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Properties of selected soils from the sub-Arctic region of Labrador, Canada

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Abstract: A total of 212 soil profiles were described and assessed for physical and chemical properties during July 2006 as part of an Ecological Land Classification study along the Churchill River in central Labrador. Two major soil types were found in the study area along the Churchill River: Podzols and Organic soils. Podzolic soils covered approximately 60% and Organic soils occurred in 24% of the study area. Approximately 15% of the study area was classified as rock and other unconsolidated material. Summary results and a sub-set of the following soil units (from 10 soil profiles) are presented here and were distinguished according to the Canadian System of Soil Classification (CSSC) (Soil Classification Working Group 1998): Orthic Humo-Ferric Podzol, Placic Ferro-Humic Podzol, Gleyed Humo-Ferric Podzol, Sombric Humo-Ferric Podzol, Gleyed Regosol and Orthic Luvic Gleysol. The basic properties of the soil units identified above included: (i) morphological descriptions of soil profiles with differentiated horizons; (ii) field-texture tests were used to determine classes and physical properties of sands, silts, loams and occurrence of mottles; and (iii) a range of soil chemical composition of different horizons (*e.g.*, pH, total organic carbon [TOC] and select metal concentrations) which indicated no anthropogenic contamination above background concentrations in the area.

Key words: Sub-Arctic, soils, taiga forest, Churchill River, Labrador.

Introduction

Labrador is located in the easternmost part of the Canadian Shield and composed of ancient Precambrian igneous and metamorphic rocks divisible into four geologic provinces, each characterized by different orogenic history. The Churchill River study area includes the Churchill Province trending northward across central Labrador. It is composed of a western belt of relatively little deformed sedimentary and volcanic rocks, and an eastern zone of high grade metamorphic rocks, both of which were last deformed in the Early Proterozoic Hudsonian orogeny (Greene 1974).

The entire Churchill River study area was covered by the Laurentide Ice Sheet (LIS) during the last glaciation (Klassen and Thompson 1993; Liverman 1997; Jansson 2003; Anders *et al*. 2007), which was the largest of the former Northern Hemisphere ice sheets and following deglaciation had a significant effect on sea levels due to the combination of glacioisostatic rebound of land and an increased meltwater pulse (Anders *et al*. 2007). As a result, thick glaciomarine sediments were deposited following deglaciation (Clark and Fitzhugh 1991). With the retreat of the LIS following the last glaciation (Clark and Fitzhugh 1991; Liverman 1997; Jansson 2003), the land mass previously underneath the ice sheet has been slowly rising (*i.e.*, glacioisostatic rebound). Till has been identified as the most common glacial deposit in the region and an extensive system of glaciofluvial terraces at various elevations have been identified along the eastern section of the Churchill River valley (Blake 1956; Ricketts 1998). Sediments within terraces are exposed in eroded sections along the north and south shores of the Churchill River. In the east, glaciofluvial sediments are underlain by a thick sequence of fine-grained bedded glaciomarine deposits and even the town of Happy Valley-Goose Bay, located at the mouth of the Churchill River at the head of Lake Melville, is built on a large sandy plateau (Liverman 1997). Till blankets, veneers and bedrock exposures are common on the upper slopes of the valley, as well as on the plateau areas adjacent to the valley slopes. Large quantities of glaciofluvial sand contribute most of the sandy bedload to the modern Churchill River; however, pebble, cobble and boulder gravel are also common. Glaciomarine sediments were deposited well below sea level and are found underlying glaciofluvial deposits east of Gull Island (Minaskuat Inc. 2009).

As the land slowly became exposed, plant species extended northward. The terrestrial, freshwater and marine ecosystems that developed in the Churchill River drainage basin are the result of biological colonization, geography and climate. Many of the freshwater fish migrated into the lower Churchill River watershed from the west as glaciers retreated. Species such as salmonids may have extended into the river from the east (Black *et al*. 1986). Some wildlife (*e.g.*, moose) colonized the area along corridors created by natural changes in the landscape or as a result of human activity. The Churchill River and its many tributaries now compose a diverse ecosystem with various animal species and a wide array of Labrador flora.

The aim of this study was to characterise the sub-Arctic soils within taiga ecozone along the Churchill River valley in central Labrador. This study formed a component of a much larger Ecological Land Classification (ELC) study and Environmental Impact Statement (EIS) for the Lower Churchill Hydroelectric Generation Project (Minaskuat Inc. 2007, 2009; Nalcor Energy 2009). Marshall and Schutt (1999) describe a hierarchical framework for ELC in Canada that formed the basis of developing updates to this regional ELC (Lopoukhine *et al.* 1977; Minaskuat Inc. 2007). This component study summarises morphological descriptions of typical soils (from 10 soil profiles) found within the Churchill River valley area, including the physical properties and a range of chemical composition of different soil horizons (*e.g.*, pH, TOC and select metal concentrations). Soils in central Labrador are poorly understood and only a few studies have been conducted to date (*e.g.*, Hendershot 1984; St. Croix 2002). Therefore, the data presented here will help contribute to an important background soil inventory for future monitoring studies in the region, particularly as the area is poised for resource and renewable energy development (*e.g.*, the Lower Churchill Hydroelectric Generation Project).

Study area

The study area (52–54°N, 60–65°W; see Fig. 1) includes the Churchill River which is the largest river in Labrador, with a watershed of over 90,000 km^2. From its headwaters near the western Labrador boundary (200 m a.s.l.), the river flows easterly through the existing hydroelectric development at Churchill Falls for over 850 km to Lake Melville at the river mouth near Happy Valley-Goose Bay (Nalcor Energy 2009). The study area is characterized by a varied natural environment and surficial geology consisting of glacial till deposits (Liverman 1997; Ricketts 1998), and the lower stretches of the river, including Muskrat Falls, are characterized by marine sediments, clays and silts in terraces and deposits that are well above current sea level. Near Lake Melville, extensive sand deposits occur in a delta at the river mouth (Liverman 1997). Northern Labrador's climate is classified as polar, while Southern Labrador's climate is classified as sub-Arctic (D'Arrigo *et al*. 2003), with winter temperatures in the area falling below -30°C and in summer rising above 30°C. In Happy Valley-Goose Bay, the average daily temperature in January is -18°C and in July it is 15°C (Nalcor Energy 2009).

