GROUND ICE ASSOCIATED WITH GRANULAR DEPOSITS IN THE TUKTOYAKTUK COASTLANDS AREA, N.W.T.

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Abstract

Bodies of massive ground ice are commonly associated with deposits of granular materials in the Mackenzie Delta - Beaufort Sea region. In this paper, data on ground ice occurrences in granular deposits of glaciofluvial origin have been summarized from geotechnical borehole data collected from previous investigations of potential granular resource deposits in the region. Information of the nature and frequency of the ice bodies, and their association with adjacent sediments and landforms is presented. Many of the ice layers are thin and occur at shallow depths, apparently associated with organic materials or the base of the active layer. Other ice layers are very thick, in many cases extending below the depth investigated. A significant proportion of the ice bodies occur within the granular sediments, not at lithostratigraphic boundaries. The results of this study are discussed in terms of possible interpretations of the origin of the ice, and of their implications on the exploitation of granular resources.

Résumé

Des couches de glace massive sont généralement associées à des dépôts de matériaux granulaires dans la région du delta du Mackenzie-mer de Beaufort. Dans cette étude, les données sur la présence de glace de sol dans les dépôts granulaires d'origine fluvio-glaciaire ont été compilées à partir d'observations accumulées lors d'investigations géotechniques effectuées pour déterminer le potentiel des dépôts granulaires de la région. L'information sur la nature et la fréquence des masses de glace, et leurs associations aux sédiments adjacents et aux formes de terrain est présentée ici. Plusieurs des couches de glace sont minces et peu profondes, associées en apparence à de la matière organique ou à la base du mollisol. D'autres couches de glace sont très épaisses et se prolongent sous les profondeurs étudiées. Une partie importante de ces masses de glace se retrouve à l'intérieur des sédiments granulaires et non aux limites lithostratigraphiques. Les résultats de cette étude sont discutés relativement aux interprétations possibles de l'origine de la glace et des implications sur l'exploitation des ressources granulaires.

Introduction

Ground ice is a common constituent of near surface materials throughout the coastal area of the Beaufort Sea and the lower Mackenzie River valley. Coastal exposures (Mackay, 1971; Rampton, 1988), geophysical surveys (Rampton and Walcott, 1974; Dallimore and Davis, in press), seismic shot holes and geotechnical borings (Mackay, 1971; Hayley and MacLeod, 1977; Pollard and French, 1980) and surface excavations (Hayley and MacLeod, 1977), have shown that, in addition to abundant thin ice lenses and veins, thick bodies of massive ice are often associated both with fine grained and coarse grained sediments. Since coarse grained sediments are generally considered non-frost susceptible by engineers and geologists, their association with, in some cases, over 20m of massive ice is of considerable interest both in terms of the limitations ground ice may pose on extraction of granular materials and in terms of the origin of the ice.

This paper examines ground ice associated with granular deposits at 75 sites in the vicinity of the Mackenzie Delta, extending from Inuvik to the Tuktoyaktuk Peninsula and Richards Island (fig. 1). The frequency of ground ice occurrence and associated stratigraphy has been reviewed by utilizing a computerized database containing the results of boreholes drilled as part of granular resource investigations in the area over the last twenty years. The character of the ground ice is discussed in terms of the surficial geology of the area with possible interpretations of the origin of the ice. Some implications of massive ground ice on the exploration and development of granular resources are also discussed.

Geological setting

Surficial geology

Granular resource investigations in the Tuktoyaktuk Coastlands area have examined granular deposits of various sizes, ages and origins. These have included beach and spit sediments along the Beaufort Sea coast, fluvial sediments along the Mackenzie River valley, colluvium and unconsolidated bedrock occurring in the vicinity of the Caribou Hills, and widespread glaciofluvial sediments.

