subsurface ice and icy sediments are relatively abundant throughout the Tuktoyaktuk Peninsula, Richards Island, and nearby areas. A statistical study, based upon shot hole records, shows that massive ice is most common at a depth of about 40 feet. Icy sediments, where present, occur with relatively constant frequency to a depth of at least 140 feet. At Tuktoyaktuk, examples of massive ice and icy sediments are readily accessible for examination in man-made excavations and coastal exposures.

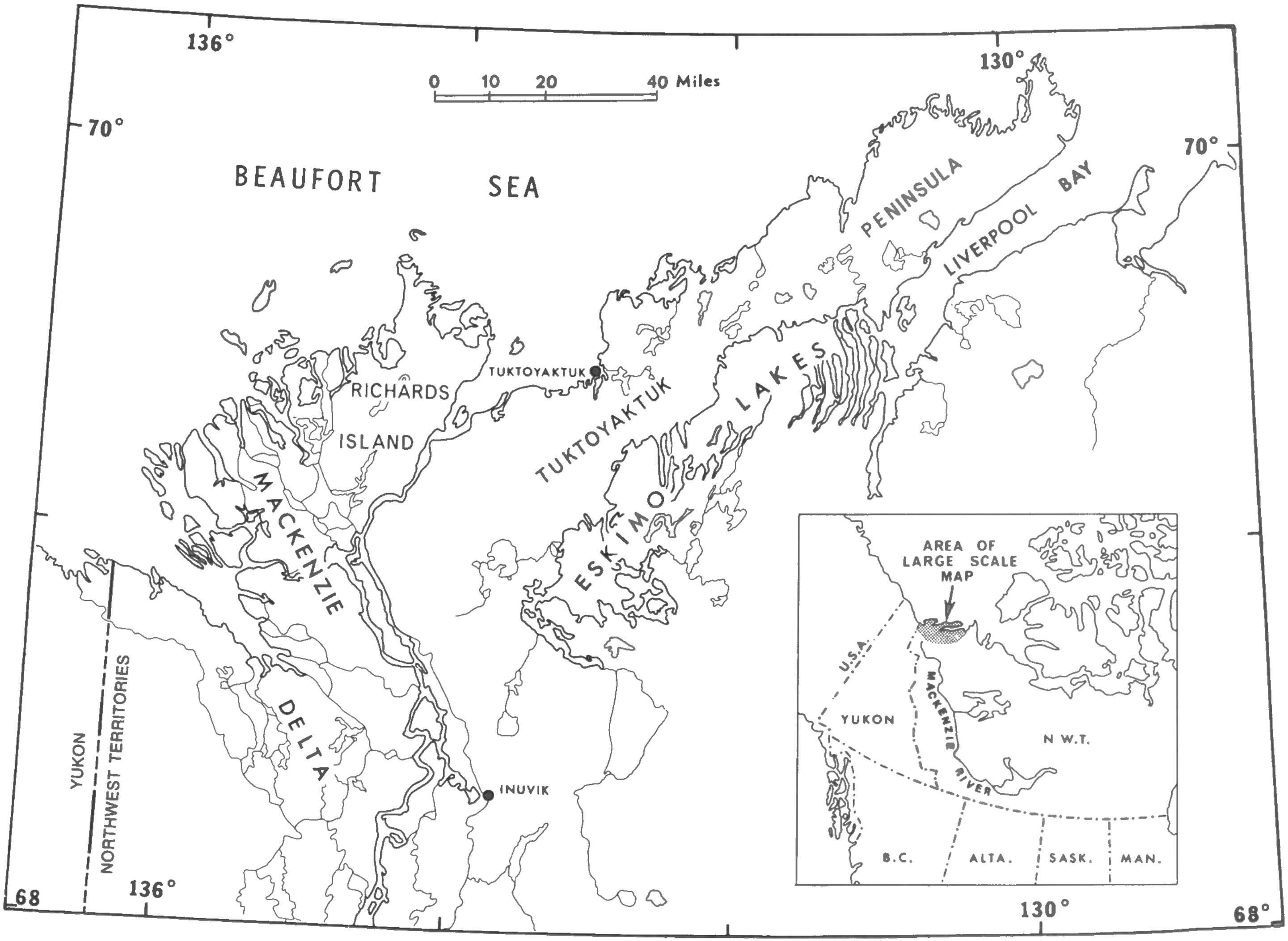

Figure 1. Index map showing Tuktoyaktuk Peninsula, Richards Island, and nearby areas.

MASSIVE ICE AND ICY SEDIMENTS THROUGHOUT THE TUKTOYAKTUK PENINSULA, RICHARDS ISLAND, AND NEARBY AREAS, DISTRICT OF MACKENZIE

INTRODUCTION

As development and exploitation of arctic and subarctic regions increases, phenomena such as massive bodies of subsurface ice and icy sediments are becoming of more direct concern to engineers, geologists, and other people involved in northern development and environmental proctection. In Canada these phenomena are abundant throughout the Tuktoyaktuk Peninsula, Richards Island, and nearby areas just to the northeast of the modern Mackenzie Delta (Fig. 1). The objectives of this paper are to outline the extent of massive ice and icy sediments and to describe local examples that are easily accessible for examination at Tuktoyaktuk.

Icy sediments are sediments that contain excess ice, usually in the form of ice lenses formed by epigenetic in situ freezing (Mackay, 1966). Upon thawing, such sediments are supersaturated with water. Massive ice is relatively pure ice: in this area it generally results from epigenetic segregation or subsurface injection processes (Mackay, 1971). However, some massive ice may be buried surface (e.g. glacier) ice.