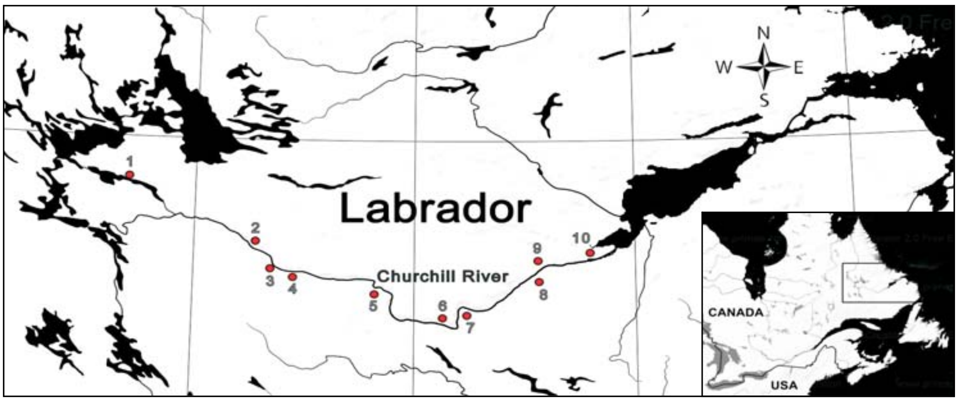


Fig. 1. Location of select soil sampling sites within the Churchill River valley.

Material and methods

An extensive field program was undertaken during July 2006, in support of the development of a detailed ELC for the area which described morphology of soils and associated vegetation cover along with collection of soil samples for chemical analysis (Minaskuat Inc. 2007). Sampling sites were selected on the basis of existing aerial photography of the study area with the objective of selecting representative habitat types that were identified in a previous study by Beak and Hunter and Associates (1978). Data on soil types were acquired from Soil Landscapes of Canada (SLC) database (Agriculture and Agri-Food Canada [AAFC 2006]). All sampling sites were within 2 km of the Churchill River and were accessed by helicopter (Canadian Helicopters Limited). Soil samples were collected from along transects which passed through representative soil and vegetation units at different points along the Churchill River and major tributaries. Where possible, sampling sites were selected along transects moved from up-slope to lower-slope positions as part of the ELC study (Minaskuat Inc. 2007, 2009).

A total of 212 soil profiles were assessed and sites were described based primarily on the CSSC (Soil Classification Working Group 1998) and to a lesser extent on the Canadian Soil Information System (CanSIS) (Expert Committee on Soil Survey 1982); and the classification of humus forms described by Green *et al.* (1993). The Canadian system of soil taxonomy used in this study is more closely related to the U.S. system than to any other. Both are hierarchical, and taxa are defined on the basis of measurable soil properties. However, the Canadian system differs in that it is designed to classify only soils that occur in Canada. The U.S. system has a suborder, which is a category is absent in the Canadian system. For example, in the Canadian system Gleysolic soils are differentiated at the highest categorical level similar to Russian and some European systems. Perhaps the main difference between the two systems is that all horizons to the surface may be diagnostic in the Canadian system, whereas horizons below the depth of plowing are emphasized in the U.S. system. This may be because 90% of the area of Canada is unlikely to be cultivated (as is the case in this study area). Site descriptions were also based on those found in the Field Manual for Describing Terrestrial Ecosystems (Province of British Columbia 1998). Soil pits were excavated to a depth of approximately 1 m, unless restrictions were encountered. Soil profiles were photographed and described. All soil chroma were determined on moist soil samples using Munsell Soil Color Charts (2000). All soil textures and humus form classifications were based on field assessments only. Separate soil samples were collected for chemical analysis from selected soil pits (mainly from areas projected to be flooded along the Churchill River), to determine any potential anthropogenic soil impacts, rather than for soil morphological determinations using chemical criteria. Samples were taken from major horizons, double bagged and labeled by profile number and horizon.

Soil samples were analyzed for: TOC; select metals (*e.g.*, Al, Ba, Cr, Cu, Fe, Mn, Pb, Hg, Zn are presented); and pH. TOC was determined by treating an aliquot of dried sediment sample with sufficient hydrochloric acid (HCl) (1:1) to remove inorganic carbon prior to instrument analysis on dried sediments at 105°C using a LECO CR-412 Carbon Analyzer (Schumacher 2002). Soil samples were ashed in a muffle furnace at 450şC overnight; a sub-sample (0.5 g) of the sediment ash was then digested in 10 mL of ultra-pure concentrated HNO_3. The digest residue (~1 mL) was diluted and filtered through Whatman No. 42 ashless filters then the volume was increased up to 50 mL using ultra-pure de-ionized water to give a final matrix of 1% HNO_3. Following acid digestion metals were analyzed using multi-element inductively coupled plasma-mass spectrometry (ICP-MS) techniques based on the US-EPA method 6020A (US-EPA 2005). Mercury in soil was analysed by manual cold vapor atomic absorption (CVAA) based on the US-EPA method 245.1 (US-EPA 2005). Soil pH was determined based on suspension of soil in 0.01M $CaCl_2$ extract. Measuring the concentration of hydrogen ions to determine net acidity or alkalinity using granplot acid titrations following the method of Legrand *et al*. (1982) is arguably a more precise measure of net acidity or alkalinity, but because of the strong buffering capacity of soil, pH was measured for the purposes of this study instead.

Results and discussion

Soil morphology. — The soil classification according to CSSC (Soil Classification Working Group 1998) was primarily used in this study and the major mineral horizons were defined as: A, B and C. The major organic horizons were defined as: L, F and H, which were mainly forest litter at various stages of decomposition, S, was occasionally used to describe *Sphagnum* moss covered forest floor and O, which was organic material derived mainly from wetland vegetation. Two major soil types were found in the study area along the Churchill River valley: Podzolic soils and Organic soils. The occurrence of soils types (by field-texture tests) that occurred in the study area are shown in Table 1.

Podzolic soils covered approximately 60% of the study area and according to Sanborn *et al*. (2011) Podzolic soils occupy over 14% of Canada and occur in two distinct areas, eastern Canada (including this study area) and in British Columbia. These Podzolic soils developed from acidic parent material, consisting of glacial and alluvial till, predominantly sand and gravel (Sanborn *et al*. 2011). These soil development processes resulted in the formation of a layer horizon enriched in Fe and Al, which leached from the surface horizons (O, L, F, H and A). These soils are typical of the sub-Arctic taiga regions of Canada. Ferro-Humic Podzols and Humo-Ferric Podzols differ in the extent of this Fe and Al enrichment and organic carbon content, but pyrophosphate extractable Al and Fe and organic C data with

Table 1

Texture, extent and coverage of soil types occurring within the Churchill River valley.

