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NEON Site Level Plot Summary
Niwot Ridge (NIWO)

Document Information

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Site Background

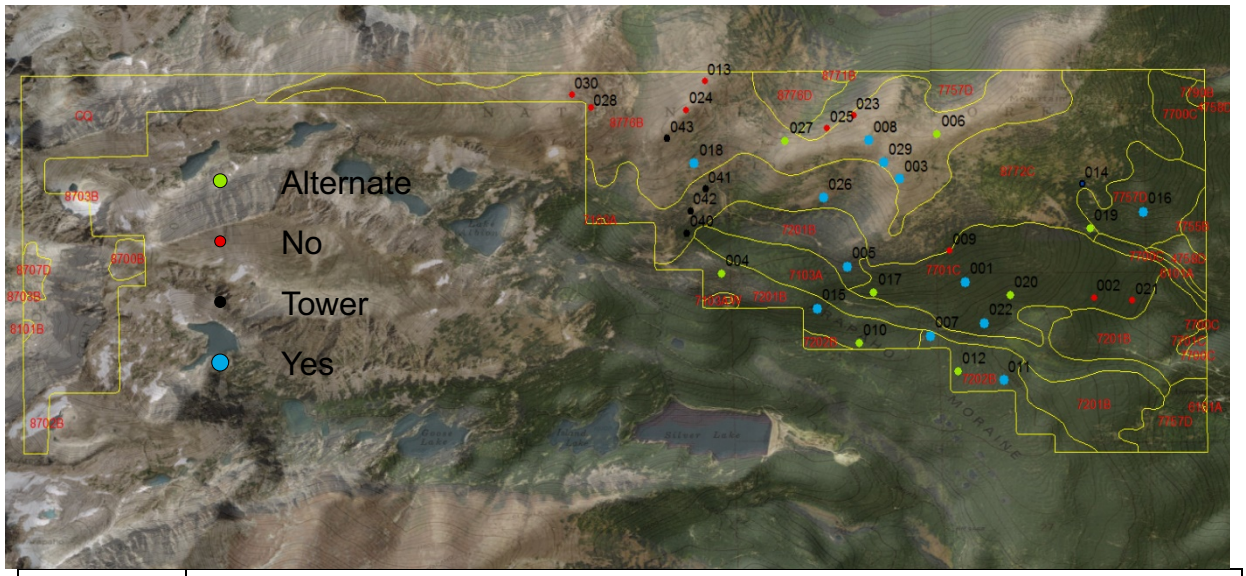
The Niwot Ridge (NIWO) NEON site is an extremely mountainous and rugged region that has some of the highest elevations and greatest relief found in the lower 48 states (Figure 1). NIWO is part of the Southern Rocky Mountains major land resource area (MLRA 48A). The site is 35 km west of Boulder, CO and is bounded to the west by the continental divide. Elevations range from approximately 2884 meters (9462 feet) to 4037 meters (13,245 feet).

Site Information

Niwot Ridge is characterized by metamorphic and igneous geology with significant glacial drift that is typical of the high-alpine and sub-alpine of the Colorado Front Range. The state-wide geology map (Figure 2) indicates most of the area is Biotite Gneiss, Schist and Migmatite (Xb) with smaller areas of glacial drift of Pinedale and Bull Lake glaciations (Qd) and a small area of Laramide intrusive rocks, mixed igneous, and non-volcanic rocks (Tki). Soil parent materials in the Niwot area consist chiefly of colluvium, glacial till, residuum, and solifluction deposits (Gable and Madole, 1976; Soil Survey Staff, 2019). The state-wide geology map (Figure 2) was used for the pre-analysis of plots for sampling, whereas the more detailed 1:24,000 scale geology map (Figure 3) was used to summarize the plot findings that follow.

The NIWO site is characterized by subalpine and alpine vegetation (Figure 4). *Abies lasiocarpa* (subalpine fir) and *Picea englemannii* (Englemann spruce) are the dominant tree species at higher subalpine elevations and *Pinus contorta* (lodgepole pine) dominates at lower elevations. Other tree species include *Pinus flexilis* (limber pine) and *Populus tremuloides* (aspen).

The break between subalpine forest and the alpine tundra above tree line ranges between approximately 3275 m (10745 feet) and 3425 m (11,237 feet) in the Niwot area. Pockets of krummholz vegetation can be found from the subalpine forested boundary to as high as 3500 m (11483’), with the frequency decreasing as elevation increases. In many areas of Niwot Ridge, the krummholz interspersed with alpine tundra serves as a transition from subalpine forest to alpine tundra, although in some locations subalpine forest transitions to the tundra without significant krummholz.



Map Unit Symbol	Map Unit Name
4758D	Catamount family-Rubble land-Bullwark family complex, 40 to 150 percent slopes
6101A	Cryaquolls-Gateview family complex, 0 to 15 percent slopes
7103A	Cryaquolls-Leighcan family, till substratum complex, 0 to 15 percent slopes
7201B	Leighcan family, till substratum, 5 to 40 percent slopes
7202B	Leighcan family, till substratum-Cryaquolls complex, 5 to 40 percent slopes
7700C	Leighcan family, 40 to 75 percent slopes
7701C	Leighcan family, 40 to 75 percent slopes, south aspects
7702B	Frisco-Catamount, moist families complex, 5 to 40 percent slopes
7755B	Leighcan-Catamount, moist families complex, 5 to 40 percent slopes
7757D	Leighcan-Catamount, moist families-Rock outcrop complex, 40 to 150 percent slopes
7790B	Lithic Cryorthents, subalpine-Rubble land complex, 5 to 40 percent slopes
8101B	Cryaquepts-Bross family complex, 5 to 25 percent slopes
8700B	Bross-Matcher families-Lithic Cryorthents complex, 5 to 40 percent slopes
8702B	Bross family-Cryaquepts complex, 3 to 25 percent slopes
8703B	Matcher family-Cryaquepts-Rock outcrop complex, 5 to 25 percent slopes
8707D	Bross family-Rubble land-Matcher family complex, 40 to 150 percent slopes
8771B	Leighcan family-Cryaquolls-Moran family complex, 5 to 40 percent slopes
8772C	Moran family-Lithic Cryorthents-Leighcan family complex, 40 to 75 percent slopes
8776B	Moran family-Lithic Cryorthents-Rubble land complex, 5 to 40 percent slopes
8776D	Moran family-Lithic Cryorthents-Rubble land complex, 40 to 150 percent slopes
CQ	Cirque land, 40 to 150 percent slopes
W	Water

Figure 1. Niwot Ridge plots with SSURGO soil mapping. Blue plots were proposed for sampling, green plots were selected as alternates, and red plots were not chosen. Black plots are located within the NEON tower airshed. Adjoining table indicates soil map unit symbol and map unit name, acres and areal percentage of NIWO site area.

