Field Handbook for the Soils of Western Canada

Section 1

Soil Genesis and Geographical Distribution

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This is one section of a Field Guide for the Soils of Western Canada.

This section is a condensed version of material from the special issue of the Canadian Journal of Soil Science on the Soil of Canada (Volume 91, PP. 671-916). The authors of each chapter are listed at the end of each section, and should be cited if material is directly quoted from this section.

Full information on the Canadian System of Soil Classification can be found at:

Soil Classification Working Group. 1998. The Canadian System of Soil Classification. 3rd Ed. Research Branch, Agriculture and Agri-Food Canada. Publication 1646. NRC Research Press, Ottawa, Ontario.

The 3rd edition of the CSSC is available on-line at http://sis.agr.gc.ca/cansis/taxa/cssc3/index.html.

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1.0 introduction

There is a pattern to the distribution of soils and our goal in this section is both to show the regional-scale pattern of western Canadian soils and briefly examine the factors that control this pattern.

The factors that control soil distribution have been well established since the early work of soil scientists such as Hans Jenny and the Manitoban pedologist Joe Ellis in the 1930s and 1940s. The distribution of soils is controlled by seven soil-forming factors: climate, organisms, parent material, topographical position (or relief), time, groundwater, and the modifying effects of human activity. These factors combine to control the specific soil-forming processes that have affected a soil during its development; in turn the particular set of soil-forming factors result in specific horizons occurring in the soil profile. These horizons are the basis for soil classification. The effects of the soil-forming factors are readily apparent in the maps of the distribution of great groups of soils that follow in this section.

The effect of **climate and organisms** are closely linked, and the regional-scale distribution of several great groups closely corresponds to this. The transitions of the Chernozemic great groups from the drier, warmer Brown great group through to the transitional Dark Gray great groups at the forest margin (Figure 1.2) are a classic example of this. In some cases the transition between Chernozems and Luvisols can be very abrupt, and is probably associated not only with the obvious vegetation difference (grassland to forest) but also with the absence of burrowing animals such as gophers (and the bioturbation associated with them) in the forest. In forested areas, the absence of Podzols from the Prairie provinces (Figure 1.10) is probably due to the colder and drier climate that occurs in the Prairies (in comparison to much of British Columbia). In this case the effect of the climate is probably less on the vegetation itself than on the soil microorganisms that produce the decomposition products required for podsolization to occur. These climatic limits to decomposition in the Prairies cause the less-developed Brunisols to dominate (Figure 1.1). The role of burrowing animals and microorganisms illustrate why organisms (and not just vegetation) are included as a soil-forming factor.

Parent material is a major factor in Canadian soils because our soils are quite young by global standards and weathering has not fundamentally altered soil properties such as texture and mineralogy, both of which are largely inherited from the parent material. The great majority of western Canadian soils are formed on parent materials deposited during the final stage of the great Pleistocene glaciations and the characteristics of the glacial parent materials has pre-determined the genetic pathway taken by some soils.

For example, In the grasslands of the Prairies the “normal” soils are Chernozemic and the distribution of other soil groups is largely controlled by parent material. Vertisolic soils are high clay soils with a significant capacity to shrink and swell with changing soil moisture and are found only on clayey glacio-lacustrine (or lake) deposits. Many examples of Solonetzic soils are also found on high clay parent materials but in this case the parent materials have significant contents of exchangeable sodium (Na^+) on the charged clay surfaces. Finally some areas of sandy glacio-fluvial or lacustrine sediments have been destabilized by the wind, and these areas of dunes are home to Regosolic soils in the Prairies.

In forests throughout western Canada the distribution of Luvisolic versus Podzolic/Brunisolic soils has a broad-level parent material control. Luvisolic soils typically form in poorly-sorted till laid down directly by the ice sheets. The till has sufficient clay present to meet the requirements for Luvisol formation. Podzols and Brunisols form on sandy deposits of glacio-fluvial or glacio-lacustrine origin, which are typically very low in clay and which rapidly transmit water through the soil.

Soils such as the Chernozems or Podzols take thousands of years to form. The great majority of western Canadian soils have formed in the 10,000 to 17,000 years since the landsurface was exposed after retreat of the glacier but in some cases the **time** of formation has been much less. This is the case wherever instability of the landsurface occurs – for example in sand dunes or in river valleys where active erosion or sedimentation occurs. Soils associated with these unstable surfaces are classified into the Regosolic order.

Topography and **groundwater** are often closely linked as controls on soil formation due to the simple fact that water moves downslope. Where water concentrates in the landscape (on the soil surface or within the soil or sediments themselves) for a sufficient length of time, a distinct set of soil processes associated with oxygen-depleted conditions occurs. In the forested areas of western Canada areas of long-term water saturation give rise to Organic soils (or peats in common language). In grassland areas episodic droughts expose pond sediments and the organic materials decompose, and distinctive Gleysolic soils form in the wetlands. In some areas of the grasslands, groundwater from deeper in the sediment interacts with the soil surface, and these discharging groundwater areas often bring high salt loads to the soil, forming saline areas.

Soils throughout western Canada have been significantly altered by **human activity**. By far the greatest transformation has been in the former grasslands, where the great majority of the soils have been converted to agricultural uses. Forest harvest has also lead to significant human impact. The most common impact of human activity has been to accelerate erosion by water, wind and tillage. In eroding areas these processes leads to truncation of soil horizons and ultimately regression of the soil back to the least-developed soils, the Regosols. Many cultivated landscapes now have Regosolic soils on highly eroded knolls. The eroded soil is often deposited in lower-slope positions, leading to difficult-to-classify buried (or cumulic) soils.

The Canadian System of Soil Classification (CSSC) is ill-equipped to deal with human disturbance as the classes in the system were developed for native soils. Soils that have undergone significant disruption through, for example, resource extraction activities such as oilsand or pipeline development no longer have “natural” soil horizons. The same is true though the urban areas of Canada – little if any of the ”natural” soil remains in urban areas. In 2011 a group of Canadian soil scientists proposed the adoption of an 11^{th} soil order in Canada - the Anthroposolic order – which would facilitate description of these human-constructed soils. Unfortunately it has proven difficult to adequately test and refine the proposed order and it remains unofficial at the time this handbook was finalized (late 2015).

In the following parts of this section we have summarized the current state of knowledge about the formation of western Canadian soils. Much more material can be found in the special issue of the Canadian Journal of Soil Science on the Soils of Canada (Volume 91, PP. 671-916). It is very important to note, however, that our understanding of the genesis of soils continues to evolve, and that revision of the CSSC to reflect our evolving knowledge is essential if soil genesis and classification is to remain a discipline grounded in science.

A note on maps: The maps through this section were developed by Darrel Cerkowniak of Agriculture and Agri-Food Canada and we are very grateful to Darrel for his work on this. They are based on the 1:1,000,000 Soil Landscapes of Canada map series, and reflect a scale of generalization appropriate for this broad scale. For all but two maps (Regosol and Gleysol) the soils indicated in the map occupy at least 40% of the map polygons shown. This means that up to 60% of the pits you dig in that polygon could have other soils associated with it – for example, the typical Chernozemic catena shown in Figure 1.3 has two other orders shown, and in some polygons Solonetzic soils also occur in these catenas.

The Gleysolic and Regosolic maps show polygons where at least 10% of the polygon has these soils. Both of these soils typically occur in association with other soils and rarely dominate (i.e., occupy > 40%) of the polygons.

1.1 The Brunisolic Order

1.1.1 Introduction:
Brunisolic soils form under forests and have brownish-coloured B (Bm) horizons. Brunisols are imperfectly to rapidly drained soils that have not developed features diagnostic of other orders, but which do features that clearly express significant pedological development (unlike the Regosolic order). Although principally a forested soil, Brunisols span the range of climates, parental materials and physiographies of western Canada (Fig. 1.1). In some cases, Brunisols form under non-forested conditions, primarily permafrost-free tundra and alpine meadow environments, or may exist as the result of cultivation in agricultural settings.

Although exceptions occur, the great majority of Brunisolic soils are associated with sandy and gravelly parent materials that are resistant to the expression of soil formation. These parent materials dominate on the Canadian Shield and on other igneous and metamorphic rocks, and on glacio-fluvial and sandy eolian deposits through western Canada.

1.1.2 Dominant Genetic Processes and Diagnostic Horizons:
No single pedogenic process operates in all Brunisols except perhaps leaching; virtually all pedogenic processes are active to some extent but none predominates. Brunisols include soils with incipient to moderate soil formation. Transformation of parent material is evident from the formation of pedogenic structure, brownish or reddish coloured B horizon and/or carbonate removal. They lack appreciable quantities of illuvial clay or organically complexed Al and/or Fe compounds within the solum and are permafrost-free within the control section.

The distinguishing feature of Brunisolic soils is development of a brownish-coloured Bm horizon under forest vegetation. This horizon generally has a rather strong chroma and redder hue and often a structure that is noticeably different from the overlying A horizon or underlying C horizon. There is very little if any accumulation of clay, and relatively minor accumulation of Fe and Al minerals in the B horizons of Brunisolic soils. Brunisolic soils have a Bm horizon (or alternatively a Bfj or Btj horizon or both) at least 5 cm thick, a diagnostic feature that separates these soils from Regosols.

1.1.3 Distribution of Great Groups
As Brunisols are primarily forest soils, much of their taxonomy at the great group level can be related to humus form. Where mor humus forms occur (i.e., LFH horizons at the mineral soil surface), the soils are classified as Eutric (pH of ≥ 5.5 (all pH values in 0.01 M $CaCl_2$)) or Dystric Brunisols (pH < 5.5) depending on the pH of

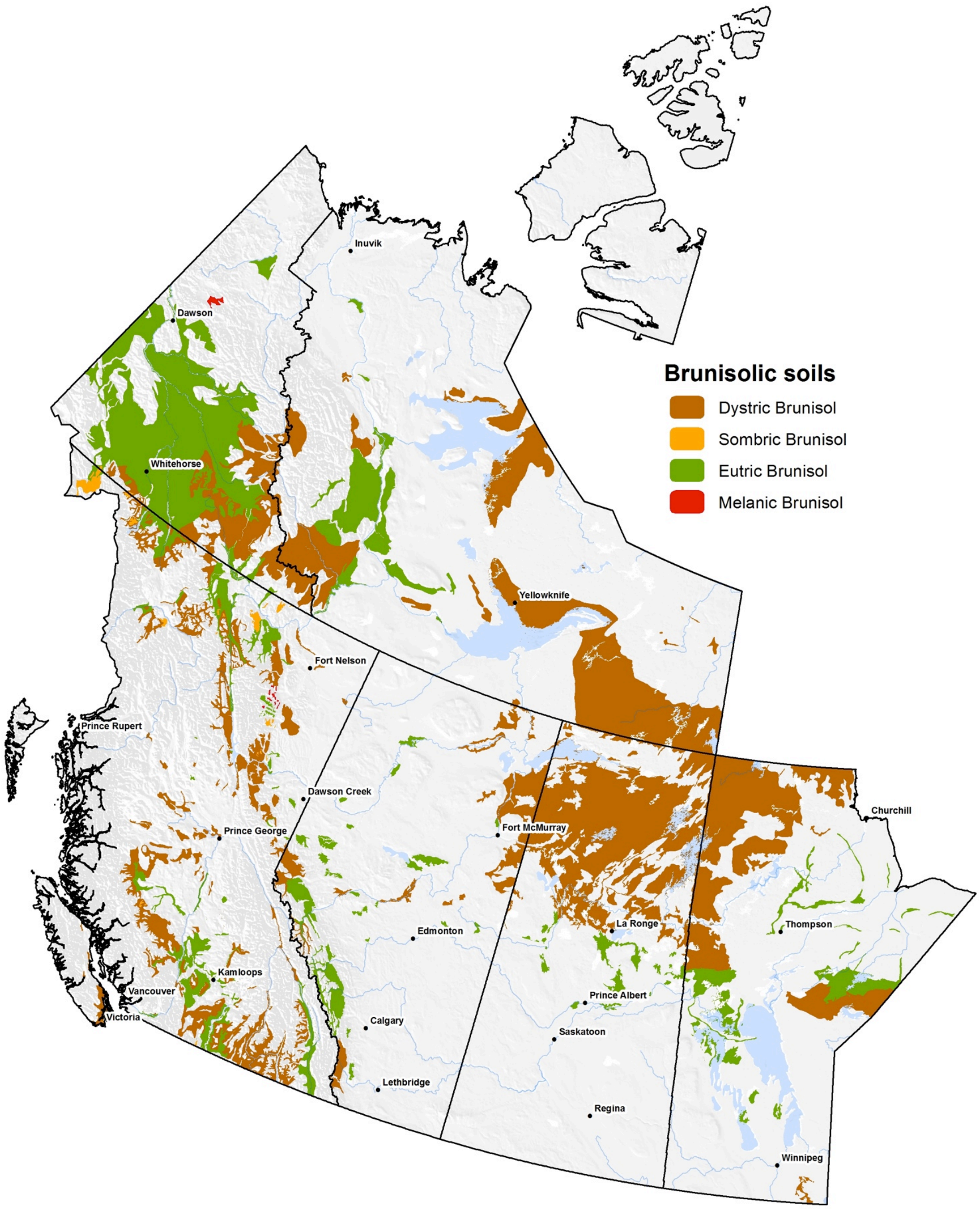

Figure 1.1: Distribution of the great groups of the Brunisolic order in western Canada.

the B horizon. Where conditions lead to mull or moder humus forms (i.e., incorporation of the leaf organic material into the mineral horizon as an Ah or Ahe horizon) through the process of active melanization, Sombric (pH < 5.5) and Melanic Brunisols (pH of ≥ 5.5) result depending again on the pH of the B horizon. As can be seen from Figure

1.1, however, these great groups are rare in western Canada, which is dominated by Eutric and Dystric great groups.

Generally the acidic great groups (Dystric and Sombric) form on parent materials derived from more acidic igneous and metamorphic rocks such as those of the Canadian Shield (Figure 1.1). The neutral and alkaline great groups (Melanic and Eutric) are associated with parent materials derived from sedimentary rocks, which have a higher initial base (e.g. Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) content.

In humid environments and acidic parent materials where Podzolic soils dominate, Dystric Brunisols form on parent materials that either lack the mineralogy or textural characteristics necessary to develop Podzolic B horizons, or are young enough that insufficient time has elapsed to allow diagnostic Podzolic features to develop. Often Podzols and Dystric Brunisols occur in the same geographic region and are difficult to distinguish in the field based on colour alone. Sombric Brunisols are much less common but are found in southern B.C. in Fraser delta and Vancouver Island.