Soil type	Texture	Coverage within the study area (%)	Area (km^2)
Humo-Ferric Podzols	Sandy Loam	18.1	28,200
	Loam	3.3	5,000
	Sandy	2.4	3,800
Ferro-Humic Podzols	Sandy Loam	35.9	55,800
	Sandy	1.2	1,935
Organic Mesisols	Mesic Sedge	20.7	32,185
Organic Mesisols	Mesic Sphagnum	3.2	4,957
Rock	–	15.0	23,259

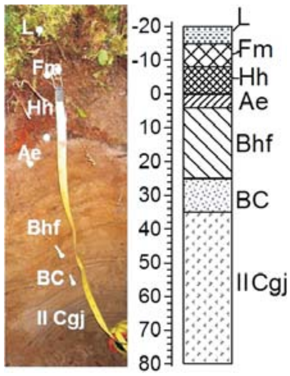
accompanying cation exchange capacity and particle size data to confirm the horizon profiles designations of podzolic soils were not used for the purposes of this study. Organic soils were those developed in areas of poor drainage, where organic matter (*e.g.*, Sphagnum moss) has accumulated more rapidly than it can decompose. Organic soils typically have surface layers consisting of organic material that are at least 50 cm thick (Denholm and Schut 1993; Province of British Columbia 1998). Organic soils occurred in 24% of the study area (Table 1). Approximately 15% of the study area was classified as rock and other unconsolidated material.

Profile 6 (Table 2) shows an example of Placic Ferro-Humic Podzol morphology. Gleyed Podzols were found where drainage was imperfect. Soils were dominantly acidic throughout (pH 4 to 5 or less), but values were higher where seepage inputs collected on long slopes. Profiles 7 (Table 3) and 10 (Table 4) are examples of the Gleyed Humo-Ferric Podzol morphology. Examples of Orthic-Ferric Podzol morphology are shown in Tables 5, 6, 7 and 8 (profiles 5, 3, 9 and 1 respectively). Profile 2 (Table 9) shows an example of the Sombric Humo-Ferric Podzol morphology. Orthic Gleysols and Organic (bog) soils were associated with poorly drained areas at higher elevations. Drainage was restricted in these areas due to bedrock (or basal till) and lack of slope. Profile 8 (Table 10) shows an example of Orthic Luvic Gleysol morphology. Orthic, Cumulic, and Gleyed Regosols were associated with alluvium deposits along the Churchill River and tributaries. Profile 4 (Table 11) shows an example of Gleyed Regosol morphology and like all Regosolic soils, lacks a well-developed B horizon (VandenBygaart 2011). Humus forms were dominated by Mors. Moders and Mulls were sometimes found in lower slope areas, where seepage inputs provided additional moisture and nutrients, and where alluvium soils were found. Many similar soils were found by St. Croix (2002) in a soil survey east of Happy Valley-Goose Bay.

Generally parent material consisted mainly of glaciofluvial sands and silts with inclusions of finer glaciomarine silts and clays. In some cases, these inclusions were associated with past slumping events, which mixed near-surface sand horizons with deeper marine sediments (*e.g.*, colluvium). There was also evidence of aeolian de-

Table 2

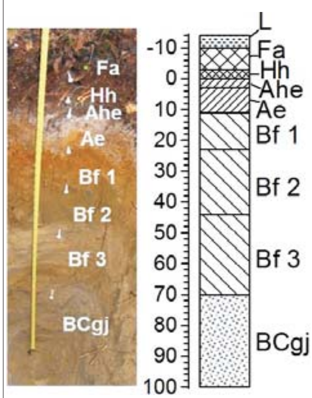
Physical and morphological characteristics of a Placic Ferro-Humic Podzol (P.FHP) in profile 6.

Soil Profile	Horizon	Depth (cm)	Description
	SFH	20–0	Leaf and litter horizons (S, Fm and Hh) were comprised of semi- decomposed organic matter; fibrous, abundant, fine and medium roots.
	Ae	0–4	Gray colour (10YR 6/1); fine sand; loose single grain with no coarse fragments; abundant, fine and medium roots.
	Bhf	4–25	Dark yellowish brown colour (10YR 4/4); fine sand; loose single grain with no coarse fragments; few, fine roots.
	BC	25–35	Light olive brown colour (2.5Y 5/4); fine sand; loose single grain with no coarse fragments; few, fine roots.
	II Cgj	35–80	Light olive brown colour (2.5Y 5/6); few (<2%) fine (<5 mm) faint mottles; fine sand; loose single grain with no coarse fragments.

Notes: Humimor humus form. Glaciomarine parent material on level terrace. Rapidly drained, non-stony and non-rocky. Spruce fir / Feathermoss forest represented 5.5% of the area surveyed and the dominant vegetation comprised of Balsam fir (*Abies balsamea*), Black spruce (*Picea mariana*), Common Labrador tea (*Ledum groenlandicum*), and Red-stemmed feathermoss (*Pleurozium schreberi*).

Table 3

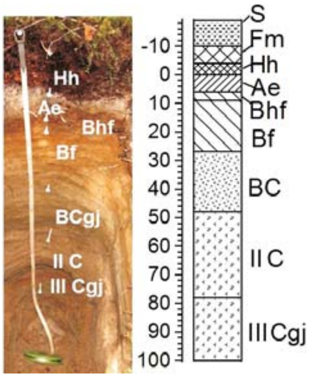
Physical and morphological characteristics of a Gleyed Humo-Ferric Podzol (GL.HFP) profile 7.

Soil Profile	Horizon	Depth (cm)	Description
	LFH	14–0	Leaf and litter horizons (Fa and Hh) were comprised of semi-decomposed organic matter; fibrous, abundant, fine and medium roots.
	Ahe	0–3	Grayish brown colour (10YR 5/2); very fine loamy sand; granular, very friable with no coarse fragments; few, fine and medium roots.
	Ae	3–11	Light brownish gray colour (10YR 6/2); very fine sand; blocky, very friable with no coarse fragments; few, fine and medium roots.
	Bf 1	11–23	Dark yellowish brown colour (10YR 4/6); silty loam; subangular blocky, very friable with no coarse fragments; few, fine roots.
	Bf 2	23–44	Dark yellowish brown colour (10YR 4/4); silty loam; blocky, very friable with no coarse fragments; few, fine roots.
	Bf 3	44–70	Brown colour (10YR 5/3); very fine loamy sand; blocky, very friable with no coarse fragments.
	BCgj	70–100	Grayish brown colour (10YR 5/2); fine sand; blocky, very friable with no coarse fragments; some magnetite banding; few, medium, distinct mottles.

