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ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

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Palaeobotanical Method in the Prediction of Sub-Surface Summer Ice Conditions in Northern Organic Terrain

by

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Palaeobotanical Method in the Prediction of Sub-Surface Summer Ice Conditions in Northern Organic Terrain

By NORMAN W. RADFORTH
Presented by G. KROTKOV, F.R.S.C.

PERMAFROST in Alaska and in the Canadian north is claiming increasing interest within the broader subject of terrain interpretation. It is prominent in the list of factors pertaining to northern development where agriculture, forestry, mining, and military planning are involved. Engineering construction and transportation are among many activities which because of permafrost must deal with circumstances not encountered in the south.

The extensive organic terrain characterizing much of the north is physically one with the permafrost, the latter being as important a component of the organic terrain as water is of mineral soils in the south. Though it has not been emphasized in the literature, the influence of permafrost is probably due to the properties of its active layer for which the expression "climafrost"* is in use in our laboratory.

It is with the climafrost and its relationships to northern organic terrain that this paper deals. The main purpose is to bring to light the chief types of frost phenomena contributing to the physiography of the terrain, to investigate their character relative to variation in muskeg constitution, to ascertain whether their presence is predictable, and to explore their usefulness as topographic agents in surface characterization of muskeg.

Examination of frost behaviour was made during the summer months in the region of Churchill, Manitoba, over a period of three years. Attempts to include in the study all characteristic types of organic terrain were encouraged.

In order to assist the reader in appreciating the results, reference should be made to work that preceded the frost studies. This is recorded elsewhere, and deals with the recognition of organization in organic terrain (1) and with the use of plant materials in predicting sub-surface change in its constitution (2). In both papers, vegetal coverage, the living component of the organic layer, was identified by combinations of class letters which described the coverage in terms of composite structural qualities rather than on the basis of plant names. Of the combinations of letters used, some were applied more frequently than others and were representative for most of the area geographically. A list of these coverage formulae is given in Table I, where their meanings in terms of vegetation structure are

*Suggested by W. J. Thorne, Research Assistant, McMaster University, to designate that part of the permafrost affected by seasonal climatic factors.

TABLE I

Sites of Occurrence for Sub-Surface Ice Phenomena

Coverage formula	Structure
HE	low, non-woody, of leathery texture, in mostly continuous mats, with low woody shrubs
FI	non-woody, grass-like clumps or patches, sometimes touching, with non-woody, low velvety plants, often in continuous mats
EH invading BEH	woody, low shrubs, with low, non-woody, stemless, leathery plants in mostly continuous mats
ABH, BHE	woody, tree-forms, with low, non-woody, leathery plants in mostly continuous mats and low woody shrubs
ABE	woody, tree-forms of varying height (from 5 to 15 feet and over), with low, woody shrubs

also expressed. The coverage formulae mentioned in the table are those to which the significant information about ice-form applies. Because of their relationship to large areas of terrain, it will be clear that the characteristics of the ice will be widely applicable in the Churchill area.

Sub-Surface Ice Forms

Discontinuous Forms

The retreat of winter conditions is followed by the occurrence of isolated and somewhat distinctive ice phenomena. These are of three main categories:

Type I. Vertical Free Lift (Fig. 1).
Type II. Vertical Confined Lift (Fig. 5).
Type III. Displacement Fault (Fig. 7).

Type I is characterized by localized heaving resulting in the upward thrust of irregular ice masses frequently exposed to view and capped by disrupted patches of the living and dead organic overburden.

Type II resembles Type I in that upward thrusting is involved. The evolution of the formation, however, differs. The effect of the vertical force is somewhat confined, with the partly frozen organic matter, depending upon its elasticity, gradually forming a dome above the disturbance. The process takes two to three weeks and the amplitude of the dome is from two to three feet. Following this, the cohesiveness in the organic roof

Figure 1.—Ground photograph showing the effect of Type I ice phenomenon (Vertical Free Lift). Figure 2.—Site typical for Type V ice phenomenon (Pond Hole) and in background site for Type VIII (Multiple Knoll). Figure 3.—Aerial view showing effect of Type IV ice phenomenon (Polygon Differential). Figure 4.—Irregular terrain of exposed and hidden boulders, site for Type VII ice phenomenon (Boulder Locus).