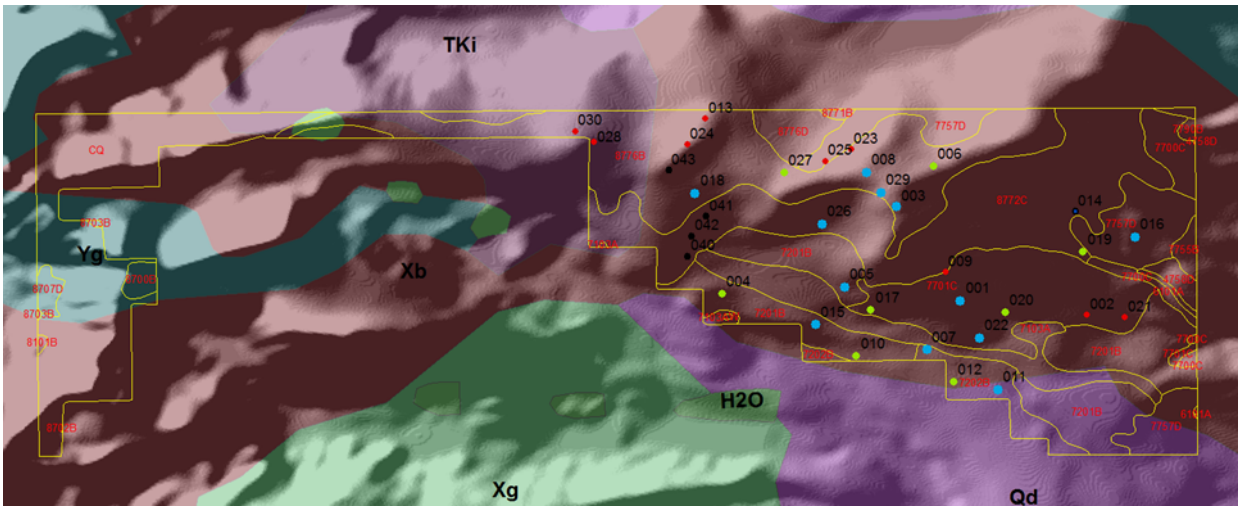


Figure 2. Niwot Ridge plots with SSURGO soil mapping overlaid on the Colorado state-wide geology map. This map was used for selecting plots to sample. Xb: Biotite Gneiss, Schist and Migmatite; Qd: glacial drift of Pinedale and Bull Lake glaciations; Tki: Laramide intrusive rocks, mixed Igneous, and non-volcanic rocks.

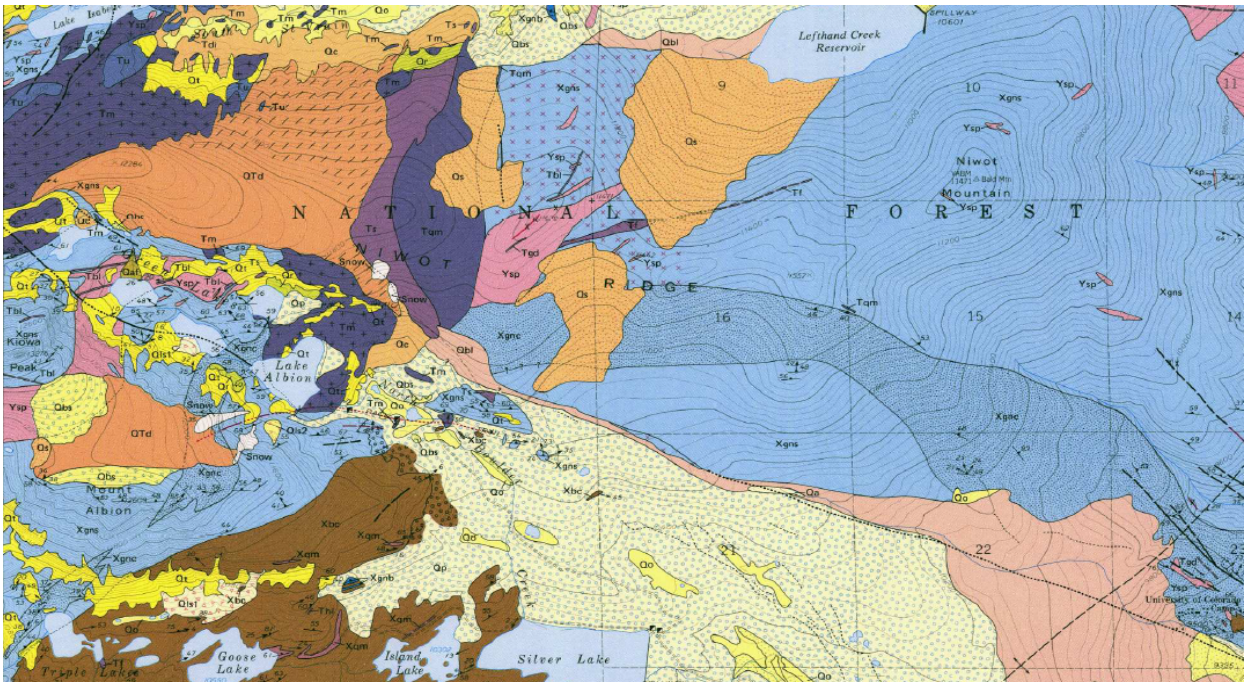


Figure 3. Geology map of the Niwot Area from the Ward 1:24,000 USGS quadrangle (Gable and Madole, 1976). This detailed map was used fo the site summary. NEON rock units include:
Holocene: Qa – Alluvial Deposit; Qs – Solifluction Deposit (some Pleistocene);
Pleistocene: Qp – Till of Pinedale Age; Qbl – Till of Bull Lake Age;
Tertiary: Ts – Syenite; Tqm – Quartz Monzonite;
Precambrian: Xgnc–Cordierite-bearing Garnet-Sillimanite-Biotite Gneiss; Xgns–Cordierite & Magnetite-bearing Sillimanite-Biotite Gneiss; Ysp–Silver Plume Quartz Monzonite

The vegetation consists of the following species groups as defined by the Colorado Vegetation Model (Figure 4):

- Alpine vegetation, alpine grasses and forb mix (pink color),
- Subalpine grass/forb mix [yellow color].
- Coniferous forest dominated by *Pinus contorta* (lodgepole pine), *Picea Englemannii* (Englemann spruce) and *Abies lasiocarpa* (subalpine fir) [grayish green color].
- Mixed coniferous/deciduous forest dominated by *Pinus Englemannii* (Englemann spruce), *Abies concolor* (white fir), *Pinus contorta* (lodgepole pine) and *Populus tremuloides* (Quaking Aspen) [bright green color].
- There are some talus and scree slopes (grey color, i.e. mostly fractured rock and bedrock) that are exposed to severe winds and are at the highest elevations above 3550 m. These are mostly in the CQ (Cirque land) soil map units on the soil survey (Figure 1). These areas consist mostly of thick rubble deposits with exposed bedrock and typically lack sufficient fine-earth material to sample. Two of the alpine NEON plots were chosen in more bouldery areas to represent some of this diversity, but there were no plots put directly in these areas for the reasons mentioned above.
- Areas of low shrubs, krumholtz and dispersed trees that occur in the transitional are between the alpine grasslands and the subalpine forest and grasslands are not shown directly on the veg model but can be seen where alpine tundra and subalpine grasslands intermingle. However, map unit 8772C (Figure 1) is the approximate boundary of this transition area.

