RECONSTRUCTION OF HOLOCENE PERIGLACIAL ENVIRONMENTS IN THE PANGNIRTUNG AREA BASED ON ICE WEDGE CHARACTERISTICS

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Abstract

Ice wedges exposed during the construction of a reservoir near Pangnirtung, N.W.T. were examined during the summer of 1986. They are contained within raised deltaic sands and gravels and overlying sandy diamict located at or slightly above the local marine limit. The ice wedges, which average 0.75 m in width and more than 1.0 m in height, are thought to have formed following emergence approximately 8700 years B.P. Near vertical sides on many of the ice wedges, together with secondary growth veins which terminate part way down the sides of the wedges, imply lateral and vertical ice growth within aggrading permafrost. Periods of ice wedge decay may be inferred from thaw unconformities observed over some ice wedges.

Résumé

Des coins de glace exposés durant la construction du réservoir d'eau à Pangnirtung, T.N.O., furent étudiées durant l'été de 1986. Ceux-ci sont contenus dans des sables et graviers deltaïques recouverts d'un diamicton à peu près au niveau de la limite marine. Les coins, qui mesurent 0.75 m de largeur et plus de 1.00 m de profondeur, ont commencé à se former avec l'émersion de la côte il y a environ 8700 ans B.P. Les bordures verticales observées sur plusieurs coins, et des veines de glace secondaires qui longent ce rebord puis se terminent abruptement, ont comme implication l'expansion autant latérale que verticale des coins de glace durant l'accroissement du pergélisol. Des périodes sporadiques de dégel durant l'Holocène peuvent être déduites suite à la présence de discontinuités de dégel au sommet de certains coins.

Introduction

In North America, ground ice investigations have focused primarily on exposures in the western Arctic, northern Quebec, and Ellesmere Island (French 1987). With the exception of work by Falconer (1966), and Savigny and Smith (1988), ground ice on Baffin Island has received only passing mention (eg. Brown 1970).

This paper describes ice wedges and related stratigraphy that were exposed during construction of a reservoir near Pangnirtung N.W.T. (fig. 1). A history of ice wedge development is interpreted from these observations.

Regional setting

The Quaternary history of the area has been studied by Dyke *et al.* (1982) and others. Correlations between moraines in Pangnirtung Fiord and deltaic deposits in neighbouring Kingnait Fiord suggest that the reservoir site was free of ice as early as 30 000 years BP. However, late Foxe (9 to 10 ka BP.) advances of both Laurentide ice and alpine ice sheets maintained significant isostatic depression in the area. Dating of raised marine sediments places the sea level very near the reservoir site 8700 years ago. Dyke (1979) and Dyke *et al.* (1982) have inferred alternating periods of warm, wet and cold, dry conditions throughout the Holocene. Warm, wet conditions are thought to have prevailed 8600-5700 years BP, 3700-3200 years BP, 1700-1100 years BP, around 600 years BP, and 50-0 years BP.

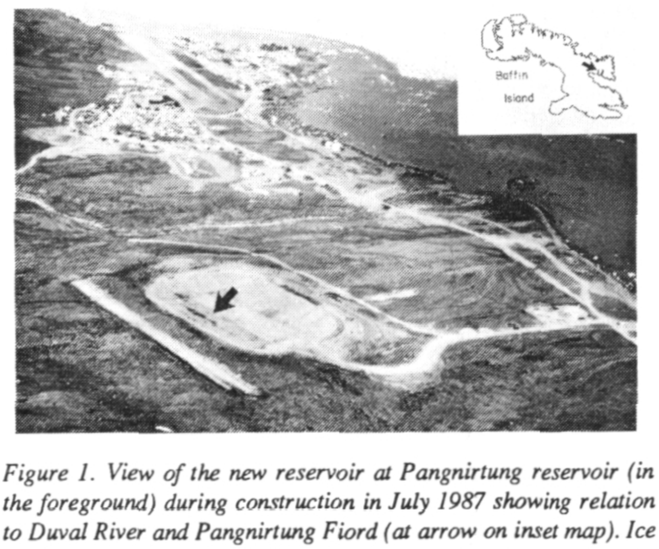

Figure 1. View of the new reservoir at Pangnirtung reservoir (in the foreground) during construction in July 1987 showing relation to Duval River and Pangnirtung Fiord (at arrow on inset map). Ice wedges observed in 1986 were exposed at the arrow on the photograph.

