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Internal Structure and Environmental Significance of a Perennial Snowbank, Melville Island, N.W.T.[1]

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ABSTRACT. A perennial snowbank located in the continuous permafrost zone was cored to obtain details of its internal structure and history. In spring the snowbank is up to 10 m thick and composed of deep snow accumulated during the previous winter, overlying ice developed by basal ice accretion over many years. The perennial ice exhibits a layered structure with alternating clear and milky bands and contains randomly oriented, variably shaped bubbles. Horizons of aeolian and mudflow deposits occur at irregular intervals and correspond to periods of aggradation and thaw truncation of the snowbank.

Tritium concentrations in a core from the deepest portion of the snowbank indicate that the basal 2 m of ice pre-dates 1957. Other layers of ice likely represent precipitation that fell between 1958 and 1962, between 1968 and 1976, and after 1983. Ice developed during the 1963 atmospheric tritium peak is no longer present. Energy balance measurements indicate that potential climatic warming is unlikely to eliminate the perennial portion of the snowbank unless accompanied by substantially less snow drifting at the site.

Key words: snowbank ice, tritium, climate change

RÉSUMÉ. On a prélevé des carottes dans une congère pérenne située dans la zone du pergélisol continu, pour obtenir des détails sur sa structure interne et son histoire. Au printemps, la congère a une hauteur de 10 m et se compose de neige profonde accumulée au cours de l'hiver précédent et recouvrant la glace créée par le gel au fond au cours de nombreuses années. La glace pérenne apparaît comme une structure en couches formée de bandes claires alternant avec des bandes laiteuses, et elle contient des bulles orientées au hasard et de formes diverses. Des horizons de dépôts éoliens et boueux apparaissent à intervalles irréguliers et correspondent à des périodes de colmatage et de troncature due au dégel dans la congère.

Les concentrations de tritium dans une carotte prélevée dans la partie la plus profonde de la congère indiquent que la glace du fond, sur une hauteur de 2 m, date d'avant 1957. D'autres couches de glace représentent probablement des précipitations qui ont eu lieu entre 1958 et 1962, entre 1968 et 1976, ainsi qu'après 1983. La glace qui s'est formée au cours de la période de concentration maximum de tritium atmosphérique n'est plus présente. Les mesures de bilan énergétique révèlent qu'il est peu probable qu'un réchauffement éventuel du climat élimine la partie pérenne de la congère, sauf s'il s'accompagne d'une diminution importante de la neige qui s'amoncelle sur le site.

Mots clés: glace de congère, tritium, changement de climat

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INTRODUCTION

The winter snowpack in lowland areas of the Canadian Arctic Archipelago is generally thin and areal snow cover diminishes rapidly during the spring. By the last two weeks in July, residual snow patches occupy less than 1% of the surface area in most of the western and central Arctic Archipelago (Lauriol *et al.*, 1986). At certain sites, however, perennial snowbanks are present because breaks-of-slope and end-of-winter snow depths are so great that a full summer's energy input is unable to ablate all the snow. At the end of the thaw season, masses of snow and ice remain to be covered by fresh accumulation during the subsequent winter.

Perennial snowbanks are of interest to a number of disciplines. Geomorphologically, large snowbanks are associated with the concept of nivation, particularly in alpine areas (e.g., Lewis, 1939; Thorn and Hall, 1980). In hydrological terms, perennial snowbanks ablate throughout the summer and thereby augment stream discharges after the main melt period (Marsh and Woo, 1981). The structure of perennial snowbank ice is significant to cryostratigraphic work because snow can be covered by slumped material, incorporated into permafrost and later exposed by erosion (e.g., French and Pollard, 1986; Fujino *et al.*, 1988; Harry and French, 1988; Pollard and Dallimore, 1988; Woo *et al.*, 1982). Finally, the longevity of a perennial snowbank and its periods of aggradation and degradation may be indicative of climate variations (e.g., Lindh *et al.*, 1988).

The purpose of this paper is to describe the internal structure of a high arctic perennial snowbank and to discuss its environmental significance. The results can be compared with those of Østrem (1963, 1965), who undertook studies of perennial snow in glaciated parts of Scandinavia.

LITERATURE AND STUDY AREA

Two studies of perennial snowbanks in lowland permafrost areas are known. The first was a limited hydrological investigation undertaken on Ellesmere Island (Ballantyne, 1978). The second, from which this paper stems, examined the energy balance and hydrology of a perennial snowbank on southeast Melville Island during the 1986 thaw season (Young and Lewkowicz, 1988, 1990; Lewkowicz and Young, 1990, in press). The observations reported here were made when revisiting this site in August 1987.

The perennial snowbank (Fig. 1) is located at 74°57′N, 107°19′W, about 3 km northeast of Ross Point. It has developed in the lee of a 36 m high break-of-slope and at the end of winter is approximately 10 m thick in its deepest part (Fig. 2). At this time, it is nearly 1 km long and up to 150 m wide, but summer ablation reduces its areal extent by about one-third and the eastern portion becomes thin. One indication that the snowbank is perennial is its banded appearance on aerial photographs taken in July 1959. These bands (see Fig. 1) are probably due to the exposure of perennial layers of debris-rich ice and snow during a year of net degradation (see Østrem, 1965).

The bottom edge of the snowbank is located 800 m from the coast at an elevation of about 12 m a.s.l. and the whole