In boreal and mixedwood forest environments, Brunisols tend to co-exist with Luvisolic soils. Luvisols occur where till and glaciolacustrine parent materials contain enough clay to allow the formation of textural-contrast B horizons, and the Brunisolic soils occur on sandy and gravelly glaciofluvial and eolian parent materials where there is insufficient clay present to allow Luvisol formation. These sediments are often derived from calcareous parent rocks, and Eutric Brunisols dominate in this region. Melanic Brunisols are rare in western Canada.

In regions of discontinuous permafrost, Brunisols tend to be found in association with Cryosolic soils, on landscape positions not underlain by near-surface permafrost such as rapidly drained materials and/or south facing slopes.

1.1.4 Secondary Genetic Processes and the Subgroups of the Brunsiolic Order: The secondary genetic processes common to all great groups are the formation of an Ae horizon at the mineral soil surface (Eluviated subgroup) and gleying (Gleyed and Gleyed Eluviated subgroups). The more acidic Dystric great group also has examples with a duric horizon (Duric subgroups) but these are rare in western Canada.

Gleyed: Gleyed subgroups of the Brunisolic order have faint or distinct mottles within 50 cm of the surface, or distinct to prominent mottles at 50—100 cm. The Gleyed identifier is also added to other Eluviated subgroup identifiers as well.

Eluviated: All great groups have Eluviated subgroups where an Ae or Aej horizon ≥ 2 cm thick occurs.

Duric: The duric horizon is a strongly cemented horizon that occurs in the Sombric and Dystric great groups.

1.1.5 Human Impact on Brunisolic Soil Classification

Some Brunisols have been cultivated for use in agriculture. In these cases, the plough layer may incorporate various native surface and subsurface horizons into an organic matter-rich Ap horizon. If the Ap is at least 10 cm thick and has a moist colour value <4 and part of the Bm, Bfj or Btj horizon remains below the Ap, these soils are classified as Melanic or Sombric depending on pH of the uppermost 25 cm of the B horizon.

For further information see:

Smith, C. A. S., K. T. Webb, E. Kenney, A. Anderson, and D. Kroetsch. 2011. Brunisolic soils of Canada: Genesis, distribution, and classification. Canadian Journal of Soil Science 91:695-717.

1.2 The Chernozemic Order

1.2.1 Introduction

Chernozemic soils are formed by the action and interaction of a host of biodynamic processes. They form in grasslands and experience substantial additions of organic matter through the root mass of the grasses. This plant-derived organic material undergoes microbial degradation and a small proportion of it forms a biochemically complex suite of soil organic matter. The upper portion of the soil also undergoes very substantial mixing (or turbation) by a range of burrowing animals and smaller soil invertebrates, creating a very porous and well aggregated surface soil layer (the Chernozemic Ah horizon). These soils are a major terrestrial reservoir of soil organic carbon.

1.2.2 Dominant Genetic Processes and Diagnostic Horizons

The addition of organic matter (OM) from grass and its subsequent transformation to soil organic matter (SOM) is central to Chernozemic soil genesis. These processes lead to the darkening of the surface soil horizon through the formation of brown to black OM-mineral aggregates. In native soils these aggregates form a well-developed granular structure. The SOM is mixed in a relatively homogenous layer (the Chernozemic A horizon) through the activity of a range of burrowing animals such as ground squirrels, pocket gophers, and badgers.

In the transitional region where the grassland grades to the boreal and cordilleran forests, graying caused by weathering and eluviation becomes evident in the surface layer, and an Ahe horizon is found in this transitional region. This horizon has a characteristic salt-and-pepper appearance when the soil is dry and the aggregates are crushed by hand.

The diagnostic horizon of the Chernozemic order is the Chernozemic A horizon. The native Chernozemic A horizon has three main pedological features: dark colours caused by relatively high SOM contents, well-developed granular structure, and high contents of exchangeable bases (i.e., Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) with Ca^{2+} dominating the base content. The colour value (i.e., the relative lightness or darkness) is the dominant criterion of the three components of the Munsell colour system for classification of the great groups of the Chernozemic order.

The Chernozemic Ah and Ahe horizons are found at the surface of native (undisturbed) soils but because of their inherently high fertility most Chernozemic landscapes have been converted to agricultural use. A ploughed A horizon is denoted with an p suffix (Ap); these Ap horizons can still meet the criteria for a Chernozemic A horizon.

1.2.3 Distribution of Great Groups

The great majority of Chernozemic soils are found in the Interior Plains in the region colloquially known as the Canadian Prairies (Figure 1.2). This region has mean annual temperatures between 0.5 and 3.5°C and substantial water deficits ranging between approximately 200 mm in the driest portions of the Brown soil zone to 80 to 90 mm in the transitional grassland-forest Boreal Plains Ecozone. Chernozemic soils are also found in the Montane Cordillera Ecozone in valleys of the southern interior of B.C., and in the Peace River region of Alberta. Small areas of Chernozemic soils also occur under localized grasslands on south-facing slopes in the Boreal Cordillera Ecozone in northwestern B.C. and southern Yukon.

The great groups of the Chernozemic order show a clear geographical zonation. The Brown great group occupies the driest region of the Prairies (in the SE corner of Alberta/SE corner of Saskatchewan) and the great groups grade through the Dark Brown, Black, and Dark Gray great groups as the water deficit decreases west, north, and east of the driest region. The darkening colour of the A horizon reflects the increase in SOM as the water deficit decreases. This geographical gradation is the basis of the soil zones, which are widely used in agricultural applications.

1.2.4 Secondary Genetic Processes and the Subgroups of the Chernozemic Order

There are seven subgroups in the Chernozemic order. Three of them (Vertic, Solonetzic, and Gleysolic) represent soils that have properties of both the Chernozemic order and another order in the CSSC. Soils in these three subgroups have horizons that resemble those of the other orders, but do not meet their strict taxonomic requirements. These horizons are normally assigned a j suffix (e.g Bnjtj or Bgj), indicating a juvenile form of the diagnostic horizon of the other three orders.

Vertic subgroup: These soils have properties of both the Chernozemic and the Vertisolic order. They develop in clay and heavy clay parent materials. They have slickenside B (Bss) and/or C (Css) horizons within 1 m of the surface and may have a weak vertic (Bvj or BCvj) horizon.

Solonetzic*:* These soils have weakly developed properties indicative of solonetzic soil processes in addition to those of the Chernozemic order. Soils of this subgroup have Bnj, Bnjtj, or Btnj horizons. The final assignment of the proper suffix (i.e., Bnj or Bn) may require a chemical test for the ratio of exchangeable calcium to exchangeable sodium. They are associated with high sodium parent materials, usually of glaciolacustrine origin.

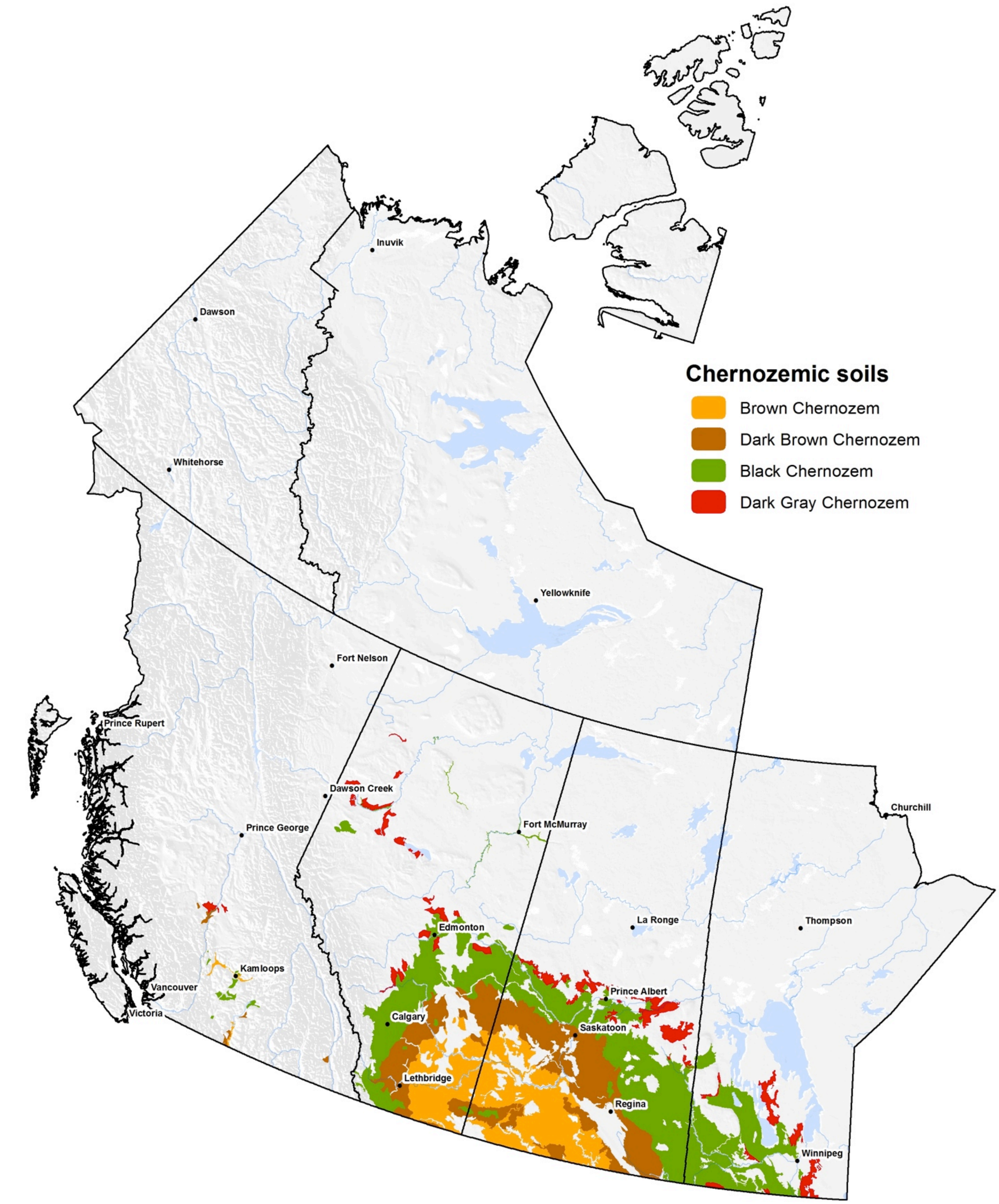

Figure 1.2: Distribution of the great groups of the Chernozemic order in western Canada.

Gleyed: Gleyed subgroups of the Chernozemic order are very common in landscapes that have wetlands. Both the Gleyed Chernozemic subgroups and soils of the Gleysolic order have mottles resulting from alternating reduction-oxidation conditions caused by periodic water saturation. The key distinction is the colour contrast of mottles: Gleyed Chernozemic subgroups have faint or distinct mottles within 50 cm of the surface, whereas soils of the Gleysolic Order have prominent mottles within 50 cm. The Gleyed identifier is also added to other subgroup identifiers for Chernozemic soils (e.g. Gleyed Rego, Gleyed Calcareous, Gleyed Eluviated etc.)

Gleyed Chernozemic subgroups are common in a fringe around wetlands in Prairie landscapes (Figure 1.3). The center of the wetland typically has Gleysolic soils. The Gleyed Chernozemic soils often also contain secondary salts that are deposited when solute-rich water from the wetland moves laterally into the surrounding landscape due to impermeable underlying sediments. The water is lost through evaporation and transpiration, and secondary salts are deposited in the upper horizons of the soil.

Where the pond water is relatively fresh, calcium carbonate is deposited in the A and/or B horizons (e.g. Ahca, Bcagj, Ccagj). Soils of the Gleyed Rego subgroups and Gleyed Calcareous subgroup occur in these situations, and the phase designator (carbonated) should be applied to these soils as well. Where the pond water is more saline, secondary salts more soluble than the carbonates occur, and a sa suffix is added (e.g. Bsagj, Csagj). No separate subgroup identifies these soils but they identified as a saline phase (e.g. Gleyed Rego Chernozem, saline phase).

Rego, Calcareous, Orthic, and Eluviated Subgroups:
The other four subgroups of the Chernozemic order represent an idealized evolutionary sequence for these soils (Figure 1.4). The first three represent different stages in the loss of calcium carbonate from the profile, and the Eluviated subgroup experiences weathering of the lower A (to form an Ae or Aej) and limited enrichment of clay in the B (i.e., Btj). All of these subgroups are commonly found together along hillslopes in undulating, rolling, and hummocky landscapes, often over relatively short (50 to 100 m) distances. Rego subgroups are now very common on knolls in agricultural landscapes due horizon truncation from erosion processes (see below).

1.2.5 Human Impact on Chernozemic Soils

The great majority of Chernozemic soils have been converted to agricultural use, and the surface horizons have been modified through tillage and erosion. Tillage mixes the upper 10 to 20 cm of the soil and creates a relatively homogeneous Ap horizon. In non-level landscapes, tillage and water erosion removes surface soil from knolls and upper portions of hillslopes, and deposits this soil in footslopes and depressional areas. Often B and C horizon material becomes incorporated into the tillage layer in eroded positions, leading to (for example) Apk or Apca horizons. This increases the areal extent of Rego subgroups and Regosolic soils in these eroded positions. Deposition of eroded A horizon sediment in lower slope position leads to over-thickening of A horizons but typically does not effect the classification. Wind erosion was very common in level landscapes on these soils prior to the adoption of soil-conserving tillage methods, and lead to the loss of A horizons.