The northern end of the Tuktoyaktuk Peninsula is a gently sloping plain dotted with oriented thermokarst lakes (Mackay, 1956, 1963). Richards Island and the southern and central parts of the peninsula consist of rolling hills with local relief sometimes attaining 300 feet. The topography of this hilly plain varies from one of closely spaced hills with steep slopes to one of broad hills with more gentle slopes. Depressions separating these broad hills may be more than a mile across. All areas are characterized by an abundance of lakes, many of which are of thermokarst origin or have been modified by thermokarst processes.

Exposures throughout Tuktoyaktuk Peninsula, Richards Island and nearby areas indicate that much of this area is underlain by fluvial sands and silts and fine-grained deltaic sands (for more details of the surficial geology see Mackay, 1963; Rampton, 1971). Some sections expose marine clays at depth. The deposits described above are capped by wind-blown sands on the northern end of the Tuktoyaktuk Peninsula and by peat, lacustrine deposits, gravel and clayey tills and till-like deposits of varying thickness on Richards Island and the southern and central parts of the Tuktoyaktuk Peninsula. Permafrost underlies all land areas, its presence and thickness being locally governed by the recent hydrologic history of each specific area.

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EXTENT OF MASSIVE ICE AND ICY SEDIMENTS

Exposed massive ice and icy sediments were noted by Mackay (1963, 1966) and Rampton (1971) during surficial geological mapping, and ground-ice slumps resulting from their melting were plotted by Mackay (1963, p. 62, Fig. 21). More recently, a considerable amount of information on both the vertical and horizontal distribution of massive ice and icy sediments has been gathered from the examination of shot hole logs obtained in cooperation with oil companies.

In the course of seismic surveys, 30 to 200 foot shot holes are drilled along seismic lines at regular intervals of less than half a mile. So far, about 5,000 shot hole logs have been examined from Richards Island, Tuktoyaktuk Peninsula and nearby areas. Many shot hole logs are incomplete;

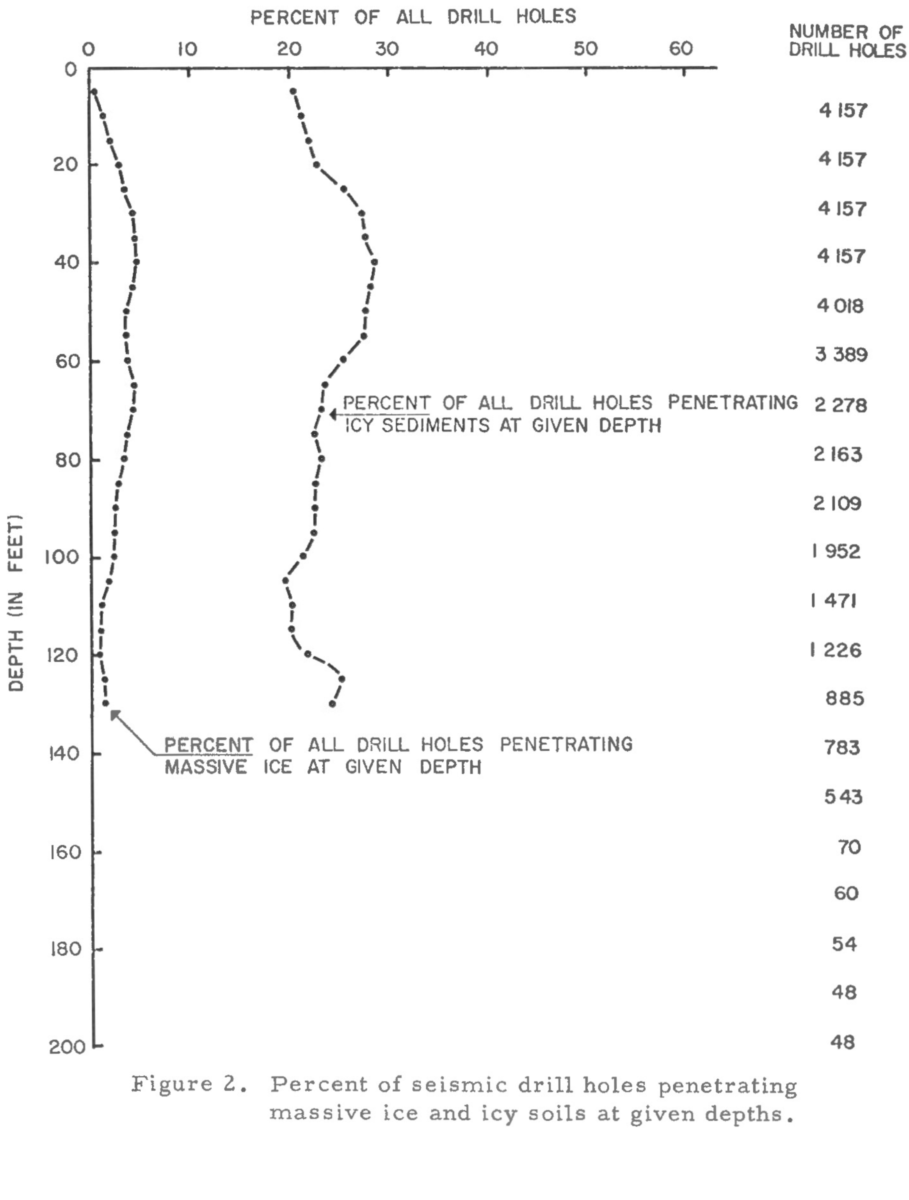

Figure 2. Percent of seismic drill holes penetrating massive ice and icy soils at given depths.

