Proposed classification for human modified soils in Canada: Anthroposolic order

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[1]Department of Renewable Resources, University of Alberta, Edmonton Alberta, Canada T6G 2H1 (e-mail: anne.naeth@ualberta.ca); [2]Paragon Soil and Environmental Consulting Inc., 14805 – 119 Avenue, Edmonton, Alberta, Canada T5L 2N9; [3]Agriculture and Agri-Food Canada, #206, 7000 – 113 Street, Edmonton, Alberta, Canada T6H 5T6; and [4]Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada, K.W. Neatby Building, 960 Carling Avenue, Ottawa, Ontario, Canada K1A 0C6.
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Naeth, M. A., Archibald, H. A., Nemirsky, C. L., Leskiw, L. A., Brierley, J. A., Bock, M. D., VandenBygaart, A. J. and Chanasyk, D. S. 2012. **Proposed classification for human modified soils in Canada: Anthroposolic order**. Can. J. Soil Sci. **92**: 7–18. With increasing anthropogenic activity, the areal extent of disturbed soils is becoming larger and disturbances more intense. Regulatory frameworks must incorporate reclamation criteria for these disturbed soils, requiring consistent descriptions and interpretations. Many human altered soils cannot be classified using the Canadian System of Soil Classification (CSSC), thus an Anthroposolic Order is proposed. Anthroposols are azonal soils, highly modified or constructed by human activity, with one or more natural horizons removed, removed and replaced, added to, or significantly modified. Defining features are severe disruption of soil forming factors and introduction of potentially new pedogenic trajectories. Disturbed layers are anthropic in origin and contain materials significantly modified physically and/or chemically by human activities. Three great groups are defined by presence of anthropogenic artefacts and organic carbon content. Six subgroups are based on a cover soil layer with higher organic carbon content than the profile below it, on depth of disturbance, on drainage characteristics and water regime at the site. Some new phases and modifiers, in addition to traditional ones used in the CSSC, are based on chemical and physical properties and origins of anthropogenic artefacts. The proposed classification has been successfully applied to reclaimed profiles and is ready for widespread field testing.

Key words: Anthropogenic soil, soil classification, human made soil, reconstructed soil, reclaimed soil

Naeth, M. A., Archibald, H. A., Nemirsky, C. L., Leskiw, L. A., Brierley, J. A., Bock, M. D., VandenBygaart, A. J. et Chanasyk, D. S. 2012. **Projet de classification des sols modifiés par l'homme au Canada : l'ordre des anthroposols**. Can. J. Soil Sci. **92**: 7–18. Les activités anthropiques allant croissant, les sols perturbés gagnent en étendue et les perturbations s'intensifient. La réglementation doit intégrer des critères de restauration pour les sols perturbés, ce qui nécessite de la cohérence dans les descriptions et les interprétations. Beaucoup de sols modifiés par l'homme ne peuvent être classés à l'aide du Système canadien de classification des sols (SCCS). C'est pourquoi les auteurs proposent l'ordre des anthroposols. Les anthroposols sont des sols azonaux, fortement modifiés ou créés artificiellement en raison des activités humaines, avec retrait, substitution, addition ou modification importante d'un ou de plusieurs horizons naturels. Les principales caractéristiques sont une sérieuse perturbation des facteurs de pédogenèse et l'apparition de nouvelles trajectoires pédogénétiques éventuelles. Les couches perturbées ont une origine anthropiques et renferment des matériaux significativement modifiés sur le plan physique, chimique ou les deux à la suite d'une activité humaine. Trois grands groupes sont définis d'après la présence d'artefacts anthropiques et la concentration en carbone organique. Six sous-groupes reposent sur une couche superficielle renfermant plus de carbone organique que le profil sous-jacent, sur la profondeur de la perturbation, sur les propriétés de drainage et sur le régime hydrique. Quelques nouveaux agents modificateurs et nouvelles phases s'ajoutent à ceux employés d'habitude dans le SCCS. Ils reposent sur les propriétés chimiques et physiques ainsi que sur l'origine des artefacts anthropiques. La classification proposée a été appliquée avec succès au profil de sols restaurés et est prête à faire l'objet de vastes essais sur le terrain.

Mots clés: Sol anthropique, classification des sols, sol créé par l'homme, sol reconstruit, sol restauré

BACKGROUND

Description

Anthroposols are azonal soils that have been highly modified or constructed by human activity. The name anthroposol is derived from the term "anthropogenic", which originates from the Greek word *ánthrōpos* (man) and the Greek suffix *genēs* (caused). Anthroposols are commonly constructed during land reclamation activities to meet regulatory requirements after anthropogenic

Abbreviations: **CSSC**, Canadian System of Soil Classification; **WRB**, World Reference Base for Soil Resources disturbances such as mining. They may arise with less deliberate soils-oriented construction, such as on land fill sites where the primary goals are burial of waste, minimized leaching and capping. These soils are common in renewable resources, industrial, commercial and urban development scenarios and in transportation, fuel and power corridors.

Anthroposolic soils have one or more of their natural horizons removed, removed and replaced, added to, or significantly modified by human activities. Manufactured materials, of domestic and/or industrial origin, may be added as a layer or as a component of a layer. These materials may have potential adverse characteristics and may include physical artefacts or visible chemical layers from a human manufacturing process (i.e., excluding natural gleying and redoximorphic processes).

Artefacts encompass materials made by humans, which may be of domestic and/or industrial origin. Artefacts may include general garbage, glass, plastic, steel, brick, iron, concrete, manufactured goods, rebar and asphalt. They are imbedded in a matrix and are not a solid layer of material.

