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Permafrost Distribution, Zonation and Stability along the Eastern Ranges of the Cordillera of North America

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ABSTRACT. Considerable quantities of new data have become available recently regarding the nature and distribution of permafrost along the eastern ranges of the Cordillera. These are used to produce an elevation view of permafrost in the ranges north of the 35°N parallel. In the south, there is a zone of sporadic permafrost up to 1000 m in vertical extent overlain by continuous permafrost. The zone of discontinuous permafrost (30-80% of the surface with permafrost) is only about 70 m in vertical extent. North of 54°N this changes, with discontinuous permafrost encroaching on the sporadic permafrost zone.

The apparent permafrost boundaries differ from those of Brown (1967), Péwé (1983a) and Cheng Guodong (1983). Their work was based on considerably less data, and it is clear that the terrain factors of mean winter snow depth, local moisture and ground water conditions, the distribution of the different air masses and cold air drainage have considerable effect locally, causing undulations and abrupt changes in the lower limit of the permafrost boundaries to about 56°N. Farther north, the climatic factors become dominant. The lower boundaries are different for a given latitude in North America and China.

Subdivision of the alpine permafrost into stable, metastable and unstable classes is useful in indicating the instability of alpine permafrost (Cheng Guodong, 1983) and shows that most of the permafrost found in mainland Canada and Alaska is unstable or metastable.

Key words: permafrost distribution, permafrost thermal stability, eastern Cordillera of North America, alpine permafrost, permafrost zonation

RÉSUMÉ. De nouvelles données en quantités considérables sont depuis peu disponibles portant sur la nature et le distribution du pergélisol le long des chaînes est de la Cordillère. Elles servent à produire une vue d'élévation du pergélisol dans les chaînes au nord du parallèle 35°N. Plus au sud se trouve une zone de pergélisol sporadique d'une longueur verticale allant jusqu'à 1000 m, recouverte d'un pergélisol continu. La zone de pergélisol discontinu (30 à 80% de la surface avec pergélisol) ne fait que quelque 70 m en longueur verticale. Au nord du 54°N, cependant, le pergélisol discontinu empiète sur la zone de pergélisol sporadique.

Les limites apparentes du pergélisol diffèrent de celles de Brown (1967), de Péwé (1983a) et de Cheng Guodong (1983). Leur travail fut fondé sur des données beaucoup plus restreintes et il est clair que les facteurs du terrain, c'est-à-dire la profondeur moyenne de neige hivernale, l'humidité locale, les conditions d'eau terrestre, la distribution des masses d'air et le drainage d'air froid, ont un effet local considérable entraînant des variations et des changements brusques dans la limite inférieure des limites du pergélisol aux environs du 56°N. Plus au nord, les facteurs climatiques dominent. Les limites inférieures diffèrent à toute latitude déterminée en Amérique du Nord et en Chine.

Il est utile de subdiviser le pergélisol alpin en classes stable, métastable et instable puisque ceci permet d'indiquer l'instabilité du pergélisol alpin (Cheng Guodong, 1983) et démontre que la plupart du pergélisol sur la partie continentale du Canada et de l'Alaska est instable ou métastable.

Mots clés: distribution du pergélisol, stabilité thermale du pergélisol, cordillère est de l'Amérique du Nord, pergélisol alpin, zonage du pergélisol

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INTRODUCTION

It has been realized for several decades that permafrost exists at various locations along the North American Cordillera, but its actual distribution is still poorly known. This is partly due to the immense size of the area (over 6000 km long and up to 1200 km wide) and partly due to the limited number of adequate field observations. This paper analyzes the available data for the eastern ranges of the Cordillera (Fig. 1) from the Beaufort Sea to northern New Mexico (some 38° of latitude).

METHODS USED

Since 1973, the author has made a continuing study of ground temperatures at various locations in the eastern ranges of the Cordillera in southwest and west-central Alberta in cooperation with the late R.J.E. Brown and, more recently, G.H. Johnston, of the Building Research Division of the National Research Council of Canada. The methods and preliminary results have been described by Harris and Brown (1978, 1982). Since 1981, further work along the Alaska Highway west of Fort Nelson has been carried out under contract with J.A. Heginbottom, Terrain Sciences Division, Geological Survey of Canada. A study was also made of the available borehole and thermistor cable data obtained by Foothills Pipelines, Yukon Ltd., along their proposed Dempster lateral route (courtesy of S. Elwood and D. Fisher). The results of the latter are published as part of a study of permafrost distribution and its prediction in the Western Yukon Territory (Harris, 1983).

Some of the available published data from south of the 49th parallel have been summarized in Péwé (1983a). Additional data are available in the form of studies of the distribution and characteristics of caves in Montana (Campbell, 1978) and Wyoming (Hill *et al.*, 1976), while similar data are available for ice caves in southwest Alberta, southeast Yukon, and southwest Northwest Territories (Thompson, 1976; Harris, 1979). By collating this information and plotting it on diagrams showing the maximum heights of the mountains at different latitudes, a reasonable idea of the zonation and distribution of permafrost in the eastern Cordillera can be obtained (Fig. 1). This can then be compared with the previous predictions of Brown (1967), Péwé (1983a) and Cheng Guodong (1983), all of whom augmented the available limited field observations by fitting mathematical curves to the data. It is clear that the data for the lowest limit of permafrost plot at a much lower elevation for a given latitude than the data quoted by Cheng Guodong (1983).

The information on ground temperatures at the level of minimum amplitude through mountain ranges along the Dempster Highway is plotted against altitude (Figs. 4 and 5) in order to check on the consistency of the changes in ground temperature with altitude. The available data on ground temperature at the level of minimum amplitude are used to produce a

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map of the thermal stability of permafrost in North America (Figs. 6 and 7), using a simplification of the classification of Cheng Guodong (1983). Finally, a new map of permafrost distribution (Fig. 8) has been drawn using the new results.

