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GROUND ICE INVESTIGATIONS, KLONDIKE DISTRICT YUKON TERRITORY

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Earth Physics Branch Open File Number 85-12
Dossier public de la Direction de la Physique du Globe No. 85-12

Department of Energy, Mines and Resources Canada
Earth Physics Branch
Division of Gravity, Geothermics and Geodynamics

Ministre de l'Energie, des Mines et des Ressources du Canada
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ABSTRACT

The origin of massive ground ice in the Klondike District, Yukon Territory is examined in an exposure in the Hunker Creek area. Stratigraphic and ice cryotexture data and ice petrofabric analyses suggest that a segregation origin is not appropriate for the massive clear ice body (1 - 3 m in thickness). A residual snowbank origin is considered and found to be the most consistent with the nature of the body.

RÉSUMÉ

L'origine de la glace massive dans le district du Klondike, Territoire du Yukon est examinée dans un affleurement de la région de Hunker Creek. La stratigraphie, les données sur la cryotexture et les analyses de la pétrologie structurale de la glace suggèrent que cette glace massive d'une épaisseur de 1 - 3 m n'a pas une origine de ségrégation. Un banc de neige résiduelle est proposé comme origine possible puisque celui-ci aurait les traits les plus conformes à la nature de la glace.

GROUND ICE INVESTIGATIONS, KLONDIKE DISTRICT

YUKON TERRITORY

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Contract Report OST84-00238, prepared for Earth
Physics Branch, Energy, Mines and
Resources, Ottawa.

January 1985

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1. INTRODUCTION

Ground ice occurs throughout the permafrost regions of the central and northern Yukon. It is an important factor influencing the design and performance of many engineering and geotechnical structures.

In a previous contract (French, Pollard and Burn, 1984) permafrost and stratigraphic studies were undertaken in the Mayo area at a locality where ice-rich permafrost is exposed. Field mapping of ground ice cryotextures was followed by ice crystallographic and fabric analyses performed in a cold room at Ottawa. It was concluded that the ground ice was of a segregated origin and reflected periods of subaqueous syngenetic freezing beneath thaw lake basins, in which the direction and rate of heat flow varied both spatially and temporally. Based on ice crystallography, the ground ice at the Mayo locality was quite distinct from other known ground ice bodies, such as pingo ice (e.g., Gell, 1978a), icing ice (e.g., Pollard, 1983) and ice wedge ice (e.g., Gell, 1978b).

Elsewhere in the central Yukon, substantial ground ice bodies are known to exist, especially in active placer mining operations in the Klondike District.

These localities provide further opportunities to examine the origins of ground ice in this region.

2. WORK SCHEDULE

Fieldwork was undertaken between September 20 and October 8 in the Hunker Creek area of the Klondike (Figure 1) where active placer mining operations are exposing substantial bodies of massive ground ice in muck deposits. Attention focussed upon the Mayes Claim, on the west side of Hunker Creek (Figure 2A, B). Previous information upon this locality can be obtained from reports by Hughes et al (1972), Hughes and van Everdingen (1978), Naldrett (1982) and French and Heginbottom (1983, pp. 35-63). Stratigraphic sections were measured and sediment samples collected for sedimentological analysis. Two oriented block samples of massive ice were cut, using a chain saw in the manner described and illustrated in the previous contract report. Additional ice samples were collected for possible isotope analyses by Dr. F. Michel, Carleton University. During late October and the first half of November, standard ice petrofabric analyses were carried out in the coldrooms of The Division of Building Research, National Research Council of Canada, Ottawa. The aim was to establish the dimensions, form and orientation of ice crystals in order to determine their growth history.

3. SITE INVESTIGATIONS

3.1 Quaternary History

Throughout Quaternary time, the Klondike District remained unglaciated (see Figure 1), and relict permafrost is widespread (Hughes et al, 1983). Numerous faunal remains preserved within the permafrost indicate that the area was part of the southeastern Bering Refugium. As a result, the topography is distinctly non-glacial (French and Heginbottom, 1983, p. 36). Valleys possess a characteristic V-shaped cross profile, often with a high level bench or terrace which suggests a history of multicyclic valley development. Intervening ridges have uniform elevations and are presumed to be remnants of an old uplifted erosion surface (Templeman-Kluit, 1980). Typically, the ridges converge into domes or groups of relatively smooth-sloped mountains.

The presence of extensive auriferous gravels of late Tertiary or early Quaternary age is the reason for numerous placer mining operations, both during and subsequent to the Klondike Gold Rush of 1896-1898, and in the last fifteen years. The gravels can be divided into valley, creek and terrace gravels (McConnell, 1905), and the latter can be subdivided into White Channel Gravel (oldest), Yellow Gravel and Klondike Gravel (youngest).

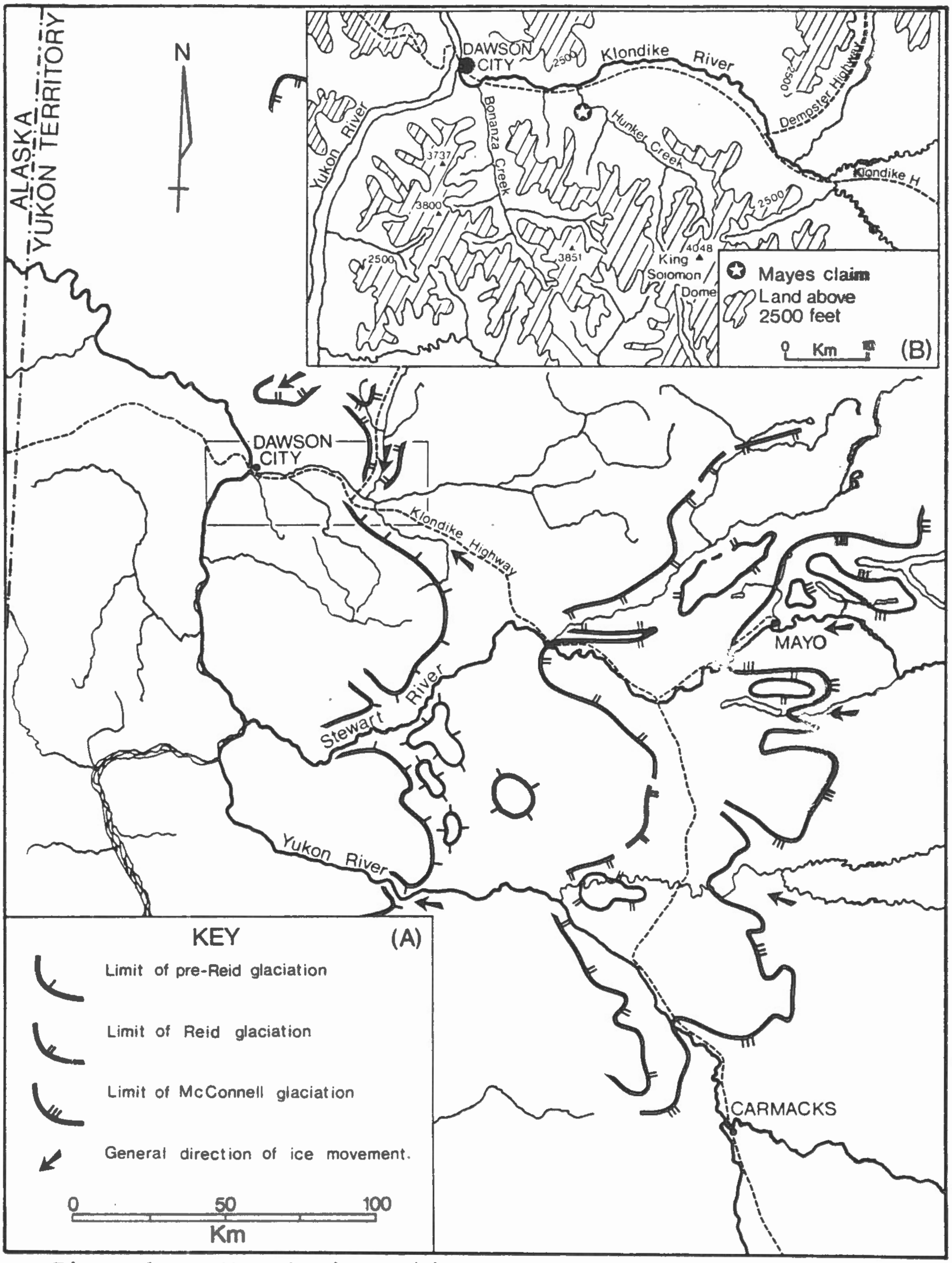

Figure 1. Map showing: (A) Location of Klondike District and central Yukon glacial limits after Hughes (1969) and Hughes et al (1983). (B) Location of Mayes Claim, Hunker Creek.