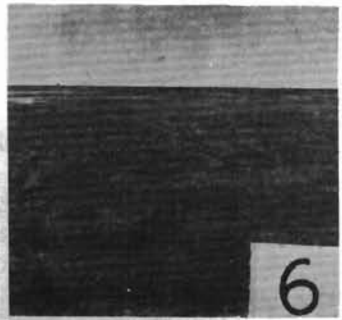

FIGURE 5.—Water-spout resulting from effect of Type II ice phenomenon (Vertical Confined Lift). FIGURE 6.—Ground photograph showing irregularities in terrain (ridges) characteristic for Type VI ice phenomenon (Ridge Elevation). FIGURE 7.—Fissured terrain resulting from the effect of Type III ice phenomenon (Displacement Fault).

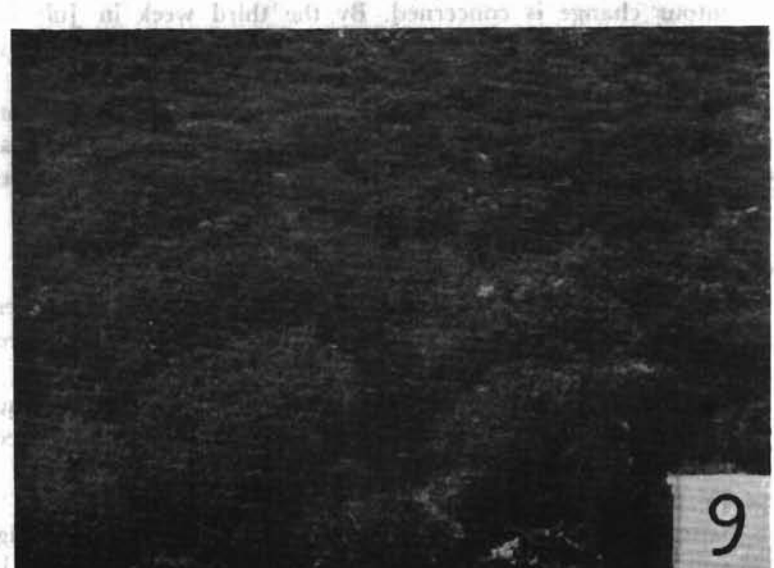

FIGURE 8.—Ground photograph showing change in topography at site of ice wedge in Type IV (Polygon Differential). FIGURE 9.—Irregular terrain showing "mounding" condition often resulting from the effect of Type VI (Ridge Elevation).

breaks down and a gush or water-spout issues forth. The water ejected maintains a steady stream rising about a foot in the air and subsides within a day or two. Flow may continue thereafter for an indefinite period depending upon local terrain conditions and water potential.

Type III arises as a result of action from lateral forces and results in the splitting of the terrain followed by horizontal displacement. The crevasse so formed is usually not deep (20 to 26 inches) but the splitting may go deeper into the mineral substratum. On the surface, one crevasse was traced for about 75 feet, but many examples are shorter. Lateral displacement is usually not more than one foot at the widest point at ground level.

Whereas Type III affects terrain composure in the linear sense, I and II disturb in terms of area so far as visual effects are concerned. The visible influence of the vertical free lift (Type I) is normally much more extensive than that of the vertical confined lift (Type II). The former may disrupt areas of as much as 10,000 sq. ft., whereas the latter disturbs usually not more than 25 sq. ft. Ultimately, however, slight subsidence in the area surrounding the ruptured dome may somewhat extend the area of physical deformity.