TOPOGRAPHY ALONG THE EASTERN RANGES OF THE CORDILLERA

If the eastern ranges of the Cordillera were viewed from the east from space, it would be seen that they become progressively higher southward from the Richardson ranges in the north to latitude 34°N, and then tend to become lower (Fig. 1). A similar slope is seen in the maximum level of the high plains adjacent to the mountains. This is the result of the Tertiary drainage pattern, which featured a drainage divide at latitude 40-44°N (Lemke *et al.*, 1965). The Yellowstone and Missouri rivers used to flow north and east to Hudson Bay. They became diverted during the latter part of the Quaternary by glacial deposits laid down by the Laurentide glaciers just south of the 49th parallel. This resulted in capture of this drainage by the Mississippi River along proglacial drainage channels.

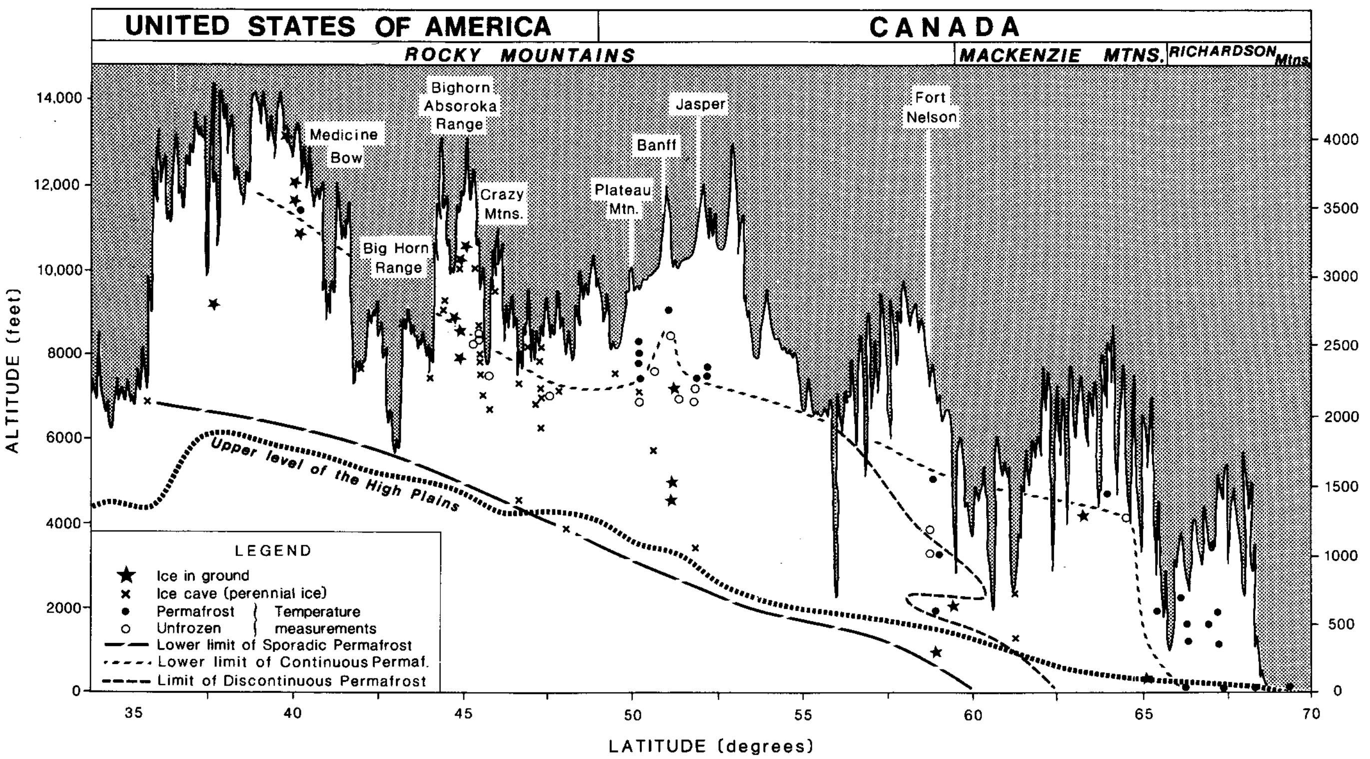

FIG. 1. Evidence for and distribution of permafrost in the eastern ranges of the Cordillera north of 35°N. The sources and data are listed in the Appendix.

This northerly slope of both the mountains and the adjacent high plains is important to the understanding of the distribution of permafrost since this slope to the north parallels the permafrost boundaries and causes the persistence of patches of continuous permafrost at high altitudes through 35° latitude of the mountains. Thus the problem of mapping the distribution of permafrost and its lower limit is one of plotting the available information on the highest peaks of each mountain range and of attempting to delimit the lower limits.

CLASSIFICATION INTO PERMAFROST ZONES

Before discussing the detailed distribution of permafrost along the eastern Cordillera, it is necessary to define the terms being used. The variety of maps, mapping units and definitions is illustrated in Heginbottom (1984), Kudryavtsev *et al.* (1978, 1980), Kreig (1985) and Washburn (1979) and in the references contained therein. This phenomenon is due to differences in the scope of the maps, the types, qualities and quantities of information available and the objectives of the classification.

Most classifications used on maps of permafrost distribution in North America and in China have been qualitative (see Brown, 1967, 1978; Cheng Guodong, 1983, pers. comm. 1985; Harris, 1979; Harris and Brown, 1978, 1982). The main detailed quantitative classifications are used in the U.S.S.R., where up to six subdivisions may be used, based primarily on the percentage of the earth's surface (including lakes and sea floor) underlain by permafrost (State Committee . . . , 1960, in Brown, 1963:viii; Kudryavtsev *et al.*, 1978). This greater detail is the result of intensive studies in permafrost areas undergoing development, but this detailed classification cannot be applied in North America at present due to the limited availability of information. Proving that there is a zone with less than 5% of the surface underlain by permafrost requires ground temperature data from more than 20 boreholes in the mapping unit. For the same reason, it would be difficult to reliably map continuous permafrost if it were defined as land 100% underlain by permafrost.

