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Article

The Investigation of Buried Snowbank Ice in Ice-rich Permafrost in Central and Northern Yukon, Canada

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Abstract

Ground ice forms an important component of perennially frozen ground where its significance relates to both the evolution of natural landscapes and problems associated with engineering activities. The interpretation of the origin of ground ice bodies, their physical characteristics and their distribution is an essential component of northern development in Canada. In the western Canadian Arctic the greatest emphasis in ground ice research has focused upon ice-wedge and massive segregated ice. Until very recently, buried surface ice has been given little consideration. This paper documents the range in stratigraphic and petrographic nature of ice bodies formed by the burial of snowbanks located in the Klondike area of north-central Yukon and the Yukon Coastal Plain.

1. Introduction

Ground ice is an important component of frozen ground and contributes significantly to the evolution and modification of periglacial landscapes (Harry, 1988). It is also a significant factor influencing engineering design and construction in areas underlain by permafrost (French and Pollard, 1986). The term *ground ice* is used to describe all types of frozen moisture occurring beneath the ground surface (Mackay, 1972). However, *massive ground ice* refers to bodies of ice with a gravimetric moisture content greater than 250% (percent sample dry weight). It displays a complexity of forms with each type distinguished by unique morphologic, structural and petrographic characteristics.

A genetic ground ice classification proposed by Mackay (1972), which modified earlier Soviet classificatons (*e.g.* Shumskii and Vtyurin, 1966 ; Shumskii, 1964), has gained widespread acceptance in North America. The absence of buried surface ice (*i.e.* glacier, sea, river, lake, icing and snowbank ice) is the major difference between this classification and similar Soviet classifications. In a recent article concerned with the field identification of ground ice, Mackay (1989) divides massive ground ice into two general categories, including : (1) buried ice and, (2) *in situ* ice. *In situ* ice is further defined as either epigenetic or syngenetic, depending on whether ice formation post-dates or is synchronous with sedimentation. It includes ice-wedge ice, intrusive ice, aggradational ice and a range of segregated ice forms. Buried ice is a generic category encompassing any form of surface ice occurring in permafrost that has been either buried in place or transported, deposited as part of a depositional sequence and preserved as the permafrost table aggraded upward into the new materials. The burial of surface ice is quite common, but its preservation is somewhat problematic.

Previously, buried glacier ice occurring in ice-cored moraines (Ostrem, 1963) was the only widely accepted example of buried ice in the North American Arctic. Suggestions of buried superimposed ice in the Tuktoyaktuk area (Fujino *et al.*, 1983) and buried glacier ice on Victoria Island (Lorrain and Demeur, 1985) have been met with controversy, although both present strong supporting arguments. However, in the Soviet Union buried glacier ice is widely recognized as a possible source of massive ground ice in permafrost (*e.g.* Astakhov and Isayeva, 1988) and is included in early Soviet ground ice classifications (*e.g.* Shumskii and Vtyurin, 1966).

To date, most ground ice research in Canada has been concerned with the origin and distribution of various forms of epigenetic ground ice, as reflected by Mackay's (1972) ground ice classification. The tentative identification of buried glacier ice in permafrost in a number of recent studies (*e.g.* Pollard, in press) and the possible widespread occurrence of buried snowbank ice (*e.g.* Pollard and Dallimore, 1987) raises serious questions concerning the significance of buried surface ice in ground ice studies. This paper describes the stratigraphic and petrographic characteristics of ground ice formed by the burial of snowbanks. Examples are taken from the Klondike Plateau near Dawson City and three locations on the Yukon Coastal Plain (Fig. 1). The sites selected include both glaciated and unglaciated landscapes.

The aim of this paper is to describe the range in stratigraphic and petrographic characteristics of ground ice derived from the burial and preservation of snowbanks in the Klondike and Yukon Coastal Plain areas, and to demonstrate how petrographic and cryostratigraphic analyses provide an effective tool in reconstruction of paleogeomorphic processes.