others are detailed and contain information on subsurface ice. Some interpretation was necessary in compiling the shot hole data. A combination of ice and sediment type as given by the drillers (e.g. ice and sand, icy sand, ice and clay, icy clay) was tabulated as icy sediment; if only the term "ice" was used, it was tabulated as massive ice. Ice reported to be only 10 to 20 feet thick and lying at a shallow depth was not included in the massive ice category as it was probably ice-wedge ice, which does not have the horizontal extent of massive ice. The accuracy of shot hole logs could readily be checked. For example, shot hole logs obtained by different drill crews on the same seismic line compared favourably both with each other and with shot hole logs from overlapping lines obtained in different years. Shot hole logs taken near coastal exposures were usually similar to the sequence in the exposures. The data given in Figures 2, 3 and 4 are, therefore, believed to reflect reason-

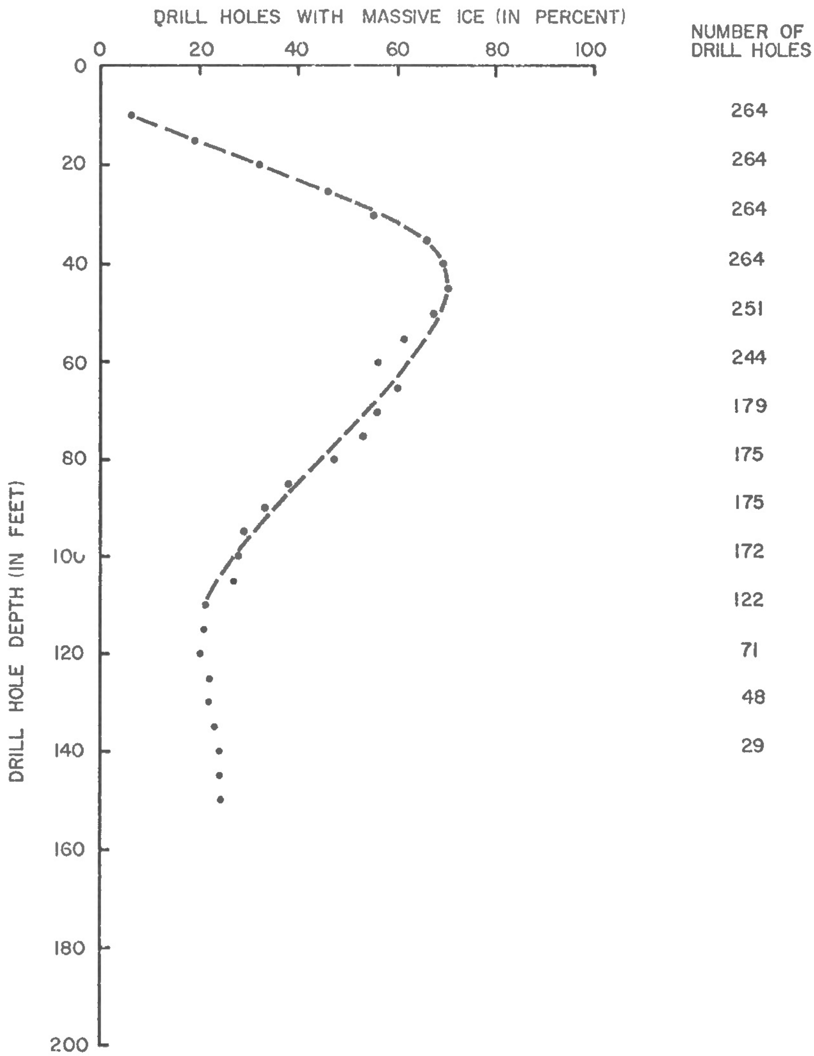

Figure 3. The percentage of shot holes that encountered massive ice at a given depth based on the total number of holes that did encounter massive ice at that depth or lower.

ably well the general pattern of massive ice and icy sediments. However, as seismic lines have generally not been run across water bodies, the sampling may not be representative of both land and water areas.

Figure 2 shows the percentage of all drillholes that penetrated into massive ice or icy sediments at given depths. For example, 4,157 shotholes examined were 40 feet deep or deeper. At a depth of 40 feet, about 5 per cent of all the drillholes were in massive ice and an additional 30 per cent were in icy sediments. Thus, at a depth of 40 feet, about 35 per cent of all the drillholes sampled were in either massive ice or icy sediments.

Figures 3 and 4 show the vertical distribution of the massive ice and icy sediments in those drillholes in which such material was encountered. Figure 3 shows that massive ice occurs most frequently at a depth of about 40 feet as 70 per cent of the 264 drillholes which penetrated into massive ice

