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A proposed Folic subgroup for the Organic Cryosols

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Abstract

Cryosols with thick surface organic horizons consisting of folic material derived from forest litter and feathermosses occur on northerly slope aspects in the Rocky Mountains of northern British Columbia. Designation of a new Folic Organic Cryosol subgroup in the Canadian System of Soil Classification would enable more realistic depiction of soil landscape patterns in future soil inventories.

Key words: Folisols, Organic Cryosols, permafrost, soil classification

Résumé

Sur les pentes des Rocheuses orientées au nord, dans le nord de la Colombie-Britannique, on trouve des cryosols recouverts d'un horizon organique de grande épaisseur, composé de matériau folique issu de la litière forestière et d'hypnes. La création d'un nouveau sous-groupe appelé « cryosols organiques foliques » dans le Système canadien de classification des sols permettrait une description plus réaliste des reliefs pédologiques de ce genre lors d'un futur inventaire des sols. [Traduit par la Rédaction]

Mots-clés : Folisols, Cryosols Organiques, pergélisol, classification des sols

Introduction

When the Canadian System of Soil Classification (CSSC) recognized Cryosolic soils, which have permafrost within either 1 or 2 m of the surface depending on the degree of cryoturbation, one of three great groups was designated as Organic Cryosols (Canada Soil Survey Committee 1978). This great group was defined as having developed principally from organic material, containing >17% organic carbon in a surface layer >40 or >10 cm thick over a lithic layer or ice. By analogy with the structure of the Organic order, the Organic Cryosols were subdivided into subgroups principally on the basis of the predominant degree of decomposition of the organic horizons (Fibric, Mesic, and Humic) as well as the presence or absence of a mineral contact within 1 m of the surface (Terric). In the next two revisions of the CSSC, this structure of the Organic Cryosols was retained with only minor changes, although the number of subgroups in the Turbic and Static great groups more than doubled (Agriculture Canada Expert Committee on Soil Survey 1987; Soil Classification Working Group (SCWG) 1998).

The major change to the Organic order in the second edition of the CSSC (Agriculture Canada Expert Committee on Soil Survey 1987) consisted of a significant refinement of the Folisol great group, composed of predominantly forest-origin organic materials, which had contained only a single subgroup (Typic) in the first edition (Canada Soil Survey Committee 1978). This revision designated upland organic materials as "folic" and distinguished them from "peat materials" that were produced by wetland development. Four great groups of Folisols were recognized: Hemic (predominant F horizon), Humic (predominant H horizon), Lignic (predominant woody materials), and Histic (F or H horizons underlain by O horizon >10 cm). Additional refinements provided more details on the thicknesses of folic material needed in various scenarios of depth to lithic contacts, or thicknesses of fragmental or skeletal material, or of mineral soil horizons. In the case of the Hemic subgroup, further details were given on the origin and composition of the folic material comprising its F horizon: "generally derived from mosses, leaves, twigs, reproductive structures, and woody materials containing numerous live and dead roots" — wording that was carried through into the third edition of CSSC (SCWG 1998). These revisions were supported by substantial additional field research conducted in the principal areas of Folisol occurrence in coastal British Columbia (BC) (Fox et al. 1987).

Although the original subdivisions of the Organic Cryosols mirrored the taxonomic treatment of the Organic order, the later refinements of the Folisol great group were not reflected in any corresponding revision of the Organic Cryosols. Both the second and third CSSC editions merely stated that "Folic materials containing permafrost at depths of 1 m or less are classified as Cryosolic soils" (Agriculture Canada Expert Committee on Soil Survey 1987; SCWG 1998) without suggesting any further taxonomic refinement for such cases. However, field work conducted in areas of discontinuous permafrost in the Front Ranges of the Rocky Mountains in Alberta (Achuff and Coen 1980) had previously reported the occurrence of Cryosolic soils with prominent forest-origin organic horizons — 35 cm in the example presented — very close in thickness to the 40 cm minimum required by the Folisols.