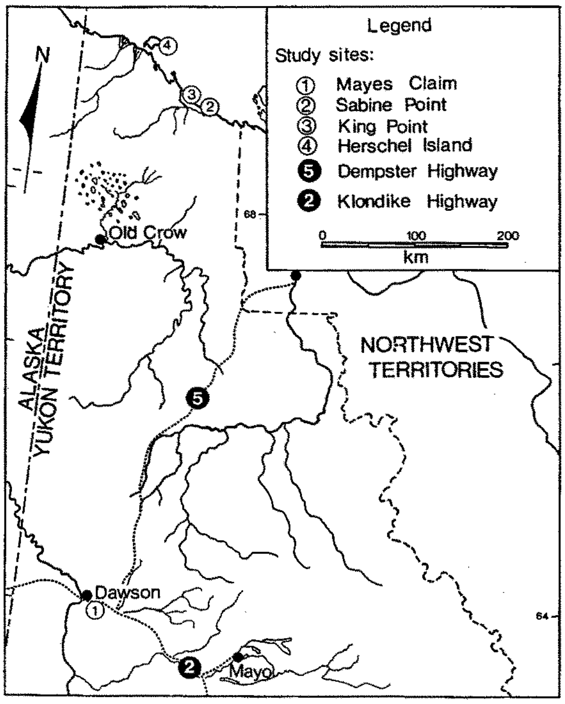

Fig. 1. Map of the central and northern portions of the Yukon Territory showing the location of the study sites ; (1) Mayes Claim, (2) Sabine Point, (3) King Point and (4) Herschel Island.

2. Study area

This study is concerned with massive ground ice in two areas in the Yukon Territory, Canada ; (1) the lower Hunker Creek area of the Klondike Plateau, 10 km east of Dawson City, and (2) the Yukon Coastal Plain at Sabine Point, King Point and Herschel Island (Fig. 1).

Klondike area - central Yukon :

Dawson City (64°03′ N ; 139°25′ W) is within the zone of widespread discontinuous permafrost. Maximum depth of permafrost is approximately 60 m (Judge, 1973). The mean annual air temperature at Dawson airport is −4.7°C. The area is characterized by a subarctic continental climate with very cold winters and warm summers, mean daily January and July temperatures are −28.6°C and +15.5°C respectively. Throughout the Quaternary, the Klondike Plateau remained unglaciated and permafrost aggraded to depths that are much greater than considered possible under current climatic conditions (French and Heginbottom, 1983). Numerous faunal remains preserved within the permafrost indicate that this area was part of the southeastern Bering refugium (Naldrett, 1981). Although the Klondike remained unglaciated during Quaternary time, pre-Reid glacial activity in the Ogilvie Mountains provided materials for the Klondike gravels and windblown silt that later became incorporated into ice-rich muck deposits covering valley sides and floors. Ground ice is a common constituent of frozen muck deposits, this is evident in placer mine operations like the "Mayes Claim" on the lower part of Hunker Creek (Fig. 2).

Yukon Coastal Plain - northern Yukon :

The Yukon Coastal Plain forms a narrow band of dissected and hilly tundra between the Beaufort Sea and the Barn/British Mountains. It is locased within the zone of continuous permafrost which is at least 300 m deep (Rampton, 1979). The mean anuual air temperature is approximately −11.0°C, while mean daily January and July temperartures are −29.0°C and +7.2°C respectively. Most of the coastal plain east of the Firth River was glaciated by the Mackenzie lobe of the Laurentide ice sheet as it moved west from the Mackenzie Valley during the Buckland Glaciation (early Wisconsin). Herschel Island is interpreted as an ice-thrust moraine formed as the Mackenzie lobe impinged on the Yukon coast. West of the Firth River the coastal plain remained unglaciated. During