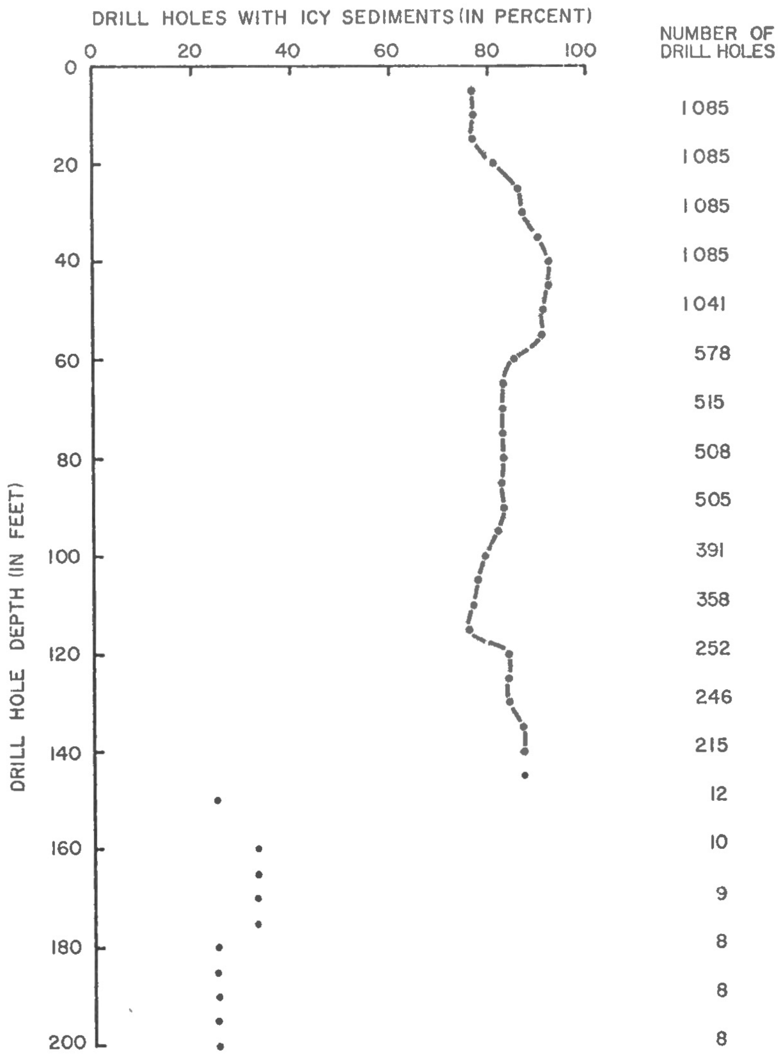

Figure 4. The percentage of shot holes that encountered icy sediments at a given depth based on the total number of holes that did encounter icy sediments at that depth or lower.

were in it at that depth. Even at 100 to 150 feet, a depth which few holes attained, massive ice was still reported in more than 20 per cent of the cases.

Figure 4 shows that there is relatively little change in the percentage of holes penetrating icy sediments at any depth. In other words, of those drillholes which encountered icy sediments, roughly 80 per cent reported icy sediments anywhere from the surface to a depth of 140 feet. The break in the curve at a depth of 140 feet is difficult to evaluate as it reflects a paucity of data for deeper holes. Although Figures 2, 3 and 4 have been plotted from the same basic data, the curves are not identical because the percentages are based upon different numbers of drillholes sampled.

The material lying above the massive ice is variable in composition, whereas the material underlying the ice is generally a coarse-grained sediment. Of the 176 bodies of massive ice that were drilled completely through, 4 per cent were overlain by peat, 19 per cent by gravel, sand and gravel, or sand, 3 per cent by sandy clay, 26 per cent by clay and 48 per cent by clay and rocks, which is interpreted as till or material derived from the reworking of till. The material lying below the massive ice was 92 per cent gravel, sand and gravel, and sand, 2 per cent sandy clay and 6 per cent clay. Where sandy clay or clay lay under ice, the latter was found to be thin. In the massive ice sampled so far, the soil found within the icy matrix tended to be fine grained (e.g. silts, silty clays, and clays): in a few cases sand has been noted. The shot hole logs also indicate a relationship between massive ice and topography: massive ice was more commonly recorded in those holes drilled on hills than in those drilled in depressions.

EXAMPLES AT TUKTOYAKTUK

Examples of massive ice and icy sediments can be readily examined at and near Tuktoyaktuk where two excavations have been dug in the permafrost and where coastal erosion is constantly exposing massive ice along the coast.

(a) Topography and surficial geology

Near Tuktoyaktuk the landscape is gently rolling and has a maximum relief of 150 feet. Thirty to 50 per cent of the area is covered by lakes (Mackay, 1963), most of which either have a thermokarst origin or have had their original configuration greatly modified by thermokarst processes. Many of the lakes at low elevations and drainage channels near the coast have been inundated with salt water as a result of the postglacial rise in sea level and coastal retreat. Pleistocene sands, which range in texture from fine to medium grained and which are more than 100 feet thick, underlie most of the area. Clayey diamicton, glaciofluvial gravel, pond deposits or peat commonly cap the Pleistocene sands. Where present, the clayey diamicton, undoubtedly a bona fide till in some localities but more often a mud-flow or basal pond deposit, is between 1 and 25 feet thick. The gravel is generally thin, never attaining more than 10 feet in thickness. The pond deposits consisting of interbedded diamicton, sand, silt and organic material have sometimes been found to be a hundred feet thick, but more commonly are 5-10 feet thick.

