AN APPROXIMATION OF PROBABLE PERMAFROST OCCURRENCE

One of the first interests of preliminary engineering planning in the north concerns permafrost and its probable occurrence. Although observations on permafrost distribution are being compiled[1,2], there are many gaps and conflicting observations in our present knowledge. In addition, many new construction developments are in areas where there is no local information and some guidance is needed to extrapolate the permafrost occurence observations of adjacent areas.

In Canada two broad categories of permafrost occurrence, based on areal distribution, are recognized: *continuous,* where permafrost is found everywhere below the natural ground surface, and *discontinuous,* where permafrost exists in combination with some areas of unfrozen material. For engineering purposes a further subdivision is highly desirable:

(1) "tundra" areas of continuous permafrost;
(2) "forested" areas of continuous permafrost;
(3) discontinuous permafrost, where areas free of permafrost are few and small in areal extent;
(4) discontinuous permafrost, where areas of permafrost are few and small in areal extent.

The prediction of permafrost occurrence is extremely complicated because permafrost exists as an energy imbalance and the sources for inducing the energy changes are many, varied, and inter-related[2]. Examination of maps showing the known southern limit of permafrost[1,2] and mean annual isotherms[3] shows a broad relationship between permafrost distribution and air temperature. Across Canada the southern limit of permafrost lies between the 25°F. (−3.9°C.) and the 30°F. (−1.1°C.) mean annual isotherms. Nevertheless, accurate prediction of permafrost occurrence cannot be based solely on this climatic factor. Local variations in areal extent and thickness of permafrost are related to variations in net radiation, evapo-transpiration, micro-relief, drainage, vegetation, snow cover, and other climatic and terrain factors (surface and subsurface). Because of the thermal sensitivity of permafrost even small changes in climate and terrain factors can produce a change in the mean ground temperature resulting in large changes in the areal distribution and thickness of permafrost, if the period of time is sufficiently long.

Although past attempts at correlating permafrost occurrence in Canada solely with air temperature have shown only a broad relationship, an empirical correlation involving the mean annual temperature and summer air temperature does appear to provide a first approximation suitable for preliminary engineering assessment purposes.

Sixty-one localities in northern Canada (*see* Table 1) were chosen on the basis of readily available meteorological records[4,5] and reported permafrost occurrences[6]. The scope and reliability of reported permafrost observations varied so widely that only the following subdivisions could be made:

(1) free of permafrost;
(2) discontinuous permafrost;
(3) continuous permafrost, forested;
(4) continuous permafrost, tundra.

The correlation of reported permafrost occurrences and air temperatures involves annual mean temperature and "thawing index" (a yearly summation of daily mean temperatures in excess of 32°F. or 0°C.). Although the thawing index is defined in terms of daily temperatures, it is sufficiently accurate to use monthly mean temperatures for this approximation of probable permafrost occurrence. Thus the thawing index was computed as a yearly summation of monthly mean temperatures in excess of 32°F. (0°C.) multiplied by the number of days in the month (*see* Table 1). A plot using the annual mean temperature and thawing index as coordinates for the 61 localities in northern Canada is shown in Fig. 1.

The plotted values of Fig. 1 suggest some conformity or grouping depending

Table 1. Permafrost occurrence, annual mean temperature, and thawing index for 61 localities in northern Canada[4,5].