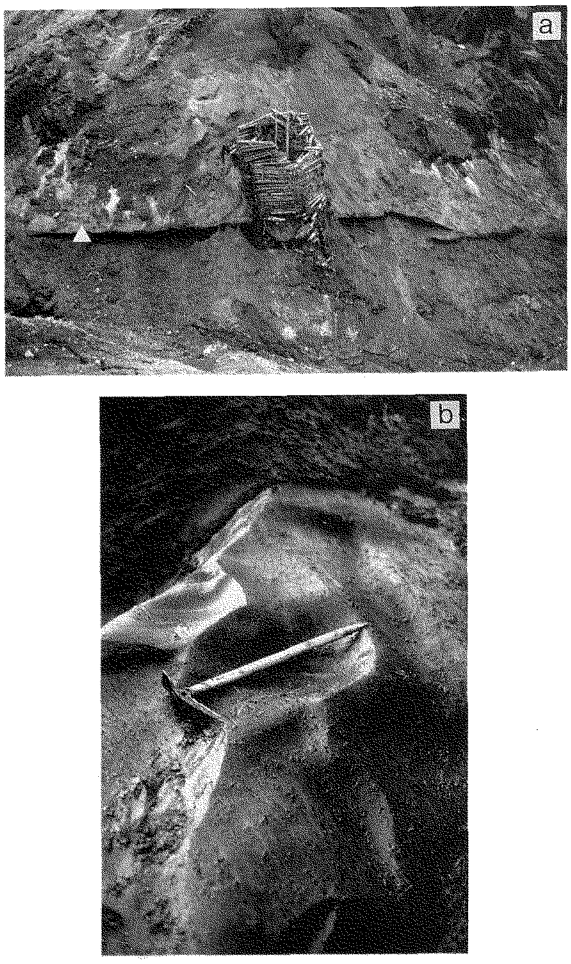

Fig. 2. Photos showing the position and nature of massive ground ice at the Mayes Claim in the Klondike area.

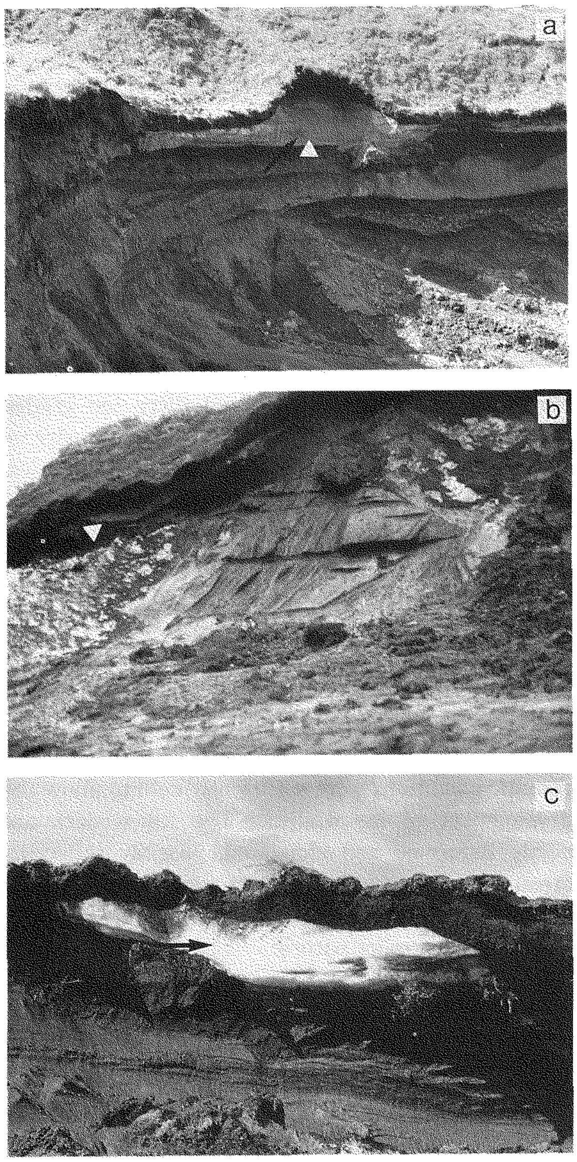

Fig. 3. Photos of ground ice sections at (a) Sabine Point, (b) King Point and (c) Herschel Island on the Yukon Coast.

deglaciation a major stillstand or readvance, termed the Sabine Phase, constructed a moraine-outwash complex parallel to the coast. Bodies of massive ground ice and large ice wedges are common in fine-grained moraine sediments corresponding with the Buckland and Sabine limits. Massive ground ice outcrops in several locations along the Yukon shoreline, including : Sabine Point, King Point, Kay Point, Stokes Point and Herschel Island (Fig. 3).