The provisional soil survey for the Niwot area is the Soil Survey of the Arapaho-Roosevelt National Forest Area, Colorado, Parts of Boulder, Clear Creek Gilpin, Grand, Park, and Larimer Counties and the survey area is defined as **CO645** (Soil Survey Staff, 2019). The provisional soil survey identifies the Niwot Ridge area as characterized by skeletal (high rock fragments) soils with loamy textures classified as Dytrocryepts (Leighcan and Catamount families), Humicryepts (Moran family), Lithic Cryorthents (no series assigned), Cryaquolls (no series assigned) and the miscellaneous areas of Rock Outcrop and Rubble Land.

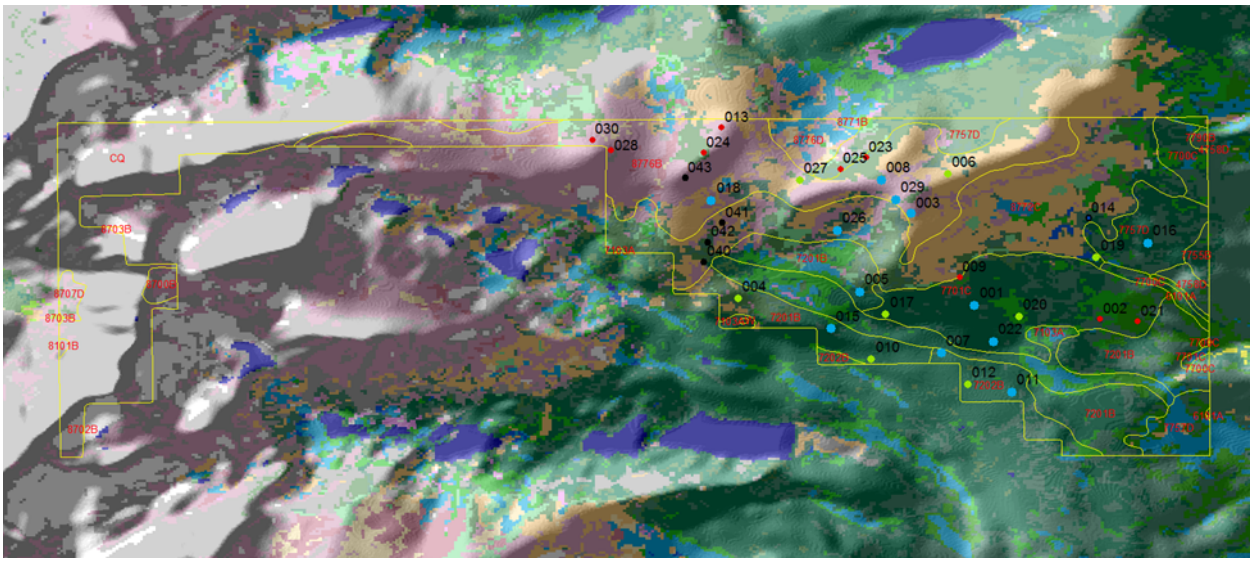


Figure 4. Niwot Ridge plots with SSURGO soil mapping overlaid on the Colorado Vegetation Model (Theobold, D., 2005. Colorado Vegetation Model (CVEG). www.nrel.colostate.edu/~davet/cvm.html)

Analysis of Plots for Sampling

The Niwot Ridge site occurs in an order-3 Soil Survey. Order-3 is less intensive than an order-2 soil survey, so there may be more soil complexity than the soil mapping indicates in some areas (Figure 1). Twenty-two soil map units are in the area, but the eight largest map units cover about 93% of the area. NEON distributed and tower plots occur in six of the eight largest soil map units; No plots occur in map units 7103A and CQ (Table 1).

The proportion of sample plots chosen roughly corresponds to their percentage of the map units (Figures 1 and 4; Table 1). Also taken into consideration were landform position, surface shapes, vegetative covers representative of the map units, and overall distribution of plots. Thirteen plots were chosen for sampling, and eight alternate plots to be used as backups (Figure 1, Table 2).

The soil map units in the Niwot area, including named components, are mapped at the soil family or subgroup level in Soil Taxonomy. Thus, the range of soil properties and parent materials in an order-3 map unit is generally greater than for an order-2 Soil Survey, such as one on the Colorado plains with areas of agriculture and other intensive land uses. Order-3 soil survey areas are common on forest service lands such as CO645. Use of soil map units at the family level allows variation from the official soil series (OSD) concepts for components within the unit. The taxonomic subgroup "Lithic Dystrocryepts" usually implies a precision level slightly less than soil series or the family level and the taxonomic great group such as "Cryaquolls" is a concept less precise than a subgroup. The third type of soil component used in the Niwot area is "miscellaneous groups", which are entities not defined as soil by Soil Taxonomy and include rubble land, cirque land, and rock outcrop.

Seven map unit components are mapped in the six different map units that contain NEON plots. These include 3 soils at the family level, a taxonomic subgroup, a taxonomic great group, and two miscellaneous areas without soil material. For the soil series at the family level, a brief introduction from the OSD is provided (Soil Survey Staff, 2019) and the variations from the OSD for the CO645 survey area. These seven components include:

Leighcan family

- The Leighcan series consists of very deep, well drained soils that formed in till, slope alluvium, or colluvium from acid igneous rocks. Leighcan soils are on mountain slopes and have slopes of 0 to 70 percent.
- Leighcan Taxonomy: Loamy-skeletal, mixed, superactive Typic Dystrocryepts
- Leighcan components for Niwot area included: Leighcan family (till substratum), Leighcan (moist), and Leighcan (south aspects):
- The Leighcan components for the Niwot area may vary from the OSD by having silt loam textures in the top two horizons instead of sandy loams and a densic contact at 50 to 100 cm.

Moran family

- The Moran series consists of very deep, well drained soils on mountain slopes, mesa summits, and foot slopes. They formed in slope alluvium, colluvium, and till. Slopes are 0 to 70 percent.
- Taxonomy: Loamy-skeletal, mixed, superactive Typic Humicryepts
- The Moran component for the CO645 varied from the OSD by having a Cr contact (weathered bedrock) at 100-150 cm.

Catamount family

- The Catamount series consists of shallow, excessively or somewhat excessively drained soils that formed in slope alluvium over residuum from granitic rocks, gneiss, and schist. Catamount soils are on mountain side slopes and ridges and have slopes of 5 to 70 percent.
- Taxonomy: Loamy-skeletal, micaceous, shallow Ustic Dystrocryepts
- Component variations: In CO645, the Catamount component is largely like the Catamount OSD.

