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Proposed new soil order — Leptosolic order for Canadian System of Soil Classification

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Abstract

Shallow soils occur throughout the world and are recognized as Leptosols at the highest level in the World Reference Base. These soils are notionally characterized as having a lithic contact close to the soil surface. Within the Canadian System of Soil Classification (CSSC), shallow soils are currently handled at the family level according to the depth at which the lithic contact is encountered. At the series level, these soils are usually designated as a shallow phase of a non-shallow soil series, ignoring the hierarchical structure of the CSSC. Shallow soils occur almost anywhere in Canada where the glacial drift is thin. The presence of bedrock close to the surface impacts drainage, the amount of available moisture, depth for rooting, and has a major influence on soil formation. Consequently, it is proposed that the importance of shallow soils be elevated to the order level, to be consistent with the frequency of their occurrence in the Canadian landscape and for consistency with other soil classification systems of the world. This requires integration at the great group and subgroup levels within all orders of the CSSC, as well as changes to the current formal definition of soil. These proposed modifications include nullifying the minimum 10 cm depth requirement as part of the current definition of soil in the CSSC for closer consistency with ecological land classification and other soil classification systems of the world. Proposed modifications to the current key to the soil orders, great groups, and subgroups are presented and discussed.

Key words: shallow soils, lithic contact, soil definition, Leptosol, leptic contact

Résumé

Les sols minces existent partout dans le monde et, dans la Base de référence mondiale, ils forment la classe des Leptosols, sols en théorie caractérisés par un contact lithique étroit avec la surface. Dans le Système canadien de classification des sols (SCCS), les sols minces sont présentement répartis entre diverses familles, selon la profondeur à laquelle se trouve la roche dure. Au niveau de la série, ces sols sont le plus souvent considérés comme la couche peu épaisse d'une suite de sols non minces et, en ce sens, ne respectent pas la structure hiérarchique du SCCS. On trouve les sols minces n'importe où au Canada, là où il y a peu de sédiments glaciaires. La proximité du substrat rocheux a une incidence sur le drainage, la quantité d'eau disponible et la profondeur de l'enracinement; cette proximité exerce aussi une très nette influence sur la pédogenèse. Les auteurs proposent qu'on élève les sols minces au rang de l'ordre dans la classification, de manière à en refléter la fréquence dans le paysage canadien et à se rapprocher des autres systèmes de classification en usage dans le monde. Pour cela, on devrait intégrer les taxons « grand groupe » et « sous-groupe » dans les ordres du SCCS et modifier la définition officielle de « sol ». Pour cela, on devrait supprimer l'exigence d'une épaisseur minimale de 10 cm qui fait actuellement partie de la définition dans le SCCS afin de rendre de dernier plus cohérent avec la classification écologique des sols et les systèmes de classification employés ailleurs dans le monde. Les auteurs présentent les modifications qu'ils suggèrent à la clé actuelle d'identification des ordres, grands groupes et sous-groupes de sols, puis discutent de ces changements. [Traduit par la Rédaction]

Mots-clés : sols minces, contact lithique, définition de sol, Leptosol, contact leptique

Introduction

Shallow soils, identified as Leptosols ("leptos" meaning thin) in the World Reference Base (WRB), the international system for classification of soils, include unconsolidated mineral material, ≤25 cm in thickness, overlying continuous coherent hard rock or fragmental subsoil (International Union of Soil Sciences (IUSS) Working Group WRB 2015; Bockheim 2015). Leptosols are recognized at the highest level in the WRB classification and are the most extensive group of soils in the WRB, with an estimated world-wide areal extent of

1.655 billion ha (ISSS Working Group RB 1998; Driessen et al. 2001). Leptosols typically have an incomplete solum and (or) lack clearly expressed morphological features (Driessen et al. 2001; Nachtergaele 2010). Lithic Leptosols are the most extensive Leptosols, which are exceedingly shallow soils with <10 cm of unconsolidated mineral material overlying continuous bedrock (Driessen et al. 2001). "Leptic" qualifiers are also used to indicate continuous hard rock between 25 and 100 cm from the soil surface in other RSGs (Driessen et al. 2001). In the Canadian System of Soil Classification (CSSC), Regosols and Brunisols (approximately equivalent to Cambisols in the WRB), both characterized by limited profile development, are the most common mineral soils associated with Leptosols (Nachtergaele 2010). Many organic soils, most notably Folisols (shallow upland organic materials), are also limited in depth by the presence of bedrock.

In US Soil Taxonomy (USDA 1999, pg. 156), "Leptic" subgroups are designated to refer to soils that are "thin" but not necessarily restricted by a lithic contact, whereas the term "Lithic" is reserved to specifically indicate the presence of a lithic contact near the soil surface. Both terms are used at the subgroup level in US Soil Taxonomy. Lithic subgroups are recognized in Soil Taxonomy for all soils <50 cm thick over hard rock (USDA 1999; Nachtergaele 2010).

Most Leptosols, as defined in the WRB, have an A (sometimes B or C), R configuration with only weakly expressed horizons (Driessen et al. 2001). Soils with a "Leptic" qualifying term signify the presence of continuous hard rock between 25 and 100 cm from the soil surface. Soils on high mountains and valleys are commonly very shallow, lacking much topsoil and are highly erodible. Some soils are considered shallow if they have root restrictive layers or a shallow groundwater table that roots cannot penetrate; however, these are not classified as Leptosols. The natural vegetation growing on shallow soils generally includes grasslands, bush-lands, and low forests, with severe limitations to agricultural use. From a soil management perspective, shallow soils having limitations due to restricted root growth are not suitable for arable agricultural production but may be used for marginal pastures and forests (Nachtergaele 2010).

Shallow soils are azonal and may be found anywhere in Canada but are very common in mountainous regions, such as British Columbia and the Yukon. In addition, shallow soils that could be recognized as Leptosols occur extensively in the vast expanses of the Canadian Shield and are very common in the Atlantic provinces. Shallow phases, which may have been mapped in the past as part of complex soil polygons, may now be identified individually using predictive digital soil mapping (PDSM) techniques at higher resolutions than ever before (Dwivedi 2017).