3. Cryostratigraphy

One approach to the study of ground ice is the analysis of cryostratigraphic and petrographic characteristics (*e.g.* Fujino, 1988 ; Gell, 1978 ; Kinosita, 1978 ; Pollard and Dallimore, 1988 ; Pollard, in press). This approach assumes that the pattern of permafrost and ground ice aggradation is related to : (1) the range in glacial and post-glacial geomorphic processes and depositional environments, (2) its thermal history, and (3) the source and mechanisms of water movement during ice formation (French and Pollard, 1986). The combination of petrographic analyses with cryostratigraphic observations can provide the basis for deductions about the nature and origin of ground ice bodies (*e.g.* French and Pollard, 1986 ; Harry *et al.*, 1988).

Klondike area :

Near Hunker Creek, buried snowbank ice occurs approximately 10-15 m below the ground surface (French and Pollard, 1986). Vertical sections produced by hydraulic placer mining of low-level terraces frequently expose ice-rich muck and fluvial gravel sequences overlying weathered bedrock. At the Mayes Claim (Fig. 2A), a 30 m section consists of a basal bedrock unit overlain by 2-3 m of coarse fluvial sand and gravel and 4-5 m of icy silt and dirty ice. This unit is overlain by 2-3 m of brown to milky white massive ice (Fig. 2B) which is interpreted as buried snowbank ice. The icy silt and dirty ice grades upward into the massive ice unit. The remainder of the exposure consists of muck deposits 10-15 m thick and a surface unit of interbedded sand, gravel and peat. Ice wedges occur in an upper muck unit.

In this section, buried snowbank ice represents a thick perennial snowbank that occurred at the base of steep valley slopes and was subsequently buried by slumping muck depisits. A long period of colluvial activity covered the ice with several metres of muck containing large blocks of peat and faunal remains that date greater than 40,000 years BP. During burial climatic conditions were sufficiently cold to allow the development of ice wedges. The ice wedges are highly deformed and elongated, possibly reflecting creep based deformation or syngenetic growth. Their burial under several metres of muck clearly indicates their relict nature.

Yukon Coastal Plain :

The buried snowbank ice bodies at Sabine Point, King Point and Herschel Island (shown in Fig. 3A, 3B and 3C respectively) occur within stabilized retrogressive thaw slumps buried beneath mudflow/diamicton deposits up to 1.5 m thick. The King Point site is described in Pollard and Dallimore (1988). In each case, it occurs as a layer of opaque whitish to pale-brown ice 1-2 m thick exposed in the headwall of a polycyclic retrogressive thaw slump. The ice unit usually occurs high in the stratigraphic section and is always associated with diamicton or mudflow deposits. The ice is unconformably overlain by 1-1.5 m of fine grained diamicton and peat. The overlying sediments have ice contents ranging between 37 and 129% on a dry weight basis. The highest ice contents are in sediments immediately overlying the ice body and occur as thin discontinuous ice lenses oriented roughly parallel to the ice-sediment contact. The upper contacts are abrupt and irregular, and in places blocks or stringers of sediment and peat are incorporated into the upper part of the ice. Large gas inclusions truncated by the upper contact are sediment filled. Sediment content in the ice averages less than 1% ; however, concentrations as high as 7% occur in the upper 10-15 cm of the ice body. The lower contacts are also abrupt and unconformable but are generally more regular in nature. Sediment inclusion content is lowest near the lower contact. The snowbank ice unit is underlain by 0.4-2.0 m of mudflow deposits which are sometimes underlain by thick massive ground ice. Radiocarbon dates for peat and detrital wood beneath the snowbank ice at King Point date 100-120 years BP. This evidence suggests that active thermokarst of massive segregated ice approximately 100 years ago was responsible for the burial of a series of snowbanks situated either at the base of the headwall or on the floor of retrogressive thaw slumps. They were buried by a sufficient volume of peat and sediment that permafrost aggraded upward into the new deposit thus preserving it. The absence of distinct layering or sediment bands suggest that these are probably not perennial snowbanks but a single seasons accumulation.

