THESIS

SOIL WEATHERING UNDER MOUNTAIN PINE BEETLE KILLED TREES,

GRAND COUNTY, COLORADO

Submitted by

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ABSTRACT

SOIL WEATHERING UNDER MOUNTAIN PINE BEETLE KILLED TREES,

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The objective of this study is to assess differences in soil weathering processes under mountain pine beetle killed trees, as compared to soil weathering under living trees. As pine beetle (*Dendroctonus pondersoae*) infected trees die, pine needles are shed and accumulate on the forest floor, which may lead to changes in soil pH and soil temperature as the organic horizon thickens and insulates the soils below. Additionally, decomposition of the dropped needles may cause chemical changes in the substrate. These changes in soil pH, temperature, and chemistry are likely to affect weathering of soil minerals. Two hypotheses related to soil weathering processes under beetle infected trees are evaluated: (1) the death of pine trees and accompanying increased pine needle decomposition has increased chemical weathering of the substrate, and (2) an increase in soil weathering under dead pine stands has increased downslope physical migration of weathered material.

This study was conducted in the Kauffman Creek watershed in the mountain pine beetle infected Arapahoe National Forest of Grand County, Colorado. Soil samples were collected from a south facing hillslope and from elevations of approximately 9100 to 9400 feet, thus minimizing differences in weathering processes related to hillslope aspect or elevation. Kauffman Creek incises mountainous terrain and the study area is hosted by Paleocene – Eocene sedimentary rocks of the Coalmont Formation. Soils of Kauffman Creek are predominately inceptisols and entisols. The field site was chosen to show a range in pine beetle infestation and health conditions of pine trees on the hillside. On the hillslope there are stands of healthy (green) or recently attacked (brown) pine trees and there are other areas where the pines are in the final stages (gray) of beetle infestation (≥4 years post attack) and have dropped most of their needles.

A study of soil characteristics (i.e. grain size, inorganic geochemistry, mineralogy, pH, and saturated paste electric conductivity) was conducted to evaluate soil weathering processes. Analytical results indicate that the mean grain size is approximately 1.3 times coarser beneath the gray stands than beneath the healthy-appearing, green pine stands. Major element geochemistry shows average concentrations of Na and K are greater, and average concentrations of Mn and Mg are smaller, in soils beneath the gray pine stands than from those under green stands. The differences in soil chemistry within the soils beneath the gray stands, compared to the soils beneath the green pine stands, suggest increased chemical weathering of soil under the gray stands. Chemical results for soils under the brown stands suggest they also have experienced increased weathering, compared to the green stands. Petrographic results show that the modal percentage of quartz is approximately 1.2 to 1.4 times greater in the soils beneath the gray stands than in the soils under the green stands, while the modal percentages of soil aggregates and micas decrease from the soils under the green stands to the soils under gray trees. The average topsoil pH is lower in the soils beneath the brown and gray trees than in the soils beneath the healthy pines. Soil conductivity data suggests an increase in soil moisture under the brown and gray pine stands. Overall, increased pine needle litter and its decomposition appear to have increased soil weathering. Downslope migration of weathered material was not evident in the results of this study.

ACKNOWLEDGEMENTS

I would like to sincerely thank my advisor Dr. Sally Sutton for making this research opportunity possible, as well as for her guidance and encouragement on my research and thorough review of my thesis. Also thank you to Dr. John Stednick and Dr. John Ridley for their assistance and support of my thesis work. I am grateful for the financial support provided by grants and scholarships from: Rocky Mountain Association of Geologists, Colorado State University Geosciences Graduate Scholarship Committee, and the Colorado Scientific Society.

DEDICATION

I dedicate this thesis to my mother, Michele, who passed away before seeing me fulfill my goals of pursuing a college education. Additionally, I would like to dedicate this thesis to my family, whose support and patience were essential to its completion.

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Chapter 1

1.1 Mountain pine beetle epidemic, Colorado

In Colorado, the epidemic of mountain pine beetles (*Dendroctonus ponderosae*) has significantly affected the lodgepole pine (*Pinus contorta*) forests. Since 1996, defoliation resulting from the mountain pine beetle (MPB) epidemic continues to spread as the infected trees are killed (Ciesla, 2009; Ciesla, 2010; Serby et al., 2011). As of 2011, the active MPB infestations encompassed 752,000 acres of the State's forests, a reduction from the 878,000 acres reported in 2010 and 1,046,000 acres reported in 2009 (Fig. 1; Ciesla, 2009; Ciesla, 2010; Serby et al., 2011). The reduction is partially due to the fact that the number of potential host trees has decreased annually (Serby et al., 2011). Mountain pine beetle outbreaks are most severe in lodgepole pine (*Pinus contora*). Other research shows that infestation is spreading and growing in the ponderosa pine (*Pinus ponderosa*) forests; 2011 reports record approximately 275,000 acres of ponderosa pines mapped as infested, compared to 229,000 acres reported in 2010 and 22,000 acres reported in 2009 (Ciesla, 2009; Ciesla, 2010; Serby et al., 2011). The current MPB epidemic is the most severe in recorded history and can be attributed to an abundance of mature, dense lodgepole forests, drought stress, and warmer temperatures (Clow et al., 2011). The outbreak has nearly run its course in the lodgepole pines of Grand and Summit Counties, where most of the trees over 60 years old have died (Witcosky, 2007; Ciesla, 2010). Grand County has some of the highest density of lodgepole pine forests in Colorado; consequently, Grand County was one of the first to have been affected by the current beetle outbreak beginning in 1996 (Price

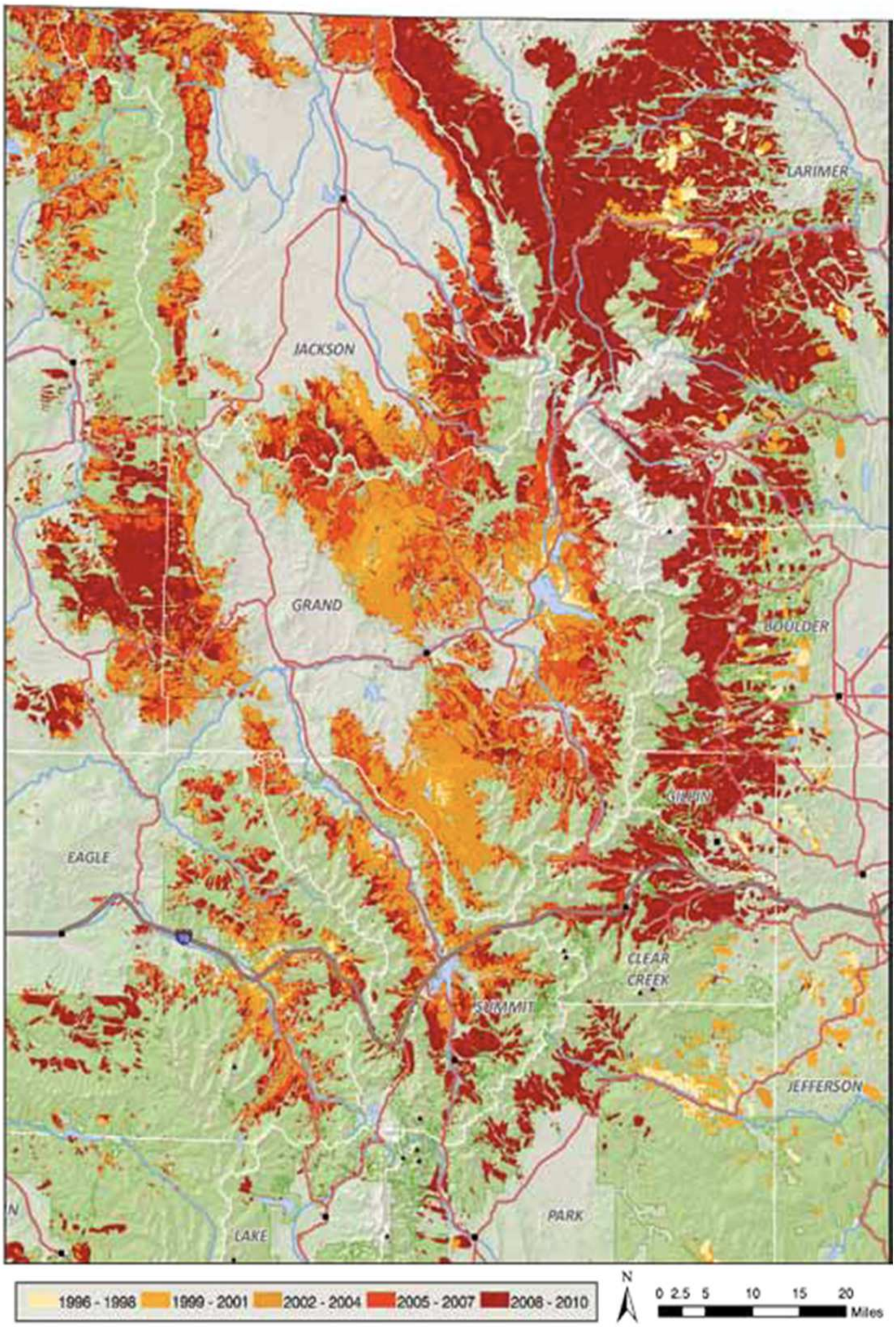


Figure 1. Aerial detection survey of the Mountain Pine Beetle progression (1996 – 2010) in Colorado. *From:* Ciesla, M.W., 2010.

et al., 2010). Approximately 443,000 acres of Grand County's lodgepole pine forests had been damaged by MPB (Witcosky, 2007)

As pine beetle activity kills trees, the dropped pine needles accumulate on the forest floor. The litter fall may lead to changes in soil temperature and soil moisture (Clow et al., 2011). The decomposition of pine needles may also lead to chemical changes, such as the production of CO_2 and organic acids in the substrate (White and Brantley, 1995). The goal of this study was to assess the effects of beetle-killed trees on soil weathering processes. To study impacts of beetle-killed trees on the substrate, a series of soil pits located under healthy and infected pine stands were dug, sampled, and evaluated to compare and document possible changes in soil weathering in response to MBB-induced tree mortality. This study involved (1) soil characterization, (2) soil grain size analysis, (3) geochemistry, (4) thin section petrography, and (5) pH & electric conductivity testing of soils beneath healthy and MPB attacked pine stands.

1.2 Hypothesis

Two overall hypotheses related to soil weathering and the MPB epidemic will be evaluated using soil characterization, grain size analysis, geochemistry, thin section petrography, soil pH and saturated paste electric conductivity: (1) the death of pine trees and accompanying increased pine needle decomposition has increased chemical weathering of the substrate, and (2) an increase in soil weathering under dead pine stands increased downslope physical migration of weathered material.

1.3 Objectives

The primary objective of this research is to assess the relationship of increased tree kill associated with pine beetle infestation to soil weathering. Decomposition of coniferous tree litter demonstrably increases soil acidity (Certini et al., 1998); therefore, MPB infestation and tree kill could increase acidity and affect chemical weathering in soils. Weathering may also be affected by changes in water infiltration and biological activity caused by pines losing their needles (Egli et al., 2008; Phillips et al., 2008).