Depth of the anthropogenic disturbance, modification or addition must be ≥ 10 cm above or below the surface of the soil. Activities that only remove surface soil or only add materials < 10 cm are not included in the Anthroposolic order. Typical tillage practices in agriculture, which are conventionally confined to the upper 30 cm, do not constitute changes sufficient for a soil to be called an Anthroposol. These changes are covered in other orders by the suffix p in the disturbed surface horizon.

Rationale

The general purpose of any soil classification system is to organize soils so they may be communicated and recalled systematically (Soil Classification Working Group 1998). Anthroposolic soils do not fit into any order in the current Canadian System of Soil Classification (CSSC). To date they have been inadequately described and classified using criteria and terms associated with the present orders in CSSC.

The current Canadian System of Soil Classification uses the p suffix to designate an A or O horizon that has been "disturbed by man's activities such as cultivation, logging and habitation" (Soil Classification Working Group 1998). Agriculturally tilled soils may be disturbed to depths > 10 cm, a prerequisite of an Anthroposol. However, since this disturbance generally does not significantly modify the soil profile, such agricultural soils are classified as being a product of their original soil-forming factors (climate, organisms, relief, parent material, time). A defining feature of the Anthroposolic order is severe human disruption of these soil-forming factors and introduction of potentially new pedogenic trajectories. These soils have not yet reached equilibrium through their physical expression in the current environment.

Anthroposols can occur on agricultural landscapes if the disturbance goes beyond typical tillage that can be accounted for with the p suffix in the CSSC. For example, Anthroposols may occur when there is a significant amount of levelling that alters natural soil profiles through excavation and burial, such as during preparation for flood irrigation. When a pipeline or well site is constructed in an agricultural field, there may be admixing, leading to classification of the disturbed soil as an Anthroposol.

Anthroposolic soils are commonly formed or developed with anthropogenic materials such as peat mineral mixes, mine spoil and phosphogypsum. Composition and arrangement of the layers within an Anthroposolic soil profile are the result of human activity. Thus, the dominant soil-forming process is anthropogenic. These issues preclude these soils from classification in the existing CSSC. The first problem is identification of the order for the modified or reconstructed soil, since the existing CSSC is pertinent only for soils that have been forming under natural conditions. The second problem is determining the most likely trajectory soil development would take. Not only would it be problematic trying to fit them into existing orders, but the equilibrium that they may settle at would only be a best guess.

To be classified as an Anthroposol, the soil disturbance or modification needs to be evident. Diagnostic horizons of other CSSC soil orders may not exist, the Anthroposolic disturbed layer may not exist (e.g., scalped horizons, which are not replaced), materials may be foreign (e.g., phosphogypsum amendment layer), and/or layers may not resemble natural soil horizons (e.g., severely admixed horizons). If the soil was minimally disturbed (the soil retains its original pedomorphic properties) and could not be distinguished from a natural soil order, it could be classified into its appropriate natural soil order. If over time an anthropogenically modified soil reaches an equilibrium that is diagnostic of a natural soil order (a goal of many reclamation programs), then the soil could be classified as such at that time.

With increasing anthropogenic activity related to resource, industrial and urban development, the areal extent of disturbed soils has increased dramatically and continues to increase. The areas of disturbance are becoming larger and the disturbances are becoming more intense. Management and land use planning have escalated as disturbed soils are required to meet growing population demands. Regulatory frameworks must incorporate soil reclamation criteria and goals. To apply these regulatory criteria, consistent descriptions and interpretations of these human altered soils are necessary. Thus, these soils can no longer remain unclassified and the Anthroposolic order is required.

Approaches to Development

The derivation of a new order within the CSSC began with an examination of definitions of human-altered soils, and an assessment of whether current classification systems and proposed or accepted classification systems of other nations could readily accommodate these soils. No existing system was readily adaptable to anthropogenic soils of Canada, although a number of them influenced development of the proposed Anthroposol order in the CSSC.

International bases for classification of anthropogenic soils include degree of alteration, presence of artefacts and soil modifying processes. The first known reference to anthropogenic soils occurred in 1847 when Ferdinand Senft used the term "anthropogenic urban soils" to describe soils in urban, industrial and mining environments with little fertility due to deposited toxic wastes (Lehmann and Stahr 2007).

Numerous attempts to use current soil taxonomic systems for anthropogenic soils have been documented and usually led to proposals for changes to current systems. Even when human-modified soils seemed to fit into current soil classification systems, qualifiers were raised and degree of fit was low.

Difficulties Using Classification Systems for Anthropogenic Soils

Classification of mine soils using the United States Department of Agriculture's taxonomic system, Soil Taxonomy (USDA system) (Soil Survey Staff 1975, 1999; International Union of Soil Sciences 2007), led to many of the earliest classification difficulties and recommendations for different classifications. Ciolkosz et al. (1985) found some Pennsylvania mine soils could be classified, but were concerned with B2 cambric horizons, which include soil structure and evidence of alteration via a stronger chroma or redder hue than the underlying horizon. Of 24 soils examined, they found only 17 met the first criterion, and of those, only five met the second criterion. Buondonno et al. (1998) found soils at a dismantled iron and steel plant in Italy were so morphologically and chemically different from natural soils they could not be classified and proposed the Foundric subgroup of the Xerorthents.

Meuser and Blume (2001) classified some soils affected by the coal and steel industry in Germany as Plaggic and Hortic Anthrosols in the USDA system, but could not classify soils of anthropogeomorphic material. Although these soils could be somewhat classified by the Food and Agriculture Organization of the United Nations, World Reference Base and German Soil Science Society Classification systems, they recommended these be improved. Using a USDA soil series, Haering et al. (2005) described particle class, texture and pH of Virginia mine soils, but unique combinations of drainage class, rock type, colour and parent materials were far outside the system's range. They initially used spot symbols or map unit inclusions, but proposed a new series when areal extent of the soils increased to several hectares.

