GROWTH AND DECAY OF LAKE ICE IN THE VICINITY OF SCHEFFERVILLE (KNOB LAKE), QUEBEC

Introduction

The work was carried out at the McGill Sub-Arctic Research Laboratory, Schefferville, Quebec, 50°48′N. 60°49′W. (Fig. 1 inset). The surrounding terrain is typical of this lake plateau region. It lies 1,600 to 1,700 ft. above sea-level, is gently undulating with relief seldom more than 500 ft. Hare[1] estimated that 18 per cent of the area lying between 54° and 55°N. and 66° and 68°W. is covered by water. In the small area under consideration (Fig. 1) this proportion is considerably higher. Schefferville lies on the western flank of the Labrador Trough which is aligned about NW. to SE. and in which the majority of lakes are elongated in the same direction.

Two lakes, Maryjo, northeast, and Knob Lake, south of the laboratory (Fig. 1) were used to follow the growth and decay of lake ice and related phenomena during the winter 1961-62. Comparative data from other lakes in the vicinity were used to round out this work. A detailed study was made of the growth of "white ice" and of the conditions producing it. "White ice" often called "snow ice"[2], forms on the ice sheet when sufficient snow accumulates on the surface to depress it below water level. Water seeping through cracks forms slush which rapidly freezes[2,3,4] into ice which is milky white in section in contrast to the normal "black ice" which grows relatively slowly by freezing at the lower ice/water interface.

Attempts have been made to construct formulae[5] for the prediction of ice growth from meteorological data and the present study was particularly concerned with the limitations of such formulae for an area in which white ice forms an important part of the lake cover.

Previous work

Ice measurements have been made on Knob Lake since 1954 and since 1956 they have been made weekly at three sites, East, West and Centre (Fig. 1). Since 1959 measurements have been made at East, West and Centre on Maryjo Lake. Jones[6], Andrews and McCloughan[7], and Fletcher[8], have reported on this work.

Field work

The extreme length of Knob Lake is approximately 2 miles and it is a mile wide; Maryjo Lake is a mile long and half a mile wide. Occasional measurements were also made on Squaw and John lakes which are somewhat larger (Fig. 1).

Black ice, white ice, total ice and the depth of snow in the vicinity of each drill hole were measured weekly using a two inch "Snabb" spoon drill and standard Department of Transport measuring equipment[9]. In addition, one area of ice was kept clear of snow and at another a drift was induced to provide information about the effects of extremes of snow cover. Water temperatures were measured in the small stream connecting Maryjo and John lakes for a period before and after freeze-up. These were a close approximation to surface water temperatures in local lakes.

Lake ice growth and decay

The winter ice season can be subdivided into the Pre-Freeze-up, Freeze-up, Post Freeze-up and Break-up periods. The general pattern of development during these periods has been described by Currie[10].

During Pre-Freeze-up, approximate water temperatures were obtained using an Ordinary thermometer and Maximum and Minimum thermometers. The maximum temperature (59.4°F., 15.2°C.) was obtained on the first day of measurements, 8 August 1961, in Maryjo Lake. The lowest temperature recorded was 32.6°F. (0.3°C.) on 23 October at the surface of Knob Lake. On 10 November the last temperature obtained was 32.8°F. (0.4°C.) at the outlet of John Lake.