4. Snowbank ice characteristics

Massive ground ice formed by the burial and refreezing of snowbanks tend to appear as irregularly-shaped, horizontally-foliated bodies or layers of opaque white or pale-brown ice (Fig. 4). The layered appearance is the result of alternating bands of bubble-rich and clear ice, as well as the presence of thin sediment layers. The ice from Hunker Creek contains a fine suspension of randomly distributed organic and silt particles. Snowbank ice from Kay Point contains fragments of arctic willow and small amounts of pollen. The internal layering is parallel to the lower contact. The shape and extent of the ice mass seems to be related to the topographic setting controlling the original snowbank accumulation and the subsequent burial process. The unconformable nature of upper and lower contacts reflect a zone of melting and refreezing. The lower contacts observed in both the Klondike and Yukon Coastal Plain dip upward into the ice face at angles from 7° to 11° and are believed to reflect the side valley slope or the slope of the thaw slump floor.

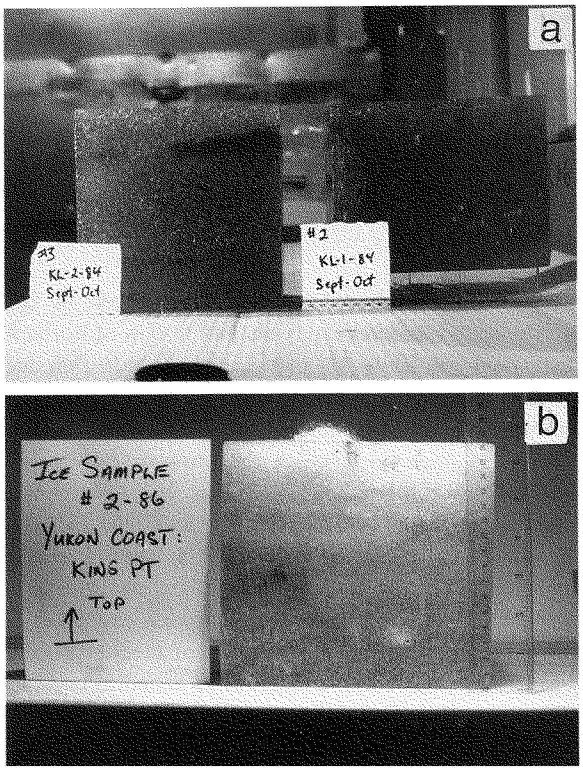

Fig. 4. Oriented block samples from (a) the Mayes Claim and (b) King Point.