Fortunately the Russians (Kudryavtsev *et al.*, 1978, 1980) use a broad subdivision into "continuous permafrost" (>80% underlain by permafrost), a category with 30-80% of the ground underlain by permafrost and "sporadic permafrost" (<30% underlain by permafrost), which is suitable for use in other countries. The most convenient term for the second category (30-80%) is "discontinuous permafrost." It has been used qualitatively in a similar sense in most previous work in North America and China and consequently will be used in this way in this paper. Using the same major divisions as Kudryavtsev *et al.* (1978) should facilitate the construction of more reliable world maps of permafrost distribution.

In the Russian literature, "island permafrost" is commonly used for a variety of classes of land underlain by varying percentages of permafrost not exceeding 80%. The subdivisions available in the English literature are highly inconsistent, so this term is not used here. In the North American literature, the term "widespread permafrost" has been defined as areas of land underlain by more than 50% permafrost (Brown and Kupsch, 1974:29). This can include continuous permafrost and is inconsistent with the definitions used by Kudryavtsev *et al.* (1978, 1980); it has therefore been abandoned.

Although polar and alpine permafrost are separated on many recent maps (see, for example, Péwé, 1983b, Heginbottom, 1984; Anon., 1985), this paper treats them as one. The exact subdivision and the reasons for and against it will be discussed elsewhere.

PERMAFROST DISTRIBUTION AND ZONATION ALONG THE EASTERN RANGES OF THE CORDILLERA

Figure 1 shows the results of plotting the available information on the north-south topographic outline. The data are listed in Appendix A and have been split into actual ground temperature measurements and the observations of perennial ice in the ground (drillholes, excavations, mines or caves). Also included are observations of the absence of both freezing temperatures and ice in the ground at high altitudes, since these are critical for the delimitation of the lower limit of continuous permafrost.

In the south, two distinct zones can be identified, *viz.*, that of sporadic permafrost (under 30% of the ground surface underlain by permafrost) and that of continuous permafrost (over 80% of the ground underlain by permafrost). The zone of discontinuous permafrost is only about 70 m thick at Plateau Mountain (Harris and Brown, 1978:387), and this appears to be typical of the mountains south of Jasper, Alberta (latitude 52°N).

Between Jasper and Fort Nelson, British Columbia (latitude 59°N), the zone of discontinuous permafrost increases to 400 m in altitudinal extent at the expense of the zone of sporadic permafrost. The reasons for this change will be discussed elsewhere, but the widening altitudinal range of discontinuous permafrost continues into the Yukon and Northwest Territories and merges with the same zones to the east in the Mackenzie River valley and on the Canadian Shield.

CAUSES OF THE VARIATIONS

Figure 1 indicates that there is considerable variation in north-south slope of the boundaries of the permafrost zones. The lower boundary of the sporadic permafrost zone is the more consistent and lies below the upper level of the high plains in northern Alberta and British Columbia and in the Territories. Southward, it climbs up the lower slopes of the mountains (300 m in 10° latitude) and is represented by perennial ice in caves and in buried ice masses surviving from colder times in the past. At present it is difficult to determine whether the undulations shown in Figure 1 are partially the result of lack of data or whether they are real. However, in general, they parallel the broad trends in the lower limit of the zone of continuous permafrost.

There is much more information available regarding the slope of the base of the zone of continuous permafrost, especially north of 49°N. In southwestern Alberta, Harris and Brown (1982) demonstrated that the undulation in the Banff-Jasper National Parks is caused by the high snowfall area centred on the region around Bow Summit. Where the snowfall is greatest, the lower limit of continuous permafrost rises 300 m above treeline, whereas in lower snowfall areas it may occur at or even below treeline.

This probably also explains the location of the base of the zone of continuous permafrost well above treeline in Niwot Ridge, Colorado (Ives and Fahey, 1971; Ives, 1974:187), and the abrupt rapid descent of the boundary in northern Wyoming and in Montana.

The terrain factors of mean winter snow depth, local moisture and ground water conditions, the distribution of the different air masses and cold air drainage control the lower limit of permafrost as far as 56°N. Beyond that latitude, the climatic factors become dominant.

The abrupt descent of the boundary of continuous permafrost at latitude 65°N corresponds to the boundary of the influence of the cold air mass from the Arctic Ocean and the common position of the Arctic Front in summer. There is an abrupt change in the trends of the freezing and thawing indices in relation to latitude on both sides of the Richardson Mountains at this position (see Harris, 1981; Harris, 1983:Fig. 5). Snowfall does not change noticeably at this location.

At least two other factors appear to cause local differences, *viz.*, cold air drainage and zones of ground water flow. In the case of cold air drainage, this appears to be most effective in northern British Columbia and southern Yukon Territory, where a depression of the air temperature of 25-30°C is quite normal in valley bottoms in January (Harris, 1982). It is sufficiently marked to show on the mean annual air temperatures at different elevations and can cause an actual reversal of the normal lapse rate as reflected in mean annual temperatures (Harris, 1983:Fig. 8). It is primarily a winter phenomenon (Harris, 1983:Fig. 7).

Ground water flow produces taliks and icings and enlarges the altitudinal range of the zone of discontinuous permafrost as the amount of evapotranspiration decreases northward. It is probably the primary cause of the changes in the roles of the discontinuous and sporadic permafrost zones between Jasper and Fort Nelson.

COMPARISON WITH PREVIOUS MAPS

There have been three main previous attempts to show the north-south variations in the permafrost boundaries along the Cordillera. The lower boundaries of the permafrost zone predicted by these authors are compared in Figure 2. The first was by the late R.J.E. Brown (1967) and was based on very little actual data, but mainly on assumed lapse rates, assumed permafrost-temperature relations and limited climatic data. The results proved quite inaccurate (Harris and Brown, 1978, 1982) and were the main reason for the subsequent detailed studies carried out jointly by the author in cooperation with the Building Research Division of the National Research Council of Canada and the Terrain Sciences Division, Geological Survey of Canada.

