PS&C
Prairie Soils &
Crops Journal

Vertisolic Soils of the Prairie Region

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Summary

The soils often referred to as 'gumbo' occur on clayey glaciolacustrine parent materials with a high content of expanding clay mineral, and are classified in the Vertisolic Order. Vertisolic soils cover about 8% of the farmland in the Prairies, and are important because of their agricultural productivity, a consequence of their fertility and high moisture storage capacity. Vertisolic soils form deep and wide cracks when dry, and have distinctive features known as slickensides in the subsoil that form because of the shrinking of soils as they dry, and their swelling as they re-wet. The shrink-swell characteristics and low bearing strength when wet result in problems when soils are used for engineering purposes such as when making roads or building foundations.

Introduction

The Vertisolic Order includes the heavy clay soils that are often called gumbo because of their stickiness when wet, and the slow rates of water infiltration into the soil. To be a Vertisolic soil, however, there must be special features that result from shrink-swell processes-that is the shrinking and cracking of soils as they dry and their expansion as they wet up again. The shrink-swell processes are due to the high content of expanding clay minerals called smectites. The diagnostic horizons for Vertisolic soils are the vertic (Bv) horizon and slickensides. Vertisolic soils occur mainly in the semi-arid and sub-humid grasslands, occasionally under forest vegetation. Vertisolic soils occur where there is a marked seasonality to precipitation, particularly a dry period long enough for cracks to form, as in the semi-arid Brown and Dark Brown soil zones, particularly in Saskatchewan. They occur as well in the more moist areas of the Black soil zone, notably the clayey soils of Manitoba's Red River Valley. Their high clay content makes Vertisols an excellent agricultural soil in droughty areas where moisture storage is critical, somewhat less ideal in wetter areas where surface water ponding often occurs after heavy rains and at snowmelt.

Factors of Soil Formation

Parent material is a key soil-forming factor because Vertisolic soils form only on clayey materials with a high content of expanding clay minerals, the smectites. Although the Vertisolic Order was not introduced into the Canadian soil classification until 1998, the special properties of clayey soils forming on glaciolacustrine deposits in western Canada have been known for decades[8]. Some of those properties include the high shrink-swell potential, low bearing capacity and extreme stickiness when wet, the formation of wide and deep cracks when dry, and generally weakly developed soil profiles with more organic matter in the subsoil, often to 1 metre depth. These properties were recognized by the word 'grumic', a term that describes the self-mulching characteristics of the soil, that is the very gradual mixing and inversion of the soil as cracks form and surface soil falls down cracks[5,6]. The high shrink-swell potential is because of the high clay content (>60%), and the dominance of smectite or montmorillonite minerals in the clay. Smectites have an expandable crystal structure. The mineral particles are able to adsorb water not only on their surfaces, but between inter-layers within the clay mineral itself. This causes the mineral to expand when moistened, and to shrink when dried out. Vertisolic soils require at least 30% smectite minerals in order for the shrink-swell process to be dominant.

Figure 1. Wide cracks in a Vertisol soil of the Sceptre Association, in late August after a warm, dry summer. The now-harvested crop was lentil on chem-fallow.