CHAPTER 2

Previous Work

2.1 Pine needle decomposition

Litter decomposition is primarily controlled by litter temperature and moisture, followed by chemical and physical composition, and lastly, soil chemistry (Berg and Ekbohm, 1993; Berg and Laskowski, 1997; Preston et al., 2009). In addition to litter (pine needles, twigs and branches) decomposing to CO_2 and organic acids (White and Brantley, 1995), decomposing litter may release nutrient elements (i.e. N, P, K, Ca, and Mg) to the soil profile at variable rates (Berg and Ekbohm, 1993; Berg and Laskowski, 1997; Thelin et al., 1998; Preston et al., 2009). Pine needles and twigs are relatively rich in N and will decay relatively quickly, while the branches and trunks are rich in C and will decay more slowly (Clow et al., 2011). Much of the released N and C will accumulate in litter and soil, or be taken up by new forest growth. An unknown fraction of N and C will leach into soil solution or groundwater, and may subsequently be transported to groundwater (Clow et al., 2011). A number of studies have characterized litter decomposition of various tree types from different geographic locations of the world using the litter bag technique (Berg and Ekbohm, 1993; Berg and Laskowski, 1997; Thelin et al., 1998; Sariyildiz et al., 2005; Preston et al., 2009). The technique involves litter sampling of brown needles from falling trees, air drying the needles to obtain even moisture level (~5 to 8%), and then drying at 85°C to obtain the dry mass weight (Berg and Ekbohm, 1993; Berg and Laskowski, 1997). The litter is then stored in a terylene mesh net and fastened to the forest ground with metal pegs. Samples are analyzed three times annually for 4 years (Berg and Ekbohm, 1993; Berg and Laskowski, 1997). Results are variable depending on the scope of the project and the tree species studied. Berg & Laskowski (1997) showed that lodgepole pine litter from a forest in Sweden contained average initial concentrations of K-0.59 mg/g, Ca-6.8 mg/g, Mg-0.96 mg/g, Mn-2.44 mg/g, N-3.8 mg/g and P-0.38 mg/g, and that the lodgepole pine litter reached a mass weight loss of approximately 70% after 4 years of natural degradation. Pine litter decomposition results show N and P are variable in that they normally do not show a mass loss until after an initial net gain greater than 100%, K usually releases very fast, with slower loss of Ca and Mg (Berg and Ekbohm, 1993; Berg and Laskowski, 1997; Preston et al., 2009). Surface litter bag studies generally show that Fe, Al, and Zn are rarely lost (Preston et al., 2009). Nutrients are released from litter through either mechanical leaching or the decomposition of structural organic components by soil organisms (Berg and Laskowski, 1997).

Additional studies in a subalpine forested region showed that the accumulation of coniferous tree litter led to intensified acidification of soil and a higher production of organic ligands in soil solutions (Certini et al., 1998). There are at least three mechanisms by which organic matter and related acids may directly affect mineral weathering rates: 1) by decreasing pH and changing dissolution rates, 2) by forming complexes with metal ions in solution and increasing the solubility of the mineral, and 3) by affecting the speciation in solution of ions such as Al^{3+} (Drever, 1994; Drever and Stillings, 1997).

2.2 Soil responses to MPB induced tree mortality

Clow et al. (2011) studied soil moisture, available N, extractable NH_4 and NO_3 from the top 15 cm of soils beneath various stages of MPB-killed pines of Grand County, Colorado, but did not study mineralogy and inorganic geochemistry of the soils. Results indicate that soil moisture, available N and extractable NH_4 and NO_3 was greater in soils under the MPB-killed pine trees than in the soils beneath the healthy pine trees (Clow et al., 2011). The results were interpreted to have been consistent with release of N from decaying litter into soil organic matter, and mineralization of N in decaying plant litter to NH_4, followed by nitrification to NO_3 (Clow et al., 2011). The increase in soil moisture and extractable NO_3 was likely related to reduced uptake of nutrients and water associated with MPB-induced tree mortality. The increase in available N and extractable NH_4 and NO_3 beneath the MPB killed trees indicate a substantial shift in soil nutrient chemistry related to the MPB epidemic. Researchers have also shown that soil acidity and soil temperature in Willow Creek, CO have increased during the current beetle infestation (personal communication, 2011, Dr. John Stednick, Colorado State University).

2.3 Mineral weathering processes and soil formation

Weathering of rocks and minerals is an important process shaping the surface of the earth. There are two classifications of weathering: chemical and physical. Physical weathering involves the physical breakdown of rocks and soils through exposure to heat, water, pressure, and ice. Chemical weathering refers to atmospheric or biologically induced chemical breakdown of rocks and soils where the products are in closer equilibrium to the Earth's surface conditions (Dixon and Thorn, 2005). The most widely recognized chemical weathering processes include solution, hydrolysis, carbonation, chelation, oxidation, and reduction. Reynolds and Johnson (1972) observed that chemical weathering is fundamentally controlled by hydrogen ion availability. Soils are a product of weathered rock materials, and form by a combination of the physical breakdown of rock, the chemical alteration of rock components and biological processes.

Soil make up is a function of climate, parent rock, topography, vegetation, and soil organisms, as well as the time over which soils have been forming (Rowell, 1994). Woodruff et al., 2009 proposed that the geochemistry and mineralogy of soils are controlled by three principle factors: (1) composition of parent materials or organic matter in which soils form, (2) chemical, biological, and physical soil-forming processes acting over time and space, and (3) anthropogenic soil disturbances. Chemical weathering contributes inorganic ions to soils underlain by silicate rocks. Ultimately these elements are used and recycled by plant communities, or transported to local watersheds (White and Brantley, 1995).

CHAPTER 3

Methods

The degree of chemical weathering and the downslope migration of weathered material beneath the pine stands were evaluated and described using the following combination of field and laboratory techniques:

1. Site selection and characterization;
2. Soil characterization and selection for analyses;
3. Grain size analysis;
4. Geochemistry;
5. Thin section petrography;
6. Soil pH and saturated paste electric conductivity measurements.

Data obtained by these methods from samples collected under living and dead pine stands were then compared to assess the potential relationship between beetle damage and substrate weathering.

3.1 Site selection and characterization

This study was conducted on a south-facing hillslope (40°26'N, 106°06'W) ranging in elevation from about 9100 to 9400 ft., approximately 0.7 miles south of Kauffman Creek between Co. Roads 482 and 485, northwest of Lake Granby in Arapahoe National Forest lands of Grand County, Colorado (40°15'37.83"N, 106°3'22.28"W)(Fig. 2). Kauffman Creek is a tributary to Willow Creek, and the headwaters of Willow Creek, near the summit of Radial Mountain, flow southward through the lodgepole pine forested mountains draining into the

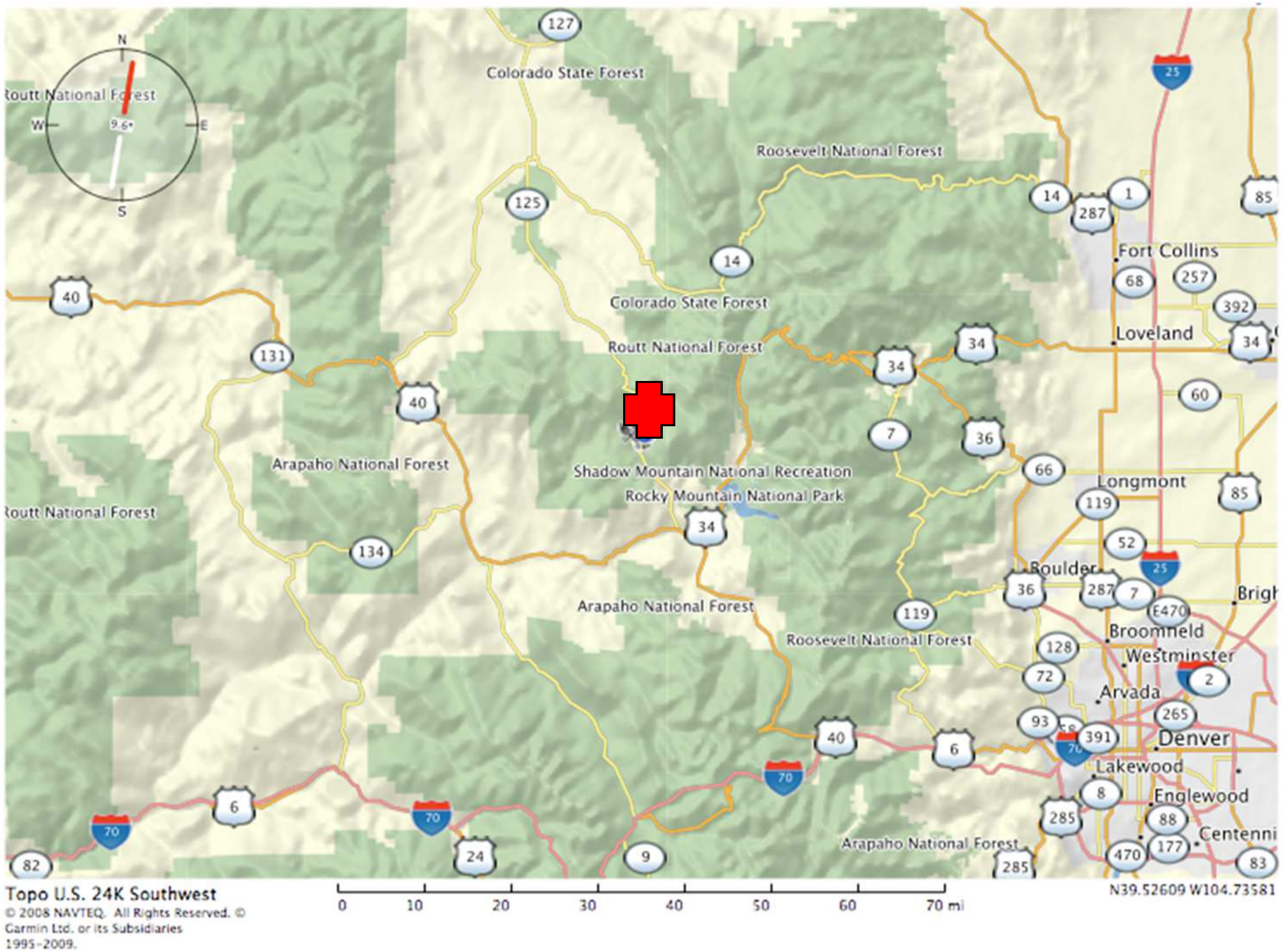


Figure 2a. Location of study (Red Cross), Grand County, Colorado (40°26'N, 106°06'W).