Cryaquolls

- In the Niwot area, these are described as soils of floodplains, drainageways and depressions with silt loam surfaces and sandy loam, loam or silt loam subsoils. They have seasonal saturation at or immediately below the surface during the wetter times of the year. Cryaquolls typically meet criteria as hydric soils and wetlands in the Niwot area.

Lithic Cryorthents

- This component is categorized at the subgroup level and is characterized by sandy loams with high rock fragments (skeletal) and an R horizon (indurated bedrock contact) at between 25 and 50 cm.

Rubble Land

- Consists of cobbles, stone and boulders without significant fine-earth material in the top 200 cm.

Rock outcrop

- Exposures of bare bedrock at the surface without overlying soil material.

Table 1 summarizes the number of plots in each soil map unit and Table 2 shows the plot IDs and the coordinates and sampling status for each NEON plot. Note that only the "Yes" plots were sampled and that none of the "Alternate" plots needed to be sampled.

The 8776D map unit in the alpine tundra had the most coverage of Niwot plots and four were chosen for sampling (NIWO_003, 008, 018 and 029). Several plots at the western end of the site (NIWO_013, 024, 020, 030) were not chosen due to access and safety concerns. The sampled alpine plots were good representatives of those soils and ecosystems. Two plots (NIWO_028 and 030) located in the Laramide intrusive non-volcanic rocks were not selected for sampling, however soil properties are often similar in the high grade metamorphic (meta-igneous) rocks of Precambrian-age (Xb formation) to the Laramide intrusive non-volcanic rocks (Tki); furthermore, the soil mapping scheme used for this area shows both areas as being mapped in the 8776B soil map unit.

The 8772C soil map unit occupies the second largest acreage of the NIWO site. Two plots (NIWO_026 and 014) were sampled in this map unit. Three additional plots (NIWO_041, 042 and 040) are also within this map unit, however they were not selected for sampling due to the inability to sample these skeletal soils using an auger, which is the only method allowable for Tower plots. This map unit is a transition zone from the alpine tundra and subalpine. It is characterized by mostly tundra-like grasslands with krumholtz trees and occasionally taller trees in the lowest elevations. These NEON plots were generally alpine tundra with small patches of krumholtz, thus sampling locations were not located directly within the krumholtz.

Three plots (NIWO_001, 016 and 022) were chosen for the 7701C and 7757D map units to represent forested map units with colluvial parent materials.

Four plots (NIWO_005, 007, 011 and 015) were chosen in the 7201B and 7202B map units that represent forested glacial till areas. Glacial till map units with a Cryaquolls component (7202B and 7103A) are mapped somewhat frequently at the Niwot Ridge site. Two (NIWO_007 and 011) of the three plots in map unit 7202B were chosen and two plots (NIWO_005 and NIWO_015) mapped in a lower landscape position of 7201B was chosen with the expectation that one of these plots will be representative of the Cryaquolls component found at the NIWO site.

Note that the soil mapping for the Niwot area while posted on the WebSoilSurvey, is provisional data and has not yet been correlated. Another consideration with plot selection is that the soil map unit delineation or polygons do not align perfectly with the imagery. The polygons appear to be offset about 60 meters. This might indicate a NAD27 to NAD83 Datum shift. This offset was taken into consideration when selecting the plots. Some plots that occurred near map unit or vegetation boundaries and plots in areas where soil polygons did not line up well with the imagery were not chosen. Conversely, plots NIWO_029 and 003 are near boundary areas based on the mapping but were chosen since they appeared to be in the "correct" map unit based on landscape position and vegetation.

Table 1. Plot distribution and Soil Map Unit areal coverages at the NIWO site. MU= map unit.

Map Unit Symbol	Map Unit Name	# Plots in MU	# Plots Chosen	# Alternates Chosen	Acres	% Site Area
4758D	Catamount family-Rubble land-Bullwark family complex, 40 to 150% slopes	0	0		24	0.6
6101A	Cryaquolls-Gateview family complex, 0 to 15% slopes	0	0		8	0.2
7103A	Cryaquolls-Leighcan family, till substratum complex, 0 to 15% slopes	0	0		222	5.4
7201B	Leighcan family, till substratum, 5 to 40% slopes	4	2	2	562	13.6
7202B	Leighcan family, till substratum-Cryaquolls complex, 5 to 40% slopes	3	2	1	111	2.7
7700C	Leighcan family, 40 to 75% slopes	0	0		92	2.2
7701C	Leighcan family, till substratum, 5 to 40% slopes	7	2	2	407	9.9
7702B	Frisco-Catamount, moist families complex, 5 to 40% slopes	0	0		0	0.0
7755B	Leighcan-Catamount, moist families complex, 5 to 40% slopes	0	0		20	0.5
7757D	Leighcan-Catamount, moist families-Rock outcrop complex, 40 to 150% slopes	2	1^	0	306	7.4
7790B	Lithic Cryorthents, subalpine-Rubble land complex, 5 to 40% slopes	0	0		7	0.2
8101B	Cryaquepts-Bross family complex, 5 to 25% slopes	0	0		3	0.1
8700B	Bross-Matcher families-Lithic Cryorthents complex, 5 to 40% slopes	0	0		22	0.5
8702B	Bross family-Cryaquepts complex, 3 to 25% slopes	0	0		0	0.0
8703B	Matcher family-Cryaquepts-Rock outcrop complex, 5 to 25% slopes	0	0		2	0.0
8707D	Bross family-Rubble land-Matcher family complex, 40 to 150% slopes	0	0		20	0.5
8771B	Leighcan family-Cryaquolls-Moran family complex, 5 to 40% slopes	0	0		5	0.1
8772C	Moran family-Lithic Cryorthents-Leighcan family complex, 40 to 75% slopes	6	2*	1	775	18.8
8776B	Moran family-Lithic Cryorthents-Rubble land complex, 5 to 40% slopes	12	4	2	797	19.3
8776D	Moran family-Lithic Cryorthents-Rubble land complex, 40 to 150% slopes	0	0		67	1.6
CQ	Cirque land, 40 to 150% slopes	0	0		670	16.3
W	Water	0	0		1	0.0
Totals		**34**	**13**	**8**	**4121**	**100.0**

^ 1 plot was on MU boundary and transition area and not suitable

* only 2 plots were suitable because 3 were tower plots (pits were not allowed, and auger samples were not feasible due to the rock fragments) and 1 was near MU boundary/transition area.

Table 2. Niwot Ridge NEON plots and their sampling designation (Yes, No, Alternate or Tower).