The second attempt was by Péwé (1983a), who summarized a considerable proportion of the available information for the contiguous United States. He did not use the data available for ice caves in Wyoming or Montana and used only selected data from southern Alberta. He fitted a straight line, which if

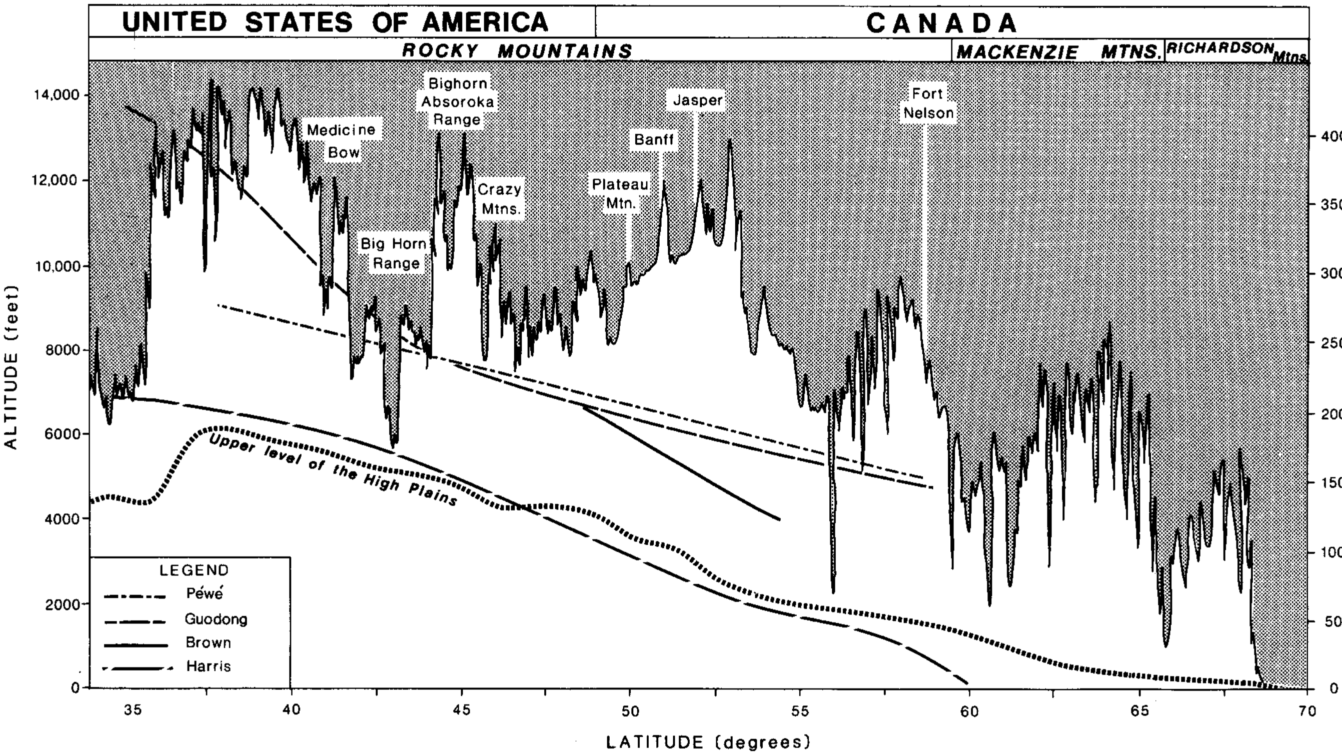

FIG. 2. Comparison of the variation in lower permafrost boundaries with latitude for the North American Cordillera (Brown, 1967; Péwé, 1983a; and this paper) and for the northern hemisphere (Cheng Guodong, 1983).

projected northward would indicate an absence of permafrost along the Mackenzie valley.

The third attempt was by Cheng Guodong (1983); he showed the similarity in the data from the People's Republic of China to that from low-latitude North America. He fitted an S-shaped curve to selected data for the lower limit of permafrost, but once again, this would indicate that no permafrost should exist along the Mackenzie valley. However, his curve may be important for low latitudes, and he explains the S-shape by pointing to the change in net radiation balance at 39°N latitude from a positive balance to a negative balance of incoming to outgoing radiation. Unfortunately the data in Figure 1 do not support this interpretation but suggest that terrain factors are dominant over climatic factors in controlling permafrost distribution south of 56°N latitude. North of there, the climatic factors become dominant.

The present results (Fig. 1) are based on considerably more actual ground temperature data for a much wider range of latitudes. Unlike previous attempts, the zone of continuous permafrost (greater than 80% of the surface underlain by permafrost) is clearly differentiated from the widely distributed zone of sporadic permafrost (under 30% of the surface underlain by permafrost). Since the sporadic zone can be up to 1000 m in vertical extent, this makes a considerable difference in the accuracy of the mapping. Coupled with detailed studies (e.g., Harris and Brown, 1978, 1982; Harris, 1983), this should ensure that the present results are based on as much information as possible at this time.

VERTICAL GRADIENTS IN GROUND TEMPERATURES

Many writers have assumed there should be a constant lapse rate in ground temperature with altitude, e.g., Brown (1967); Péwé (1983a). It is now possible to obtain a better idea of the validity of this assumption.