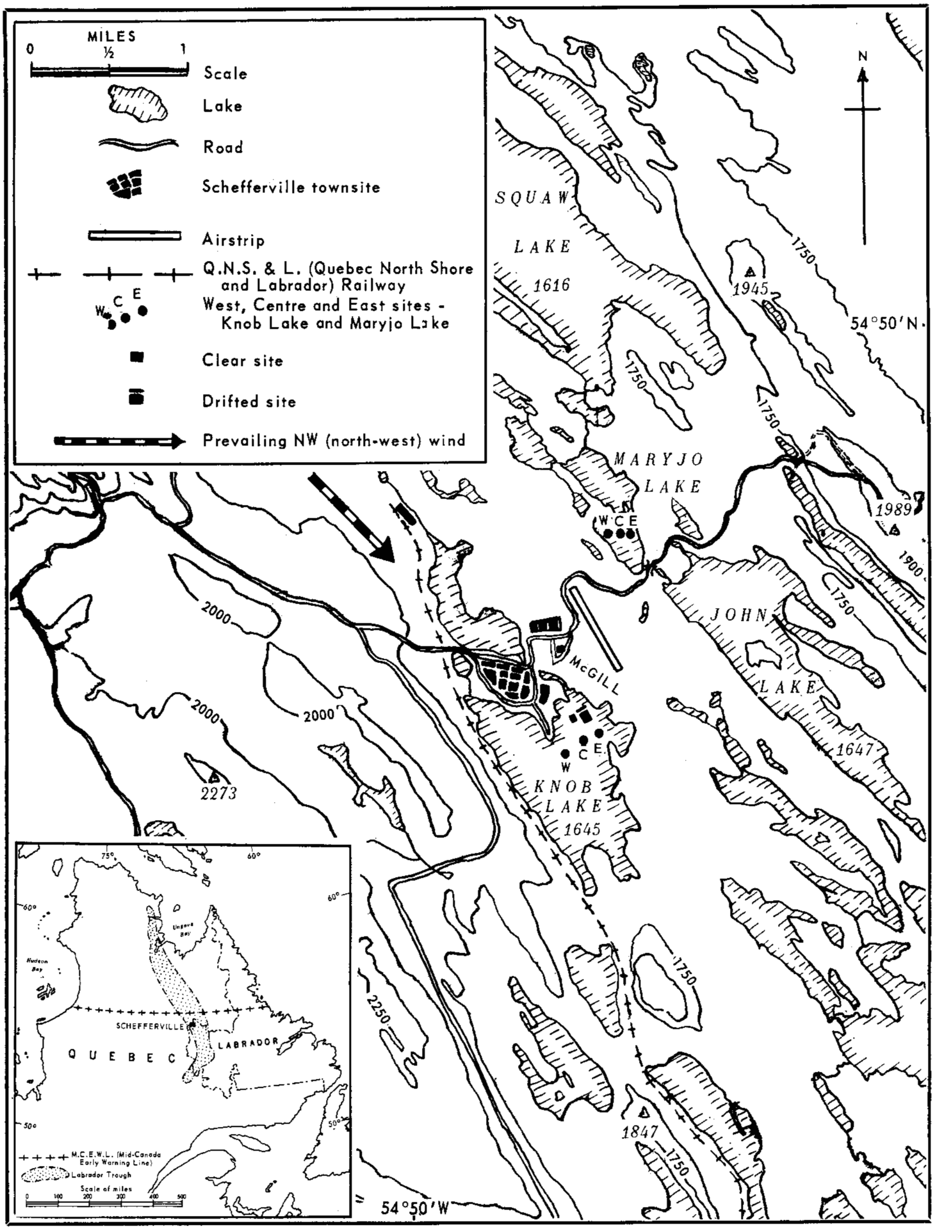


Fig. 1. Labrador-Ungava, showing Schefferville and vicinity.

Maximum lake depths measured were only 30 ft. The greatest range of temperature in this depth was 3.1°F. (1.7°C.) on 28 August as compared with a minimum range of 0.2°F. (0.1°C.) on 9 October. There was a steady decline of water temperatures during the period (Fig. 2) with diurnal effects in the thin surface layer.

The Freeze-up period has varied from a few days to a month in the Schefferville area. In 1961, thin ice formed on shallow bays between 15 and 21 October and a Freeze-over[11] occurred on Knob Lake and Maryjo Lake over 22-23 October, a calm clear night with a minimum air temperature of 8°F. (−13.3°C.). John Lake did *not* attain a complete ice cover on this date. During the succeeding two weeks the mean air temperature of 27°F. (−2.8°C.) was not sufficiently low to offset the effects of conduction in the undisturbed water layers beneath the ice (Fig. 2) so that the two lakes were 50% clear by 6 November. The Freeze-up[11] occurred on the following day by which time 139 freezing degree-days (based on 32°F. and 1 July) had accumulated compared with a mean of 130 for the Pre-Freeze-up period for the years 1956-61 and 175 estimated by Hare[1] as the approximate number necessary for Freeze-up.

After Freeze-up, periods of steady ice growth at the ice/water interface, controlled by the usual factors[5], were interrupted by short periods in which the growth rate increased rapidly. This increase was due to the laying down of white ice at the ice/snow interface. During and immediately after these periods of white ice growth, the correlation between the rate of ice growth and accumulating freezing degree-days was extremely poor (Fig. 3). These phases of growth were generally not concurrent between lakes or between locations on the same lake but the general nature of the pattern on Knob Lake in 1961-62 appeared to be typical for other lakes in the area.

The mean ice thickness for the three Knob Lake sites on 17 November 1961 was 9 in. There was little change in this value in the following 2 weeks (a slight decrease in thickness was noted at one site) due to the insulation of a moderate snow cover. This was despite mean air temperatures of 25°F. (−3.9°C.). However, during the week preceding 8 December, each site gained some 3 in. of white ice. On this occasion the increment appeared to affect most of the lake but subsequent white ice growth varied considerably between the measuring sites and over the lake as a whole.