Although the area remained unglaciated throughout Quaternary times, it is probable that the pre-Reid glaciations to the south provided source material for the Klondike Gravel and for the wind-blown silt that later became incorporated into the ice-rich muck deposits covering the valley and creek gravels. During the late Pleistocene time, the main Klondike valleys were repeatedly infilled by clastic sediments that varied in amounts and physical characteristics with climatic cycles. Because of the cold climate prevailing at the time, permafrost aggraded into these sediments and massive icy bodies formed, especially ice wedges. The enclosing sediments are usually silty, having originated as lacustrine silt or silty windblown deposits and colluvium, and typically contain organic and faunal remains (Harington, 1978; Harington and Clulow, 1973). A similar erosional history of downcutting in late Tertiary-early Quaternary times followed by repeated infilling of valleys during late Quaternary times is found in unglaciated central Alaska (e.g., Péwé, 1975; 1977).

3.2 Local stratigraphy - Mayes Claim

The Mayes Claim, located on the south-west side of Hunker Creek near the junction of the Hunker and Klondike Valleys, is a placer mining operation extracting creek gravels found on a low bedrock terrace.

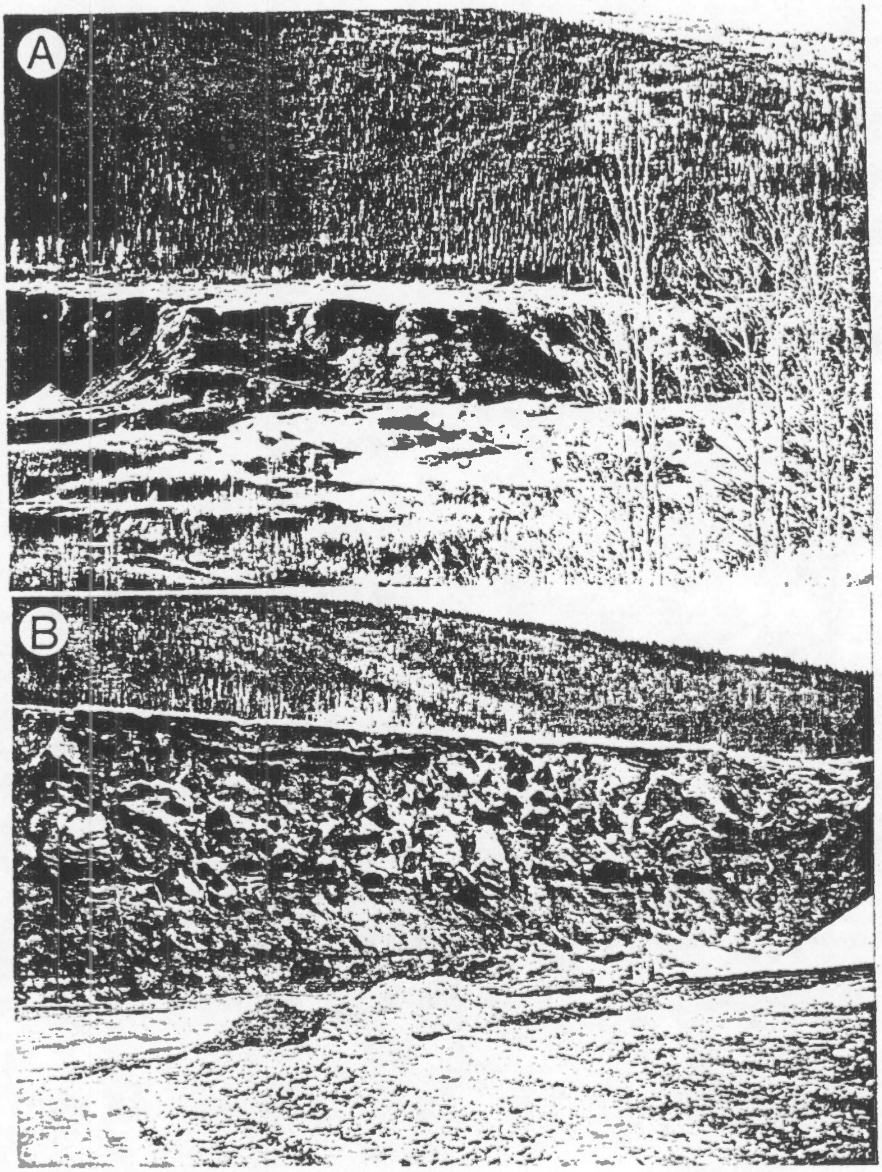

Figure 2. Mayes Claim exposure, September 1984. (A) View looking north of low level terrace on Mayes Claim in Hunker Creek. (B) Exposure at Mayes Claim showing 15-20 metres of muck deposits overlying creek gravels and bedrock.

Approximately 20-30 metres of frozen ice-rich organic muck must be removed before the gold-bearing gravels are exposed.

Through hydraulicking and stripping activities a permafrost exposure up to 35 metres in height and over 80-100 metres long had been created in September 1984. Based on two measured sections (Figure 3) the following stratigraphic sequence was identified:- At the base of the section (Figure 4A), 1.0-3.0 metres of in situ and shattered chlorite schist and shaley bedrock are exposed (unit #1), overlain by between 2.0-3.5 metres of medium to coarse fluvial quartz gravel and sand (unit #2). A layer of organic-rich silty (dirty) ice from 4.0-5.0 metres thick (unit #3) overlies the gravel unit (Figure 4B) and is subsequently overlain by 2.0-3.0 metres of massive, clean ice (unit #4). The dirty ice grades into, and is locally interlayered with, the clean ice. The remainder of the exposure consists of muck deposits (units #5 and 6), 10.0-15.0 metres thick in total, overlain by 2.0-3.5 metres of interbedded sand, gravel and peat (unit #7). The contact between the massive ice and the overlying muck is abrupt (Figure 4C). The upper muck unit (#6) contains large relict ice wedges.

Attention focussed upon the silty ice unit (#3) and the overlying massive ice body (unit #4).

The silty ice unit was partially obscured by debris at the time of fieldwork in late September 1984.