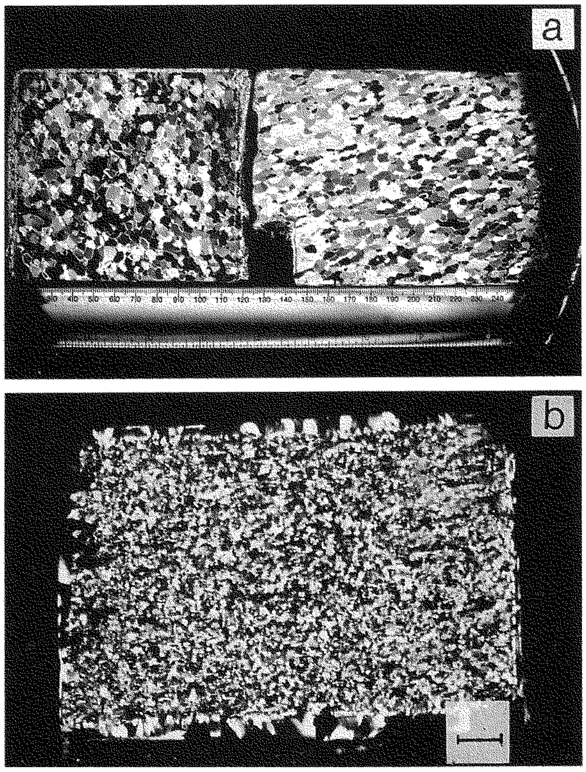

Fig. 5. Thin sections of buried snowbank ice from the (a) the Mayes Claim, Klondike District and (b) Herschel Island, Yukon Coastal Plain.

5. Petrography

Texture

The stratigraphic position of the ice, together with the age of the enclosing sediments, indicate that the buried snowband ice along the Yukon coast is considerably younger than snowbank ice from the Hunker Creek in the Dawson City area. Klondike snowbank ice is composed of vertically-elongated crystals (L : W ratios of 1.5 to 3.0) averaging 25 mm long oriented roughly perpendicular to the steeply dipping internal layering. Crystal size and shape are constant through the ice unit. Gas inclusions form 2 distinct patterns: (1) small spherical bubbles (<10 mm in diameter) dispersed randomly through the ice body with slightly higher concentrations near sediment bands, and (2) long (up to 15 mm), vertically-oriented tubular bubbles that cut across the steeply dipping sediment bands. Sediment inclusions occur as thin discontinuous bands of fine silt-sized organic material and as a fine suspension of silt through the entire unit.

By comparison, snowbank ice at King Point and Sabine Point is composed of small crystals averaging 1-3 mm long with maximum lengths of 3-5 mm. Crystals are slightly elongated (L : W ratios range between 1.2 and 1.8) in a vertical to sub-vertical direction. This reflects the influence of heatflow and percolation of water during recrystallization. Crystal shapes are predominantly euhedral to subhedral with short straight boundaries. Crystal size is constant through the ice unit with little change at either contact or at sediment bands (*i.e.* no chill zone characteristic of massive segregated or intrusive ice). A thin layer of superimposed ice occurs in several places at the upper contact. Gas and sediment inclusions are predominantly intercrystalline (>82%). Gas inclusions range from small spherical and flat bubbles (<1 mm in diameter) to thin, vertically-oriented tubular and irregularly-shaped bubbles up to 25 mm long. The long axes of these bubbles are aligned roughly normal to sediment layering.

Ice fabrics

Fabric diagrams of c-axis orientations are based on standard universal stage techniques and analysis of vertical thin sections. Fabric patterns for Klondike snowbank ice display vertical to steeply dipping point maxima and a secondary maximum forming a loose girdle inclined 20-30° to the horizontal (Fig. 6A and B).

For ice from the Yukon coast the primary fabric is characterized by a random pattern of c-axes (Fig. 6F) with weak secondary maxima (6-7%) oriented normal to the internal layering (Fig. 6C, D, and E).

These textures and fabrics are believed to primarily reflect the crystalline characteristics of the original snowbank. The horizontal layering, suspended sediment, occasional leaf or twig fragment and contact characteristics illustrate the depositional nature of the snowbank and the accumulation of windblown detritus. The vertically-oriented bubbles and secondary c-axis maxima suggest post-depositional modification, probably due to compaction and recrystallization.