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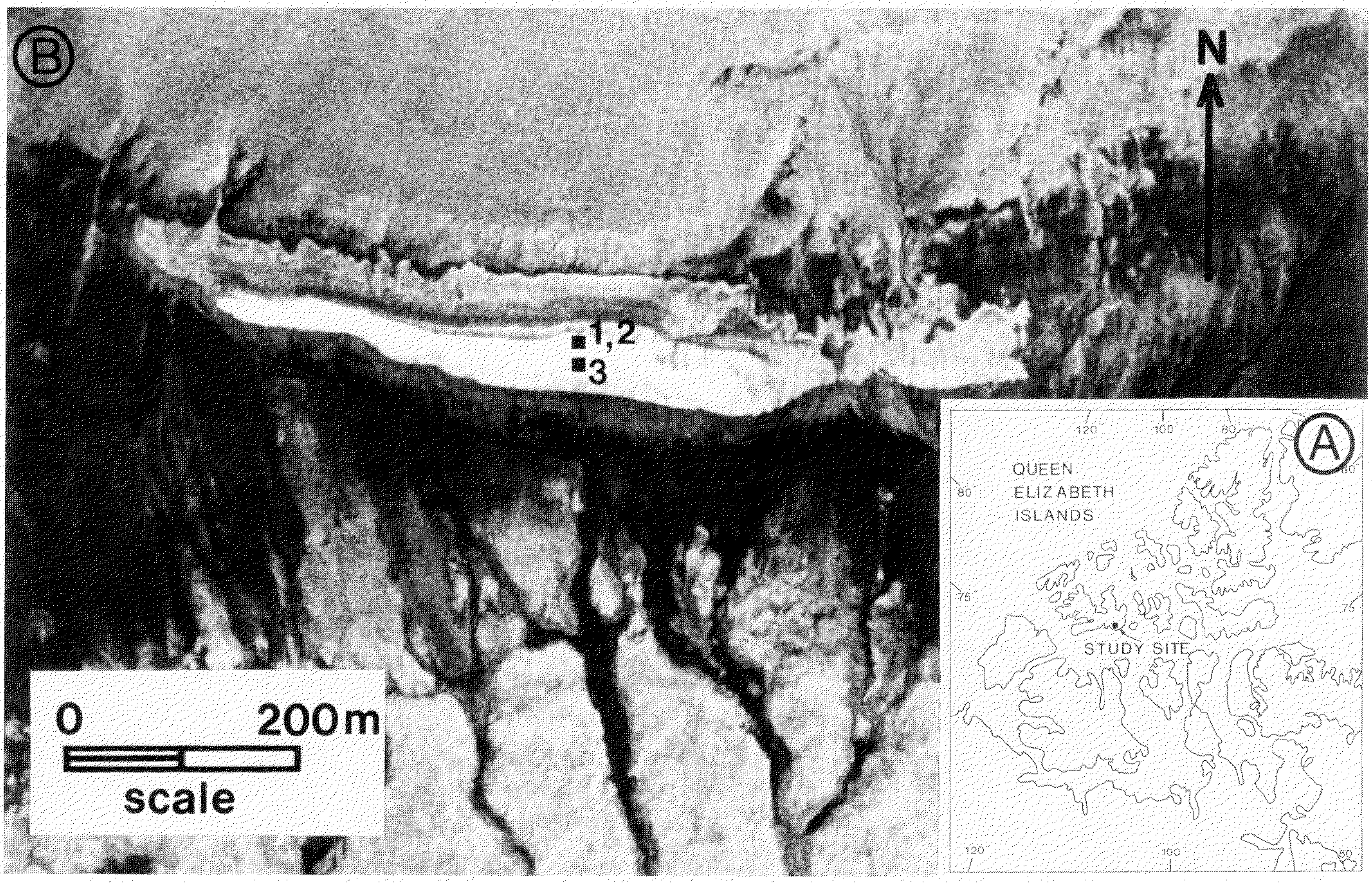

FIG. 1. **A)** Location of Ross Point study site on Melville Island in the Canadian Arctic Archipelago. **B)** Vertical aerial photograph of the study site (enlargement of part of Energy, Mines and Resources Canada photo A16766-99) showing the perennial snowbank in July 1959 and the locations of the August 1987 drill holes. Note the light and dark grey bands running parallel to the snowbank edge, which are characteristic of perennial snowbanks. The outermost band is basal ice, while those nearer the centre result from the exposure of debris-rich layers within the core.

site is below the Holocene marine limit (Hodgson *et al.*, 1984). It is likely that the break-of-slope that traps blowing snow during the winter is a former cliff line. Marine sediments at an elevation of 22 m at nearby Ross Point have been dated at 7565 ± 235 years B.P. (McLaren and Barnett, 1978), so the snowbank could not have developed until after this time.

The climate of the study area is not known in detail but is probably similar to that of Rea Point, located 70 km away on the eastern coast of Melville Island. The mean annual air temperature there is −17.2°C (Table 1), and daily air temperatures in winter frequently fall below −40°C. The summer is cool and only three months have mean temperatures above 0°C. Winter snowfall amounts are low (Table 1) but are redistributed by prevailing winds from the northwest and north-northwest (Environment Canada, 1982c; Lagarec *et al.*, 1990). Consequently, perennial snowbanks in the study area face south, having developed in the lee of east-west breaks-of-slope.

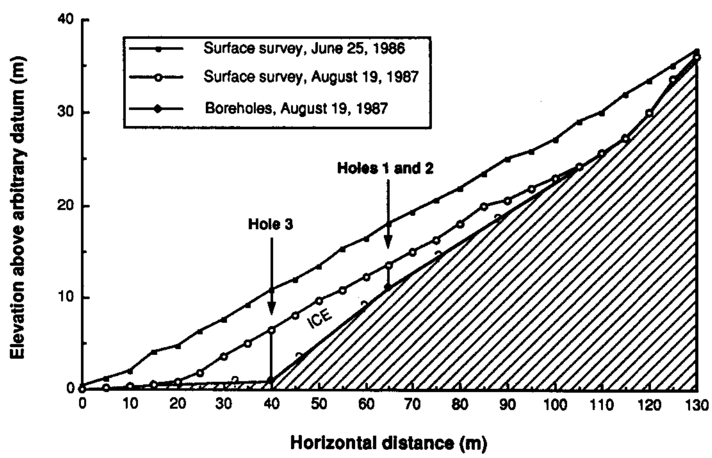

FIG. 2. Cross-section of the perennial snowbank derived from surveys along a snow course using a theodolite in 1986 and 1987. The ground profile beneath the perennial ice is interpolated from the boreholes described in the text.

In July 1986, the mean screen-height air temperature at Ross Point was 1.7°C lower than the long-term mean for Rea Point (Young and Lewkowicz, 1990). Since both stations are close to the coast, their summer climates are probably quite similar. Consequently, temperatures recorded at Ross Point are believed to have been below average, the result of unsettled weather conditions that were widespread over the central Arctic during the summer of 1986.