It is worth noting that "Lithic" subgroups were previously recognized for all great groups in the System of Soil Classification for Canada (Canada Department of Agriculture 1974), which was the precursor to the first version of the Canadian System of Soil Classification (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978). Under that version of the system, Lithic subgroups were defined for all great groups having a lithic contact within 50 cm of the surface. The rationale for dropping the Lithic subgroups between 1974 and 1978 was not apparent, but we postulate it was aligned with the adoption of a formal definition for the subgroup taxa in 1978, which stated that "subgroups are differentiated on the basis of the kind and arrangement of horizons or additional special features within the control section". The control section is the key item to highlight, since in mineral soils, "if bedrock occurs at a depth of less than 1 m, the control section is from the surface to the lithic contact", thus the lithic contact is outside the control section, and therefore could no longer be used at the subgroup level. It should be noted that the control section for organic soils was from the surface to a depth of 160 cm or to a lithic contact.

Current status of shallow soils in Canada

Based on the current (third) version of the CSSC:

> "Soil is defined herein as the naturally occurring, unconsolidated mineral or organic material <u>at least 10 cm thick</u> that occurs at the earth's surface and is capable of supporting plant growth". (SCWG 1998, pg. 9).

Historically, Canadian soil taxonomy has had an agricultural bias, or, at the very least, a bias toward classification of soils to support the production of food (agriculture) and fibre (forestry). The primary evidence is rooted in the definition of soil provided above, which emphasizes depth and capacity to sustain plant growth for agricultural production. Further evidence of an agricultural bias can be seen in the extent of very detailed (1:14 000 or larger) and detailed (1:50 000 or larger) soil surveys in Canada, which are mostly restricted to agricultural areas and their fringes. Finally, the CSSC has historically been developed, maintained, and published by Agriculture and Agri-Food Canada (third edition), or its predecessor Agriculture Canada (first and second editions), through committees and working groups predominantly composed of federal and provincial agricultural staff, and academic members from departments of soil science and (or) agriculture from across Canada (e.g., Hoffman 1968; Canada Department of Agriculture 1974, 1976; ECSS 1983; SCWG 1998). This is not a criticism of the current CSSC, but rather a recognition of an intrinsic bias and to offer an explanation as to the relatively little attention afforded to shallow soils in the Canadian taxonomic system.

Based on the current definition of soil in the CSSC (SCWG 1998, pg. 9), any unconsolidated mineral or organic materials <10 cm thick are classified as "non-soil", and typically appear on soil maps as "rockland" or other types of named miscellaneous soil map units. Although not appropriate for most agricultural uses, these materials are included in other classification systems as they fulfill the current definition of soil except for the arbitrary restriction of a minimum 10 cm depth criterion. In ecological classification schemes in Ontario, for example, all soil materials, including those <10 cm thick over bedrock, are collectively termed "substrates" (OMNR 2015). Although these materials may not be suitable for agriculture and do not satisfy the current minimum depth criterion, they do support plant growth in the form of deciduous and coniferous trees. In the case of being underlain with limestone or dolomitic bedrock, shallow soils generally <10 cm thick are defined as "alvars" in ecological classification, which are

Table 1. Current soil family lithology depth classes in the third edition of the CSSC (SCWG 1998).

CSSC family class (SCWG 1998)	Depth to lithic[a] contact	
	Mineral soils	Organic soils
Non-soil (by definition)	0 to <10 cm	0 to <10 cm
Extremely shallow lithic	10 to <20 cm	10 to <40 cm
Very shallow lithic	20 to <50 cm	40 to <100 cm
Shallow lithic	50 to 100 cm	100 to 160 cm
Non-shallow (inferred)	>100 cm	>160 cm

[a]Designated R layer defined as an unconsolidated bedrock layer too hard to break with the hands (>3 on Mohs' scale) or to dig with a spade when moist (SCWG 1998).

unique ecologic niches in the landscape typically supporting grasses, shallow rooted trees, and shrubs (Belcher et al. 1992; Catling and Brownell 1995). Soil "substrates" overlying Precambrian bedrock cover a substantial part of the boreal forest region spanning from the Yukon in the west, to Newfoundland and Labrador in the east and cover about 526 million hectares, or almost 60% of Canada's land area (NRC 2020). These lands covered by forests and shrubs growing on shallow soils will require special attention in the near future (Dwivedi 2017). Therefore, inclusion of "substrates" <10 cm deep over bedrock within the formal definition of soil recognizes the importance and extent of shallow soils in Canada and may aid in future management efforts, particularly in light of environmental factors such as climate change.

Consolidated bedrock, designated R (SCWG 1998, pg. 12), is a bedrock layer, regardless of composition, too hard to break with the hands (>3 on Mohs' scale) or to dig with a spade when moist (SCWG 1998). A lithic contact is the boundary between the R "layer" and the overlying unconsolidated material (SCWG 1998). The current depth classes for mineral and organic soils are reflected at the soil family level and are summarized in Table 1. Soils having a lithic contact within 1 m of the surface in mineral soils are currently recognized at the family level (fourth level) of the classification scheme with attributes: shallow lithic (bedrock at >50–100 cm depth); very shallow lithic (bedrock at 20–50 cm depth) or extremely shallow lithic (bedrock at <20 cm depth) (SCWG 1998, pg. 139). Similarly, organic soils having a lithic contact within 160 cm of the surface are recognized at the family level with attributes: shallow lithic (bedrock at >100–160 cm depth); very shallow lithic (bedrock at 40–100 cm depth) or extremely shallow lithic (bedrock at 10–40 cm depth) (SCWG 1998, pg. 144).