NEON plotID	Easting	Northing	Decimal Lat	Decimal Long	NLCD Class	Sampling Designation
NIWO_001	452295.4	4432587	40.04216	-105.559	evergreenForest	Yes
NIWO_002	453312.4	4432438	40.04088	-105.547	evergreenForest	No
NIWO_003	451784.2	4433578	40.05107	-105.565	grasslandHerbaceous	Yes
NIWO_004	450374.3	4432678	40.04288	-105.582	evergreenForest	Alternate
NIWO_005	451365.2	4432739	40.04348	-105.57	evergreenForest	Yes
NIWO_006	452084.5	4433999	40.05487	-105.562	grasslandHerbaceous	Alternate
NIWO_007	452020.8	4432077	40.03756	-105.562	evergreenForest	Yes
NIWO_008	451544.8	4433938	40.05429	-105.568	grasslandHerbaceous	Yes
NIWO_009	452174.8	4432888	40.04487	-105.561	evergreenForest	No
NIWO_010	451454.2	4432020	40.03701	-105.569	evergreenForest	Alternate
NIWO_011	452594.4	4431657	40.03381	-105.556	evergreenForest	Yes
NIWO_012	452234.4	4431746	40.03459	-105.56	evergreenForest	Alternate
NIWO_013	450254.3	4434509	40.05936	-105.583	grasslandHerbaceous	No
NIWO_014	453224.5	4433517	40.0506	-105.548	evergreenForest	Yes
NIWO_015	451126.4	4432346	40.03993	-105.573	evergreenForest	Yes
NIWO_016	453704.5	4433248	40.0482	-105.543	evergreenForest	Yes
NIWO_017	451574.2	4432499	40.04133	-105.568	evergreenForest	Alternate
NIWO_018	450166.1	4433727	40.05232	-105.584	grasslandHerbaceous	Yes
NIWO_019	453285	4433097	40.04682	-105.548	evergreenForest	Alternate
NIWO_020	452652.5	4432469	40.04112	-105.555	evergreenForest	Alternate
NIWO_021	453616.1	4432407	40.04062	-105.544	evergreenForest	No
NIWO_022	452444.8	4432199	40.03868	-105.557	evergreenForest	Yes
NIWO_023	451424.2	4434178	40.05645	-105.57	grasslandHerbaceous	No
NIWO_024	450105.7	4434238	40.05692	-105.585	grasslandHerbaceous	No
NIWO_025	451214.3	4434058	40.05536	-105.572	grasslandHerbaceous	No
NIWO_026	451185.8	4433396	40.04939	-105.572	grasslandHerbaceous	Yes
NIWO_027	450885.1	4433938	40.05426	-105.576	grasslandHerbaceous	Alternate
NIWO_028	449355	4434268	40.05714	-105.594	grasslandHerbaceous	No
NIWO_029	451662.6	4433727	40.0524	-105.567	grasslandHerbaceous	Yes
NIWO_030	449205.3	4434385	40.05818	-105.596	grasslandHerbaceous	No
NIWO_040	450103.2	4433068	40.04637	-105.585	evergreenForest	Tower
NIWO_041	450254.7	4433488	40.05017	-105.583	shrubScrub	Tower
NIWO_042	450134.8	4433278	40.04827	-105.585	grasslandHerbaceous	Tower
NIWO_043	449955	4433968	40.05447	-105.587	grasslandHerbaceous	Tower

Plot Findings

Tables 3, 4 and 5 summarize the conditions found at the sampled Niwot plots. While the plots were selected to cover a wide range of conditions, some soil properties were similar across all the Niwot plots. Twelve out of thirteen pedons were loamy skeletal (> 35% by volume coarse rock fragments in the subsoil particle-size control section) and the other pedon was coarse-loamy. Of the 12 Loamy-skeletal soils, seven were estimated to be between 18 and 30% clay in the subsoil particle-size control section and five were estimated to be coarser, with between 8 and 18% clay in the subsoil. All sampled plots were estimated to have a Typic Udic moisture regime and a cryic soil temperature regime.

Although the shallow soils of Lithic Cryorthents and Catamount are considered 2nd components in some of the map units, we did not observe any bedrock contacts within or immediately below the 100 cm sample depths. Further, we estimated at each of the plots that soil depth was very deep (>150 cm), as observation of landforms, gullies, roadcuts and surface characteristics showed little if any evidence of bedrock contacts near the vicinity of any of the neon plots sampled. We also did not observe rock outcrops near the NEON plots sampled. However, the NEON NIWO tower soil pit described in 2015 found a Cr/C (e.g. rock) contact at 110 cm, meaning parts of the pit had unconsolidated C material and other parts had a soft rock (paralithic) contact. These data show some evidence of the Moran family component data for CO645. The Moran OSD is very deep but the CO645 Moran family deviates from the OSD by describing the soil as deep (100 – 150 cm) to a Cr contact.

The range in field-measured soil pH was between 5.0 and 5.6 for all horizons in 9 out of the 13 pedons. Deviating from the norm were surface pH values of 6.4 on NIWO_008 (tundra) and 7.2 on NIWO_014 (forested) and subsoil pH values of 6.0 on NIWO_011 (forested) and 4.4 on NEON_029 (tundra). It was not readily apparent that vegetation, patent material or other factors such as aeolian/dust deposits had an influence on these variations in pH.

All five alpine plots had a dark surface horizon (umbric epipedon) that qualified them as Typic Humicryepts, and four of these fit the Moran soil series while one was similar to Moran. Only one of the eight forested plots (NIWO_015) had an umbric epipedon, a poorly drained Aquic Humicryept.

The SSURGO mapping did not indicate any Alfisols except as minor components, however, our investigation revealed several Alfisols with argillic horizons in the subalpine forested areas.

Three of the four colluvial forested plots (NIWO_011, 014 and 016) and one of four forested glacial till plots (NIWO_007) exhibited argillic horizons. None of the five tundra plots had an argillic horizon, which is not surprising given the severe cold temperatures and unstable peri-glacial environments.

Pinedale till is generally considered to have less weathering of the rock fragments, greater amounts of aquic soil conditions and less mature soil development than soils formed in the older Bull Lake tills. However, with only 4 pedons described and sampled in the glacial till and the fact that all four plots occurred near the boundaries between the two different tills or with colluvium, our sampling scheme and frequency were not conducive to identifying these differences in the field. Two of the glacial till pedons had higher clay (18-30%) estimates in the subsoils and two were lower in clay (8-18%).

There was one pedon, classified as a spodosol (NIWO_005) and another that had spodic-like properties in some parts (NIWO_011). The Leighcan OSD suggests that this series often has properties that approach the Spodosol soil order.

In Table 3 and the following summary, three levels of agreement were found between the observed soil properties and the previous soil survey map units. If the pedon fits either the OSD or the component data for CO645 then we identified that series. Interestingly, most of the NIWO plots fit the OSD criteria better than the CO645 component data for this area. If the pedon varied by one or two attributes but would manage the same for most land uses, it is referred to as "somewhat similar". Depending on the research purpose, "somewhat similar" soils may or may not be appropriate matches for a particular focus. Finally, if the pedon did not fit the series or component concept it was considered "dissimilar".

Many of these determinations, especially those related to argillic horizons, particle-size analysis, minerology and spodic criteria are subject to change pending laboratory results.

Table 3. Soil characteristics observed for each of the NEON plots.