FIELD AND LABORATORY METHODS

Cores were extracted from the snowbank using a 75 mm diameter modified CRREL auger driven by a Stihl powerhead. Drilling was undertaken late in the ablation season (19–20 August), when no granular snow remained on the surface of the snowbank (Fig. 3A). A survey showed the ablation surface to be 1.5–2.0 m lower than on 7 August 1986.

Three holes were drilled (see Figs. 1 and 2). Hole 1 was in the central part of the snowbank and reached a depth of

TABLE 1. Rea Point, Melville Island: selected climatological data (1969–85)

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Mean air temperature (°C)	−33.0	−34.6	−32.1	−24.0	−10.8	0.3	4.0	1.5	−5.3	−16.7	−25.9	−30.2	−17.2
Mean precipitation (mm)	1.4	0.3	1.4	0.9	3.0	3.2	9.2	15.2	6.3	7.6	2.1	1.6	52.2

Sources: Environment Canada (1982a,b) and station records 1981-85.

1.1 m before the auger became frozen within the ice. Hole 2 was drilled 0.5 m upslope of hole 1 and their cores are considered to be identical. A depth of 2.38 m was reached before refusal on a rocky substrate. Hole 3 was drilled 25 m downslope in the lower part of the snowbank and reached a depth of 5.67 m, finishing in frozen sand. Continuous core was obtained from all three holes and was described in the field. A YSI tele-thermometer probe accurate to ±0.25°C was lowered down the holes to obtain temperature information.

Core samples taken for $\delta^{18}O$, δD and tritium analyses were allowed to melt in large polyethylene jars in the field and were transferred within 12 hours into 50 ml polyethylene bottles, which were filled completely before being sealed. Ice containing organics or mineral particles was also thawed in the larger jars and the mixture poured into 250 ml bottles. Tritium concentrations were determined for 20 samples from hole 3, and the same number of samples from hole 3 plus 11 more from holes 1 and 2 were analyzed for $\delta^{18}O$ and δD.

Amounts of organic material in the cores were too small for standard ^{14}C dating, but four samples from hole 3 were dated by accelerator mass spectrometry. One of these (5.60–5.65 m depth) was submitted in September 1987 without treatment. The other three were retained unfrozen for two

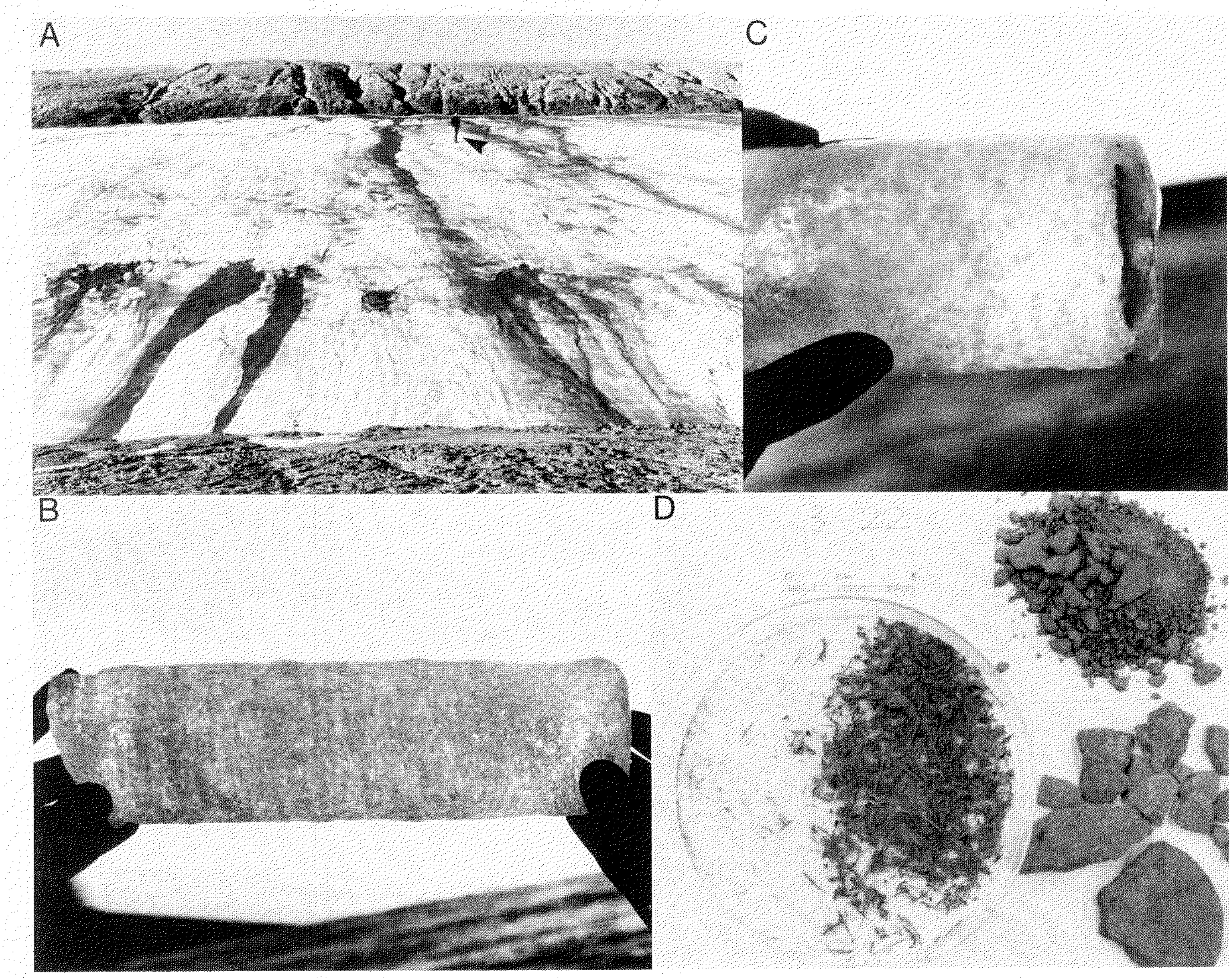

FIG. 3. Photographs of the perennial snowbank. **A)** Surface in August 1987 after all the granular snow had ablated. Note the surface wash moving aeolian sediment downslope over the ice. Person (arrowed) is 1.9 m tall. **B)** Typical core (approximately 25 cm long) exhibiting crude banding produced by varying bubble sizes and concentrations. Milky ice contains numerous very small bubbles while clearer ice contains fewer bubbles up to 1 mm in diameter. **C)** Core section containing a distinct band of aeolian mineral and organic material 1-2 mm thick. **D)** Organic detritus and mineral particles from depths of 3.70–3.75 m in hole 3. This material is thought to have been transported onto the snowbank by mudflow and wash processes.

months, then refrozen to prevent the breakdown of the organic material. Upon thawing in April 1988, the samples were poured through a #230 sieve and the organic particles were removed using tweezers. The air-dried organics were stored in petri dishes prior to submission for analysis.