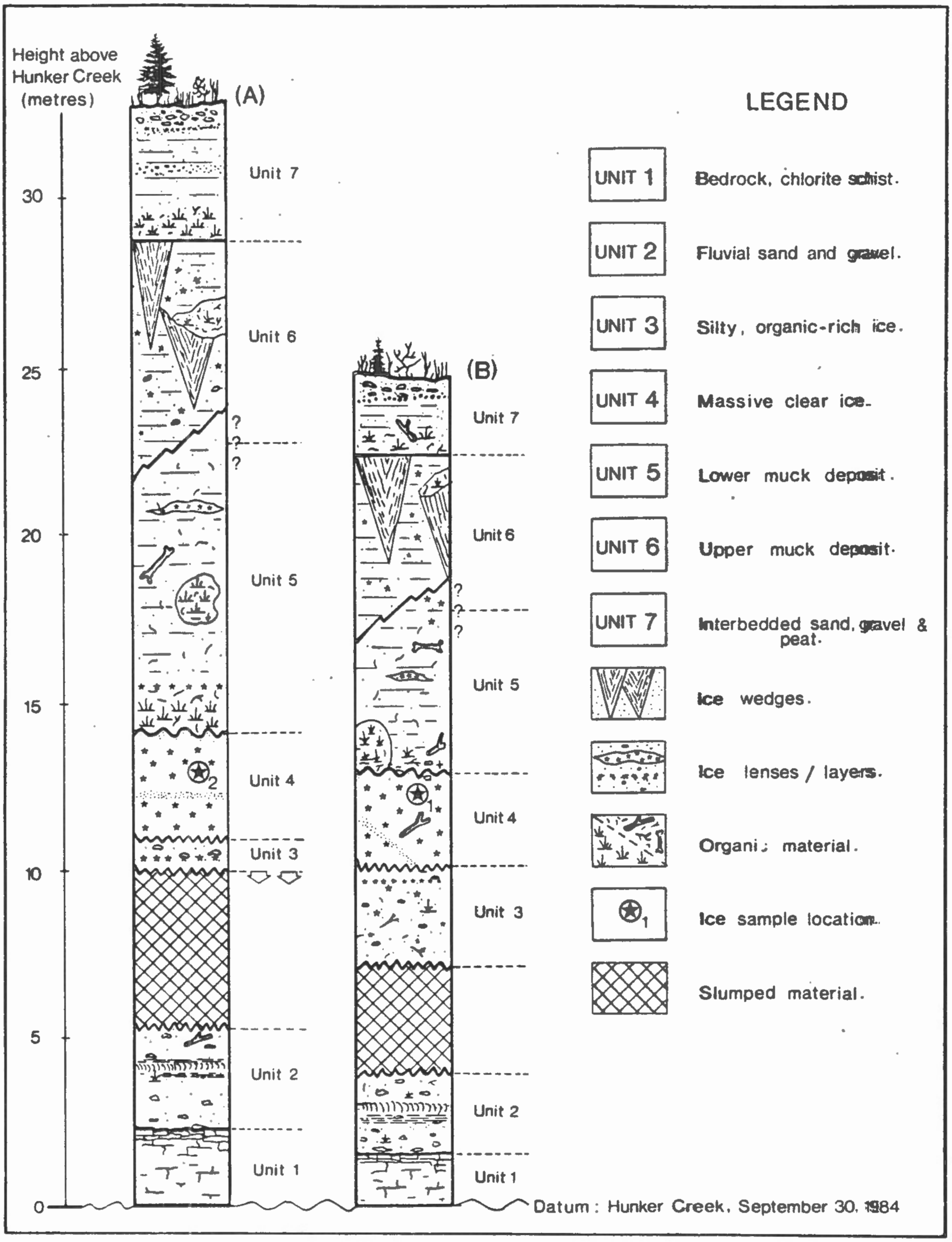

Figure 3. Two detailed stratigraphic sections illustrating relationships between ground ice bodies and enclosing sediments, Mayes Claim, Hunker Creek.

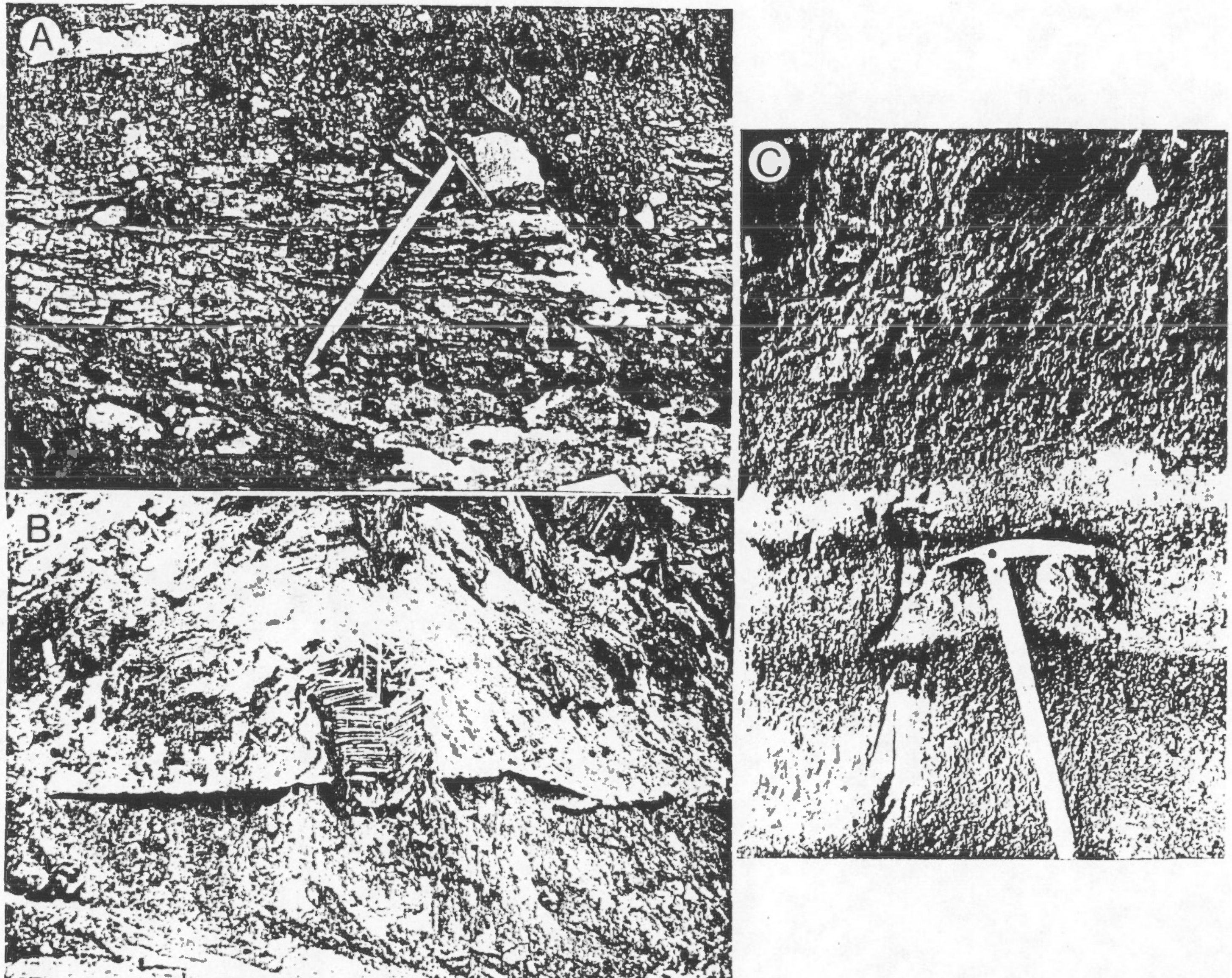

Figure 4. Photographs showing sediments and stratigraphy at Mayes Claim, September 1984. (A) Chlorite schist bedrock is overlain by auriferous creek gravels. (B) Massive ice and icy sediments (units #3 and #4) overlie the creek gravels and bedrock. Note undercutting of icy sediments by Hunker Creek and old mining shaft currently exposed. (C) Upper contact of massive ice (unit #4) with overlying muck deposits. Note the cobble within the ice and the coarse layering of the ice body.

The contact with the underlying creek gravels was irregular and transitional in nature. The ice content was high varying between 60-80% ice by volume. Stratigraphically, the unit was characterised by distinct bands of almost pure ice (10-27 cm thick), and organic silt (10-20 cm thick) with discontinuous layers and pods of peat. Large angular cobbles (clast sizes up to 35 cm in diameter) occurred throughout the unit.

The silty ice unit graded, with decreasing silt and organic content, into a massive ice body (Figure 5A). This unit varied between 1.0-3.0 metres in thickness across the exposure. Numerous sediment and organic inclusions occurred throughout the ice, as did large angular cobbles. The ice was translucent and grey or pale brown in colour due to a high bubble inclusion content and a suspension of fine sediment. In places the ice had a foliated appearance resulting from thin, discontinuous layers of fine settlement. The upper contact with the overlying muck deposits was abrupt and highly irregular in nature (see Figure 6A). In places, some interlayering between the ice and the overlying muck deposits was observed.

