I.1. DISTRIBUTION OF PERMAFROST IN THE DISCONTINUOUS ZONE OF WESTERN CANADA

R. J. E. Brown[1]

(Summary)[2]

This conference has been organized to consider engineering problems encountered in the discontinuous permafrost zones of western Canada and Alaska. Before construction is undertaken in this zone, it is essential to obtain knowledge of the character of the permafrost and the environment in which it exists.

DEFINITION OF PERMAFROST

Permafrost, or perennially frozen ground, is defined exclusively on the basis of temperature, referring to the thermal condition under which earth materials (mineral and organic soils, and rock) exist at a temperature below 32°F continuously for a number of years. Permafrost includes ground which freezes in one winter and remains frozen through the following summer and into the next winter. This is the minimum limit for the duration of permafrost; it may be only a few inches thick. This definition includes "climafrost" (Reference 1 - p.58) and the Russian "pereletok" (Reference 2 - p.11). At the other end of the time scale is permafrost which is thousands of years old and hundreds of feet thick. Thus, permafrost is not permanently frozen especially in the southern portion of the permafrost region where it is thin and close to 32°F.

DEFINITION OF DISCONTINUOUS PERMAFROST

In the discontinuous zone, there are discontinuities in the permafrost both in its horizontal and vertical extents. For several years American and Russian investigators have defined the discontinuous zone on a temperature basis - the temperature of the permafrost just below the depth of seasonal variation is above 23°F (-5°C) (Reference 3, Reference 4 - p.23). Ground temperature observations in Canada are insufficient in number to enable a delineation

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[1] See Appendix "A" for affiliation.

[2] The full paper will be published by the Division of Building Research, National Research Council, Ottawa.

of the discontinuous permafrost zone on a temperature basis. Until they are available, the discontinuous zone can be delineated only quantitatively on the basis of the horizontal and vertical extent of permafrost.

LOCATION AND BOUNDARIES OF DISCONTINUOUS PERMAFROST ZONE

From a study of available literature and field observations over the past decade, the approximate distribution and nature of the discontinuous zone in western Canada has been established (Figure 1). This map also shows the land communications in this zone. There is a well developed road network in northern British Columbia and Yukon Territory. In the Prairie Provinces and Mackenzie District, land communications are just beginning to penetrate into the discontinuous zone except in Manitoba where the Hudson Bay Railroad has been in existence for 35 years. No land communications exist in the discontinuous permafrost zone of Ontario.

The southern and northern limits of this zone are known only approximately. The southern limit[1] refers to the most southerly occurrence of any known permafrost and thus includes substantial areas where now no permafrost exists. Similarly, the northern limit refers to the most northerly extent of areas that remain thawed throughout the year; this includes areas where permafrost is widespread, occurring virtually everywhere beneath the ground surface.

The southern limit of the discontinuous zone extends from the west coast of James Bay at latitude 53°N in the vicinity of the Attawapiskat River northwest to about latitude 54°N in central Saskatchewan and about latitude 56°N in Alberta. In the Cordillera, comprised of mountain ranges, plateaus and intermontane valleys and trenches, permafrost occurs at high elevations south to the 49th parallel and even farther south into the United States.

The northern limit of the discontinuous zone extends from the vicinity of Churchill, Manitoba, northwest between Great Slave Lake and Great Bear Lake and into Yukon Territory in the vicinity of Porcupine River - about latitude 68°N.

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[1]The southern limit refers to the most southerly occurrence of permafrost. The southern fringe refers to the southern portion of the discontinuous zone where permafrost occurs in scattered islands.

NATURE OF DISCONTINUOUS PERMAFROST ZONE

In the southern fringe permafrost occurs in scattered islands, a few feet to several acres in extent, a few inches to a few feet thick, confined to specific types of terrain having temperatures only a few tenths of a degree below 32°F. Northward, it becomes increasingly widespread and thicker; it is associated with a greater variety of terrain types having temperatures several degrees below 32°F.