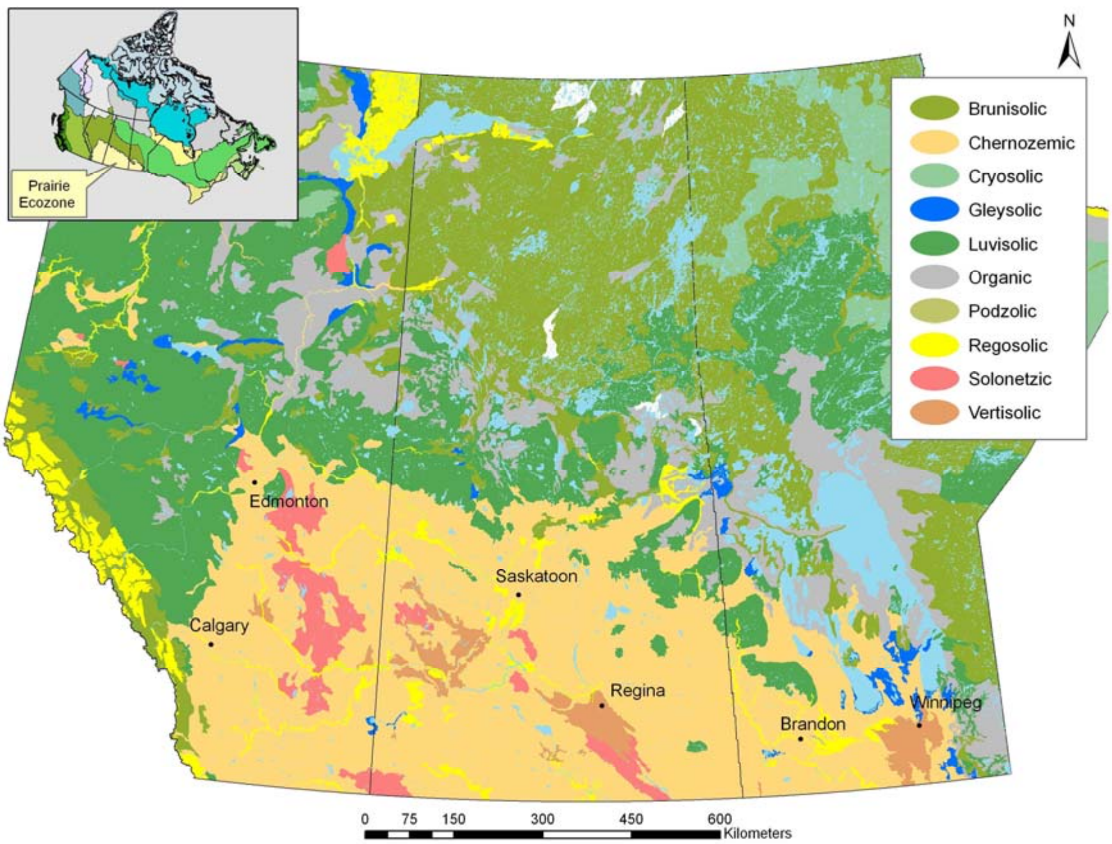


Figure 2. Soil order map of the Prairies, showing the major areas of Vertisolic soils, in the Red River Valley of Manitoba, the Regina Plains, the Eston and Rosetown plains of southwest Saskatchewan[7], and the Drumheller Plain northeast of Calgary.

Climate is the second important soil-forming factor. The cracking that occurs during dry periods are integral to the formation of Vertisolic soils. Soils of the Vertisol Great Group have less evident Ah or Ap horizons with low organic matter contents, and are typical of the drier parts of the Prairies, where droughts are more frequent and moisture deficits occur almost yearly[1]. Humic Vertisols, the second Great Group, have dark Ah or Ap horizons with more organic matter, and occur in the more moist areas where biomass production is greater and cracking less frequent.

Vegetation Vertisolic soils were formed mainly under grassland, vegetation typical of areas with less moisture and more frequent droughts. Grasslands produce relatively more roots than forest or crop, resulting in more feed stock to produce humus. In addition, clay minerals form stable complexes with humus, generally resulting in higher organic matter contents in more clayey soils. Interestingly, two distinctive grassland communities are associated with Vertisolic soils: the June grass- wheatgrass stands that were once common in drier areas, and the Tallgrass Prairie that once covered much of the Red River Valley[10]. Virtually all of these lands have been cultivated, with the Matador Grassland of southwestern Saskatchewan representing a sizeable area of the June grass-wheatgrass community.

Topography Most glaciolacustrine plains are level or nearly level and topography generally is not a factor influencing soil profile development. There are, however, lands with broad flat-bottomed depressions in which water ponds after snowmelt or heavy rains, mainly because of the slow rate of infiltration into clayey soils. Imperfectly drained 'gleyed' and poorly drained 'gleysolic' Vertisolic soils occur there.

Interestingly, a distinctive micro-topography known as gilgai often develops in uncultivated Vertisolic soils. Hummocks about 1 metre across and about 10 or 15 cm high form polygons that are surrounded by v-shaped grooves[2]. Concentrations of dark-coloured organic matter under the grooves indicate that these are areas where soil cracks repeatedly, with surface soil falling into cracks (Figure 7)

Time The glaciolacustrine deposits of the Prairie Region are all of similar age, forming as the glaciers melted about 10,000 to 14,000 years ago. It is likely that those same processes that affect the soils today have been going on in the Vertisolic soils for thousands of years, mainly under grassland vegetation.

Groundwater generally is not a significant factor influencing Vertisolic soils, mainly because ground water occurs at considerable depth. Interestingly, one of the reasons for the comparatively late settlement on many of the lands with clayey soils was the scarcity of water, particularly groundwater.