Cold, dry conditions occurred 4700-4300 years BP, around 2100 years BP and 900 years BP, and 400-250 years BP.

An average of 395 mm of precipitation falls yearly in Pangnirtung. Of this, approximately 44% occurs as rain between June and September (Masterton and Findlay 1976). Mean annual air temperature is -10 °C (Maxwell 1980). Ground temperature data collected at an undisturbed area adjacent to the study site indicate a mean annual ground surface temperature ranging from -8 °C to -9 °C, and a maximum thaw depth of 1.6 m.

Excavation of the reservoir began in November 1985 with blasted material being used to build a large containment berm down-slope from the excavation. A detailed account of site investigation findings and construction activities is given by Notenboom *et al.* (1988) and Smith *et al.* (1989).

Observations

Excavation for the reservoir exposed near-surface sediment and ground ice in a section 183 m long and 3.5 m high. A thin layer of surface vegetation and mineral soil was removed from the site before mapping could begin. The exact thickness of this layer is unknown. However, the area around the reservoir is generally flat and there is no surface relief over the ice wedges. Consequently, construction machinery would have removed a uniform thickness of surfacial material during initial excavation activities. The depth of various ice wedges below the top of the excavation wall, therefore, reflects true differences in the relative depths of these ice bodies.

Stratigraphy

Four stratigraphic units were identified. An undetermined thickness of poorly to moderately well-sorted slightly gravely sand (Unit D) is partially exposed at the base of the section. Unit D, interpreted to be a deltaic sand deposit, contains abundant primary sedimentary structures, is devoid of shells, and has an average gravimetric moisture content of 15%. A poorly sorted gravely sand (unit C), 0.5 to 1 m thick, discontinuously overlies and in places underlies unit D. Unit C is massive to poorly stratified, has a moisture content of 17% by weight and is interpreted to be a coarse-grained deltaic sand and gravel similar to unit D. Overlying unit C and D is a 1-1.5 m thick gravel and sand matrix diamict (unit B). It contains convolution structures, and has a moisture content of less than 16%. Unit B is thought to be colluvium generated by gelifluction from the slope which averages 6° upslope from the reservoir site. Surface tundra vegetation and mineral soil, collectively called Unit A, was removed from the site prior to mapping. A textural comparison of units B, C, and D is given in Table 1.

Ground ice

The location and stratigraphic setting of 28 vertically oriented ice bodies observed at the reservoir are shown in fig. 2. These ice bodies, which include 8 ice veins, and 20 symmetrical, asymmetrical, and multi-stage ice wedges, are contained within units D and C, and in some cases, extend into unit B. Eight of the 9 symmetrical ice wedges were tapered with side angles ranging between 5° and 41° from vertical. The single symmetric ice wedge was nearly vertical with sides dipping at less than 5° from vertical. Seven ice wedges possessed asymmetrical forms with side angles differing by 10° to 20°. Ice examined in the field and laboratory contained abundant bubbles and sediment. Diffuse to well-developed angular folia, which often terminated part way down the side of the ice wedge, were observed. One ice wedge had up to 18 vertical bands of sediment. In addition, half of the ice wedges observed had angular truncated tops dipping between 10° and 20° from horizontal.

Multiple growth stages, like those shown in fig. 3, were evident in four ice wedges and are indicative of locally aggrading permafrost. Fig. 4 compares the depth of primary, secondary and tertiary ice wedge surfaces from eastern and western arctic sites. An inferred active layer attenuation of 10% to 40% for the Pangnirtung ice wedges is similar to western estimates (Mackay 1976, Harry *et al.* 1985). The much greater active layer thickness in Pangnirtung is due to a thin layer of insulating surface vegetation, and the sandy nature of the soils.

Two distinct levels of ice wedges were observed at mean depths of 0.98 and 1.68 m below the top of the excavation. The ice wedges in these groups (hereafter referred to as shallow "S" and deep "D" ice wedges) are shown in fig. 2. In general, these ice wedges are small and thin with mean maximum apparent widths of 0.75 m. In comparison, most

Table 1. Textural comparison of Units B, C, and D.

