I. 3. PEDOGENIC STUDIES ON SOILS CONTAINING PERMAFROST IN THE MACKENZIE RIVER BASIN

J. H. Day

In this paper, the Mackenzie River basin is defined as the portion that lies north of the approximate southern limit of discontinuous permafrost, east of the main mass of the Cordillera, and west of a line joining Fort Smith, Yellowknife, Fort Franklin at the western end of Great Bear Lake and Tuktoyaktuk on the Beaufort Sea.

In this region the rocks are mainly of Palaeozoic, Ordivician, Devonian and Cretaceous age; they are sedimentary and include limestone, dolomite, shale and sandstone. The region is mainly low-lying, heavily wooded for the most part, poorly drained with many lakes and widespread muskeg, but the surface here and there is broken by a number of hills or higher plateaux which rise from 1,000 to 3,000 feet above the level of the surrounding country.

The region was glaciated by the Wisconsin-Laurentian ice sheet which left large moraines and thick drift on much of the area. During the final retreat of the ice sheet, lakes were widespread. Probably the largest lake that was formed was that in the Great Slave Lake-Great Bear Lake basins, and along the topographic low that lies between them (1). A southward extension of this lake extended along the Slave River valley, in which direction the lake drained during its early stages. Draining of these lakes during deglaciation, followed by isostatic changes and siltation, has considerably altered some of the lakes; siltation is still in progress in Great Slave Lake.

The following paragraphs outline briefly the history of soil investigations in this region, and summarize the characteristics of the great soil groups that have been described.

In 1944 Dr. A. Leahey and Mr. F. S. Nowosad, of the Canada Department of Agriculture, traversed the Fort Nelson and Liard rivers between Fort Nelson, B.C., and Fort Simpson, N.W.T. Observations were also made by Leahey between Fort Simpson and Waterways, Alberta (5). In 1945 Leahey traversed the route between Waterways and Aklavik, N.W.T. (3). The observations in this and the preceding year necessarily were confined to a narrow strip of land adjacent to the rivers. In 1952 Leahey examined the soils adjacent to that portion of the Mackenzie Highway within the Northwest Territories (4). In 1955 Leahey and the author mapped the soils of the Slave River lowland on a broad reconnaissance scale (2). In 1957 the Alberta Research Council initiated the exploratory soil survey of the northern area of that province. The programme is nearly

completed and so far 63 million acres have been mapped, using helicopters for transport. In 1960 the author visited Reindeer Depot, Inuvik and Norman Wells, all situated in the Northwest Territories, spending only one month in the field. In 1961, the author conducted a broad reconnaissance survey in the Fort Simpson area and along the Laird River to the British Columbia border.

In this region, most of the parent materials are youthful, but generally the alluvium along stream channels is the youngest deposit. Young soils lack horizons, or at best, the surface horizon is an accumulation of organic material. The profile has lost nothing less soluble than calcium carbonate. This type of profile is called a Regosol.

Older parent material that has had time or conditions permitting more intense weathering usually show brown colours at the mineral soil surface. This infers weathering, in the upper horizons, of the clay minerals with liberation of sesquioxides, leaching of bases from the clay complex and removal of calcium carbonate. These profiles are called Brown Wooded.

As the weathering process continues, more bases are removed from the clay complex, clay is mobilized and translocated, organic matter destruction is accelerated and conspicuous eluviated (Ae) and illuviated (Bt) horizons develop. Such profiles are called Gray Wooded.

As the weathering process continues, the eluvial (Ae) horizon becomes more siliceous as sesquioxides are leached from it, and the sesquioxides are deposited, mainly just below the eluvial horizon, forming a new illuvial horizon (Bf). The clayey (Bt) horizon present in the Gray Wooded profile is broken down and more or less completely destroyed. Such a profile is called a Podzol.

In this chain of events some stage may be bypassed, for example, some Regosols go directly to Gray Wooded, while some Brown Wooded soils go directly toward the Podzol.

Organic soils, which have one foot or more of peat over mineral material, may be associated with any of these groups.

At the southern limit of the region, as here defined, many soil inspections have been made by the Alberta Research Council. In the first two areas covered (essentially that between 56° N and 58° N) only a few occurrences of frozen organic soil were reported. In the third area (between 58° N and 59° N) frozen organic soils were more frequent. In the fourth area (between 59° N and 60° N) nearly all organic soils were frozen at shallow depths, but very few, if any,

mineral soils contained frozen material within three feet of the surface. Prof. W. Odynsky, Head of the Soils Division, Alberta Research Council, states that about 80 per cent of the land adjacent to the Alberta border is covered by organic soils with permafrost. In the remaining area, the presence of Brown Wooded soils with Gray Wooded soils is interpreted by Odynsky as a retarding of soil development by the presence of ice conditions at depth.

In the Slave River lowland, the soils are mostly peaty Meadow soils, with Regosols on the better drained ridges. In the northern portion of the area, permafrost was general but any conclusions as to whether or not its presence had retarded soil development were prevented by the youthfulness of the soil material in the whole area.

In the Mackenzie Highway - Hay River area, most of the recent alluvial soils are Regosols, but on the higher alluvial terraces and on the upland above the escarpment Brown Wooded and Gray Wooded soils are the dominant mineral soils. Organic soils are common everywhere and are frozen at shallow depths.