Notes: Mormoder humus form. Glaciofluvial parent material on an almost flat terrace. Well to moderately well drained, non-stony and non-rocky. Mixedwood forest represented 4% of the area surveyed with the dominant vegetation comprising of Balsam fir (*Abies balsamea*), Heart-leaved paper birch (*Betula cordifolia*), Black spruce (*Picea mariana*), Quaking aspen (*Populus tremuloides*) and Green alder (*Alnus viridis*).

Table 4

Physical and morphological characteristics of a Gleyed Humo-Ferric Podzol (GL.HFP) in profile 10.

Soil Profile	Horizon	Depth (cm)	Description
	SFH	19–0	Leaf and litter horizons (S, Fm and Hh) were comprised of semi-decomposed organic matter; fibrous, abundant fine and medium roots.
	Ae	0–6	Grayish brown colour (10YR 5/2); fine sandy loam; subangular blocky, very friable with no coarse fragments; few, fine and medium roots.
	Bhf	6–9	Dark reddish brown colour (5YR 3/4); fine loamy sand; blocky, very friable with no coarse fragments; few, fine roots.
	Bf	9–27	Strong brown colour (7.5YR 4/6); fine loamy sand; blocky, very friable with no coarse fragments; few, fine roots.
	BCgj	27–48	Brown colour (10YR 4/3) few (<2%) fine to medium distinct mottles; very fine sand; blocky, very friable with no coarse fragments; few, fine roots.
	II C	48–78	Brown colour (10YR 5/3); medium sand; subangular blocky, loose with no coarse fragments; some magnetite banding.
	III C	78–100	Dark grayish brown colour (10YR 4/2); common (2–20%), medium (5–15 mm), distinct mottles; very fine sandy loam to medium sand; subangular blocky, friable to loose with no coarse fragments; some magnetite banding.

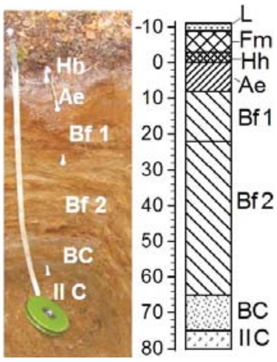
Notes: Humimor humus form. Glaciomarine parent material on level terrace. Moderately well drained, non-stony and non-rocky. Spruce fir / Feathermoss forest represented 5.5% of the area surveyed and the dominant vegetation (>80%) comprised of Balsam fir (*Abies balsamea*), Black spruce (*Picea mariana*), Common Labrador tea (*Ledum groenlandicum*), and Red-stemmed feathermoss (*Pleurozium schreberi*).

posits in the area between soil profiles 7 and 9 (*i.e.*, Muskrat Falls and Gull Island), which would have originated from glaciofluvial sands and silts. Colluvium, glacial till, and bedrock derived soils had textures ranging from sandy loam to sand and were often stony or rocky (mainly gneiss). Drainage in upland areas was mainly rapid to well; however, drainage was sometimes slowed by sub-surface horizons of massive structures. Where this occurred, drainage changed to moderately well, imperfect, or even poor. Drainage was also moderately well to imperfect at lower slope positions due to seepage inputs.

Texture classes derived from field tests, generally ranged from sandy loam to sand, but in many cases, the sand size fraction was very fine often graded to silt with textures ranging from silty sand to silt loam classes. Silty clay loam, clay loam and silty clay horizons were also found occasionally where fine marine sediments were close to the surface. Dark/gray horizontal banding was conspicuous in some sandy C horizons consistent with the study by Kletetschka and Stout (1998) that documented the presence of magnetite in rocks and soils in Central Labrador. However, it is likely that some of this dark/gray horizontal banding would be due to the presence of iron sulfides. Charcoal fragments were also observed in approxi-

Table 5

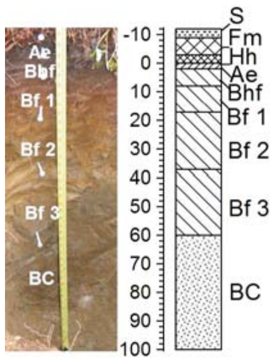
Physical and morphological characteristics of an Orthic Humo-Ferric Podzol (O.HFP) in profile 5.

Soil profile	Horizon	Depth (cm)	Description
	LFH	11–0	Leaf and litter horizons (L, Fm and Hh) were comprised of semi-decomposed organic matter; fibrous, abundant, fine and medium roots.
	Ae	0–8	Brown colour (7.5YR 5/2); very fine loamy sand; blocky, very friable with no coarse fragments; abundant, fine roots.
	Bf 1	8–22	Brown colour (7.5YR 4/4); very fine loamy sand; blocky, very friable with no coarse fragments; few, fine roots.
	Bf 2	22–65	Dark yellowish brown colour (10YR 4/4); fine sand; blocky, very friable with no coarse fragments; few, fine roots.
	BC	65–75	Dark yellowish brown colour (10YR 4/4); medium sand; loose single grain with no coarse fragments.
	II C	75–80	Medium sand; loose single grain with 60% gravel / cobble and 20% stone / boulder fragments.

Notes: Hemimor humus form. Glaciofluvial parent material on an almost flat terrace. Rapidly drained, non-stony and non-rocky. Fir-White spruce forest represented 4% of the area surveyed with the dominant vegetation comprising of Balsam fir (*Abies balsamea*), White spruce (*Picea glauca*), Speckled alder (*Alnus incana*), Dwarf dogwood (*Cornus canadensis*), Stair-step moss (*Hylocomium splendens*) and Red-stemmed feathermoss (*Pleurozium schreberi*).

Table 6

Physical and morphological characteristics of an Orthic Humo-Ferric Podzol (O.HFP) in profile 3.