Each of the types mentioned represents a transient condition so far as terrain-contour change is concerned. By the third week in July in the vicinity of Churchill, visible detection of any of the types is difficult if not impossible.

Sites of occurrence for Types I and II are almost invariably found in organic terrain designated by coverage formulae FI or occasionally I (Table I). Type III, on the other hand, characterizes terrain supporting the BEH category of coverage (Table I).

Continuous Forms

Ice patterns of wider influence, which contribute more fundamentally to the physical character of the terrain in the summer, are not so readily recognized.

In the course of palaeovegetographical study (1, p. 12) sub-surface inspection has revealed variation in contour of the climafrost as it recedes. Four main contour patterns are common.

Type IV, Polygon Differential (Figs. 3, 8).

This pattern, represented in section in the schematic diagram Fig. 10, remains consistent in form until September when its identity is partly lost through melting. Until nearly the end of July its form persists no more than 20 inches below the surface of the organic matter and still high within it. Towards the end of August, it is still to be found within the organic matrix and in some cases persists up to the third week in September when frost conditions start the winter cycle at the surface. The wedges marking the margins of the ice polygons conform to the topographic character. (Fig. 8). The ice-surface plateau across the face of each ice polygon there-

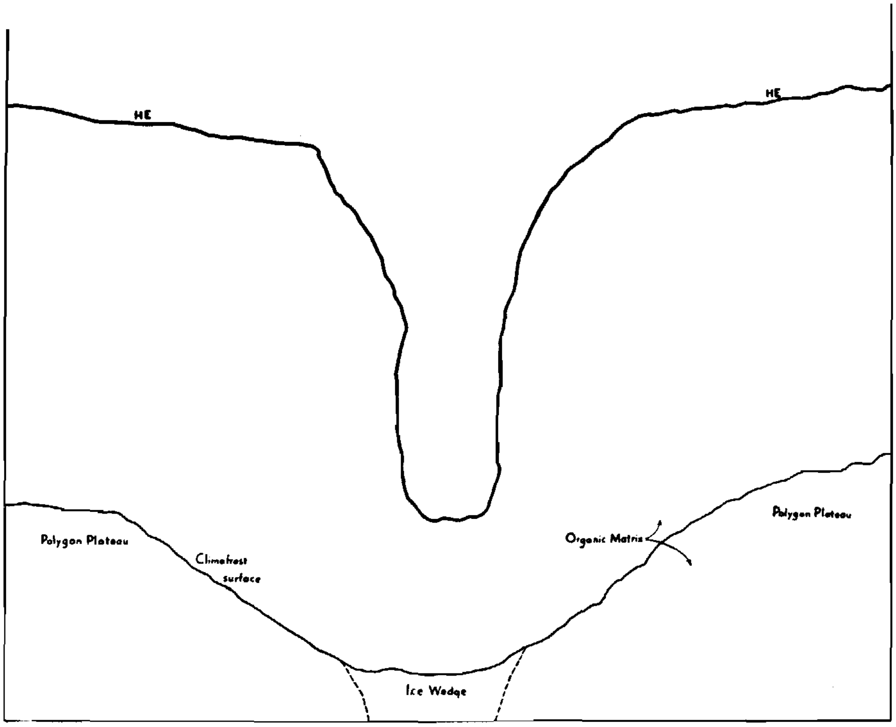

FIGURE 10.—The junction of two polygonal areas seen in sectional view, horizontal scale 1" = 28", vertical scale 1" = 8".

fore varies with the corresponding dimension measurable at the terrain surface. This distance may vary from 5 or 6 feet to about 50 feet. The ice at the wedges usually has less organic matter in it, is often aerated, and fractures very irregularly. That towards the centres of the polygons is normally impregnated with peat except for occasional ice lenses which vary in thickness from a few inches to a foot in depth. Until August the frozen peat is highly resistant to mechanical stress and repels the cutting edge of ordinary hand drills when attempts are made to drive them in with a sledge hammer.