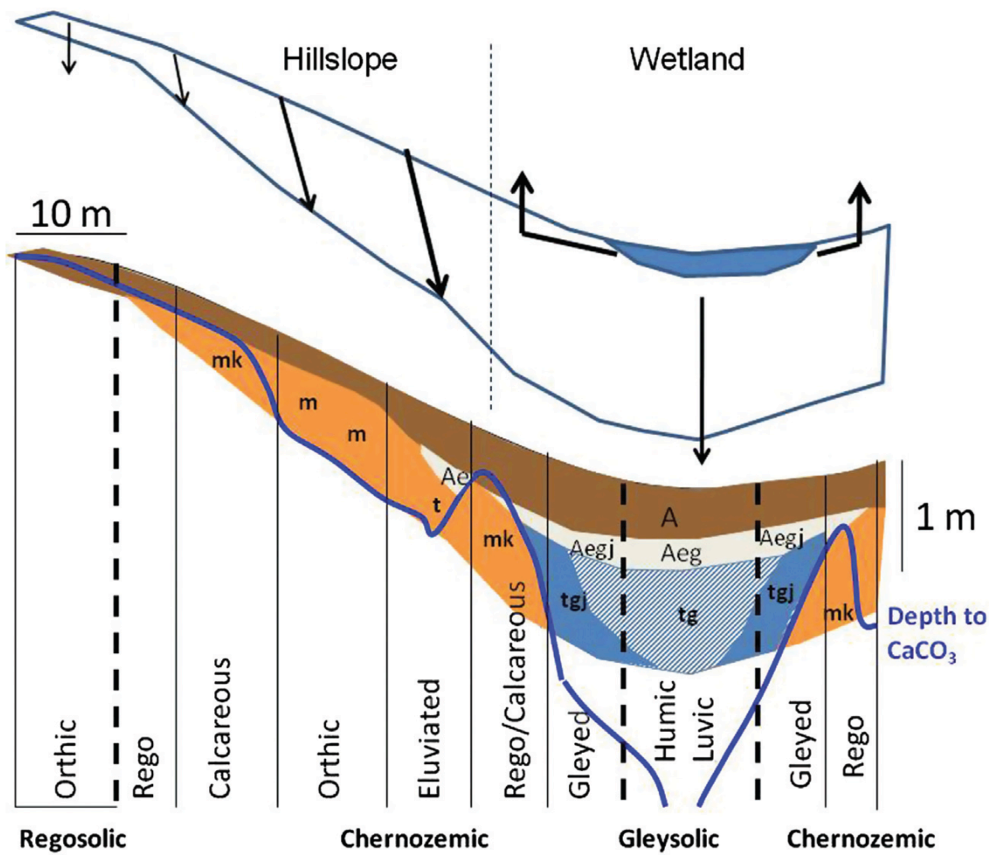

Figure 1.3: Schematic diagram of a typical catena in an agricultural landscape.

The figure shows the main hydrological process domains, water flow directions, depth to CaCO3, development of B horizon features and the distribution of orders and subgroups along a catenary sequence in hummocky till landscapes (from Pennock et al. 2011).

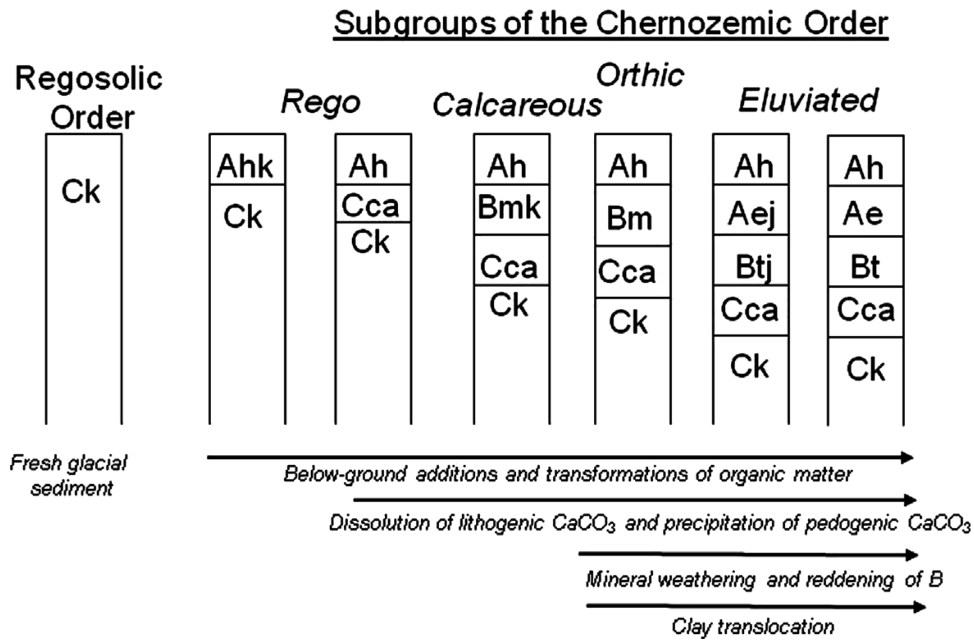

Figure 1.4: Simplified evolutionary sequence of Chernozemic subgroups.

(from Pennock et al. 2011).

For further information see:

Pennock, D., A. Bedard-Haughn and V. Viaud. 2011. Chernozemic soils of Canada: Genesis, distribution, and classification. Canadian Journal of Soil Science 91:719-747.

1.3 The Cryosolic Order

1.3.1 Introduction

Cryosolic soils are defined by the influence of permafrost and are the most extensive soil order, occupying 35% of Canada's soil area. Soils in this order must have permafrost within 1 m of the surface, or within 2 m if cryoturbated (i.e., horizons disrupted by mixing and/or displacement related to frozen conditions).

1.3.2 Dominant Genetic Processes and Diagnostic Horizons

Although the Cryosolic order does not have a specific diagnostic horizon, a characteristic suite of morphological features results from cryogenic processes (e.g. segregated ice lens formation and frost heave), both within the soil profile and as their surface expression. The latter include a diversity of patterned ground types (e.g. ice wedge polygons, sorted circles, earth hummocks, net, stripes), which are mirrored by cyclic patterns of horizonation at the pedon scale (Figure 1.5). Cryoturbated horizons, designated by the "y" suffix, exhibit broken boundaries and provide evidence for the mixing processes that are an important pathway for organic matter incorporation at depth within and below the active layer. Distinctive patterns of structure development within horizons are created by cryogenic processes, with platy structures attributed to ice lens formation, and rounding of granular aggregates resulting from frost action.

1.3.3 Distribution of Great Groups

The distribution of Cryosolic soils broadly parallels permafrost zonation at the national scale, with Turbic Cryosols being the most extensive great group. Near the southern margin of the Discontinuous Permafrost Zone, Organic Cryosols are predominant in the peatlands of the Hudson Bay Lowlands. In the more complex topography of the Cordillera, Cryosols can occur near the southern limits of permafrost where suitable microclimatic conditions have allowed isolated patches of permafrost to develop, such as on northerly aspects or on exposed ridges with limited snow cover.

1.3.4 Secondary Genetic Processes and the Subgroups of the Cryosolic Order

Similar subgroups are designated within the Turbic and Static great groups. The degree of brunification (moderate degree of weathering and formation of brownish B horizons) is captured by Orthic and Brunisolic subgroups which are separated based on the presence of Bm horizons < 10 cm or ≥ 10 cm thick, respectively. These distinctions are combined with soil reaction criteria which separate Dystric and Eutric subgroups at a pH limit of 5.5.

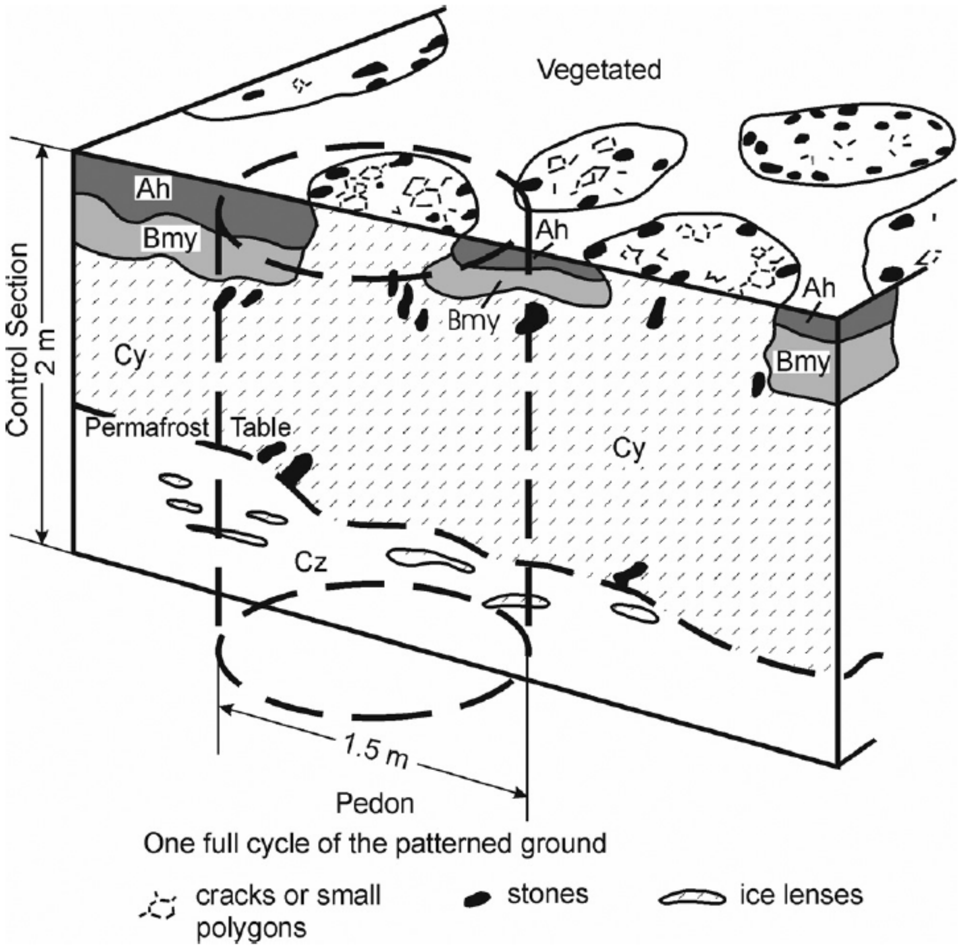

Figure 1.5: Diagram showing the location and extent of a pedon in an Orthic Turbic Cryosol;
Note the discontinuous Ah and Bmy horizons resulting from cryoturbation (From Tarnocai and Bockheim 2011)

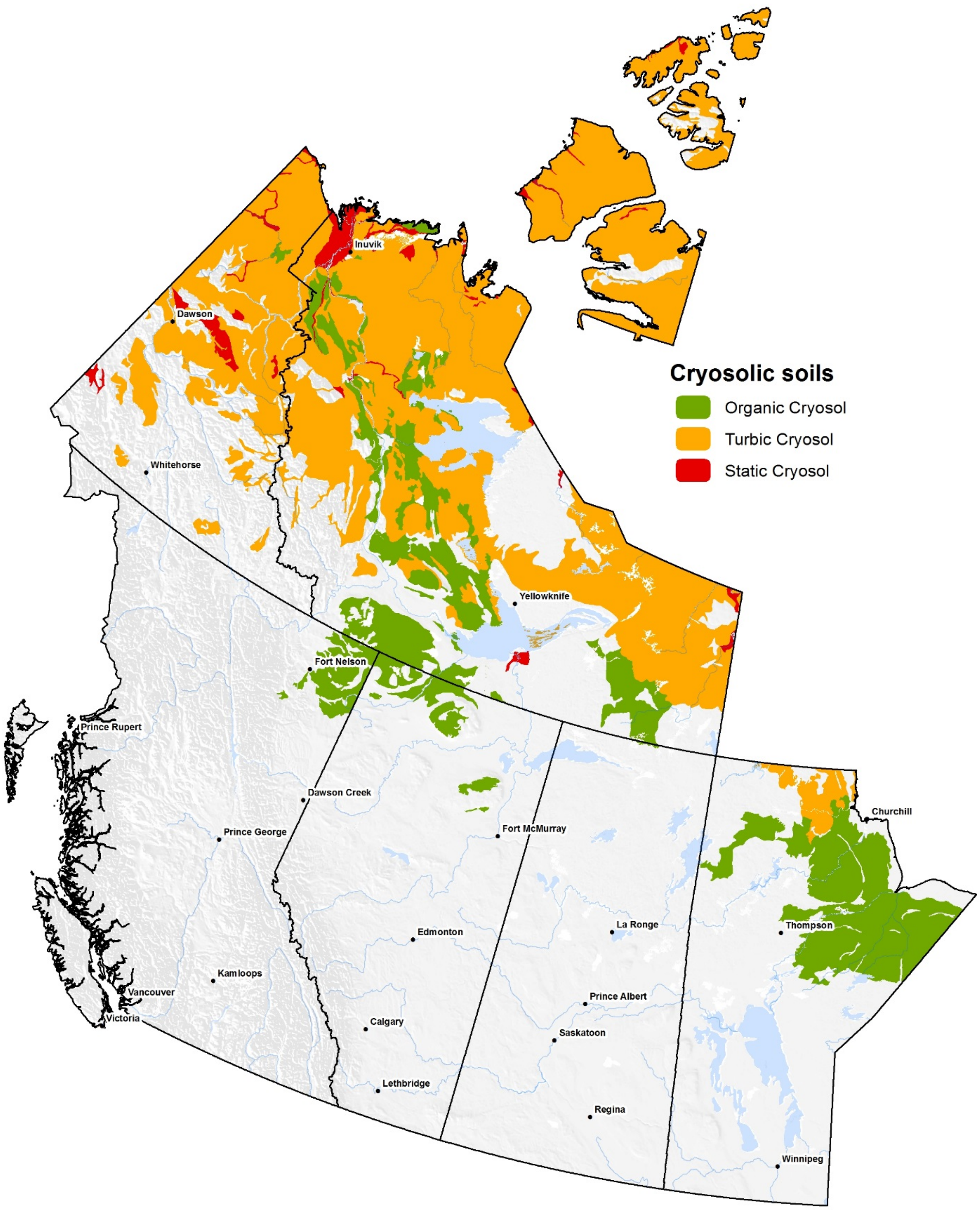

Figure 1.6: Distribution of the great groups of the Cryosolic order in western Canada.

Regosolic subgroups are designated where Bm horizons are completely absent. The high moisture content prevailing in active layers results in some degree of gleying in most Turbic and Static Cryosols, so only a degree of gleying analogous to that of Gleysolic soils is specifically recognized (Gleysolic subgroups). Clay translocation can be an accessory process in finer-textured Cryosols, but sufficient development of Bt horizons to designate Luvisolic subgroups is recognized only for the Static Cryosol great group.

Organic matter accumulation as a surface peaty layer (O or H horizons) 15- to-40 cm thick is designated by Histic subgroups in the Turbic and Static Crysols, but Cryosols with thicker accumulations (> 40 cm) are placed in the Organic great group. Similar to distinctions made in the Organic order, which has subgroups based on degree of humification (Fibric, Mesic, Humic), proximity of underlying mineral material (Terric), and presence of ice layers (Glacic).