Sencindiver and Ammons (2000) discussed continuing classification efforts for anthropogenic soils in the USA. Although series criteria have been formally established, the general consensus among pedologists who have studied mine soils is that current classes do not recognize key features of mine soils and do not convey important information about their management (Anderson 1977; Sencindiver 1977; Schafer 1979; Short et al. 1986; Indorante et al. 1992; Strain and Evans 1994). Ammons and Sencindiver (1990) concluded that mine soil properties were unique, did not always fit established categories of soil taxonomy and proposed a new classification to the family level in the USDA system. Sencindiver (1977) and colleagues (Sencindiver et al. 1978; Thurman et al. 1985; Thurman and Sencindiver 1986; Ammons and Sencindiver 1990) have proposed a new suborder, Spolents, for mine soils they studied primarily in West Virginia, but include other eastern and mid-western states. They proposed nine subgroups of Udispolents.

Fanning and Fanning (1989) proposed revisions to the definition of Typic Udorthents. They also proposed new subgroups for scalped land surfaces (Scalpic): locally derived fill materials moved by earth-moving equipment and have few or no manufactured inorganic artifacts (Spolic), miscellaneous urban fill materials that contain inorganic manufactured artifacts (Urbic) and organic wastes of human activity (Spolic Garbic or Urbic Garbic). Strain and Evans (1994) used the diagnostic criteria established by Fanning and Fanning (1989) for spolic, urbic or garbic materials or scalped land surfaces for sand and gravel pit soils and proposed Anthrosols as a new order in Soil Taxonomy. The Anthrosols concept was originally proposed by Kosse (1998), but was expanded by Strain and Evans (1994). Suborders of Garbans, Urbans, Spolans and Scalpans were suggested. Kosse (2001) also proposed distinguishing between anthropogenesis and anthropogeomorphology and addition of Noosols to the World Reference Base for Soil Resources (WRB).

In Germany, Zikeli at al. (2005) tried to classify lignite ash substrate and natural volcanic soil using the WRB. Their young Anthrosols were dominated by lithogenic (parent material) properties, not properties resulting from pedogenic processes. They recommended the WRB include technogenic materials in anthropogeomorphic soil materials, and introduced a subunit of technogenic anthrosols. They suggested recognition of other characteristics and properties at the third and fourth levels according to the group of related natural soils, and included information about important soil constituents such as coal and gypsum, texture, type of deposition and type of material.

Bryant and Galbraith (2002) suggested not including all anthropogenic soil processes in current classification systems since they do not leave morphological evidence.

They found evidence of anthropogenic activity was often expressed in lack of horizonation, altered chemistry or differences in landform relative to surrounding parent materials. Lehmann (2006) presented a similar argument for urban soils strongly influenced by human activities such as construction, transportation, manufacturing processes, industry, mining and rural housing. He indicated these soils were young and may show weak signs of soil genesis, but were more often identified by easily differentiable substrate linked features. Since early soil genesis will likely be influenced by these substrate features, he thought taxonomic differentiation should be based on substrate linked properties. Hartman et al. (2004) recommended combining useable parts from various proposed disturbed soil taxonomy systems and discussed the implications of a new system after no single taxonomic system seemed to be sufficient to describe two anthropogenic soil profiles.

Current Classification Systems for Anthropogenic Soils

Since 1995, France has included Anthroposols as a major group at the highest level (Baize and Girard 1998; Lehmann and Stahr 2007). Three subclasses encompass soils profoundly changed by agriculture (Anthroposols transformés), for agricultural use (Anthroposols reconstitutés), and for anthropogenic urban soils (Anthroposols artificiels) (Lehmann and Stahr 2007). Anthroposols transformés developed in situ, consist of natural soil material and are strongly affected by human impacts (primarily agriculture) so they do not classify as natural soils. Anthroposols reconstitutés derive from transported soil material while Anthroposols artificiels are from materials like overburden and industrial sludges.

The German soil classification system focuses on anthropogenic urban soils at the soil class level and mainly avoids soil classification terms characterized by substrate properties (Finnern 1994; Sponagel 2005; Lehmann and Stahr 2007). An example is Pararendzina from excavated soil material with rubble, which describes a typical urban soil with lime throughout the profile (Lehmann and Stahr 2007). In Germany, soils of anthropogenic deposits (natural sediments, natural soil substrates, technogenic substrates) result from anthropogenic lithogenesis (Blume and Giani 2005). These anthropogenic deposits are not classified as soils, but as human-made parent substrate. They are further classified in the same way as soils of natural substrates. For example, the soil class Reduktosole comprises the soil type Reduktosol, a soil showing signs of reduction by methane. Such soils develop mainly in household waste or in other materials with a high content of young and less decomposed organic matter (Lehmann and Stahr 2007).

The Morphogenetic Soil Classification System of Slovakia includes an anthropogenic soils group with Kultizems (cultivated soils) and Anthrozems (human made soils) (Collective 2000; Sobocka 2000; Sobocka et al. 2000). The differentiating criterion for Anthrozems is >35 cm of transported (removed) materials called anthropogenic materials. There are natural, natural-technogenic and technogenic subgroups of Anthrozems. The diagnostic Ad horizon is characterized by thickness >1 cm, organic carbon content $>0.3\%$ and/or presence of artefacts (brick, pottery fragments, glass, plastic, iron, slag, coal). The system includes the contaminated Ax horizon for soils affected by exceeded concentrations of toxic or emission elements or compounds.

