Four Soil Orders on a Vermont Mountaintop—One-Third of the World's Soil Orders in a 2500-Square-Meter Research Plot

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As part of the Vermont Long-Term Soil Monitoring Project, five 50 × 50 m plots were established on protected forestland across Vermont. In 2002, ten randomly selected subplots at each monitoring plot were sampled. The 10 pedons sampled at the high-elevation spruce–fir "Forehead" plot on Mount Mansfield were found to include soils of four taxonomic Orders: Entisols, Histosols, Inceptisols, and Spodosols. Soil forming factors such as climate, vegetation, and time are uniform, and podzolization is the major soil forming process, but small variations in parent material thickness and microtopography result in the presence of four orders. A 1-cm difference in the thickness of a horizon can affect the placement of a soil in one of these orders.

The overall goal of the Vermont Long-Term Soil Monitoring Project, under the auspices of the Vermont Monitoring Cooperative (VMC, 2009) is to monitor forest soils for changes due to human-caused impacts, such as climate change and air pollution. This project is a long-term experiment testing the hypothesis that soils in their natural setting can be used to monitor environmental change. The monitoring strategy is to measure changes in soil properties via sampling and lab analysis at regular 5-yr intervals over a period of more than 50 yr in forest settings without obvious human intervention. Major partners in this project are the Vermont Agency of Natural Resources, University of Vermont, USDA-NRCS, USDA-FS Green Mountain National Forest, and USGS.

Initial planning for the project began in 1998. In 2000, five 50 × 50 plots were established on protected forestland in Vermont (Villars, 2000; Villars and Bailey, 2001). Two of the plots are in the Green Mountain National Forest, and three plots are in the Mount Mansfield State Forest. Each monitoring plot was subdivided into 100 5 × 5 m subplots. Basic soil characterization sampling was completed in 2000 with the assistance of the NRCS Kellogg Soil Survey Laboratory; KSSL Site and Pedon ID number S00VT015001 is associated with the plot reviewed in this article. NRCS Soil Climate Analysis Network (SCAN) stations were also installed adjacent to two of the five sites in 2000 (Villars, 2007).

The five sites chosen for long-term soil monitoring have glacial till soils that typify large forested areas in Vermont, represent a range of forest cover types and elevation, and are located within a 30-min walk of a road or trailhead using hiking trails and some bushwhacking. Each plot measures 50 by 50 m. Initial impressions were that the relatively uniform slope and vegetation within the plots indicated that the soils would also be fairly uniform. "Year Zero" sampling was performed in 2002, followed up by Year 5 and Year 10 sampling in 2007 and 2012.

This paper looks at a few lessons learned in the initial stages of the project: that there is greater natural variation of soils within the monitoring plots than anticipated, that the tight "tolerances" of US soil taxonomy affect classification of similar soils all the way up to the order level, and that when there is more than one soil scientist or teams of soil scientists working on a project, lack of consistency in observing and recording soil features can have a serious impact on how soils are classified.

Forehead Plot Landscape Setting

The Forehead long-term soil monitoring plot is located in Lamoille County, Vermont, near the western county line with Chittenden County (Fig. 1). The plot elevation is approximately 1120 m (3696 ft) on the shoulder of Mount Mansfield, the highest summit in the state at 1361 m (4493 ft). At this elevation in Vermont, the soil temperature regime is considered to be *cryic* (Soil Survey Staff, 2014; Villars, 1996), although the closest SCAN station at 697 m (2300 ft) has a frigid temperature regime (Villars, 2007). Vegetation at this site is montane spruce–fir

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Abbreviations: SCAN, Soil Climate Analysis Network.

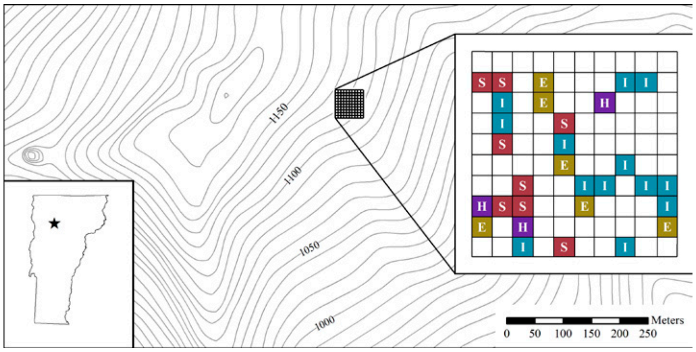

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Fig. 1. Location of Forehead 50 × 50 m soil monitoring plot in Vermont and distribution of soil orders among the 30 subplots sampled in 2002 through 2012. Each subplot is 5 × 5 m. Ridgetop on contour map west of monitoring plot is part of summit ridge of Mt. Mansfield. E, Entisols; H, Histosols; I, Inceptisols; S, Spodosols.