RESULTS

Physical Structure of the Snowbank

Core from all three holes consists of ice, generally with a layered structure and punctuated at varying intervals by horizons containing mineral and organic material (Fig. 4). The layers are alternating clear and milky ice ranging in definition from crude to well defined, in thickness from 3 to 20 mm, and with gas inclusions of various sizes and shapes (Fig. 3B). Bubble diameters ranged from about 0.1 mm up to 1.5 mm, with shapes that varied from spherical to flattened to highly irregular. In clearer layers of the core, bubbles were frequently clumped together, but bubble trains with a preferred orientation were not observed.

Particles within the core occurred either as distinct organic and mineral concentrations in layers up to several mm in thickness (Fig. 3C) or diffused and suspended in several cm of ice, giving rise to a beige or brown colouration. Mineral particles in core from holes 1 and 2 were all in the fine-sand grain-size range. Core from hole 3 also included layers containing gravel and pebbles up to 50 mm in diameter, which were cut by the auger (Fig. 3D). Organic particles included lichen fragments and the leaves and stems of vascular plants.

Observations of the perennial portion of the snowbank indicate that it has the characteristics of basal ice. This generally develops at the base of seasonal snow in spring when melt-waves from the surface refreeze at or near the interface with the ground (Woo and Heron, 1981; Woo *et al.*, 1982). Basal ice growth requires sub-zero snow or a negative temperature gradient beneath the snowpack so that latent heat released by freezing can be absorbed. The resultant ice petrographic structure retains some characteristics of the original snow because the snow crystals are inundated by water already at 0°C and includes air bubbles because freezing is relatively rapid. Since basal ice forms as a result of successive melt-waves, its structure includes layers oriented approximately parallel to the local ground surface, as observed in core from the base of hole 3, where layers dipped at 15°.

Measurements by Østrem (1963) showed typical crystals in perennial snowbank ice to have areas of 0.04–0.38 cm^2. The larger crystals were due to recrystallization and were found in association with mineral and organic dirt bands. The ice in the perennial snowbank probably developed during multiple periods of basal ice accretion, and except for the formation of the bottom-most layer of the snowbank, the substrate was ice rather than frozen soil. During the 1986 thaw season, for example, at least 0.5–0.7 m of new basal ice formed over perennial ice in the middle and lower portions of the snowbank (Lewkowicz and Young, 1990).

A comparison of the core with massive ground ice collected in the Klondike District, Yukon Territory, and hypothesized to be residual snowbank ice (French and Pollard, 1986) reveals some similarity in structure, especially in terms of sediment inclusions. However, bubble shapes differ, with tubular bubbles being absent in the Ross Point core and irregularly shaped bubbles absent in the Klondike ice. If the Klondike samples are snowbank basal ice, these differences may result from the colder substrate temperatures on Melville Island, which could reduce melt and subsequent recrystallization within the basal snow.

Isotopic Structure of the Snowbank

Profiles of $\delta^{18}O$ for holes 1 and 2 combined and hole 3 are shown in Figure 5. Values vary from -24 to -33‰, indicating a considerable range of precipitation temperatures. These may not be the most extreme values experienced at the site, since little summer precipitation is likely to have been incorporated into the perennial ice. Furthermore, variability in winter isotopic composition may be smoothed, since surface meltwater refreezes within snow of a different isotopic concentration during basal ice growth. On glaciers, $\delta^{18}0$ variability in the "soaked" zones can be reduced or eliminated (Arnason, 1981). In the upper 1.5 m of the snowbank, $\delta^{18}0$ values from the two parts of the snowbank are reasonably similar, but they diverge below this depth. This divergence indicates that individual ice layers are not continuous and can be preserved in the central part of the snowbank while being destroyed by ablation near the margins.

Values of δD in the snowbank ice range from -259 to -181‰. Regression of δD against $\delta^{18}O$ produces a best-fit line with a slope of 8.7 (r^2 = 0.99), indicating that fractionation has not occurred and that the ice is derived directly from meteoric water. The best-fit line lies slightly above the global meteoric water line, a result attributable to the isotopic composition of the local precipitation (see Yurtsever and Gat, 1981).

Tritium concentrations in samples from hole 3 vary from <6 to 72 T.U. (tritium units) (Fig. 6). All concentrations are accurate to ± 8 T.U., so that the <6 values could represent from 0 to 14 T.U. The samples fall into three distinct groups: 1) from 8 to 32 T.U. in the top 1.4 m of core; 2) from 37 to 72 T.U. between 1.4 and 3.6 m, and 3) four samples with <6 and one sample with 12 T.U. between 3.6 m and the base of the snowbank. These groups are bounded by some of the major unconformities in the core, as indicated by thick sediment bands (see Fig. 4).

Snowbank Temperatures

Snow temperatures above the top of the perennial ice are <-16°C at the end of winter (Lewkowicz and Young, 1990). In mid-August, the ice was at 0°C to depths of about 3 m but colder below, with temperatures down to -5°C. These measurements were made at approximately the time of deepest penetration of the summer heating wave from the surface, and it is clear that the snowbank maintains cryotic ground beneath it throughout the year.

Origin of Mineral and Organic Inclusions

Particles within the snowbank probably originate in two ways. First, aeolian processes deposit material during periods of strong winds in summer, when source areas for deflation are snow free. Particles derived in this manner consist of well-sorted fine sand and reach maximum concentrations of 315 $g \cdot m^{-2}$ in the core. The maximum organic concentration in these layers is 11 $g \cdot m^{-2}$ (see Fig. 4).