The muck deposits, which constitute the majority of the exposure at Mayes Claim, are only briefly described in this report. It is generally believed that Yukon muck, of which there are numerous sub-facies

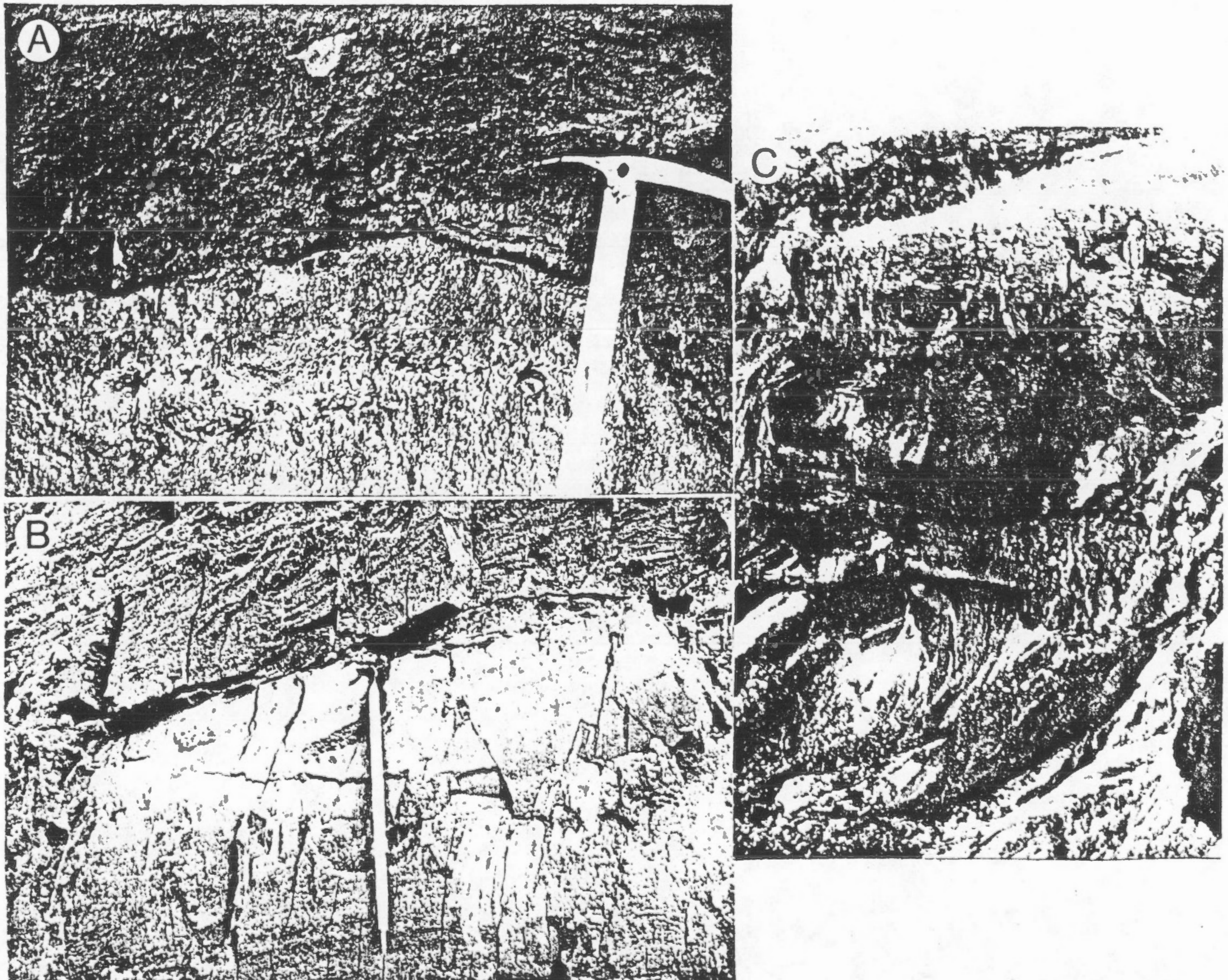

Figure 5. Photographs showing sediment and stratigraphy at Mayes Claim, September 1984. (A) Massive ice (unit #4) shows abrupt contact with overlying muck deposits. (B) Lower muck deposits (unit #5) consist of structureless silty sands containing organic fragments, and sub-horizontal segregated ice lenses. (C) General view of upper muck deposits (unit #6) containing ice wedges, and overlain by sand, gravel and peat.

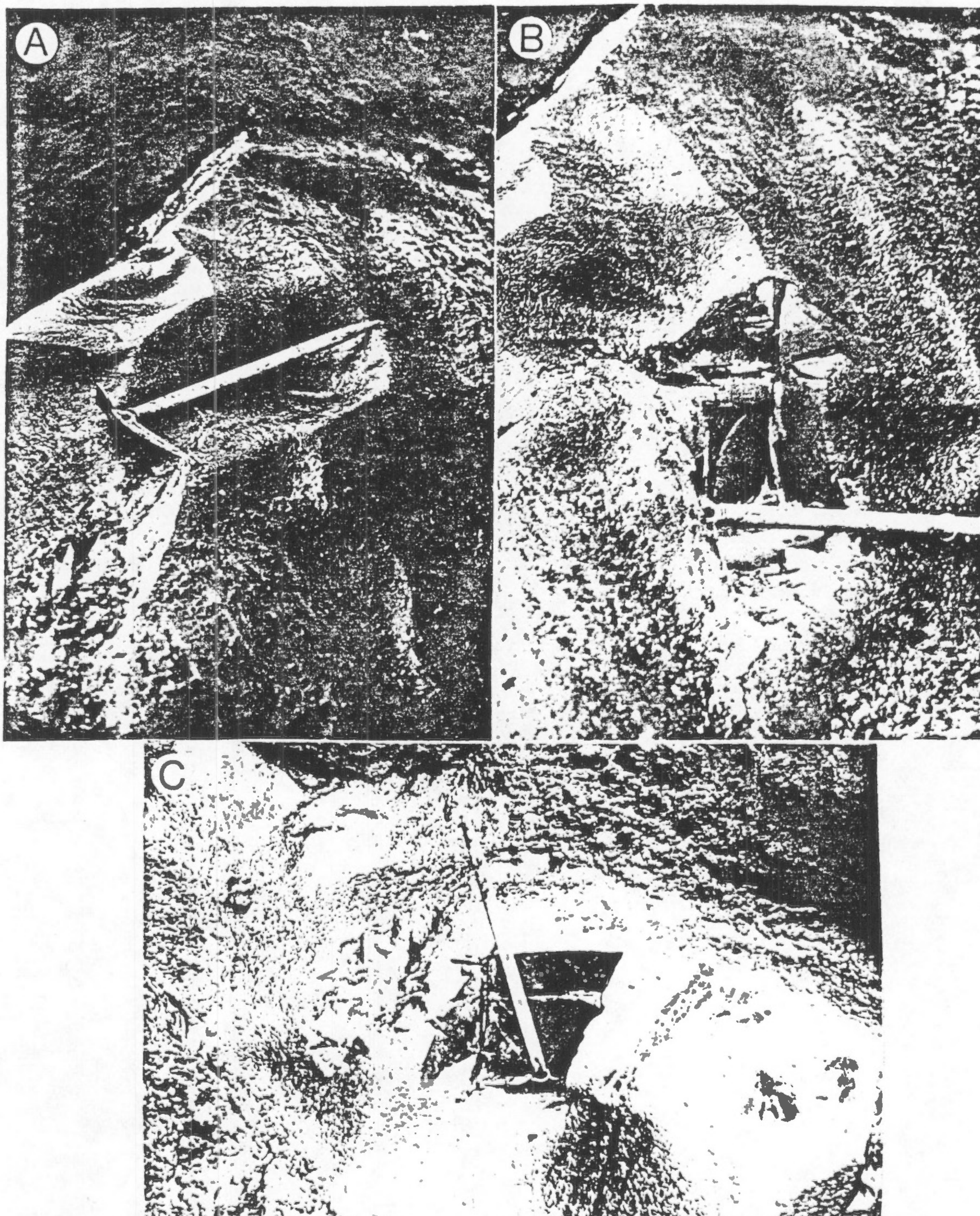

Figure 6. Massive ice (unit #4), Mayes Claim exposure, September 1984. (A) Upper portion of massive ice showing contact with overlying muck deposits. (B) Site of extraction of ice sample #1. (C) Site of extraction of ice sample #2.