Fig. 2. Montane spruce–fir vegetation at the Forehead soil monitoring plot on Mt. Mansfield, Vermont.

forest vegetation (Fig. 2), primarily balsam fir [*Abies balsamea* (L.) Mill.], red spruce (*Picea rubens* Sarg.), and American mountain ash (*Sorbus americana* Marshall) (Siccama, 1974; Thompson and Sorenson, 2000; Villars, 2006). The soil map unit, based on the NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/, accessed 12 Oct. 2015), is Londonderry–Stratton complex, 25 to 60% slopes. The Londonderry series classification is loamy, mixed, active, acid Lithic Cryorthents; the Stratton series classification is loamy-skeletal, isotic Lithic Humicryods. Bockheim (2010) described these high-elevation northeastern US soils as "disjunct" soils, which have formed on "widely separated mountain peaks over a broad geographic region."

Materials and Methods

Pedons were described using the *Field Book for Describing and Sampling Soils* (Schoeneberger et al., 2012). Following field sampling, the pedons were classified using US soil taxonomy. When initially classifying these pedons, the eighth edition of *Keys to Soil Taxonomy* (Soil Survey Staff, 1998b) was used. Currently the 12th edition of *Keys to Soil Taxonomy* (Soil Survey Staff, 2014) is in effect and was used as the reference for all taxonomic criteria in this paper. The chapter "Horizons and Characteristics Diagnostic for the Higher Categories" was used to describe pedon features and horizons. It is worth noting that in some instances, a horizon that meets the criteria for one diagnostic horizon can also meet the criteria for a second diagnostic horizon. For example, an albic horizon 15 cm or more thick also meets the criteria for a cambic horizon.

Once diagnostic horizons were identified, pedons were classified at the order level. Referring to the "Key to Soil Orders" in the chapter "Identification of the Taxonomic Class of a Soil" in *Keys to Soil Taxonomy*, pedons were classified to specific Orders by their diagnostic horizons and other characteristics, along with specific depth information. The 12 soil orders key out in a specific sequence. In US soil taxonomy, note that Histosols come before Spodosols, which come before Inceptisols, which are then followed lastly by Entisols.

Results

With relatively steep slopes at the Forehead site, ranging from 16 to 38%, none of the soils sampled were considered to have aquic conditions; that is, no horizons were likely be saturated for more than 30 d (cumulative) in normal years. All pedons had a lithic contact to schist bedrock. Depth of solum ranged from 12 to 69 cm from the top of the soil surface and from 4 to 60 cm from the top of the mineral soil surface. The range in textures for mineral horizons centered on "fine sandy loam," with coarse fragment content about 20%. Particle-size textural class for all mineral layers was "loamy" or "coarse-loamy." These findings were similar to those recorded by Munroe (2008) in a study of alpine soils on Mount Mansfield.

The 10 pedons described and sampled at the Forehead plot in 2002 (Fig. 3) had the following features and horizons: ochric and folistic epipedons, albic and spodic materials, and albic, cambic, and spodic subsurface horizons (Table 1). All pedons had O horizons on the surface, ranging from 4 to 17 cm thick, comprised of organic material derived from the montane spruce–fir forest vegetation. Depending on thickness, they classified as either folistic or ochric epipedons. Three pedons had folistic horizons with combined O horizon thickness (Oi, Oe, and Oa horizons) of 15 cm or more. The other seven pedons had ochric epipedons (which allows horizons of organic materials too thin to meet requirements for folistic or histic epipedons). One pedon had a thin mineral A horizon that was considered part of the ochric epipedon. All pedons had E horizons comprised of albic materials that classified as albic horizons. Two pedons had B horizons that met the requirement for spodic horizons (Bhs). A third B horizon observed was labeled a Bw horizon because it did not meet the requirements for spodic materials.