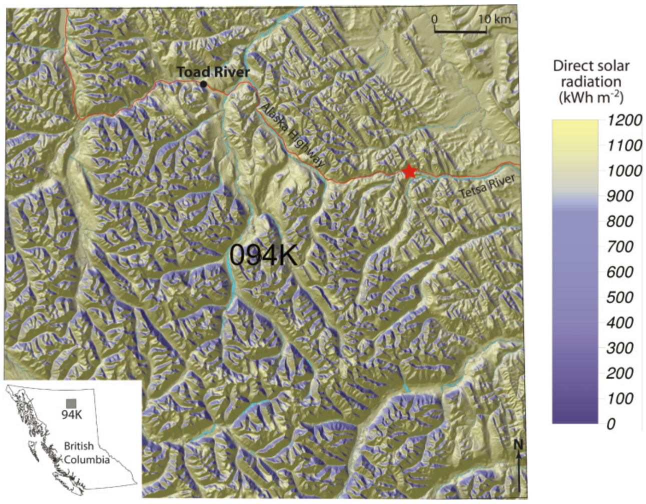
In the third edition, Histic subgroups of the Turbic and Static Cryosols were introduced, which required the presence of "thick (>15 cm) organic (peaty) horizons in the upper 1 m of the solum" (SCWG 1998). More specifically, the identifying properties for this subgroup included "either a continuous surface organic horizon (Ohy, Hy) ranging in thickness from >15–40 cm, or a combination of surface and subsurface organic horizons >15 cm thick" (SCWG 1998). Although this new subgroup would have accommodated the example described by Achuff and Coen (1980), it lacked specificity in that it included soils with organic horizons (O and H) that could have formed in quite different ecological settings.

This paper reports new data from the northern Rocky Mountains in BC for Cryosols from forested settings in which folic material has accumulated to well in excess of the thickness threshold established for Folisols. Basic site and soil characterization data are provided for a representative pedon, along with microclimatic evidence that areas suitable for formation of such Cryosols are likely to be extensive in that region. Addition of a new Folic subgroup of the Organic Cryosols to the CSSC is proposed to accommodate such cases, and the potential utility of this designation for application to soil inventory in that region is discussed, along with analogous categories in major international taxonomic systems.

Study area

Field work was conducted in late August 2012 along the Alaska Highway in the vicinity of Toad River, BC, approximately 130 km west of Fort Nelson, BC. Pedons were examined on a north-facing slope adjacent to the North Tetsa River at kilometre 585 of the Alaska Highway (Fig. 1). At this latitude (~58–59° N), the low solar angle enhances microclimatic differences related to slope aspect. For example, Buffo et al. (1972) calculated that at latitude 60°, a 15° (27%) north-facing slope will have yearly direct solar radiation that is 43% lower than for a 15° (27%) south-facing slope; for 30° (58%) slopes, the reduction is 68% for north- relative to south-facing aspects. When similar calculations are applied at the landscape level in complex mountainous topography, an intricate pattern of contrasting microclimates results (Fig. 1). With the pronounced northwest–southeast orientation of the mountain ridges, microclimates with the lowest direct solar radiation are strongly concentrated on steep northeast-facing slopes. With an estimated mean annual air temperature at the North Tetsa River study sites of –0.3 °C based on the ClimateWNA tool of Wang et al. (2016) using historical data for 2001–2010, these patterns will dictate a highly localized pattern of permafrost distribution, as well as vulnerability to natural disturbances (fire, slope instability), which might alter properties such as organic horizon thickness that influence soil temperature regimes. When displayed for the National Topographic System grid cell 94 K, the resulting pattern suggests that sites with low direct solar radiation, which should be favourable for permafrost occurrence, are abundant and widely dispersed throughout the landscape, with strong control by slope aspect (Fig. 1). Other considerations in predicting the pattern of permafrost distribution in mountain landscapes of northwestern Canada have been treated in more detail by Bonnaventure et al. (2012) and Lewkowicz et al. (2012).

Fig. 1. Study area location (star) and predicted solar radiation in relation to topography. Solar radiation and a hillshade overlay was calculated using SAGA-GIS (Conrad et al. 2015) from a 100 m resolution digital elevation model available to the public at HectaresBC.org. Additional data used to prepare the map were obtained under open government licenses for British Columbia (river locations) and Canada (roads). The map was prepared in the NAD83-BC Albers projection. [Colour online]