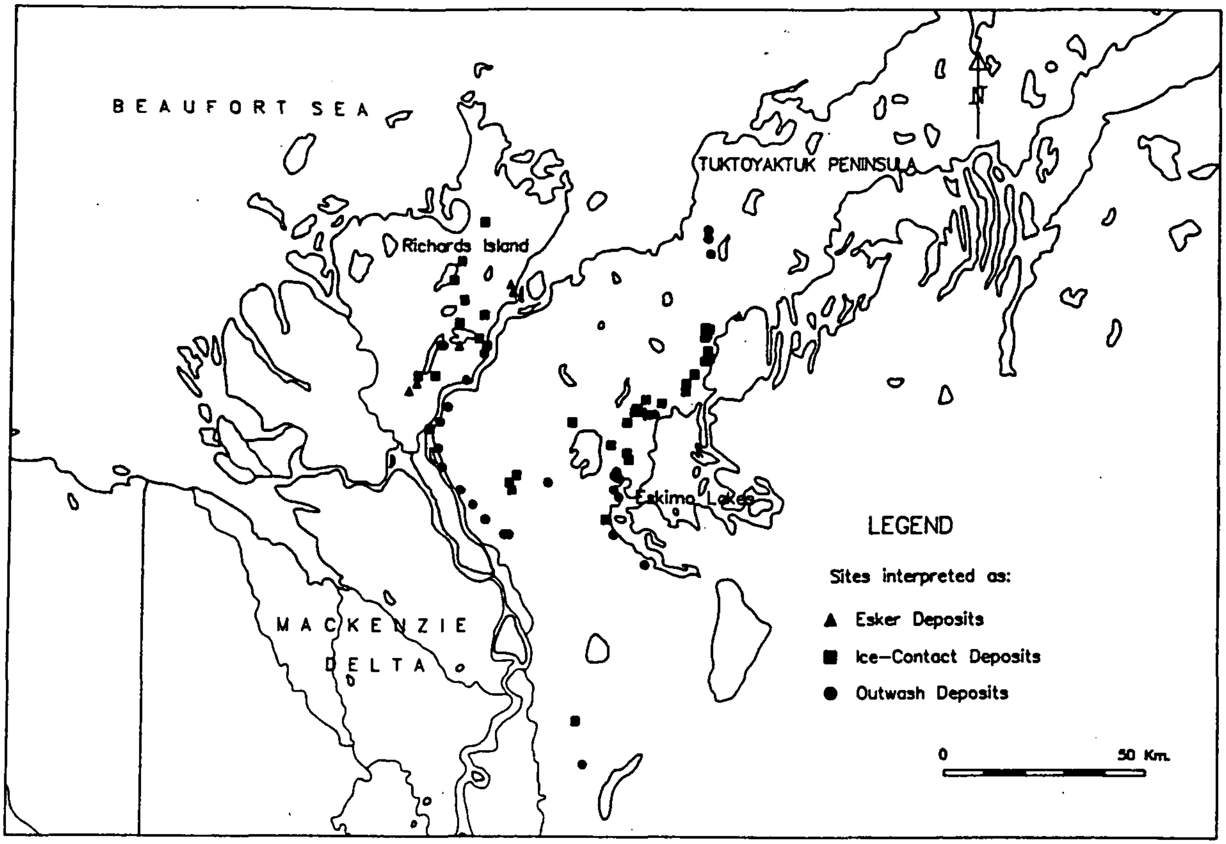

Figure 1. Location map showing granular sites of glaciofluvial origin that were examined in this study.

This study has concentrated exclusively on glaciofluvial sediments. These account for the greatest volumes of granular materials and for the largest number of known granular sources. These sediments can generally be subdivided into ice contact or outwash deposits. As their name suggests, ice contact deposits originate in close association with glacial ice. Landforms include eskers and kames. Outwash deposits are generally characterized by uniform planar landforms, deposited marginal to the glacial ice. In some cases, well defined outwash terraces have been identified.

A summary of the geology of the main glaciofluvial features in the area is given on Figure 2. Glaciofluvial sediments on the Tuktoyaktuk Peninsula and Richards Island are distinct from those to the south, and are thought to be related to the early Wisconsinian Toker Point Glaciation (Rampton, 1988). The pattern of these outwash systems suggests that several major drainage systems carried melt water across the Tuktoyaktuk Peninsula towards the Beaufort Sea from an ice front near the north shore of the present Eskimo Lakes (Tuktoyaktuk phase, fig.2). Several of these outwash systems may continue some distance offshore, which would indicate a major lowering of sea level during their deposition. Ice marginal landforms and glaciofluvial sediments occurring in the vicinity of Sitidgi Lake and the upper Mackenzie River are thought to define a distinct late Wisconsinian Sitidgi ice limit in this area (fig. 2). Glaciofluvial sediments related to this ice limit are confined to the southern Eskimo Lakes area.