Unit	Number Samples	%Gravel mean	%Gravel Stand. Dev.	%Sand mean	%Sand Stand. Dev.	%Silt mean	%Silt Stand. Dev.	%Clay mean	%Clay Stand. Dev.
B	38	22.6	9.7	64.4	9.3	12.6	8.4	0.4	0.8
C	13	15.7	8.2	69.6	7.6	14.2	6.4	0.5	0.8
D	21	7.6	5.9	87.1	9.0	5.3	5.4	0.0	0.0

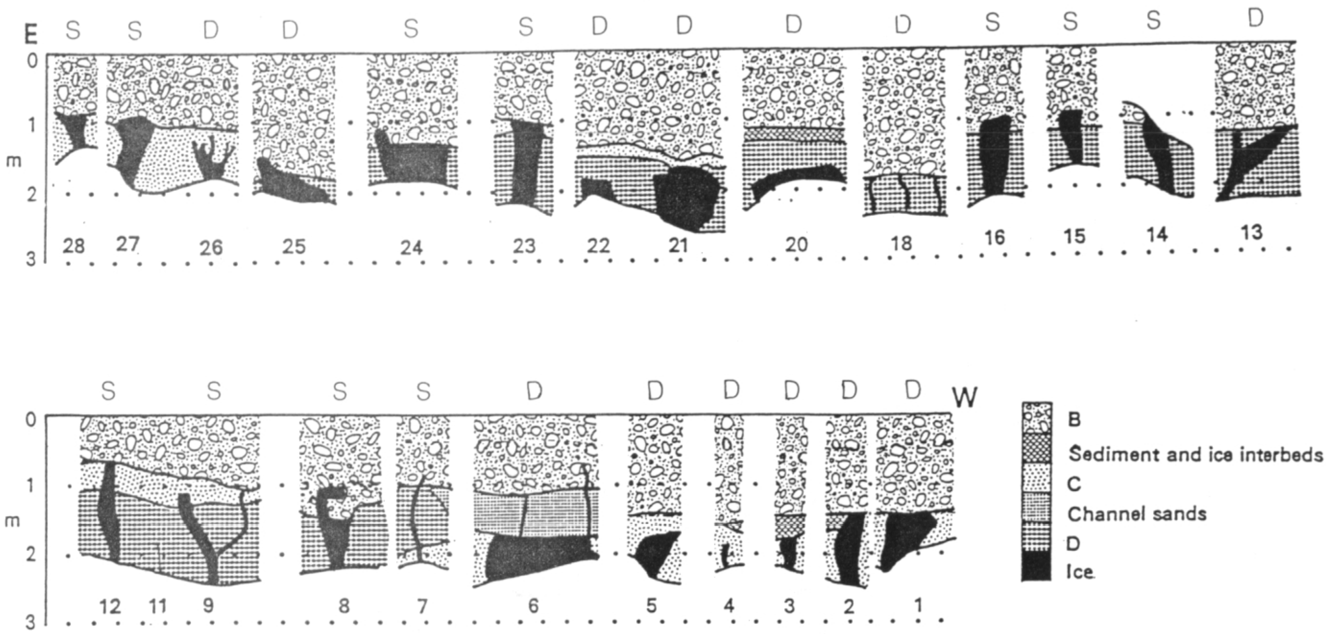

Figure 2. Stratigraphic setting of ice bodies mapped at the reservoir in 1986. Horizontal and vertical scale is the same. Classification of shallow (S), and deep (D) ice bodies refers to groups described in the text. B, C, and D refer to stratigraphic units described in the text.

Figure 3. Example of a multistage ice wedge (number 8 on figure 2). The short vertical marks around and above the ice wedge were produced by a hammer which was used to clean the section.

ice wedges reported in the western Arctic are larger (e.g. Harry *et al.* 1985). The shallow ice wedges lie at the base of the present active layer, while the deep ones exist well beneath the current active layer, implying that they are relict.

Ice wedge crystals were examined to help determine if the wedges were relict. Mean crystal sizes varied between 4.5 mm^2 and 10.5 mm^2 , with diameters ranging from 1 mm to 12 mm. The long axes of the crystals were most commonly oriented parallel to the foliation. C-axis orientation for vertically-oriented thin sections normal to the axial plane of 1 shallow and 2 deep ice wedges were examined under crossed Polaroids. The ice wedges display weak sub-horizontal to sub-vertical preferred orientations which are inclined away from the axial plane of the ice wedge. Strong horizontal and sub-horizontal fabric, typical of many ice wedges (eg. Pollard and Dallimore 1989), is not present. Corte (1962) suggests that vertical and inclined