At the West site, ice thickness increased slowly until 29 December by increments mainly at the ice/water interface. During the following two weeks 2½ in. of slush were laid down and

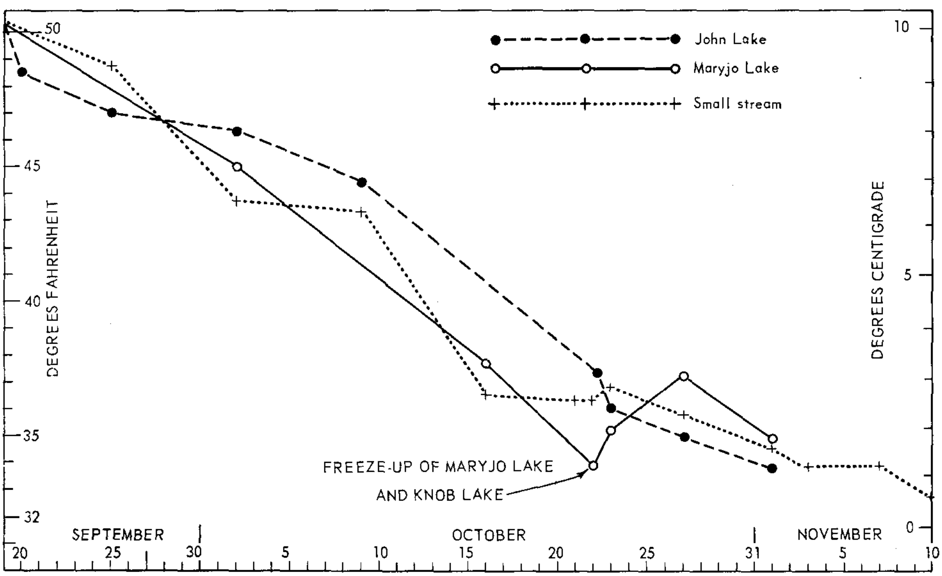
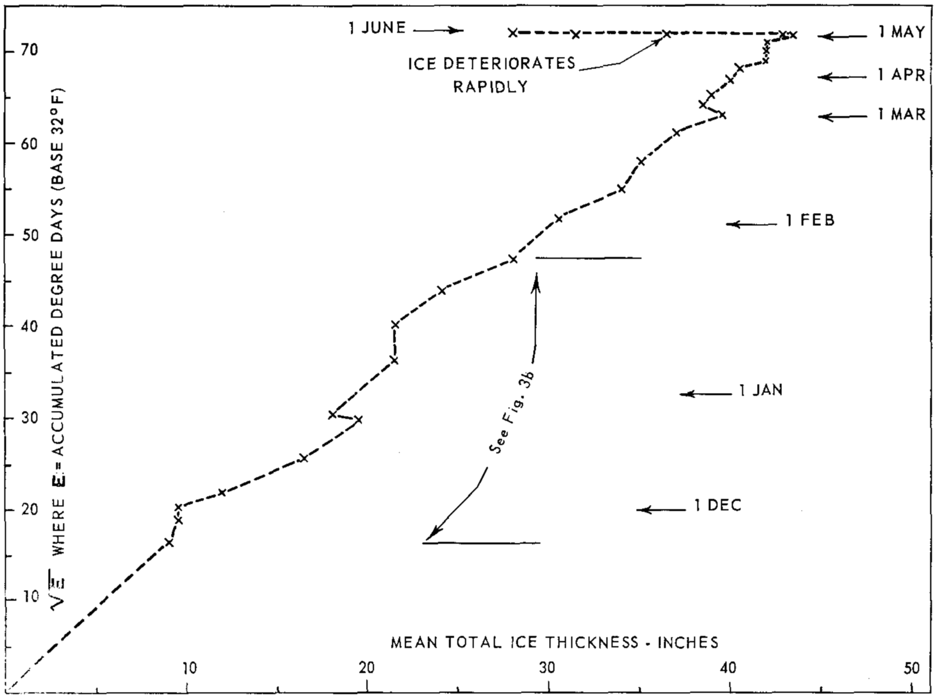


Fig. 2. Decline of surface water temperatures in John Lake, Maryjo Lake and a small stream connecting the two from 19 September to 10 November 1961.