It should be noted that there are conflicting interpretations, based mainly on regional studies in other areas (Hughes *et al.*, 1981; Dyke and Prest, 1987), of the age of the above ice positions. These two studies suggest that the late Wisconsinian ice may have covered nearly all of the Tuktoyaktuk Peninsula.

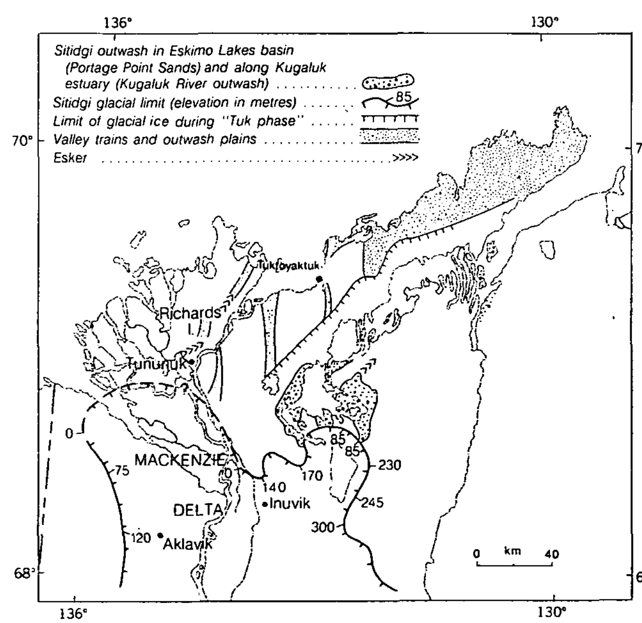

Figure 2. Distribution of glaciofluvial deposits associated with the early Wisconsinan Tuktoyaktuk phase of the Toker Point Glaciation and with the Sitidgi Glaciation (after Rampton, 1988).

Origin of massive ice

A considerable effort has been devoted over the past twenty years to determine the origin of thick bodies of massive tabular ice, which are common throughout the Tuktoyaktuk Coastlands. Possible ice types include intrasedimental ice and buried ice. Intrasedimental ice is generally thought to have formed within the surrounding sediments and includes segregation ice, intrusive ice and a combination of these termed segregation-intrusive ice (Mackay, 1971, 1989; Rampton and Mackay, 1971; Rampton, 1988). Buried ice may be formed by burial of surface ice or glacial ice. Reports of buried ice are rare in the Tuktoyaktuk Coastlands: a superimposed ice origin is proposed for a site near Tuktoyaktuk (Fujino *et al.*, 1988) and a glacial ice origin, for a site on Richards Island (Dallimore and Wolfe, 1988). Snow bank ice has been identified at several sites on the Yukon coastal plain, in areas with a similar geologic setting to the Tuktoyaktuk Coastlands (Pollard and Dallimore, 1988).

Source data and methodology

The data presented in this paper are derived from geotechnical investigations of potential sources of granular resources for construction materials that were conducted in the Mackenzie Delta—Tuktoyaktuk Peninsula area between 1971 and 1986. At least 173 sites in this area have been described in some 35 geotechnical reports. This includes 125 sites that are interpreted to be of glaciofluvial origin. Each site was originally identified through air photo interpretation, and varying degrees of field verification followed. Among the glaciofluvial sites, 50 had either no subsurface information or limited data based on reconnaissance level ground checking, with shallow test pits or observations on natural exposures. Geotechnical drilling had been completed at each of the remaining 75 glaciofluvial sites, but at a preliminary, exploratory level only for 64 of these sites. Some additional delineation work had been undertaken at six of the glaciofluvial sites. For each of the remaining five sites, data from a more detailed subsurface investigation, involving between 20 and 104 boreholes, were available.