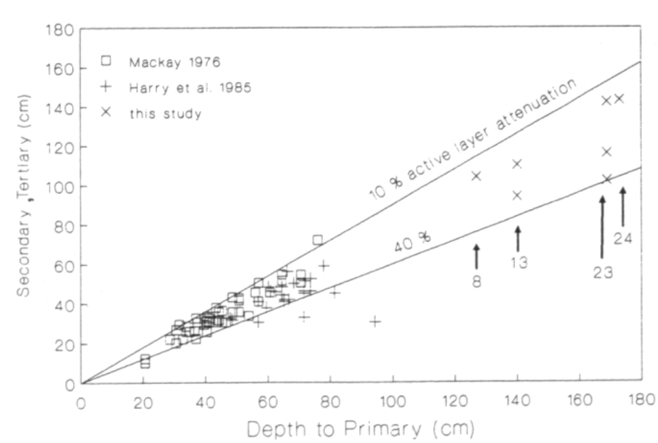

Figure 4. Comparison of the depth to primary, secondary and tertiary ice wedge surfaces in the eastern and western Arctic. Numbers refer to specific ice wedges shown in Figure 2.

fabrics may be the result of stress induced recrystallization during ice wedge growth. Similarly, Black (1978) indicates that recrystallization in buried "relict" wedges may produce more vertical fabrics. However, crystals in the Pangnirtung ice have been subjected to a variety of stresses including thermal erosion by surface streams and blasting during reservoir construction. Therefore, the presence of weak inclined fabrics in these ice wedges does not conclusively indicate that ice wedges are relict.

Thaw transformation and thermal erosional structures were observed above several ice wedges. For example, a local thermal erosional truncation of an ice wedge by a small surface stream is shown in fig. 5. The sharply truncated ice wedge is overlain by a coarse gravel lag and two fining-upward depositional sequences. Debris penetrating into the top of the ice wedge indicates that some thaw of the ice occurred prior to deposition. It seems most likely that a small surface stream was channelled along the ice wedge following a flood. As the flood subsided, material was laid down, thereby protecting and insulating the underlying ice. A more regional thaw event may be interpreted from a primary thaw transformation structure observed above ice wedge 21 at a depth of 1.6 m. Preservation of upturned sediment next to a thaw transformation structure, like that observed near ice wedge 21, implies a minor increase in thaw depth (Harry and Gozdzik 1988).

Interpretation

The ice wedges observed at the reservoir are contained within non-fossiliferous sediments which possess abundant primary sedimentary structures. This sediment package is interpreted as a raised deltaic fan which is an upstream equivalent of a lower elevation delta. The delta occurs at, and is contemporaneous with, the local marine limit which has been dated at 8690±90 years BP (Dyke 1979). The diamict overlying these units contains abundant convolution structures which incorporate sand from below. This together with the prevalence of gelifluction lobes on the present surface upslope from the reservoir suggest that the diamict is colluvium derived up slope and deposited by gelifluction. Therefore, the sediments and associated ice bodies in the immediate study area are no older than 8.7 ka B.P.

Ice wedges began to form within the sands and gravels shortly following deposition. Warm, wet conditions during the early Holocene (Dyke 1979), produced a thick active layer which truncated the ice wedges at a low level. As the sea level fell and the climate deteriorated (Dyke 1979), these deep ice wedges continued to grow. Wet periglacial conditions, associated with Cockburn glacial events (Andrews and Ives 1978), promoted colluvial transport of sediments from up slope areas onto the sands and gravels at the reservoir site. Small surface streams were subject to flooding due to the wet conditions. One such stream cut through the colluvium to erode and then deposit sands and gravels over ice wedge number 6 (fig's 2 and 6). Cooler conditions, following the Hypsithermal, together with a thickening layer of colluvium drew the permafrost table upward and promoted renewed ice wedge growth on some of the lower multi-stage wedges (numbers 8, 23, 24, and 28 in fig. 2). At some locations a new shallow level of ice wedges also began to form at this time. Alternating warm and wet, with cool and dry conditions during the late Holocene (Dyke 1979) resulted in fluctuations in active layer thickness. This produced thaw transformation structures over some of the ice wedges (wedge 21, for example). Continued active gelifluction has masked surface expression of the ice wedges even though the shallow ice wedges, which reside at the base of the present active layer may still be active. The deep ice wedges are found well below the present active layer and have inclined upper surfaces presumably due to slope creep since their formation. In addition,