Aeolian layers can represent a single year's aeolian deposition during surface aggradation or a combination of several years' activity during a period of net degradation (Østrem,

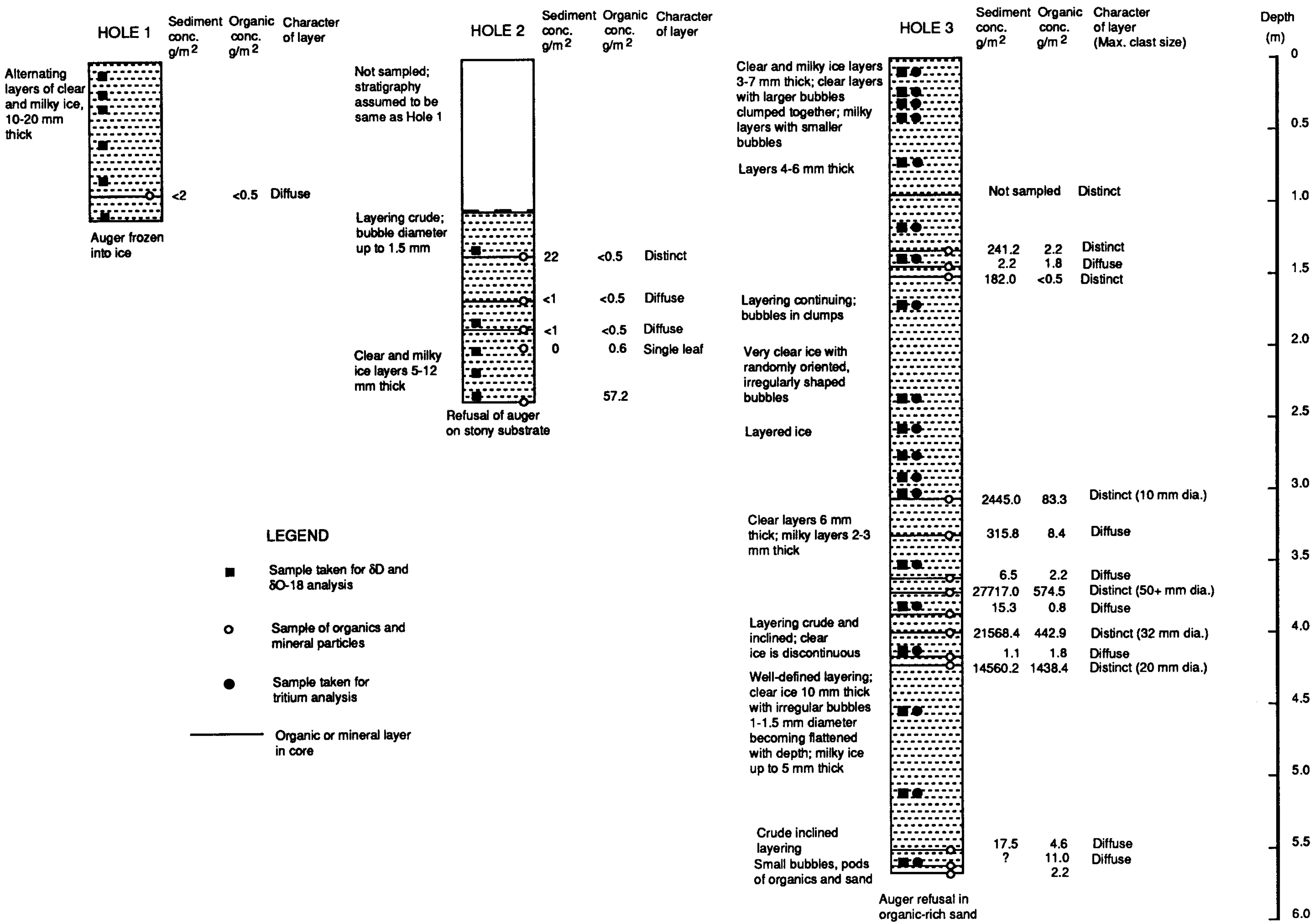

FIG. 4. Drill logs for the three holes showing physical descriptions of the ice and mineral/organic inclusions. Concentrations of organics and mineral particles are calculated from dry weights based on a core cross-sectional area of 45.6 cm^2.

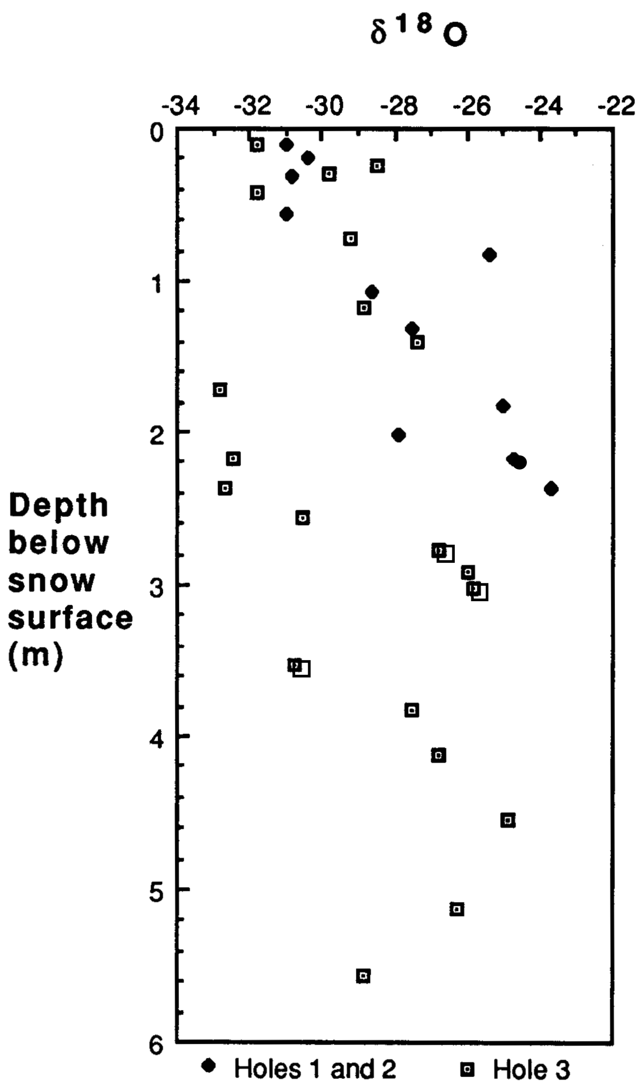

FIG. 5. Profiles of $\delta^{18}O$ from holes 1 and 2 combined and hole 3.