Processes of Soil Formation

Additions: The addition of organic matter (mainly organic carbon and nitrogen) is the dominant process, particularly for those Vertisolic soils of the grasslands. Organic matter is added to the upper part of the soil, and distributed to about 1 metre depth because of surface soil falling down cracks. The C horizons of Vertisolic soils contain about 1% organic matter, even at 0.5 to 1.5 m depth[4]. The Humic Vertisols with deep Ah horizons typically contain 200 to 300 tonnes of carbon per hectare, significantly more than nearby Chernozemic soils on less clayey parent materials. The organic matter of clayey soils generally contains more nitrogen in relation to carbon than medium-textured soils, i.e. they have a narrower C:N ratio, making reserves of organic nitrogen significant even in the subsoil.

Removals: Because Vertisols have a high water-holding capacity, they seldom contain enough water to dissolve and completely remove even soluble components from the entire profile. Soils of the Vertisol Great Group often have concentration of sparingly soluble gypsum salts in the subsoil at about 0.5 to 1 metre depth, the approximate depth moistened by 25 cm of precipitation (Figure 3). The gypsum is thought to be a natural feature of the soils, probably does not reduce crop yields, and appears not to be a problem.

Translocation: Soil components are moved about in Vertisolic soils, although the processes are not generally related to materials moving in the soil water as in most other soils. The translocation is due to physical processes as the soils dry and then re-wet, such as surface soil falling down cracks, and by argilopedoturbation. This is a long word that may be broken down into argilo (French for clay), pedo (referring to soil) and turbation (disturbance or disruption).

Two distinctive features form from this process. Slickenslides are shear surfaces with a shiny or glossy appearance that form when one soil mass slips by another as the subsoil re-wets unevenly (Figures 3). Slickenslides have unidirectional grooves parallel to the direction of movement, and usually occur at an angle of 20 to 60 degrees to the surface. Slickenslides often intersect, resulting in the formation of wedge-shaped aggregates that often occur in Vertisolic soils. Horizons with slickenslides are designated with the letters "ss", as in Bss or Css.

Figure 3. Slickensides in the Ckss horizon a Vertisol soil of the Sceptre Association. The glossy pressure faces result from one block of soil sliding by another as the expanding subsoil wets up unevenly. The whitish flecks are gypsum salts, common at about 0.5 to 1 m depth in Sceptre soils. The 'loonie' coin provides scale.

Vertic horizons also form by argilopedoturbation. A vertic horizon occurs below the Ah or Ap, and is designated as a Bv horizon. The Bv is characterized by blocky structure, with irregularly shaped, randomly oriented, wedge-shaped chunks of soil all mixed together. There also may be evidence of vertical cracks that have been filled with dark-coloured soil that has fallen down the cracks (Figure 4).

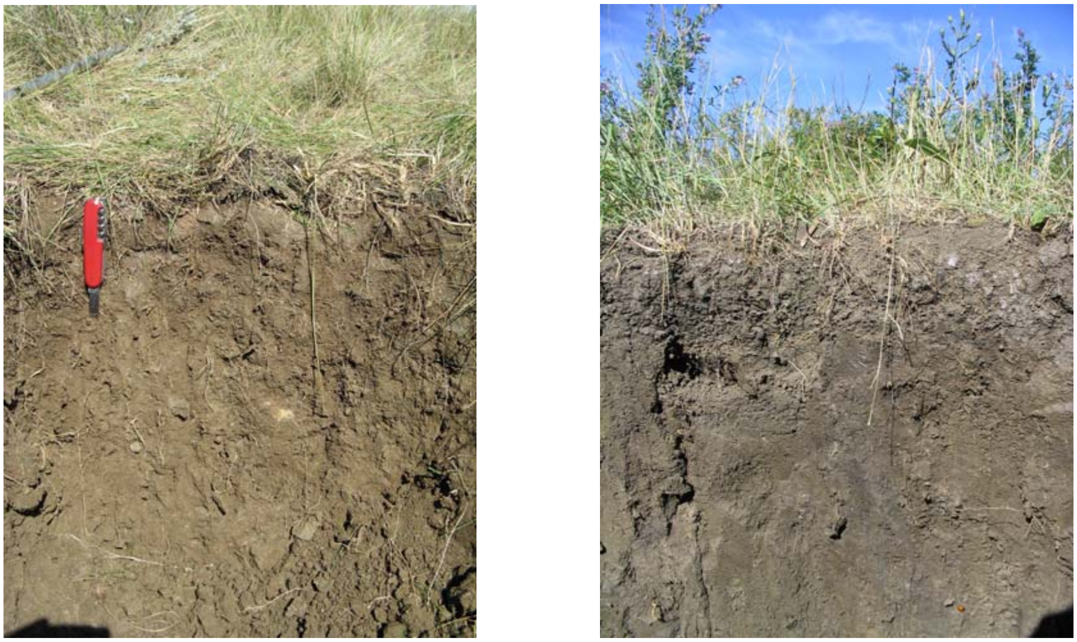
Transformations: Transformations or changes due to weathering are minimal in cool and dry Vertisolic soils. The clay minerals in these soils were all present in the parent material. Changes that may be termed transformations include the formation of humus from plant residues, and the transformation of mineral forms of phosphorus to organic forms. The phosphorus ions are released by weathering, taken up by plants, and returned to the soil in organic matter.