Soil descriptions and laboratory test data for each of the potential granular resource sites had been compiled previously in a geotechnical borehole database (using the ESELog/ ESEBase program from ESE Software Ltd.) as part of a separate study. The database essentially duplicates the detail of the borehole logs from the original reports, in which soils were classified according to the Unified Soil Classification system and described based on the proportions of textural classes (Burmister, 1964). Supporting data such as detailed sediment analyses and moisture content data are in some cases quite extensive. Many of the logs, particularly those from recent studies, also include descriptions of soil structure and bedding.

Ground ice was classified according to the NRC ice classification system (Pihlainen and Johnston, 1963). This study used a subset of the database containing only boreholes which were known to represent frozen materials and interpreted to be of glaciofluvial origin. The subset contained 557 boreholes from 75 sites.

The data analyses focussed on stratigraphic units that were originally logged as "ICE" or as "ICE+(<50 % soil)", as defined by Pihlainen and Johnston (1963), and on the immediately overlying and underlying layers. The ice-soil associations, based on the descriptions of soil inclusions or layers within and adjacent to the ice bodies, were coded for inclusion in the database. Adjacent layers of ICE and ICE+(soil), which had been recorded in the original logs as separate stratigraphic units, were combined and re-classified as single ice bodies, but multiple ice units within a borehole that were separated by soil strata were treated as distinct ice bodies. Then, the data records for the ice bodies were extracted to a separate file for sorting and summarizing. Data manipulation was carried out utilizing Ashton-Tate's dBase III+ software.

Data presentation

Frequency and thickness of ice body occurrence

A total of 411 separate ice bodies (ICE and/or ICE+[soil] strata) were identified in 326 boreholes (almost 60 % of the 557 boreholes examined). These comprised a total thickness of 840 metres (or 20 % of the 4350 metres logged in the 557 boreholes). This is considered to be a minimum thickness. Because disposal of potentially thick bodies of massive ice at depth is generally not feasible in granular resource extraction operations, the site investigation programs rarely made an attempt to drill through a massive ice body if it was encountered more than a few metres below the surface. As a result, it is not possible to estimate the maximum thickness of ground ice in 190 of the boreholes (58 % of those containing massive ice).

Layers of clean ice, or ice with only traces of soil particles (ICE units) account for 524 metres of the total ice thickness (or 12 % of the total length of the boreholes). Many of the early studies did not include estimates of volumetric ice content within the ICE+(soil) units, so it was not possible to determine the equivalent total ice thickness; however, if an average ice content of 75 % by volume is assigned arbitrarily to these units, this total could exceed 800 metres (18 %). Inclusion of ice in the form of thin lenses and veins, which was not examined in this study but which was noted to comprise frequently greater than 10 % and occasionally as high as an estimated 40 % to 50 % by volume of the "soil" units, would substantially increase the total volumetric ice content.

The frequency of ground ice occurrence with depth is shown in Figure 3. The number of boreholes containing a massive ice body within each 0.2 m depth interval is expressed as a percentage of the total numbers of boreholes penetrating that interval (solid line in fig. 3) and also as a percentage of those boreholes that encountered massive ice bodies (broken line in fig. 3). A general trend of increasing ice frequency with depth is evident, and there appear to be a thin but distinct layer of relatively greater ice frequency near