No.	*Locality*	*Altitude above sea-level feet*	*Years of observations*	*Annual mean temperature °F.*	*Thawing index degree-days °F.*
	No permafrost reported				
1	Fort George, P.Q.	320	23	25	2399
2	Great Whale River, P.Q.	50	22	23	1941
3	Moose Factory, Ont.	29	16	29	3282
4	Moosonee, Ont.	34	17	30	3371
5	Trout Lake, Ont.	720	12	26	3038
6	Fond du Lac, Sask.	690	23	22	2789
7	La Ronge, Sask.	—	14	30	3559
8	Fort Chipwyan, Alta.	714	20	28	3464
9	Embarras, Alta.	775	11	30	3712
10	Dease Lake, B.C.	2678	5	30	2798
11	Watson Lake, Y.T.	2248	12	28	3186
12	*Flin Flon, Man.	968	23	31	3951
13	*Whitehorse, Y.T.	2289	10	31	3063
14	Teslin, Y.T.	2300	10	30	2818
15	Carcross, Y.T.	2171	30	29	2665
16	Fort Nelson, B.C.	1230	13	30	3797
17	Fort Vermillion, Alta.	950	30	29	3555
18	Goose Bay, Lab.	144	10	32	3249
	Discontinuous permafrost reported				
19	Brochet, Man.	1180	5	23	2703
20	Gillam, Man.	454	11	23	2581
21	God's Lake, Man.	610	9	27	3315
22	Port Nelson, Man.	49	14	20	2123
23	Wabowden, Man.	786	10	28	3373
24	Aishihik, Y.T.	3170	10	25	2311
25	Mayo, Y.T.	1625	26	26	2920
26	Snag, Y.T.	1925	10	22	2708
27	Hay River, N.W.T.	529	29	25	2943
28	Fort Providence, N.W.T.	547	9	25	3125
29	Fort Resolution, N.W.T.	549	22	24	3004
30	Fort Simpson, N.W.T.	415	27	25	3339
31	Yellowknife, N.W.T.	682	10	22	2911
32	*Knob Lake, P.Q.	1605	5	24	2206
33	*Norway House, Man.	720	24	29	3532
34	*Dawson, Y.T.	1062	30	24	3157
35	*Reliance, N.W.T.	539	5	19	2306
36	*Fort Smith, N.W.T.	665	30	26	3127
37	*Wrigley, N.W.T.	511	8	24	3247
	Continuous permafrost reported — forested				
38	Fort Chimo, P.Q.	117	10	22	1881
39	Aklavik, N.W.T.	30	22	16	1992
40	Fort Good Hope, N.W.T.	251	30	18	2726
41	Fort McPherson, N.W.T.	150	30	17	2359
42	Port Radium, N.W.T.	600	11	20	2125
43	*Fort Norman, N.W.T.	300	25	21	2819
44	*Norman Wells, N.W.T.	240	10	21	3027
	Continuous permafrost reported — tundra				
45	Churchill, Man. (Port)	43	19	19	1975
46	Baker Lake, N.W.T.	30	6	10	1307
47	Cambridge Bay, N.W.T.	45	14	6	988
48	Chesterfield Inlet, N.W.T.	13	29	11	1261
49	Coppermine, N.W.T.	19	13	12	1292

50	Frobisher Bay, N.W.T.	68	10	16	1106
51	Pangnirtung, N.W.T.	43	12	16	1106
52	Pond Inlet, N.W.T.	10	21	7	648
53	Resolute, N.W.T.	56	6	3	458
54	*Port Harrison, P.Q.	—	18	18	1395
55	Arctic Bay, N.W.T.	36	13	8	740
56	Clyde, N.W.T.	26	11	11	525
57	Coral Harbour, N.W.T.	193	11	11	1018
58	Holman Island, N.W.T.	30	10	11	955
59	Lake Harbour, N.W.T.	54	19	18	1197
60	Nottingham Island, N.W.T.	54	21	16	800
61	Resolution Island, N.W.T.	127	19	21	461

* Denotes uncertain opinion.