Classification of Clayey Soils

The Vertisolic Order was established in 1998 as the tenth order of the Canadian System of Soil Classification, to include the heavy-textured (mostly >60% clay, with one-half of the clay being smectite minerals) soils, which lack the distinct horizons typical of other soils and contain a vertic (Bv) horizon and slickenside horizon[8].

Great groups are defined on the basis of properties that reflect the strength or intensity of the main soil-forming process. Two great groups have been defined for the Vertisolic Order based mainly on surface colour value.

Great Group Name	Munsell colour	Profile characteristics	Typical soil zone
Vertisol	Value >3.5	Lack a distinct Ah/Ap	Brown and Dark Brown
Humic Vertisol	Value, 3.5	Dark Ah/Ap horizon	Black



a b

Figure 4. a. Orthic Vertisol soil of the Sceptre Association, with a hardly discernible Ah horizon underlain by a vertic B horizon or Bv. The self-mulching process, essentially surface soil falling down cracks, results in a mixing of the soil and restricts the development of well-defined horizons. b. Humic Vertisol soil near Saskatoon, with a dark Ah horizon, and vertic (Bv) horizon. Cracks are evident, as well as the dark streaks (pointed to by the grass stem in the middle of the photo) that form by surface soil falling down open cracks.

Subgroups The Vertisol and Humic Vertisol great groups have the same set of subgroups, defined based on the degree of gleying, as an indicator of the drainage / wetness of the soils. Well-drained soils are 'orthic' as in Orthic Vertisol, with no indications of poor or slow drainage. Imperfectly drained soils with some indicators of slow drainage are 'gleyed', as in Gleyed Humic Vertisol. Poorly drained Vertisolic soils are classified as 'gleysolic', as in Gleysolic Humic Vertisol.

Vertic Intergrades of other Soil Orders Soils developed from clayey parent materials often have the properties considered to be distinctive or diagnostic of another soil order, and secondary properties that are similar to, but less strongly developed, than those features characteristic of Vertisolic Order soils. These intergrade'soils are designated as 'vertic' subgroups (except for Vertic Solonetz, which is a great group), occurring in the Chernozemic, Solonetzic, Luvisolic and Gleysolic orders. Generally, the vertic intergrades have a slickenside horizon, but lack the vertic (Bv) horizon diagnostic for the Vertisolic Order (Figure 5).

Figure 5 Vertic Gray Luvisol soil under Boreal Forest near Flin Flon, Manitoba. The profile includes a thick surface organic horizon (LFH), a thin, gray Ae horizon, and a clayey Btss horizon. The glossy surfaces or slickensides are visible at about 30 cm depth, just below the large cut-off tree root.

Typical Soil Landscapes and Agriculture

Three landscapes with Vertisolic soils will be discussed, differing somewhat in their properties and in their potential for arable cropping:

1. Level to gently rolling landscapes with Vertisol soils of the Sceptre Association are characteristic of the best farming lands of the Brown soil zone of southwestern Saskatchewan (Figure 6). The main areas of Sceptre soils are south of the S. Saskatchewan River near Sceptre and Leader, and in the Kyle, Eston and Kindersley areas. The clayey soils are able to store about 25 cm of water (about 2/3 of the yearly average) to 1.2 m depth, an important property in this generally dry and drought-prone region. The traditional rotation in these areas was cereal- summer fallow, making good use of the moisture storage capacity, although the lack of residue cover makes the soil susceptible to wind erosion, especially in late winter and early spring. This occurs just after snowmelt, when freeze-thaw cycles break down larger aggregates to silt-sized aggregates that are readily eroded by drying winds. Conservation (no-till) tillage is common in these areas today, substantially reducing susceptibility to wind erosion and improving the structure or tilth of the Ap horizons. No-till farmers Lyle and Rob Minogue of Kyle have noted that water from heavy rains or snowmelt enters the soil more rapidly and evenly, and that field operations can be resumed sooner than on nearby lands in conventional tillage. Many farmers include summer fallow in their rotation, using herbicides rather than tillage to control weeds, a practice termed “chem-fallow”.