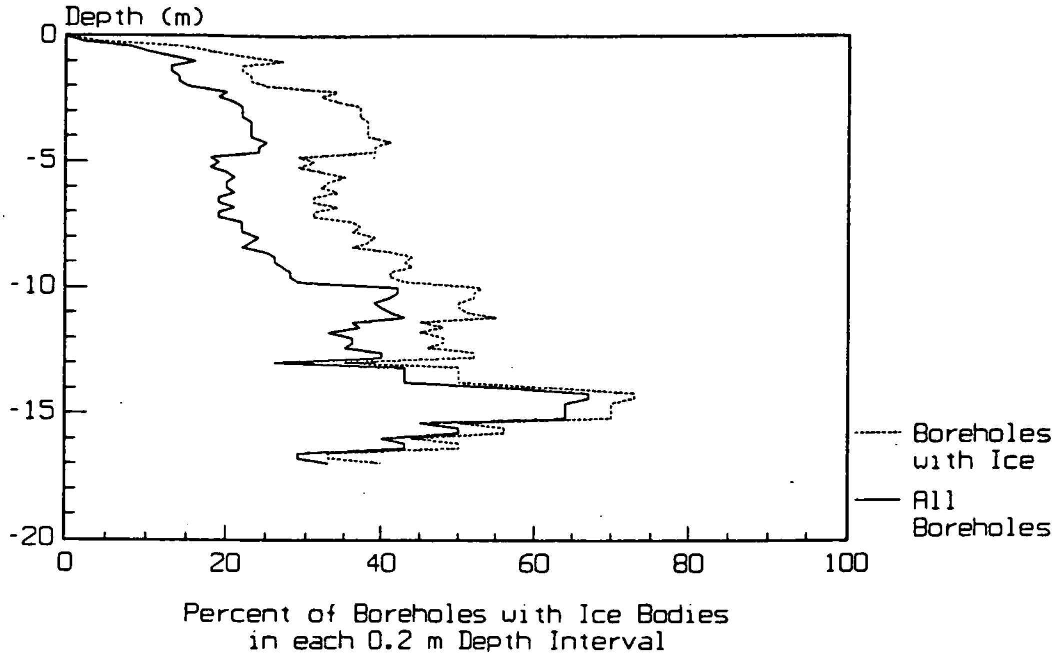

Figure 3. Frequency with depth of ice bodies in glaciofluvial deposits in the Tuktoyaktuk Coastlands, expressed as a percentage of all (557) boreholes examined, and as a percentage of only those (326) boreholes that encountered ice at any depth.

1m depth (probably at the base of the active layer) and considerably thicker layers at 5m, 10m and 15m depth. These fluctuations should view with caution; however, since one-third of all boreholes terminated above or within the high ice frequency zone between about 2m and 5m depth and the total numbers of boreholes decreases significantly below 10 m. The increase in ice frequencies at depth, will however, limit the development of these deposits.

Some relationships between the depth of the upper surface of the ice bodies and their thickness are summarized in Table I. The distributions of ice bodies of various thicknesses within each depth zone are expressed relative to the total number (411) of ice occurrences. While approximately one-third of the ground ice occurrences are less than 1m in thickness, one-quarter of the total are at least 3m thick, and there are many occurrences with more than 6m of ice. Again, these data are considered to represent minimum values since so many of the holes terminated in the ice.

Sediment associations with ice bodies

Sediment within ice bodies

The sediments contained within the ice bodies as either disseminated particles or soil inclusions and layers were

Table I. Thickness of Ice Stratigraphic Units with Depth

Depth to Top of Ice Unit	No. of Units	% Ending[2] in Ice	Percentage[1] Occurrence of Ice Units of Specified Thickness: < 1m	1 - 3m	> 3m	Total
0 - 2m	144	10	13	13	9	35
2 - 4m	116	15	8	14	6	28
4 - 6m	54	6	5	3	5	13
6 - 8m	55	9	4	5	4	13
8 - 10m	30	5	3	3	1	7
10 - 12m	7	1	1	<1	0	2
12 - 14m	2	<1	0	<1	<1	<1
14 - 20m	3	<1	<1	<1	0	1
Total	411	47	35	40	25	100

1 *Percentages of ice bodies of each thickness class and each depth range are expressed in terms of the total number (411) of ice layers.*
2 *Percentages of ice bodies which extended below the maximum borehole depth are expressed in terms of the total number (411) of ice layers.*

examined in order to establish the relationship between the ice and the adjacent soil layers. The ice classifications, associated sediment types and the thicknesses of these groupings, are shown in Table II. Thirty-one percent of the ice bodies were clean ice, 29 % contained only traces of soil particles and a few ice bodies (4 %) contained a significant proportion of soil of undefined texture. The remainder (36 % of the ice occurrences) are grouped according to the texture and USC symbol of the associated sediment.

The predominance of silt within the ice bodies (54 % of known ice-soil inclusion associations) contrasts with the observed association of ice with the overlying and underlying sediment layer, described in the following section. Sand inclusions are also significant (27 %) and associations with other textural classes are minor.