NEON plotID	MU SYM	BR depth (cm)**	Series	Field Determined Taxonomic class^	% Clay^^	PM identified at the pedon pit
NIWO_001	7701C	>150	SND+	Loamy-skeletal, mixed, superactive Typic Haplocryalf	24% (19-29)	Colluvium from Granite Gneiss
NIWO_003	8776B	>150	Moran	Loamy-skeletal, mixed, superactive Typic Humicryept	8% (3-13)	Colluvium from Gneiss
NIWO_005	7701C	>150	Grenadier	Loamy-skeletal, isotic, superactive Entic Haplocryod	23% (18-28)	Colluvium from Hornblende Gneiss
NIWO_007	7202B	>150	SND+	Loamy-skeletal, mixed, superactive Typic Haplocryalf	19% (14-24)	Till from Honblende Gneiss
NIWO_008	8776B	>150	SND+	Loamy-skeletal over fragmental, mixed, superactive Typic Humicryept	21% (16-26)	Colluvium & Solifluction from Granite over Residuum from Gneiss
NIWO_011	7202B	>150	Leighcan	Loamy-skeletal, mixed, superactive Typic Dystrocryept	8% (3-13)	Till from granite & Gneiss
NIWO_014	8772C	>150	SND+	Loamy-skeletal, mixed, superactive Typic Haplocryalf	21% (16-26)	Colluvium from Biotite Gneiss
NIWO_015	7201B	>150	SND+	Loamy-skeletal, mixed, superactive Aquic Humicryept	30% (26-34)	Slope Alluvium over Till from Hornblende Gneiss
NIWO_016	7757D	>150	SND+	Loamy-skeletal, mixed, superactive Typic Haplocryalf	27% (22-32)	Colluvium from Gneiss
NIWO_018	8776B	>150	SND+	Coarse-loamy, mixed, superactive Typic Humicryept	16% (11-21)	Solfluction from Hornblende Gneiss
NIWO_022	7701C	>150	Leighcan	Loamy-skeletal, mixed, superactive Typic Dystrocryept	15% (10-20)	Till from Granite
NIWO_026	8772C	>150	Moran	Loamy skeletal, mixed, superactive Typic Humicryept	15% (11-19)	Colluvium from Granite
NIWO_029	8776B	>150	Moran	Loamy skeletal, mixed, superactive Typic Humicryept	14% (9-19)	Colluvium and Solifluction from Gneiss

** BR depth = bedrock depth, estimated from looking at the material excavated to sample and extract the bottom horizon (typically around 110 cm) and by observing the landform, surface characteristics, road cuts, tree throw and trail cuts in the area. It is possible that a paralithic or lithic contact occurred above 150 cm in some of these soils.
+ SND = Series Not Defined
^ Field determined taxonomic classes and soil series are subject to change upon completion and review of lab data.
^^ Estimated in subsoil control section. Ranges in parentheses are +- 4% and reflect typical error ranges for field estimates of clay.

Table 4. Climate, Geormorphic and Geologic Setting for the sampled NEON plots.

NEON plotID	MU SYM	Precip mm	Effective precip. mm	Elev. m *feet*	Slope gradient	Slope aspect	Shape^ vertical/ horizontal	Relative slope position	Geology map unit name	Geology map unit \dDescription
NIWO_001	7701C	934	925	3224 *10,578*	13	133	V/L	middle	Xgns	Codierite- & Magnetite-bearing Sillimanite-Biotite Gneiss
NIWO_003	8776B	1007	925	3503 *11.493*	13	183	L/V	upper	Xgns (near Xgnc boundary)	Codierite- & Magnetite-bearing Sillimanite-Biotite Gneiss
NIWO_005	7201B	995	925	3267 *10,719*	39	181	L/L	center	Xgns	Codierite- & Magnetite-bearing Sillimanite-Biotite Gneiss
NIWO_007	7202B	924	950	3030 *9,941*	5	100	L/L	middle /lower	Qp (near Qbl boundary)	Pinedale Glacial Till
NIWO_008	8776B	1015	1,025	3504 *11,496*	9	15	C/L	upper	Xgns	Codierite- & Magnetite-bearing Sillimanite-Biotite Gneiss
NIWO_011	7202B	860	900	3129 *10,267*	24	15	V/L	upper	Qp (near Qbl boundary)	Pinedale Glacial Till
NIWO_014	8772C	917	850	3210 *10,532*	23	143	L/V	upper	Xgns	Codierite- & Magnetite-bearing Sillimanite-Biotite Gneiss
NIWO_015	7201B	985	1,050	3217 *10,554*	10	20	L/C	middle	Qbl (near Xgns & Qp boundaries)	Bull Lake Till
NIWO_016	7757D	871	800	3125 *10,253*	36	195	L/L	middle	Xgns	Codierite- & Magnetite-bearing Sillimanite-Biotite Gneiss
NIWO_018	8776B	1023	1,000	3485 *11,434*	10	165	C/L	upper	Qs	Solifluction

NIWO_022	7701C	902	875	3148 *10,326*	19	135	L/L	middle	Qbl (near Xgns boundary)	Bull lake Till
NIWO_026	8772C	1022	1,050	3378 *11,083*	14	163	C/C	lower	Xgnc	Codierite-bearing Garnet=Sillimanite-Biotite Gneiss
NIWO_029	8776B	1013	950	3497 *11,473*	28	246	L/L	upper	Xgns	Codierite- & Magnetite-bearing Sillimanite-Biotite Gneiss

Definitions (left to right) come from Schoeneberger and Wysocki, 2017: "Effective precip."= relative quantity of precipitation stored in the soil; "Slope aspect"= in degrees, range 0-360; "Shape =slope shape described in two directions: 1) "vertical" =up and down, perpendicular to the contour and 2) "horizontal" =across slope, parallel to the contour) L=linear, C=concave and V=Convex.

Table 5. Vegetation frequency of selected species for the NEON sampled plots. Only species that were codominant on at least one plot are included in this list.

NEON plotID	Elev. m	MU SYM	Veg. structure	Limber Pine	Lodgepole Pine	Engelmann Spruce	Subalpine Fir	Vaccinium sp.	common juniper	stiff clubmoss	Mt. Albert Goldenrod	Creeping Sibaldia	Common Yarrow	Sedges (Carex)	Lousewort	Alpine clover	Twinflower sandwort	Alpine lewisa	Moss campion	Caspitose four-nerve daisy
NIWO_001	3224	7701C	forest		F	R	F	F	F		F									
NIWO_003	3503	8776B	alpine tundra														R		F	F
NIWO_005	3267	7201B	forest	R		F	F	F	F		R									
NIWO_007	3030	7202B	forest		R	A	A	R	R	R										
NIWO_008	3504	8776B	alpine tundra											F		F			F	
NIWO_011	3129	7202B	forest		F	F	F	A		R										
NIWO_014	3210	8772C	forest	F		R	A	F			R			F						
NIWO_015	3217	7201B	forest			F	F	F	F											
NIWO_016	3125	7757D	forest	F	R		R		F		R				F					
NIWO_018	3485	8776B	alpine tundra				R(k)				R				F		F	F	R	
NIWO_022	3147	7701C	forest		F	F	F	F	F	F				R						
NIWO_026	3378	8772C	alpine tundra	R(k)		R(k)		R	R		F	F	F	R			R			
NIWO_029	3497	8776B	alpine tundra											F		F	F		F	R

A = abundant – 40-60% coverage of pedon area; F = frequent to Occasional – 5-40% coverage of pedon area; R = rare -- <5% coverage of pedon area; K = krummholz, indicates that the species is only found in the krummholz growth form at pedon area.