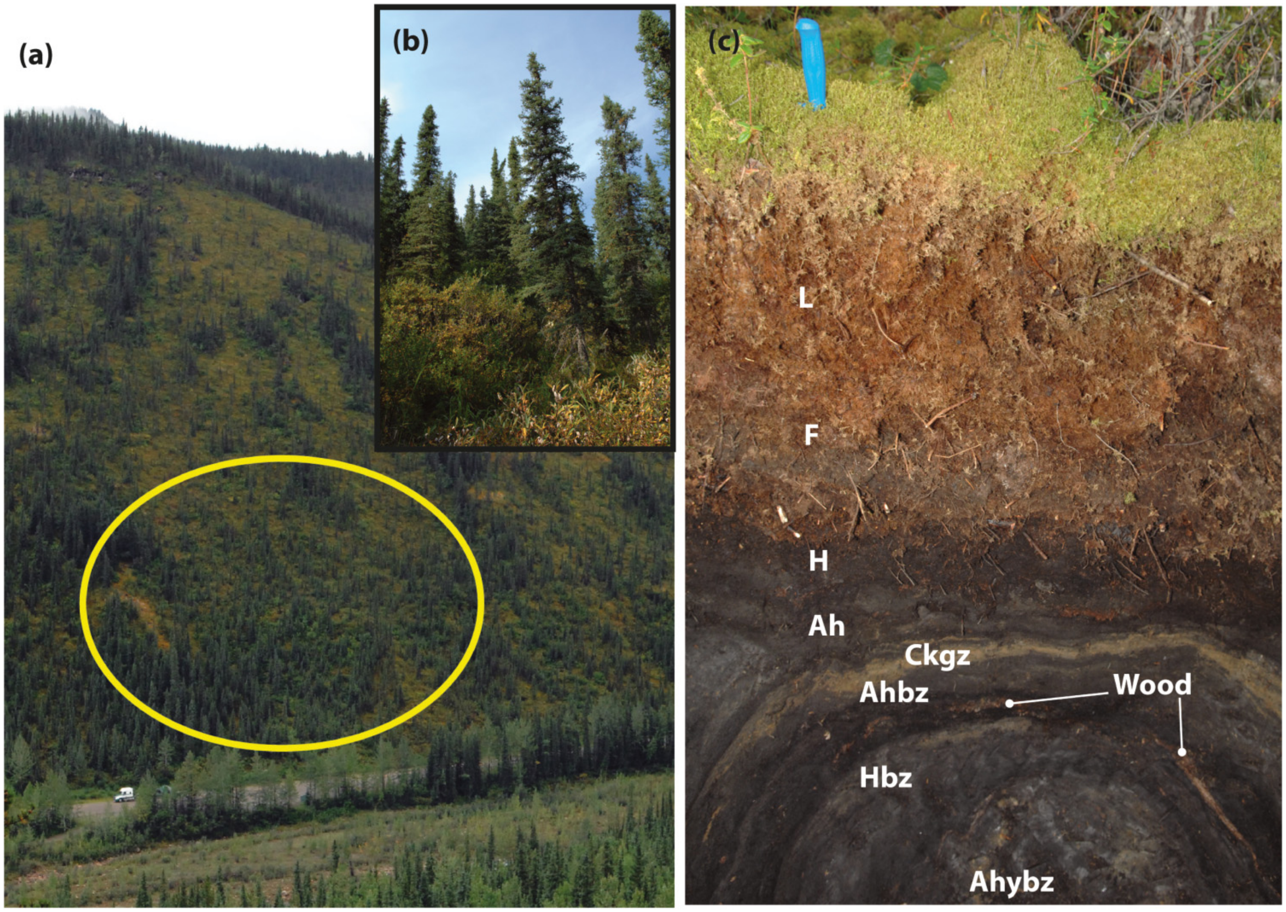
Methods

The pedon from the North Tetsa River valley used here to illustrate characteristics of the proposed subgroup was selected for its proximity to a soil temperature monitoring site subsequently discussed by Hasler et al. (2015). Particle size analysis was performed by the pipette method after destruction of organic matter by hydrogen peroxide. Total carbon (C) and nitrogen (N) were determined with a LECO Truspec CN Analyzer, and total sulfur (S) with a LECO Truspec Sulphur Analyzer. Soil reaction was determined with a pH meter and combination electrode in suspensions with deionized water and 0.01 mol/L $CaCl_2$. Iron (Fe) and aluminum (Al) were extracted by the pyrophosphate method (Carter 1993). Exchangeable cations were determined by the $BaCl_2$ method (Hendershot and Duquette 1986).