It is hoped that this account of the ice features associated with the polygons will appropriately augment the account of polygon classification admirably devised by A. L. Washburn (3).

Type V, Pond Hole (Fig. 2).

This type, represented in section by Fig. 11, is also of frequent occurrence. That part of the ice contour adjacent to open water recedes in depth faster than the remainder of the contour as the summer thaw advances. Thus high shoulders of ice may be found adjacent to ponds or drainage reservoirs.

It will be noted in the composite diagram, Fig. 12, which is derived from actual measurement in the field, that the configuration is almost bilaterally symmetrical about a vertical axis running through the water.

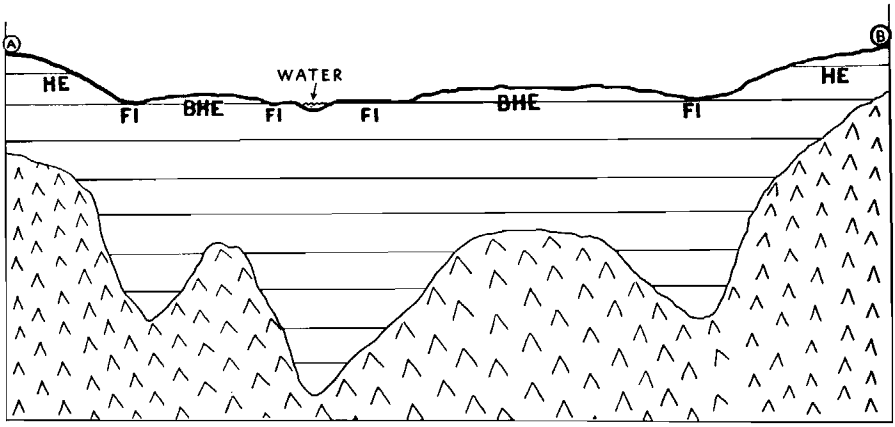

FIGURE 11.—Sectional view of ice contour change (lower line) for Type V (Pond Hole, cf. Fig. 12).