Table II. Ice and included sediment types

Ice and Soil Types	Ice Occurrences	
A. All Ice Units		
	Number	Percent[1]
ICE (clean)	126	31
ICE (traces soil)	119	29
ICE + (soil)	166	40
TOTAL	411	100
B. ICE + (soil)[2]		
	Number[2]	Percent[2,3]
ICE + PEAT (PT)	4	2
ICE + ORGANICS (OL)	10	6
ICE + CLAY	7	4
- (CL)	(5)	(3)
- (TILL)[4]	(1)	(tr)
- (C ?)[5]	(1)	(tr)
ICE + SILT	89	54
- (ML)	(35)	(21)
- (TILL)[4]	(8)	(5)
- (M ?)[5]	(46)	(28)
ICE + SAND	45	27
- (SP)	(8)	(5)
- (SM)	(5)	(3)
- (TILL)[4]	(—)	(—)
- (S ?)[5]	(32)	(21)
ICE + GRAVEL[4]	1	1
ICE + undeterm. soil	10	6
TOTAL	166	100

1Percentage of all ice occurrences
2Values in parenthesis are included in totals for main soil types
3Percentage of ICE + (soil) bodies
4Classified as TILL based on soil descriptions; may be several USC classes
5Textural class known, USC class not specified

Sediment above and below ice bodies

The relationship between ground ice occurrence and the adjacent sediments is shown in Table III. This information can prove useful in interpreting the origin of the ground ice and in anticipating stability aspects should the ground ice be disturbed by extraction processes. Of the subset of 411 ground ice occurrences, 50 % (205) were overlain by sand or gravel, 21 % (88) by clay and silt, 17 % (70) by organic-rich materials, and 12 % (48) by till.

The sediments beneath the ground ice were only identified in 221 instances since many of the boreholes ended in massive ice. Of the holes which did penetrate the ice unit, 22 (56 %) were underlain by sand or gravel while 60 (27 %) were underlain by clay and silt, 37 (17 %) by till and two occurrences were underlain by buried organic material.

Comparison of the sediments contained within each ice body (as summarized in the previous section) and the sediment layers located above and below the ice indicated that 21 of the ice bodies (8 % of those for which ice-sediment relationships could be determined) contain sediment that differs from both the overlying and underlying sediments. In another 68 cases (20 %), the included sediment in the ice bodies was different than that overlying the ice unit, and the association with the underlying unit could not be determined. Most significant with respect to this study, is the association of about 65 % of the ice bodies containing a known sediment type to granular sediments.

Excluding the associations involving organic material, more than one-half (88 of 164) of the ice bodies were overlain and underlain by the same material type, and 68 of the ice occurrences (40 % of those associated only with mineral soil) were contained within granular sediments. These data present a striking comparison with shot hole data from other areas of the Tuktoyaktuk Peninsula presented by Mackay (1971) and for some models of ground ice aggradation which suggest that ground ice is most likely to be overlain by fine grained sediments and underlain by coarse grained sediments (Rampton, 1974; 1988).

Landform associations

The granular sources included in this study were grouped by landform, origin and age to investigate the influence of sediment genesis on ground ice distribution. These associations are shown in Table IV. Surficial mapping (at 1:500,000 and 1:250,000 scale) by Rampton (1979, and 1988) was used as a guide for these assignments. On this basis nearly all of the sources were related to glaciofluvial sediments from Toker Point Stade (see fig. 2). More than half of the boreholes drilled in ice contact and outwash sediments related to Toker Point Stage encountered ice. Although the number of samples was smaller, approximately 80 % of the boreholes drilled through distinct eskers or esker-like features encountered ice. Only 23 boreholes were drilled in outwash or ice contact sediments related to the Sitidgi Stage ice, however the frequency of ice occurrence was similar to that for Toker Point ice.