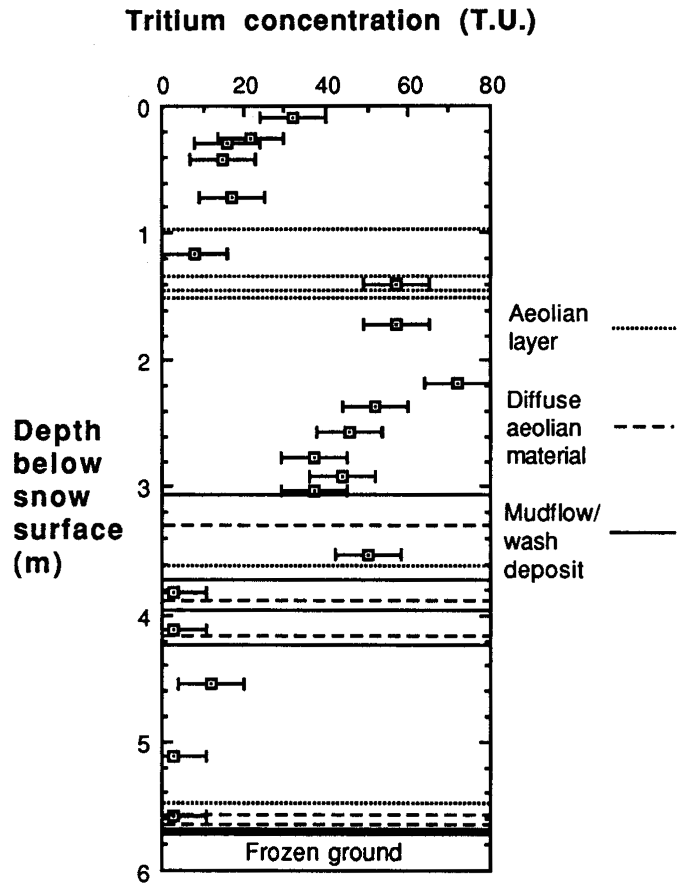

FIG. 6. Tritium concentrations, aeolian and mudflow/wash layers in hole 3. Samples with concentrations <6 T.U. have been arbitrarily plotted as 3 T.U. Error bars represent ±8 T.U.

1965). In the latter case, some of the sediment may be washed off the ice (see Fig. 3A). Distinct aeolian layers in the core are thought to be aggradational, since observations in 1986 showed aeolian sediment confined to a well-defined layer on top of clean snow. In contrast, diffusion of sediment within the core may relate to degradation and candling of perennial ice exposed to ablation.

The second potential source of material is the steep slope above the snowbank. This is progressively exposed as the snow ablates (see Fig. 2) and could exceed 80 m in length in a year of pronounced net degradation. In these circumstances, thawing soil, normally maintained as permafrost beneath the perennial ice, may be transported onto the snowbank surface by wash and mudflow. Four layers in hole 3 at depths of 3.05, 3.70, 3.95 and 4.20 m are thought to have originated in this manner. All have high concentrations of mineral and organic particles, ranging from 2445 to 27 717 $g \cdot m^{-2}$ and 83 to 1438 $g \cdot m^{-2}$ respectively (see Fig. 4). Since the mineral particles are typically poorly sorted, gravelly sand, with sandstone clasts up to 50 mm in diameter (see Fig. 3D), aeolian processes can be excluded as a transport mechanism.

Four samples of organic material from the core were accelerator ^{14}C-dated in an attempt to ascertain the age of the snowbank (Table 2). These samples were taken from layers identified as aeolian in origin, since it was believed that these would give the most precise dates relative to snowbank growth and decay. The lack of sequence in the dates confirms the results of Østrem (1965) that detrital material in such a situation is unsuitable for establishing the age of snowbank ice.

Recent History of the Snowbank

Tritium concentrations within the ice can be used to derive a history of recent variations in snowbank size and this can be compared with climatic information. In the analysis, it is assumed that there has been minimal movement of tritium within the perennial part of the snowbank after the initial formation of basal ice. The validity of this assumption rests on the relatively short time involved (35 years) and the impermeability of basal ice (see Young and Lewkowicz, 1988).

In order to compare snowbank tritium to atmospheric values, a proxy record of tritium in precipitation at Ross Point was derived from Ottawa records. Average concentrations are higher in arctic precipitation than at Ottawa, ranging from 35% more at Resolute Bay (standard error of 15%) to 90% more at Nord (standard error of 8%) (Table 3). Ross Point values are assumed to lie between the Resolute Bay average minus twice its standard error and the Nord average plus twice its standard error — i.e., from 1.05 to 2.06 times the Ottawa value. Monthly concentrations of tritium can then be decayed using a half-life of 12.43 a to produce values comparable with those of the field samples when analyzed in January 1988.

TABLE 2. Radiocarbon ages of organic layers in the core from hole 3

Sample depth below snowbank surface (m)	Isotrace no.	Description	Age[a] (yr B.P.)
1.35-1.45	TO-1386	Detrital organics from a combination of one distinct and one diffuse aeolian layer	7810±250
5.47-5.55	TO-1140	Detrital organics from one diffuse aeolian layer	1750±110
5.60-5.65	TO-837	Detrital organics from one diffuse aeolian layer	3230±50
5.65-5.67	TO-1141	Detrital organics from sandy surface beneath snowbank; obtained from flights of auger	1960±70

[a]Results are average of two machine-ready targets in uncalibrated radiocarbon years. The error represents the 68.3% confidence limit.

Calculated tritium concentrations increase from the mid-1950s to 1963, when above-ground nuclear bomb testing peaked, decline rapidly until 1972, and then decrease slowly to the present (Fig. 7). Superimposed on these trends are seasonal fluctuations with maxima in summer and minima in winter.