(Naldrett, 1982) is derived from the mixing of wind-blown silt with slope colluvium which has mass-wasted (i.e., soliflucted) into the valley bottoms incorporating peat and other organic remains. The lower muck unit (unit #5) is composed of dark grey, brown and black organic-rich silt, containing layers of coarse sand and gravel (Figure 5B). A peat and organic layer, containing well preserved root fibres, wood fragments and branches, occurs at the junction with the underlying massive ice.

The upper muck deposit (unit #6) is differentiated from the lower unit primarily on its ice content. The upper muck unit contained a system of large inactive ice wedges, 1.0-3.0 metres wide and up to 4.0 metres deep (Figure 5C). The enclosing sediments were also ice-rich (between 30-80% by volume) and contrasted with the lower muck unit (#5) which typically contained only 30-50% excess ice.

4. ICE PETROGRAPHY

Two oriented block samples of massive ice were obtained from unit #4 and subjected to standard petrographic analyses. Sample locations (Figure 6B, C) were determined by ice purity, access to the face and safety. Ice sample #1 came from the face adjacent to stratigraphic profile B, while ice sample #2 was from the vicinity of profile A (see Figure 3). Both samples are from the mid to upper portion of the unit.

4.1 Ice description

In general, both samples (Figure 7A, B) appeared translucent to cloudy and milky grey/brown in colour. This was due to suspension of fine sediment and a high bubble content. For example, ice sample #1 was roughly 20.0 cm x 19.0 cm x 16.0 cm in dimensions (Figure 7A). Concentration of small spherical bubbles and fine sediment produced a banded or layered appearance. The layering was inclined approximately 30° upward across the face of the block and approximately 25-30° into the block. This translates into a definite dip across the face of the section and towards the present valley floor.

Gas inclusions formed two distinct patterns. First, small (<1.0 mm in diameter) spherical bubbles, without layering or bubble train development, occurred throughout the ice but were more numerous adjacent to sediment bands. A second bubble type consisted of long (up to 15.0 mm) narrow (1.0-2.0 mm) vertically-oriented tubular bubbles. Since these tended to cut across the sediment layering, they may have elongated through thermo-migration.

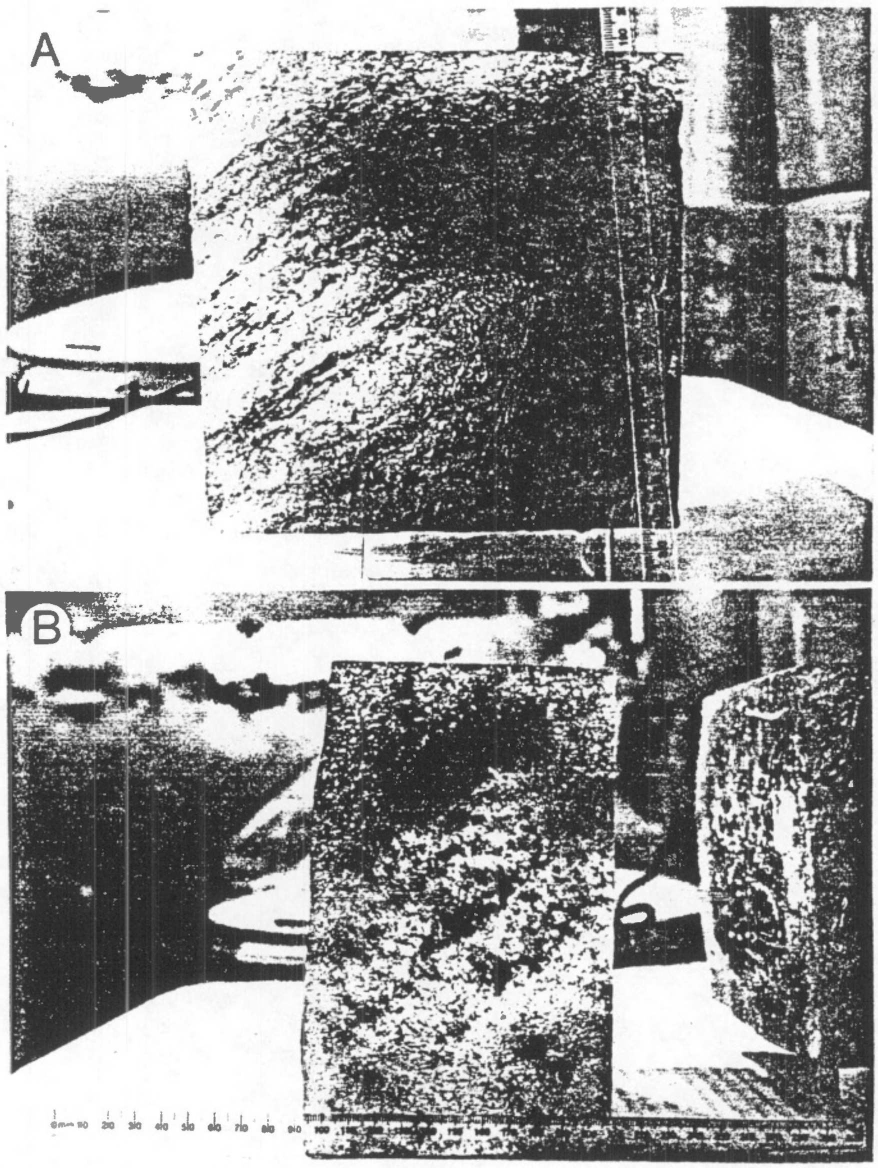

Figure 7. Photographs, taken under plain light, of: (A) Ice sample #1. (B) Ice sample #2. Note the translucent appearance caused by the sediment and gas inclusions.

The most obvious sediment inclusions were distinct discontinuous bands of fine organic silt. The bands were enhanced by the gas inclusion concentration along the sediment planes. Individual sediment bands had a slight undulating nature and were clearly inclined (Figure 8A). Other sediment inclusion consisted of disseminated fine silt. A total sediment content of the ice was low, roughly 3-7% by volume.

There was a conspicuous lack of faults, thermal fractures and strain shadows in the ice body.

Ice sample #2 (Figures 7B, 8B) was similar to the first sample. It was cloudy and translucent. Sediment layers were not as clearly defined as sample #1 and dipped at angles of 30-40° towards the valley floor. Gas inclusions consisted of small spherical bubbles and randomly distributed, vertically oriented, long tubular bubbles. The latter were occasionally bulbous in shape, tapering upward.

In both samples, the absence of fractures, faults and strain shadows suggested a constant thermal history and an absence of rapid thermal change.