In terms of mapping soils in Canada, it has been common practice for shallow soils to be identified and mapped simply as a shallow phase within a soil series. For example, in Ontario, about 10% of the more than 1000 named soil series in the province are characterized as having a lithic contact within 1 m of the surface and classified as a shallow phase of a non-shallow series. Use of a soil phase was intended to:

> "recognize and name, at a relatively high categorical level, soil properties that are used as differentiae at a lower categorical level. For example, depth to a lithic layer is a family criterion, but it can be used as a phase criterion at the order, great group, and subgroup levels…" (SCWG 1998, pg. 149).

Therefore, given the fact that depth to a lithic contact is a characteristic at the family level, using it as a phase applied to the soil series, which is a lower categorical level, in effect, ignores the systematic hierarchical structure of the CSSC and is not correct usage. It has even been recognized by some non-Canadian authorities that poor development of the higher levels of the taxonomy, particularly at the family level, does not allow successful grouping of series in the CSSC (Krasilnikov et al. 2009).

Realignment with other classification schemes

The minimum 10 cm criterion, used in the formal definition of soil, is included in both the Glossary of Terms in Soil Science (Canada Department of Agriculture 1976) and the third edition of the CSSC (SCWG 1998). The original definition, including the 10 cm minimum thickness restriction, first appeared in 1967 and was included as part of the CSSC in 1968 (Hoffman 1968), borrowing from the Seventh Approximation (Soil Survey Staff 1960). The minimum criterion was originally adopted from the US definition for soil at the time (Canada Department of Agriculture 1974, 1976; Soil Science Society of America 1965). The definition for soil in US Soil Taxonomy has since evolved with a minimum depth criterion no longer appearing as part of the formal definition of soil (e.g., USDA 2015); however, the minimum depth criterion remains in the CSSC. The Canadian National Vegetation Classification (NRC 2013) recognizes that plant growth occurs even on surfaces "constrained by rock or other hard substrates" and a minimum depth or thickness is not a requirement. The minimum 10 cm depth criterion is also not a requirement in the WRB or many other national classification systems (Krasilnikov et al. 2009). Removal of the minimum depth criterion from the formal definition of soil in the CSSC would allow the Canadian classification system to evolve, align with other systems, and provide a mechanism to start refining our understanding of thin soils in the Canadian context.

Proposed Leptosolic order

Central to the concept of the Leptosolic order is the definition of a restrictive layer, which we propose to define as a "leptic contact". We propose that soils belonging to the Leptosolic order be defined as any mineral soil ≤25 cm in thickness above a leptic contact, for consistency with the WRB, or any organic (>17% organic C by weight) soil materials <60 cm in thickness if composed of fibric materials above a leptic contact or other organic (>17% organic C by weight) soil materials <40 cm in thickness above a leptic contact. The thresholds of 40 cm and 60 cm for Organic soils instead of a 25 cm threshold are proposed to maintain alignment with the current criteria within the Organic order of the CSSC for soils overlying a lithic contact (SCWG 1998, pg. 98). The occurrence of Cumulic (thin mineral) layers (SCWG 1998, pg. 19) are applied in a similar manner to that of the Organic order. In general, it is proposed that a leptic contact be considered as a "restricting feature" limiting the depth to which roots can penetrate. A leptic contact therefore encompasses lithic, paralithic, and fragmental contacts as defined herein.

A lithic contact is currently defined in the CSSC as: "the boundary between the R layer and any overlying unconsolidated material…" where an R layer is consolidated bedrock too hard to break with the hands (>3 on Mohs' scale of hardness) or to dig with a spade when moist (SCWG 1998, pg. 12). A paralithic contact is the boundary between a paralithic layer and any overlying unconsolidated material, where paralithic is defined as rock where the hardness is ≤3 on Mohs' scale (Canada Department of Agriculture 1974). Paralithic materials, borrowing from US Soil Taxonomy, can be further defined as: relatively unaltered geologic materials that are weakly to moderately cemented mineral materials such that roots cannot enter (USDA 1999). Cemented horizons of pedogenic origin currently defined under the CSSC (SCWG 1998, pg. 16–17), such as Ortstein, Fragipan, Placic, and Duric horizons, are exempt and not considered paralithic materials. Commonly, paralithic materials are partly weathered bedrock or weakly consolidated bedrock such as sandstone, siltstone or shale. Finally, a fragmental contact would be defined as fragmental materials (i.e., gravel, cobbles, stones, boulders) constituting 90% coarse materials by volume (SCWG 1998, pg. 137).

Currently, paralithic and fragmental materials are included in the control section and described as horizons (usually B or C horizons) as part of a profile description, while lithic contacts are described as bedrock (R) layers (SCWG 1998, pg. 12) and are considered outside the control section. Whereas a lithic contact defines one of the exceptions limiting the depth of the control section of a mineral soil (SCWG 1998, pg. 11), paralithic and fragmental contacts occur within the control section and do not limit the defined depth of the control section. This requires a modification to the definition of the control section.

To allow the integration of the Leptosolic order into the CSSC, three subtle modifications to the definition for the control section of mineral soils (SCWG 1998, pg. 11) will be required as follows:

> "If ~~bedrock~~ a leptic contact occurs at a depth ~~of 10 cm or but~~ less than 1 m, the control section extends from the surface to the ~~lithic~~ leptic contact and includes the leptic contact".

The first modification, changing the term lithic for leptic, reflects the recognition of a leptic contact (lithic, paralithic, and fragmental) as described above. The second modification, the removal of the 10 cm depth criteria, allows for the inclusion of all soil materials, regardless of thickness, into the CSSC, and specifically into the Leptosolic order. The third modification, which recognizes a leptic contact as part of the control section, allows the integration of Leptic at the subgroup taxa in the existing mineral soil orders and great groups. The definition of the control section for organic soils will also require modification as follows:

> "The control section for Fibrisols, Mesisols, Humisols and Folisols extends from the surface either to a depth of 1.6 m or to a ~~lithic~~ leptic contact and includes the leptic contact".