The Russian system classifies anthropogenic soils according to degree of naturalness or alteration due to anthropogenic activity (Stolbovoi 2002). It has three groups: managed, semi-natural and natural. Managed soils have soil-forming processes guided by humans to meet land use objectives, resulting in non-natural soil layers, such as a ploughed layer. Semi-natural soils have characteristics of a naturally formed horizon sequence, but reflect some human influences, such as a chalk layer in a topsoil horizon. Natural soils developed under natural soil-forming conditions and show no evidence of anthropogenic alteration. This is consistent with the three soil classes of naturally developed, anthropogenically modified and technogenically disturbed soils used to classify Azerbaijani transformed soils (Babaev et al. 2005). A more detailed approach from an urban soil classification view has been to divide urban soils into open, unsealed areas (Urbanozems) and areas sealed by road surfaces (Ekranozems) (Strogonova and Prokofieva 2002). Within Urbanzems are natural, human-transformed (surface or deep) and human-made soils. Ekranozems can occur on or over any of the Urbanozem classes.

The presence of artefacts in the soil and/or an indication that the soil has been modified by human activity are key criteria for identification of the great group Anthroposols in the Australian system (Commonwealth Scientific and Research Organization 2007). Anthroposols result from human activities leading to a profound modification of the soil, but do not include soils modified by agricultural practices or those artificially drained or flooded. The Australian system has Cumulic, Hortic, Garbic, Urbic, Dredgic, Spolic and Scalpic suborders based on composition of the material and the process through which the material was deposited. These two criteria are also the basis for classification of anthropogenic soils in New Zealand, although classification occurs at the order rather than the suborder level (Landcare Research 2011).

In the United Kingdom, classification of artificial (human-made) ground and natural superficial deposits is applied to geological maps and datasets for extraction of thematic material comprising identified classes of superficial deposits (McMillan and Powell 1999; Rosenbaum et al. 2003). Artificial ground is divided into five classes: made, worked, infilled, landscaped and disturbed. Made ground is deposited by humans on the former, natural ground surface. Worked ground has been cut away by humans. Infilled ground has been cut away and then had artificial ground (fill) deposited. Landscaped ground has been extensively remodelled, but it is impractical or impossible to separately delineate areas of made ground and worked ground. Disturbed ground occurs where surface and near surface mineral workings are ill-defined excavations, where areas of human induced subsidence caused by the workings and spoil are completely associated with each other. Soil groups and soil undergroups are further defined (Hollis 1991).

The WRB classification system distinguishes degree of soil alteration and presence of artefacts to define Anthrosol and Technosol groups (International Union of Soil Sciences 2007). Anthrosols have been subjected to intensive agricultural use for some time, while Technosols contain artefacts or technic hard rock (a consolidated product of an industrial process), and can often be toxic. Technosols include soils from wastes such as landfills or mine spoils, pavements and underlying materials, soils with geomembranes and constructed soils in human-made materials (Nachtergaele 2005; International Union of Soil Sciences 2007). In an early review of Technosols, the tradition of splitting organic and mineral soils at the highest level while still recognizing technical origin of these soils was emphasized (Rossiter 2007). Technosols are keyed out as the third Reference Soil Group, after Histosols (soils dominated by organic matter) and Anthrosols (cultivated soils profoundly influenced by long-term human activity).

Some Suggestions for Refining Classification of Anthropogenic Soils

As new classification systems are applied, the variability in human-influenced soils becomes apparent. What to take into consideration when revising current classification systems or developing new ones is highly debated among soil taxonomists (Ahrens and Engel 1999; Kimble et al. 1999; Burghardt and Dornauf 2000; Sencindiver and Ammons 2000; Wilding and Ahrens 2002; Tejedor et al. 2009).

Burghardt (1994) suggested that when classifying soils in urban and industrial areas, the role of soils in urban ecosystems, effect of change of urban landscape, influence of uses on soils, specific demands in urban areas and their fulfilment by soils, and required and available potentials of soils must be considered. Therefore characteristics, genesis and degree of contamination of soils should be known. Blume and Sukopp (1976) differentiated euhemerob (sites such as arable land and lawn), polyhemerob (deposits of organic wastes, spolic material or urban rubble) and metahemerob (contain toxic materials or are sealed) soils in urban areas. Reinirkens (1988) differentiated soils of buildings, traffic and recreation sites.

Yaalon and Yaron (1966) suggested a systematic framework for human-made soil changes and named human-induced processes and changes in the soil profile metapedogenesis. They suggested a metapedogenetic system concept provides a suitable framework so all relevant factors can be marshalled and the system can serve as a basis for prediction of expected soil changes. They suggested behaviour of a metapedogenetic system (the resulting soil) depends on intensity of the particular topographical, hydrological, chemical or cultivation factor and on capacity of adjustment of the initial soil.

Diagnostic horizons are not always clearly defined and are certainly not universal. For example, a geomiscic horizon of the WRB Anthrosols describes a horizon that develops when a layer, at least 30 cm thick, of different kinds of earthy materials, is added to the soil using earth moving equipment (Dazzi et al. 2009). The urbic diagnostic horizon being considered in the Russian system is defined as a surface organo-mineral horizon resulting from mixing, filling, burial or pollution (Stroganova and Prokofieva 2002).

The International Committee on Anthropogenic Soils (ICOMANTH) has been working on a system to classify anthropogenic soils (ICOMANTH 2009). They appear to be focusing on soils derived from human activities that have major problems; soils that have been so transformed by anthropedogenic processes that the original soil is no longer recognizable or survives only as a buried soil. They are comparing existing classification systems for anthropogenic soils, but have not yet developed a definitive international approach or terms. In light of the variable soil classification systems currently in existence around the world, it is unlikely that a universal classification for anthropogenic soils will be forthcoming, as each must meld with the non-anthropogenic soil classification system of its jurisdiction. Our proposed system may eventually be used as another section in this collection.