A. Location of fish cellar.
B. Entrance of tunnel in pingo.
C. Major axis of pingo.

Figure 5. Airphoto of Tuktoyaktuk and immediate vicinity. (A 21019-39)

(b) Icy sediments in ice cellar

An excellent example of Pleistocene sands containing excess ice, which locally exceeds 80 per cent of the total volume, can be found in the village of Tuktoyaktuk in an ice cellar excavated to serve as a refrigerated storage unit (see Fig. 5 for location). Thirteen feet of very icy sand are overlain by 6 feet of sand and 2 feet of gravel in the vertical shaft leading into the cellar. Layers of sand 2 to 8 inches thick separated by layers of ice up to 10 inches thick are exposed throughout the ice cellar itself which consists of three horizontal tunnels 45, 50 and 60 feet in length and numerous 10 foot square storage cubicles. A channel sample taken on one wall over a vertical extent of 6 feet contained excess ice amounting to 80 per cent of the total volume (sample A, Table 1). The icy sands have been thrown into horizontally overturned folds (Fig. 6), probably as a result of being overridden by glacial ice. The icy sands evidently underlie most of the land-area north and west of B in Figure 5 as photographs taken immediately following a storm in September of 1970[1] appear to reveal bands of ice and sand underlying gravels in a fresh wave-cut exposure on the west side of the peninsula on which Tuktoyaktuk is located.

(c) Icy sediments in pingo tunnel

Segrated ice in silts and sands also can be seen in a tunnel dug into the side of a small oblong pingo at Tuktoyaktuk (Fig. 5). The icy sands contain excess ice amounting to 90 per cent of the total volume, whereas the silts have a lower ice content and only occasionally contain visible segregated ice. The tunnel, which penetrates peat, pond silt, gravel, sand and ice (Fig. 7), is 15 to 18 feet wide, 5 to 8 feet high, and extends 150 feet into

Figure 6. Folded ice and sand in ice cellar at Tuktoyaktuk; dark bands are ice, light bands are sand. (G.S.C. photo 158963)

[1] Design Branch, Department of Public Works, Marine Terminal Study - Herschel Island, Progress Report No. 9, October, 1970.

TABLE I

Ice Content of Samples Collected from Ice Cellar and Tunnel at Tuktoyaktuk[1]

Description of sample (letters indicate location on Fig. 7)	Per cent water by dry weight	Per cent excess water by dry weight	Volume of excess ice as a percentage of total volume
Channel sample taken in 6-foot interval from icy sand in ice cellar.	340	310	80
Channel sample taken in 3-foot interval from icy sand in core of pingo (A)	500	470	90
Silt containing visible ice lenses in central part of pingo (B)	55	25	30
Icy silt near entrance to pingo (C)	115	65	45
Silt near entrance to pingo (D)	65	15	15

[1] Data results from crude measurements made in the field. Samples were air dried only.

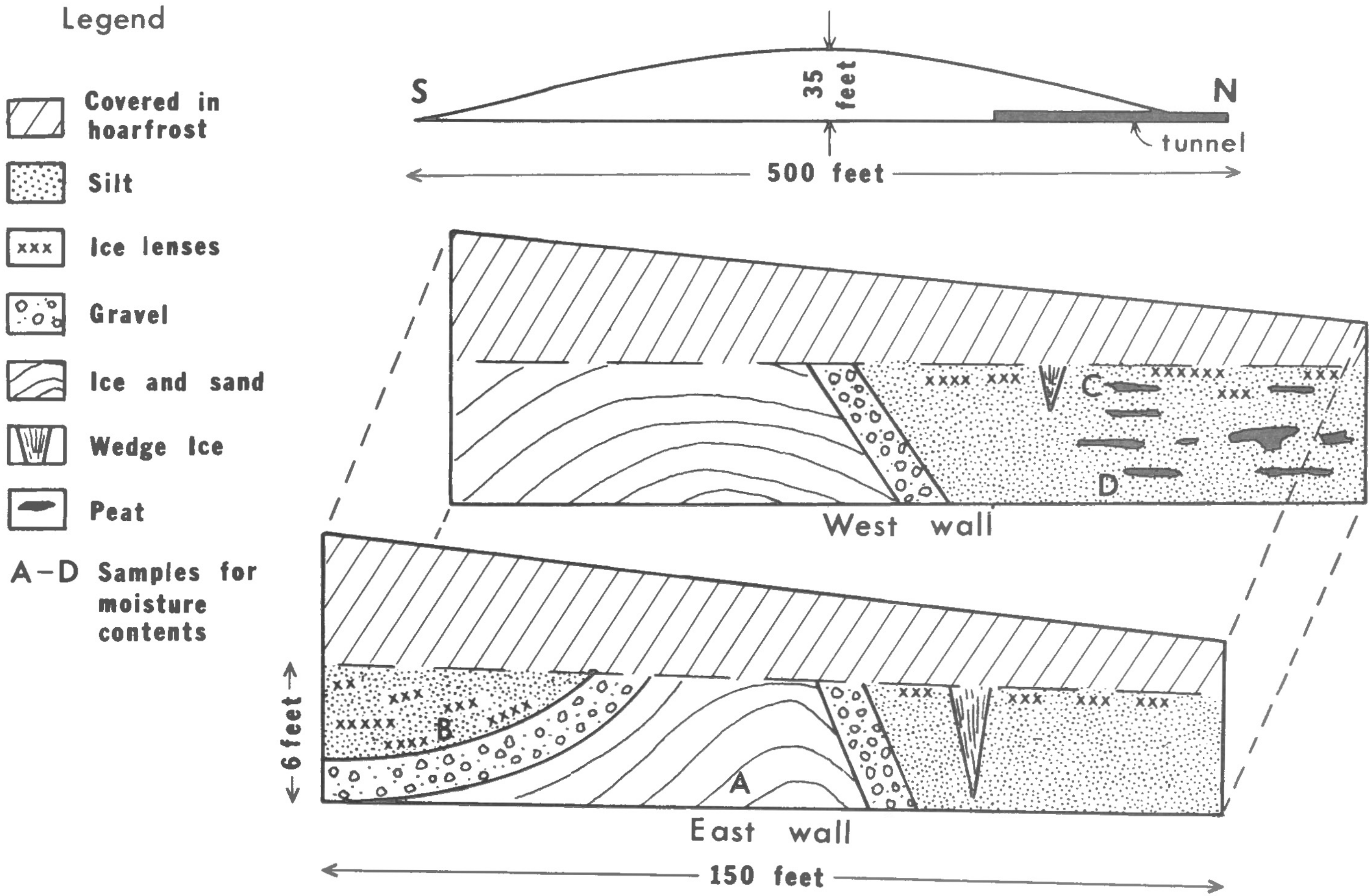

Figure 7. Geological sketch of tunnel walls in small pingo at Tuktoyaktuk.