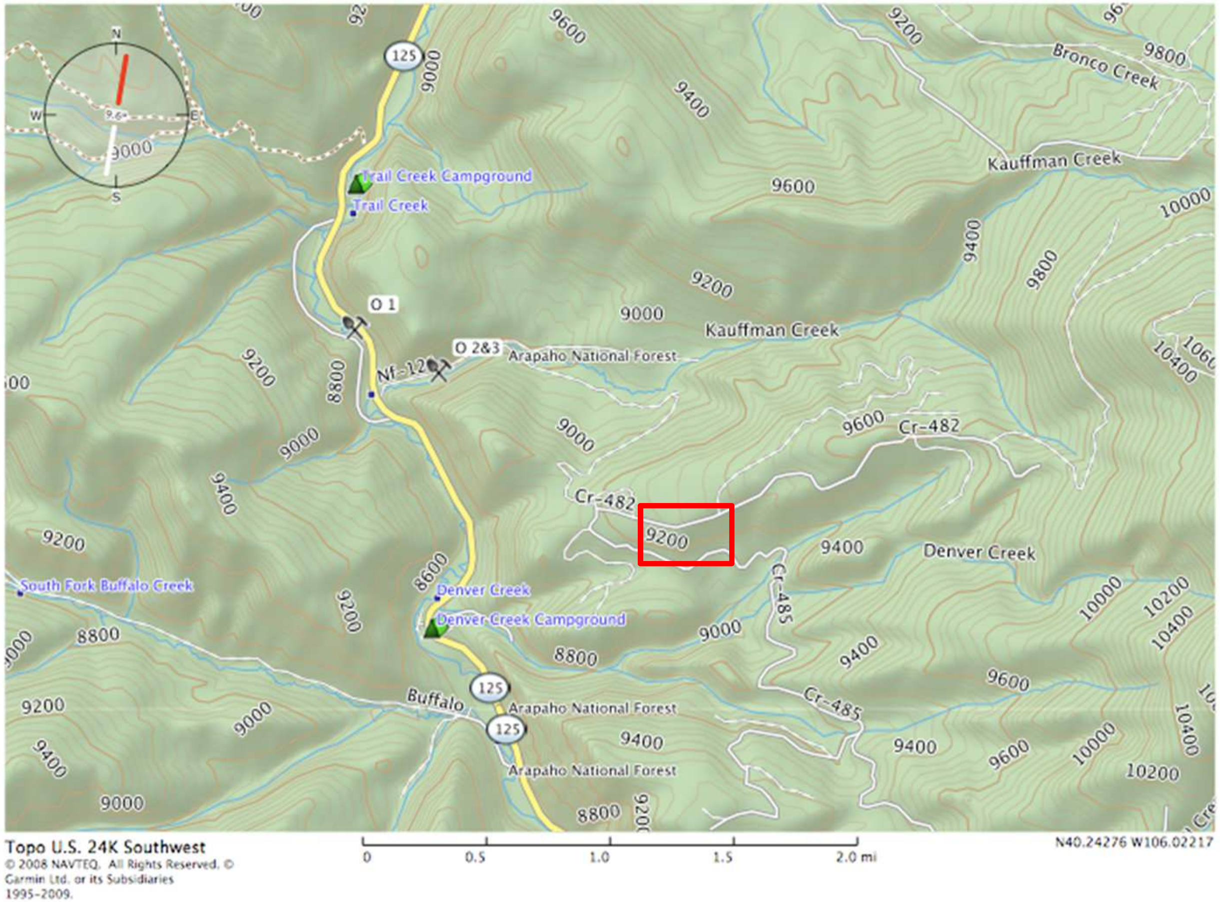


Figure 2b. Topographic map showing the rock and soil sample collection sites. The red rectangle represents the approximate soil sampling locations , and the mining symbols represent the rock sampling "O" locations.

This site was located approximately 0.7 mi south of Kauffman Creek between Co. Roads 482 and 485, northwest of Lake Granby in Arapahoe National Forest lands of Grand County, Colorado (40°26'N, 106°06'W).

Willow Creek Reservoir (Green, 1992). The nearest weather station is in Walden, CO and is approximately 30 miles northwest of the study area. The climate is characterized by a mean maximum annual air temperature of 52.6°F, a mean minimum annual air temperature of 21.4°F and a mean annual precipitation of 10.95 inches (Western Regional Climate Center. Walden, Colorado (058756)).

Willow and Kauffman Creek incise the sedimentary rocks of the Coalmont Formation, which is Paleocene – Eocene in age. The Coalmont Formation is subdivided into three members: the lower member or Middle Park Member, the middle member and the upper member (Hendrix, 1978; Roberts and Rossi, 1999). The lower and middle members are considered to be Paleocene in age and the upper member is considered to be Eocene in age. The Middle Park Member of the Coalmont Formation is comprised of conglomerate, conglomeratic and arkosic sandstone, sandy claystone, and occasional carbonaceous shale and coal. The middle member of the Coalmont Formation consists of conglomerate, conglomeratic sandstone, sandstone, siltstone, carbonaceous shale and sparse coal. The upper member of the Coalmont Formation is characterized by interbedded sandstone, siltstone, mudstone, carbonaceous shale, and coal (Hendrix, 1978; Roberts and Rossi, 1999). Additional mapping in the area reports Tertiary igneous dikes cutting the Paleocene – Eocene sedimentary package (Green, 1992). The preserved aggregate thickness of the Coalmont Formation may approach 11,000 to 12,000 feet; however, the original thickness of the formation has not been preserved due to erosion (Tweto, 1975; Hendrix, 1978; Roberts and Rossi, 1999). The thickness of individual units is variable throughout the Coalmont Formation (Hendrix, 1978).

The Coalmont Formation was deposited during late Paleocene – early Eocene tectonic uplift, subsidence, and basin fill. The fluvial system is estimated to have been a moderate- to high-velocity braided/ meandering stream as wide as 0.5 miles and as deep as 75 feet; paleotransport directions trended toward the east-southeast (Hendrix, 1978). Detrital material was supplied from the west by the Park Range uplift. The abundance of granitic rock fragments in conglomerates indicates that the Precambrian core of the Park Range was exposed by late Paleocene. Sandstone rock fragments are likely derived from the Dakota Formation (Hendrix, 1978). The coarser fractions of the Coalmont Formation were deposited by high-energy braided alluvial systems and the finer fractions were deposited as overbank deposits during channel migration, and occasionally as levee deposits (Hendrix, 1978). The carbonaceous shales and coals are overbank and swamp deposits (Hendrix, 1978).

Soils of Kauffman Creek developed on the Coalmont Formation are predominantly inceptisols and entisols. Soils in the study area consist of Scout Family-Haplocryolls Complex, Sandstone Substratum (40 to 75 percent slopes), Cryaquolls-Gateview Complex (0 to 15 percent slopes), Goosepeak, Sandstone Substratum-Howlett-Scout Families, Moist Complex (5 to 40 percent slopes) and Scout-Goosepeak Families Complex (40 to 75 percent slopes) per the Soil Survey of Arapaho-Roosevelt National Forest Area, Grand County, Colorado (Soil Survey Staff, United States Department of Agriculture, Available online http://websoilsurvey.nrcs.usda.gov/. Accessed 08/27/2012). The description of these soil type is as follows:

Scout Family-Haplocryolls Complex, *Sandstone Substratum* (40 to 75 percent slopes) consists of somewhat excessively drained soils that are derived from residuum and/or slope alluvium derived from sandstone. Typically, the profile consists of strata of slightly decomposed plant material (0 to 1 inches), moderately decomposed plant material (1 to 3 inches), very cobbly loam (3 to 13 inches), very stony loam (13 to 24 inches), extremely stony sandy loam (24 to 39 inches), extremely stony sandy clay loam (39 to 48 inches) and extremely stony sandy loam (48 to 51 inches). Available water capacity is low (about 4.1 inches in the upper 60 inches of depth) and permeability is moderately high to high (0.60 to 2.00 in/hr).

Cryaquolls-Gateview Complex (0 to 15 percent slopes) consists of poorly drained soils that are derived from gravelly alluvium and/or gravelly glaciofluvial deposits derived from igneous, metamorphic and sedimentary rock types. Typically, the profile consists of strata of moderately decomposed plant material (0 to 4 inches), silt loam (4 to 30 inches), sandy loam (30 to 40 inches), and silt loam (40 to 64 inches). Available water capacity is high (about 11.1 inches in the upper 60 inches of depth) and permeability is moderately high to high (0.60 to 2.00 in/hr).

Goosepeak, Sandstone Substratum-Howlett-Scout Families, Moist Complex (5 to 40 percent slopes) consists of well drained soils that are derived from colluvium and/or residuum derived from sandstone. Typically, the profile consists of strata of slightly decomposed plant material (0 to 1 inches), moderately decomposed plant material (1 to 3 inches), sandy loam (3 to 5 inches), cobbly fine sandy loam (5 to 13 inches), very cobbly sandy clay loam (13 to 32 inches) and extremely cobbly sand loam (32 to 62 inches). Available water capacity is low (about 4.2 inches in the upper 60 inches of depth) and permeability is moderately high to high (0.60 to 2.00 in/hr).

Scout-Goosepeak Families Complex (40 to 75 percent slopes) consists of well drained soils that are derived from alluvium and/or residuum derived from sandstone. Typically, the profile consists of strata of slightly decomposed plant material (0 to 1 inches), moderately decomposed plant material (1 to 3 inches), very cobbly loam (3 to 13 inches), very stony loam (13 to 24 inches), extremely stony sandy loam (24 to 39 inches), extremely stony sandy clay loam (39 to 48 inches) and extremely stony sandy loam (48 to 51 inches). Available water capacity is low (about 4.1 inches in the upper 60 inches of depth) and permeability is moderately high to high (0.60 to 2.00 in/hr).

Field studies and soil sampling began in June of 2010 and continued through August of 2010. This field site was chosen based on the range of MPB infected lodgepole forests on the hillside (Fig. 3). There were some healthy (uninfected) ponderosa pines on the hillslope, but the majority of the trees on the hillslope consisted of lodgepole pine trees (Appendix A). The trees on the western end of the hillslope were brown in color and had lost many of their needles. Near the middle of the study area is a large area of healthy-appearing pine trees (green). Further to the east, the majority of the mature pines are in the later stages of MPB infestation; these pines are gray with all to most of their needles dropped. Green trees likely represent healthy pines, or were freshly attacked by the MPB; the brown trees reflect 1 to 3 years post MPB infestation; and the gray pines reflect conditions ≥4 years post MBB infestation (Clow et al., 2011).

Sampling sites were categorized by canopy color. 1) Sites with an abundance of live pine trees with green foliage are classified as green "Gn" (Fig. 4a), 2) sites with pines that had sparse brown foliage were classified as brown "Bn" (Fig. 4b), and 3) sites with pine trees that were gray with all to most of their needles shed to the forest floor were classified as gray "Gy" (Fig. 4c). Sample collection sites were selected and categorized as green, brown, or gray by the condition of pine trees within a 30 ft. radius of the soil pit dug (Appendix A). One hundred and thirty-one soil samples were collected from 22 soil pits, dug at 7 green sites, 8 brown sites, and 7 gray sites (Fig. 5); an additional 3 rock samples were collected from the closest outcroppings along CR-485, approximately 1.2 to 1.5 miles from the soil sampling locations (Fig. 2b). These sandstones from the Coalmont Formation may be representative of the parent material for soils.