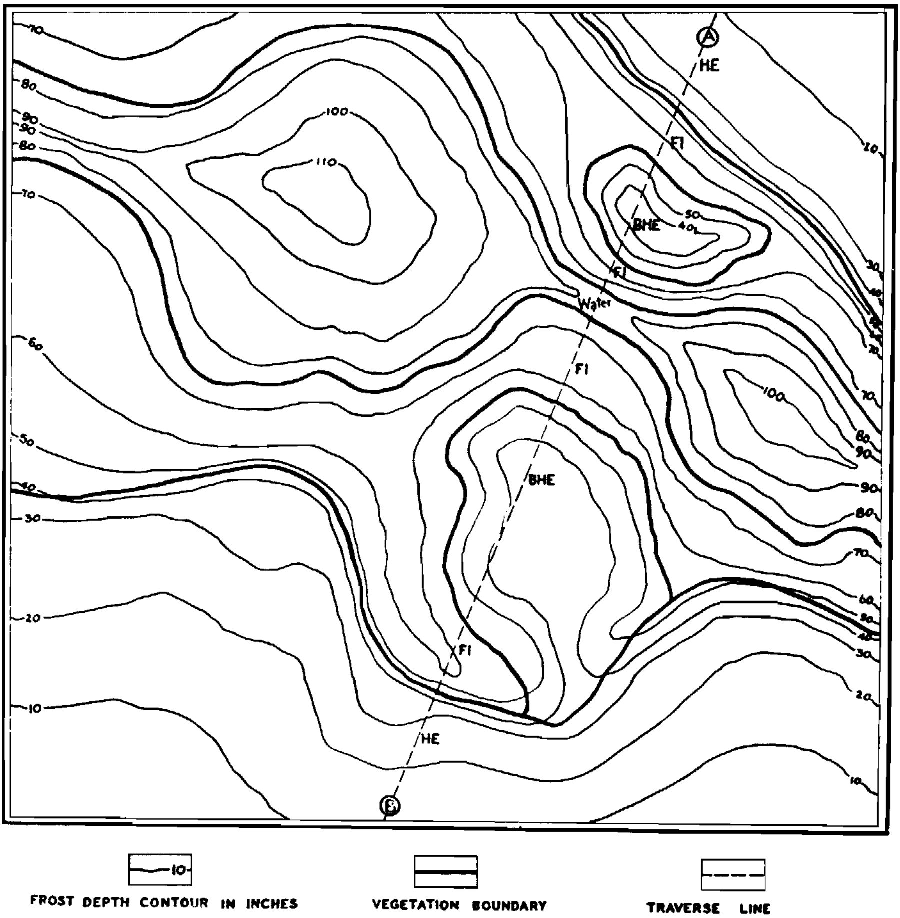

FIGURE 12.—Type V permafrost contour map.

Since reservoirs of this nature are of frequent occurrence and ice contour is characteristic for the physiographic condition, the contour pattern is correspondingly prevalent. Only the ratios of amplitudes of the peaks and depressions change with season; the basic pattern remains as a seasonal feature even though by mid-September the ice represented by the central part of the curve (Fig. 11) thaws to a level below the organic matter.

Type VI, Ridge Elevation (Fig. 6).

The ice contour line rising into the peaty shoulder in Fig. 11 eventually flattens out unless polygons are encountered or unless relatively poor drainage conditions obtain. In the latter circumstances, the contour line will lower. In this kind of terrain, however (Fig. 6), ridges of different lengths are often in evidence topographically. Sometimes they form concentric arcs of very shallow curvature. If, on the other hand, the ridges are irregularly disposed, they are much broken and the segments are often so short that their length hardly exceeds their width, and a "mounding" condition exists (Fig. 9). Notwithstanding this, the ice contour is high in the sub-surface directly beneath the ridge; hence, the marked irregularity shown in the section (Fig. 13).

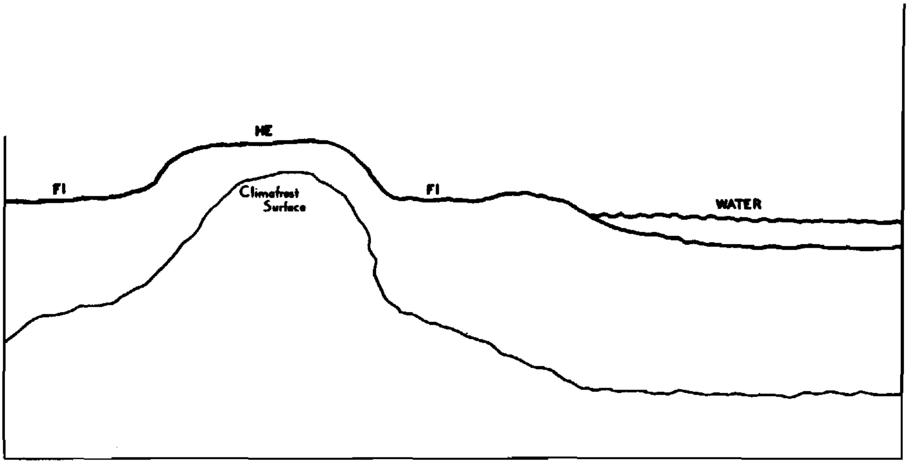

FIGURE 13.—Ice surface contour for Type VI (Ridge Elevation) seen in cross section. Scale, horizontal and vertical 1″ = 5.6′.

Type VII, Boulder Locus (Fig. 4).

Where rock intrusions exist in the organic layer, depth of frost may be to some extent a function of the thickness and type of the organic overburden characteristic of the area. It is more likely, however, that the ice contour is controlled by drainage conditions. The contour pattern shown in Fig. 14 is typical for frost-depth measurements on a traverse through a boulder site.