INFLUENCE OF CLIMATE ON DISCONTINUOUS PERMAFROST

Climate is basic to the formation of permafrost and is one of the most important factors influencing the existence of this phenomenon. Of all the climatic factors, the temperature of the air is the most readily measured and most directly related to ground heat losses and heat gains. Observations indicate the existence of a broad relation between mean annual air and ground temperatures in permafrost. Many investigators have estimated the mean annual air temperature required to produce and maintain a perennially frozen condition in the ground (Reference 5 - p.3).

East of the Cordillera the southern limit of permafrost corresponds roughly with the 30°F mean annual isotherm (Figure 1, Reference 6 - p.31). South of this isotherm, permafrost occurrences are rare and of small extent. North of the 25°F mean annual isotherm, it is widespread and found in most types of terrain. The northern limit of the discontinuous zone corresponds approximately with the 20°F mean annual isotherm. In the Cordillera the mean annual air temperature decreases with elevation. Although field observations are virtually non-existent in this region, it is assumed that the distribution of permafrost changes vertically up the slope of each mountain range in response to the decreasing mean annual air temperature in the same manner as it changes horizontally from south to north to the east of the Cordillera.

Another important climatic factor is radiation. The type of ground surface influences the amount of solar energy that enters the ground from the atmosphere and thus affects the underlying permafrost. The exposure of sloping ground and degree of slope also determine the amount of radiation that will reach the ground surface. In the Cordillera permafrost frequently occurs on north facing slopes and not on opposite south facing slopes. Even in

areas of subdued relief, variations in permafrost distribution can be attributed to differences in radiation received on gentle slopes having different exposures (Reference 7 - p.43).

INFLUENCE OF TERRAIN ON DISCONTINUOUS PERMAFROST

The distribution of permafrost in the discontinuous zone is related broadly to climate as discussed in the previous section. Within this general pattern, local variations in the occurrence of permafrost are caused by differences in terrain conditions.

Relief

Between James Bay and the Cordillera, the relief is fairly subdued except for isolated highlands (Reference 8 - Map 11). (Saskatchewan - Thunder Hills (2230 ft.) and Wapawekka Hills (above 2000 ft.); Alberta - Buffalo Head Hills (2700 ft.), Clear Hills (3600 ft.), Swan Hills (4000 ft.), Birch Mountains (2765 ft.), Caribou Mountains (3047 ft.)). Permafrost occurs in peat bogs on the summits of the latter two highlands. Elevations vary from sea level to 500 ft. above sea level in the east to 3000 to 4000 ft. at the western edge of the prairies.

In the Cordillera, elevations vary from 4000 ft. to mountain peaks rising more than 10,000 ft. above sea level. The decrease of mean annual air temperature with elevation at the rate of about 1°F/300 ft. is illustrated by an example from southern British Columbia. The mean annual air temperature on Old Glory Mt. (7700 ft.) at 49°9'N, 117°55'W is 28.4°F. At nearby Rossland (3305 ft.), it is 42.9°F. At Garibaldi Park, B.C. (49°58'N, 123°00'W), permafrost occurs at about 6000 ft. (Reference 9 - p.95). At Cassiar, B.C. near the 60th parallel, no permafrost occurs at the townsite (3500 ft.); just below 4500 ft. permafrost is patchy and above 4500 ft. it becomes widespread. Along the Alaska Highway and branch roads south of Whitehorse, Y.T., permafrost was found only in certain types of terrain - mostly peat bogs - up to 4000 ft. Thus it is improbable that permafrost occurs in the Interior Plateau because of its elevation being below 4000 ft. (Figure 1). Between 4000 ft. and 6000 ft., it appears that permafrost occurs in scattered patches; between 6000 ft. and 8000 ft. permafrost is probably discontinuous but widespread and above 8000 ft., it is probably continuous. Thus by examining the orography map in the Atlas of Canada (Reference 8 -

Map 11) it is possible to delineate approximately the probable locations of permafrost in the Cordillera.

Physiographic Regions

The discontinuous permafrost zone extends over four physiographic regions having varying terrain features and permafrost conditions (Reference 8 - Map 13).