In the Fort Simpson area, upland mineral soils are mainly Brown Wooded and Gray Wooded. Permafrost is present at shallow depths in the sphagnum-black spruce bogs, on east-facing slopes along the riverbanks, and at greater depth on Simpson Island and probably elsewhere in the area. In the Liard River valley from the British Columbia border to Fort Simpson, Regosols occupy the lowest position and Brown Wooded the highest position where the soil material is inferred to be the oldest. Organic soils with permafrost were found with both Brown Wooded and Gray Wooded soils; the presence of permafrost in the area was not considered to have had any influence on the associated well-drained mineral soils. Organic soils with permafrost probably occupy 80 per cent of the area between the Liard River valley and northern Alberta.

In the area from Camsell Bend to Arctic Red River, N.W.T., and in the Mackenzie River delta, permafrost is present in practically all soils, excepting those that flood annually. It is the opinion of the author and his colleagues that the continuous permafrost boundary should be placed further south to include most of this area. Here the land generally has a continuous cover of mosses and patterned ground is common, whereas to the south the moss cover is discontinuous and patterned ground is uncommon. Regosols with permafrost occupy the lowest land, Brown Wooded with permafrost the higher land on well-drained locations. In poorly drained sites, peaty Dark Gray Gleysolic with permafrost, peaty Gleysol with permafrost and Organic soils with permafrost are present. Organic soils cover most of the land back from the Mackenzie River.

The Brown Wooded soil with permafrost is essentially the same as the orthic Brown Wooded in more southerly areas. The Dark Gray Gleysolic soils are characterized by a thin peaty horizon, by a high organic-matter content in the mineral surface horizon, by high base saturation, and by dull colours and mottling in the subsoil.

The boreal forest changes to the essentially treeless tundra both on the west and east sides of the Mackenzie River delta. On the west side, Leahey described a well-drained soil that had a slightly acid surface mineral horizon high in organic matter, a brown, slightly basic subsoil horizon, and a lower horizon that contained streaks of organic matter. Since then, Mackay has shown that this buried organic matter resulted from the progressive burial of the organic tongues that extend downward in the depressions between the hummocks. Mackay and others in Canada, and Tedrow and others in Alaska, have shown that the buried organic layer is common to most soils of the tundra (6, 7, 8, 9).

At Inuvik, soils examined under the tundra-forest transition vegetation were similar to those examined under tundra vegetation at Reindeer Depot. Both areas had hummocky topography although the hummocks apparently were higher and more frequent at Reindeer Depot. At Reindeer Depot the centres of some hummocks had a profile with little or no expression while others had a relatively well expressed profile that had a brownish surface over a gleyed subsoil. All the profiles had acid, unsaturated, surface horizons that became less acid or slightly alkaline with depth. They all had uniform textural profiles with no signs of clay translocation and all profiles were uniform in clay mineralogy. However, the tundra profiles had buried organic horizons while the forest profiles did not. The author examined these profiles in mid-July, when the depth to frozen ground under the knolls was two to three feet. These layers were not observed in the field because in one case the mineral material was very dark coloured, and in the other the layer was frozen. These layers in the tundra profiles were detected by chemical analysis.

At Inuvik on the gravelly outwash fan of Boot Creek, a Podzol with permafrost was sampled. While the profile was thin, the eluvial (Ae) and illuvial (Bf) horizons common to Podzols were reasonably well developed. Probably the degree of development expressed in this profile was possible because of the porous, gravelly nature of the material, which is not so susceptible to frost-heaving as the clayey glacial till on the upland area. It is also probable that this Podzol represents the maximum stage of soil development under the prevailing climate.

At this time, our observations are too few to permit revision

of the classification scheme to accommodate the few soils studied at Inuvik and Reindeer Depot.

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Discussion

N. W. Radforth asked if one can make any generalizations concerning the genesis and morphology of soils in the permafrost region of Canada, to which the author replied that it is impossible at present because only a limited number of profiles have been examined. Considerable work has been done on the arctic brown soils in Alaska and this has been reported in numerous papers by Tedrow and other investigators.

R. E. Beschel commented that this paper seems to discuss mostly stable soils and it is surprising to have such a large number of these. In reply to his question of what proportion of the soils are unstable, the author answered that if the term "unstable" refers to

disturbances caused by frost action, then the profiles described in the paper are disturbed. Nevertheless, there are evidences of weathering which means that frost action effects are slow. There was no evidence of newly formed soils.

A question was asked whether any brown wooded soils were encountered, to which the author replied that they were encountered in the south which lacked permafrost. Brown wooded soils were encountered also at Norman Wells in permafrost and showed some effect of frost action.

A. Corte enquired firstly if any soil sampling was undertaken laterally from hummocks, secondly, if the soil was uniform throughout the hummocks, and, thirdly, if grain size analyses were made of any of the soils. The author replied in the negative to the first question and in the affirmative to the second. The reply to the third question was that a number were done in a vertical section. As an example, one imperfectly drained tundra soil showed the following grain size distribution:

Depth	Sand (%)	Silt (%)	Clay (%)
0" - 5"	7	41	52
5" - 9"	6	39	55
9" - 23"	8	45	47
23" - 28"	6	37	57

N. W. Radforth asked what was the temperature at the 18 inch depth in organic terrain at Norman Wells, for example. The author replied that permafrost was encountered there at a depth of 16 inches. Radforth added that the present and past vegetation has an effect on the freezing index line.

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