Existing international classification systems cannot be effectively used to address the reclamation and other disturbed soil scenarios common in Canada. These classifications combine material composition and activities. To describe anthroposols within Canadian settings we defined great groups on the basis of composition of the material and recognized activities at lower levels within the classification system. Thus, we propose an anthropogenic soils classification for Canada that uses the systematic framework of the CSSC, and aims to facilitate the description and management of human altered soils by soil scientists, soil managers and industry personnel. Attempts were made to use terms and suffixes that are consistent with their meaning and connotation in the CSSC.

THE ANTHROPOSOL ORDER

Anthroposols

Anthroposols are azonal soils that have been highly modified or constructed by human activity. The soil disturbance or modification is visibly evident, occurring

$\geq$10 cm above or below the soil surface. One or more natural horizons may be removed, removed and replaced, added to, or significantly modified by human activities; manufactured materials, of domestic and/or industrial origin, may be added as a layer or a component of a layer. Artefacts may be imbedded in a matrix. Natural soil-forming factors have been severely disrupted anthropogenically and potentially new pedogenic trajectories have thus been introduced.

Disturbed Layers

Anthroposols have disturbed layers, designated D layers. These layers are anthropic in origin and contain materials that have been significantly modified physically and/or chemically by human activities. The soil can be modified in situ, physically translocated, or added on top of existing natural soil or subsoil materials. In situ modification can include physical manipulation of structure or addition and incorporation of natural or human made materials. Multiple D layers may be described in one soil profile, each one recognized on the basis of different chemical or physical properties.

Anthroposolic D layers vary, as described in the following examples. Anthroposols in the Alberta oil sands are built with multiple D layers including peat-mineral mixes on top of suitable overburden material on top of unsuitable overburden material. Anthroposolic D layers developed after coal mining or on pipelines were excavated, stored, then replaced in the relative sequence of the undisturbed soils. In these cases soil structure has been disrupted and materials, particularly topsoil, may be shallower than in the original soil. Anthroposolic D layers may be of amendment material such as peat or phosphogypsum, alone or mixed with mineral soil. The D layer may comprise severely admixed horizons, and no longer recognizable as the original undisturbed soil horizons. The D layer may be a removed or scalped layer that has not been replaced; thus, its absence makes the soil an Anthroposol.

Suffixes

Suffixes used in the current CSSC can also be used with the D layer. Current suffixes describe natural processes of soil genesis and, although these natural processes did not directly create anthropogenic soils, the disturbed material can still reflect some of its original pedogenesis. The D layer designation represents human influence and allows the use of the natural suffixes. Roman numerals are used in anthropogenic soil descriptions to indicate textural discontinuities (a change of more than two textural classes) between sub-surface layers and anthropogenic materials with an obvious size difference (e.g., garbage, admixed clods).

New suffixes are required to articulate features of anthropogenic soils that cannot be expressed with current suffixes. A w suffix is used for artefacts (w for waste); a q suffix for hydrocarbons (contained in the quintessential reclamation profile) and an o suffix for organic materials with >17% organic carbon in the Carbic great group.

Great Groups

Great Group Rationale

The great group level in the CSSC, by definition, is "based on properties that reflect differences in the strengths of dominant processes, or a major contribution of a process in addition to the dominant one" (Soil Classification Working Group 1998). In the Anthroposol order, the dominant process is human influence on the composition, arrangement and/or replacement of layers following an intensive human disturbance. Several great group options were considered, including the nature and intensity of the disturbance (such as an intensive mining operation versus simple topsoil stripping), the remedial procedure used (such as a reclamation prescription) and the physical and/or chemical composition of the modified soil (such as the use of human made amendments). The final decision was to use the composition of the materials of the layers of the soil to define great groups. Justification for this decision was based upon the common scenario where pedologists are dropped onto a landscape, without prior knowledge of the activities that took place, and are required to classify the soil beneath their feet. By basing the great group level on material composition of the layers, the pedologist does not need a detailed history of the site, which is often not available. The classification is dynamic and will change as the newly formed soil changes with time. The classification will provide insight into potential future uses of the site, management options and challenges that may lie ahead.

Great groups are based on material composition of the layers of the control section. This control section is defined as a depth of 120 cm, which is consistent with the current CSSC. The diagnostic disturbed D layer of an Anthroposol great group is the one encompassing the greatest cumulative proportion of the disturbed profile, to a maximum of 120 cm. The cumulative proportion refers to layers of similar material composition, regardless of the position in the profile, added together to determine the proportion of the profile they occupy.

When layers of different material composition are found in equal proportions, the uppermost layer will be used for classification. When a modified profile is <120 cm, a natural soil horizon will exist without modification within the 120 cm control section. The great group description will then apply to the material composition layer that occupies at least 50% of the depth of the modified profile or the greatest cumulative proportion thereof. For example, if the depth of modification is 40 cm, the layer upon which the great group level of classification applies would be $\geq$20 cm in thickness or the greatest cumulative proportion.

Great Group Descriptions

The three great groups proposed are Technic, Spolic and Carbic. They are defined by the presence or absence of anthropogenic artefacts and organic carbon content. Terms are mainly developed from Latin origins. A summary of great groups is provided in Table 1 and a key is presented with the steps for identification.

The diagnostic feature of the Technic great group is the presence of a D layer containing $\geq$10% (by cumulative volume) physical anthropogenic artefacts within the greatest cumulative proportion of the soil profile. This material justifies the Technic great group name, regardless of the amount of organic carbon. If less than the requisite volume of physical artefacts is present, the next two great groups should be considered. Technic is from the word technical denoting human made or artificial; its origin is the Latin *artificialis* or *technicus*.