The Hudson Bay Lowland in northern Ontario and northeastern Manitoba is a low flat area, beach ridges marking the limits of postglacial marine submergence being the only major relief features. Between river valleys, drainage is poor. Soils consist of thick peat deposits overlying marine clays and till. Local micro-relief features include palsas, peat plateaus and ridges. Permafrost occurs in scattered patches mostly in these better drained micro-relief features.

The Precambrian Shield lying west of the Hudson Bay Lowland consists of rock knobs interspersed with poorly drained swamps and bogs. In these depressions, the soils are till varying from clay to gravel overlain by peat. In the southern fringe of the discontinuous zone, permafrost islands occur in the better drained portions of bogs. In the north, permafrost is more widespread.

The Interior Plains lie between the Precambrian Shield and the Cordillera in western Saskatchewan, Alberta and northeastern British Columbia including the Mackenzie River valley. The relief is rolling with isolated highlands. Soils are frequently gravelly along the rivers and fine-grained inland. In the southern fringe of the discontinuous zone, permafrost occurs in scattered patches in bogs; further north, it becomes more widespread.

The Cordillera region in the west of the discontinuous zone is mountainous with plateaus, intermontane valleys and trenches. The distribution of permafrost is marked by a vertical zonation with variations between north and south facing slopes in addition to the usual increase in horizontal and vertical extent towards the north of the discontinuous zone.

Glacial Geology

The entire discontinuous permafrost zone was glaciated during the Pleistocene except for the western

portion of Yukon Territory (Reference 8 - Map 15). It is probable that the permafrost in the glaciated portion formed after the retreat of the ice or subsequent post-glacial marine or lacustrine submergence. In western Yukon Territory, the permafrost could have formed during the cold period at the beginning of the Pleistocene. Referring to the glacial geology map in the Atlas of Canada, the youngest permafrost probably occurs in the areas of glacial marine or lacustrine deposition.

Vegetation

The discontinuous permafrost zone lies generally within the boreal forest and subarctic forest - tundra transition (Reference 8 - Map 38). In the Cordillera, there are extensive areas above the treeline in the alpine tundra. The predominant tree species is spruce with scattered jack-pine and poplar.

Snow Cover

Snow cover plays a critical role in the distribution of permafrost in the discontinuous zone. Detailed local studies of the influence of snow cover on permafrost islands are very limited. Maps of mean monthly and annual snowfall are available in the Climatological Atlas (Reference 5 - pp. 109 to 123). A heavy fall and accumulation of snow in the fall reduces the depth of frost penetration. Conversely, snow lying late in the spring delays thawing of the ground. It has been observed that the thickest permafrost in the Hudson Bay Lowland occurs in palsa mounds on which snow cover is thin because of their exposure to wind (Reference 10 - p. 219). The southern limit of permafrost in Quebec is several hundreds of miles north of the southern limit west of James Bay. One of the main factors may be that snowfall in the late fall is considerably higher in Quebec than across the Bay in Ontario (Reference 11 - p. 175).

OCCURRENCE OF PERMAFROST

In the southern fringe of the discontinuous zone, permafrost is restricted mainly to peat bogs. Figure 2 shows a cross-section through a typical peat bog with variations in vegetation, drainage and micro-relief and related permafrost occurrences. A typical peat bog with permafrost in the Precambrian Shield is shown in Figure 3 (Reference 12 - Figure 24). A typical peat bog with

permafrost in the Interior Plains is shown in Figure 4. The marked difference in photographic tone between the gravel ridge in the foreground and the peat bog in the background contrasts markedly with the similarity in tone of these two terrain features on the aerial photograph shown in Figure 5.

In the northern portion of the discontinuous zone permafrost is not restricted to one type of terrain and is thicker than in the southern fringe. Between Thompson and Churchill in Manitoba, permafrost is 50 to 100 ft. thick. At Yellowknife, N.W.T., it exceeds 100 ft. in thickness, at Dawson, Y.T., it is about 200 ft. thick and northeast of Dawson on the Peel Plateau, its thickness is several hundred feet. Figure 6 shows an extensive wet peat bog near Dawson, Y.T. where permafrost is widespread and probably 100 ft. thick. Permafrost would not occur in a similar bog in the southern fringe because of the wet conditions.