1.3.5 Human Impact on Cryosolic Soils

Localized impacts of human activity on Cryosolic soils can be severe, particularly where surface disturbances change the thermal balance of surficial materials with high ground ice contents. The seasonally thawed (active) surface layer of Cryosols will usually have a high moisture content, giving it limited bearing capacity and a tendency to thixotropic behaviour (liquification when mechanically vibrated) when high in silt content. Subsidence, thermokarst formation, and mass wasting can result from inadequate design and construction practices during resource extraction and infrastructure development. At the national, and in fact global, scale, the most dramatic human impacts on Cryosolic soils are resulting from the amplification of climate change at high latitudes. Potential northward shifts in the southern limits of permafrost could enable thawing and oxidation of the enormous reserves of organic carbon currently sequestered in Cryosolic soils, estimated at 39% of all organic carbon in Canadian soils.

For further information see:
Tarnocai, C. and Bockheim, J. G. 2011. Cryosolic soils of Canada: Genesis, distribution, and classification. Can. J. Soil. Sci. 91: 749_762.

1.4 The Gleysolic Order:

1.4.1 Introduction

Soils developed under periodic or prolonged saturated (or waterlogged) conditions belong to the Gleysolic Order in the Canadian System of Soil Classification. The oxygen-depleted (or anoxic) conditions that occur due to saturation lead to distinctive morphological features such as dull matrix colours and mottles, which are generally termed gley features.

Gleysolic soils are not unique to any particular climate or parent material and, as such, are found throughout western Canada, often in associations or complexes with other orders (Figure 1.X). They are commonly found in wetland environments, providing key ecosystem services such as wildlife habitat and filtration of pollutants in runoff.

1.4.2 Dominant Genetic Processes and Diagnostic Horizons

Gleysolic soils are primarily classified based on their diagnostic colour criteria, which are readily observable in the field and reflect a reducing (anoxic) environment. For non-red soils (soils with red parent material are very rare in western Canada), low chroma of the ped faces or the soil matrix as a whole is one of the first observable criteria noted in the field; low chroma can also be described as "gley", "dull", "drab", "grey" or "blue-grey" in colour. Mottles are spots or blotches within the soil that are of a contrasting colour to the matrix as a whole. Mottles tend to be reddish- to yellowish-brown. For those horizons with low chroma, prominent mottles, or both, the suffix "g" is used (for example, Aeg, Btg, Cg, etc.) and is the diagnostic horizon for the Gleysolic order.

The oxidation-reduction (redox) processes associated with gleization, whereby iron (Fe), and to a lesser extent manganese (Mn), are transformed and transferred, give rise to the characteristic morphological features of Gleysolic soils: dull-coloured (reduced) soil matrix and brightly coloured (oxidized) mottles. In simplest terms, in saturated, anaerobic soils, Fe^{3+} is used as an alternate electron acceptor by Fe-reducing bacteria, and is reduced to Fe^{2+} . Because Fe^{2+} is more mobile, it can be removed from the profile, creating the dull-coloured matrix; where the soil dries out, creating oxidizing conditions, iron oxides (Fe^{3+}) re-precipitate, creating the brightly coloured mottles.

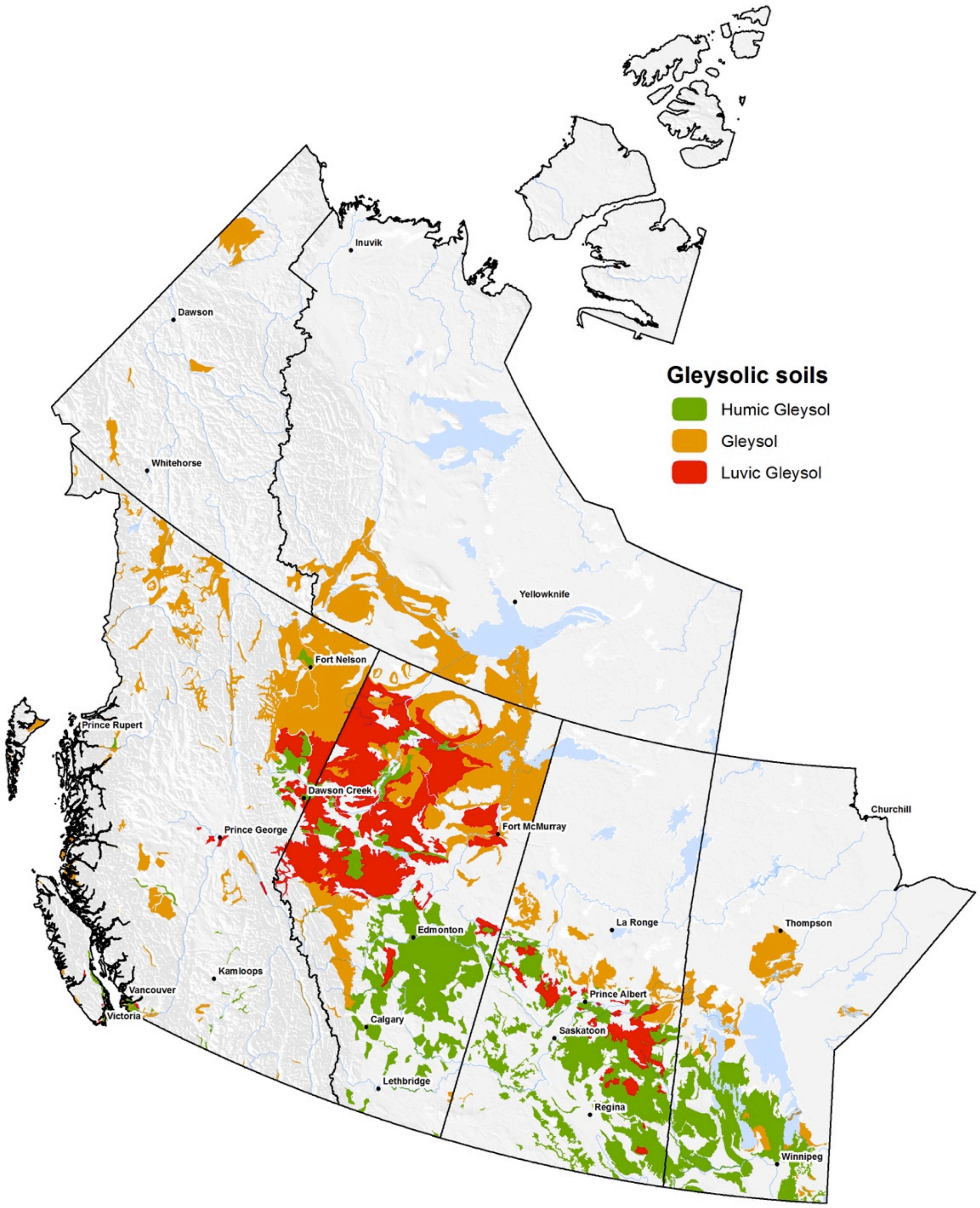

Figure 1.7: Distribution of Gleysolic soils in western Canada.

Slight variations in topography can determine the degree of gleying, with those positions lowest in the landscape being most prone to reducing conditions. As a result, one might observe highly anaerobic conditions in the lowest position of the landscape with oxidizing conditions just a few meters away.

The anoxic conditions retard the decomposition of organic matter, and it is common to have an organic (O) layer on the surface of undisturbed Gleysolic soils. Fibric O Horizons between 15 and 60 cm thick and mesic or humic O horizons 15 to 40 cm thick are recognized as phases (e.g. Humic

Luvic Gleysol, peaty phase). If the O horizons are thicker than these limits they are classified as Organic soils.

1.4.3 Distribution of Great Groups:
There are three great groups within the Gleysolic order: Luvic Gleysol, Humic Gleysol, and Gleysol. Gleysol is the only great group with no additional (to gleying) major process. Clay translocation is the secondary major process in the Luvic Gleysol great group and is reflected by the presence of a horizon of clay accumulation (Btg) and often an eluvial horizon as well (Aeg). Organic matter decomposition is the secondary major process in the Humic Gleysol great group, leading to development of a thick (≥ 10 cm) Ah horizon (or Ap ≥ 15 cm) with at least 2% organic carbon and dark colours similar to those associated with the Chernozemic order reflecting significant additions of humus.

1.4.4 Secondary Genetic Processes and the Subgroups of the Gleysolic Order
Vertic subgroup: The Vertic subgroups are used for profiles that have all of the characteristics of a given great group as well as a slickenside horizon (Bgss or Cgss) for the Vertic subgroup.

Solonetzic subgroup: The Solonetzic subgroups are used for profiles that have all of the characteristics of a given great group as well as a solonetzic B horizon (Bng, Bntg) for the Solonetzic subgroup. They are associated with high sodium parent materials, usually of glaciolacustrine origin.

Fera subgroup: The Fera subgroup is typically found in association with soils of the Podzolic order, and include a horizon of accumulated hydrous iron oxide (Bgf or Btgf).

Fragic subgroup: (Luvic Gleysols only). Fragic Luvic Gleysols have a fragipan (Btgx or Btg and Bxg), which is a loamy subsurface horizon that seems to be cemented when dry but is weak to moderately brittle when moist.

Humic subgroup: (Luvic Gleysols only). These soils have the characteristics of the Luvic Gleysol great group as well as an Ah or Ap horizon that meets the criteria outlined for the Humic Gleysol great group. In many cultivated landscapes the surface A horizon in Gleysolic soils has been overthickened by deposition of sediment (see below).

Rego subgroup: (Humic Gleysol and Gleysol great groups only) Gleysolic soils where the B horizon is less than 10 cm thick.

1.4.5 Human Impact on Gleysolic Soils
In some regions of the Prairies, Gleysolic soils have been artificially drained by producers to increase the arable area in fields. Subsurface drainage may increase translocation of carbon and other nutrients, movement of clay (i.e., lessivage), and induce changes in Fe and Mn dynamics. Changes in redoximorphic features and increased structure were observed in gleyed soils of other regions within 30 yr of drainage. The increase in structure was attributed to increased faunal activity (earthworms, etc.) under increasingly aerobic conditions, increased

lessivage with greater vertical water movement, and the effects of more frequent wet-dry cycles on shrink-swell clays. The most significant change in the type and intensity of soil-forming processes occurs within a few meters of the drainage line, dramatically increasing the variability of soil properties over short distances.

In cultivated hummocky prairie landscapes, one of the most striking features associated with many Gleysolic profiles is the very thick Ap horizon, which is a consequence of tillage translocation in combination with water erosion. Deposition of eroded soil in lower-slope positions results in an over-thickened A horizon. Normally the diagnostic horizon with the g suffix must occur within 50 cm of the surface, but if the Ah or Ap is thicker than 50 cm, the colour criteria apply to the mineral horizon immediately below the over-thickened horizon.

For further information see:

Bedard-Haughn, A. 2011. Gleysolic soils of Canada: Genesis, distribution, and classification. Canadian Journal of Soil Science 91:763-779.

1.5 The Luvisolic Order

1.5.1 Introduction

Luvisolic soils are the predominant forest soils of much of western Canada, occurring under coniferous, mixedwood, and deciduous forests. Soils of this order are characterized by an B horizon (Bt) in which silicate clay has accumulated, underlying a light-coloured eluvial horizon.

1.5.2 Dominant Genetic Processes and Diagnostic Horizons

Formation of the required Bt horizon, which must exhibit a higher amount of silicate clay relative to the overlying Ae horizon, occurs primarily through the physical process of lessivage: dispersion of colloids in the upper solum, downward transport in the soil solution, and deposition of films of oriented clay on ped surfaces in the B horizon. Field designation of Bt horizons relies heavily on recognition of these illuvial clay skins, but these features can disrupted by freeze-thaw processes, and may be difficult to distinguish from films created by the stresses of shrink-swell activity. In situ weathering and formation of clay can further augment the clay content of some B horizons, and the presence of lithological discontinuities within the solum can further complicate the interpretation of vertical textural gradients in some pedons.

From a practical perspective in the field, soils that meet the textural criteria for Bt horizons are normally classified as Luvisolic soils regardless of the genetic cause of the higher amount of clay in the Bt horizon. Soils with the higher clay Bt horizons share the same forest productivity and management regimes regardless of the origin of the clay in the Bt horizon.

1.5.3 Distribution of Great Groups

Of the two Luvisolic great groups, the Gray Luvisols account for almost all occurrences of this order in western Canada. (Minor occurrences of Gray Brown Luvisols have a distribution in southern coastal British Columbia which is too restricted to appear at the map scale of Figure 1.8.)

Parent material influences on Luvisol genesis are evident in the broad geographical distribution of these soils. The largest continuous area of Luvisols extends from central Saskatchewan through northern Alberta, to northeastern British Columbia and extreme southeastern Yukon. These soils form on glacial parent materials (usually till) derived from calcareous, finer-grained sedimentary rocks, which have sufficient clay to enable Bt horizons to form. Luvisolic soils are largely absent from the Canadian Shield, except where glaciolacustrine sediments provide clay-rich parent materials, notably in northern Manitoba. In British Columbia, Luvisolic soils predominate in the plateau landscapes of the central and southern interior where medium-textured till deposits are the most common parent material.