In addition to the changes outlined above, minor revisions to text in the Organic order will also be required. First, in the specifications for organic materials (O) that are commonly saturated with water, the following text (SCWG 1998, pg. 98, bullet 3) should be removed because these materials will now be captured in the Leptosolic order:

> "If a lithic contact occurs at a depth shallower than 40 cm, the organic material must extend to a depth of at least 10 cm. Mineral material less than 10 cm thick may overlie the lithic contact, but the organic material must be more than twice the thickness of the mineral layer".

Second, for folic materials (L, F, and H) not usually saturated with water, the following text (SCWG 1998, pg. 98, bullet 2) should be removed because these materials will now be captured in the Leptosolic order:

> "Greater than 10 cm of folic materials if directly overlying a lithic contact or fragmental materials".

Third, modifications are required to the definition of the Folisol great group (SCWG 1998, pg. 104) as follows:

> "Soils of the Folisol great group are composed of upland organic (folic) materials, generally of forest origin, that are ~~either~~ 40 cm or more in thickness, ~~or are at least 10 cm thick if overlying bedrock or fragmental material. Deep~~ Folisols ~~(greater than 40 cm of folic material)~~ occur frequently in cool, moist, and humid forest ecosystems, particularly on the West Coast of Canada. They also develop in northern regions where soil temperatures are low, but the soil is without permafrost. ~~Shallow~~ Folisols are found throughout Canada and commonly occur on upper slope shedding positions over bedrock and on, or incorporated in, fragmental or skeletal material".

The following text (SCWG 1998, pg. 104, bullet 2) should be removed because these materials will now be captured in the Leptosolic order:

> "Folic material is 10 cm or more in depth if directly overlying a lithic contact or fragmental material, or if occupying voids in fragmental or skeletal material; or"

And fourth, the diagrammatic representation of depth relationships in the control section used to classify Fibrisol, Mesisol, and Humisol great groups (SCWG 1998, pg. 98, figure 34) will need to be revised in consideration of the proposed changes for shallow organic soils and their inclusion in the Leptosolic order.

Soils belonging to the Leptosolic order would be defined in the key as "mineral soils with a leptic contact within 25 cm of the surface, or fibric organic soil materials (>17% organic C by weight) <60 cm in thickness above a leptic contact, or other organic (>17% organic C by weight) soil materials <40 cm in thickness above a leptic contact". The 25 cm threshold for mineral soils is proposed for consistency with WRB definitions. The 40 cm and 60 cm thresholds for organic soils is proposed for consistency in the CSSC with the current depth intervals for organic soils overlying lithic contacts (SCWG 1998, pg. 98) and to minimize revisions to the Organic order. Mineral soils with a leptic contact between 25 and 100 cm will continue to be classified according to the existing orders of the CSSC with the presence of a leptic contact captured using the Leptic qualifying term as described below. Organic soils with a leptic contact within the 1.6 m control section, ≥60 cm below the surface if the organic material dominantly fibric materials, or ≥40 below the surface for other organic materials, will be classified as Leptic subgroups within the Organic order.

The proposed Leptosolic order within the CSSC should be placed at the beginning of the key to the soil orders (SCWG 1998, pg. 33). The addition of the Leptosolic order will require changes at the subgroup level to all soil orders in the CSSC and we propose the use of a "Leptic" subgroup qualifier (as described below) as a means to avoid doubling the size and length of the current key. It should be recognized that this would be a reversal of the elimination of "subgroup modifiers" adopted for the first edition of the CSSC (SCWG 1998, pg. xii).

In addition to the use of a Leptic subgroup qualifier, the Organic order would see a major change in that organic materials dominated by fibric materials <60 cm in thickness above a leptic contact and, other organic materials (humic, mesic, or folic) <40 cm in thickness above a leptic contact, would no longer be classified in the Organic order but rather as Organic Leptosols.

An additional chapter for the proposed Leptosolic order in the revised edition of the CSSC including an Introduction; a section on "Distinguishing Leptosolic Soils from Soils of Other Orders" and detailed descriptions for the two proposed great groups and 36 proposed subgroups will be drafted on condition of acceptance of the Leptosolic order into the CSSC. The following is an abbreviated description of the great groups and subgroups of the Leptosolic order to compliment the definition at the soil order level provided above.

Two great groups within the Leptosolic order are proposed: Leptic Leptosols and Leptosols. Soils belonging to the Leptic Leptosol great group would be defined as: "Any mineral or organic soil material with a leptic contact <10 cm from the surface". This great group includes all circumstances where materials are identified as non-soil under the current definition for soil. Soils belonging to the Leptosolic great group (following the concept of the Gleysol great group within the Gleysolic order) would be defined as "Mineral soils with a leptic contact <25 cm from the surface or, dominantly fibric organic materials <60 cm in thickness overlying a leptic contact or other organic materials (humic, mesic, or folic) <40 cm in thickness overlying a leptic contact". Under the current system, organic soil materials overlying a lithic contact are a special case within the CSSC where the minimum thickness is not required for classification under the Organic order (SCWG 1998, pg. 98). We propose that these soils now be classified as Organic Leptosols, in an effort to minimize revisions to the Organic order.