The diagnostic feature of the Spolic great group is the presence of a sufficiently deep D layer to meet the depth criterion, and containing <17% organic carbon. This great group may or may not have physical artefacts present, but, if present, they must constitute <10% by cumulative volume. This great group may include visible chemical layers such as buried sumps or materials deposited as a slurry from human processes such as mining (e.g., tailings ponds). It may include removed, or removed and replaced, soil horizons or materials deposited in a layer from human activities such as dredging. For example, a soil profile with a few shards of glass or a thin layer of an unnatural amendment (such as drilling mud) would be included within this great group. Spolic is from the Latin *spolio* (to strip).

The diagnostic feature of the Carbic great group is the presence of a sufficiently deep D layer to meet the depth criterion, and containing $\geq$17% organic carbon. This great group may or may not have physical artefacts present, but if present, they must constitute <10% by cumulative volume. The organic material may be of natural or manufactured origin. This great group may include manufactured organic wastes, composts and mulches added as amendments. This great group will usually describe reclamation prescriptions requiring peat or in some cases, peat-mineral mixes that are, for example, currently being used in the oil sands of Alberta. Carbic is used to imply organic matter (organic carbon) of a variety of origins. Carbic is from the Latin *carbo* (carbon).

Table 1. Great groups of the Anthroposolic order

	Technic Anthroposol	Spolic Anthroposol	Carbic Anthroposol
Anthropogenic materials	$\geq$10% by volume	<10% by volume	<10% by volume
Organic carbon	Any	<17%	$\geq$17%

Key to the great groups of the Anthroposolic order.

A. Soil material contains 10% or greater artefacts throughout the dominant material (layers) of the profile ....TECHNIC.

B. Soil does not have requisite amount of artefacts.

1. Soil material contains more than 17% organic carbon in the dominant material (layers) of the profile.........CARBIC.

2. Soil material does not meet any of the previous criteria......... SPOLIC.

Subgroups

Subgroup Rationale

Subgroups are differentiated on "the kind and arrangement of horizons that indicate conformity to the central concept of the great group, intergrading towards soils of another order, or additional special features within the control section" (Soil Classification Working Group 1998). Subgroups in the Anthroposolic order are based on the presence or absence of a 10-cm topsoil or cover soil layer with a higher organic carbon content than the profile below it, on depth of disturbance, on drainage characteristics and water regime present at the site.

Subgroup Descriptions

Proposed subgroups are Egeo, Albo, Fusco, Carbo, Techno, Spolo, Terro, Aquo and Cryo. Each of these terms is developed from Latin or Greek origins, mainly reflecting the amount of organic material, water regime, natural material composition or permafrost. Egeo, Albo and Fusco are only applied to surface layers, while the remaining groups can be used regardless of the layer's location within the profile. When listing the subgroups, Terro and Aquo subgroups are written first.

The Egeo subgroup denotes layers that lack depth. This subgroup refers to soils with a distinguishable surface layer that is <10 cm thick, regardless of its organic carbon content, over another layer(s) of disturbed material. The Egeo subgroup is named from the Latin *egeo* meaning to lack or to be without.

The Albo subgroup denotes soils with a surface layer that is $\geq$10 cm thick and has <2% organic carbon. This low amount of organic carbon would normally account for its light colour. The Albo subgroup is named from the Latin *albus*, meaning white.

The Fusco subgroup denotes soils with a surface layer that is $\geq$10 cm thick and has 2 to 17% organic carbon. This higher amount of organic carbon would normally account for its darker colour relative to the Albo subgroup. The Fusco subgroup is named from the Latin *fusc*, meaning to make dark.

The Carbo subgroup denotes soils with a layer that is $\geq$10 cm thick and has >17% organic carbon, but is not sufficiently deep to be classified in the Carbic great group. Carbo, the same as for the Carbic great group, reflects organic carbon from a variety of sources. The Carbo subgroup is named from the Latin *carbo*, meaning carbon.

The Techno subgroup denotes soils with a technic layer present, but not in a sufficient cumulative thickness for the soil to be classified in the Technic great group. The minimum thickness for inclusion in the

Techno subgroup is 10 cm. As in the Technic great group, Techno is from the Latin *artificialis* and *technicus*, denoting technical or artificial.

The Spolo subgroup denotes soils with a spolic layer present, but not in a sufficient cumulative thickness for the soil to be classified in the Spolic great group. The minimum thickness for inclusion in the Spolo subgroup is 10 cm. As in the Spolic great group, the term spolic is from the Latin *spolio* (to strip).

The Terro subgroup denotes soils with shallow disturbances. The depth of disturbance is less than the depth of the control section as indicated by the presence of original parent material within the control section. At least 10 cm of original parent material must be present for inclusion in the Terro subgroup. The word *terro* in Latin connotes earth, a sense of naturalness.

The Aquo subgroup denotes soils with imperfect, poor or very poor drainage. Mottles and gleying are not necessarily diagnostic in the anthropogenically disturbed environment as they may be legacies of the undisturbed soil. To be classified in the Aquo subgroup, there must be evidence of prolonged wetness in the soil profile, such as a water table or saturated soil in a layer, hydrophilic vegetation and particle size discontinuities which may result in perched water tables. Aquo is from the Latin *aqua*, meaning water.

The Cryo subgroup denotes soils with the presence of permafrost. Cryo is from the Greek, *kruos*, meaning icy cold.

PHASES

Phases Rationale

Phases are used in the Anthroposolic order to denote specific characteristics of anthropogenic soils, as with the natural soil orders in the CSSC. Several new phases in addition to the traditional ones used in the CSSC are used with the Anthroposolic order.