Reference has been made to the variations in permafrost distribution in the Cordillera because of elevation and exposure. A typical valley on the Alaska Highway with permafrost on the north facing slope but none on the opposite south facing slope is shown in Figure 7.

CONCLUSION

The discontinuous permafrost zone in western Canada is characterized by considerable variations in climate and terrain throughout its extent. This in turn results in variations in the distribution and character of the permafrost. The broad influence of climate on the formation and continued existence of permafrost is borne out by the location of the mean annual air isotherms relative to the distribution of permafrost. Local variations in permafrost conditions within the discontinuous zone are related to variations in terrain. The thermal sensitivity of permafrost is such that even small changes in climate and/or terrain will produce changes in the horizontal extent, thickness and temperature of the permafrost.

The discontinuous permafrost zone is experiencing increasing economic development. Engineering problems arise mainly because of the erratic distribution of permafrost and the proximity of its temperatures to 32°F. The northern portion of the discontinuous zone presents the most difficult engineering problems. Permafrost is widespread and not restricted to one type of terrain; however, it does not exist everywhere beneath the ground surface and its

occurrence is unpredictable. It is sufficiently thick so that it cannot be ignored or easily removed during construction. Its temperature is within a few degrees of 32°F so that it may thaw during the life span of the structure. Thus, the engineer is confronted with a complex variety of physical features and permafrost conditions in the discontinuous zone, knowledge of which is a vital requirement for construction.

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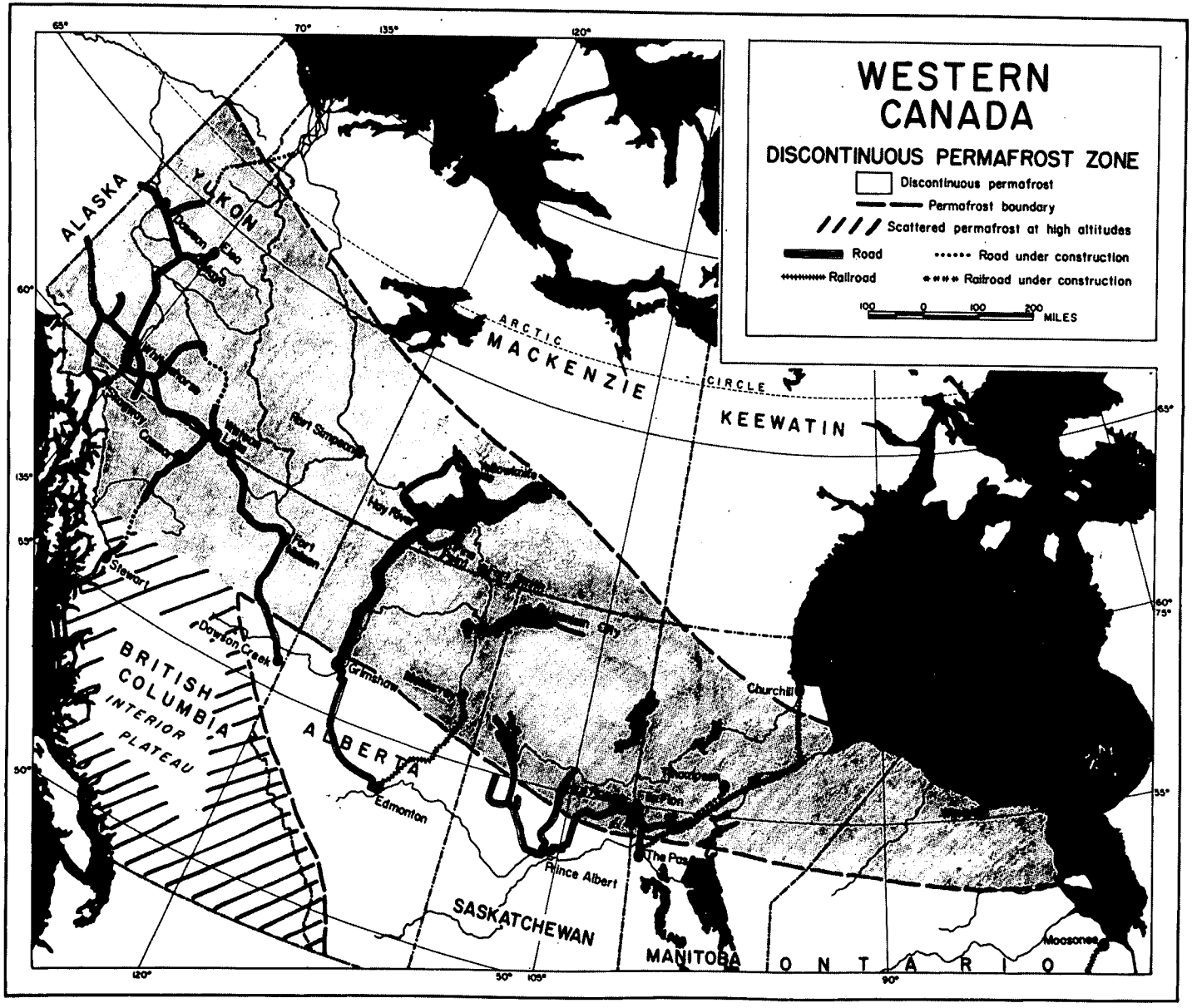