the pingo at an angle of about 20 degrees to the minor axis of the pingo. The pond silt in the central part of the pingo contains an abundance of ice lenses, some as thick as one inch. One sample from the silt contained excess ice amounting to 30 per cent of the total volume (sample B, Table 1). Most of the pond silt and peat on the outer edge of the pingo did not contain readily

Figure 8. Ice wedge exposed on tunnel wall. (G.S.C. photo 158962)

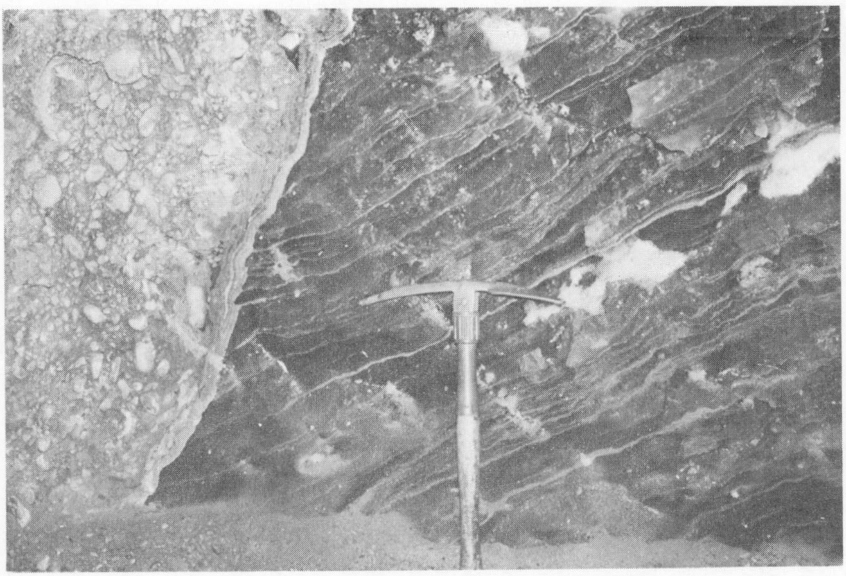

Figure 9. Contact between gravel and icy sand exposed on tunnel wall; dark material is ice. (G.S.C. photo 158960)

visible horizontally segrated ice, but even melted samples that did not have visible segregated ice contained excess water, and measurements indicate that their excess ice content was as much as 15 per cent of the total volume (sample D, Table 1). The pond silt and peat are also cut by ice wedges composed of nearly pure ice (Fig. 8). There are about 3 feet of gravel under the silts. The base of the gravel is marked by a fault plane between the gravel and the interlayered sand and ice that form the core of the pingo (Figs. 9 and 10). On the north flank of the sand and ice, the gravel beds dip between 40 degrees and 60 degrees, whereas the interlayered sand and ice only dip around 25 degrees. Normal faulting undoubtedly occurred as the near-surface strata were bowed upward during the formation of the pingo (see Mackay, 1962 and Williams, 1967, p. 109 for a description of pingo formation). The interlayered sand and ice consist of sand layers 1/8 to 2 inches thick and ice layers up to 5 inches thick. A channel sample over a vertical extent of 3 feet shows that this unit contains excess ice up to 90 per cent of the total volume. The ice layers are generally clear of sand and contain few air bubbles.

(d) Massive ice in ice slump

One particularly good coastal exposure of massive ice lies about 4 miles southwest of Tuktoyaktuk (Fig. 11). When the photograph was taken in 1969, the slump face was about 30 to 40 feet high. The slump face was composed of an upper layer of stony clay (Fig. 11A) and a lower layer of massive ice (Fig. 11B). As the slump face melted back, surface vegetation, stony clay, and water and debris from the massive ice moved from the bottom of the face as a viscous to liquid mudflow (Fig. 11C). An old scarp from a former melt period shows up at Figure 11D, and crudely sorted mudflow debris overlies the ice at Figure 11E. The mudflow debris usually shows layering, which often corresponds to annual summer thaw. The material is