Phases Description

Calcareous, dystric, hydrocarbic, contaminic, saltic, clayic, compactic, sablic, thick, garbic and slurric phases are proposed to describe chemical properties, physical properties or the presence of anthropogenic artefacts of the soil profile. In soil names, chemical phases are listed before physical phases. The depth at which the phases apply varies with the attributes. Pedologists and land managers would need to know whether garbic, hydrocarbic, saltic and sablic attributes were present in the control section. Thus, their presence will be noted in the 120 cm control section. Root growth is critical to plant growth and development, so calcareous, dystric, compactic and clayic attributes, which mainly affect root growth, will be determined within a 50 cm depth since that is where the majority of roots will occur in most profiles. Slurric attributes will be determined within a 50 cm depth since it is most likely to occur there.

To avoid subjectiveness in the field with a presence or absence focus for phases, a 10 cm layer of cumulative material must be identified for a phase to be applied. Cumulative means the material may not all be in a 10 cm layer, but if all their thicknesses were added together they would be $\geq$10 cm thick.

Calcareous, dystric, hydrocarbic, contaminic and saltic describe soil layers with specific chemical properties.

- Calcareous denotes mineral soil that has a layer ($\geq$10 cm cumulative material) containing alkaline earth carbonates occurring in the uppermost 50 cm. A calcareous layer is identified by the presence of visible effervescence with 10% hydrochloric acid.
- Dystric denotes mineral soil that has a layer ($\geq$10 cm cumulative material) with pH $<$5.5 in a saturated paste extract (0.01 M $CaCl_2$ solution) or pH 6.0 in water occurring in the uppermost 50 cm.
- Hydrocarbic denotes any mineral soil with a layer ($\geq$10 cm cumulative material) containing petroleum hydrocarbons, defined by the Canadian Council of Ministers for the Environment (CCME) (2001) as mixtures of organic compounds from geological substances such as coal, oil and bitumen, and excluding benzene, toluene, ethylbenzene and xylenes (BTEX) occurring in the uppermost 120 cm. Minimum limits for hydrocarbon fractions 1 through 4 are 30, 150, 300 and 2800 mg kg^{-1}, respectively. These are the Tier 1 levels (in surface soils) for coarse textured agricultural soils in the CCME Canada-Wide Standards for petroleum hydrocarbons in soil, and are the most conservative of all categories presented.
- Contaminic denotes any mineral soil with a layer ($\geq$10 cm cumulative material) containing contaminants such as industrial chemicals, pesticides, wood preservatives and radionuclides. Although most of these substances are regulated by criteria to limit their concentrations in reclaimed soils, they may occur below criteria concentrations. It is important to include the presence of contaminants as criteria levels may change in the future.
- Saltic denotes mineral soil that has a layer ($\geq$10 cm cumulative material) with an electrical conductivity $>$4 dS m^{-1} and/or a sodium adsorption ratio $>$13, indicative of salinity and sodicity occurring in the uppermost 120 cm.

  Clayic, compactic, sablic and thick describe soil layers with specific physical properties.
- Clayic denotes soil that has a fine textured ($>$40% clay) layer ($\geq$10 cm cumulative material). Forty percent clay represents a major change in class in textural class occurring in the uppermost 50 cm.
- Compactic denotes mineral soil showing evidence of root restriction in a layer ($\geq$10 cm cumulative material) as indicated by compacted structure and very to extremely firm consistence occurring in the uppermost 50 cm.

- Sablic denotes mineral soil with a layer (≥10 cm cumulative material) with textures ranging from sand to loamy sand. It is loose or very friable, structureless or weakly structured, rapidly permeable, uncompacted material occurring in the uppermost 120 cm.
- Thick refers to soil with a surface layer >40 cm deep.

  The final two phases are garbic and slurric. They are used to denote origin of the artefacts and slurries found in the soil profile.
- Garbic denotes refuse from human activity either high in organic matter or primarily of manufactured origin such as glass, plastic or concrete occurring in a layer (≥10 cm cumulative material) in the uppermost 120 cm. Middens may be included in this category.
- Slurric denotes materials that are deposited as a slurry layer (≥10 cm cumulative material) occurring in the uppermost 50 cm. This phase is only applied in situations where the use of a slurry process is still discernible (e.g., fresh drilling mud). Slurric materials must exhibit a high degree of human modification. Dredged materials that have been moved from an aquatic environment to dry land without physical or chemical modification may be included as this movement constitutes a high degree of human modification.

EXAMPLE PROFILES AND CLASSIFICATIONS

Urban Examples

Fusco Spolo Technic Anthroposol – calcareous, garbic phase

Setting: landfill site capped with spolic material.

Horizon	Depth (cm)	Texture	Colour	Comments
Dh	0–20	Loam	10YR 3/2 (d)	5% organic carbon
Dm1	20–30	Clay loam	10YR 5/4 (d)	5% coarse fragments
Dm2	30–40	Clay loam	7.5YR 6/4 (d)	15% coarse fragments
Dk	40–55	Clay loam	2.5YR 5/2 (d)	15% coarse fragments, moderately calcareous
IIDw	55–120+	Loam	10YR 2/1(d)	Organic rich loam matrix, 20–30%; human artefacts of plastics, metal scraps, pieces of lumber

Rationale

- Technic because technic material (>10% human artefacts) is the dominant layer in the control section (120 cm of the surface).
- Spolo because spolic material (<10% artefacts and <17% organic carbon) is >10 cm thick in the control section.
- Fusco because the surface layer is >10 cm thick and organic carbon content is between 2 and 17%.
- Calcareous because carbonates are present in a 10 cm layer within 50 cm of the soil surface.
- Garbic because human refuse is present in a 10 cm layer within 120 cm of the soil surface.

Terro Albo Spolic Anthroposol – calcareous, compactic phase

Setting: road cut on an Orthic Black Chernozem.