4.2 Ice texture

A number of thin sections were prepared and examined under cross-polarised light. A minimum of fifteen thin sections were prepared for each ice sample

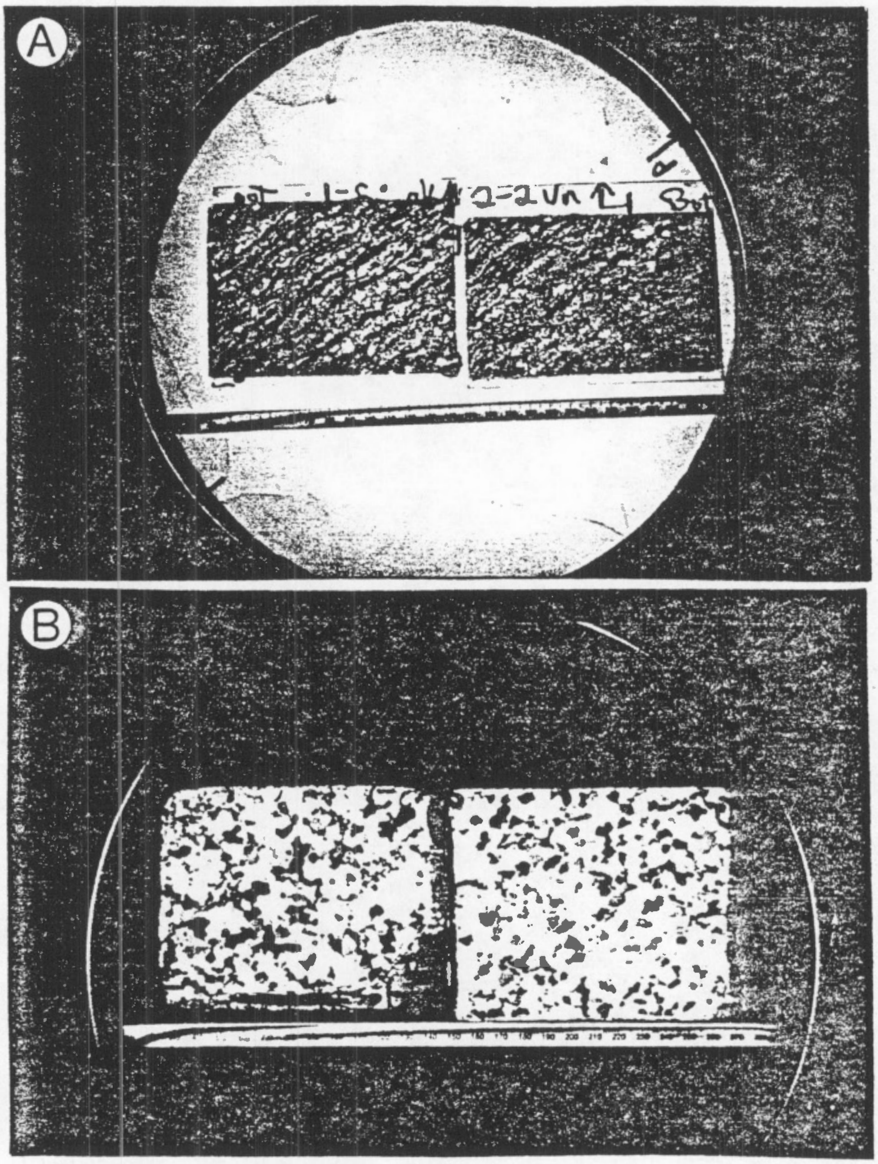

Figure 8. Photographs of ice sample #1: (A) Vertical thick sections viewed under plain polarised light. (B) Vertical thin sections viewed under cross-polarised light.

and both vertical and horizontal orientations were analysed.

Even though both samples are from locations at least 40.0-50.0 metres apart, the ice crystal textures were similar. The ice had a granular texture characterised by a predominantly fine to medium grain size (Figure 8B). Crystal shapes were anhedral to subhedral and equigranular in nature. The ice crystals were elongated and the preferred orientation of the dimensional long axis was roughly parallel to the layering of sediment inclusions and the local dip of the ice unit. The average crystal size for vertical thin sections from sample #1 was 25.2 mm^2 (Figure 9A, B). Average crystal length (i.e., long axis) was 5.9-6.0 mm and average width (i.e., short axis) was 4.1-4.2 mm, giving a mean length:width ratio of 1:4. Horizontal thin sections displayed even smaller crystal dimensions: The average crystal size was 20.4 mm^2, average grain length was 5.1 mm and average width was 4.0 mm, giving a mean length:width ratio of 1:3. Ice sample #2 possessed similar small crystal sizes (Figure 10A, B, C, D).

Ice crystal shapes in both samples were predominantly anhedral to subhedral in nature, ranging from highly irregular, multi-sided grains to fairly regular, equi-angular grains with traces of crystal symmetry. In vertical thin sections, particularly in the case of sample 1, there was some tendency toward elongation

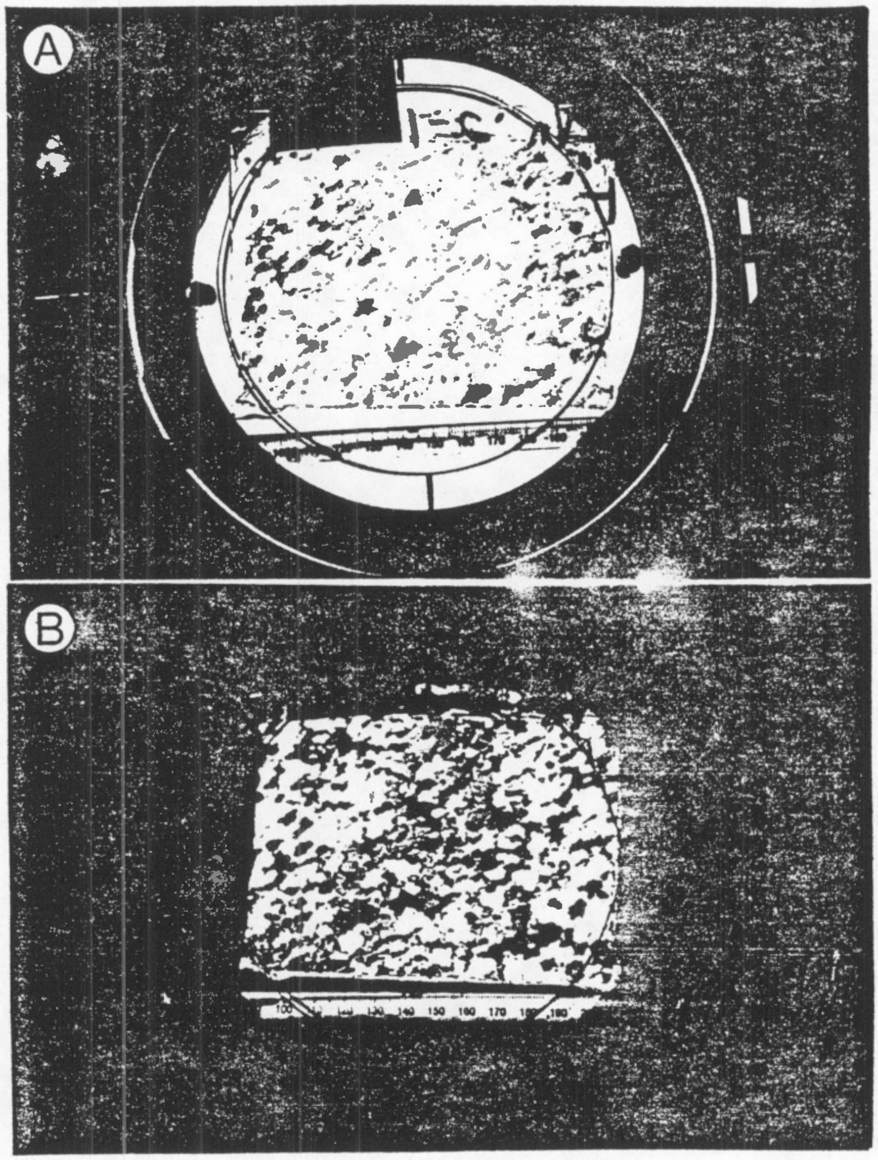

Figure 9. Photographs of ice sample #1: (A) Vertical thin section viewed under plain polarised light. (B) Vertical thin section viewed under cross-polarised light.