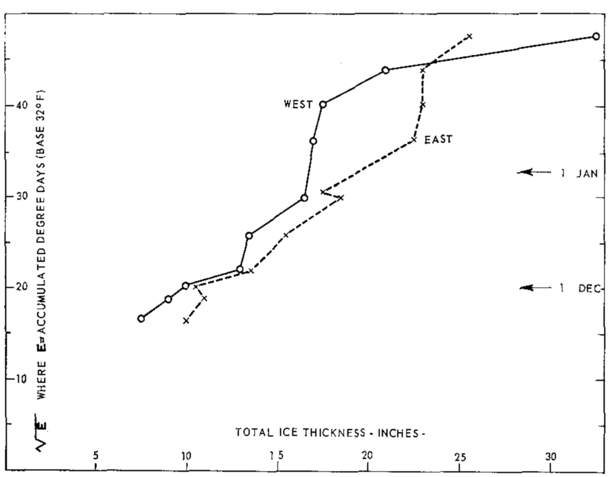


Fig. 3a. Mean total ice thickness for the three sites on Knob Lake against $\sqrt{E}$

Fig. 3b. Data from East and West measuring sites similarly plotted during this most active period of white ice growth.

froze to form white ice by 12 January. The ice at this site was still relatively thin (Table 1) so that a third phase of white ice growth was initiated by the 17 in. snowfall of 12/19 January (Fig. 4). The smooth white ice surface, which resulted from the complete saturation of the snow cover, remained relatively snow free throughout the winter thus promoting the rapid growth of black ice. The lack of snow and the great thickness of ice (52½ in. on 20 April 1962) prevented further white ice growth. This site provided an excellent example of the ice *building* potential of a heavy snow cover.

Ice growth at the Centre site was erratic (Fig. 5) and 2 further periods of rapid white ice accumulation were recorded. After 8 December the relatively thin ice cover underwent further slushing producing an increase of 14½ in. of white ice by 22 December. The last significant increase of white ice was measured on 19 January. A considerable depth of snow remained on the surface as the slush layer which produced the final increment was relatively shallow. The maximum total ice thickness at this site was 41½ in. on 4 May 1962.

At the East site only one more period of rapid white ice growth occurred after 8 December; this was measured on 12 January. After this the black ice thickness increased slowly with few anomalous measurements to a maximum of 37½ in. on 4 May. The snow cover was relatively thin throughout the winter.

In Table 1 the phases of growth described (periods of normal ice growth ending with an abrupt increase in white ice) are picked out. The increments of white ice are accompanied by a sudden decrease in the snow cover. Generally the greatest increase in ice thickness occurred where the depth of snow was greatest in proportion to total ice thickness. This has also been observed in relation to the growth of sea ice[12]. Even allowing for the insulating effect of the snow cover there is little correlation between mean air temperatures and ice growth during the period when white ice was forming. This amounts to about half the season (Table 1). The lack of correlation between accumulating degree-days and total ice during December and January can be seen from Fig. 3b. It would appear that, in various combinations, the controlling climatic variables will produce growth phases of different duration and magnitude. For

Table 1. Knob Lake

Date	*Total ice* (in.)	*White ice* (in.)	*Snow depth* (in.)	*Accumulated*† *snow* (in,)	*Mean air*† *temp.* (°*F.*)	*Phases of Ice Growth*
West Site						
17 Nov.	7½	0	0	5	20	
24	9	0	2½	3	20	1
1 Dec.	10	½	20	15	25	
8	13	4	6	5	20	
15	13½	4	4	4	7	
22	16½	4	6	3	− 1	
29	16½	4	15	14	24	2
5 Jan.	17	5½	9½	1	−19	
12	17½	6½	14	3	−12	
19	21	10	15	17	−10	3
26	32½	16	5	3	−17	
Centre Site						
17 Nov.	10	0	0			
24	9½	0	2½			1
1 Dec.	8½	½	7			
8	10	3	8			
15	20	—	4			2
22	24½	10½	2	*see above*		
29	20	10	16			
5 Jan.	25	12	12			
12	24	14	12			3
19	28	14½	11			
26	26½	14½	11			
East Site						
17 Nov.	10	0	0			
24	11	2	3			1
1 Dec.	10½	3	20			
8	13½	4	8			
15	15½	4½	2			
22	18½	4½	3	*see above*		
29	17½	4½	17			2
5 Jan.	22½	4½	8			
12	23	7	10			
19	23	7½	8			
26	25½	7	9			

†Values measured at McGill Sub-Arctic Research Laboratory.