Horizon	Depth (cm)	Texture	Colour	Comments
Dm	0–10	Clay loam	7.5YR 6/4 (d)	Compacted (very firm consistence), surface has caterpillar tractor treads, 0.5% organic carbon
Bmb	10–40	Sandy clay loam	7.5YR 6/4 (d)	10% coarse fragments, 0.5% organic carbon
Ckb	40–120	Sandy clay loam	10YR 5/3 (d)	10% coarse fragments, moderately calcareous

Rationale

- Spolic because the dominant layer has <10% artefacts and contains <17% organic carbon.
- Albo because the surface layer is >10 cm and has <2% organic carbon.
- Terro because depth of disturbance (10 cm) is <depth of the control section.
- Calcareous because carbonates are present in >10 cm layer within 50 cm of the soil surface.
- Compactic because there is evidence of compaction in a 10 cm layer within 50 cm of the soil surface.

Oil and Gas Examples

Terro Albo Spolic Anthroposol – slurric phase

Setting: drilling mud spread on the surface of an Orthic Black Chernozem.

Horizon	Depth (cm)	Texture	Colour	Comments
Dm	0–10	Loam	10YR 5/1 (d)	Drilling mud, 0.6% organic carbon
Ahb	10–30	Clay loam	10YR 2/2 (d)	4% organic carbon
Bmb	30–60	Clay loam	7.5YR 6/4 (d)	5% coarse fragments
Ckb	60–85	Clay loam	10YR 5/3 (d)	10% coarse fragments, moderately calcareous

Rationale

- Spolic because dominant material has <10% artefacts and contains <17% organic carbon.
- Albo because the surface layer (10 cm D horizon) contains <2% organic carbon.
- Terro because the original soil is present in the control section.
- Slurric because a 10 cm slurry layer occurs within 50 cm of the soil surface.

Terro Egeo Spolic Anthroposol
Setting: well site pad located on a fen, west central Alberta.

Horizon	Depth (cm)	Texture	Colour	Comments
Dh	0–5	Loam	10YR 4/2 (d)	Organic carbon 3%
Dm	5–15	Clay	10YR 6/2 (d)	
IID	15–45	Boulders		Rip rap with 75% boulders, little matrix material
Omb	45–120			Original surface layer of organic fen (mesic)

Rationale

- Spolic because dominant disturbed material in the control section (120 cm of the surface) is spolic (<10% artefacts and <17% organic carbon).
- Terro because the original soil material (organic fen) occurs within 120 cm of the surface.
- Egeo because the surface Dh layer is <10 cm thick.

Fusco Spolic Anthroposol – calcareous, saltic phase
Setting: reclaimed pipeline (3 lift), in southern Alberta.

Horizon	Depth (cm)	Texture	Colour	Comments
Dh	0–15	Loam	10YR 3/3 (m)	Organic carbon 3%
Dm	15–30	Clay loam	10YR 4/3 (m)	
Dks	30–120	Clay loam	2.5Y 5/3 (m)	Moderately calcareous, EC 6 dS m^{-1}

Rationale

- Spolic because the dominant disturbed material in the control section (120 cm of the surface) is spolic (<10% artefacts and <17% organic carbon).
- Fusco because the surface layer is >10 cm thick and contains >2 and <17% organic carbon.
- Calcareous because carbonates are present in >10 cm layer within 50 cm of the surface.
- Saltic because free salts (electrical conductivity >4 dS m^{-1}) are present in a >10 cm layer within 120 cm of the surface.

Oil Sands Examples

Carbo Spolic Anthroposol – calcareous, sablic phase
Setting: reclaimed area in the Athabasca oil sands region, northwest of Fort McMurray, Alberta.

Horizon	Depth (cm)	Texture	Colour	Comments
Do	0–20			Mesic peat, organic carbon 35%
Dk	20–45	Clay loam	10YR 2/2 (d)	Mixture of original B and C layers, weakly calcareous
IIDk	45–120+	Sand	10YR 5/3 (m)	Tailings sand, weakly calcareous

Rationale

- Spolic because the dominant disturbed material in the control section (120 cm of the surface) is spolic (< 10% artefacts and <17% organic carbon).
- Carbo because the surface layer is organic material containing >17% organic carbon and is >10 cm thick.
- Calcareous because carbonates are present in >10 cm layer within 50 cm of the soil surface.
- Sablic because sand textured material (tailing sands) is present in a >10 cm layer within 120 cm of the soil surface.

Fusco Spolic Anthroposol – calcareous, hydrocarbic phase
Setting: reclaimed area in the Athabasca oil sands region, northwest of Fort McMurray, Alberta.

Horizon	Depth (cm)	Texture	Colour	Comments
Dh	0–20	Loam	–	Peat mineral mix, 10% organic carbon.
Dqk	20–120	Clay loam	10YR 3/1 (d)	Overburden containing lean oil sand with 2% hydrocarbons, weakly calcareous.

Rationale

- Spolic because the dominant disturbed material in the control section (120 cm of the surface) is spolic (<10% artefacts and <17% organic carbon).
- Fusco because the surface layer (peat mineral mix) is >10 cm thick and organic carbon content is >2% and <17%.
- Calcareous because carbonates are present in >10 cm layer within 50 cm of the soil surface.
- Hydrocarbic because hydrocarbons are present in a >10 cm layer within 120 cm of the soil surface.

NEXT STEPS

The proposed Anthroposolic order has been applied to a small number of example scenarios which are derived from actual field data. It will be field tested across Canada beginning in summer 2011. Once the order has been modified, if needed, based on this field testing, it will be submitted to the Pedology Subgroup of the Canadian Society of Soil Science to be considered for inclusion in the Canadian System of Soil Classification. Please contact us (anne.naeth@ualberta.ca) if you wish to participate in the field trials.

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