Samples from the upper 1.4 m of the core exhibit concentrations of 8 to 32 ± 8 T.U. (see Fig. 6) and fall into the range of winter values for years after 1976. Concentrations of 37 to 72 ± 8 T.U. in the central section of the core correspond to winter values for 1959-62 and 1966-76. High tritium concentrations of 1963-65 are not present in the core, so ice developed during this period must have ablated at a later date. Low concentrations in the basal 2 m of the core indicate that it pre-dates 1957. Hence the perennial snowbank has existed continuously for at least the past 30 years.

A more detailed history of the snowbank can be inferred by comparing these dates with climatic variables. The best available indication of energy input to the snowbank is mean summer air temperature (Fig. 8). Since this includes the effects of sub-zero temperatures, which halt rather than reverse ablation, it is also pertinent to examine the record of thawing degree-days.

Peaks and troughs in the summer air temperature and thawing degree-days coincide throughout the recorded and estimated data, but the relative magnitudes are not always identical. For example, 1974 appears as the coldest summer in terms of mean temperature, but 1953, 1967, 1969 and 1976 all exhibit fewer thawing degree-days. Both records show that 1983 was likely the warmest summer at Rea Point over the past four decades. Moreover, both snowfall and the maximum winter snow depth at Rea Point in the winter of 1982-83 were below average (Atmospheric Environment Service, Monthly Record), so that snow accumulation at Ross Point may have been less than normal.

The 1983 ablation surface is believed to be at a depth of 1.35 m in hole 3, since a substantial change in tritium concentrations occurs in the ice beneath. The ice above 1.35 m developed later, while the aeolian deposit at this level represents the remains of several previous years of accumulation. The single aeolian layer in the core above this elevation may be from 1984, which was cooler than 1983, but experienced less snowfall than in the preceding winter. The 1985 aeolian layer is presumed to have been destroyed during the 1987 thaw, which certainly eliminated the 1986 sediment band since the ablation surface was 1.5–2.0 m lower than at the end of that year.

The second discontinuity in the tritium record occurs at depths between 3.55 and 3.8 m (Fig. 6). Concentrations suggest that ice between 1.4 and 3.05 m developed during 1966-76. The most likely year for thaw truncation prior to aggradation is 1968 (see Fig. 8), and this would have produced the diffuse sediment within the ice between 3.3 and 3.6 m. No snowfall records exist, but considering that 1983 was probably warmer than 1968 and that its ablation surface penetrated less, it appears likely that snow accumulation in the winter of 1967-68 was low. After aggradation, thaw in 1971 or 1973 likely reduced the snowbank to an elevation only 25 cm above that of 1968 and also resulted in sediment from the slope moving onto the snowbank (see Fig. 4).

Beneath the inferred 1968 thaw truncation is a layer of ice with diffused sediment that lies above the coarsest sediment deposit. The single tritium sample places this portion of the snowbank either in the winters of 1966-68 or between 1959 and 1962. The earlier period seems more likely, since the thaw truncation prior to accumulation could only otherwise have occurred in 1966 or 1967, which exhibited average and below-average air temperatures respectively. If the ice dates from the earlier period, then thaw truncation and sediment movement onto the ice likely occurred in 1958, which is estimated to have had the second highest thawing degree-day total in the past 40 years (see Fig. 8).

The actual age of the pre-1957 ice below 3.65 m is not known, but it contains four further diffuse sediment zones and two distinct mudflow/wash events. The continuous existence of the snowbank for many years is suggested by energy balance measurements from 1986. Total energy absorbed at the snowbank surface from the time it became isothermal in late June until 9 August was 506 $MJ \cdot m^{-2}$ (Young and Lewkowicz, 1990). Assuming the ablation season ended 10 days later and that energy absorption remained at its average rate, an estimate of 559 $MJ \cdot m^{-2}$ is obtained for the whole summer. To thaw 1 m of ice in the perennial portion of the snowbank requires approximately 270 $MJ \cdot m^{-2}$. Assuming winter snow accumulation at the 1986 level, about 3.5 times the summer energy absorbed in that year would be needed to ablate the entire snowbank. Furthermore, sediment layers within the ice would be exposed at the surface during such pronounced degradation and would help to retard further ablation by insulating the surface. Ablation cones

TABLE 3. Comparison of tritium concentrations in precipitation at Ottawa and at monitoring stations in the central and eastern Arctic

Monitoring station	Lat.	Long.	Monitoring period	No. of months of data comparable with Ottawa	Regression vs. Ottawa	Std. error of estimate	r^2
Resolute Bay, Canada	74.7°N	94.8°W	1955–58	16	Y = 1.35 X	0.15	0.50
Nord, Greenland	81.6°N	16.7°W	1962–71	77	Y = 1.90 X	0.08	0.81
Thule, Greenland	76.5°N	63.8°W	1966–70	45	Y = 1.44 X	0.09	0.62
Ottawa, Canada	45.5°N	75.6°W	1953–83	355			

Data source: International Atomic Energy Agency (1969, 1970, 1971, 1973, 1975, 1979, 1983, 1986).