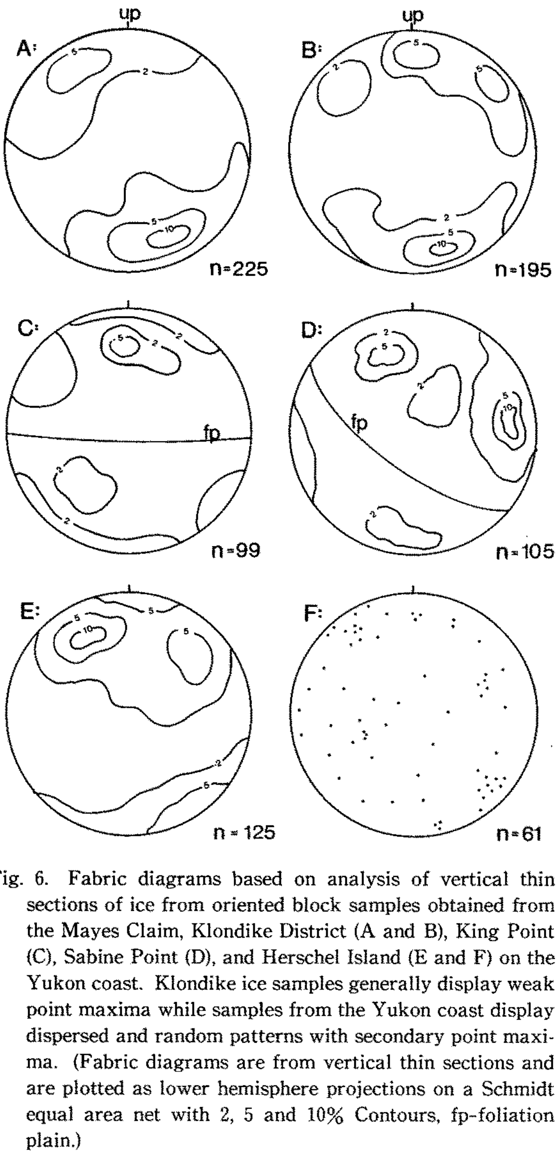

Fig. 6. Fabric diagrams based on analysis of vertical thin sections of ice from oriented block samples obtained from the Mayes Claim, Klondike District (A and B), King Point (C), Sabine Point (D), and Herschel Island (E and F) on the Yukon coast. Klondike ice samples generally display weak point maxima while samples from the Yukon coast display dispersed and random patterns with secondary point maxima. (Fabric diagrams are from vertical thin sections and are plotted as lower hemisphere projections on a Schmidt equal area net with 2, 5 and 10% Contours, fp-foliation plain.)

6. Discussion

The buried snowbank ice documented in this study occurs as irregularly shaped bodies of horizontally-layered white to pale-brown bubble-rich ice. The upper and lower contacts of the ice body are abrupt and unconformable. The lower contact reflects the slope upon which the snowbanks were deposited. In the Hunker Creek area they formed near the base of valley sides. At King and Sabine Points the snowbanks were deposited at the base of retreating headwalls in retrogressive thaw slumps. The upper contact reflects the burial process and a period of melting. The ice is composed of medium to fine-grained equigranular subhedral to euhedral crystals. However, older and deeper ice bodies in the Klondike tend to contain larger and vertically elongated ice crystals. They also display stress induced structures including curved crystal boundaries, boundary dislocations and vertically-oriented tubular bubbles. Younger ice bodies are fine grained with distinct banding. Crystal c-axis orientations range from random or weak vertically-oriented girdles in young snowbank ice to stronger vertical to sub-vertical maxima for older bodies. The latter also develop secondary maxima probably associated with thermal or stress histories. Buried snowbanks may provide useful paleoenvironmental information and if widespread, may be recognized as cryostratigraphic markers.

Based on field studies in central and northern Yukon, the following conclusions can be made.

(1) Snowbank ice is a distinct and common component of ice-rich permafrost in areas where either thermokarst or mass wasting processes have rapidly buried seasonal or perennial snowbanks by a layer of sediment equal to, or greater than, the depth of seasonal thaw.

(2) The petrographic texture and fabric of snowbank ice clearly reflects the crystalline nature of the original snowbank. The degree of metamorphism and recrystallization is a function of depth and time of burial.

(3) The petrographic and stratigraphic study of buried snowbanks, together with analysis of ice chemistry, environmental isotopes and included materials (pollen and macrofossil) may provide a useful approach to reconstruction of past permafrost environments.

(4) Buried surface ice should be included in any subsequent North American ground ice classification.

Acknowledgments

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