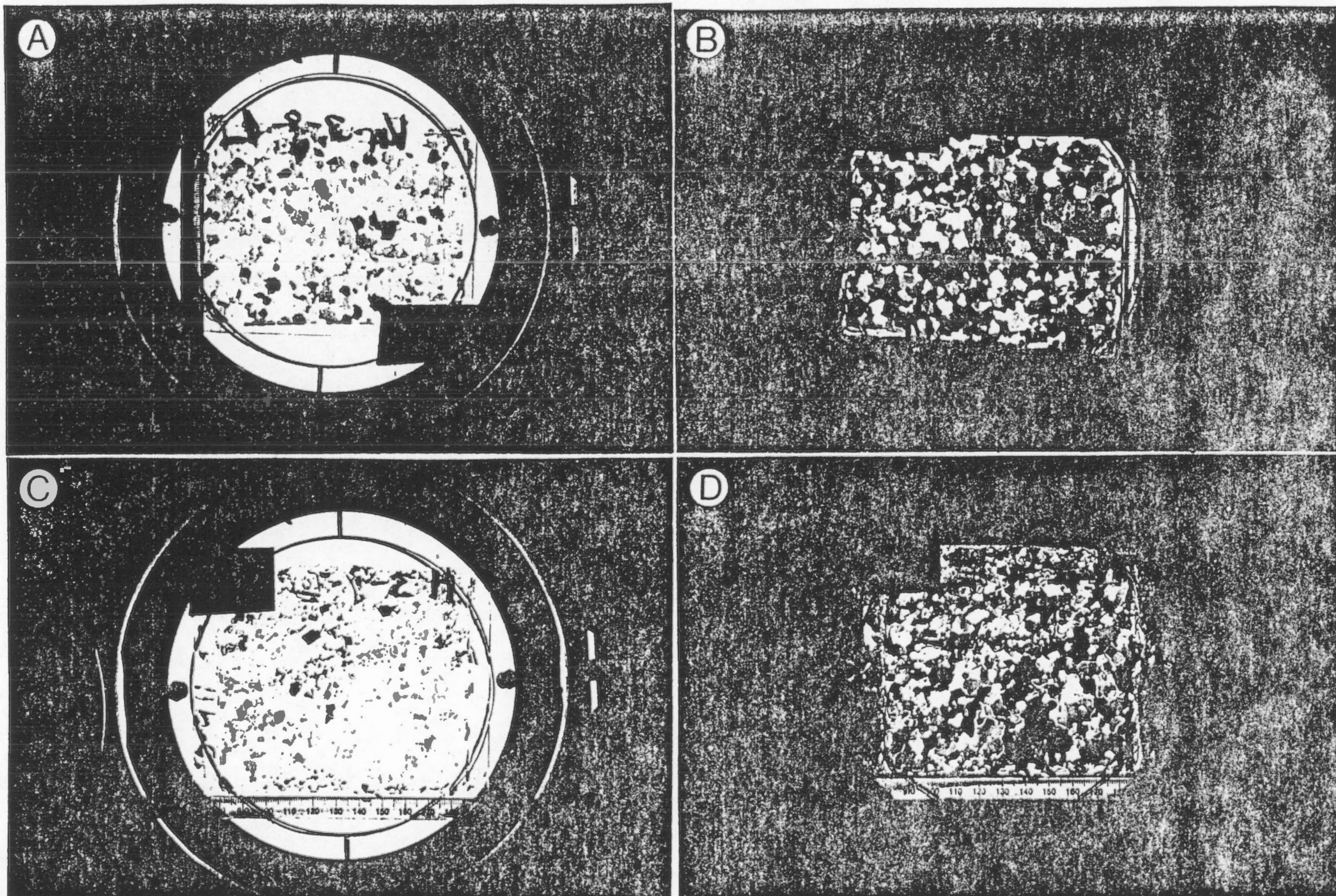

Figure 10. Photographs of ice sample #2: (A) Vertical thin section viewed under plain polarised light. (B) Vertical thin section viewed under cross-polarised light. (C) Horizontal thin section viewed under plain polarised light. (D) Horizontal thin section viewed under cross-polarised light.

in the larger grains. This orientation showed a preferred direction parallel to the sediment layering within the ice.

4.3 Petrofabrics

C-axis orientations are depicted graphically on Schmidt equal area stereo-nets as diagrams of the density distribution of optic axes projected onto a spherical surface. A Schmidt equal area lower hemisphere projection was chosen as the basis for plotting fabric data because it permits a statistical count of the number of points per unit plain surface without distortion. Contouring was undertaken using the Kamb method. The small grain size of the Klondike ice permitted measurement of a large number of crystals. The average number of crystals visible on each thin section ranged from 200-300. Between 80-100 crystals per thin section were measured.

Fabric diagrams of C-axis orientations for both vertical and horizontal thin sections in sample 1 are presented in Figure 11. The data from vertical thin sections (Figure 11A) show a weak preferred pattern of C-axis orientations contained in a single primary maxima with a concentration of 10% forming a broad girdle-band ranging from nearly vertical to 60°. For horizontal thin sections (Figure 11B), the pattern of C-axis

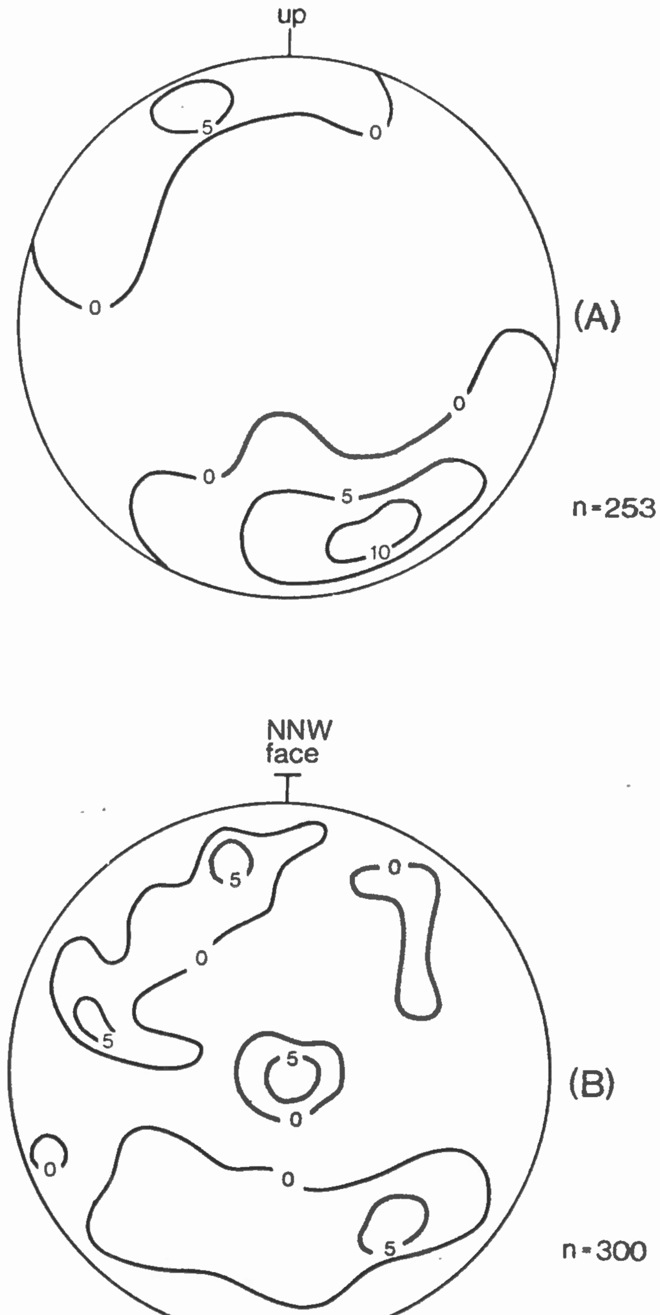

Figure 11. Fabric diagrams for ice sample #1: (A) C-axis distribution of 253 ice crystals from 3 vertical thin sections for planes oriented normal to the thaw face and oblique to the local slope. The sample represents approximately 40% of the total number of crystals visible in the thin sections. (B) C-axis distribution for 300 ice crystals from 3 horizontal thin sections within the sample.

orientations is widely dispersed and almost random. A series of weak maxima are found inclined 20-50° to the vertical.