Subgroups of the Leptic Leptosols may be either organic or mineral. Peaty organic materials (fibric, mesic and humic) <10 cm in thickness overlying a leptic contact would be classified collectively as Histic Leptic Leptosols regardless of the degree of decomposition of the organic material in the control section. Differentiation based on the degree of deposition of peaty organic material in a thin (<10 cm) layer over a leptic contact is considered unnecessary. Folic organic materials are formed under ecosystems different from the peaty organic materials and are therefore recognized separately as Folic Leptic Leptosols. Where both organic and mineral materials <10 cm thick are present, then the thickness of organic materials must be greater than or equal to twice (≥2×) the thickness of the mineral material for the soil to be classified as organic; otherwise it is classified as a mineral Leptic Leptosol. Subgroups of the mineral Leptic Leptosols (leptic contact <10 cm from the surface) would be differentiated based on the abundance of soluble salts, the degree of gleying and the pH of the mineral material in the control section. Gleysolic Leptic Leptosols would have gley features diagnostic of the Gleysolic order or prominent mottles within the control section. Saline Leptic Leptosols and a Gleyed version are included based on the presence of saline (EC ≥4 dS/m) materials. In this case, the presence of saline materials is deemed sufficient to define a Saline subgroup as opposed to a Solonetzic subgroup since development of a true Solonetzic B horizon (Bn or Bnt) within 25 cm of mineral material is thought to be unlikely. Brunisolic versions would include soils having a recognizable Bm horizon. In the absence of any other diagnostic criteria, differentiation would be based on the pH (measured in 0.01 mol/L $CaCl_2$) of the mineral material in the control section (Orthic Eutric Leptic Leptosols pH ≥ 5.5 and Orthic Dystric Leptic Leptosols pH < 5.5). Such profiles would have an A, C, R sequence, an A, R sequence, or contain a paralithic or fragmental horizon within 10 cm of the surface. Gleyed versions of the Eutric (pH ≥ 5.5) and Dystric (pH < 5.5) Leptic Leptosols would be characterized by the presence of faint or distinct mottles within the control section.

The Leptosolic great group would be comprised of mineral soils <25 cm in thickness overlying a leptic contact. Organic materials <60 cm overlying a leptic contact if dominantly fibric material would be classified as Fibric Leptosols and other organic materials <40 cm overlying a leptic contact would be classified as either Mesic or Humic Leptosols in the case of peaty materials based on the degree of decomposition or as Folic Leptosols if composed of upland organic materials of forest origin. Where both organic and mineral materials are present, then the thickness of organic materials must be greater than or equal to twice (≥2×) the thickness of the mineral material for the soil to be classified as organic. Subgroups of the mineral Leptosolic great groups are differentiated based primary on diagnostic criteria for each of the Gleysolic, Vertisolic, Podzolic, Solonetzic, Chernozemic, Luvisolic, and Brunisolic orders or, in the absence of other diagnostic criteria, differentiated as either Orthic Dystric or Orthic Eutric based on the pH (measured in 0.01 mol/L $CaCl_2$) of the mineral material in the control section (Eutric pH ≥ 5.5 and Dystric pH < 5.5). In addition, gleyed versions of each of these subgroups, except for the Gleysolic Leptosols, would be recognized based on the presence of faint or distinct mottles in the control section. The Gleysolic great group and gleyed subgroups are found in the key prior to their corresponding non-gleyed equivalent recognizing that the presence of the leptic contact may impede drainage and profile development.

Mineral soils ≥25 cm, but <100 cm, in thickness overlying a leptic contact, or organic materials ≥60 cm, but <160 cm,

Table 2. Proposed modifications to the CSSC classification key.

Order	Great group	Subgroup	Criteria
Leptosolic			Mineral soil <25 cm in thickness above a leptic contact or organic (>17% organic C by weight) materials <60 cm overlying a leptic contact if dominantly fibric material and other organic materials <40 cm overlying a leptic contact
	Leptic		Unconsolidated mineral or organic (>17% organic C by weight) soil materials <10 cm in thickness above a leptic contact
		Folic	Leptic Leptosols with organic material composed of upland (folic) materials
		Histic	Other Leptic Leptosols with other organic materials
		Gleysolic	Other Leptic Leptosols with mineral material having a gleyed layer similar to soils of the Gleysolic order or having prominent mottles within the control section
		Gleyed Saline[a]	Other Leptic Leptosols with saline (EC ≥4 dS/m) materials, and faint or distinct mottles within the control section
		Saline[a]	Other Leptic Leptosols with saline (EC ≥4 dS/m) materials
		Gleyed Brunisolic Eutric	Other Leptic Leptosols that have a Bm horizon ≥5 cm in thickness, and a pH ≥ 5.5 and faint or distinct mottles within the control section
		Gleyed Brunisolic Dystric	Other Leptic Leptosols that have a Bm horizon ≥5 cm in thickness and a pH < 5.5 and faint or distinct mottles within the control section
		Brunisolic Eutric	Other Leptic Leptosols that have a Bm horizon ≥5 cm in thickness and a pH ≥ 5.5 within the control section
		Brunisolic Dystric	Other Leptic Leptosols that have a Bm horizon ≥5 cm in thickness and a pH < 5.5 within the control section
		Gleyed Eutric	Other Leptic Leptosols with a pH 5.5 that have faint or distinct mottles within the control section
		Gleyed Dystric	Other Leptic Leptosols with a pH <5.5 that have faint or distinct mottles within the control section
		Orthic Eutric	Other Leptic Leptosols with a pH ≥5.5
		Orthic Dystric	Other Leptic Leptosols with a pH <5.5
	Leptosol		Other Leptosolic mineral soils <25 cm in thickness above a leptic contact or organic (>17% organic C by weight) soil materials <60 cm in thickness if composed of fibric materials above a leptic contact or other organic (>17% organic C by weight) soil materials <40 cm in thickness above a leptic contact
		Folic	Leptosols composed dominantly (>50%) of upland organic (folic) materials generally of forest origin and rarely saturated with water <40 cm in thickness above a leptic contact
		Fibric	Other Leptosols composed dominantly (>50%) of relatively undecomposed organic (fibric) materials <60 cm in thickness above a leptic contact
		Mesic	Other Leptosols composed dominantly (>50%) of organic materials in an intermediate stage of decomposition <40 cm in thickness above a leptic contact
		Humic	Other Leptosols composed dominantly (>50%) of organic materials in an advanced stage of decomposition <40 cm in thickness above a leptic contact
		Gleysolic	Other Leptosols that have a gleyed layer similar to soils of the Gleysolic order or prominent mottles within the control section
		Gleyed Vertic	Other Leptosols with a vertic horizon and slickenside, and faint or distinct mottles within the control section
		Vertic	Other Leptosols with a vertic horizon and slickenside within the control section.
		Gleyed Podzolic	Other Leptosols with a Podzolic B horizon, and faint or distinct mottles within the control section
		Podzolic	Other Leptosols with a Podzolic B horizon within the control section.
		Gleyed Saline[a]	Other Leptosols with saline (EC ≥4 dS/m) materials, and faint or distinct mottles within the control section
		Saline[a]	Other Leptosols with saline (EC ≥4 dS/m) materials
		Gleyed Chernozemic	Other Leptosols with a Chernozemic A horizon, and faint or distinct mottles within the control section
		Chernozemic	Other Leptosols with a Chernozemic A horizon
		Gleyed Luvic	Other Leptosols with a Bt horizon and faint or distinct mottles within the control section
		Luvic	Other Leptosols with a Bt horizon within the control section
		Gleyed Brunisolic Eutric	Other Leptosols that have a Bm horizon ≥5 cm in thickness with a pH ≥ 5.5 and faint or distinct mottles within the control section
		Gleyed Brunisolic Dystric	Other Leptosols that have a Bm horizon ≥5 cm in thickness with a pH <5.5 and faint or distinct mottles within the control section