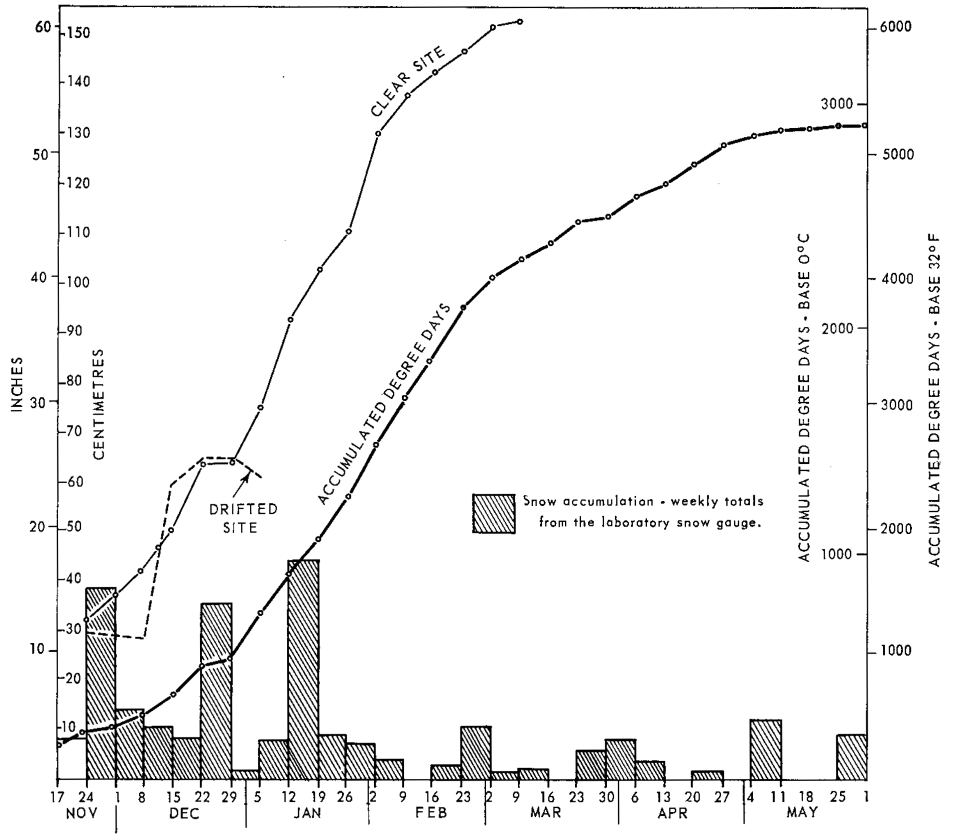


Fig. 4. Ice (total) growth curves for the Clear and Drifted sites — Knob Lake 1961-1962.

example, a combination of low temperature, snowfall and strong winds would promote black ice growth and reduce the frequency of periods of white ice growth, whereas a combination of high temperature, snowfall and light winds would increase the proportion of snow to total ice and thus promote white ice growth. This control is apparent in the annual development of white and black ice during the 8 years of measurement on Knob Lake. The amount and distribution of snowfall in early winter seems especially important.

Throughout November and December 1961, above average temperatures and snowfall and average winds created near optimum conditions for slush formation, hence the occurrence of 2 or 3 periods of white ice growth on most of the lake surface. The 17.4 in. snowfall during the week 12/19 January was sufficient to initiate a third major phase at the West site because it had 6 inches less total ice than the other two sites.

From 19 January to 4 May only a further 20 in. of snowfall was recorded and most of this was blown off Knob Lake. The variations in timing and magnitude of the phases in different parts of the lake significantly affected final total ice thickness.

Break-up, in a broad sense, begins when the ice reaches its maximum thickness and on Knob Lake and other lakes in the Schefferville area the Break-up followed a well defined pattern (Fig. 5).

Increasing insolation and greater diurnal ranges of air temperature produced the first signs of melting in the snow cover in early March. Wind crusts softened and film crusts developed[13]. Ridges in the snow surface became less well defined and thawing was aided by the presence of dust in the snow cover. Deterioration of the ice sheet itself was hardly perceptible during March, and occasional reversals in the warming trend produced hard crusts on the thinning snow cover and the ice regained some of the brittleness characteristic of mid-winter. A moderate fall of snow combined with low temperatures in early May brought the accelerating process of decay to a temporary halt.

The erratic trends of the ice growth curves for the East and Centre sites late in the season (Fig. 5) gave no clear indication of when the melting of the ice began. This was in strong contrast to the relatively smooth growth curve of the West site. A definite thinning of the ice at the latter site was first measured on 4 May immediately it became clear of snow; this was two weeks earlier than at the other sites which retained a snow cover.

Once the snow had gone the ice sheet thinned rapidly at both the upper and lower surfaces. Candling[6] and other symptoms of decay were observed during late May and early June. The ice sheet melted away from the shores producing a shore lead which prevented further access to the measuring sites after 1 June 1962.