Fabric diagrams for ice sample 2 are presented in Figure 12. They show an essentially similar pattern to sample #1. The C-axes are widely distributed with a single primary maxima ranging from vertical to an angle inclined 20-25° to the vertical in a direction into the face.

5. DISCUSSION AND INTERPRETATION

Although the origin of the massive ice described above from the Mayes Claim, Hunker Creek, cannot be deduced with certainty, the physical characteristics of the ice and its stratigraphic occurrence, as described above, provide useful information.

Several considerations suggest that a segregation origin for the ice body is not appropriate. First, the crystals are exceedingly small and uniform. Other studies of segregated ice bodies usually describe larger and more variable-sized ice crystals, reflecting either slow growth or variable growth conditions (e.g., Penner, 1972; French, Pollard and Burn, 1984; Shumskii, 1964). Second, although there is a coarse stratification or layering in the ice, the gas (bubble) inclusions indicate

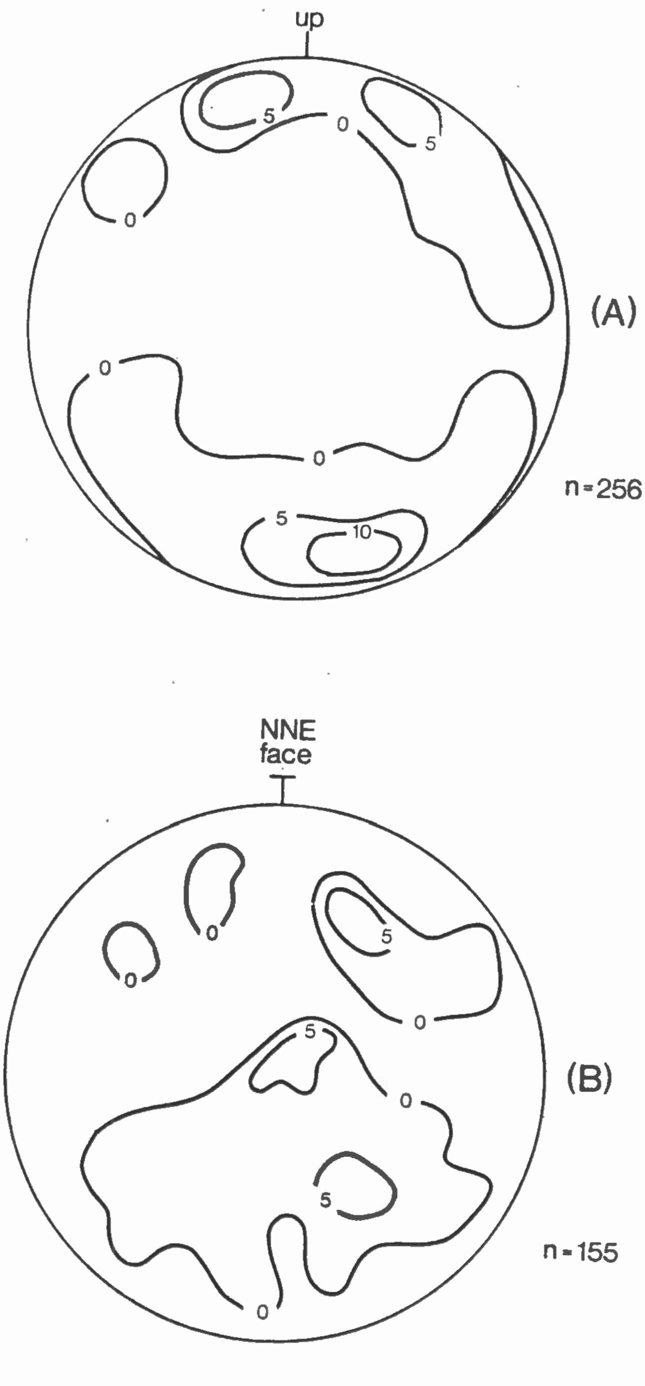

Figure 12. Fabric diagrams for ice sample #2. (A) C-axis distribution from 2 vertical thin sections for planes oriented normal to the thaw face and oblique to the local slope. The sample represents approximately 35% of the total number of crystals visible in the thin sections. (B) C-axis distribution for 155 ice crystals from 2 horizontal thin sections within the sample.

that the heat flow direction is at an angle of approximately 30-45° to the layering. This would not be the case if the ice were of a segregation origin, formed as permafrost aggraded downwards through the overlying muck deposits. Third, sediment inclusions are widespread throughout the ice and consist of fine silty particles apparently in suspension within the ice, with a few larger and coarser sediment particles in distinct intracrystalline bands. Since segregated ice forms by water migrating through pores to the freezing front, sediment would not normally be suspended throughout the ice and instead, would occur as more distinct bands separated by relatively clear ice lenses.

A number of other possible origins for the ice can also be eliminated. For example, since the Klondike District escaped glaciation, the ice cannot be buried glacier ice. Equally, it is clear that the ice is neither pingo, wedge nor seasonal frost mound ice. The possibility that the ice is buried river icing ice is also rejected since earlier investigations of river icing ice in the North Fork Pass area, Ogilvie Mountains, by one of us (Pollard, 1983, pp. 153-155) indicates that the ice body under discussion at Mayes Claim lacks the rhythmic layering typical of river icing ice.

One possible origin, which by default therefore must be considered, is that of a residual snowbank, subsequently buried by muck deposits and having undergone recrystallisation. In the Soviet Union, buried snowbank ice is a recognised form of ground ice (e.g., Shumskii, 1964) which has been overlooked in the North American literature (e.g., Mackay, 1972). Evidence in support of such an interpretation for the Klondike ice body under discussion includes (a) the stratigraphic position of the ice body extending across the face and apparently dipping upwards towards the valley side, (b) the gradational nature of the ice body with the underlying gravels and the sharp contact with the overlying muck, suggesting burial from above, (c) the small crystal size, showing a slight degree of orientation, possibly the result of regelation and infiltration of snowmelt waters, (d) the bubble inclusions oriented normal to the ground surface but at an angle to the internal layering of the ice body, (e) the silty nature of the included sediment, possibly indicative of an eolian origin for the sediment, (f) the absence of strain shadows indicating no strong changing thermal history, and (g) the absence of fractures or other evidence of ice deformation.

The presence of occasional large pebbles and cobbles (e.g., see Figure 4C) and wood fragments in the ice (see Figure 3) is problematic, but they seem best interpreted as debris which has slumped or flowed across the snowbank surface in the spring. Such an occurrence is commonly observed in the western and High Arctic islands today.

Therefore, while we are not entirely certain, we are of the belief that a residual snowbank origin is most consistent with the nature of the ice body which we have examined. It is entirely possible that a snowbank existed at the foot of the north-east facing slope of Hunker Creek for many tens, hundreds or even thousands of years. Since the overlying muck deposits contain organic and faunal remains similar to those found in adjacent valleys and variously dated from 20,000-35,000 years B.P. (Harington and Clulow, 1973; Harington, 1978), it seems reasonable to assume that the snowbank was buried by an increase in colluvial and slope deposits arriving in the valley bottom during the latter stages of the last cold period, i.e., during the McConnell glaciation. At this time, the Cordilleran ice was confined to the Selwyn and Mackenzie Mountains to the south and west (Hughes, 1969) and limited alpine glaciation probably occurred in the southern Ogilvie Mountains to the north (Vernon and Hughes, 1966). In all probability, as the climate ameliorated from the cold of the glacial maximum, an increase in humidity and mass wasting activity would have supplied large quantities of colluvium and muck to the Klondike Valleys, burying any large residual snowbanks which might have existed in sheltered localities.

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