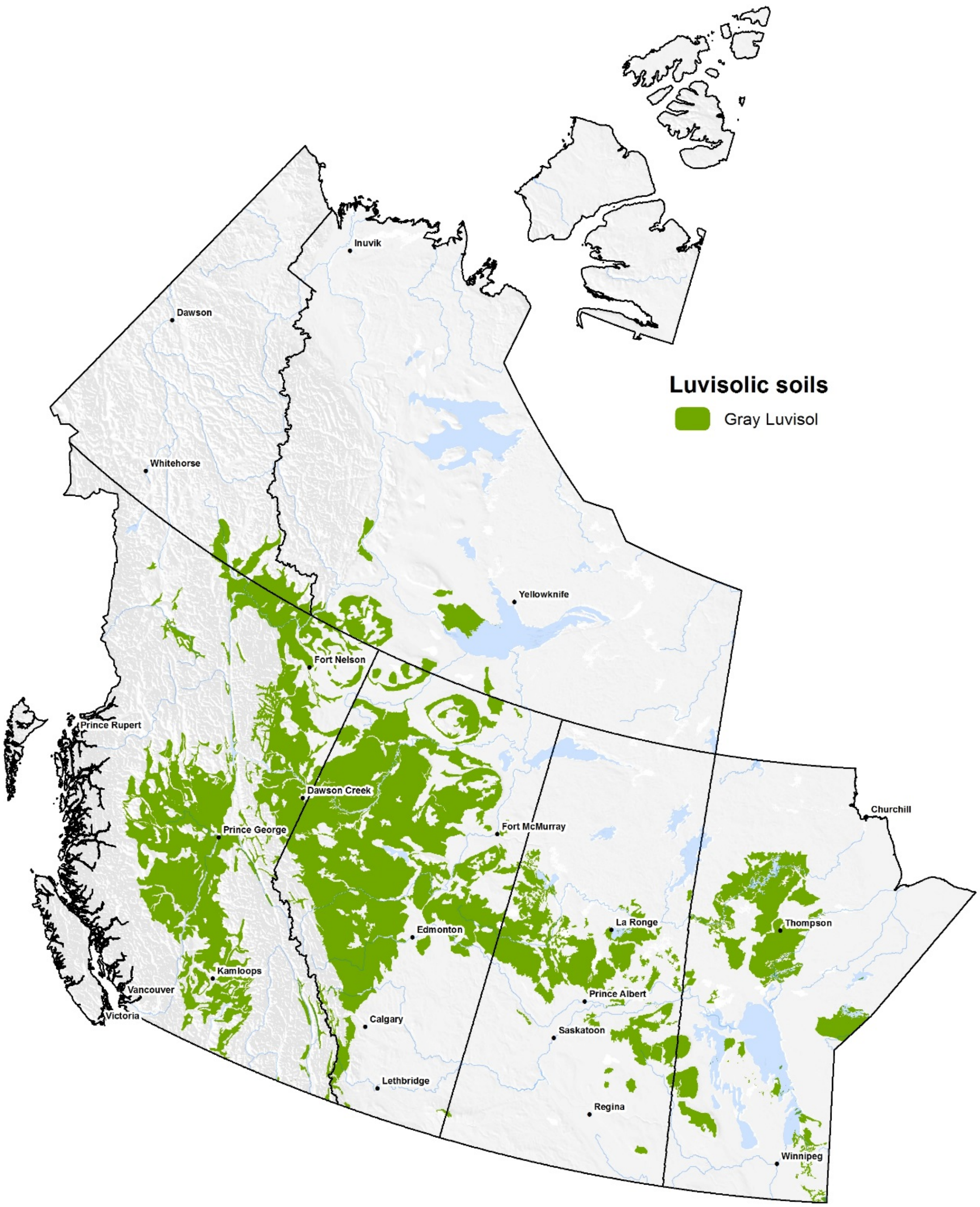

Figure 1.8: Distribution of Gray Luvisols in western Canada. Gray Brown Luvisols do not occur in western Canada.

Transitions from Luvisolic to Chernozemic soils occur with progressively reduced moisture availability southward in the Interior Plains. A similar climatic gradient is mirrored by elevational belts of soil distribution in the major valleys of the southern and central British Columbia interior, with Luvisolic soils occurring at the higher elevations above the forest-grassland transition.

Thick (> 1 m), clay-enriched B horizons can occur in soils formed on older Pleistocene glacial landforms in the west-central Yukon Territory. Clay films on coarse fragments can be easily recognized, but Ae horizons are usually absent, and the taxonomic status and genetic pathway of these distinctive soils remain uncertain.

1.5.4 Secondary Genetic Processes and the Subgroups of the Luvisolic Order

Fourteen subgroups occur in the Gray Luvisol great group, of which seven reflect the operation of gleying, as indicated by mottling in response to fluctuating redox conditions, e.g. Gleyed, Gleyed Podzolic, Gleyed Dark Gray etc. Unlike soils of the Gleysolic order, these subgroups have distinct (rather than prominent) mottles within 50 cm of the mineral surface, or prominent mottles at depths of 50-100 cm.

Eight subgroups include the identifiers Brunisolic, Podzolic, Solonetzic, or Vertic and represent transitions to other orders.

The Brunisolic and Podzolic subgroups of Gray Luvisols have the upper Bt horizon within 50 cm of the mineral surface, and are examples of bisequa soils (i.e. those that exhibit horizons from two distinct genetic pathways). Their inferred genesis involves initial mobilization of clay to form Bt horizons, followed by further transformation of a portion of the eluvial horizon to form Bm and then Bf horizons, respectively. These bisequa soils are common in the British Columbia central interior, with Podzolic Gray Luvisols generally occurring in moister climates at higher elevations than the Brunisolic Gray Luvisols. Brunisolic Gray Luvisols are also common in the Interior Plains.

In some cases these bisequa soils form where a sandy mantle overlies a till layer, and the Bm/Bf horizons form in the sandy mantle. In these cases the till layer is denoted with a Roman numeral II (to indicate that a different parent material occurs) but the soil is still classified within the Luvisolic order.

Solonetzic Gray Luvisols have Btnj horizons, which differ from most Gray Luvisol Bt horizons in having harder consistence, more pronounced ped coatings, and a lower exchangeable Ca:Na ratio. They are relatively uncommon.

Vertic Gray Luvisols have a slickenside horizon (Btss or Ckss) within 1 m of the mineral soil surface, and may have a weak vertic horizon (Btvj). Again, these are relatively uncommon.

Dark Gray Luvisols have dark-coloured Ah (or Ahe) horizons at least 5 cm thick, and form part of the continuum between Chernozemic and Luvisolic soils that has resulted from the complex history of the forest-grassland transition in the Prairie provinces.

1.5.5 Human Impact on Luvisolic Soils

Luvisols occur over a large proportion of the managed forest land base of western Canada, and require careful soil conservation practices to sustain their productivity. In particular, the medium- to fine textures of these soils make them vulnerable to compaction and puddling by ground-based harvesting equipment when moisture content is high and under unfrozen conditions. Displacement of surface soil by harvesting or site preparation can result in restricted rooting depths where firm, coarsely structured Bt horizons are close to the mineral soil surface.

Clearing and cultivation of Luvisolic soils have occurred on the northern frontier of agricultural development in the Prairie provinces. Unlike for the more productive Chernozemic soils to the south, agricultural management of these soils can be limited by adverse physical conditions (crusting), greater acidity, and lower organic matter and nutrient concentrations in Ap (former Ae) horizons. In the British Columbia central interior, till deposits tend to have higher coarse fragment contents than in the Prairie provinces, so agricultural development of Luvisols has been largely restricted to areas with glaciolacustrine parent materials.

For further information see:

Lavkulich, L. M. and Arocena, J. M. 2011. Luvisols of Canada: Genesis, distribution, and classification. Can. J. Soil Sci. 91: 781_806.

1.6 The Organic Order

1.6.1 Introduction

The Organic order accommodates soils formed primarily of materials containing more than 17% organic carbon (30% organic matter), and form either in wetlands experiencing prolonged saturation, or on well- to imperfectly drained upland sites where detritus from forest vegetation is the main source of organic matter. Distinguishing Organic soils from those of other orders depends on detailed criteria for organic material thickness and composition, as well as depth to permafrost, if present.

1.6.2 Dominant Genetic Processes and Diagnostic Horizons

The extent of accumulation of organic matter represents the balance between additions from detrital inputs and losses due primarily to oxidation (decomposition). Conditions which depress decomposition consist of seasonally or perennially high water tables, limited oxygen supply, and cool soil temperatures. In upland settings, a cool, moist climate can enhance organic matter accumulation in the absence of saturation, in part by suppressing forest fires which can be a major mechanism of organic matter loss. In wetlands, organic matter is mostly derived from senescent *Sphagnum* moss and feathermosses, while forest litter, including woody materials, is the major organic matter source at upland sites.

The formation of Organic soils transforms lowland landscapes through the processes of paludification and terrestrialization. The former is more spatially important, and involves both vertical accretion of organic materials under conditions of limited decomposition, and lateral expansion of *Sphagnum*-dominated wetlands.
Terrestrialization involves infilling of depressional water bodies with organic and inorganic materials to the point where water table conditions favour peat accumulation.
Unlike the mineral soil orders, the Organic soils do not have a designated diagnostic horizon, beyond the required carbon concentration and minimum thickness of organic materials. The extent of humification of O horizons, increasing in the order of Of (fibric), Om (mesic), and Oh (humic), is tied directly to the designation of great groups of wetland Organic soils: Fibrisols, Mesisols, and Humisols, respectively.

1.6.3 Distribution of Great Groups

Only three of the Organic great groups have any appreciable abundance in western Canada (Fibrisol, Mesisol, Folisol) (Figure 1.9). Humisols are largely absent except as a minor component of Columbia. Mesisols and Fibrisols dominate poorly drained boreal lowlands across a broad swath of central Manitoba and Saskatchewan, northern Alberta, northeastern British Columbia, and the upper Mackenzie River valley of the Northwest Territories, with the less humified Fibrisols increasing in relative

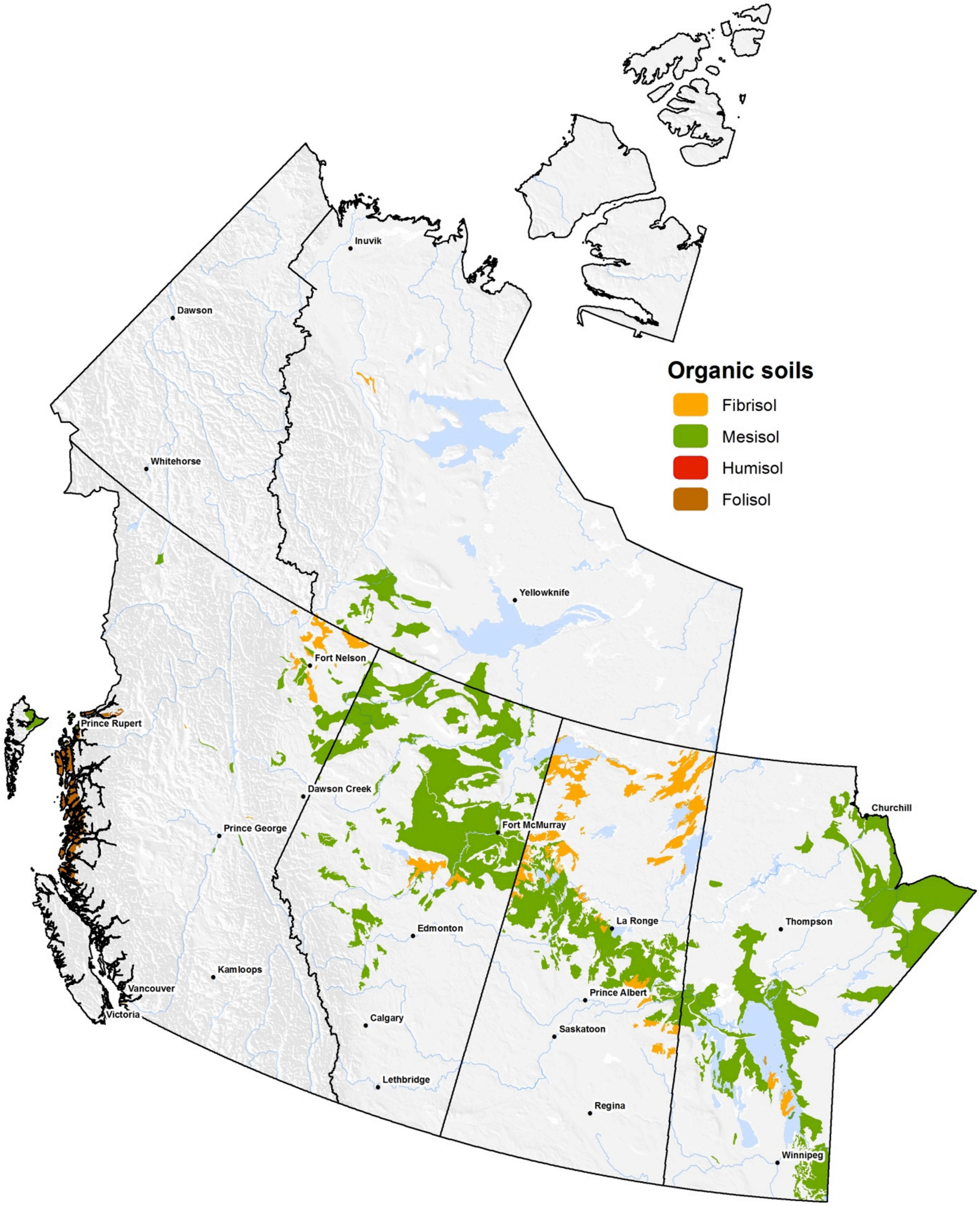

Figure 1.9: Distribution of Organic soils in western Canada.

abundance northward. This concentration of Organic soils in the prairie provinces is bounded by the grasslands to the south, and the southern edge of the Canadian Shield to the north. Mesisols and Fibrisols also occur as inclusions within the rolling glaciated plateau landscape of the British Columbia central interior. Folisols are confined to the wetter climates of coastal British Columbia, particularly on the northern mainland, and western Vancouver Island and Haida Gwaii.

1.6.4 Secondary Genetic Processes and the Subgroups of the Organic Order

For the wetland Organic soils, the three great groups each have the same assemblages of subgroup designations, and these recognize differing proportions of fibric, mesic, and humic materials, mineral sediment inputs (cumulic), underlying mineral substrate (terric), water layers (hydric), and biologically-derived freshwater sediments (limnic). Unlike in the other orders, these subgroup designations don't correspond to distinctive secondary genetic processes so much as they capture distinct phases of wetland evolution as recorded by parent material properties. In the case of upland Organic soils (Folisols), the subgroups indicate the degree of humification of the organic materials (as indicated by the dominant horizon type: F – Hemic; H – Humic), abundant woody materials (Lignic), and presence of underlying wetland peat materials (Histic).

1.6.5 Human Impact on Organic Soils

Artificial drainage of lowland Organic soils for agricultural production in western Caanda has been limited to a few areas near large population centres, such as in the lower Fraser River valley of southwestern British Columbia. Controlling accelerated oxidation of drained Organic soils requires careful water management to maintain this effectively non-renewable soil resource. Organic soils of forested wetlands in the boreal region have not been artificially drained as an operational forest management practice, however, harvesting of stands on poorly drained mineral soils may sufficiently alter the water balance that wetland expansion can occur through paludification. Folisols in coastal British Columbia tend to support lower productivity forest stands, and have seldom received intensive management due to poor growth responses and difficulties in regeneration. Where Folisols directly overlie bedrock, soil displacement during harvesting or site preparation, and high-impact broadcast burning need to be avoided.