TABLE III Ice-sediment stratigraphic associations

Underlying Sediment	Overlying Sediment							
	Peat	Organics	Clay	Silt	Sand	Gravel	Till	Total
A. All Soil Types								
Peat	0	0	<1	0	0	0	0	<1
Organics	<1	0	0	0	0	0	0	<1
Clay	5	<1	1	1	0	<1	0	8
Silt	2	2	0	7	7	<1	<1	19
Sand	4	4	2	6	21	3	3	43
Gravel	2	1	1	2	2	4	1	13
Till	4	1	2	0	4	1	5	17
Sub-Total	18	8	7	16	34	8	9	100
Unknown	0	3	1	8	20	7	7	46
Total	10	7	4	17	39	11	12	100
B. Mineral Soils Only								
Clay			2	1	0	1	0	4
Silt			0	10	9	1	1	20
Sand			3	9	28	4	4	47
Gravel			1	2	3	5	1	13
Till			2	0	6	1	7	16
Sub-Total			9	22	46	11	12	100
Unknown			1	10	25	8	8	52
Total			5	21	47	14	14	100

NOTES: 1. Row entries and Column Sub-Totals are percentages of known associations with both overlying and underlying sediment. 2. Unknown represents percent of all ice bodies for which underlying soil is unknown. 3. Column Totals are percentages of all ice occurrences.

Discussion

ORIGIN OF GROUND ICE

Although the current study was directed mainly at establishing the nature and frequency of ground ice occurrences, information on depth and sediment association may suggest or limit interpretations as to the mode of origin of the ice. Firstly, it is clear that a certain portion of the ice occurs at shallow depth (35% in depth range of 0-2m), essentially just below the active layer. Since in many instances these ice occurrences are associated with a cover of organic-rich sediments, peat, and fine grained sediments, we speculate that much of this shallow ice is recent aggradational ice or Holocene aged segregation ice. Data presented by Dallimore and Wolfe (1988) and Mackay (1983) suggest that this shallow type of ice may have distinct ice chemistry and isotopic character.

Table IV Frequency of Ice in glaciofluvial landforms

Landform/material:	Outwash	Ice contact	Eskers	Total
Number of sources	30	38	7	75
Sources with ice	23	32	7	62
Frequency in percent	77	82	100	83
Number of boreholes	335	179	43	557
Boreholes with ice	190	106	30	326
Frequency in percent	57	59	70	59
Number of ice bodies	230	141	40	411

Perhaps the most interesting data in this study, with respect to the origin of ice, are those pertaining to thick ground ice bodies occurring at depth, which are common in glaciofluvial sediments of both the Sitidgi and the Toker Point Stages. A majority of these ice occurrences were both overlain and underlain by coarse-grained sediments, in contrast to data presented for other areas of the Tuktoyaktuk Peninsula by Mackay (1971) and Rampton and Mackay (1971). While our data do not resolve categorically whether this ice is intrasedimental ice or buried ice several interesting observations help to refine our understanding of ice occurrence in this setting and serve to constrain the nature of ice formation, as discussed in the following paragraphs.

Investigation of the coarse grained overlying and underlying sediments revealed that in most instances they are either well-sorted or poorly-sorted sands and gravels with little silt or clay. Since these materials are generally thought to be non-frost susceptible, it is difficult to imagine that these ice bodies formed by ice segregation under normal freezing conditions. The only intrasedimental ice we can envisage in these cases is injection ice or possibly segregation-injection ice formed under constrained freezing conditions with elevated pore water pressures. To some degree, the variety of ice types found in pingos serve as examples of this type of freezing (e.g. Mackay, 1981). However, these features form under very specific permafrost and ground water conditions that should be confirmed when considering an intrasedimental ice origin.

In the case of the sediment and ice associations investigated in this study, we found that ground ice occurs in sediments of varying origin distributed over a very large area. In addition, since segregation-injection and injection ice are thought to have formed after sediment deposition, it follows that the surface expression of the feature should mimic the ice body at depth, provided substantial surface disturbance hasn't occurred after the ice formed. Many of the glaciofluvial deposits included in this study are essentially planar with little or no evidence of widespread surface modification. Sections such as those presented by Dallimore and Wolfe (1988) and Hayley and MacLeod (1977) however, show that ice distribution at depth is quite complex.