Type VIII, Multiple Knoll (Fig. 2, wooded background).

It is difficult to construct a type-configuration curve for this contour form. The reason lies in the presence of many combinations and disposi-

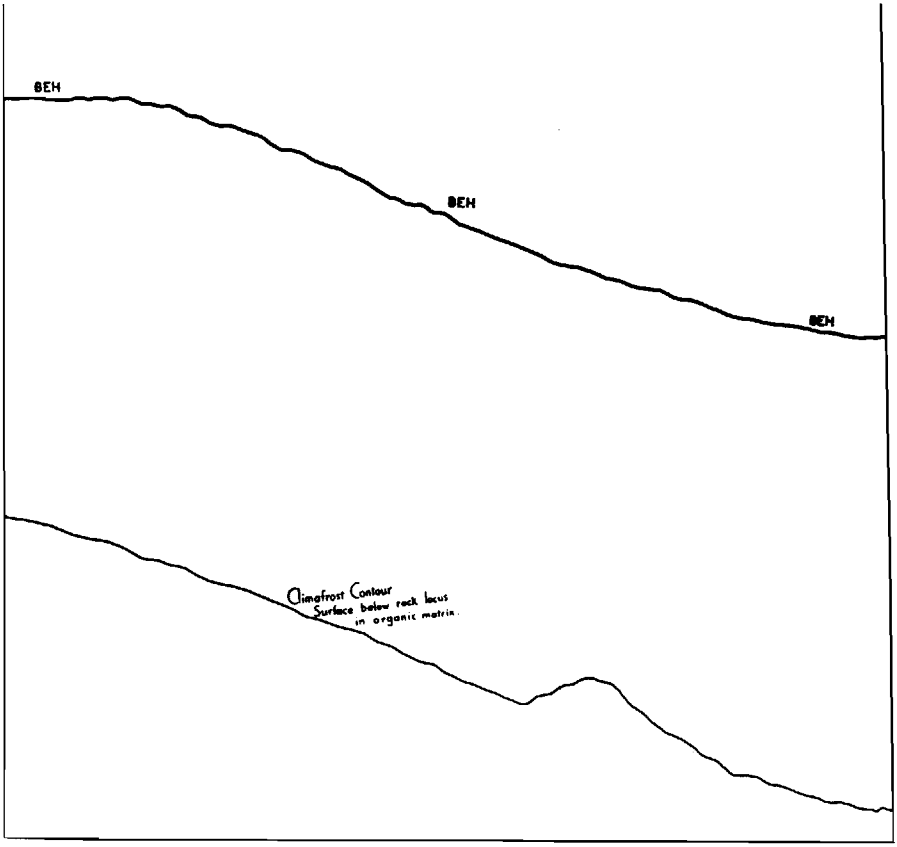

FIGURE 14.—Ice contour for Type VII (Boulder Locus) seen in section. Vertical scale 1″ = 20″.

tions of small and large knolls which constitute the elevated ice plateaus formed by the knolls. The top curvatures of the knolls differ in the length of their horizontal axes on an average of from one to four feet. Also, the extremities of their amplitudes come at different heights. These features are easily appreciated when an observer attempts to traverse the terrain either in a vehicle or on foot. On the other hand, though the ice knolls can be detected as they are passed over, they cannot always be seen. Often the inter-knolls, so far as surface topography is concerned, are packed with growth which attains a height approaching that of the plants growing on the knolls, suggesting that the whole area in question is a level plateau with irregular sides.

In many cases, intermittent curves of horizontal, long tree-roots, and woody thickenings caused by two or more roots overlapping, form the nuclei for the knolls. Here, following the first week in August, knolls diminish in size rapidly though their presence can still be detected at the end of the same month.

Climafrost Relations with Macrofossil Constitution of the Organic Terrain

In the description of the multiple-knoll type of climafrost contour, there is suggestion of relationship between sub-surface vegetal parts and the ice contour pattern. It is frequently the case that the woody cores of the knolls are not root parts of present-day trees but preserved woody segments of trees of past generations. Indeed, such macrofossils characterize the areas where knolling effect prevails.