Field observations

Slope aspect-related microclimatic influences produce striking vegetation patterns, in which areas of open black

Fig. 2. (*a*) Site view of North Tetsa River valley showing area of interest (ellipse) on north-facing slope; (*b*) view of vegetation immediately upslope from sampled pedon, showing open black spruce stand with willow-dominated shrub layer; and (*c*) profile view of pedon BC12-08 (the "z" suffix indicates that horizon is frozen). Knife handle is 11 cm long. [Colour online]



spruce (*Picea mariana*) forests have a distinctive yellowish-green understory dominated by stepmoss (*Hylocomium splendens*) and shrubs (Figs. 2*a* and 2*b*). This vegetation type is associated with permafrost occurrence on north- and northeast-facing aspects as verified by manual probing. Slopes ranged from 40% to 60%. Nearby south-facing slopes were occupied by more closed boreal mixedwood forest vegetation, with soils consisting predominantly of Dystric and Eutric Brunisols with forest floors 7–12 cm thick.

The pedon example presented here (Tables 1 and 2; Fig. 2*c*) exhibited key morphological and chemical characteristics encountered in other pedons where permafrost was present at sites examined along the Alaska Highway in the North Tetsa River valley and in the vicinity of Toad River (Fig. 1): (*i*) a thick (20–40+ cm) accumulation of feathermoss-derived litter overlying an F horizon, which appeared to be derived from the same organic matter source; (*ii*) considerable evidence of instability on colluvium-mantled slopes (e.g., buried horizons, and incorporation of woody debris, some of which was charred) and fluvial fans (multiple buried Ah horizons); (*iii*) absence of B horizons; (*iv*) on steep slopes, the late August permafrost table was present just below the base of the folic material; and (*v*) carbon concentrations in Ah and Ahb horizons often exceeded 10%, and occasionally the 17% threshold for organic horizons.

Morphologically similar pedons, classified as Hemic Folisols, which differed only by having permafrost absent or at a depth exceeding 100 cm were also observed.

Proposed classification revision

Pedons such as the example presented here do not fit well within the current (third) version of the CSSC, as the existing subgroups within the Organic Cryosols recognize only O horizons as diagnostic. Table 3 presents criteria for a proposed Folic Organic Cryosol, consistent with the format and content used for other CSSC subgroups. The proposed wording provisionally designates L, F, and H, as well as Cz horizons as diagnostic; additional field investigations may suggest revisions to these criteria as more pedons are observed and studied. Regarding correlation with major international soil classifications, the proposed subgroup would correspond to the Folistels in Soil Taxonomy (Soil Survey Staff 2014) and the Folic Cryosols in the World Reference Base (IUSS Working Group WRB 2015).

Table 1. Site and pedon descriptions, North Tetsa River, BC, site BC12-08.

Latitude: 58° 39.872′N	Longitude: 124° 27.186′W	
Aspect: North	Slope: 40%	Elevation: 990 m
Vegetation: Open black spruce forest with willow, alder, and feathermoss understory		
Parent material: Silty colluvial blanket over inclined bedrock		
Horizon (sample)	Depth (cm)	Description
L (BC12-08-01)	0–40	Brown (7.5YR 4/4 m); feathermoss litter; plentiful, very fine, fine, and medium roots; abrupt, smooth boundary; 30-45 cm thick; strongly acid (pH 5.06).
F (BC12-08-02)	40–60	Dark brown (7.5YR 3/2 m); partially decomposed feathermoss; matted; few mycelia; abundant, very fine, fine, medium, and coarse roots; clear, wavy boundary; 15–25 cm thick; neutral (pH 6.79).
H (BC12-08-03)	60–74	Black (10YR 2/1 m); humified organic matter; plentiful, very fine and fine roots; clear, wavy boundary; 12–17 cm thick; neutral (pH 6.65).
Ah (BC12-08-04)	74–83	Black (2.5Y 2.5/1 m); very fine sandy loam; friable; moderate, fine, subangular blocky; plentiful, very fine and fine roots; 5% gravel; abrupt, smooth boundary; 8–15 cm thick; neutral (pH 6.76).
Ckgz (BC12-08-05)	83–86	Dark yellowish brown (10YR 4/4 m); sandy loam; single grain; common, fine, distinct, strong brown (7.5YR 5/6 m) mottles; weakly effervescent; abrupt, smooth boundary; 3–6 cm thick; neutral (pH 7.07).
Ahbz (BC12-08-06)	86–95	Black (2.5Y 2.5/1 m); very fine sandy loam; massive; abrupt, smooth boundary; 8–12 cm thick; neutral (pH 6.60).
(Wood) (BC12-08-07)	95–98	Slightly decomposed woody materials; 1–3 cm thick.
Hbz (BC12-08-08)	98–102	Black (2.5Y 2.5/1 m); humified organic matter; abrupt, wavy boundary; 3–5 cm thick; slightly acid (pH 6.51).
Ahybz (BC12-08-09)	102–105+	Black (2.5Y 2.5/1 m), very dark gray (2.5Y 3/1 m); silt loam; massive; neutral (pH 6.77).