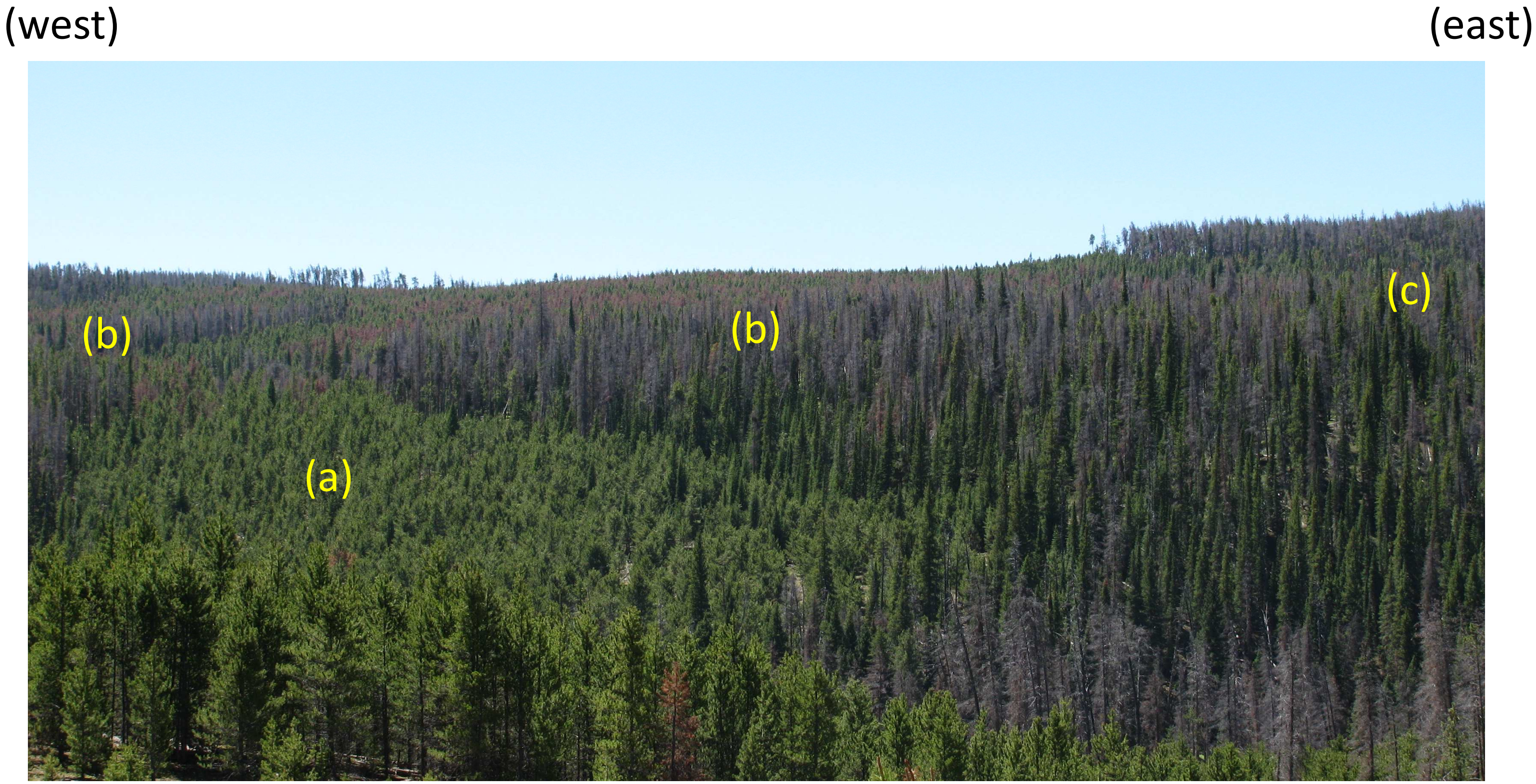


Figure 3. Photo of study area showing the spectrum of beetle-killed trees on the hillside. (a) Younger-healthy pine trees generally not affected by the MPB, but with abundant downed woody debris from clear cutting, classified as “green”. (b) Mostly lodgepole pines infested by the MPB, classified as “brown”. (c) Lodgepole pines in later stages of MPB infestation , classified as “gray”.

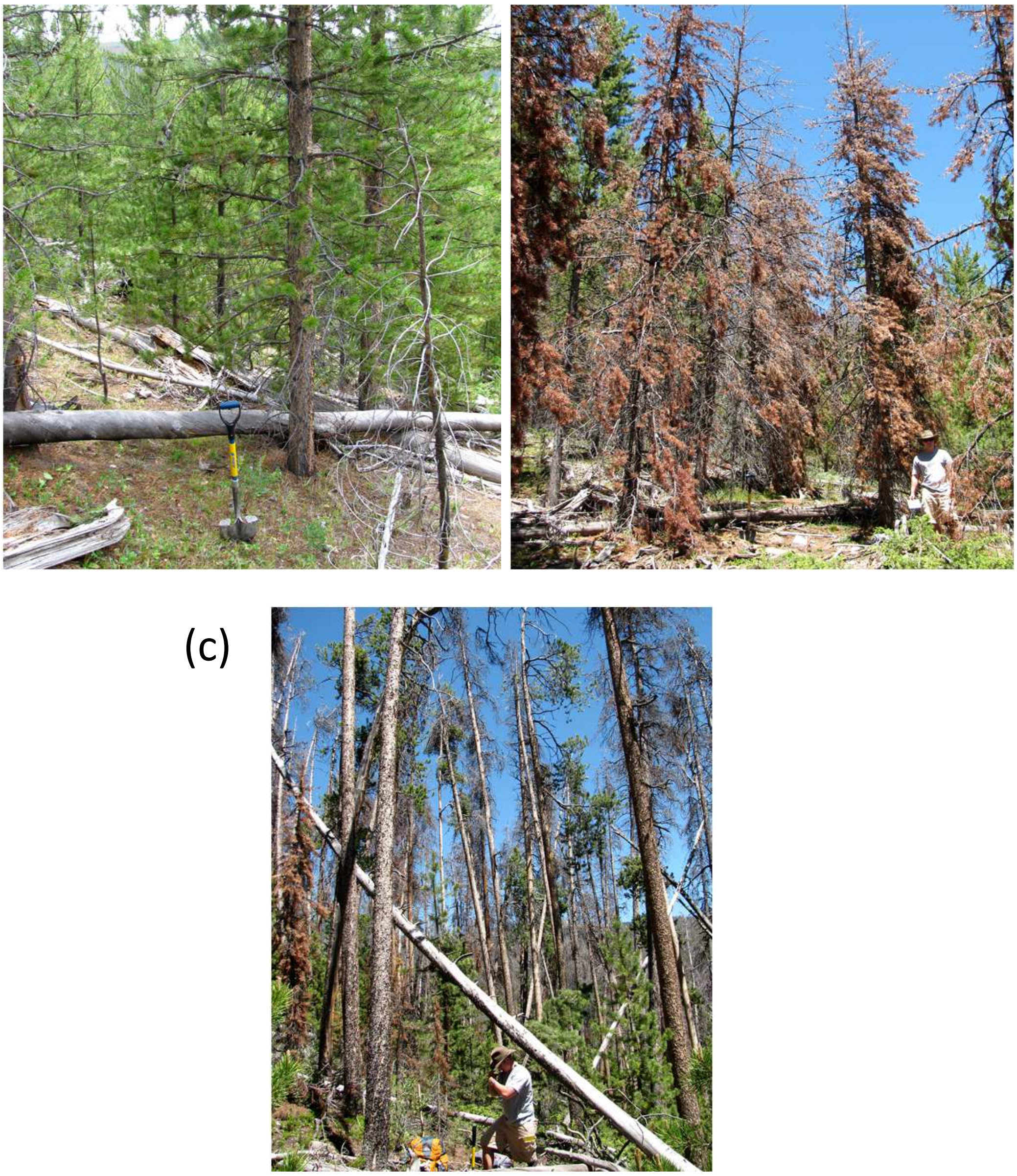


Figure 4: Pictures of the three different classifications of field sites. Field sites were classified by color of pine trees within a 30-foot radius of soil pit dug. (a) Sites with live pine trees with green foliage were classified as green “Gn” (b) sites with pines that have sparse brown foliage were classified as brown “Bn” (c) sites with pine trees gray in color with all to most of their needles shed to the forest floor were classified as gray “Gy”.

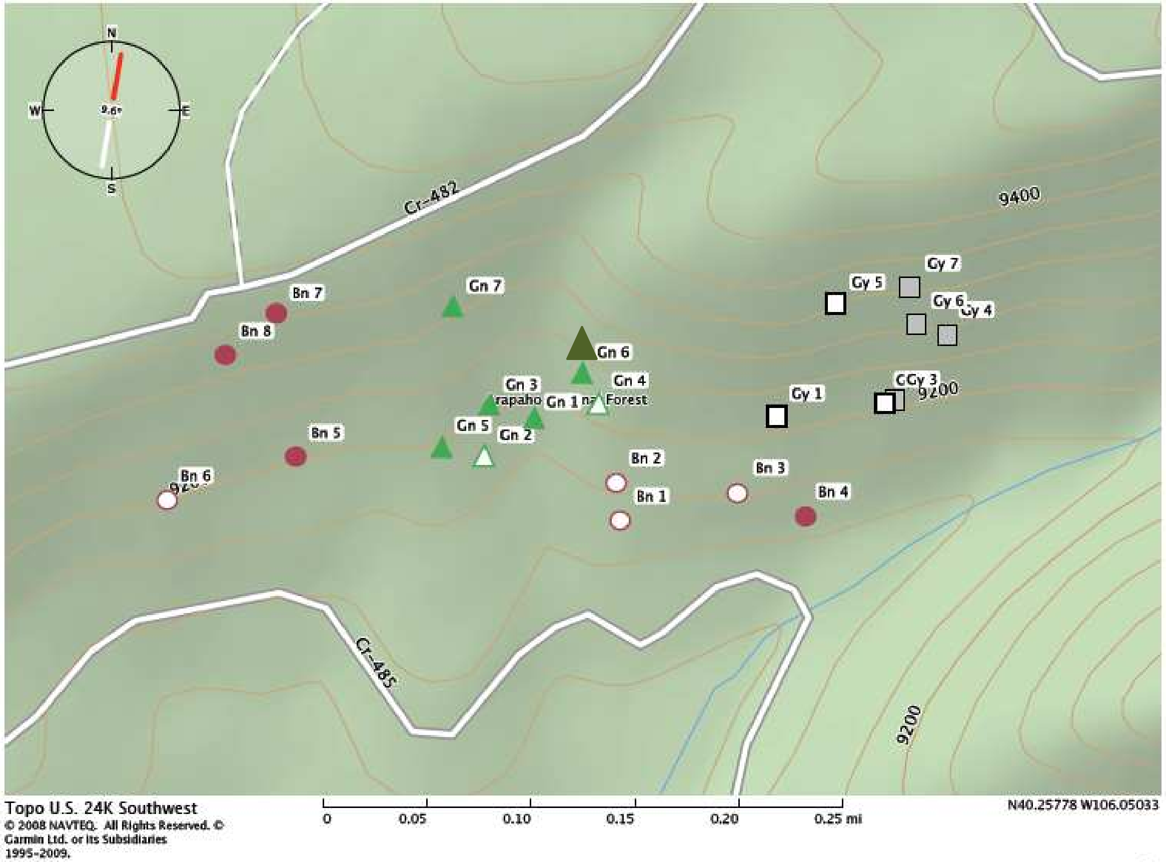


Figure 5. Topographic map showing all of the soil sampling locations chosen for analytical methods (i.e. grain size analysis, geochemistry, petrography, and pH/EC tests). The green triangle, brown circle, and gray square symbols represent the soil samples in the green "Gn", brown "Bn" and gray "Gy" pine stands, respectively. The shaded symbols represent the locations of soil samples chosen for analytical methods (i.e. grain size analysis, geochemistry, pH and electric conductivity). The shaded symbols in the green and gray pine stands were chosen for petrographic analysis. The non-shaded symbols represent the additional samples used in grain size analysis and pH/EC tests. Soil pit Gn 6 was collected, but not utilized in this study.