The fertility, landscape and moisture storage capacity make Sceptre soils well-suited to growing a wide variety of crops, including cereals, pulse crops and oilseeds. A rotation including cereals, lentil and canola has developed over the decades. Including lentil gradually builds nitrogen fertility, resulting in higher yields of cereals. Lentil also benefits from the generally smooth landscapes, absence of stones, and moisture storage capacity which generally supplies crop needs until near harvest, running out as the crop matures.

Figure 6. The level landscape of the glaciolacustrine Eston Plain, with clayey soils of the Sceptre Association. The photograph was taken in early spring, illustrating the cover of crop residues that protects the soil from wind erosion.

Sceptre soils occur in other glaciolacustrine plains, in lands not as extensive as those described above. This includes lands near Assiniboia and Gravelbourg in southwestern Saskatchewan, and many areas of a few to perhaps 10 or 20 square kilometres here and there throughout the Brown soil zone.

2. Generally level landscapes with Vertisol and Humic Vertisol soils of the Regina Association occur in the Dark Brown soil zone on the Regina Plains, and on the Rosetown Plain extending northwest to Unity[7]. These farmlands have many of the same characteristics as the Sceptre soil landscapes discussed above, differing mainly by the more moist climate. The additional moisture makes continuous cropping more possible, reducing the requirement for chem-fallow. Many of the same crops are grown. Clayey soils benefit from a timeliness of tillage, that is doing field operation when soils are dry enough to bear the machines, but not too dry and hard. This less of an issue with no-till.
   Important lands with Humic Vertisol soils occur on major glaciolacustrine plains in the Black soil zone of Saskatchewan and Manitoba, generally in combination with Vertic Black Chernozem soils. Vertic Chernozems are intergrades between Vertisolic and Chernozemic, having both the distinctive Ah/Ap and B horizons of Chernozemic Order soils, and less strongly developed vertic properties, namely some slickensides in the C horizon. Examples include the clayey soils of the Indian Head and Melfort associations in Saskatchewan, and the Dauphin Series of the Dauphin Lake Plain in Manitoba[3].
3. Gleyed Humic Vertisols of the Red River Series are characteristic of the Red River Valley of Manitoba, on the very level landscapes formed in glacial Lake Agassiz thousands of years ago[3]. Despite somewhat more serious problems of surface ponding of water in spring and after heavy rains, the soils have a high yield potential and are considered prime farmland.

USDA Soil Taxonomy

Vertisols have been a soil order in the US Soil Taxonomy since its beginning, and defined to include soils on clayey materials, with slickensides, in which cracks form as the soils dry. Around the world, there are many ‘cracking clay’ soils, mainly in sub-tropical and tropical climates. Initial versions of Soil Taxonomy excluded the clayey soils of cool climates, thinking that soils with prominent cracks are more likely in warm, dry climates. A recent revision to Soil Taxonomy includes the clayey soils of the cooler climate regions of Western Canada, parts of North

Dakota and Montana, and other cool regions (cryic temperatures) as a specific suborder, the Cryerts[9].

Vertisolic Soils and Engineering Problems

The amount and mineralogy of the clay in Vertisolic soils often results in problems when soils are used to support structures or roads. The high shrink-swell potential and low bearing capacity, especially when wet, are the main reasons for failures of engineering works, requiring that special practices be adopted[3]. There are difficulties with foundations, streets, sidewalks and highways. Travelling Highways 1 and 75 across the Red River Valley brings to mind both a solution to the problem of heavy clay soils, and a reminder of their shrink-swell properties. The highways are constructed with 10- or 15-m long sections of concrete, rather than continuous asphalt, because of the low bearing capacity of the soil. Adjacent sections all seem to have a centimetre or so difference in elevation, and the tires thump over each joint, a constant reminder of the shrink-swell nature of the smectite clays. There is little doubt that Vertisolic soils present special problems to those building on them, and soil-specific solutions are required.

Figure 7. The photograph was taken by an unidentified engineer working on a new subdivision in Saskatoon. It illustrates the polygonal pattern of dark, organic matter-enriched topsoil that has fallen down cracks in a Vertisolic soil, probably at a depth of 50 to 80 cm, and exposed as surface soil was excavated. The photo also indicates the need for special practices to deal with the swelling clays, and possible future problems with streets, sidewalks and basements.

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