Table 2. Continued

Order	Great group	Subgroup	Criteria
		Brunisolic Eutric	Other Leptosols that have a Bm horizon ≥5 cm in thickness with a pH ≥ 5.5 within the control section
		Brunisolic Dystric	Other Leptosols that have a Bm horizon ≥5 cm in thickness with a pH < 5.5 within the control section
		Gleyed Eutric	Other Leptosols with a pH ≥ 5.5 that have faint or distinct mottles within the control section
		Gleyed Dystric	Other Leptosols with a pH <5.5 that have faint or distinct mottles within the control section
		Orthic Eutric	Other Leptosols with a pH ≥ 5.5
		Orthic Dystric	Other Leptosols with a pH <5.5
Other			
	Other		
		Mineral orders	A "Leptic" qualifying term will be added to all remaining subgroup names in the key to indicate the presence of a leptic contact occurring ≥25 and <100 cm depth. In the case of the Orthic subgroups the "Leptic" qualifying term will be substituted for Orthic to indicate the presence of a leptic contact occurring ≥25 and <100 cm depth (e.g., Orthic Humic Gleysol → Leptic Humic Gleysol)
		Organic order	A "Leptic" qualifying term will be added to all remaining subgroup names in the key to indicate the presence of a leptic contact occurring ≥60 and <160 cm depth for the Fibric great group or ≥40 and <160 cm depth for other soils of the Organic order. In the case of the Typic subgroups the "Leptic" qualifying term will be substituted for Typic (e.g., Typic Mesisol → Leptic Mesisol) to indicate the presence of a leptic contact occurring ≥40 and <160 cm depth

[a]The presence of saline materials (EC ≥ 4 dS/m) is deemed sufficient in this instance to define a Saline subgroup as opposed to a Solonetzic subgroup as development of a true Solonetzic B horizon (Bn or Bnt) within 25 cm of mineral material is thought to be unlikely.

Table 3. Proposed changes to Soil Family Leptology Depth Classes.

	Depth to leptic[a] contact (cm)	
Proposed CSSC Family Class	Mineral soils	Organic soils
Exceedingly shallow leptic	<10 cm	<10 cm
Extremely shallow leptic	10 to <25 cm	10 to <40 cm
Very shallow leptic	25 to <50 cm	40 to <100 cm
Shallow leptic	50 to <100 cm	100 to <160 cm
Non-leptic (inferred)	≥100 cm	≥160 cm

[a]A leptic contact encompasses lithic, paralithic, and fragmental contacts that are "restricting features" limiting the depth to which roots can penetrate. A lithic contact is defined as "the boundary between the R layer and any overlying unconsolidated material". A paralithic contact is the boundary between a paralithic layer and any overlying unconsolidated material. A paralithic layer is defined as rock with hardness is ≤3 on Mohs' scale that are relatively unaltered but extremely weakly to moderately cemented mineral materials such that roots cannot enter. A fragmental contact is defined as fragmental materials (i.e., gravel, cobbles, stones, boulders) constituting of 90% coarse materials by volume directly overlying a lithic or paralithic contact.

overlying a leptic contact if dominantly fibric material, or other organic materials ≥40 cm, but <160 cm, in thickness overlying a leptic contact, will be classified at the subgroup level of the respective non-Leptosolic orders. It is proposed that a "Leptic" qualifying term be added to the soil key at the subgroup level instead of defining individual definitions for each Leptic subgroup within the key, each with identical definitions, to reduce the length and size of the key. For example, a Gleyed Humo–Ferric Podzol with a leptic contact occurring >25 and ≤100 cm from the surface would be classified as a Leptic Gleyed Humo–Ferric Podzol. The term would be applied similarly throughout the remainder of the classification key for all subgroups. The only exception would be soils falling into the "Orthic" subgroups where the Orthic term is dropped. For example, an Orthic Dystric Brunisol with a leptic contact occurring >25 and ≤100 cm from the surface would be classified as a Leptic Dystric Brunisol. Additions to the soil key are summarized in Table 2. The adoption of the Leptic qualifier as opposed to the Lithic qualifier is proposed to accommodate the broader concept of the Leptosols which includes paralithic and fragmental contacts. The adoption of a "qualifying term" to the key at the subgroup level would provide the ability to recognize attributes within the subgroups without cluttering the key unnecessary with repetitive definitions.