Other than differing pine foliage conditions, collection sites were chosen based on similar physical characteristics including hillslope orientation, and drainage. Soil profiles from well-drained areas were chosen for sampling. Sites that were logged and had an abundance of logs and branches were generally avoided. This field site is on federal forestland, and loggers began clear-cutting the dead pine trees during the summer of sampling, so some logs and branches were unavoidable, and when encountered the tree debris was moved aside before soil sample collection.

Sampling strategies were to sample each of the three stands (i.e. green, brown and gray) and from higher (~9400 ft.) to lower (~9100 ft.) elevations. Each collection site consisted of a soil pit dug to a depth of 17 to 30 inches with a shovel and pick axe; samples were collected in about 3-4 inch increments including the organic horizon (Fig. 6). Samples collected from each pit consist of 5 to 7 depth-based samples containing approximately 200 to 700 grams of soil per bag. Any roots, tree branches, or rocks larger than an inch in diameter were discarded. A description of each soil pit was recorded and included information pertaining to soil horizons, distinguished on the basis of color, texture, structure and other observable features. Additional data taken from each sample site include: GPS coordinates (latitude/ longitude) and elevation, number of brown to gray and number of green pine trees within a 30 ft. radius, thickness of overlying organic horizon, depth each sample was taken from, and the nature of the soil horizons (Appendix A).

Hillslope aspect and position are two important topographic factors that may influence microclimates, mainly because they determine the amount of solar radiation received by the hillslope (Barnes et al, 1998; Sariyildiz et al., 2005). South-facing slopes receive the greatest amount of solar radiation, and are typically hotter, dryer, and subject to more rapid changes in

Figure 6. Photo of depth based sampling. Samples were collected approximately every 3- to 4-inches from the forest floor to the bottom of the pit extending to depths of 17 to 30 inches..

seasonal and diurnal microclimate than the north-facing slopes (Sariyildiz et al., 2005). This study does not compare north- and south-facing hillslopes, but samples were collected from various hillslope elevations, and there may be local influences on microclimate related to changes in canopy cover related to the beetle-kill in the area.

3.2 Soil characterization and selection for analyses

After samples were collected, and while still naturally moist from field conditions, each soil sample was characterized according to the national system of soil taxonomy (Soil Survey Staff, 1999) and the Munsell soil color index (Munsell Book of Color, 1976) (Appendix A). Back in the laboratory the samples were air dried and then each sample was split into four subsamples. Each of the subsamples was designated for grain size analysis, geochemistry, thin section petrography, soil pH and/ or saturated paste electric conductivity measurements.

Not all samples were utilized in each of the four procedures. For example, soil pit Gn 6 was dug and sampled, and the analytical results are included within the appendices of this study, but the soils will not be discussed in the results and discussion that follows. Soil pit Gn 6 was located within ~30 ft. of a small outcrop of igneous rock interpreted to be a Tertiary igneous dike which commonly cuts the Coalmont Formation (Appendix A). The parent material for soils in this location are likely igneous in origin (rather than sedimentary) or the parent material may have been altered by the intrusion of this dike; therefore, the soil pit has been excluded from the results of this study. For additional information on soil pit Gn 6 refer to the appendices of this study. Soil samples from the brown pine stand type were not selected for petrographic analysis and only the green and gray pine stand types were petrographically evaluated. Table 1 records the number of the soil pits utilized in the various analytical procedures.

Table 1. Number of soil pits utilized in each of the analytical procedures.

Analytical Procedure	Green Pine Stand	Brown Pine Stand	Gray Pine Stand
Grain Size Analysis	5	5	5
Geochemistry	4	4	4
Petrography	4	0	4
pH & Electric Conductivity	5	7	7

Appendix B is a more comprehensive list of the soil pits and samples assigned for the various procedures listed above. Figure 5 illustrates the locations of the samples chosen for each of these analyses. The soil samples analyzed are from pits in each of the three pine stand types, and are from various hillslope locations; a minimum of 4 samples were analyzed from each pit.

3.3 Grain size analysis

Seventy three samples from 15 soil pits were mechanically sieved through a Ro-Tap machine supplied by Colorado State University. There are a total of 23 samples from 5 soil pits in the green stand, 24 samples from 5 soil pits in the brown stand and 25 samples from 5 soil pits in the gray stand (Appendix B). The sieves used to separate all samples include: -0.75, 0.00, 0.75, 1.25, 2.00, 2.75, 3.50, 4.00, 4.50, and ≥4.75 phi-sized screens, ranging from pebbles to clay-sized fractions. Soil pits Gn 2, Bn 2, and Gy 1 were also sieved through additional screens with intervals of ¼-phi between screens (Appendix C). Before sieving, and while still in the sampling bag, each sample was pounded with the handle of a screw driver for approximately one minute to break up dried clumpy soils and aggregates, any remaining solid constituents larger than an inch were discarded from the sample. When sieved, the dry sample was placed on the top of the sieve column and shaken by the Ro-Tap machine for 15 minutes/soil sample. The contents of each sieve were collected, weighed with an accuracy of ±0.01 g, recorded, and then converted to individual and cumulative weight percentages. The grain size is described using the phi scale of Krumbein (1934), where the diameter (d) is defined as the negative binary logarithm of the diameter measured in mm:

$$d_{phi} = -\log_2(d_{mm})$$

Classification of size fractions are according to Krumbein (1934) and defined to be -1.0-0.0 phi as very coarse sand, 0.0-1.0 phi as coarse sand, 1.0-2.0 phi as medium sand, 2.0-3.0 phi as fine sand, 3.0-4.0 phi as very fine sand, 4.0 - 5.0 as silt and 5.0 < clay.

Cumulative frequency diagrams were constructed from the cumulative weight percentage data (Appendix C). From the frequency plots the 5^{th}, 16^{th}, 25^{th}, 50^{th}, 75^{th}, 84^{th}, and 95^{th} percentiles were estimated by hand and used to calculate the mean, median, mode, standard deviation, skewness, and kurtosis of grain size distributions in the soil profiles. These statistics were calculated from histograms and cumulative frequency diagrams using the logarithmic graphical measure method of Folk and Ward (1957) (Table 2).

Table 2. Statistical formulae used in the calculation in grain size parameters and suggested descriptive terminology, modified from logarithmic graphical measure of method of Folk and Ward (1957).

Mean	Standard Deviation
$\mathrm{Mz} = \frac{\emptyset 16+\emptyset 50+\emptyset 84}{3}$	$\sigma = \frac{\emptyset 84-\emptyset 16}{4} + \frac{\emptyset 95-\emptyset 5}{6.6}$
Skewness	**Kurtosis**
$Sk = \frac{\emptyset 16+\emptyset 84-2\emptyset 50}{2(\emptyset 84-\emptyset 16)} + \frac{\emptyset 5+\emptyset 95-2\emptyset 50}{2(\emptyset 95-\emptyset 5)}$	$KG = \frac{\emptyset 95-\emptyset 5}{2.44(\emptyset 75-\emptyset 25)}$

Table 2 cont. Statistical formulae used in the calculation in grain size parameters and suggested descriptive terminology, modified from logarithmic graphical measure of method of Folk and Ward (1957).

Sorting (σ)		***Skewness (Sk)***		***Kurtosis (KG)***	
Very well sorted	<0.35	Strong fine skewed	>+0.3	Very platykurtic	<0.67
Well sorted	0.35 to 0.50	Very fine skewed	+0.3 to +1.0	Platykurtic	0.67-0.90
Moderately well sorted	0.50 to 0.71	Fine skewed	+0.1 to +0.3	Mesokurtic	0.90 to 1.11
Moderately sorted	0.71 to 1.00	Symmetrical	+0.1 to -0.1	Very leptokurtic	1.11 to 1.50
Poorly sorted	1.00 to 2.00	Coarse skewed	-0.1 to -0.3	Extremely leptokurtic	1.50 to 3.00
Very poorly sorted	2.00 to 4.00	Very coarse skewed	-0.3 to -1.0		
Extremely poorly sorted	>4.00				

3.4 Geochemistry

Fifty two soil samples and 3 outcrop samples were analyzed for bulk geochemistry. There are 18 samples from 4 soil pits in the green stand, 17 samples from 4 soil pits in the brown stand and 17 samples from 4 soil pits in the gray stand (Appendix B). Preparation for this geochemical procedure included sieving and collecting the soils that pass through a ¼ inch screen. The soil constituents > ¼ inch were discarded prior to geochemical analysis. The ¼ inch screen was chosen as a cut-off point to remove any roots and cobbles.

The samples for geochemical analysis were sent to Activation Laboratories Ltd., Ancaster, Ontario, where they were pulverized with mild steel to the appropriate sized fractions needed for the lithium metaborate/tetraborate fusion ICP whole rock (WRA-ICP) analysis. Samples were analyzed for major oxides (i.e. SiO_2, TiO_2, Al_2O_3, $Fe_2O_{3(T)}$, MnO, MgO, CaO, Na_2O_3, K_2O, P_2O_5) and selected trace elements (i.e. Ba, Sr, Y, Sc, Zr, Be, and V) on a combination simultaneous/sequential Thermo Jarrell-Ash ENVIRO II ICP or a Varian Vista 735 ICP. Detection limits for the WRA-ICP procedure are 0.01% for the major oxide elements, 5ppm for V, 2 ppm for Ba, Sr, and Zr, and 1 ppm for Y, Sc, and Be (Geochemical package 4B; www.actlabs.com).