Soil profile	Horizon	Depth (cm)	Description
	SFH	12–0	Leaf and litter horizons (S, Fm and Hh) were comprised of semi-decomposed organic matter; fibrous, abundant, fine and medium roots.
	Ae	0–2	Very dark gray colour (7.5YR 4/1); silty loam; subangular blocky, very friable with no coarse fragments; discontinuous horizon; abundant, fine roots.
	Bhf	2–8	Dark reddish brown colour (5YR 2.5/3); silty loam; subangular blocky, very friable with no coarse fragments; few, fine roots.
	Bf 1	8–17	Dark brown colour (7.5YR 3/3); silty loam; subangular blocky, very friable with no coarse fragments; few, fine roots; few, fine roots.
	Bf 2	17–37	Brown colour (7.5YR 4/4); very fine sand; platey, very friable with no coarse fragments; few, fine roots.
	Bf 3	37–60	Dark yellowish brown colour (10YR 4/4); fine sand; platey, very friable with no coarse fragments; few, fine roots.
	BC	60–100	Grayish brown colour (10YR 5/2); fine sand; platey, very friable with no coarse fragments.

Notes: Hemimor humus form. Glaciofluvial parent material on an almost flat terrace. Well drained, non-stony and non-rocky. Black spruce / Feathermoss / Lichen woodland represented 40% of the area surveyed and the dominant vegetation (>80%) was comprised of Black spruce (*Picea mariana*), Common Labrador tea (*Ledum groenlandicum*), Red-stemmed feathermoss (*Pleurozium schreberi*), Reindeer lichen (*Cladonia stellaris*) and Grey Reindeer lichen (*C. rangiferina*) (see Walker 2007).

mately 15% of soil profiles (mostly within A horizons), revealing evidence of the importance of post-fire vegetation development in the area. Foster (1985) reported significant differences in the pattern of vegetation development in the maritime region of Labrador compared to other taiga forests in North America, which was attributed to the much longer fire cycle allowing the accumulation of a thick organic soil layer which is incompletely removed by fire.

Ecological relationships to soil units. — Black spruce/lichen woodland ecotypes, represented by profile 9 (Table 7), were found primarily on deep substrates originating from colluvial, eolian, fluvial, glaciofluvial and till deposits. Water drainage was typically well to moderately well and vegetation is characterized by small patches of Black spruce within carpets of *Cladina* lichens. Shrub cover consisted mainly of stunted Black spruce and common Labrador tea (*Ledum groenlandicum*). Small Black spruce (*Picea mariana*) was restricted to patches near mature trees of the same species, while common Labrador tea was generally widely distributed. Lichen carpets were composed largely of *Cladina rangiferina* and *C. stellaris*. Red-stemmed feathermoss (*Pleurozium schreberi*) was also abundant, but was typically restricted to the understory of Black spruce patches.

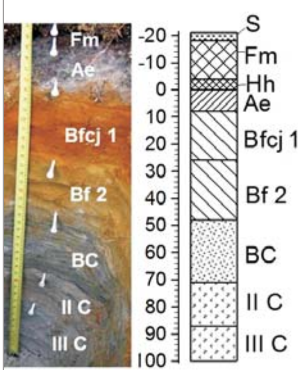
Riparian meadows, represented by profile 4 (Table 11), were found on sites with substrates derived solely from fluvial deposits along the shores of the Churchill River. Drainage was highly variable, ranging from poor to well. This ecotype developed in areas where sediments have been deposited on river bends, confluences, tributaries, and on islands in the river. Early successional plant communities that have developed on fluvial deposits vegetation typically consist of meadows dominated by Blue-joint reedgrass (*Calamagrostis canadensis*), Tall meadow-rue (*Thalictrum pubescens*) and Dwarf red raspberry (*Rubus pubescens*) that are interspersed with patches of shrubs. Shrub cover was typically less than 2 m tall and was composed mainly of Sweet bayberry (*Myrica gale*), Speckled alder (*Alnus incana*) and Silky dogwood (*Cornus sericea*). Tree cover was not present in this ecotype.

Black spruce/feathermoss ecotypes, represented by profile 3 (Table 6), were found on a wide range of substrates derived from relatively deep colluvial, eolian, fluvial and galciofluvial deposits and are generally nutrient-poor and well-drained; occurring on a variety of slope positions. This ecotype was characterized by moderately dense tree canopies composed of Black spruce (*P. mariana*). The shrub layer was also moderately dense and was dominated by common Labrador tea (*L. groenlandicum)*, Velvetleaf blueberry (*Vaccinium myrtilloides*) and small *P. mariana*. The ground vegetation layer consisted of moss carpets composed mainly of Red-stemmed feathermoss (*P. schreberi*). Other common ground vegetation species included: Stair-step moss (*Hylocomium splendens*), Knight's plume moss (*Ptilium cristacastrensis*) and *Cladina* lichens.

Mixedwood forest ecotypes, represented by profiles 2 and 7 (Tables 9 and 3), were found on material derived from colluvial, fluvial and glaciofluvial and till deposits. Drainage was variable and ranged from imperfect to rapid. The mixedwood

Table 7

Physical and morphological characteristics of an Orthic Humo-Ferric Podzol (O.HFP) in profile 9.

Soil profile	Horizon	Depth (cm)	Description
	SFH	21–0	Leaf and litter horizons (S, Fm and Hh) were comprised of semi-decomposed organic matter; fibrous, abundant, fine roots.
	Ae	0–8	Gray colour (10YR 5/1); fine sand; subangular blocky, very friable with no coarse fragments; abundant, fine roots.
	Bfcj 1	8–26	Yellowish red colour (5YR 4/6); fine sand; subangular blocky, friable to firm with no coarse fragments; few, fine roots.
	Bf 2	26–48	Dark yellowish brown colour (10YR 4/6); fine sand; blocky, very friable with no coarse fragments.
	BC	48–71	Dark grayish brown colour (10YR 4/2); fine sand; blocky, friable with no coarse fragments.
	II C	71–87	Light brownish gray colour (10YR 6/2); medium sand; single grain, loose with no coarse fragments.
	III C	87–100	Gray colour (10YR 6/1); fine sand; single grain, loose with no coarse fragments.

Notes: Hemimor humus form. Glaciofluvial parent material on an almost flat terrace. Well drained, non-stony and non-rocky. Black spruce / Lichen woodland represented 22% of the area surveyed and the dominant vegetation comprised of Black spruce (*Picea mariana*), Common Labrador tea (*Ledum groenlandicum*), Reindeer lichens (*Cladonia stellaris, C. arbuscula*) and Grey Reindeer lichen (*C. rangiferina*) (see Walker 2007).