Summary of Soils

The soil characteristics can be summarized as three groups:

1. Forested soils formed in colluvium: These occur in Codiertie and Magnetite-bearing Sillmanite-Biotite Gneiss (Xgns geology unit). Plots NIWO_001, NIWO_005, NIWO_014 and NIWO_016. Generally, 7701C and 7757D best fit this concept. However, NIWO_014, which occurred within 8772C in a forested area along the 7757D map unit boundary was also included in this grouping. Although NIWO_014 does seem to exhibit some characteristics of tundra soils, it was a better fit for the forested 7757D map unit.
2. Forested soils formed in glacial till: These are of the Pinedale (Qp) or Bull Lake origin (Qbl). Plots NIWO_007, NIWO_011, NIWO_015 and NIWO_022. Map units 7201B, 7202B best fit this concept. However, NIWO_022, which occurred close to the 7103A (a glacial till unit) boundary and the Qbl geology unit boundary, was also included in this grouping.
3. Alpine tundra soils formed in colluvium and/or solifluction: These occur in the Codiertie and Magnetite-bearing Sillmanite-Biotite Gneiss (Xgns), Codiertie-bearing Garnet-Sillmanite-Biotite Gneiss (Xgnc), or Quaternary Solifluction (Qs) geology unit. Plots NIWO_003, NIWO_008, NIWO_018, NIWO_026 and NIWO_029 are located within this group. Map unit 8776B and the alpine portions (Moran and similar components) of map unit 8772C fit this grouping.

Forested Soils formed in colluvium

NIWO_001

Map Unit: 7701C - Leighcan family, 40 to 75% slopes, south aspects

Field Investigation: Loamy-skeletal, mixed, superactive Typic Haplocryalf - Series not defined.

Prominent characteristics include an argillic horizon (48-102, Bt1, Bt2), and an estimate of 24% clay in the subsoil. E horizon (8-48 cm) colors were almost but not quite pale enough to meet albic criteria.

This pedon was “somewhat similar” to the Leighcan series. It displayed more development with an argillic horizon (Alfisol instead of an Inceptisol) and more clay than is allowed with the Leighcan series.

NIWO_005

Map Unit: 7701C - Leighcan family, 40 to 75% slopes, south aspects

Field investigation: Loamy-skeletal, isotic, superactive Entic Haplocryod - Grenadier.

Note in the mapping data used for plot selection, this plot fell just inside the 7201B map unit but when accounting for the 60-meter spatial error mentioned in the *analysis of plots for sampling* section, the pedon was located within a 7701C map unit delineation. The 7701C map unit

concept is more consistent with the parent material observed in the field and noted on the geology maps.

Prominent characteristics include an albic (E, 4-9 cm) and spodic horizon (Bs, 19-49 cm). This soil was loamy-skeletal in the subsoil with a field estimated clay content of 23%.

This pedon was "somewhat similar" to the Leighcan series but displays spodic characteristics and has more subsoil clay than a typical Leighcan. Soils with spodic characteristics are a common component within the Leighcan map units. Also, while this pedon did have a subsurface clay increase typical of argillic horizons, it lacked evidence of clay eluviation (argillans). Mineralogy, spodic properties, and particle size may or may not be confirmed by the lab analyses.

NIWO_014

Map Unit 8772C - *Moran family-Lithic Cryorthents-Leighcan family complex, 40 to 75% slopes*

Field Investigation: Loamy-skeletal, mixed, superactive Typic Haplocryalfs - Series not defined.

Prominent characteristics include an argillic horizon (Bt1, Bt2, Bt3, 23-110 cm), and loamy skeletal particle sizes with an estimate of 21% clay in the subsoil.

This pedon is "somewhat similar" to the Leighcan soils but with more development, an argillic horizon (Bt1, Bt2, Bt3) and more clay in the subsoil.

The EA horizon is somewhat dark (3/3 moist color and 6/3 dry color) but its dry color and color after mixing with the upper E horizon (the top 25 cm from the mineral surface) are not dark enough to meet criteria for an umbric epipedon.

Although occurring in 8772C, this pedon was near the boundary of 7757D - Leighcan-Catamount, moist families-Rock outcrop complex, 40 to 150% slopes. However, in this analysis it best fits in the grouping with the forested soils formed in colluvium and does seem to exhibit some characteristics of both forested soils and tundra soils.

NIWO_016

Map Unit 7757D Leighcan-Catamount, moist families-Rock outcrop complex, 40 to 150% slopes

Field Investigation: Loamy-skeletal, mixed, superactive Typic Haplocryalf - Series not defined

Prominent characteristics include an argillic horizon (Bt & 2BCt 37-100cm), and loamy skeletal particle sizes with an estimate of 27% clay in the subsoil. This pedon has a moderately dark (10YR 3/3) but thin A horizon and when mixed with the upper E horizon does not meet umbric epipedon criteria.

The development of an argillic with higher clay estimates makes this soil "somewhat similar" to the Leighcan component and very "dissimilar" to the Catamount component.

Forested soils formed in glacial till

NIWO_007

Map Unit: 7202B - *Leighcan family, till substratum-Cryaquolls complex, 5 to 40% slopes*

Field Investigation: Loamy-skeletal, mixed, superactive Typic Haplocryalf - Series not defined

Prominent characteristics include a weakly developed argillic horizon (BE, 21-44 cm), and loamy skeletal particle sizes with an estimate of 19% clay in the subsoil.

As described this soil is "somewhat similar" to the Leighcan series except it had a weak argillic horizon and slightly more subsoil clay than typical for Leighcan. However, the development of the argillic was weak and it is possible that lab data will not support a clay increase or subsoil clay greater than 18%.

This plot was mapped in the Pinedale Till but is close to the boundary of the Bull Lake Till.

NIWO_011

Map Unit 7202B - *Leighcan family, till substratum-Cryaquolls complex, 5 to 40%*

Field Investigation: Loamy-skeletal, mixed, superactive Typic Dystocryept - Leighcan series.

Prominent characteristics include a cambic (Bw, 37-74 cm) and albic (E, 5-37 cm) horizon and a Loamy-skeletal subsoil with an estimated 8% clay.

While this pedon had an albic horizon, the Bw horizon was bicolored but dominantly a yellowish-brown color (10YR hue) that does not meet spodic criteria without further lab data support. It is not uncommon for the Leighcan series to have soil properties that approach the Spodosol soil order.

This soil occurred in the Pinedale till about 100 meters upslope from the transition to Bull Lake Till and the 7201B map unit.