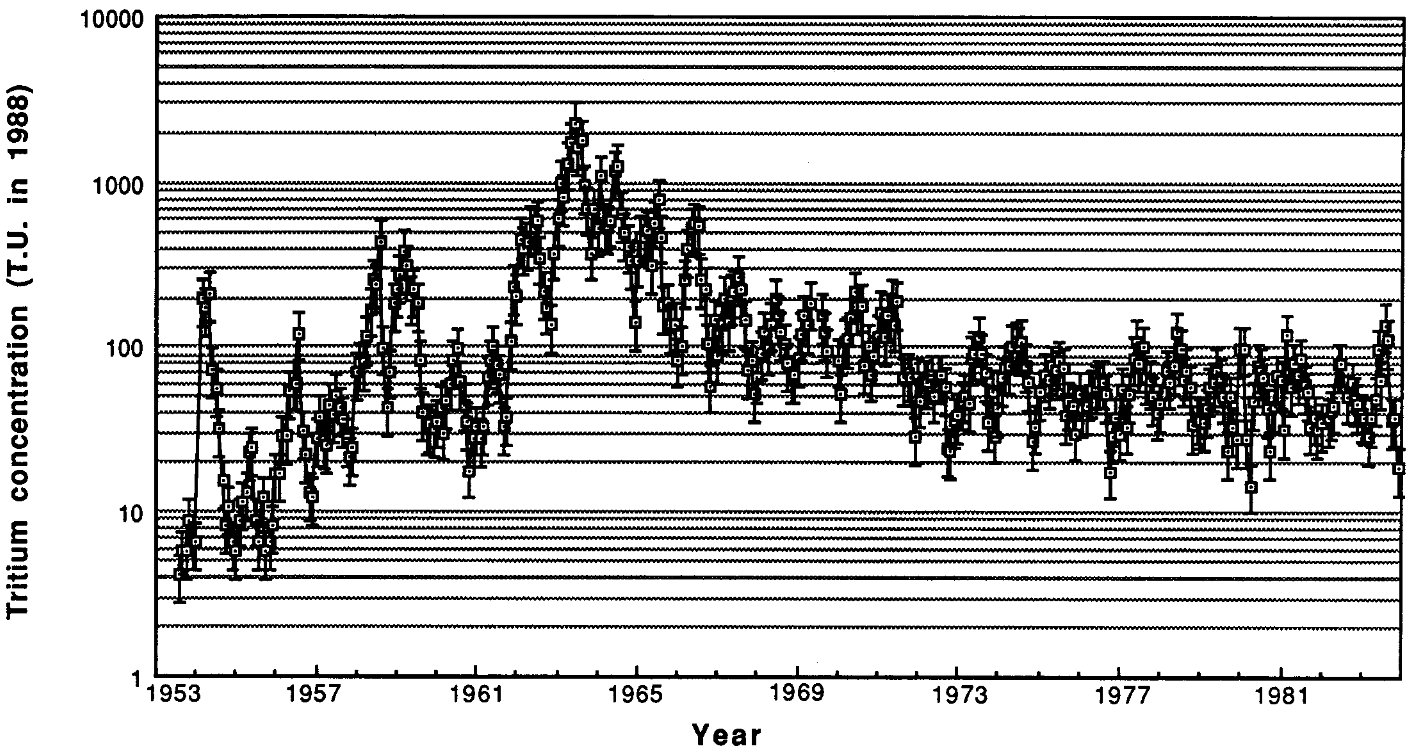

FIG. 7. Estimated monthly variation of tritium concentrations in precipitation for Ross Point, 1953–83. Points represent 1.55 times the Ottawa concentration and error bars bracket between 1.05 and 2.06 times the Ottawa value (see text). Concentrations shown have been decayed using a half-life of 12.43 years to January 1988 values.

developed on the snow in 1986 had sediment covers of 10–20 mm (Young and Lewkowicz, 1990) and some layers within the core were of equal or greater thickness.

The energy balance measurements suggest that it is virtually impossible for the snowbank to entirely ablate under the present climate. Deep former thaw truncations likely relate to both warmer summers and much reduced snow accumulations. The latter could result from lower snowfall or from a change in prevailing winds, so that less snow builds up in the lee of the break-of-slope.

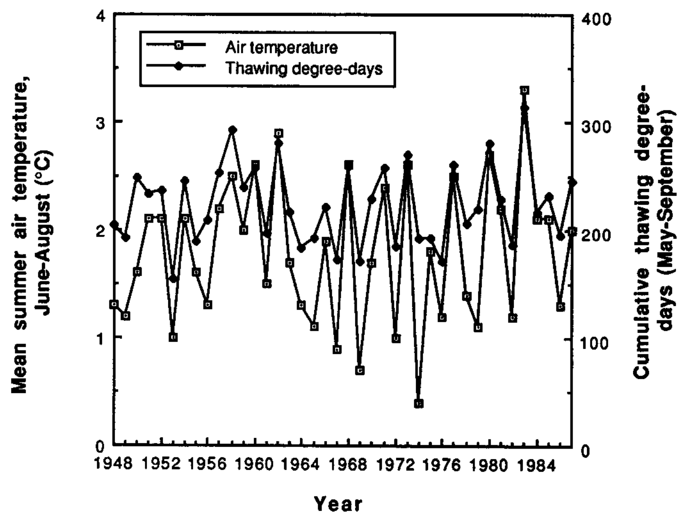

FIG. 8. Mean summer air temperatures and thawing degree-days for Rea Point, Melville Island, 1948–87, derived from measured values for 1969–85; for other years, air temperatures for individual months are estimated from linear regressions against Mould Bay means 1948–68, 1986–87 (June r^2=0.77; July r^2=0.68; August r^2=0.49); thawing degree-days are estimated for individual months from linear regressions against Resolute values (May r^2=0.35) and Mould Bay values (June r^2=0.57; July r^2=0.61; August r^2=0.43; September r^2=0.71).

CONCLUSIONS

First, perennial snowbank ice develops as a result of the superimposition of successive annual layers of basal ice. This ice has a number of distinctive characteristics that should assist in its identification in permafrost sections (e.g., Fujino *et al.*, 1988), notably a banded structure with randomly oriented irregularly shaped bubbles, small crystal sizes (Østrem, 1963) and the presence of mineral and organic layers. However, as first shown by Østrem (1965), detrital organic layers cannot be used for accurately dating the ice itself.

Second, tritium concentrations in the perennial ice permit a recent history of periods of growth and decay of the snowbank to be derived. The ice in the Ross Point snowbank is inferred to have fallen as snow 1) prior to 1957 (3.65–5.65 m depths), 2) between 1958 and 1962 (3.30–3.65 m), 3) between 1968 and 1976 (1.40–3.30 m), and 4) after 1983 (1.40 m depth to the ice surface). Major thaw truncations took place at the beginning of these periods and result in the absence of ice from the 1963 atmospheric tritium peak within the core.

Third, an increase in mean summer temperatures in the Arctic as a result of global climatic warming might have relatively little direct impact on the size of the Ross Point snowbank. The warmest summer in the last four decades (1983) did not produce the deepest thaw truncation. Energy balance calculations indicate that variations in snow accumulation may be more significant to the mass balance than probable changes in summer energy inputs. If climatic warming is accompanied by greater winter precipitation, it is possible that the perennial snowbank will increase in size.

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