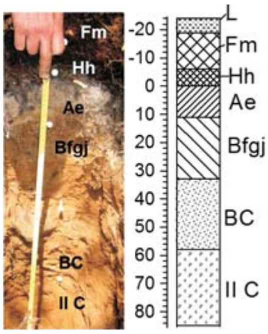
forest ecotype was typically found on mesic or submesic sites that were moderately fertile found mainly along the Churchill River valley and along the valleys of its tributaries. This ecotype was characterized by dense tree canopies that are composed largely of a mixture of Heart-leaved paper birch (*Betula cordifolia*), Balsam fir (*Abies balsamea*) and Black spruce (*P. mariana*). The shrub understory was well developed and consisted largely of a mixture of tall shrubs, such as Green alder (*Alnus viridis*) and Squashberry (*Viburnum edule*) and advanced regeneration of Balsam fir and Black spruce. The ground vegetation layer was characterized by a patchy cover of mosses. Soils associated with this ecotype were very similar to those associated with hardwood ecotypes.

Hardwood forest ecotypes, represented by profile 1 (Table 8), were associated with colluvial, fluvial, glaciofluvial, glaciomarine and till deposits with moderately well-drained conditions.

The hardwood forest ecotype was typically found on submesic to mesic sites occuring on a wide range of soil nutrient conditions but was most frequently encountered in areas with moderate to rich soils. This ecotype was found on both level sites and on slopes within the Churchill River valley and generally occurred as scattered stands on the slopes of large hills in upland areas. Tree species associated with this ecotype included: Heart-leaved paper birch (*B. cordifolia*), Paper birch (*Betula papyrifera*), Quaking aspen (*Populus tremuloides*), Balsam poplar (*Populus balsamifera*), Balsam fir (*A. balsamea*) and White and Black spruce

Table 8

Physical and morphological characteristics of an Orthic Humo-Ferric Podzol (O.HFP) in profile 1.

Soil profile	Horizon	Depth (cm)	Description
	LFH	24–0	Leaf and litter horizons (L, Fm and Hh) were comprised of semi-decomposed organic matter; fibrous, abundant, fine and medium roots.
	Ae	0–11	Light gray colour (5YR 7/1); fine clay loam; subangular blocky, soft with 10% gravel / cobble and 10% stone / boulder fragments; abundant, fine roots.
	Bfgj	11–33	Reddish brown colour (5YR 4/4) common (2–20%) fine (<5 mm) faint mottles; fine sandy clay; subangular blocky, soft with 20% gravel / cobble and 20% stone / boulder fragments; plentiful, fine roots.
	BC	33–58	Yellowish red colour (5YR 4/6); fine to medium sandy clay (granular, loose with 20% gravel / cobble and 20% stone / boulder fragments.
	II C	58–85	Reddish brown colour (5YR 4/3); medium sandy loam; granular, loose with 20% gravel / cobble and 10% stone / boulder fragments.

Notes: Hemimor humus form. Steeply sloped glacial till. Rapidly drained, slightly-stony and moderately-rocky. Hardwood forest represented 1.5% of the area surveyed with the dominant vegetation comprising of Heart-leaved paper birch (*Betula cordifolia*), Paper birch (*Betula papyrifera*), White spruce (*Picea glauca*), Quaking aspen (*Populus tremuloides*), Speckled alder (*Alnus incana*), Balsam poplar (*Populus balsamifera*), Dwarf dogwood (*Cornus canadensis*) and Red-stemmed feathermoss (*Pleurozium schreberi*).

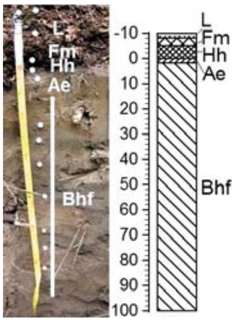
(*Picea glauca* and *P. mariana*). The ground vegetation layer consisted mainly of Dwarf dogwood (*Cornus canadensis*), Creeping snowberry (*Gaultheria hispidula*), Twinflower (*Linnaea borealis*) and Northern starflower (*Trientalis borealis*). Moss cover was found in small patches and consisted mainly of Red--stemmed feathermoss (*P. schreberi*).

Spruce-fir/feathermoss ecotypes, represented by profiles 6, 10 and 8 (Tables 2, 4 and 10 respectively), were most often associated with material derived from colluvial, fluvial, glaciofluvial and till deposits that were generally well drained. The spruce-fir/feathermoss forest ecotype was generally found on mesic to sub-hydric sites with poor to moderately fertile soils and occurred on both level and slope sites. Tree cover was moderately dense and consisted of a mixture of Black spruce and Balsam fir. The shrub layer was composed almost entirely of advanced regeneration of the canopy tree species. Ground vegetation was characterized by a well-developed moss carpet composed of a mixture of Red-stemmed feathermoss (*P. schreberi*), Knight's plume moss (*Ptilium crista–castrensis*) and Stair-step moss (*Hylocomium splendens*). Sphagnum moss (*Sphagnum angustifolium*) was often mixed in with the three dominant mosses. Other common ground vegetation species included: Dwarf dogwood (*C. canadensis*), Creeping snowberry (*G. hispidula*) and Mountain cranberry (*Vaccinium vitis–idaea*). This ecotype was largely restricted to the valley of the Churchill River and its larger tributaries.

Fir-white spruce woodland ecotypes, represented by profile 5 (Table 5), were associated with fluvial and, to a lesser extent, till deposits and were found on

Table 9

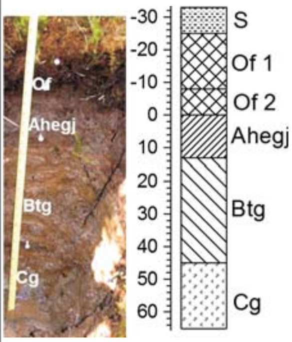
Physical and morphological characteristics of a Sombric Humo-Ferric Podzol (SM.HFP) in profile 2.

Soil profile	Horizon	Depth (cm)	Description
	LFH	10–0	Leaf and litter horizons (L, Fm and Hh) were comprised of semi-decomposed leafy organic matter; fibrous, abundant fine and medium roots.
	Ae	0–2	Light brownish gray colour (10YR 6/2); fine loamy sand (granular, soft with no coarse fragments; plentiful, medium roots.
	Bhf	2–100	Light brownish gray colour (10YR 4/4); medium sandy clay loam; granular, soft with no coarse fragments; few, medium roots; alternate horizons of clay with approximately 3 layers of clay.