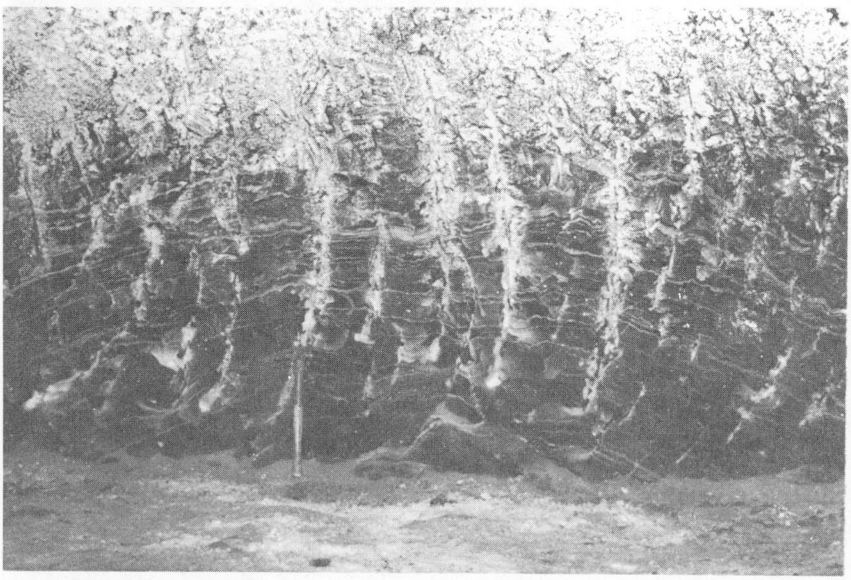

Figure 10. Axis of segregated ice and sand exposed on tunnel wall; dark bands are ice, light bands are sand. (G.S.C. photo 158961).

Figure 11. Coastal exposures of ground-ice west of Tuktoyaktuk. See text for explanation of letters.

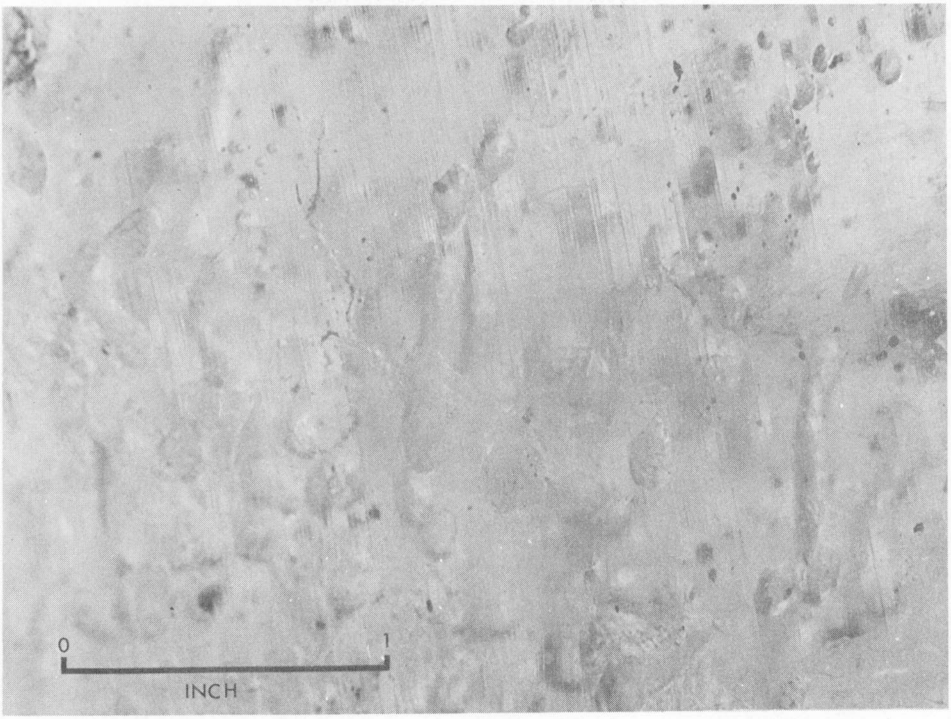

Figure 12. Air bubbles in ground-ice from Site B, Fig. 11. The bubbles are oriented normal to the banding. The fine, near-vertical streaks are marks made in smoothing off the ice face.

a mixture of stony clay, organic material, and locally well stratified silty clays which were laid down in pools or spread out in small delta-fans. The massive ice maintains a melt slope of about 50 degrees to 60 degrees. The dark bands in the ice are composed of ice with a few rounded pebbles and scattered pellets of silty clay. Between the dirt bands, the ice is generally pure and locally bubbly. Many bubbles are elongated normal to the banding (Fig. 12), which suggests downward freezing from the surface unless subsequent bubble migration has occurred, in response to a thermal gradient. The "bedding" in the ice tends to be horizontal but, during the 16 years it has been under observation, some folding or arching, with dips up to 50 degrees, have been observed. The origin of the folding is unknown. It could be, for example, the result of an original structure, of ice segregation of folding through over-riding by glacier ice, or of differential overburden pressures.

Regular observations of this locality since 1954 have revealed that the massive ice is much thicker than is indicated in Figure 11. Periodically, wave erosion has produced fresh slump faces in the mudflow debris below the main slump face. Massive ice has been observed in these lower slump faces at various levels and up to 22 feet in thickness. Exposures at sea level indicate that the ice continues below sea level to an unknown depth (Fig. 13). If all the exposed ice is part of a single body, as is suggested by the continuity of the ice observed over a period of many years, the ice must be a least 50 feet thick.

Figure 13. Fresh exposure of ground-ice overlain by mudflow debris at sea level (photo taken in 1954).

This massive body also appears to underlie a very wide area. Slump faces similar to that in Figure 11 show up in 1935 air photographs (e.g. A5023-87R) and in 1950 air photographs (e.g. A12981-93). Figure 14 shows the approximate positions of the coast in 1935, 1950 and 1967, which is the date of the base photograph (A19973-13). In the 32 years from 1935 to 1967, the coast has retreated a total distance of about 800 feet at an average rate of about 20 to 30 feet per year. The rapid rate of retreat is due, in part, to the high ice content of the coastal bluffs and, possibly, to offshore thermokarst steepening of the bottom profile. As the part of the dome-shaped hill still remaining has surface characteristics similar to the melted parts of the hill, there is every reason to believe that massive ice underlies the entire hill.