The proposed addition of the Leptosolic order will necessitate changes to the soil family lithology depth classes as outlined in Table 3. The current "lithic" classes will therefore be changed to "leptic" classes to maintain alignment and consistency with the proposed new Leptosolic order and to recognize paralithic and fragmental contacts along with lithic contacts. Both mineral and organic materials with a leptic contact <10 cm of the surface will be defined as "exceedingly shallow leptic" at the family level. This includes all substrates currently classified as nonsoil due to the current minimum 10 cm depth criteria. Mineral material with a leptic contact ≥10 to <25 cm from the surface and organic materials with a leptic contact ≥10 to <40 cm from the surface will be defined as "extremely shallow leptic". Mineral material with a leptic contact ≥25 to <50 cm from the surface and organic materials with a leptic contact ≥40 to <100 cm from the surface will be defined as "very shallow leptic". Mineral material with a leptic contact ≥50 to <100 cm from the surface and organic materials with a leptic contact ≥100 to <160 cm from the surface will be defined as "shallow leptic". Other mineral soils with a leptic contact not confining the control section or organic materials with a leptic contact ≥160 cm depth will be defined as "non-leptic". These categories at the family level are retained as they provide refinement to the divisions of the Leptosolic order at the great group and subgroup levels as described above.

Summary of recommendations

It is proposed here that the minimum depth criteria of 10 cm be removed from the formal definition of soil as well as from all other related definitions in the CSSC for consistency with other classification systems. The following modification to the formal definition of soil within the CSSC is proposed:

> "Soil is defined herein as the naturally occurring, unconsolidated mineral or organic material ~~at least 10 cm thick~~ that occurs at the earth's surface and is capable of supporting plant growth" (SCWG 1998, pg. 9).

The following changes are proposed for the CSSC for inclusion of the Leptosolic order:

- The Leptosolic order should be adopted as part of the CSSC for consistency with the WRB and other soil classifications systems of the world. The Leptosolic order will be inserted prior to the current Cryosolic order in the soil key (see Appendix A).
- Central to the concept of the Leptosolic order is the definition of a subsurface layer restricting water movement and the ingress of roots, defined herein as a "leptic contact", which encompasses lithic, paralithic, and fragmental materials.
- All mineral soils having a leptic contact <25 cm depth will be classified as Leptosols at the order level in the CSSC.
- All organic materials <60 cm overlying a leptic contact if dominantly fibric material and other organic materials <40 cm overlying a leptic contact would be classified as Leptosols at the order level in the CSSC.
- All mineral and organic materials <10 cm overlying a leptic contact will be classified as Leptic Leptosols at the great group level in the CSSC.
- All mineral soils having a leptic contact ≥10 cm but <25 cm depth will be classified as Leptosols at the great group level in the CSSC.
- All organic materials ≥10 cm but <60 cm overlying a leptic contact if dominantly fibric material and other organic materials ≥10 cm but <40 cm overlying a leptic contact would be classified as Leptosols at the great group level in the CSSC.
- A "Leptic" qualifying term should be added at the subgroup level in the soil key to indicate the presence of a leptic contact occurring ≥25 but <100 cm depth in mineral soils. The use of a "Leptic" subgroup qualifier (as described below) is proposed as a means to avoid unnecessary doubling of the size and length of the current key.
- A "Leptic" qualifying term should be added at the subgroup level in the soil key to indicate the presence of a leptic contact occurring ≥60 but <160 cm depth in organic materials dominantly fibric material or ≥40 but <160 cm depth for other organic materials. The use of a "Leptic" subgroup qualifier is proposed as a means to avoid unnecessary doubling of the size and length of the current key.
- Inclusion of an additional chapter in the revised version of the CSSC summarizing the characteristics of the proposed Leptosolic order following the format of other orders in the current third edition of the CSSC (SCWG 1998) to be drafted upon acceptance of the Leptosolic order as part of the CSSC.
- The Soil Family Lithology Depth Classes (SCWG 1998, pg. 139) will be changed to Soil Family Leptology Depth Classes, which encompass paralithic and fragmental materials along with lithic materials. Changes to depth ranges will be adopted based on Table 3 herein to be consistent with the depth criteria for the proposed Leptosolic order.
- Other changes referring to depth to a lithic and leptic contact from the surface will be required on acceptance of the changes proposed herein.

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Appendix A: A listing of the proposed Leptosolic great groups and subgroups with proposed abbreviations and proposed revisions to the key

Leptosolic order

Great group	Subgroup
Leptic Leptosol	Folic Leptic Leptosol FO.LL
	Histic Leptic Leptosol HI.LL
	Gleysolic Leptic Leptosol GLC.LL
	Gleyed Saline Leptic Leptosol GLSZ.LL
	Saline Leptic Leptosol SZ.LL
	Gleyed Brunisolic Eutric Leptic Leptosol GLBRE.LL
	Gleyed Brunisolic Dystric Leptic Leptosol GLBRD.LL
	Brunisolic Eutric Leptic Leptosol BRE.LL
	Brunisolic Dystric Leptic Leptosol BRD.LL
	Gleyed Eutric Leptic Leptosol GLE.LL
	Gleyed Dystric Leptic Leptosol GLD.LL
	Orthic Eutric Leptic Leptosol OE.LL
	Orthic Dystric Leptic Leptosol OD.LL
Leptosol	Folic Leptosol FO.LP
	Fibric Leptosol FI.LP
	Mesic Leptosol ME.LP
	Humic Leptosol HU.LP
	Gleysolic Leptosol GLC.LP
	Gleyed Vertic Leptosol GLV.LP
	Vertic Leptosol V.LP
	Gleyed Podzolic Leptosol GLPZ.LP
	Podzolic Leptosol PZ.LP
	Gleyed Saline Leptosol GLSZ.LP
	Saline Leptosol SZ.LP
	Gleyed Chernozemic Leptosol GLCH.LP
	Chernozemic Leptosol CH.LP
	Gleyed Luvisolic Leptosol GLLU.LP
	Luvisolic Leptosol LU.LP
	Gleyed Brunisolic Eutric Leptosol GLBRE.LP
	Gleyed Brunisolic Dystric Leptosol GLBRD.LP
	Brunisolic Eutric Leptosol BRE.LP
	Brunisolic Dystric Leptosol BRD.LP
	Gleyed Eutric Leptosol GLE.LP
	Gleyed Dystric Leptosol GLD.LP
	Orthic Eutric Leptosol OE.LP
	Orthic Dystric Leptosol OD.LP

Key to soil orders

A. Soils that either

1. have organic (>17% organic C by weight) materials <60 cm overlying a leptic contact if dominantly fibric material or other organic materials <40 cm overlying a leptic contact
   or
2. have one or more mineral horizons above a leptic contact at a depth of <25 cm ………… **Leptosolic order**

Remainder of key remains unchanged with the exception of lettering changes as a result of inserting the Leptosolic order.