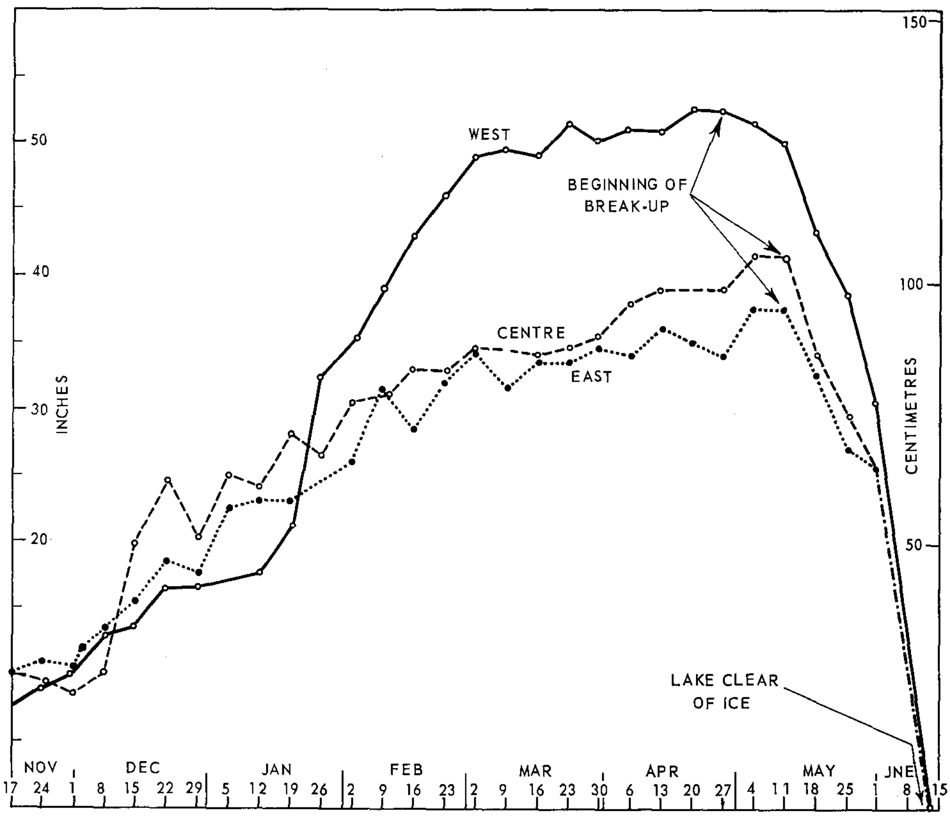


Fig. 5. Total ice thickness curves for 3 sites on Knob Lake 1961-1962.

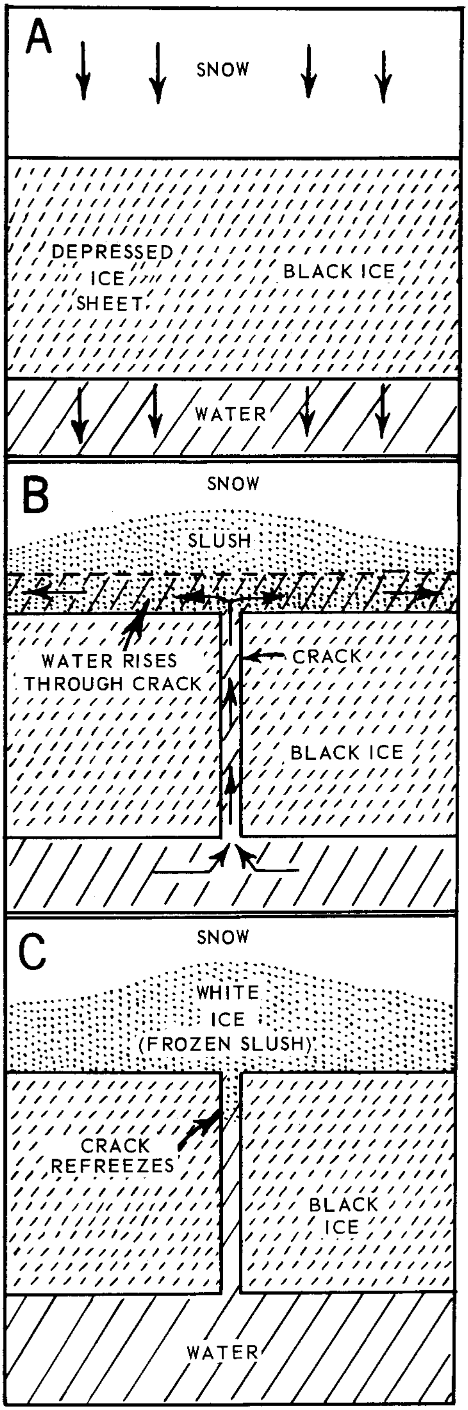


Fig. 6. The three stages in the formation of white ice.

A. Ice sheet depressed by weight of snow cover.
B. Ice sheet cracks and water infiltrates the snow cover to form a layer of slush.
C. Slush layer freezes to form white ice.