FIGURE 1

WESTERN CANADA - DISCONTINUOUS PERMAFROST ZONE AND LAND COMMUNICATIONS. (DBR PHOTO BR 13,635)

BR 3459-1

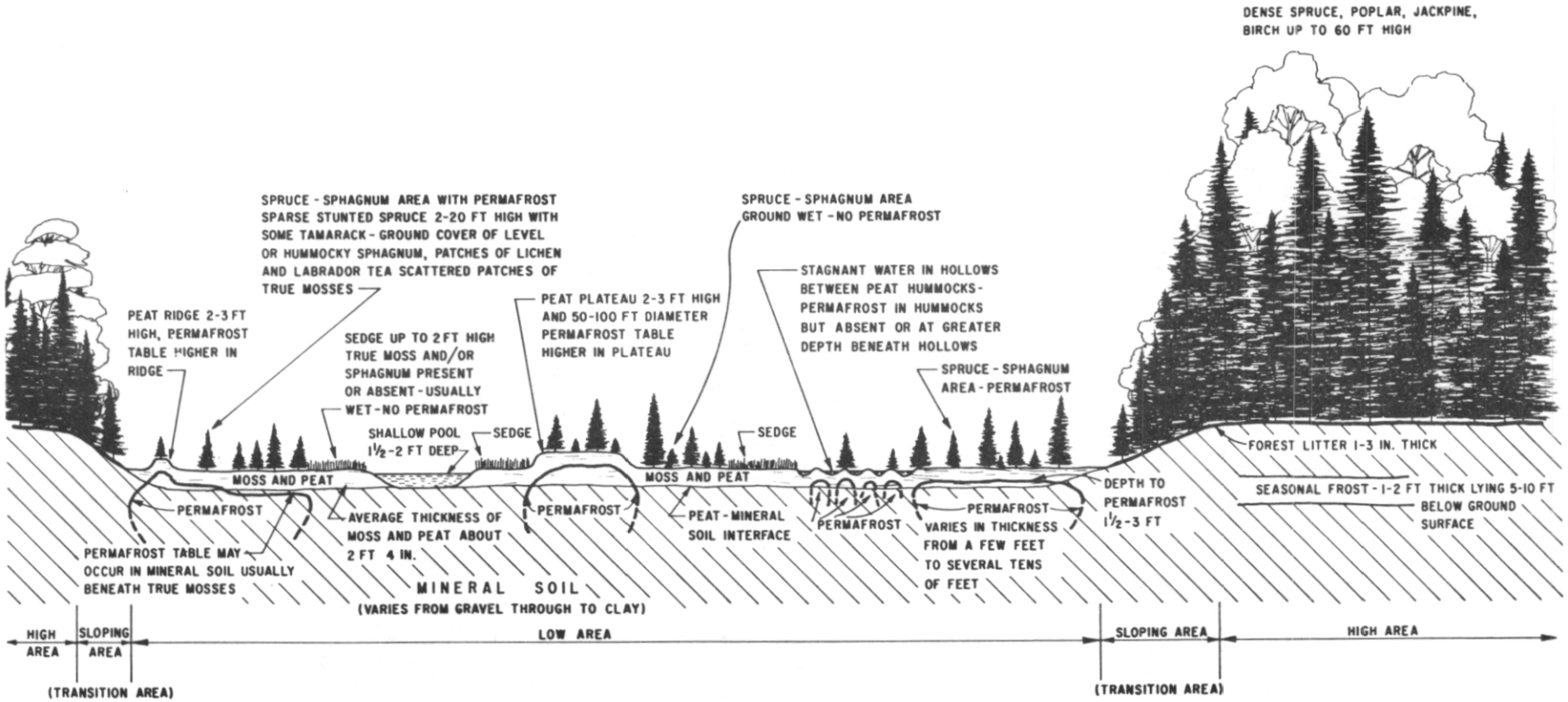

FIGURE 2

PROFILE THROUGH TYPICAL PEAT BOG IN SOUTHERN FRINGE OF DISCONTINUOUS ZONE SHOWING VEGETATION, DRAINAGE AND MICRO-RELIEF, AND ASSOCIATED PERMAFROST DISTRIBUTION (BR 3119-11)

BR 3459-2

Figure 3 Peat bog in Precambrian Shield, 26 miles north of LaRonge, Sask. in the southern fringe of the discontinuous permafrost zone. It is about 200 yards in diameter near the top of a hill flanked by a rock outcrop in the background. The tree growth on the bog is spruce up to 20 ft high and the ground vegetation is Sphagnum, Labrador tea and scattered lichen patches below which is peat exceeding 7 ft in thickness. The permafrost table is at the 1'-6" depth and the permafrost is 1'-5" thick. 15 September 1963 (BRS 2421).

Figure 4 Airstrip on gravel ridge (no permafrost) in foreground at Steen River, Alberta, 270 miles north of Grimshaw on Mackenzie Highway in southern fringe of discontinuous permafrost zone. Dark area beyond airstrip is a peat bog having tree growth of scattered spruce up to 20 ft high with ground vegetation of hummocky Sphagnum, lichen and Labrador tea below which is peat to a depth of 3'-4" overlying silty sand. The permafrost table is at the 2'-0" depth and the permafrost exceeds 2'-0" in thickness. 17 September 1962 (BRS 1447).

Figure 5 Section of RCAF air photo A15156-129 at Steen River, Alberta. Airstrip is white elongated rectangle beside Mackenzie Highway. Peat bog is slightly curved elongated area beside airstrip. Note similar air photo tones which belie dissimilarity of soils and permafrost conditions and contrast markedly with differences in ground photo tones shown in Figure 4 (BR 12158).

BR 3459-4

Figure 6 Peat bog 90 miles east of Dawson, Y. T. in northern portion of discontinuous permafrost zone. Permafrost occurs everywhere in this bog even in wet areas and beneath pools of water. Beneath one pool 1'-3" deep, the permafrost table occurs at a depth of 3'-6" beneath the water surface. 24 September 1964 (BRS 3407).

Figure 7 North and south facing slopes of a valley at Mile 383.5 on the Alaska Highway in the Cordillera in British Columbia. The slope on the left is north facing with spruce and poplar tree growth, ground cover of Sphagnum and permafrost at shallow depth. The slope on the right is south facing with poplar and scattered spruce tree growth and no permafrost. 14 September 1964 (BRS 3320).

BR 3459-5