For further information see:

Kroetsch, D. J., Geng, X., Chang, S. X. and Saurette, D. D. 2011. Organic order - Part 1. Wetland Organic soils. Can. J. Soil Sci. 91: 807_822.

Fox, C. A. and Tarnocai, C. 2011. Organic soils of Canada: Part 2. Upland Organic soils. Can. J. Soil Sci. 91: 823_842.

1.7 The Podzolic Order

1.7.1 Introduction

The strongly differentiated profiles of Podzolic soils typically display a light-coloured eluvial horizon overlying a darker illuvial B horizon enriched in aluminum and iron oxides and/or organic matter. These soils usually occur on medium- to coarse sand textured acidic parent materials rich in quartz. Diversity in Podzolic soil morphology, such as the distinctness of the eluvial horizon and the colouration of the B horizon, reflects the intensity of chemical weathering and translocation processes, as well as the extent of organic matter accumulation in the mineral horizons.

1.7.2 Dominant Genetic Processes and Diagnostic Horizons

The podzolic B horizon has the most intricate chemical and morphological criteria of any of the diagnostic mineral horizons. Subject to minimum thickness (10 cm) and colour requirements. Three varieties of podzolic B horizon categories reflect differences in the nature of illuvial constituents: primarily organic matter accumulation with low iron concentrations (Bh), and iron and aluminum accumulation with either intermediate (0.5-5.0%; Bf) or high (> 5%; Bhf) organic carbon concentrations.

The combination of chemical and biological transformations of primary minerals, organic matter, and secondary phases involved in Podzol formation is collectively termed the podzolization process. Theories of podzolization must account for the range of properties exhibited by this diagnostic horizon. As recently summarized by Sanborn et al. (2011), podzolization involves: (a) acidification and enhanced weathering of primary minerals immediately below the forest floor/mineral soil boundary through the formation and downward leaching of organic acids, (b) release of iron and aluminum through in situ weathering in the B horizon, and their re-precipitation as hydrous oxides, (c) accumulation of materials translocated into the B horizon and immobilized by pH-related precipitation, microbial activity, and adsorption, and (d) death and decay of root detritus in situ, which augments organic matter pools and metal-binding capacity.

1.7.3 Distribution of Great Groups

Although Podzolic soils are the 2nd most extensive soil order in Canada, their distribution in the western provinces is highly concentrated, occupying almost one-third of British Columbia but being largely absent elsewhere except in some alpine and subalpine areas of the Rocky Mountains in western Alberta (Figure 1.10). The absence of Podzolic soils from the western boreal forest and adjacent portions of the Canadian Shield is in strong contrast to their distribution in eastern Canada, reflecting the drier and colder climates in forested areas of Manitoba, Saskatchewan, and Alberta.

Within British Columbia, climatic zonation controls the broad distribution patterns of Humo-Ferric vs. Ferro-Humic Podzols, with the latter being largely restricted to the wetter climates of the mainland coast, western Vancouver Island, and Haida

Gwaii, where soil organic matter accumulation is enhanced. Minor areas of Ferro-

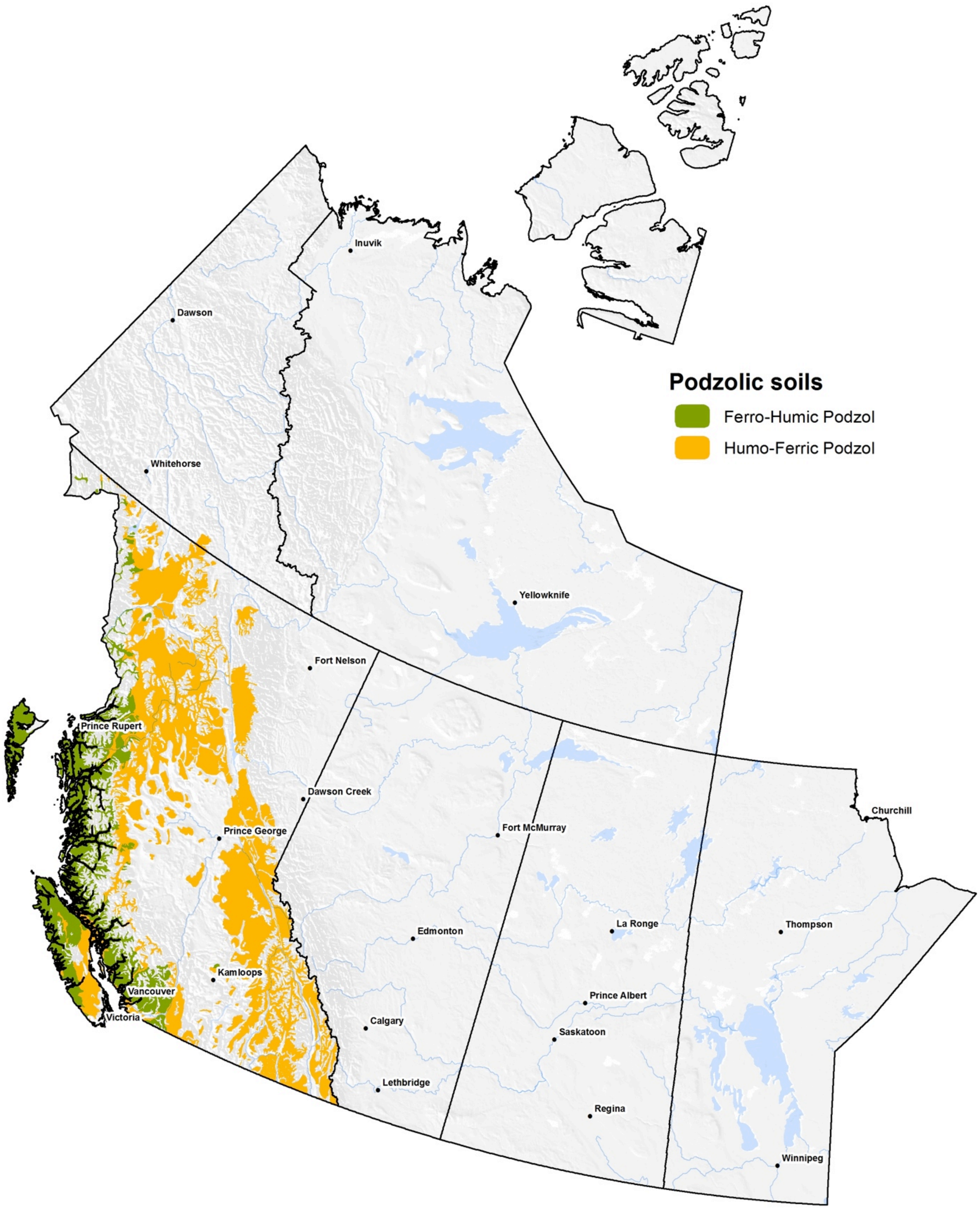

Figure 1.10: Distribution of great groups of the Podzolic order in western Canada.

Humic Podzols also occur on the windward slopes of the southern Rocky and Columbia Mountains. Organic carbon concentrations can exceed 10% in Ferro-Humic Podzols in coastal British Columbia, resulting in masking of eluvial horizons. Between the Coast and Rocky Mountains, extensive areas of Humo-Ferric Podzols occur in northern half of the interior plateau, while drier climates farther south are accompanied by a much greater predominance of Luvisolic soils.

Humic Podzols are much more restricted in their distribution, and are found as a component of soil landscapes only in the wettest hypermaritime areas of the outer coast.

1.7.4 Secondary Genetic Processes and the Subgroups of the Podzolic Order

Cementation takes several forms in Podzolic soils, especially in coastal British Columbia, and is designated by four subgroups of which only Duric , Ortstein, and Placic subgroups occur to any significant degree. These features can be important modifiers of soil hydrological behaviour, as well as providing restrictions to rooting depth. Duric horizons are strongly cemented, and are found below the podzolic B horizon, with colours resembling those of the parent material. Orstein comprise strongly cemented zones within Bh, Bhf, or Bf horizons. Placic horizons are thin (≤5 mm), hard, impervious and dark reddish brown to black, and can occur singly or in multiples within and/or below the podzolic B horizon.

Clay translocation can be a significant accessory process in Podzolic soils with medium- and finer-textured parent materials, and is designated by Luvisolic subgroups if the Bt horizon occurs below 50 cm depth. These bisequa soils are part of a continuum with Podzolic subgroups of Luvisolic soils, and have been reported by soil surveys at scattered locations in coastal and interior British Columbia. In situ organic matter accumulation in the form of Ah horizons is recognized by Sombric subgroups, and can occur in surprisingly diverse settings, ranging from grassy oak savannas of southern Vancouver Island to lush herbaceous subalpine meadows.

Although Podzolic soils are usually well-drained, given the importance of downward translocation of materials in the podzolization process, Gleyed subgroups are designated in both the Ferro-Humic and Humo-Ferric great groups where gley features such as mottling and grayish matrix colours are present. Gleyed subgroups are not recognized in the Humic Podzols because these soils occur in wet sites and some degree of gleying is regarded as an inherent property.

1.7.5 Human Impact on Podzolic Soils

Podzolic soils in western Canada are influenced by human activity primarily through forest management, and have largely been unaffected by agriculture except in a few minor areas of southern coastal British Columbia. Some of the most highly productive forest sites in Canada occur on Podzolic soils, and these have tended to receive the most intensive management, for example, as with Douglas-fir (*Pseudotsuga menziesii*) plantations in southwestern British Columbia. Elsewhere, Podzolic forest soils in less productive climatic regimes are characterized by a less intensive style of management, with conservation of existing site productivity during harvesting and site preparation receiving relatively more attention than practices intended to enhance productivity or shorten rotations. Unlike in eastern Canada, Podzolic soils in interior British Columbia remain largely unaffected by anthropogenic acid deposition, and in fact exhibit pronounced regional deficiencies of sulphur.

For more information see Sanborn, P., L. Lamontagne, and W. Hendershot. 2011. Podzolic soils of Canada: Genesis, distribution, and classification. Can. J. Soil Sci. 91: 843_880.

1.8 The Regosolic Order

1.8.1 Introduction

Soils of the Regosolic order are at boundary between unaltered parent materials and soil – the alteration of the parent material is sufficient to support plant growth but insufficient to cause the formation of diagnostic horizons associated with other orders. Because the alteration of parent material is so limited the nature and properties of the parent material has a major influence on the properties of the Regosols.

Regosols occur due to five major conditions: recent exposure, which limits the time for soil formation; weathering-resistant parent material, where the imprint of pedogenesis is greatly limited; arid or cold climates, where the action of pedogenic processes is limited; erosion of A and B horizons, especially in agricultural fields, and discharge of solute-rich water at the fringe of wetlands.

Recent exposure occurs on recently deposited parent sediments such as river floodplains, drained ponds, lakes, and swamps, beaches and shorelines, mass wasting/movement on slopes, volcanic eruption, and continental sand dunes. The latter represent the largest areal extent in Prairie Canada in features such as the Great Sand Hills in Saskatchewan and the Spirit Sand Hills in Manitoba. Regosols are also very common on convex knolls and ridges in hummocky, undulating, and rolling agricultural landscapes, where truncation of the soil due primarily to tillage erosion has occurred.

The Precambrian rocks of the Canadian Shield are very resistant to both pulverization by glacial erosion and weathering by pedogenic processes. Sediments in this region are often dominated by weathering-resistant sand and gravel, and bare rock is commonly exposed at the surface. In either situation the imprint of pedogenesis is faint or essentially absent, and soils are often classified as Regosolic or Rock (a non-soil). The Field Guide to the Substrates of Ontario (Ontario Ministry of Natural Resources, 2011) has a more comprehensive approach to the description of these materials than the CSSC.

Climate-induced Regosols also occur in Arctic landscapes where arid conditions inhibit the formation of Cryosolic soils.

Finally, in many wetlands in western Canada water moves from the pond to the fringe of soil surrounding the wetland due relatively impermeable underlying sediments. Capillary and transpiration processes draw this water to the soil surface where it is lost to the atmosphere, and the solutes in the water precipitate out. Because the direction of water movement is vertically towards the surface it is difficult for a B horizon to form. These soils may have a thick Ahca/Ahsa/Ahcasa directly overlying a Cca/Ccak/Ccasa etc. horizon. These discharge soils were not well understood at the time of the development of the CSSC, and are a problem soil for classification.

1.8.2 Dominant Genetic Processes and Diagnostic Horizons

Regosolic soils have undergone little pedogenic alteration. Although many pedogenic processes (e. g. decarbonation, podzolization) may be active, they have not left diagnostic features in the soil. The diagnostic feature of the Regosols is either the complete lack of a B horizon or, if a B horizon is present, it must be less 5 cm thick.

The most common process occurring is melanization, the darkening of the surface horizon associated with the accumulation of partially decayed organic material in the profile. This can lead to the presence of an Ah horizon in undisturbed soils. In truncated agricultural soils we can also find an Apk or Apca horizon directly overlying the C horizon; incorporation of carbonate into the C horizon occurs mixing of the upper soil through tillage.

1.8.3 Distribution of Great Groups

Soils of the Regosolic Order occur in one of two great groups: Regosol and Humic Regosol. Soils of the Regosol great group either lack an Ah horizon or have Ah horizons less than 10 cm thick, whereas Humic Regosols contain Ah horizons at least 10 cm in thickness. These Ah horizons do not, however, meet the additional criteria required for the Chernozemic A horizon.

Soils of the Regosol great group are the most common in western Canada (Figure

1.8.4 Secondary Genetic Processes and the Subgroups of the Regosolic Order:

Soils of both great groups are further subdivided into four subgroups:

Cumulic subgroup: Cumulic Regosols usually develop from parent materials deposited during intermittent floods commonly within alluvial plains. During periods between flooding there is sufficient time for the melanization process to be established to develop Ah horizons. Commonly, they have multiple Ah layers in their profile representing periods between sedimentation events by intermittent flooding.

Gleyed subgroup: Gleyed subgroups have a horizon with a gj suffix (indicating faint to distinct mottles) within 50 cm of the surface. Both Gleyed and Gleyed Cumulic subgroups occur.

Orthic subgroup: The Orthic subgroups meets the criteria of the Regosolic order but lacks any cumulic or gleyed features.