White ice

After the last important period of white ice growth, 27 to 55 per cent of the ice at the measuring sites was white ice. At the peak of the season, when total ice had reached its maximum thickness it was only averaging 28 per cent. In other years on Knob Lake it has ranged from 21 to 46 per cent with an average for 7 years of 34 per cent at the end of the season.

The importance of white ice has been widely recognised and here measurements at 6 sites and other random drillings in 1961-62, brought out the great variations in it.

White ice, as already described, forms when the ice sheet is depressed by its snow cover (Fig. 6). In some cases the distribution of the weight of the snow cover may be sufficient to initiate cracking, in other cases cracking may arise from different causes, but produces flooding only where the surface of the ice sheets is depressed below water level. The condition of the snow cover at the time of flooding, especially its temperature, greatly affects the extent of white ice formation and the character of the white ice. For example, at the East site on Maryjo Lake between 12 January and 2 February 1962 total ice thickness increased from 18 to 33 in. A deep snow cover produced a slush layer of over 13 inches which, because of the now thinner snow cover and the low prevailing air temperatures, was able to form white ice. The character of the 5½ in. of white ice which had been present on 12 January and the top 5 in. of new white ice which formed very quickly, were very different from the layer of ice which formed more slowly between the two (Fig. 7). Throughout this period the West site on Maryjo Lake, which had only a 4 in. snow cover, gained a mere 5 in. of black ice.

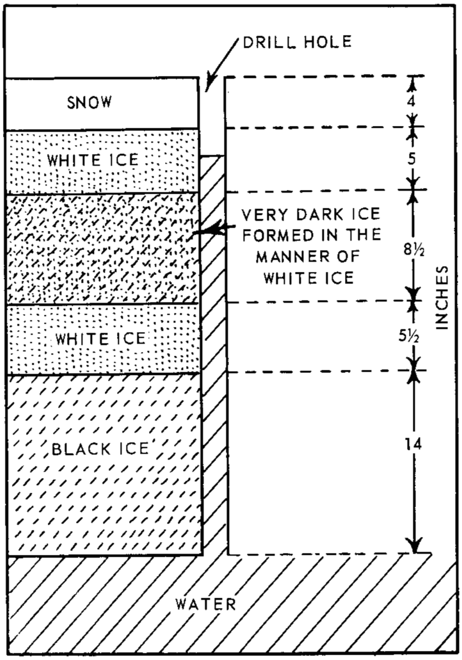


Fig. 7. Ice profile — East site on Maryjo Lake, 2 February 1962.

A slushed-over area on Knob Lake was examined (Fig. 8). In the diagram the localised nature of slushing and the effect of the capillarity of the snow cover can be seen. The addition of water to the snow cover must further submerge the ice sheet and extend the flooding. Mounds of white ice formed in this way tend to limit the movements of later incursions of water over the ice sheet.

The ability of the snow cover to retard or promote ice growth is clearly illustrated in Fig. 4. Ice growth at the site which was kept clear of snow (Fig. 1) reflected the accumulation of degree-days whereas the Drifted site at first showed the effects of the insulation of its snow cover but then, by 29 December, developed a greater ice thickness than the Clear site due to induced slushing and white ice formation. The maximum thickness recorded at any of the 6 measuring sites on this date was 20 in. at the Centre site on Knob Lake.