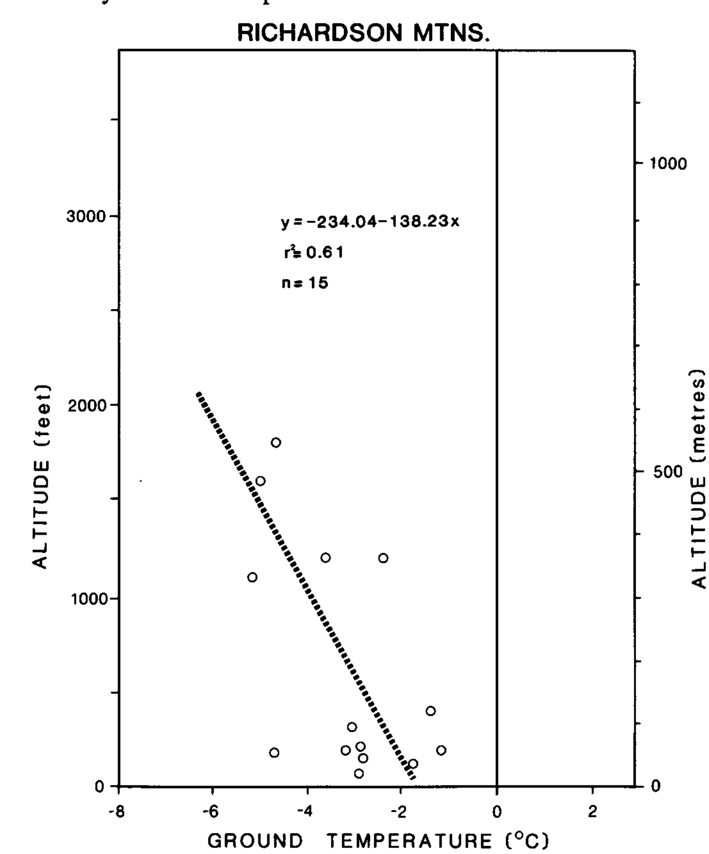

FIG. 3. Relationship of ground temperature at the level of minimum amplitude to altitude along the Richardson Mountains.

Figures 3 and 4 show the results of plotting actual data for ground temperatures in the zone of minimal amplitude against altitude for two mountain ranges in the Yukon and Northwest Territories. The results indicate different lapse rates for different mountain ranges, but also show that there is considerable local variability. This suggests that presumed lapse rates form a rather unreliable source of information. Presumed lapse rates based on air temperatures at low altitudes would be a particularly poor source of data.

THERMAL STABILITY OF PERMAFROST IN THE CORDILLERA

In the U.S.S.R., Kudryavtsev *et al.* (1978:Fig. 2) have subdivided permafrost according to the mean annual temperatures of earth materials, and the results have been reproduced by Washburn (1979:Fig. 3.10, p. 32). The value of these maps lies in the fact that the colder the permafrost materials, the more resistant they are to thawing, i.e., they indicate the degree of thermal stability of the frozen ground. Cheng Guodong (1983) has proposed that a stability classification based on mean ground temperature be used in place of the present subdivision into continuous, discontinuous and sporadic permafrost. The latter is based on percentage area underlain by permafrost, and in the U.S.S.R. it is subdivided further. Since the percentage of land surface underlain by permafrost is most important for development of these areas, this classification must continue to be used.

In spite of this, the concept of a stability classification is obviously very useful. At present, the ground temperature data available for North America will only support a simplified division into stable (temperature less than –5°C), metastable (temperature from –2°C to –5°C) and unstable permafrost

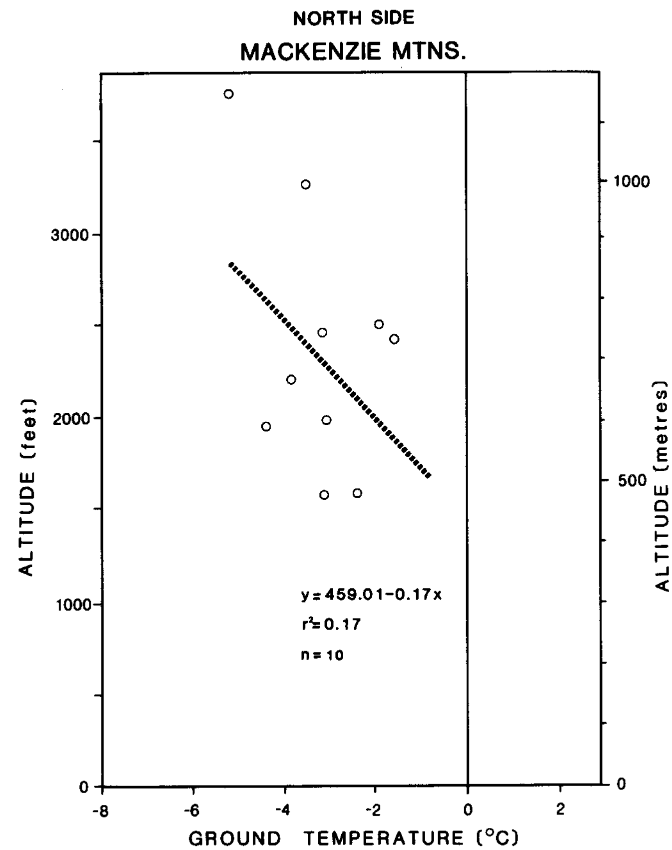

FIG. 4. Relationship of ground temperature at the level of minimum amplitude to altitude along the north slope of the Mackenzie Mountains.