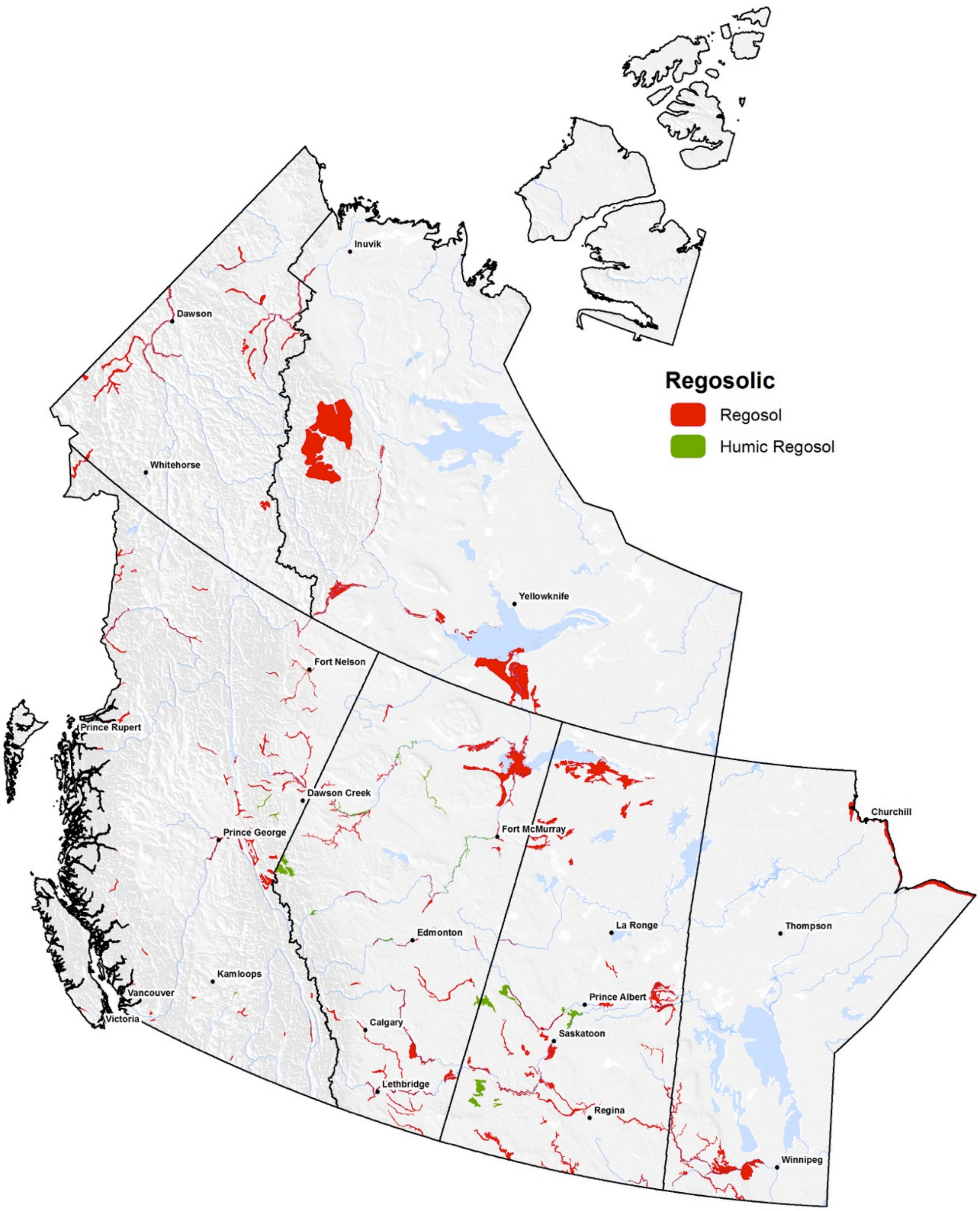

Figure 1.11: Distribution of Regosolic soils in western Canada

1.8.5 Human Impact on Regosolic Soils

Destabilization of the surface by human activity can result in the truncation of the surface soil horizon and the creation of Regosolic soils. This is most common in agricultural landscapes where tillage erosion (and to a lesser extent wind and water erosion) cause progressive incorporation of the A and B horizons into the underlying C horizon. As well, destabilization of dune areas may cause loss of soil through wind erosion and Regosolic soils to occur.

For further information see:

Ontario Ministry of Natural Resources. 2011. Field Guide to the Substrates of Ontario. pp. 76 .

VandenBygaart, A. J. 2011. Regosolic soils of Canada: Genesis, distribution, and classification. Canadian Journal of Soil Science 91:881-887.

1.9 The Solonetzic Order

1.9.1 Introduction:

In Canada, Solonetzic or sodic soils are found only in the western provinces, and are characterized by Bn or Bnt horizons with high exchangeable Na, prismatic or columnar structure with dark coatings on peds, and hard to very hard consistence when dry (Soil Classification Working Group 1998). The unique physical and chemical properties of Solonetzic soils often limits crop production and cause problems with other land uses such as metal corrosion, cement foundations and road construction. The interaction of saline and sodic parent material, low relief, groundwater discharge of saline groundwater and shallow water tables, high evapotranspiration, and grasses and forbs over time has likely contributed to the genesis of Solonetzic soils within areas generally dominated by Chernozemic soils.

Solonetzic soils are found where there is thin layer glacial material overlying shallow bedrock composed of saline and alkaline marine shales. High salt concentrations in glacial sediments may be related to the shallow underlying marine bedrock and groundwater discharge. Solonetzic soils generally occur on topographic relief that is level to undulating, especially on lowlands with restricted drainage and that are adjacent to upland areas.

1.9.2 Dominant Genetic Processes and Diagnostic Horizons

Solonetzic soils are thought to develop via the stepwise pedogenic processes of salinization, solonization (desalinization and alkalization), and solodization (Figure 2). Salinization is the process by which soluble salts accumulate at or near the landscape surface by evapotranspiration. To initiate Solonetzic genesis in the western Canadian landscapes, a dominance of sodium salts must be concentrated and maintained at the soil surface or within the upper section of the soil by a shallow water table or groundwater discharge .

Soluble salts move upward to the soil surface during soil salinization. Less soluble evaporate minerals such as calcite and gypsum precipitate in the subsoil, whereas more soluble Na-Mg-SO_4 evaporate minerals precipitate on the soil surface as efflorescence or white salt crusts. The sequence of preferential mineral precipitation in saline soils results in the high concentrations of Na and SO_4 salts in the upper soil, and these salts are required to initiate solonization.

For solonization to proceed from salinization (Fig. 2), three conditions must be met: (1) gradual desalinization must occur to lower the total concentration of soluble

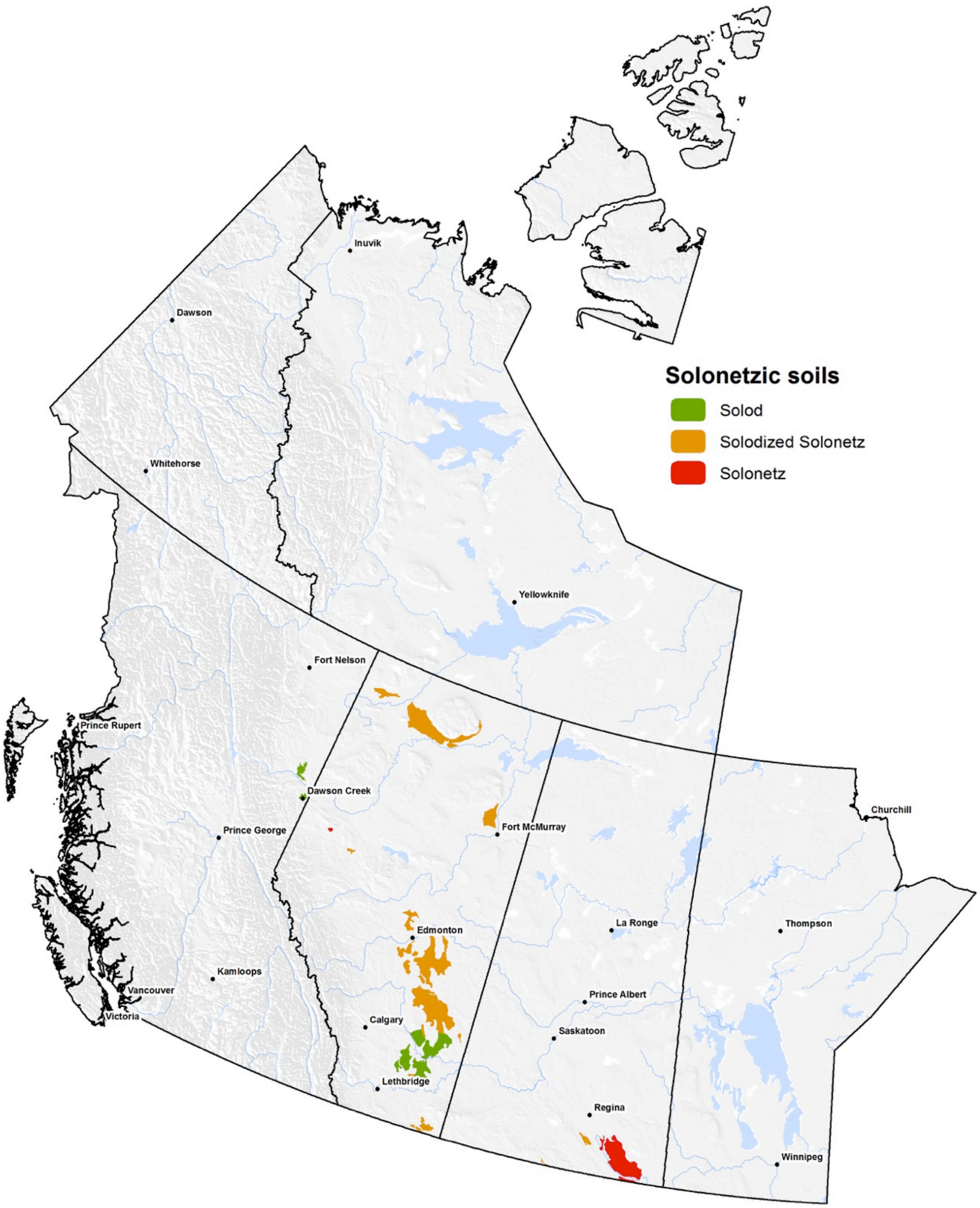

Figure 1.12: Distribution of great groups of the Solonetzic order in western Canada.

salts, which initiates alkalization or accumulation of Na ions on the exchange complex of clay minerals; (2) there must be a high concentration of Na ions to initiate alkalization; and (3) there must be significant expandable clay minerals to initiate clay dispersion. Desalinization is thought to have occurred in the Interior Plains because a change in climate (increased precipitation) and lower water tables resulted in leaching of soluble salts or desalinization. The action of these processes results in the formation of a Bn horizon, diagnostic of the Solonetz Great Group. The unique columnar structure of the Solonetzic Bn horizon likely develops from a combination of wetting and drying forming prismatic structure, and eluviation of soil material from the top corners of the prisms results in the rounded tops or columnar shape.

Sufficient dispersed clay eventually eluviates from the A to the B horizon to form a dense and impermeable Bnt horizon. Weathering of the upper soil profile results in a mildly weathered and acidic A horizon (Ae) overlying a dense Na-dominated B horizon. This process is called solodization.

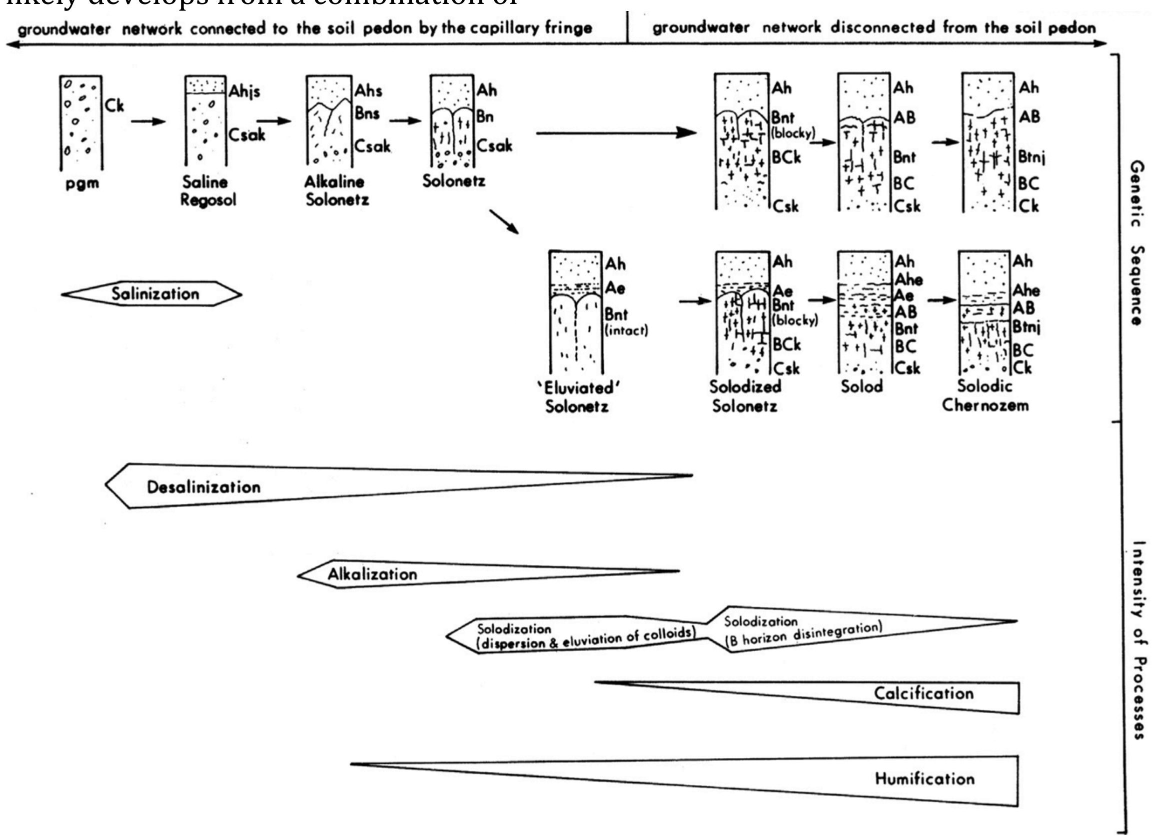

Figure 1.13. Major genetic or pedogenic processes in the genesis of Solonetzic soils in Canada (modified after Pawluk 1982).

The eluvial Ae horizon has a coarse texture, platy structure, and an ashy gray color that is indicative of strong weathering conditions and eluviation. Further weathering of the upper B results in the formation of a transitional AB or BA horizon.