3.5 Thin section petrography

Thirty five soil samples and 3 outcrop samples were analyzed petrographically. There are 18 samples from 4 soil pits in the green stand and 17 samples from 4 soil pits in the gray stand (Appendix B). The soils from the brown pine stand type were not analyzed in this procedure. Grain mount samples were sieved through -1.0 phi (coarse sand) and 4.0 phi (fine sand) screens; the sand-sized grains ($4.0 \leq$ grain diameter ≤ -1.0 phi) were collected and packaged for grain mounting. The rock samples were cut into slabs using the lab equipment of Colorado State University. After preparation, samples were sent to Spectrum Petrographics in Vancouver, WA for thin section preparation. All the thin sections are of standard size (27x46 mm), mounted in Loctite Impruv 363, embedded with EPOTEK 301, and stained for potassium feldspar. The mineralogy of the sand-sized grain mounts and rock thin sections was determined petrographically using optical microscopes supplied by Colorado State University and Grand Valley State University. Rock sample thin sections and selected grain mounts were also digitized using a Nikon SUPER COOLSCAN 5000 ED. Modal analyses were performed by point counting approximately 250 points per sample for mineralogy and mineral alterations. All constituents were counted, including major minerals, accessory minerals, soil aggregates, rock fragments, pore space, and cements/grain replacements, if discernible (Appendix D).

3.6 Soil pH and saturated paste electric conductivity testing

Samples assigned for soil pH and saturated paste electric conductivity tests were analyzed using an Oakton PCTestr 35 Waterproof Multiparameter pH/Conductivity Tester. One hundred and fourteen soil samples (including the organic horizons) from 19 soil pits were analyzed. There are 29 samples from 5 soil pits in the green stand, 43 samples from 7 soil pits in the brown stand and 43 samples from 7 soil pits in the gray stand (Appendix B). Soil pH in deionized water was determined on air-dried soils using a 1:1 soil/solution ratio (i.e. 10g of soil to 10mL of distilled water). Some of the soils of the organic horizons had to be mixed with 2 or 3 parts deionized water in order to achieve the proper viscosity for measurement with the Oakton tester. Samples were mixed with appropriate amounts of deionized water and stirred for 2 to 3 minutes prior to measurements. The resolution of the Oakton pH/Conductivity Tester is 0.1 for the pH units and 0.1 µS/cm for saturated paste electric conductivity; the accuracy is ±0.1 for pH and 1% full scale for conductivity.

CHAPTER 4

Results

4.1 Soil/ sampling site characterization

Soils of the study area are predominately entisols and inceptisols with minimal to no morphologic or horizon development (other than an A-horizon) in the depths of sampling; such soil types are common in forested mountainous areas. Soils contained an abundance of granitic cobble- and boulder-sized slope colluvium, some soil pits contained more than others. See Appendix A for descriptions of site conditions.

The soils within the green pine stand type were generally yellowish brown, brown to dark brown in color and were comprised of coarse sandy loam soils with variable abundances of slope colluvium and alluvium within the soil pits. The contact between A- and B-horizon within the soil profiles was minimal/ gradational and the soil grains coarsen with increased depth. The average O-horizon/ pine litter depth was approximately 2-inches in thickness. The trees within a 30-foot radius contained green foliage and generally consisted of ponderosa pines and lesser amounts of lodgepole pines.

The soils within the brown pine stand type were generally dark yellowish brown to dark brown in color and were comprised of coarse sandy loam soils with variable abundances of slope colluvium and alluvium within the soil pits. The contact between A- and B-horizon within the soil profiles was minimal/ gradational and the soil grains coarsen deeper into the soil pit. The average O-horizon/ pine litter depth was approximately 3- to 4-inches in thickness. The trees within a 30-foot radius were predominately lodgepole pines with some ponderosa pines, and approximately 60% to 70% of the trees were brown in color/ dead and the remaining 30% to

40% of the trees were green and appeared to be healthy. The healthy pine trees were smaller and younger (often ponderosa) than the dead pines on the hillslope.

The upper soils within the gray pine stand type were generally very dark brown to black in color and the deeper soils were generally yellowish brown to dark brown in color and were comprised of coarse sandy loam soils with variable abundances of slope colluvium and alluvium within the soil pits. Many of the soil pits contain more clays within the deeper depths of sampling. Soil bleaching and lighter soil colors were evident within the upper foot of soil depth within a few of the soil pits (i.e. Gy 5, 6 & 7) within the gray pine stand type. The average O-horizon/ pine litter depth was approximately 3- to 4-inches in thickness. The trees within a 30-foot radius were predominately lodgepole pines with some ponderosa pines, and the majority of the trees were gray in color/ dead and have lost the majority of their pine needles. The smaller/ younger trees within the area of the hillslope contained green foliage and did not appear infested by the beetles.

4.2 Grain size analysis

Grain size analysis was accomplished by dry sieving the soils, as outlined in section 3.3. Appendix C records the weights of sieved portions, individual size fraction weight percentages, and the cumulative percentage data from the 77 sieved soil samples. Fine-earth (<2 mm) texture was characterized by sands with varying amounts of sand, silt, and clay (Appendix C). The dominating soil texture is sand (>90% by weight sand-sized grains); samples Gn 2.1 and Bn 8.1 have a loamy sand texture. Table 3 lists the grain size percentile data and statistics of sieved soils. The grain size percentiles are ordered from the coarsest material (5^{th} percentile) to the finest material (95^{th} percentile). Variations in grain size distribution from sample to sample range

Table 3: Grain size percentile data, and results of statistical analysis using logarithmic method of Folk and Ward (1957).

Sample #	Percentiles (Φ)							Graphical Statistics (Φ)							
	5th	16th	25th	50th	75th	84th	95th	Mean	Median	Mode	Stdev.	Skewness		Kurtosis	
Gn 1.1	-0.99	-0.51	0.09	1.13	2.31	2.86	3.99	1.16	1.13	0.75	1.60	0.088	symmetrical	0.919	mesokurtic
Gn 1.2	-1.03	-0.68	-0.25	0.79	2.29	3.13	4.27	1.08	0.79	0.00	1.76	0.271	F. skew	0.855	platykurtic
Gn 1.3	-1.01	-0.60	-0.23	0.88	2.27	2.54	3.64	0.94	0.88	2.75	1.49	0.122	F. skew	0.762	platykurtic
Gn 1.4	-0.96	-0.43	-0.05	1.18	2.61	3.53	4.42	1.43	1.18	0.75	1.81	0.196	F. skew	0.829	platykurtic
Gn 1.5	-1.10	-0.69	-0.25	0.83	2.41	2.98	3.84	1.04	0.83	0.00	1.67	0.195	F. skew	0.761	platykurtic
Gn 1.6	-1.10	-0.72	-0.31	0.76	2.38	3.13	3.80	1.06	0.76	0.00	1.70	0.236	F. skew	0.747	platykurtic
Gn 2.1	-0.77	-0.38	-0.06	1.18	2.88	3.89	4.49	1.56	1.18	4.75	1.86	0.264	F. skew	0.733	platykurtic
Gn 2.2	-0.88	-0.50	-0.19	0.71	1.33	2.13	3.75	0.78	0.71	1.00	1.36	0.197	F. skew	1.248	leptokurtic
Gn 2.3	-0.86	-0.40	-0.09	1.01	2.05	2.69	3.09	1.10	1.01	3.25	1.37	0.070	symmetrical	0.756	platykurtic
Gn 2.4	-0.82	-0.52	-0.22	0.61	1.81	2.52	4.24	0.87	0.61	0.25	1.53	0.346	S. F. skew	1.022	leptokurtic
Gn 3.1	-0.96	-0.59	-0.23	0.83	2.21	3.03	3.84	1.09	0.83	0.00	1.63	0.235	F. skew	0.806	platykurtic
Gn 3.2	-1.18	-0.72	-0.38	0.65	2.23	3.15	3.89	1.03	0.65	0.00	1.74	0.285	F. skew	0.796	platykurtic
Gn 3.3	-1.14	-0.80	-0.52	0.51	2.04	2.87	3.76	0.86	0.51	0.00	1.66	0.306	S. F. skew	0.784	platykurtic
Gn 3.4	-1.02	-0.68	-0.28	0.79	2.13	2.82	3.91	0.98	0.79	0.00	1.62	0.213	F. skew	0.838	platykurtic
Gn 5.1	-0.88	-0.40	0.03	1.51	2.83	3.36	3.90	1.49	1.51	0.00	1.66	-0.008	symmetrical	0.700	platykurtic
Gn 5.2	-0.87	-0.26	0.28	1.69	3.01	3.68	4.01	1.70	1.69	4.00	1.72	-0.020	symmetrical	0.733	platykurtic
Gn 5.3	-0.85	-0.41	0.04	1.48	2.46	2.85	3.81	1.31	1.48	2.75	1.52	-0.080	symmetrical	0.789	platykurtic
Gn 5.4	-0.98	-0.40	0.21	1.65	2.91	3.37	3.82	1.54	1.65	3.50	1.67	-0.092	symmetrical	0.729	platykurtic
Gn 5.5	-0.91	-0.35	0.12	1.60	2.52	3.01	3.81	1.42	1.60	2.75	1.56	-0.112	C. skew	0.806	platykurtic
Gn 7.1	-0.81	-0.23	0.27	1.71	2.82	3.38	3.91	1.62	1.71	2.75	1.62	-0.071	symmetrical	0.759	platykurtic
Gn 7.2	-0.90	-0.43	0.00	1.26	2.51	2.95	3.60	1.26	1.26	2.75	1.53	0.020	symmetrical	0.735	platykurtic
Gn 7.3	-0.97	-0.41	0.10	1.45	2.53	2.99	3.73	1.34	1.45	2.75	1.56	-0.062	symmetrical	0.793	platykurtic
Gn 7.4	-0.95	-0.38	0.12	1.40	2.53	2.97	3.53	1.33	1.40	2.75	1.52	-0.056	symmetrical	0.76	platykurtic
Bn 2.1	-0.81	-0.44	-0.11	0.80	2.06	2.49	3.45	0.95	0.80	1.75	1.38	0.199	F. skew	0.805	platykurtic
Bn 2.2	-0.88	-0.53	-0.21	0.88	1.81	2.35	3.18	0.90	0.88	1.75	1.34	0.077	symmetrical	0.824	platykurtic
Bn 2.3	-0.91	-0.58	-0.31	0.42	1.70	2.20	2.99	0.68	0.42	0.25	1.29	0.299	F. skew	0.795	platykurtic
Bn 2.4	-0.92	-0.62	-0.28	0.55	1.79	2.34	3.39	0.76	0.55	-0.50	1.39	0.264	F. skew	0.853	platykurtic
Bn 4.1	-0.80	-0.20	0.19	1.39	2.33	2.75	3.87	1.31	1.39	2.75	1.45	-0.008	symmetrical	0.894	platykurtic
Bn 4.2	-0.89	-0.60	0.00	1.22	2.52	3.11	3.80	1.24	1.22	0.00	1.64	0.060	symmetrical	0.763	platykurtic
Bn 4.3	-0.90	-0.38	0.13	1.38	2.48	2.91	3.76	1.30	1.38	2.75	1.53	-0.024	symmetrical	0.813	platykurtic
Bn 4.4	-0.85	-0.25	0.25	1.41	2.68	3.24	3.74	1.47	1.41	2.75	1.57	0.032	symmetrical	0.774	platykurtic
Bn 4.5	-0.75	-0.35	0.27	1.52	2.74	3.16	3.75	1.44	1.52	2.75	1.56	-0.037	symmetrical	0.747	platykurtic
Bn 4.6	-0.87	-0.36	0.08	1.20	2.36	2.71	3.53	1.18	1.20	2.75	1.43	0.021	symmetrical	0.791	platykurtic
Bn 5.1	-0.82	-0.20	0.19	1.39	3.12	3.62	4.38	1.60	1.39	0.75	1.74	0.159	F. skew	0.727	platykurtic
Bn 5.2	-0.90	-0.50	0.08	1.14	2.66	3.38	4.08	1.34	1.14	0.75	1.72	0.168	F. skew	0.791	platykurtic
Bn 5.3	-0.90	-0.41	0.09	0.99	2.61	3.39	3.92	1.32	0.99	0.75	1.68	0.239	F. skew	0.784	platykurtic
Bn 5.4	-0.83	-0.40	0.04	1.24	2.71	3.35	3.84	1.40	1.24	0.75	1.65	0.119	F. skew	0.717	platykurtic
Bn 5.5	-0.77	-0.20	0.27	1.31	2.59	3.14	3.99	1.42	1.31	0.75	1.56	0.111	F. skew	0.841	platykurtic

Table 3 con't: Grain size percentile data, and results of statistical analysis using logarithmic method of Folk and Ward (1957).