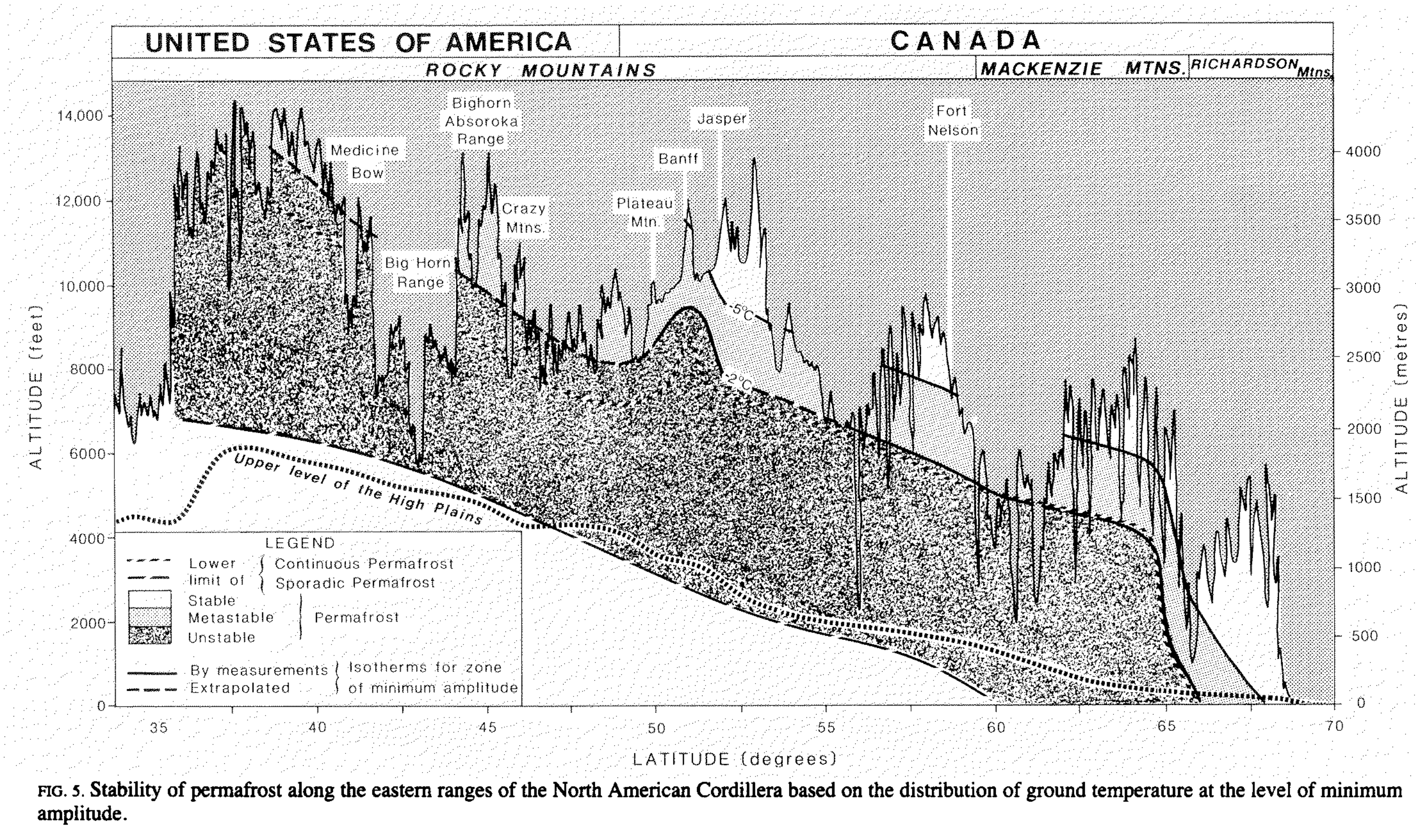

FIG. 5. Stability of permafrost along the eastern ranges of the North American Cordillera based on the distribution of ground temperature at the level of minimum amplitude.

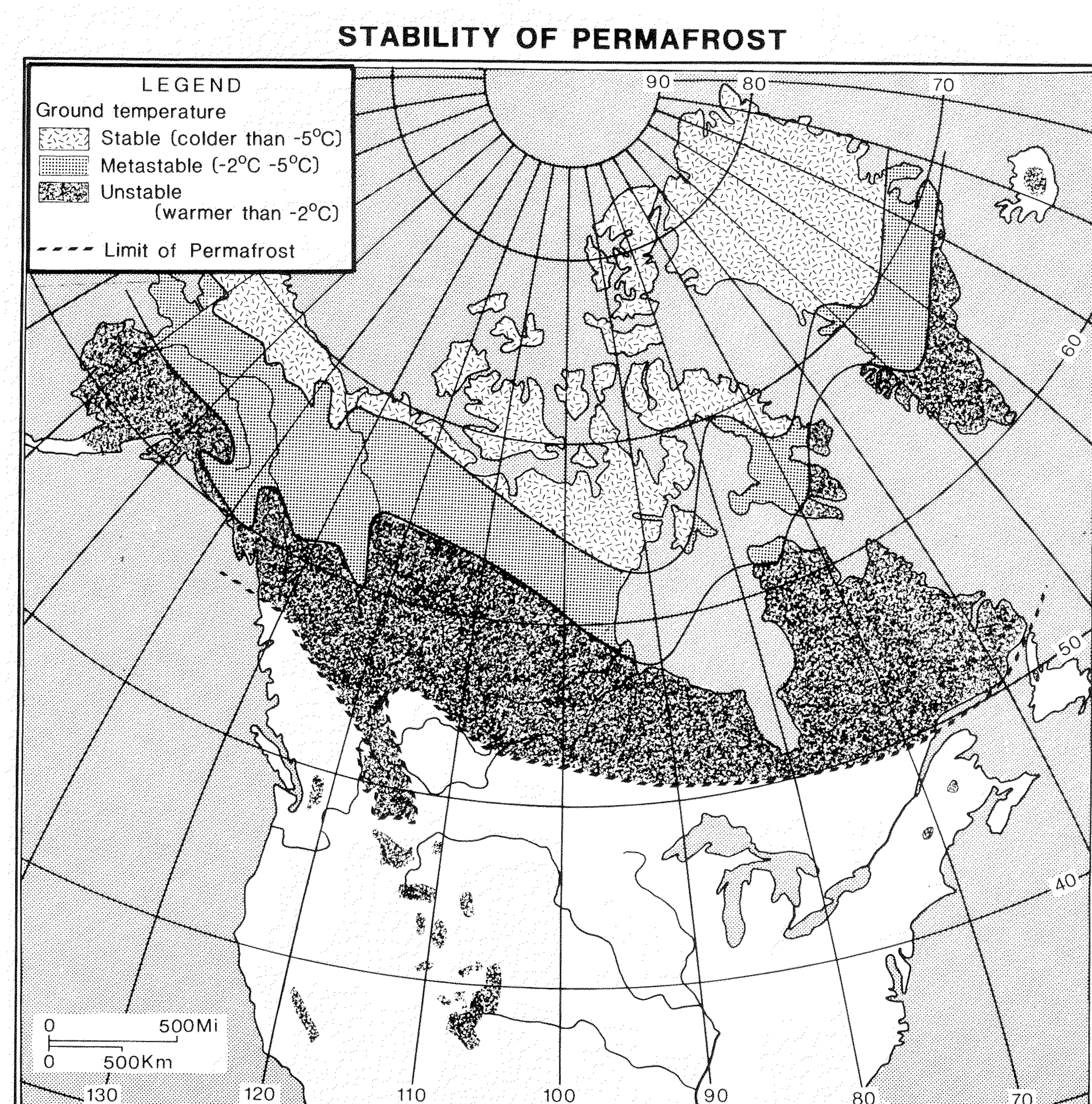

FIG. 6. Stability of permafrost in North America, based on the distribution of ground temperature at the level of minimum amplitude.