The great variations in white ice growth in the Schefferville area and on

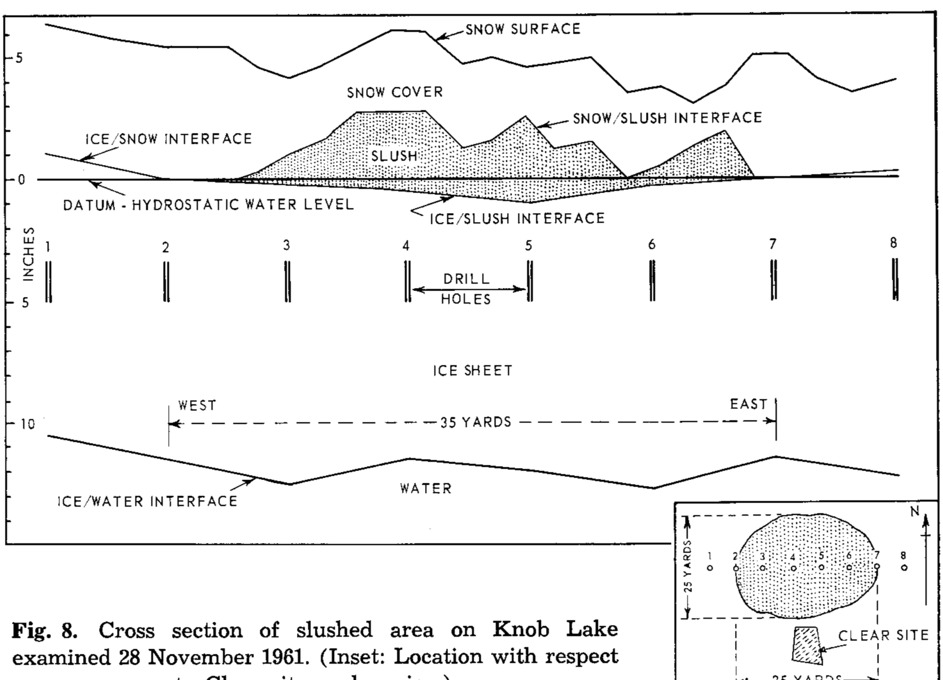


Fig. 8. Cross section of slushed area on Knob Lake examined 28 November 1961. (Inset: Location with respect to Clear site — plan view).

Knob Lake itself in 1961-62 and the considerable differences in its importance at the measuring sites during each season since measurements began, indicate that white ice measurements must become a normal part of ice surveys if its full significance is to be made clear. There is no reason to believe that this area, with relatively cold winters and moderate snowfall, is particularly susceptible to the development of white ice. At least one example of an ice sheet being 100 per cent white ice has been recorded: Frankenstein[14] says that "In December 1955, Dr. Andrew Assur and the author tested the ice on Lake Anne, near the Keweenaw Field Station (U.S.A. SIPRE field station near Houghton, Michigan). The ice was *all* snow ice with its temperature very near 0°C".

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[1]Hare, F. K. 1950. The climate of the eastern Canadian arctic and sub-arctic and its influence on accessibility. Doctoral Thesis, University of Montreal (unpublished).

[2]Butkovitch, T. R. 1954. Ultimate strength of ice. U.S. Army Snow Ice and Permafrost Research Establishment, Corps of Engineers, Res. Rep. 11, 12 pp.

[3]Persson, B. O. E. 1954. Durability and bearing capacity of an ice layer. Investigations of construction and maintenance of airdromes on ice, 1953-54. Arctic Construction and Frost Effects Laboratory, New England Division, Corps of Engineers, U.S. Army, ACFEL Translation 22, 19 pp.

[4]Andrews, J. T. 1962. Variability of lake ice growth and quality in the Schefferville region, central Labrador-Ungava. Journ. Glaciol. 4:337-347.

[5]Callaway, E. B. 1954. An analysis of environmental factors affecting ice growth. U.S. Navy Hydrographic Office, Technical Report 7, 31 pp.

[6]Jones, K. J. 1958. Fresh water ice in Quebec-Labrador and its utilization by aircraft. McGill Sub-Arctic Research Papers No. 4, pp. 59-87.

[7]Andrews, J. T. and C. H. McCloughan. 1961. Patterns of lake ice growth on Knob Lake. Ann. Rep., McGill Sub-Arctic Res. Pap. No. 11, pp. 64-89.

[8]Fletcher, D. J. 1962. Ice thickness report for the winter of 1960-61. Ann. Rep., McGill Sub-Arctic Res. Pap. No. 12, pp. 53-64.

[9]Manice. 1959. Manual of standard procedures and practices for ice reconnaissance. Cir-3188, Ice-3, 23 April 1959, Dept. Trans. Meteorolog. Br.

[10]Currie, B. W. 1953. Prairie provinces and Northwest Territories ice soil temperatures. Physics Dept., Univ. Sask., 28 pp.

[11]Shaw, J. B. 1963. Ice survey Knob Lake 1961-62: a critical re-evaluation of main environmental factors of lake ice growth. Ann. Rep. 1961-62, McGill Sub-Arctic Res. Pap. No. 15, pp. 34-60.

[12]Weeks, W. F. and O. S. Lee. 1958. Observations on the physical properties of sea-ice at Hopedale, Labrador. Arctic, 11:135-155.

[13]Klein, G. J., D. C. Pearce, and L. W. Gold. 1950. Method of measuring the significant characteristics of a snow cover. National Research Council of Canada Associate Committee on Soil and Snow Mechanics, Tech. Mem. No. 18, 22 pp. and append.

[14]Frankenstein, G. E. 1959. Strength data on lake ice. U.S. Army Snow Ice and Permafrost Research Establishment, Corps of Engineers, Technical Report 59, 6 pp.

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W. K. Kellogg Foundation grant

The University of Alaska has announced the receipt of a five year grant of $336,520 from the W. K. Kellogg Foundation for investigations of the suitability of the musk ox as a domestic animal for use in the Far North. The project is to be administered by John J. Teal, Jr., Professor of Animal Husbandry and Human Ecology, who has already captured the breeding herd. Preliminary research has been carried out since 1954 by Professor Teal and the Institute of Northern Agricultural Research upon a herd located in Huntington Center, Vermont.