Sample #	Percentiles (Φ)							Graphical Statistics (Φ)							
	5^{th}	16^{th}	25^{th}	50^{th}	75^{th}	84^{th}	95^{th}	Mean	Median	Mode	StDev.	Skewness		Kurtosis	
Bn 7.1	-0.92	-0.52	-0.19	0.83	2.15	2.80	3.78	1.04	0.83	0.00	1.54	0.221	F. skew	0.823	platykurtic
Bn 7.2	-0.89	-0.41	0.02	1.01	2.15	2.52	3.59	1.04	1.01	0.75	1.41	0.091	symmetrical	0.862	platykurtic
Bn 7.3	-0.87	-0.53	-0.10	1.02	2.11	2.38	2.91	0.96	1.02	2.75	1.30	-0.033	symmetrical	0.701	platykurtic
Bn 7.4	-0.91	-0.51	-0.10	0.90	2.01	2.51	3.59	0.97	0.90	0.75	1.44	0.131	F. skew	0.874	platykurtic
Bn7.5	-0.99	-0.49	-0.12	0.80	2.15	2.56	3.60	0.96	0.80	0.75	1.46	0.187	F. skew	0.829	platykurtic
Bn 8.1	-0.90	-0.42	0.01	1.28	2.95	3.79	4.60	1.55	1.28	0.75	1.89	0.200	F. skew	0.767	platykurtic
Bn 8.2	-0.89	-0.39	0.09	1.17	2.21	2.50	3.21	1.09	1.17	2.75	1.34	-0.042	symmetrical	0.793	platykurtic
Bn 8.3	-0.99	-0.50	-0.10	0.98	2.17	2.51	3.68	1.00	0.98	0.75	1.46	0.086	symmetrical	0.843	platykurtic
Bn 8.4	-1.06	-0.55	-0.19	0.79	2.12	2.61	3.66	0.95	0.79	0.75	1.51	0.184	F. skew	0.837	platykurtic
Bn 8.5	-0.87	-0.39	0.04	0.97	2.11	2.56	3.46	1.05	0.97	0.75	1.39	0.114	F. skew	0.857	platykurtic
Gy 1.1	-0.97	-0.62	-0.18	0.29	1.49	2.12	3.31	0.60	0.29	0.00	1.33	0.373	S. F. skew	1.050	mesokurtic
Gy 1.2	-0.88	-0.28	-0.03	0.61	1.71	2.27	3.12	0.87	0.61	0.25	1.24	0.278	F. skew	0.942	mesokurtic
Gy 1.3	-0.91	-0.69	-0.39	0.36	1.46	2.04	2.72	0.57	0.36	-0.50	1.23	0.266	F. skew	0.804	platykurtic
Gy 1.4	-0.90	-0.68	-0.43	0.23	1.47	1.88	3.12	0.48	0.23	0.25	1.25	0.363	S. F. skew	0.867	platykurtic
Gy 1.5	-0.88	-0.59	-0.29	0.41	1.47	1.84	2.98	0.55	0.41	1.75	1.19	0.254	F. skew	0.899	platykurtic
Gy 1.6	-0.90	-0.67	-0.46	0.12	1.09	1.61	2.49	0.35	0.12	-0.25	1.08	0.353	S. F. skew	0.896	platykurtic
Gy 3.1	-0.85	-0.36	0.11	1.27	2.38	2.77	3.71	1.23	1.27	2.75	1.47	0.014	symmetrical	0.823	platykurtic
Gy 3.2	-0.86	-0.52	0.11	0.91	2.31	2.98	3.82	1.12	0.91	0.75	1.58	0.213	F. skew	0.872	platykurtic
Gy 3.3	-0.93	-0.49	-0.18	0.79	2.19	2.62	3.69	0.97	0.79	0.75	1.48	0.216	F. skew	0.799	platykurtic
Gy 3.4	-1.02	-0.71	-0.36	0.52	1.78	2.39	3.62	0.73	0.52	0.00	1.48	0.271	F. skew	0.889	platykurtic
Gy 3.5	-0.92	-0.52	-0.12	0.78	2.08	2.72	3.77	0.99	0.78	0.75	1.52	0.236	F. skew	0.874	platykurtic
Gy 4.1	-0.88	-0.48	0.13	0.78	1.97	2.27	2.77	0.86	0.78	0.75	1.24	0.087	symmetrical	0.813	platykurtic
Gy 4.2	-0.88	-0.56	0.22	0.54	1.72	2.23	3.11	0.74	0.54	0.00	1.30	0.250	F. skew	1.090	mesokurtic
Gy 4.3	-0.99	-0.62	-0.22	0.55	1.69	2.20	2.28	0.71	0.55	0.00	1.20	0.114	F. skew	0.702	platykurtic
Gy 4.4	-0.99	-0.68	-0.40	0.39	1.40	2.02	3.29	0.58	0.39	0.00	1.32	0.281	F. skew	0.974	platykurtic
Gy 6.1	-0.88	-0.30	0.19	1.50	2.58	2.95	3.61	1.38	1.50	2.75	1.49	-0.084	symmetrical	0.770	platykurtic
Gy 6.2	-0.90	-0.48	-0.36	0.89	2.25	2.61	3.63	1.01	0.89	2.75	1.46	0.161	F. skew	0.711	platykurtic
Gy 6.3	-0.90	-0.49	0.38	0.93	2.28	2.85	3.80	1.10	0.93	0.75	1.55	0.185	F. skew	1.014	mesokurtic
Gy 6.4	-0.95	-0.60	-0.26	0.74	2.03	2.63	3.70	0.92	0.74	0.00	1.51	0.222	F. skew	0.832	platykurtic
Gy 6.5	-1.02	-0.60	-0.27	0.79	2.11	2.53	3.74	0.91	0.79	0.75	1.50	0.176	F. skew	0.820	platykurtic
Gy 7.1	-0.88	-0.40	0.02	1.24	2.38	2.81	3.60	1.22	1.24	2.75	1.48	0.016	symmetrical	0.778	platykurtic
Gy 7.2	-0.88	-0.59	0.10	0.92	2.31	2.74	3.68	1.02	0.92	0.75	1.52	0.152	F. skew	0.846	platykurtic
Gy 7.3	-0.89	-0.48	-0.13	0.86	2.11	2.60	3.40	0.99	0.86	0.75	1.42	0.157	F. skew	0.785	platykurtic
Gy 7.4	-0.82	-0.41	0.08	1.11	2.67	3.22	3.76	1.31	1.11	0.75	1.60	0.160	F. skew	0.725	platykurtic
Gy 7.5	-0.85	-0.50	0.12	0.79	2.12	2.68	3.75	0.99	0.79	0.75	1.49	0.238	F. skew	0.943	mesokurtic

from positively (fine) skewed (i.e. 10 samples in green stand, 14 samples in brown stand, and 18 samples in gray stand) to symmetrical (i.e. 10 samples in green stand, 11 samples in brown stand, and 4 samples in gray stand)(Table 3). Many of the topsoil samples within each of the pine stand types record a symmetrical grain size distribution. As a group, many of the samples within the gray stand record a fine skewed grain size distribution, whereas many of the samples in the green and brown stand record a symmetrical grain size distribution (Table 3). One of the samples (i.e. sample Gn 5.5) is negatively (coarse) skewed. Soil samples from most soil pits show platykurtic distributions (i.e. 20 samples in green stand, all 25 samples in brown stand, and 20 samples in gray stand), some show mesokurtic distributions (i.e. 1 sample in green stand and 5 samples in gray stand), and 1 sample in the green stand records a leptokurtic distribution (Table 3).

The percentile data is grouped according to the three beetle-killed stand types (i.e. green, brown, and gray) (Table 3; Fig. 7 & 8). The soil pits are also ordered according to hillslope elevation at the point of collection. The data is from the upper soils (approximately 2- to 8-inches below ground surface), as well as from samples taken from intermediate to deep depths (approximately 13- to 20-inches below ground surface). The sampling depths represented were chosen to compare grain size distributions near the surface of the profile as well as from below the surface. Plotting by hillslope elevation was chosen in an attempt to identify physical downslope migration of weathered material.