Most Histosols are located in low-lying wetlands, but a small subset in the Northeast are found on cold mountain summits and upper sideslopes, such as the Mount Mansfield Forehead plot (Villars, 1996; Soil Survey Staff, 1998a; Bockheim, 2010). These Histosols have organic soil materials that “constitute two-thirds or more of the total thickness of the soil to a densic, lithic, or paralithic contact and have no mineral horizons or have mineral horizons with a total thickness of 10 cm or less” (Soil Survey Staff, 2014, p. 38, key to soil orders B2c). For example, Pedon 77 has 8 cm of organic soil materials and only 4 cm of a mineral horizon. The organic soil material is two-thirds of the total thickness to the lithic contact. This pedon classifies as a Histosol, even though it has neither a histic or folistic epipedon. It fits within the range of characteristics of the established Ricker series. Pedon 48 misses classification as a Histosol by 1 cm. If the depth to the boundary between the lowest O horizon and the E horizon was 1 cm deeper (thus increasing O thickness by 1 cm and decreasing the mineral E horizon by 1 cm), it would meet both the two-thirds organic vs. mineral thickness criteria and the <10-cm mineral horizon thickness criteria.

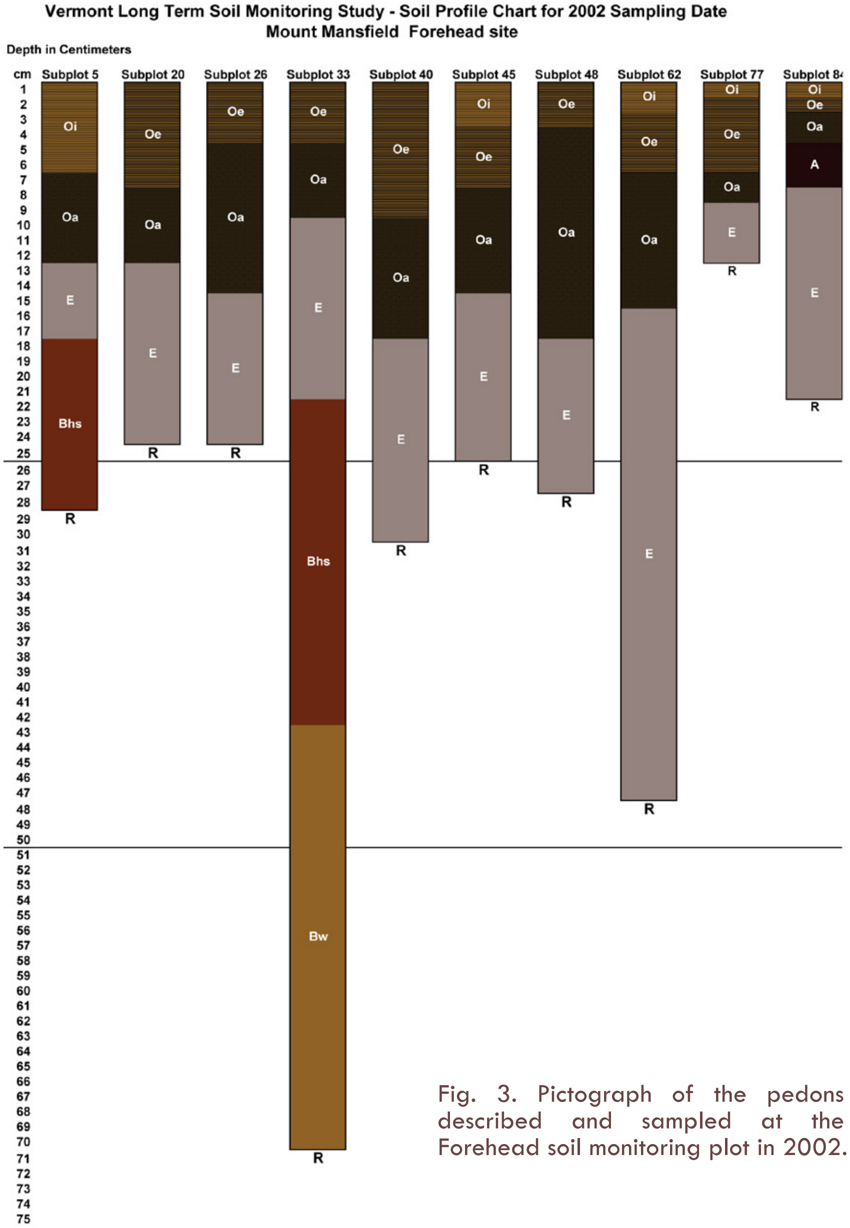

Fig. 3. Pictograph of the pedons described and sampled at the Forehead soil monitoring plot in 2002.