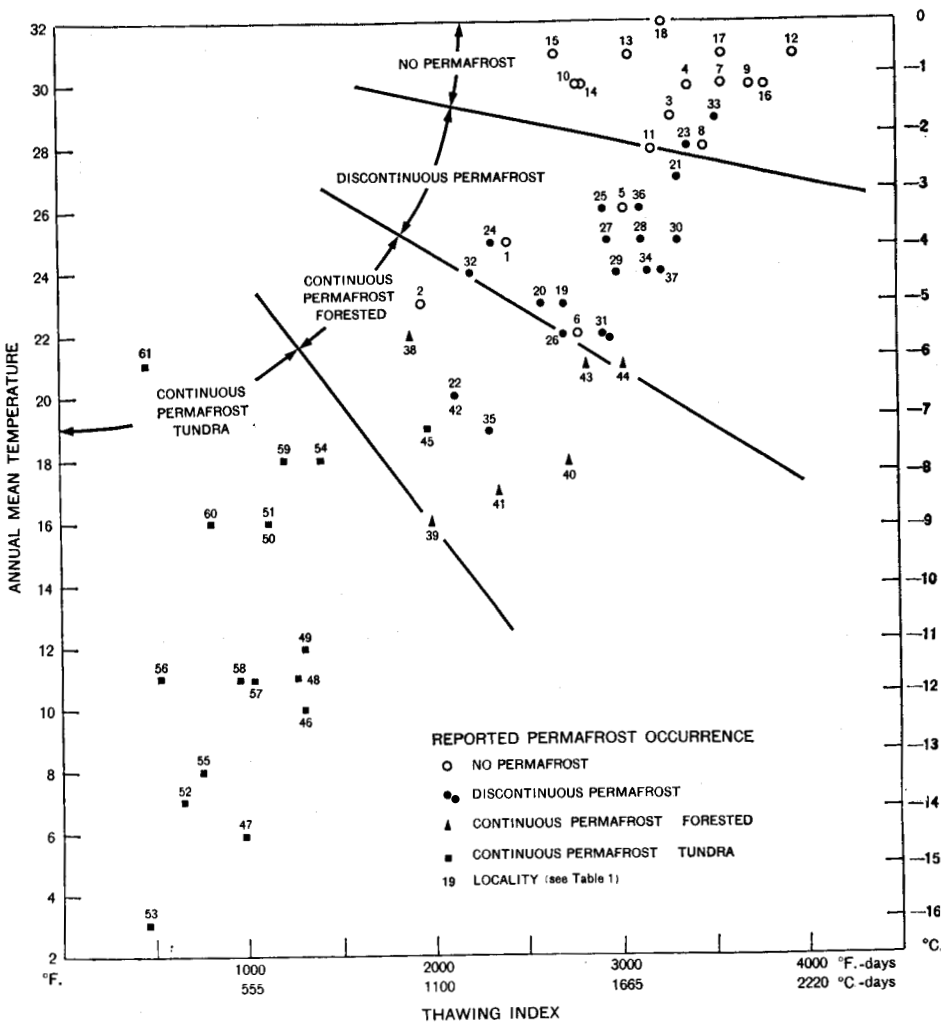

Fig. 1. An approximation of probable permafrost occurrence using annual mean temperature and thawing index for 61 localities in northern Canada.

on the occurrence of permafrost. Accordingly, straight-line boundaries (with origin at 32°F. (0°C.) and zero degree-days) were fitted by inspection to separate the most frequent observations of a given permafrost occurrence. Some exceptions to the selected boundaries are evident in Fig. 1. In many of these current or generally accepted opinion is open to question and thus some individual comments are in order.

1. *Churchill, Man.* (Locality No. 45), designated as a tundra, continuous permafrost location although it is at the tree line. It is suggested that the engineering implications of permafrost be treated in a manner similar to that of forested, continuous permafrost.
2. *Reliance, N.W.T.* (Locality No. 35); designated as a discontinuous permafrost area although opinion is uncertain. It is suggested that permafrost is continuous.
3. *Port Nelson, Man.* (Locality No. 22); very old permafrost records questioned. Could be continuous permafrost.
4. *Great Whale River, P.Q.* (Locality No. 2); probability of discontinuous and even continuous permafrost in the locality is suggested.
5. *Fort Norman, N.W.T.* (Locality No. 43); discontinuities in the occurrence of permafrost are suggested.
6. *Norman Wells, N.W.T.* (Locality No. 44); discontinuities in the occurrence of permafrost are suggested.
7. *Fond du Lac, Sask.* (Locality No. 6); reported free of permafrost but the probability of discontinuous permafrost is suggested.
8. *Fort St. George, P.Q.* (Locality No. 1); remarks for No. 7 apply.
9. *Trout Lake, Ont.* (Locality No. 5); remarks for No. 7 apply.
10. *Fort Chipewyan, Alta.* (Locality No. 8); remarks for No. 7 apply.
11. *Watson Lake, Y.T.* (Locality No. 11); remarks for No. 7 apply.
12. *Norway House, Man.* (Locality No. 33); discontinuous permafrost has been reported but it is suggested that the locality is generally free of permafrost.

Conclusion

Annual mean temperature and thawing index appear to provide a first approximation of probable permafrost occurrence that is suitable for preliminary engineering assessment purposes. Comments, especially on its applicability in other countries, would be welcome.

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