1.9.3 Distribution of Great Groups

The Solonetzic Order includes four great groups: Solonetz, Solodized Solonetz, Solod, and Vertic Solonetz. All great groups have the diagnostic Bn or Bnt horizon. The great groups are separated based on the presence of and thickness of the Ae horizon, the breakdown of the upper part of the Bn or Bnt horizon, and the occurrence of vertic features. The Solonetz great group does not have an Ae horizon that is continuous and ≥ 2 cm. The Solodized Solonetz great group has an Ae ≥ 2 cm thick, and an intact, columnar Bnt or Bn horizon. The Solod great group have an Ae ≥ 2 cm thick, a distinct AB or BA horizon (from disintegration of top of Bnt), and a Solonetzic B horizon. The Vertic Solonetz great group has any features of the previous three great groups, and the presence of a slickenside horizon whose upper boundary is within 1 m of the mineral soil surface.

The great groups of the Solonetzic order do not exhibit the type of regional zonation seen in the Chernozemic order. Indeed often two or even three great groups can be found in a single hillslope catena. Two common Solonetzic catenas are found in the prairies. In the first sequence, Gleyed Solonetz or Solonetz occur in the depressional areas of the landscape, and soils then grade through Solodized Solonetz, Solods, and in some cases, Chernozems at higher elevations. The depressions are typically areas with shallow water tables and groundwater discharge that bring soluble salts upward into the soil solum, and the groundwater effect becomes less dominant moving upslope.

In the second sequence, Solods are found in the lowest topographic position, while Solodized Solonetz, Solonetz and Chernozems are found at progressively higher slope positions. This catenary sequence has been described for soils in Saskatchewan . Surface runoff occurs from the upper to lower slope positions, and a deep water table and groundwater recharge at the lowest slope position allows leaching of soluble salts to occur in the Solod.

1.9.4 Secondary Genetic Processes and the Subgroups of the Solonetzic Order

Colour subgroups: The most common of the subgroups of the Solonetzic soils correspond to the soil zones that are characteristic of the great groups of the Chernozemic order, and the criteria for placement of the soils into subgroups are the same as for the Chernozemic order (table X).

Gleyed subgroups: Both the Gleyed Solonetzic subgroups and soils of the Gleysolic order have mottles resulting from alternating reduction-oxidation conditions caused by periodic water saturation. The key distinction is the colour contrast of mottles: Gleyed Solonetzic subgroups have faint or distinct mottles within 50 cm of the surface (indicated by a gj horizon), whereas soils of the Gleysolic Order have prominent mottles within 50 cm (a g horizon). The Gleyed identifier is also added to other subgroup identifiers for Solonetzic soils (e.g.

Gleyed Brown, Gleyed Dark Brown, Gleyed Dark Gray etc.)

Subgroup	Solonetz	Solodized Solonetz	Solod	Vertic Solonetz	Criteria (Colours for A horizon and dry samples)
Alkaline	Present				Alkaline A with pH ≥ 8.5
Brown	Present	Present	Present	Present	Color value > 4.5, chroma > 1.5 or exposed Solonetzic B
Dark Brown	Present	Present	Present	Present	Color value 3.5—4.5, chroma > 1.5 or exposed Solonetzic B
Black	Present	Present	Present	Present	Color value < 3.5, chroma < 2
Dark Gray		Present	Present		Color value 3.5—4.5, chroma <2
Gray		Present	Present		Color value >4.5, chroma <2
Gleyed + Colour	Present	Present	Present	Present	Horizon with gj suffix + colour criteria

Table 1.1: Subgroups and associated criteria for soils of the Solonetzic order

Saline soils:
Saline soils in Canada are currently classified as a phase of other soil orders such as Chernozemic, Gleysolic, Regosolic, or Solonetzic. To qualify as a saline phase (e.g., saline Calcareous Dark Brown Chernozem), the soil horizon should have a ‘‘sa’’ suffix (e.g., Bmksa) in the A or B horizon. The ‘‘sa’’ horizon has a secondary enrichment of soluble salts more soluble than Ca and Mg carbonates (e.g., gypsum), the conductivity (EC) of the saturation extract must be ≥ 4 dS m^{-1} , and the EC must exceed that of the C horizon by at least one-third.

1.9.5 Human Impact on Solonetzic Soils

The sharp textural contrast between the coarser A horizons and the fine-textured B horizon makes Solonetzic soils particularly vulnerable to soil erosion, especially by wind. Large areas of Solonetzic soils experienced significant loss of A horizons due to wind erosion in the 1930s, and the Solonetzic B is exposed at the soil surface. This is most common in soils in the Brown soil zone, and to a lesser degree those in the Dark Brown zone. For further information see:
Miller, J.J. and J. A. Brierley. 2011. Solonetzic soils of Canada: Genesis, distribution, and classification. Canadian Journal of Soil Science 91:889-902.

1.10 The Vertisolic Order

1.10.1 Introduction

Vertisolic soils are the product of contraction and expansion of the soil mass and the resulting self-mulching (churning and mixing) of the soil material. In Canada, these processes occur where the clay content of the parent material exceeds 60%, and the fine earth (< 2 mm) fraction is dominated by 2:1 smectitic (swelling) clay minerals.

Vertisols occur on level to gently inclined and undulating landscapes of glaciolacustrine or glaciomarine origin. In conjunction with these essential parent material characteristics, the climate where Vertisolic soils occur must be dry enough to create fluctuations in soil moisture content that cause defined wetting and drying cycles. These three essential components are required for the formation of Vertisolic soils as recognized within the Canadian System of Soil Classification.

Vertisolic soils are difficult to describe because the B horizon is often not apparent; horizons are disrupted by turbation, so boundaries can be tilted and in some cases almost vertical. These turbated horizons are assigned a v suffix in the CSSC. As well, displacement of peds along each other creates polished ped surfaces at depth, which are termed slickensides (ss suffix). The presence of both the vertic horizon and slickensides is required for placement into the Vertisolic order; soils that lack one of the features are classified as intergrades of other orders (e.g. Vertic Dark Brown Chernozem).

1.10.2 Dominant Genetic Processes and Diagnostic Horizons

Upon drying of a clayey soil mass (high in 2:1 smectitic clay minerals), surface cracks develop due to shrinkage. These surface cracks become a zone of weakness within the soil mass, and these cracks tend to repeatedly close and re-open with reoccurring wetting and drying cycles. When the cracks are open material from the surrounding soil surface falls into the cracks. The presence of this sloughed-in (infill) material provides preferential areas or zones of weakness within the soil mass. Over time, the original cracks grow in both depth and width. The product of this cyclical drying and wetting is the formation of wedge-shaped features within the soil profile. Since the content of the wedge generally consists of organic rich soil that is darker-coloured and lighter-textured soil material than the subsoil, these features are easily recognizable.

During the periods of re-saturation of the clayey material internal pressures increase as the clay expands, due to the hydration of the 2:1 silicate clay minerals. Internal swelling pressures are relieved by oblique and upward movement of areas adjacent to the infilled cracks. With increasing depth, the mass of soil increases and therefore the resistance to swelling commensurately increases. When swelling pressures exceed resistance, or shear strength of the soil, failure occurs along internal planes of weakness. Well-developed shear planes are referred to as slickensides and typically occur at depths between 50 and 125 cm. When a block of soil moves due to shear failure, multiple shear planes may be associated with the block. This internal movement can occur in multiple directions, so ultimately shear planes intersect producing slickensides. The resulting network of intersecting shear planes or slickensides forms the boundaries of internal wedge-shaped structures.

The diagnostic horizons of the Vertisolic order result from these processes. The slickenside (ss) horizon has two or more slickensides, often with unidirectional grooves parallel to the direction of soil displacement cut into their shiny surfaces. The vertic (v suffix) horizons are characterized by irregular shaped, randomly orientated, intrusions of displaced materials within the and wedge-shaped features extending from the surface resulting from the infilling of cracks over time. The combination of these features results in the apparent homogenization of the soil materials and so the development of diagnostic horizons associated with other orders is impeded. Both the vertic and slickenside horizons must be present for classification into the Vertisolic order.

1.10.3 Distribution of Great Groups
Two great groups are recognized within the Vertisolic order: the Vertisol and Humic Vertisol. Soils of the Vertisol great group are associated with the arid portions of the Prairie ecozone, specifically the Mixed Grassland ecoregion and the Brown soil zone . The organic carbon content of native surface horizons of the Vertisol great group is less than 3% and, hence, the surface horizons are very similar in color to the underlying horizons. The dry colour value of the surface A horizon is greater than 3.5 and the chroma is usually greater than 1.5.

Humic Vertisols are associated with the moister areas of the Prairie ecozone. The surface A horizons of native profiles contain more than 3% organic carbon (Soil Classification Working Group 1998), reflecting the climatic characteristics of the Moist Mixed grassland and Lake Manitoba Plain ecoregions (Ecological Stratification
Working Group 1995). As a general rule, Vertisolic soils of this great group occur within the Dark Brown and drier portions of the Black soil zones. The chroma and value of the A horizon is less than 3.5 and 1.5, respectively.

Vertisolic soils were not mapped in British Columbia, but some soils developed on fine-textured parent materials in the Okanagan Valley and interior plateau are either vertic intergrades of other orders or true Vertisolic soils/

1.10.4 Secondary Genetic Processes and the Subgroups of the Vertisolic Order:
Each Vertisolic soil great group contains three subgroups: Orthic, Gleyed and Gleysolic. Classification to this level is based on the presence of mottles (reflecting the duration of soil saturation) within the upper 50 cm of the surface. The Orthic subgroups are defined as having no mottles within 50 cm of the surface. Gleyed subgroups have faint and distinct mottles within this depth, while Gleysolic subgroups are poorly

drained, and prominent mottles occur within the upper 50 cm

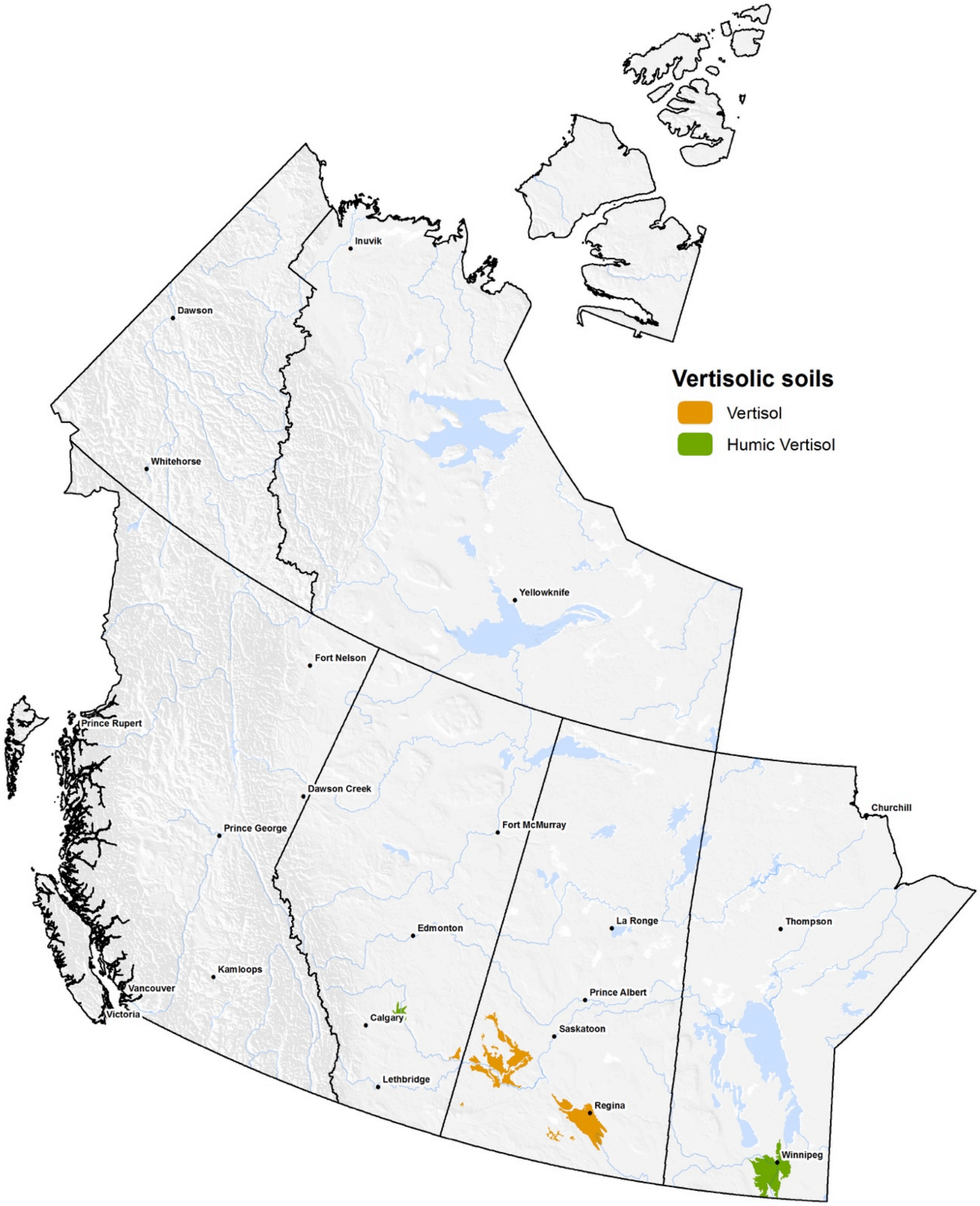

Figure 1.14: Distribution of great groups of the Vertisolic order in western Canada.

of the surface. The Gleysolic subgroup is an anomaly in the CSSC; normally soils with prominent mottles in the upper 50 cm are classified into the Gleysolic order.

1.10.5 Human Impact on Vertisolic Soils

Vertisolic soils are excellent soils for agricultural production and have been almost entirely converted to agricultural production. Although these soils are inherently fertile, they are susceptible to compaction if too wet and are difficult to cultivate, and are susceptible to clodding when too dry. As well, the high shrink-swell potential of clay-textured materials causes problems for construction and the permanence of rigid structures. Potential cracking of building foundations, roads and sidewalks and subsidence of earthen structures are common issues that need to be addressed when constructing on Vertisolic soils.

For further information see:

Brierley, J. A., H.B. Stonehouse, and A.R. Mermut. 2011. Vertisolic soils of Canada: Genesis, distribution, and classification. Canadian Journal of Soil Science 91:719-747.