Notes: Mor/Moder humus form. Steep glaciofluvial slope. Rapidly drained, non-stony and non-rocky. Mixed-wood forest represented 4% of the area surveyed with the dominant vegetation comprising of Balsam fir (*Abies balsamea*), Heart-leaved paper birch (*Betula cordifolia*), Black spruce (*Picea mariana*), Quaking aspen (*Populus tremuloides*) and Green alder (*Alnus viridis*).

Table 10

Physical and morphological characteristics of an Orthic Luvic Gleysol (O.LG) in profile 8.

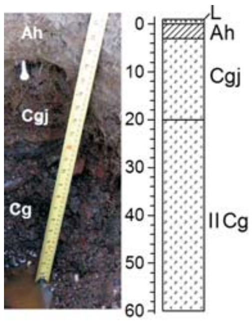
Soil profile	Horizon	Depth (cm)	Description
	S, O	33–0	Leaf and litter horizons (S, Of 1 and Of 2) were comprised of semi-decomposed organic matter; fibrous, abundant, fine and medium roots.
	Ahegj	0–13	Very dark grayish brown colour (10YR 3/2) many (>20%) distinct and coarse mottles; silty loam; subangular blocky, slightly sticky with no coarse fragments; plentiful, fine roots.
	Btg	13–45	Brown colour (10YR 4/3) many (>20%) prominent and coarse mottles; silty clay loam, blocky, sticky with no coarse fragments; few, fine roots to 20 cm.
	Cg	45–65	Dark grayish brown colour (10YR 4/2) many (>20%) prominent and coarse mottles; silty loam to very fine sandy loam; blocky, slightly sticky with no coarse fragments.

Notes: Fibrimor humus form. Glaciomarine parent material on level ground. Poorly drained, non-stony and non-rocky. Spruce fir / Feathermoss forest represented 5.5% of the area surveyed and the dominant vegetation (>80%) comprised of Balsam fir (*Abies balsamea*), Black spruce (*Picea mariana*), Common Labrador tea (*Ledum groenlandicum*), and Red-stemmed feathermoss (*Pleurozium schreberi*).

sub-mesic to mesic sites with moderate soil fertility. Sites were well drained and were generally found on level sites or on lower slopes. The tree canopy was dense and composed mainly of Balsam fir (*A. balsamea*) and White spruce (*P. glauca*). Heart-leaved paper birch (*B. cordifolia*) was present in many stands. The shrub understory was composed largely of advanced regeneration of Balsam fir along with some Speckled alder (*A. incana*) and Squashberry (*V. edule*). Ground vegetation consisted of large patches of moss. The most abundant moss species were Stair-step moss (*H. splendens*) and Red-stemmed feathermoss (*P. schreberi*).

Table 11

Physical and morphological characteristics of a Gleyed Regosol (GL.RP) in profile 4.

Soil profile	Horizon	Depth (cm)	Description
	LFH	1–0	Leaf horizon was very shallow; plentiful, fine roots.
	Ah	0–3	Very dark grayish brown colour (10YR 3/2); very fine loamy sand; subabgular blocky, very friable with no coarse fragments; plentiful, fine roots.
	Cgj	3–20	Brown colour (10YR 4/3); many (>20%) coarse and distinct mottles; very fine loamy sand; blocky, very friable with no coarse fragments; few, fine roots.
	II Cg	20–60	No colour for II Cg because of texture class; very coarse sand, loose single grain with 50% gravel / cobble and 5% stone / boulder fragments; few, fine roots to 35 cm.

Notes: Hydromull humus form. Alluvium parent material located on a gravel bar floodplain. Imperfectly drained, non-stony and non-rocky. Riparian meadows represented only 0.3% of the area surveyed with the dominant vegetation comprising of Speckled alder (*Alnus incana*), Sweet bayberry (*Myrica gale*), Blue-joint reedgrass (*Calamagrostis canadensis*) and Tall meadow-rue (*Thalictrum pubescens var. pubescens*).

Other common ground vegetation species included: Dwarf dogwood (*C. canadensis*), Wild lilly-of-the-valley (*Maianthemum canadense*), Naked bishop's-cap (*Mitella nuda*) and Northern starflower (*T. borealis*). This ecotype was largely restricted to the Churchill River valley and its larger tributaries.

Species representing the dominant vegetation cover associated with each soil profile are described in profile descriptions (Tables 2–11). According to the ELC study (Minaskuat Inc. 2007, 2009), the dominant plant and forest communities in the region were represented by taiga forest (commonly referred to as boreal forest in Canada), which were characterized by low nutrient regimes and low productivity. However, it seems that despite the low productivity of the taiga forest, there were favourable conditions for the accumulation of organic matter due to the low rates of mineralization. Low temperature and high humidity level in the sub-Arctic are the main factors that determine the intensity of mineralization (Melke and Chodorowski 2006) and the maritime climate of central Labrador has been documented by Foster (1985) as being largely responsible for the accumulation of a thick organic soil layer despite the occurrence of forest fires in the region.

Table 12 shows pH, TOC and metal concentrations for select horizons for all soil profiles presented here. The pH of the soils studied varied considerably and usually increased in the soil profile with depth. The acidic nature of the L, F, H and A horizons were likely the main cause of the Al and Fe leaching into the deeper B and C horizons. Concentrations of Cu also showed a similar pattern to Al and Fe, in that Cu concentrations increased with increasing depth. Other metals (*e.g.*, Ba, Cr, Mn and Zn) did not exhibit any consistent pattern with respect to increasing depth (Table 12). Not surprisingly, the highest TOC concentrations were measured in the surface organic horizons. The highest Hg concentrations were measured in the L,

Table 12

Chemical properties of different soil types and horizons within the Churchill River valley.