(temperature higher than –2°C). Figure 5 shows the results of applying this classification to the alpine permafrost along the eastern ranges of the Cordillera, while Figure 6 shows the results of applying the system to North American permafrost. In general most of the permafrost on the mainland is either unstable or metastable. Stable permafrost chiefly occurs around the Arctic Ocean and the Arctic Islands. This highlights the problems faced in developing the resources of the northern portions of this continent and also explains why the main areas of active zonal permafrost landforms in the alpine areas are in the northern Yukon (Harris, 1983). However, caution must be used when comparing these maps to particular cases since unusual microenvironments such as high water tables and deep snow drifts can cause local variations from the normal values in a given area. Comparison with the normal subdivisions (Fig. 7) shows that the lower part of the continuous permafrost is metastable in southern Canada and in the contiguous United States, while some discontinuous permafrost in the same area is unstable. In the far north, the continuous permafrost is primarily stable and the discontinuous permafrost is metastable.

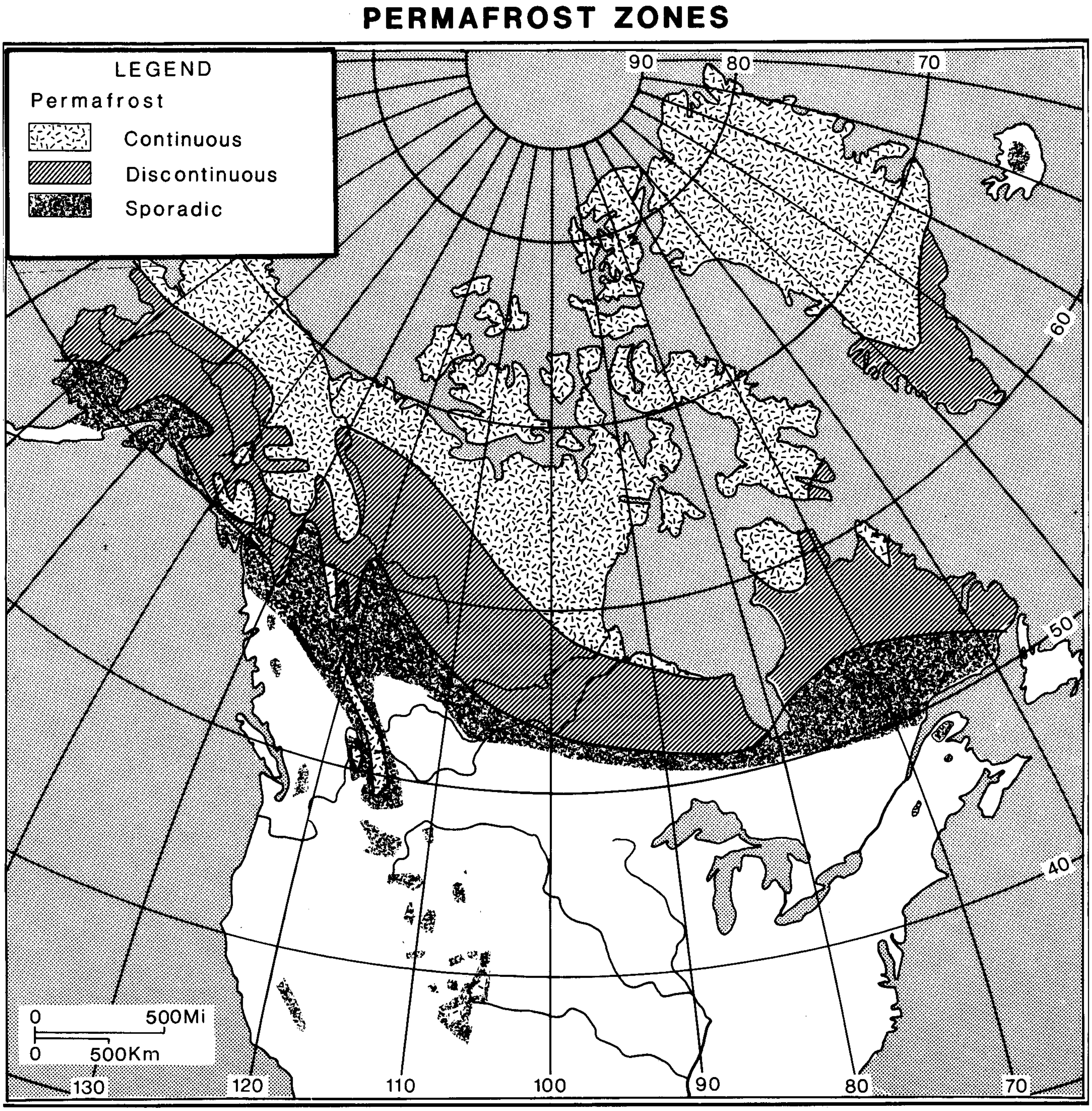

FIG. 7. Distribution of permafrost in North America.

APPENDIX. Data and sources used in constructing Figure 1

Latitude	Elevation m	Elevation ft	Location	Type of Evidence	Reference
35°25′	2134	c. 7000	Main Road, Gallup to Sante Fé	perennial cave ice	R. Barry, pers. comm. 1984
37°30′	3500	11 482	San Juan Mts.	ice-cemented rock glaciers; perennial ice in mine	Howe, 1909:33; Spencer, 1900:188; Brown, 1925:465; S.E. White, 1981, in Péwé, 1983a

(continued)

APPENDIX (continued)