Note: Reaction classes based on laboratory determination of pH in 0.01 mol/L $CaCl_2$.

Table 2. Selected analytical data for pedon BC12-08, North Tetsa River, BC.

	Depth	%								pH	pH
Horizon	(cm)	Sand	Silt	Clay	Total C	Total N	Total S	Al_p	Fe_p	(H_2O)	($CaCl_2$)
L	0–40	n.d.	n.d.	n.d.	52.3	0.88	0.09	n.d.	n.d.	5.54	5.06
F	40–60	n.d.	n.d.	n.d.	26.3	0.87	0.09	n.d.	n.d.	7.17	6.79
H	60–74	n.d.	n.d.	n.d.	40.6	1.92	0.21	n.d.	n.d.	7.10	6.65
Ah	74–83	22.8	60.4	16.9	11.6	0.68	0.12	0.08	0.73	7.33	6.76
Ckgz	83–86	62.9	29.0	8.1	4.3	0.13	0.05	0.04	0.28	7.68	7.07
Ahbz	86–95	13.8	66.8	19.4	13.8	0.78	0.13	0.09	0.79	7.10	6.60
(Wood)	95–98	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Hbz	98–102	n.d.	n.d.	n.d.	22.8	1.04	0.17	0.08	0.66	7.02	6.51
Ahybz	102–105+	30.6	53.6	15.8	7.6	0.42	0.09	0.07	0.51	7.29	6.77
	Depth			Exchangeable cations (cmol (+)/kg)							
Horizon	(cm)	Al^{3+}	Ca^{2+}	Fe^{3+}	K^+	Mg^{2+}	Mn^{2+}	Na^+	Sum		
L	0–40	0.24	58.61	0.05	3.10	20.06	0.19	0.36	82.61		
F	40–60	0.02	87.86	0.00	0.80	23.50	0.02	0.07	112.27		
H	60–74	0.02	175.84	0.00	0.24	18.97	0.01	0.07	195.15		
Ah	74–83	<0.001	62.86	<0.001	0.04	7.14	0.01	0.02	70.07		
Ckgz	83–86	<0.001	14.53	<0.001	0.02	1.97	0.01	0.01	16.55		
Ahbz	86–95	0.02	66.51	0.01	0.06	7.54	0.01	0.02	74.17		
(Wood)	95–98	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.		
Hbz	98–102	<0.001	88.32	<0.001	0.05	10.08	0.01	0.04	98.51		
Ahybz	102–105+	<0.001	45.92	<0.001	0.06	3.69	0.04	0.02	49.73		

Note: Al_p, Fe_p = pyrophosphate-extractable; n.d. = not determined.

Table 3. Proposed text for Folic Organic Cryosol subgroup in the Canadian System of Soil Classification.

Folic Organic Cryosol

Common horizon sequence: L, F, H, O, Ahz, Cz

These Organic Cryosols are identified by the following properties:

1. They are composed dominantly of folic material in the control section below a depth of 40 cm.
2. When O horizons are also present, their combined thickness must be less than that of the combined L, F, and (or) H horizons.

A further consideration arises from the evidence of multiple cycles of slope instability and aggradation recorded by such soils in our study area. Bedard-Haughn (2021) noted that repeated aggradation and pedogenesis are not restricted to the Cumulic Regosols, and her observations, in addition to those reported here, justify wider recognition of Cumulic subgroups in other soil orders.

Implications

Soil patterns in the northern Cordillera of BC remain poorly explored, and there have been no substantive revisions to the 1:1 million scale reconnaissance mapping that identified Cryosols as an important landscape component only in the Fort Nelson lowlands of extreme northeastern BC (Agriculture and Agri-Food Canada 1995). This preliminary study suggests that Cryosols are likely more abundant than previously realized in the northern Cordillera, with a complex distribution closely linked to fine-scale microclimate patterns controlled by slope aspect. Revising the CSSC to recognize a distinctive and potentially extensive soil taxon will assist future efforts to improve soil inventories of this region. This takes on added significance in view of the significant reserves of organic carbon in such soils occurring in settings vulnerable to natural disturbance processes such as wildfire-triggered slope instability.

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Author notes

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