Spodosols are extremely common in the Green Mountains of Vermont, yet only two pedons, at Subplots 5 and 33, have spodic horizons (Fig. 4). These Bhs horizons have a matrix color of 5YR 3/3. It is 11 cm thick in Subplot 5 and 21 cm thick in Subplot 33. Because these soils have a cryic soil temperature regime, they classify as Spodosols without further review of horizon depths or thickness (Soil Survey Staff, 2014, p. 38, key to soil orders C1). Pedon 5 fits the range in characteristics for the mapped Stratton series. Pedon 33 fits the range in characteristics of the Glebe series.

Pedons 40, 48, and 62 also have folistic epipedons with combined O horizons 15 cm or more thick. Beginning with the 12th edition to *Keys to Soil Taxonomy* (Soil Survey Staff, 2014), these pedons key out as Inceptisols in the *Keys to Soil Orders*. They also meet other criteria related to sulfidic materials, *n* value, and percentage clay required in the Keys. Pedon 62 has an E horizon 32 cm thick. This horizon is an altered horizon greater than 15 cm thick and thus meets the basic requirements of a cambic horizon, along with meeting the criteria for an albic horizon. Before the release of the 12th *Keys to Soil Taxonomy*, this would have been the only pedon that classified as an Inceptisol; pedons 40 and 48 would have classified as Entisols. These pedons all now classify as Lithic Dystrocryepts. They do not fit the range in characteristics for any established soil series. There are 11 soil series in the taxonomic subgroup, but they are mapped in the Rocky Mountains or the Pacific Northwest.

Pedons 20, 26, 45, and 84 key out as Entisols. They are not Histosols because their O horizons are too thin to equal two-thirds of the total thickness to the lithic contact. The O horizons are also too thin to be folistic epipedons, and their albic horizons are too thin to meet the requirements for a cambic horizon. They lack a spodic horizon. All four of these pedons fit the range in characteristics of the mapped Londonderry series.

After subsequent 5-yr interval sampling of 10 more subplots at the Forehead soil monitoring plot in 2007 and again in 2012, the classification of the 30 pedons sampled to date key out as 13% Histosols, 27% Spodosols, 40% Inceptisols, and 20% Entisols. In one corner of the plot, the four soil orders were described within a 15 × 15 m area (Fig. 1).

Table 1. Selected features of pedons sampled at the Forehead soil monitoring plot during initial sampling round in 2002.

Subplot	Thickness of horizons, cm	Diagnostic horizons	Soil order	Soil series	Comments
5	O, 12 E, 5 Bhs, 11	Ochric, albic, spodic	Spodosols	Stratton	
20	O, 12 E, 12	Ochric, albic	Entisols	Londonderry	
26	O, 14 E, 10	Ochric, albic	Entisols	Londonderry	Misses Inceptisol by 1 cm: if O = 15 cm thick instead of 14 cm, then is folistic
33	O, 9 E, 11 Bhs, 21 Bw, 28	Ochric, albic, spodic, cambic	Spodosols	Glebe	
40	O, 17 E, 13	Folistic, albic	Inceptisols	No series-Lithic Dystrocrypets	
45	O, 14 E, 11	Ochric, albic	Entisols	Londonderry	Misses Inceptisol by 1 cm: if O = 15 cm thick instead of 14 cm, then is folistic
48	O, 17 E, 10	Folistic, albic	Inceptisols	No series-Lithic Dystrocrypets	Misses Histosol by 1 cm: if O = 18 cm and E = 9 cm, then O is 2/3 of profile
62	O, 15 E, 32	Folistic, albic, cambic	Inceptisols	No series-Lithic Dystrocrypets	Cambic includes thick albic horizon
77	O, 8 E, 4	Ochric, albic	Histosols	Ricker	Organic materials = 2/3 of profile
84	O, 4 A, 3 E, 14	Ochric, albic	Entisols	Londonderry	Misses Inceptisol by 1 cm: if E = 15 cm thick instead of 14 cm, then is cambic