Latitude	Elevation m	ft	Location	Type of Evidence	Reference
37°40′	2800	9186	Sangre de Cristo Range	ice-cemented rock stream	Johnson, 1967:2218
39°50′	4000	13 123	McClellan Mts.	perennial ice in mine	Weiser, 1875:77
40°01′	3570-3710	11 713-12 172	Arapaho Rh. Gl.	active rock glacier	White, 1971:46
40°04′	3500	11 482	Niwot Ridge	ground temperature data	Ives and Fahey, 1971
40°04′	3520-3320	11 549-10 892	Fair Rk. Gl.	active rock glacier	White, 1971:53
40°04′	3500	11 482	Niwot Ridge	ground temperature data	Ives, 1974:187
40°05′	3500	11 482	Colorado Front Range	ice-cemented rock glaciers	White, 1976:83
40°16′	3560-3330	11 614-10 925	Taylor Rk. Gl.	active rock glacier	White, 1971:51
42°43′	2397	7860	Casper Mt. cave	perennial ice cave	Hill *et al.*, 1976:51
43°36′	2745	9000	Rainbow Ice Cave	perennial ice cave	Hill *et al.*, 1976:164-165
43°36′	2806	9200	Fossil Mt. Ice Cave	perennial ice cave	Hill *et al.*, 1976:163
44°11′	2684	8800	Ridiculous Ice Cave	perennial ice cave	Hill *et al.*, 1976:163
44°38′	2700	8858	Absaroka Mts.	ice-cemented rock glacier	Potter, 1972
44°42′	3048	10 000	July Ice Cave	perennial ice cave	Hill *et al.*, 1976:85
44°50′	2284	7490	South Fork Ice Cave	perennial ice cave	Hill *et al.*, 1976:96
44°50′	2400;2600	7874;8530	Beartooth Mts.	ice in peat	Pierce, 1979:F7
44°53′	2950	9678	Beartooth Mts.	ice in peat	Pierce, 1961:B155
44°54′	2950	9678	Shoshone National Forest, Wyo.	palsa	Collins *et al.*, 1984
45°00′	3230	10 597	Beartooth Mts.	bogs with perennial ice	Johnson and Billings, 1962:121
49°34′	2292	7520	Coulthard Mt.	perennial ice in cave	Ford *et al.*, 1972:252-253 (*cf.* Marshall and Brown, 1974:510, for elevation)
50°13′	2195-2499	7200-8200	Plateau Mt.	nine ground temperature cables	Harris and Brown, 1978, 1982
50°15′			Plateau Mt. Ice Cave	perennial ice cave	Thompson, 1976:94; Harris, 1979
50°50′	1433	4700	Canyon Cr. Ice Cave	perennial ice cave	Thompson, 1976:94; Harris, 1979
50°50′	2316	7600	Fortress Mt.	three ground temperature cables	Harris and Brown, 1978, 1982
51°05′	2712-1676	9000	Sunshine Ski Resort	five ground temperature cables	Harris and Brown, 1982
51°13′	1402	4600	Banff Traffic Circle	ground ice in cutting	D.G. Smith, pers. comm.
51°15′	1524	5000	Vermilion Pass	ground ice in cutting	D.G. Smith, pers. comm.
51°43′	2088	6850	Bow Summit	two ground temperature cables	Harris and Brown, 1978, 1982
52°10′	2743-2277	9000-7470	Sunwapta Pass/Parker Ridge	three ground temperature cables	Harris and Brown, 1982
52°47′	2195-2286	7200-7500	Marmot Ski Resort	four ground temperature cables	Harris and Brown, 1982
53°05′	2150	7053	Jasper N. Pk.	ice-cemented rock glacier	Luckman and Crockett, 1978:545
53°09′	1082	3550	Disaster Pt. Ice Cave	perennial ice cave	Thompson, 1976:126
58°38′	1539	5050	Summit Lake A	ground temperature cable	author's data
58°40′	982	3220	Summit Lake C	ground temperature cable	author's data
58°40′	1170	3840	Summit Lake B	ground temperature cable	author's data
58°45′	274	900	Rail Bridge	ground ice in drillholes	J. Elwood, pers. comm. 1982
58°45′	441	1450	River Crossing Alaska Highway	ground ice in drillholes	J. Elwood, pers. comm. 1982
58°45′	441	1450	Summit Lake E	ground temperature measurements	author's data
58°48′	441	1450	Fort Nelson	thermokarst	author's data
61°14′	396	1300	Grotte Mickey	ice cave	Thompson, 1976:136
61°18′	701	2300	Grotte Valerie, Nahanni Pk.	ice cave	Thompson, 1976:135
63°15′	1300	4265	MacMillan Pass	palsas	Kershaw and Gill, 1979:Porsild, 1945, 1951

(continued)

APPENDIX (concluded)

	Elevation				
Latitude	m	ft	Location	Type of Evidence	Reference
63°56′	1472	4829	Keno Hill	ground temperature in mine	Brown, 1967
64°30′	1250	4100	N. Fork Pass	ground temperature cables	Klohn Leonoff Consultants, Ltd., 1978
65°10′	—	—	Canol Road, Heart Lake	ground temperature measurement; ground ice	Kurfurst and Van Dine, 1973
65°13′	76	250	Canol Road	perennial ice in borehole, GL2U site	Kurfurst and Van Dine, 1973
65°22′	579	1900	Ogilvie R.	ground temperature cables	Klohn Leonoff Consultants, Ltd., 1978
66°18′	53	174	Ft. Good Hope	ground temperature measurement; ground ice	Kurfurst and Van Dine, 1973
66°26′	488	1600	Dempster Hwy.	ground temperature cables	Klohn Leonoff Consultants, Ltd., 1978:165
66°27′	366	1200	Eagle River Crossing	ground temperature cables	Johnston, 1980
66°50′	488	1600	Dempster Hwy.	ground temperature cables	Klohn Leonoff Consultants, Ltd., 1978:171
67°03′	1067	3500	Rat Pass	ground temperature cables	Klohn Leonoff Consultants, Ltd., 1978:174
67°16′	335	1100	Dempster Hwy.	ground temperature cables	Klohn Leonoff Consultants, Ltd., 1978:182
67°26′	43	140	Fort McPherson 1-MP-72	ground temperature measurement; ground ice	Judge, 1973:53, 176
68°22′	67	220	Beaverhouse Ck. H-13	ground temperature measurement; ground ice	Judge, 1973:74
69°06′	27	90	Reindeer D-27	ground temperature cable	Judge, 1973
69°51′	33	110	Horton River G-02	ground temperature cable	Judge, 1973:71

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