In our minds, there is a case, at least by association, for speculation that buried glacial ice is a possible source for some of the ice described in this study. The potential for preservation of glacial ice is relatively high in glaciofluvial deposits. We believe that nearly all of the sediment associations described could be expected in terminal zone of a stagnant ice sheet with an abundance of supraglacial, englacial and subglacial water flow. Till was identified in many of the boreholes, and there are some differences, in terms of texture, at least, between the sediments within the ice bodies (Table II), and those of the adjacent layers (Table III). If some of the ice reported here is in fact glacial ice it is interesting to note that the Sitidgi Stage and Toker Point Stage sediments have similar ice contents.

Implications for granular exploitation

The results of this study have shown that massive ice can be expected to occur in most glaciofluvial deposits in the Mackenzie Delta—Tuktoyaktkuk Peninsula area. The occurrence of ice or ice-rich sediments in association with granular materials may pose severe restrictions on the exploitation of granular resources in the study area. Ice-related problems can affect all phases of development, from deposit identification to borrow site rehabilitation.

Glaciofluvial features that may contain exploitable granular materials are generally relatively easy to identify through air photo interpretation. In areas of abundant massive ground ice, the typical landforms may be distorted by ice segregation or melting. Since the size and shape of the ice bodies are often not reflected at the ground surface, topographic information is unreliable in estimating the potential size of deposits, and extensive exploration programs are required to evaluate both the extent of ice and the quantity of granular materials available.

Comparison of ice frequency and type of landform (Table IV) has shown that the eskers examined in this area are more likely to contain massive ice, and in greater proportions, than either ice-contact features or outwash. There is also an apparent trend to increasing ice content with depth, that may limit the depth to which any resources can be developed. Source development plans that will allow the production of annual borrow material requirements, but also ensure future access to remaining materials, maximize recoverable volumes and prevent environmental damage, can become extremely complex. The maximum extent of massive ice in many of the sites examined in this study could not be determined since the boreholes did not penetrate through the ice.

The presence of ground ice, and especially massive ice, has a significant impact on pit operation costs. Normally, this involves advanced site stripping and thawing of frozen materials, windrowing or stockpiling of excavated materials to permit drainage of excess moisture, and extensive drainage control to ensure pit floor trafficability and to prevent thermokarst ponding and siltation of adjacent water bodies. If the distribution and extent of massive ground ice is not well known and considered in site development plans, the quantities of material recovered in a single season may be limited and extraction may require costly ripping and re-handling and the excavation and disposal of ice. Where the ice bodies are irregular in shape and erratic in distribution, the use of blasting may be ineffective as much of the blast energy may be absorbed in fragmenting the ice.

Extensive site rehabilitation is essential, even for temporary (seasonal) abandonment of pit operations in granular sources containing massive ice bodies. Ice exposed in the sides and floor of the active pit must be blanketed with sufficient soil material to prevent their thawing. If the geothermal regime is drastically altered in areas adjacent to or underlain by thick bodies of massive ice, widespread thaw settlement and slope instability may be initiated.

Some examples of these problems and some practical solutions are demonstrated in the case studies described by Hayley and MacLeod (1977). If granular resources are sufficient to warrant pit development the constraints posed by ground ice should be thoroughly evaluated. Although most of the granular reports we have reviewed acknowledge these constraints, in practice, pit development carried out to date has had only limited success in dealing with these concerns. We recommend that in the future more emphasis be placed on delineating ground ice occurrence. An effort should be made to drill through ice bodies at several locations to establish their true thickness. Recent studies (Dallimore and Wolfe, 1988; Dallimore and Davis, in press) have shown that ground penetrating radar is a useful tool for mapping the location and continuity of massive ground ice in coarse grained sediments.

Conclusions

The data presented in this paper have shown that massive ground ice occurs commonly in association with a wide variety of granular materials throughout the study area. In the deposits investigated, ice bodies occur most frequently either within or below the granular materials, rather than between an overlying finer grained material and a granular material, as considered in some aggradational ice formation models. The overall high frequency and widespread extent of massive ice in the study area may present severe problems in the development of many granular sources if it is not adequately delineated and considered in site development plans. Although drilling and geophysics may aid in determining the distribution of ground ice at a site specific scale, more information is needed to establish the origin of the ice. This will aid greatly in predicting ground ice distribution and anticipating the likelihood of more ground ice at depth.

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