Order	Sub-group	Profile No.	Horizon	Depth (cm)	pH $CaCl_2$	TOC	Al	Fe	Ba	Cr	Cu	Hg	Mn	Pb	Zn
						($g.kg^{-1}$)			($mg.kg^{-1}$)						
Gleysolic	Orthic Luvic Gleysol	8	Of 1+2	33-0	3.14	380	4.7	8.0	100	3	8	0.17	55	6.9	20
			Ahegj	0-13	3.78	34	11.0	16.0	91	27	9	0.03	290	3.6	38
			Btg	13-45	4.07	15	11.0	16.0	95	26	9	0.01	420	3.1	42
			Cg	45-65	4.38	17	12.0	16.0	120	34	12	ND	230	3.5	48
Podzolic	Orthic Humo-Ferric Podzol	5	LFH	11-0	3.59	370	0.6	0.9	49	ND	4	0.21	780	6.6	35
			Bf 1	8-22	4.42	9.8	1.1	2.0	62	29	14	0.03	1100	3.3	38
			Bf 2	22-65	4.54	2.4	7.7	1.3	65	19	13	ND	370	2.1	34
		3	SFM	12-0	2.98	390	0.4	0.5	52	ND	4	0.15	25	22	30
			Bhf	2-8	3.59	67	7.3	1.3	42	20	10	0.03	87	5.2	19
			Bf 1+2	8-37	4.22	11	8.8	17.0	61	22	11	ND	180	3.4	30
			Bf 3	37-60	4.49	2.8	8.2	14.0	84	21	15	ND	260	2.8	35
		9	SFH	21-0	2.70	350	2.5	0.8	50	2	2	0.06	12	10	21
			Bfcj	8-26	4.77	7	13.0	8.4	19	16	4	ND	97	2.1	21
			BC	48-71	5.14	0.5	4.0	3.8	35	7	6	ND	130	1.5	16
			II C	71-87	5.09	0.4	4.8	4.8	57	8	7	ND	160	1.3	23
		1	LFH	24-0	3.20	310	3.0	4.6	130	4	8	0.01	16	2.5	7
			Ae	0-11	3.84	17	2.5	4.4	50	8	5	ND	30	2.7	9
			BC	33-58	4.46	4.5	5.5	12.0	89	19	6	ND	110	2.4	22
			II C	58-85	4.60	2.7	3.3	7.3	32	10	6	ND	85	3.6	14
	Placic Ferro-Humic Podzol	6	Bhf	4-25	4.17	3.1	4.6	5.7	44	9	8	0.01	170	1.4	22
			BC	25-35	4.32	2.3	5.9	6.0	68	11	10	ND	210	1.5	29
	Gleyed Humo-Ferric Podzol	7	Fa+Hh	14-0	4.20	260	1.2	1.7	120	3	4	0.21	1000	14	34
			Ahe+Ae	0-11	3.48	5	2.1	2.0	13	4	nd	0.01	42	2.9	8
			Bf 1+2	11-44	4.78	4.5	10.0	14.0	78	25	9	0.01	240	2.7	40
			Bf 3	44-70	4.83	1.8	5.6	5.9	62	10	7	nd	170	1.6	21
			BCgj	70-100	4.83	0.8	6.2	6.9	68	14	12	nd	190	1.7	27
		10	SFH	19-0	2.93	410	0.8	0.7	37	nd	4	0.1	62	24	39
			Ae	0-6	3.38	12	4.6	5.1	25	10	3	0.02	100	2.8	17
			Bf 1+2	6-27	4.17	6.9	7.6	11.0	72	19	7	nd	210	1.7	33
			BCgj	27-48	4.31	1.8	6.1	7.3	65	13	6	nd	200	1.7	29
			II C	48-78	4.46	0.5	3.2	3.8	30	6	5	nd	130	1.1	17
	Sombric Humo-Ferric Podzol	2	LFH	10-0	3.78	370	0.9	1.4	120	3	6	0.04	33	16	10
			Bf	2-100	4.36	2.1	6.0	8.4	78	12	14	nd	170	2.4	25
Regosolic	Gleyed Regosol	4	Cgj	3-20	5.03	2.3	6.5	12.0	90	17	13	nd	250	2.7	32
			II Cg	20-60	5.38	0.5	3.5	5.6	47	11	11	nd	120	1.4	19

Notes: nd = not detected; Grey columns = TOC, Al and Fe concentrations in soil were used as a guide for morphological descriptions.

F, H horizons, compared to in the C horizon. In many horizons, Hg was below detection limits (0.01 mg kg^{-1}). Concentrations of Pb also showed a decrease in concentration with increase in depth (Table 12).

Measurements of pH and select metals were comparable (or lower than) those reported for background soils in other studies in the Arctic and sub-Arctic regions (Ta-

Table 13

Background chemical concentration ranges for some sub-Arctic and Arctic A- and O-horizon soils.

Study	pH	Ba	Cr	Cu	Hg	Mn	Pb	Zn
		(mg.kg^{-1})						
Labrador (this study)	2.8–4.7	5–140	2–29	2–18	0.01–0.17	4–820	1–24	5–48
Alaska (Gough *et al.* 1987)	4.0–6.0	200–800	10–70	5–35	nd	nd	4–20	20–80
Spitsbergen (Melke and Chodorowski 2006)	3.6–6.5	nd	nd	10–34	nd	55–301	16–29	43–81
Norway (Reimann *et al.* 2009)	3.7–5.6	16–151	2.3–22	3.9–24	0.09–0.29	9–123	19–213	15–127
NE European Russia (Walker 2003; Walker 2005; Walker *et al.* 2003)	3.5–4.4	50–100	nd	1.5–4.2	nd	50–70	4–12	5–18

nd = dot determined.

ble 13). Therefore, the data presented here does not indicate any anthropogenic contamination of metals in the Churchill River valley and these soil data represent typical background concentrations for measured parameters. Measurements of pH and select metals were comparable to other background soil data reported in the taiga forests of Finland (Riemann *et al.* 2009); taiga forests of NE European Russia (*e.g.*, Walker 2003, 2005; Walker *et al.* 2003); forests of Alaska (Gough *et al.* 1987) and in soils measured in the Arctic tundra in Spitsbergen (Melke and Chodorowski 2006).

Conclusions

- Two major soil types were found in the study area along the Churchill River valley: Podzolic soils (60%) and Organic soils (24%). Approximately 15% of the study area was classified as rock and other unconsolidated material.
- The following soil subgroup units were distinguished and measured in this study: Orthic Humo-Ferric Podzol, Placic Ferro-Humic Podzol, Gleyed Humo-Ferric Podzol, Sombric Humo-Ferric Podzol, Gleyed Regosol and Orthic Luvic Gleysol.
- Soil pH varied considerably from strongly acidic to weakly acidic. The content of organic carbon was quite high, which can be considered a prominent feature of these sub-Arctic soils.
- Measured chemical parameters in soils were comparable to background concentrations measured in other studies in the Arctic and sub-Arctic. Therefore, no anthropogenic metal contamination was detected in the soils of the Churchill River valley.

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