PRACTICAL CONSIDERATIONS

The presence of large bodies of massive ice and icy sediments under much of the area indicates that construction and development within the area should be undertaken with caution. Any natural or man-made disturbance causing permafrost degradation, in other words, a thickening of the active layer and subsequent thawing of massive ice or icy sediment, can have potentially disastrous results. Severe disturbances of the active layer on hillslopes that are underlain by massive ice or icy sediment may lead to thermal erosion (Mackay, 1971), which would be very difficult to control when the icy material became exposed. If thickening of the active layer, even on level areas, or the introduction of a subsurface heat source (e.g. hot pipeline) resulted in a thaw line intersecting massive ice or icy sediments, extensive thaw and major thermokarst subsidence could result unless preventative measures were taken.

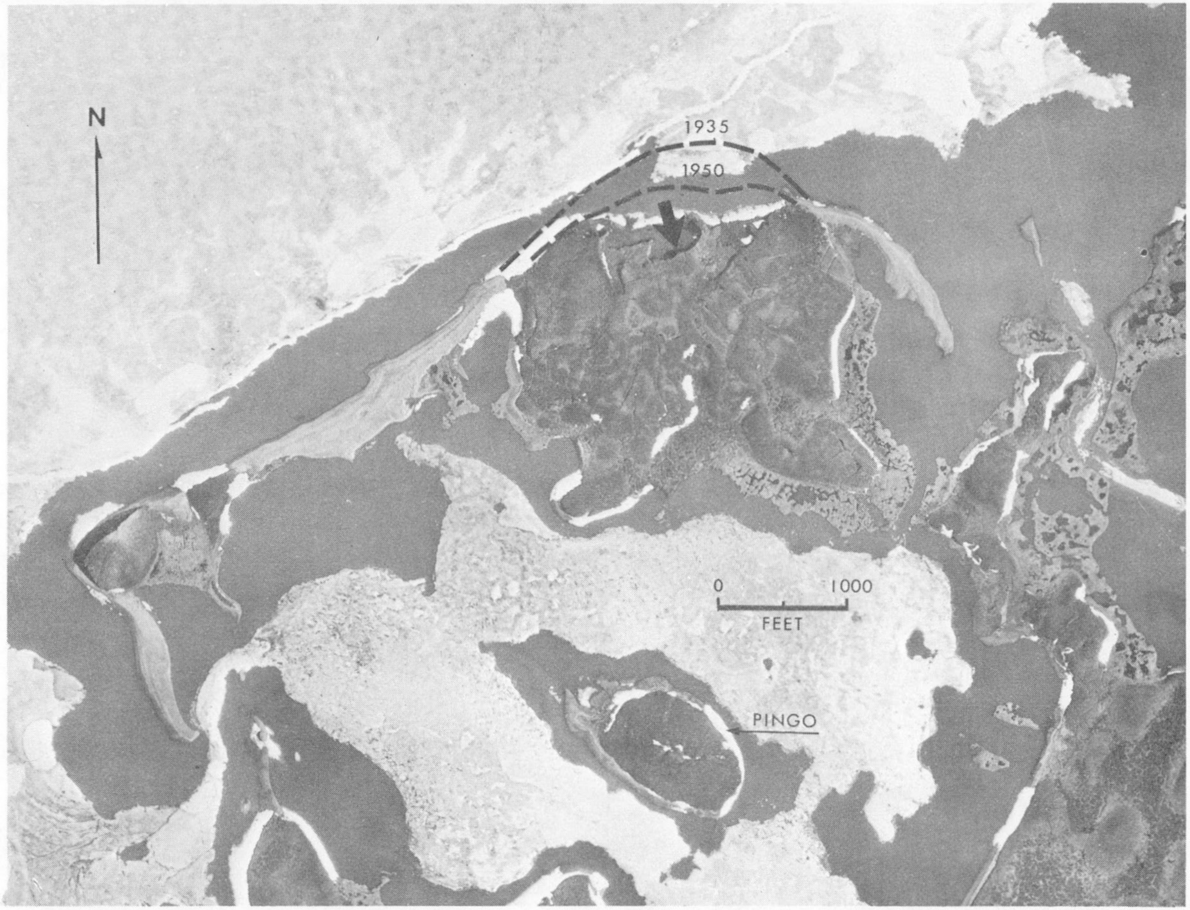

Figure 14. Airphoto showing coastal retreat at ground-ice exposure west of Tuktoyaktuk. The arrow points at Site B, Fig. 11. See text for further explanation.

In cases where the meltwater would percolate to the surface but would be locally confined, a thermokarst lake would form. If the lake became deeper than winter lake-ice thickness, it would perpetuate melting and further increase the size of the depression. Where the free water from the melted icy sediments could not filter to the surface, a slurry would be created which could provide no support to overlying structures (Lachenbruch, 1970). In the case of masses of ice or icy sediments 30 to 40 feet below ground surface, some years would elapse before melting commenced, but the melting would be difficult to stop once it had started.

The distribution of large masses of buried ice and icy sediments below a variety of surface materials indicates that detailed investigations on the subsurface ice content should be undertaken wherever an alteration to the local thermal regime might result from man's activities. In addition, the widespread occurrence of massive ice in the Tuktoyaktuk Peninsula and nearby areas suggests that other parts of the arctic that are potentially favourable to an occurrence of ground ice should be studied to see if ground ice is present.

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