Key to soil great groups

A.	Leptosolic order
AA.	Leptosolic mineral or organic soils that have a leptic contact at a depth of <10 cm ……………………….. **Leptic Leptosol**
AB.	Other Leptosolic soils that:

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1. other Leptosolic mineral soils that have a leptic contact <25 cm depth
   or
2. other Leptosolic organic (>17% organic C by weight) materials <60 cm overlying a leptic contact if dominantly fibric material or other organic materials <40 cm overlying a leptic contact ……………. **Leptosol**

Remainder of key remains unchanged with the exception of lettering changes as a result of inserting the Leptosolic order.

Key to soil subgroups

AA.	**Leptic Leptosols**
AAA.	Leptic Leptosols with organic material composed mainly of folic material over a leptic contact …………………….. **Folic Leptic Leptosol**
AAB.	Other Leptic Leptosols with organic soil materials over a leptic contact ………… **Histic Leptic Leptosol**
AAC.	Other Leptic Leptosols with mineral material having a gleyed layer similar to soils of the Gleysolic order or prominent mottles within the control section…………. **Gleysolic Leptic Leptosol**
AAD.	Other Leptic Leptosols with saline (≥4 dS/m) materials, and faint or distinct mottles within the control section ……………. **Gleyed Saline Leptic Leptosol**
AAE.	Other Leptic Leptosols with saline (≥4 dS/m) materials ………………. **Saline Leptic Leptosol**
AAF.	Other Leptic Leptosols with a pH ≥ 5.5 that has faint or distinct mottles within the control section …………… **Gleyed Eutric Leptic Leptosol**
AAG.	Other Leptic Leptosols with a pH < 5.5 that has faint or distinct mottles within the control section ……….... **Gleyed Dystric Leptic Leptosol**
AAH.	Other Leptic Leptosols with a pH ≥ 5.5 ………… **Orthic Eutric Leptic Leptosol**
AAI.	Other Leptic Leptosols with a pH < 5.5 …………… **Orthic Dystric Leptic Leptosol**
AB.	**Leptosols**
ABA.	Leptosols composed dominantly (>50%) of upland organic (folic) materials generally of forest origin and rarely saturated with water <40 cm in thickness above a leptic contact ……..… **Folic Leptosol**
ABB.	Other Leptosols composed dominantly (>50%) of relatively undecomposed organic (fibric) materials <60 cm in thickness above a leptic contact ……………… **Fibric Leptosol**
ABC.	Other Leptosols composed dominantly (>50%) of organic materials in an intermediate stage of decomposition <40 cm in thickness above a leptic contact …………… **Mesic Leptosol**
ABD.	Other Leptosols composed dominantly (>50%) of organic materials in an advanced stage of decomposition <40 cm in thickness above a leptic contact …………… **Humic Leptosol**
ABE.	Other Leptosols that have a gleyed layer similar to soil of the Gleysolic order or prominent mottles within the control section ……………………. **Gleysolic Leptosol**
ABF.	Other Leptosols that have a vertic horizon and slickenside, and faint or distinct mottles within the control section …………. **Gleyed Vertic Leptosol**
ABG.	Other Leptosols that have a vertic horizon and slickenside ………. **Vertic Leptosol**
ABH.	Other Leptosols that have a Podzolic B, and faint or distinct mottles horizon within the control section ………… **Gleyed Podzolic Leptosol**
ABI.	Other Leptosols that have a Podzolic B horizon within the control section …………… **Podzolic Leptosol**
ABJ.	Other Leptosols that have a Solonetzic B horizon, and faint or distinct mottles within the control section ………. **Gleyed Solonetzic Leptosol**
ABK.	Other Leptosols that have a Solonetzic B horizon within the control section ………………. ….. **Solonetzic Leptosol**
ABL.	Other Leptosols that have a Chernozemic A horizon, and faint or distinct mottles within the control section ………….………… **Gleyed Chernozemic Leptosol**
ABM.	Other Leptosols that have a Chernozemic A horizon within the control section ……………….……………… **Chernozemic Leptosol**
ABN.	Other Leptosols that have a Bt horizon, and faint or distinct mottles within the control section …..…………………… **Gleyed Luvic Leptosol**
ABO.	Other Leptosols that have a Bt horizon within the control section..………………………… **Luvic Leptosol**
ABP.	Other Leptosols that have a Bm horizon ≥5 cm in thickness with a pH ≥5.5 and faint or distinct mottles within the control section……………… **Gleyed Brunisolic Eutric Leptosol**
ABQ.	Other Leptosols that have a Bm horizon ≥5 cm in thickness with a pH <5.5 and faint or distinct mottles within the control section …………… **Gleyed Brunisolic Dystric Leptosol**
ABR.	Other Leptosols that have a Bm horizon ≥5 cm in thickness with a pH ≥ 5.5 within the control section ……………. **Brunisolic Eutric Leptosol**
ABS.	Other Leptosols that have a Bm horizon ≥5 cm in thickness with a pH < 5.5 within the control section …………… **Brunisolic Dystric Leptosol**
ABT.	Other Leptosols with a pH ≥ 5.5 that has faint or distinct mottles within the control section ……………. **Gleyed Eutric Leptosol**
ABU.	Other Leptosols with a pH <5.5 that have faint or distinct mottles within the control section ……x2026;..…. **Gleyed Dystric Leptosol**
ABV.	Other Leptosols with a pH ≥ 5.5 ……. **Orthic Eutric Leptosol**
ABW.	Other Leptosols with a pH <5.5 ……. **Orthic Dystric Leptosol**

Remainder of key remains unchanged with the exception of lettering changes as a result of inserting the Leptosolic order.