It has been demonstrated elsewhere, that the sub-surface constitution of the organic terrain varies widely depending upon size, form, frequency, and placement of the fossil components in the matrix (2). Because of this variation, frost depths were measured in all types of muskeg that commonly constitute the terrain. Results of the analysis show that mean depths to frost line for types of peaty coverage differed. Relationship among the means is expressed in the diagram Fig. 15. Further comparison between muskeg type and climafrost contour type is given in Table II (cf. columns 2 and 4).

It should be emphasized that where structural constitution of the organic matter is uniform in depth and uninterrupted across the terrain, irregularity of ice-form contour is slight. It is equally important to stress, however, that the depth to the frost line will differ depending upon the macrofossil constitution of the muskeg type in question.

With seasonal shift, change in ice-form contour proceeds more rapidly

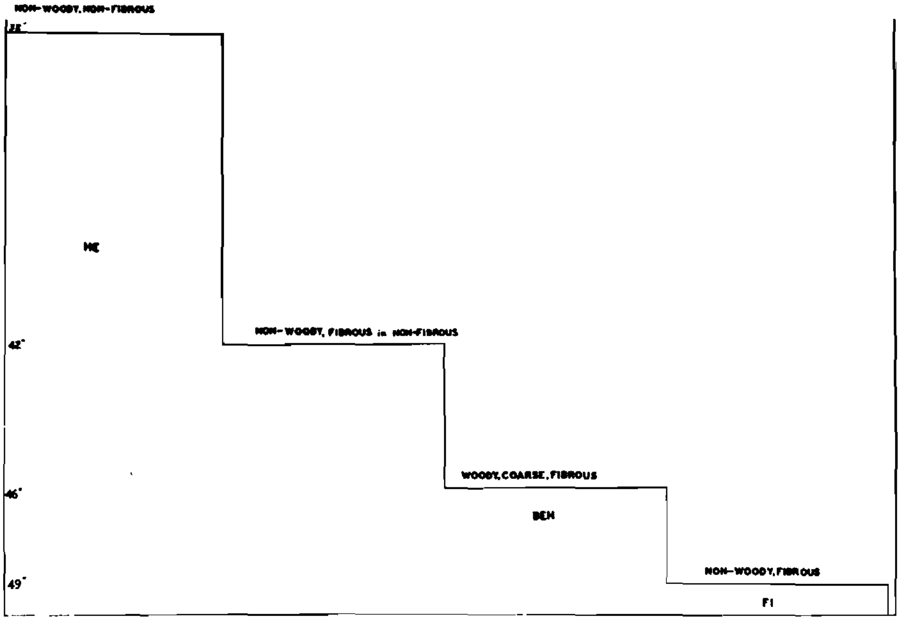

Figure 15.—Mean depths to ice contour for selected categories of organic terrain construction.

TABLE II

Coverage and Sub-Surface Ice Relations

Muskeg identification			Ice condition		
1	2	3	4	5	6
Coverage formulae	Sub-surface constitution (macroscopic)	Special topographic feature where present	Contour pattern type	Contour change rating	Consistency of occurrence in related muskeg class
HE	non-woody, non-fibrous	extensive peat plateaus	Polygon Differential	low	high
FI	non-woody, fibrous	grouped nigger heads open or filled in ponds	Vertical Free-Lift Vertical Confined Lift	medium to high	medium to low
			Pond Hole	high	high
EH invading BEH	woody, fine fibrous	exposed or covered boulders occurring singly or in groups	Boulder Locus	high	high
ABH, BHE, BEH	woody, coarse fibrous	moderately irregular often ridged	Displacement Fault	medium	low
			Ridge Elevation	high	medium
ABE	large roots and log remnants	highly irregular 5 to 20 foot wide plateaus with wide clefts, 1 to 3 feet deep	Multiple Knoll	high	high

in some macrofossil assemblages than in others. A qualitative assessment of this circumstance is suggested in Table II, column 5. Comparative rates of change in depth corresponding to different macrofossil constitutions are expressed qualitatively in Table II, column 6. Though these designations are relative and empirical, they have been found to be useful in assessing and predicting seasonal dynamics in the climafrost.