Discussion

That there are soils from four different taxonomic orders in this small area is surprising, considering that the site was selected for its supposed uniformity of soils, landscape position, and slope. Excluding the pedons with spodic horizons, soils with just O, E, and R horizons classify as three different soil orders. Does this matter, or is it just a curiosity? What this situation certainly points out is that while the 12 soil orders generally represent distinctly different types of soils in various geographic areas around the globe, there are instances where very similar soils can end up looking considerably different when viewed through the lens of US soil taxonomy.

The skill and attention to detail that a soil scientist applies to the task of observing and describing a soil profile is an important factor in field studies. When there is more than one soil scientist or teams of soil scientists working on a project either simultaneously or in sequence, consistency and oversight are critical. Every soil scientist at one time or another has been accused of being a “lumper” or a “splitter.” The Vermont Long-Term Soil Monitoring Project team realized that the best way to ensure consistency in the 50 soil descriptions collected during each sampling interval was to limit the number of people making the descriptions in the first place and to develop a set of protocols to aid in identifying soil horizons. A single soil scientist also reviewed all of the descriptions after sampling to check for discrepancies.

Fig. 4. Soil with spodic horizon at Subplot 33. This soil, with bedrock at 71 cm below the soil surface, was the deepest soil sampled in 2002.

Roughly one-quarter of the soils sampled to date have spodic horizons. Why are these horizons so discontinuous at this site? Several researchers have noted the role of hydrologic pulses in podzolization (Schaetzl et al., 2015), which may be an influence at this site. Bailey et al. (2014) found similar spodic horizon discontinuity in soils along a bedrock-controlled ridgeline at lower elevation within a Lyman–Tunbridge–rock outcrop complex in New Hampshire. At that site at Hubbard Brook Experimental Forest, O horizons varied from 7 to 60 cm thick, E horizons from 2 to 40 cm, and spodic horizons from 0 to 18 cm thick.

Although taxonomic determinations were not made, a review of the unpublished profile descriptions suggests that the same four orders could be keyed out in this lower elevation bedrock-controlled landscape. At both the Mt. Mansfield Forehead and Hubbard Brook sites, rock outcrops and shallow bedrock greatly enhance the amount of runoff flowing through the minimal soil volume in these steeply sloping soils. In addition to pulses of runoff during snowmelt, these soils develop episodic saturation during heavy rain events throughout the year, which dissipates almost immediately following cessation of precipitation (Bailey et al., 2014; Gannon et al., 2014).

US soil taxonomy implicitly assumes vertical soil profile development, yet there appear to be certain situations where this assumption is likely not met so purely. Lateral soil podzolization has been observed in several landscapes (Sommer et al., 2000; Bourgault et al., 2015) and translocational soil catenas have been proposed (Sommer and Schlichting 1997; Bailey et al., 2014). The podzolization process in these shallow sloping soils at the Mount Mansfield site appears to be predominately oriented downslope, with the spodic horizon found in one soil possibly developed by lateral translocation from an upslope soil whose vertical profile shows no indication of spodic development. This brings up a question of whether it is always appropriate to apply taxonomy strictly at the pedon scale—or perhaps in this specific instance, should the size of the soil pedon encompass a larger area than a less-sloping site to account for the lateral development of soil horizons?

Conclusions

Soils representing four of the world's 12 soil orders—Entisols, Histosols, Inceptisols, and Spodosols—were identified in 10 randomly selected subplots within a 50 × 50 m plot on the upper sideslope of Mt. Mansfield, Vermont, during initial sampling for the Vermont Long-Term Soil Monitoring Project.

With the exacting depth requirements throughout the *Keys to Soil Taxonomy,* the difference of 1 cm in the recorded depth to the boundary between two horizons can create a significant difference in the classification of a pedon. Soils that have very similar properties and factors of soil formation can look strikingly different when viewed through the lens of US soil taxonomy. This situation makes it imperative to take into account the individual skills and biases of each team member when there is more than one soil scientist or teams of soil scientists working on a project to ensure consistency.

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