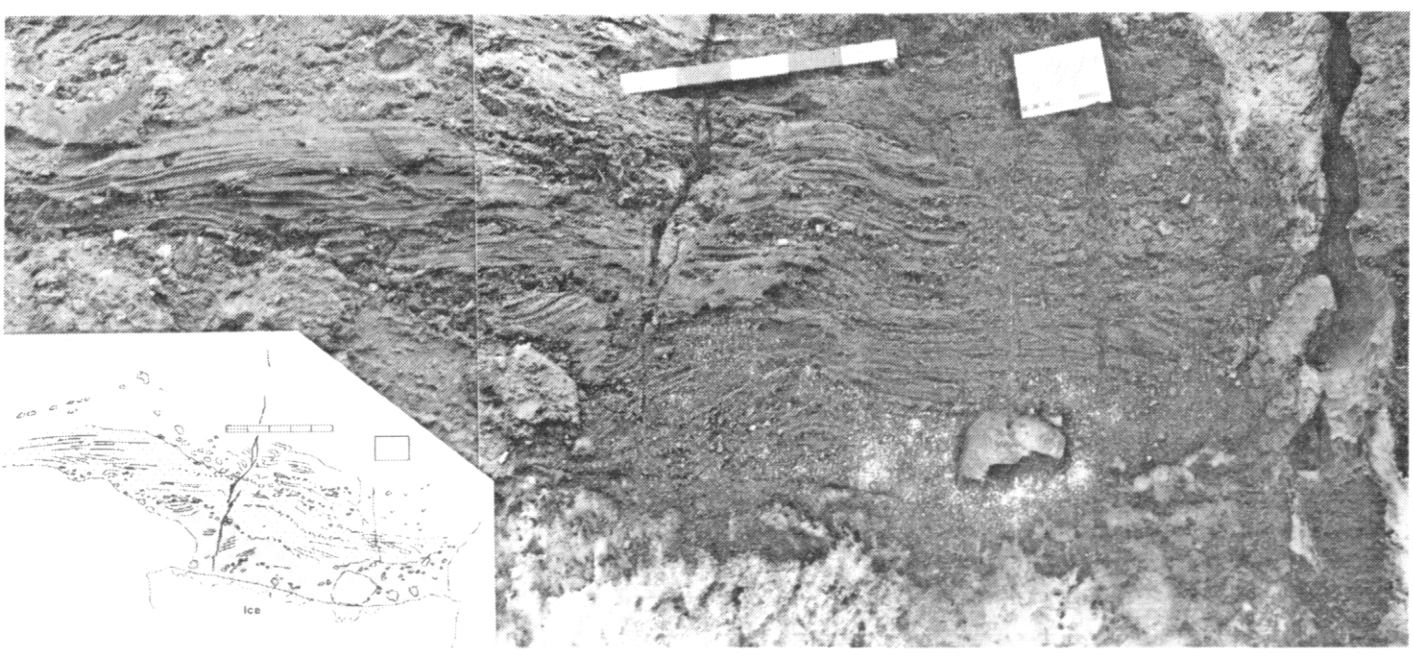

Figure 5. Evidence of thaw truncation of ice wedge 6 by a small surface stream. The stippled areas in the inset identify 2 depositional sequences which overly the truncated ice wedge.

inclined foliations and angled tops on many of the ice wedges indicate that they have been tilted and may be inactive.

Conclusions

Although ice wedges at Pangnirtung are smaller than those reported in the western Arctic, they are abundant, and their presence here suggests a widespread distribution in sedimentary environments of the eastern Arctic. The presence of 2 distinct levels of ice wedges, secondary growth veins, and thaw transformation structures indicates periods of permafrost aggradation and degradation which reflects Holocene climatic fluctuations. Morphologic and stratigraphic characteristics of the ice wedges suggests that the shallow ice wedges are active and the deep wedges are relict.

Acknowledgments

Research was supported by grants to Robert Gilbert from the Natural Sciences and Engineering Research Council of Canada, Indian and Northern Affairs Northern Scientific Training Grant, and the Government of the Northwest Territories Department of Highways and Public Works. Assistance in the field by M. Campbell (Reinders associates), C. DaSilva, N. Etoonak (Canadrill), R. Francoeur and E. Onraet (Tower Arctic Construction), M. Ikalukjuak, Parks Canada, and fellow Queen's students is greatly appreciated. The author wishes to thank Dr. Robert Gilbert and 2 anonymous reviewers for their constructive criticism of the paper.

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