Vegetal Coverage in Relation to Climafrost

In the previous work (2), where the author established that coverage classes of the living organic layer could be correlated with sub-surface constitution, no reference was made to ice formation. This matter has since been reviewed and the results of inquiry show that climafrost contours most frequently relate to the types of coverage listed in Table I. These, in terms of coverage formulae, are listed in Table II, column 1. Inspection of this table will suggest that corresponding ice-form contour types are characteristic for the coverage type in question. This is confirmed if a comparison of coverage formulae and ice-form pattern contour is made in Figs. 10–14 inclusive.

It is useful to recognize that coverage class is often associated with characteristic topographic features (Table II, columns 1 and 3). In ascertaining or predicting sub-surface ice conditions in the field, the utilization of this relationship is helpful.

It has been indicated elsewhere (1) that coverage formulae can be used validly for purposes of predicting sub-surface muskeg constitution, provided limited laboratory microfossil inspection is supplied as collateral information. It may also be inferred that the sub-surface organic terrain conditions can be mapped since coverage distribution can be charted (1, pp. 6, 7). The author might have suggested this in a previous work but was prevented only because there was uncertainty then whether the evidence contributed through analysis of the organic contents could be related to climafrost conditions. This difficulty is now obviated, and coverage formulae support the view that sub-surface ice phenomena can be predicted and charted in terrain mapping and in interpreting aerial records.

Acknowledgments

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LIST OF TECHNICAL MEMORANDA

1 Proposed field soil testing device. August 1945.*

2 Report classified "restricted". September 1945

3 Report classified "confidential". November 1945

4 Soil survey of the Vehicle Proving Establishment, Ottawa. Oct. 1945.*

5 Method of measuring the significant characteristics of a snow-cover. G. J. Klein. Nov. 1946. *

6 Report classified "confidential". November 1946

7 Report classified "restricted". March 1947

8 Report classified "confidential". June 1947

9 Proceedings of the 1947 Civilian Soil Mechanics Conference. Aug.1947 *

10 Proceedings of the Conference on Snow and Ice, 1947. Oct. 1947

11 Proceedings of the 1948 Civilian Soil Mechanics Conference. Oct.1949 *

12 Index to Proceedings of Rotterdam Soil Mechanics Conference. May 1949

13 Canadian papers: Rotterdam Soil Mechanics Conference. June 1949

14 Canadian papers presented at the Oslo meetings of the International Union of Geodesy and Geophysics. December 1949

15 Canadian survey of physical characteristics of snow-covers. G. J. Klein. April 1950

16 Progress report on organic terrain studies. N.W.Radforth. April 1950

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21 The Canadian snow survey, 1947-1950. D.C.Pearce,L.W.Gold. Aug. 1951

22 Annual report of the Canadian Section of the International Society of Soil Mechanics and Foundation Engineering (June 1950 - June 1951) October 1951

23 Proceedings of the Fifth Canadian Soil Mechanics Conference, Jan. 10 and 11,1952. May 1952

(Continued on back of cover)

* Out of print

LIST OF TECHNICAL MEMORANDA (Continued)

24 A suggested classification of muskeg for the engineer. N.W.Radforth. May 1952

25 Soil mechanics papers presented at the Building Research Congress 1951. November 1952

26 Annual report of the Canadian Section of the International Society of Soil Mechanics and Foundation Engineering (June 1951 to June 1952). December 1952

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28 The use of plant material in the recognition of northern organic terrain characteristics. N. W. Radforth. March 1954

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