NIWO_015

Map Unit 7201B - *Leighcan family, till substratum, 5 to 40% slopes*

Field Investigation: Loamy-skeletal, mixed, superactive Aquic Humicryepts - Series not defined.

Prominent characteristics include an Umbric epipedon (0-59 cm, A, Baw and ABb horizons), evidence of saturation between 17 and 115 cm (Aquic subgroup conditions) and Loamy-skeletal particle size family with a field-estimate of 30% clay in the subsoil.

This pedon is "somewhat similar" to the Cryaquolls component. The pedon was apparently not subject to long enough periods of saturation to develop aquic conditions synonymous with hydric soils and wetlands. It was however, poorly drained and met the "aquic" subgroup category of soil taxonomy with evidence of a shorter duration water table below 17cm. It will not meet hydric or wetland criteria and will not support as many hydrophytic species as the typical Cryaquolls component.

Despite the high clay increase from the A horizon to the subsoil, we did not find evidence of clay illuviation and surmised that the clay increase was more related to slope alluvium deposits. In addition, we found buried A materials (39-59cm) evident of a soil with horizons more affected by deposition than pedogenesis.

While the plot occurred in 7201B, it was very close to 7103B. The southwestern portion of the plot fits more into the concept of 7201B but the northeastern part of the plot where the pedon was located is more consistent with the components of 7103A.

This pedon occurred near the boundary of the Bull lake tills and the Pinedale tills.

NIWO_022

Map Unit 7701C - Leighcan family, 40 to 75% slopes, south aspects

Field Investigation: Loamy-skeletal, mixed, superactive Typic Dystocryept - Leighcan series.

Prominent characteristics include a cambic (13-110, Bw1, Bw2, BC1 and BC2) and a Loamy-skeletal subsoil with clay estimated at 15%.

This plot was located in the 7701C map unit but was close to the 7103A (Cryaquolls-Leighcan family, till substratum complex, 0 to 15 percent slopes) boundary. It was also near a geologic boundary as it was mapped as Qbl (Bull lake till) but within a few meters of Xgns (Codierite- & Magnetite-bearing Sillimanite-Biotite Gneiss) on the geology quadrangle. Although the clast and landform showed possible indications of both colluvium and glacial till we determined this plot was a better fit with the glacial till soils.

Alpine tundra soils formed in colluvium and/or solifluction

NIWO_003

Map unit 8776B - *Moran family-Lithic Cryorthents-Rubble land complex, 5 to 40% slopes*

Field Investigation: Loamy-skeletal, mixed, superactive Typic Humicryepts - Moran series

Prominent characteristics include umbric epipedon (0-19, A and BA horizons) and a cambic (15-40, Bw) horizon. Subsoil clay was estimated at 8%.

NIWO_008

Map unit 8776B - *Moran family-Lithic Cryorthents-Rubble land complex, 5 to 40% slopes*

Field Investigation: Loamy-skeletal over fragmental, mixed, superactive Typic Humicryepts - Series not defined

This pedon was “somewhat similar” to the Moran series except that the fragmental layer was found at 40cm.

Prominent characteristics include an Umbric epipedon (0-15, A horizon plus mixing with the upper Bw) and cambic horizon (15-40, Bw horizon) and a fragmental horizon with 90% rock fragments from 40 to 100 cm (C horizon). Pedon rock fragments for the Bw horizon were estimated at 65% and clay at 21%.

NIWO_018

Map unit 8772C - *Moran family-Lithic Cryorthents-Rubble land complex, 5 to 40% slopes*

Field Investigation: Coarse-loamy, mixed, superactive Typic Humicryepts – Series not defined.

Prominent characteristics include an Umbric epipedon (0-17, A1 and A2horizons) and cambic horizon (17-115, EB, Bw1 and Bw2 horizons). Pedon rock fragments for the subsoil control section was 17% making this pedon Coarse-loamy and our only non-skeletal pedon. Estimated subsoil clay was 16%.

This soil is "somewhat similar" to the Moran series component. Notably, this was the only Niwot pedon that did not classify as a loamy-skeletal particle-size family.

This pedon was formed in solifluction materials. The EB horizon had what we judged to be relict redoximorphic features. However, the Bw1 and Bw2 horizons had very large numbers of roots compared to the EB, so the horizons could have been functioning as densic-like horizons, although the similar excavation difficulty and particle-sizes as the horizons above did not indicate a densic horizon. There were also some platy-like features in the BW1 and Bw2 that we judged to be geogenic rather than pedogenic origin. Lab data, especially bulk density may shed more light on these horizons.

NIWO_026

Map unit 8772C - Moran family-Lithic Cryorthents-Leighcan family complex, 40 to 75% slopes

Field Investigation: Loamy-skeletal, mixed, superactive Typic Humicryepts - Moran series

Prominent characteristics include an Umbric epipedon (0-44, A1, A2 and BAt horizons) and cambic horizon (44-110, Bt and BCt horizons). Pedon rock fragments for the subsoil control section was 35% placing this soil barely into Loamy skeletal particle size family with an estimated subsoil clay of 15%.

Note that while we called Bat, Bt and BCt horizons in the field because of significant clay films, our field estimates for clay did not show an increase in clay from the A1 and A2 horizons, thus if our field clay estimates are accurate it will not meet the definition of an argillic horizon and instead qualifies as a cambic horizon.

This pedon represented the alpine tundra component of this map unit.

NIWO_029

Map unit 8776B - *Moran family-Lithic Cryorthents-Rubble land complex, 5 to 40% slopes*

Field Investigation: Loamy-skeletal, mixed, superactive Typic Humicryepts - Moran series

Prominent characteristics include an Umbric epipedon (0-8, A plus mixing with the upper Bw) and a cambic horizon (8-64, Bw and BC), and loamy-skeletal particle sizes with an estimate of 14% clay in the subsoil.

Even though the A horizon is relatively thin (0-8cm), the mixing of its very dark color (10YR 2/1) with the upper Bw horizon (10YR 4/3) meets umbric epipedon criteria.

This soil occurred in a periglacial patterned-ground area between stone stripes. The stone stripes would be included in the Rubble-land component of this map unit.

References

Gable Dolores J. and Madole, Richard F. 1976. Geologic map of the Ward quadrangle, Boulder County, Colorado. USGS Geologic Quadrangle Map GQ-1277, scale 1:24,000.

Soil Survey Staff, 2019. Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions. Available online. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053587 Accessed [2/14/2019].

Soil Survey Staff, 2019. Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey of the Arapaho-Roosevelt National Forest Area, Colorado, Parts of Boulder, Clear Creek Gilpin, Grand, Park, and Larimer Counties (CO645). Available at the following link: https://websoilsurvey.sc.egov.usda.gov/. Accessed [2/15/2019]

Schoeneberger, P.J., and Wysocki, D.A. 2017. Geomorphic Description System, Version 5.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Theobold, D., 2005. Colorado Vegetation Model (CVEG). Available online at the following link. www.nrel.colostate.edu/~davet/cvm.html). Accessed [1/30/2017]