The grain size distribution of soils collected from the various hillslope positions, depths, and pine stand types show slight variations. The mean, standard deviation and standard error of each grain size percentile was compared for the upper and intermediate to deep samples from the three pine stand types (Table 4). Results show that the mean of grain sizes is coarser from the green to brown to gray stands (Table 4; Fig. 9). The means of the upper soil samples are slightly

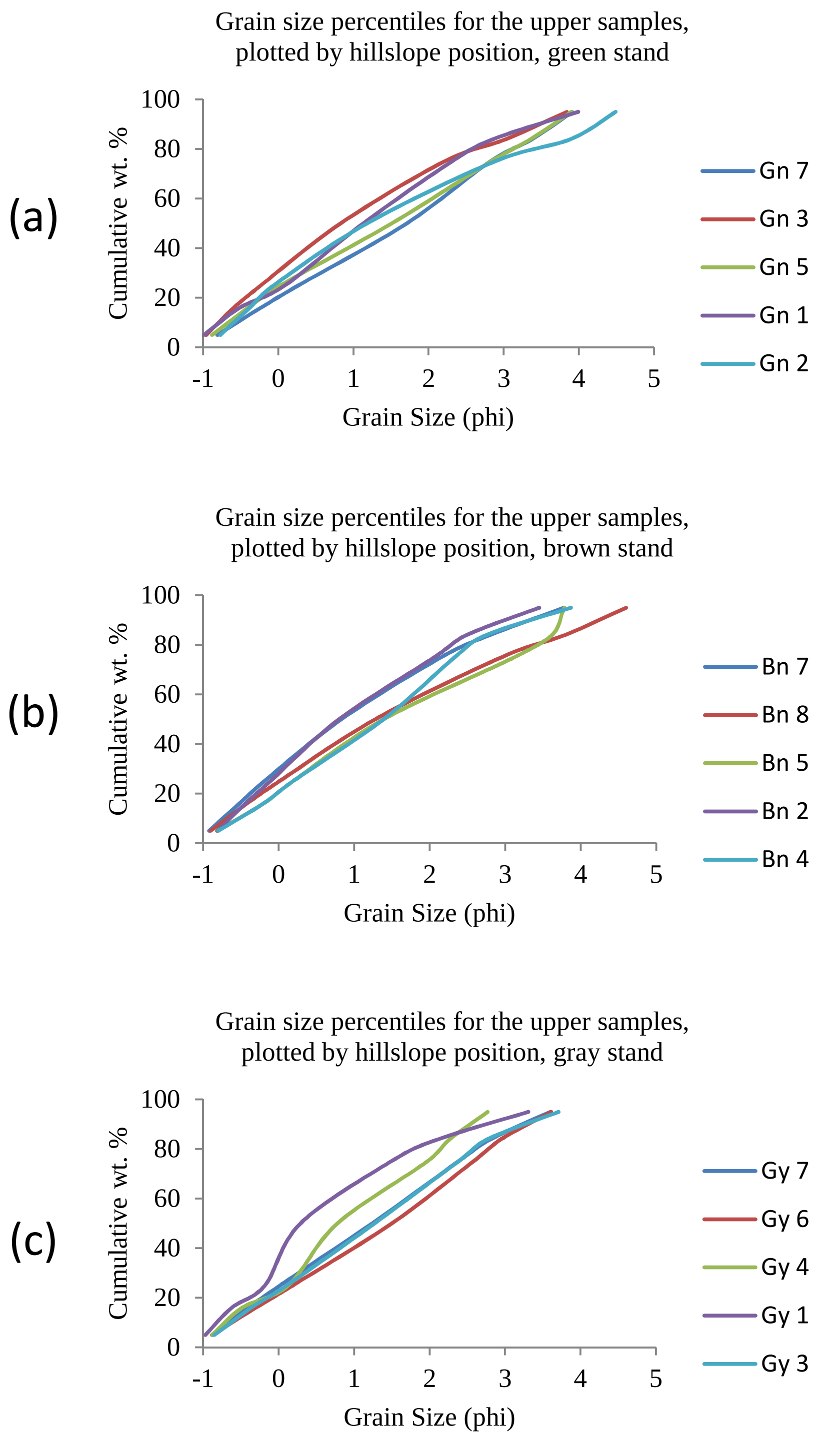


Figure 7. Grain size distribution plots for the topsoil immediately below the organic horizon in the (a) green stand type, (b) brown stand type, (c) gray stand type. The soil pits are ordered by elevation with the top samples collected from greater elevations than the bottom samples.

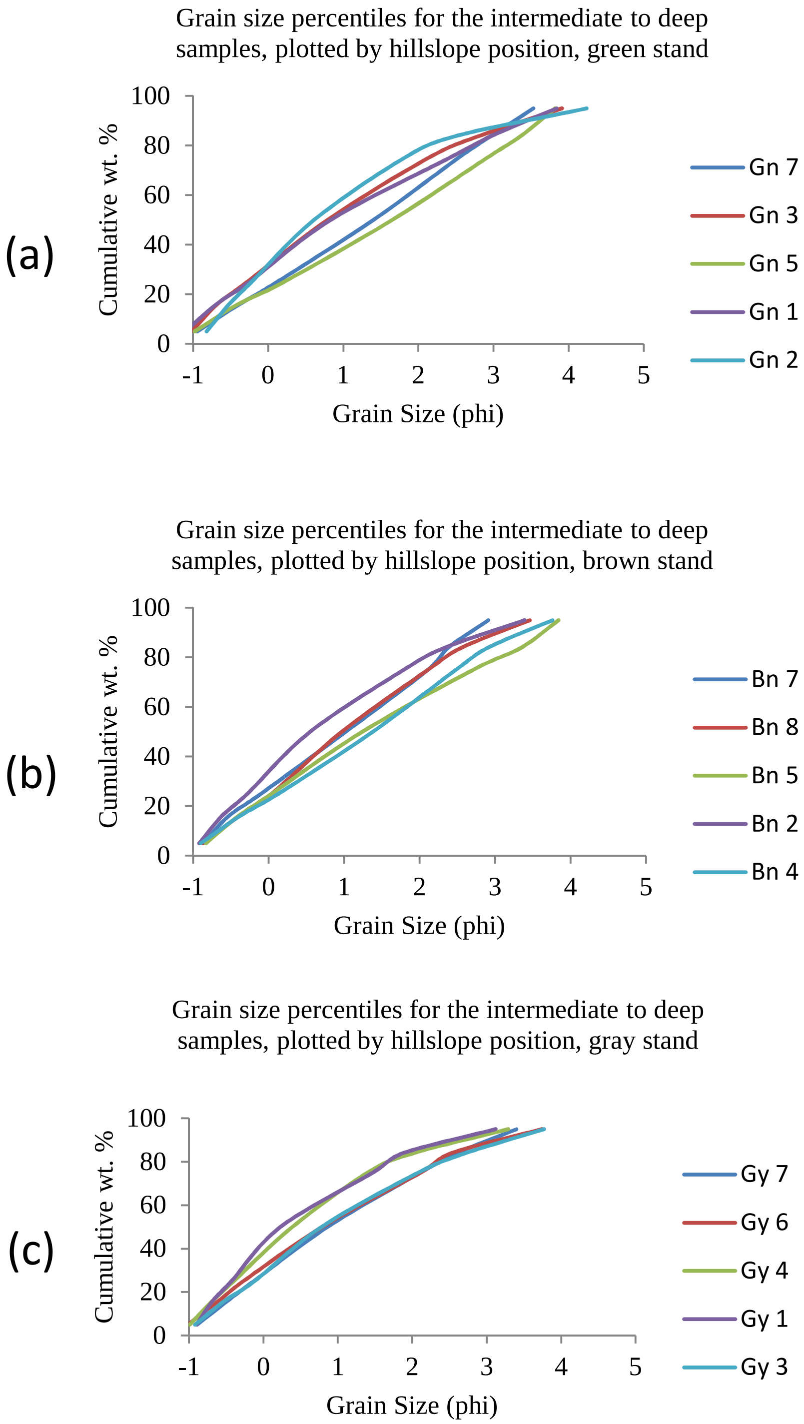


Figure 8. Grain size distribution plots for the soils at intermediate to deep sample depths in the (a) green stand type, (b) brown stand type, (c) gray stand type. The soil pits are ordered by elevation with the top samples collected from greater elevations than the bottom samples.

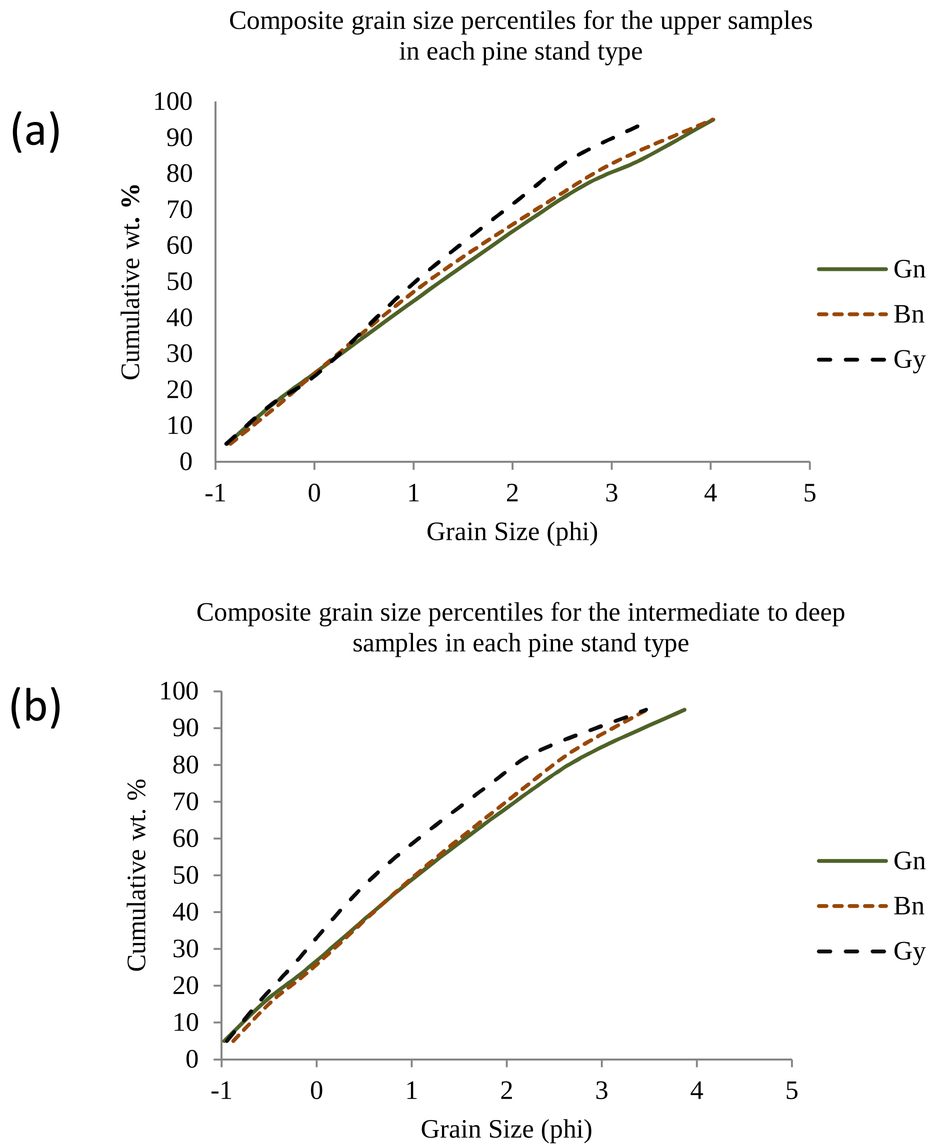


Figure 9. Composite grain size percentile data from each pine stand type. (a) Upper samples below the organic horizon. (b) Intermediate to deep samples.

finer than the soils from intermediate to deep depth. There were no differences identified between the soil grain size distribution and soil sampling elevation.

Table 4a: Composite grain size percentiles for upper samples.

Pine Stand Type	**5th (Φ)**	**16th (Φ)**	**25th (Φ)**	**50th (Φ)**	**75th (Φ)**	**84th (Φ)**	**95th (Φ)**	**Mean (Φ)**	**Std. Dev. (Φ)**	**Std. Error (Φ**
Green	-0.88	-0.42	0.02	1.27	2.61	3.30	4.03	1.42	1.93	0.73
Brown	-0.85	-0.36	0.02	1.14	2.52	3.09	4.02	1.27	1.87	0.71
Gray	-0.89	-0.43	0.05	1.02	2.16	2.58	3.40	1.13	1.63	0.62

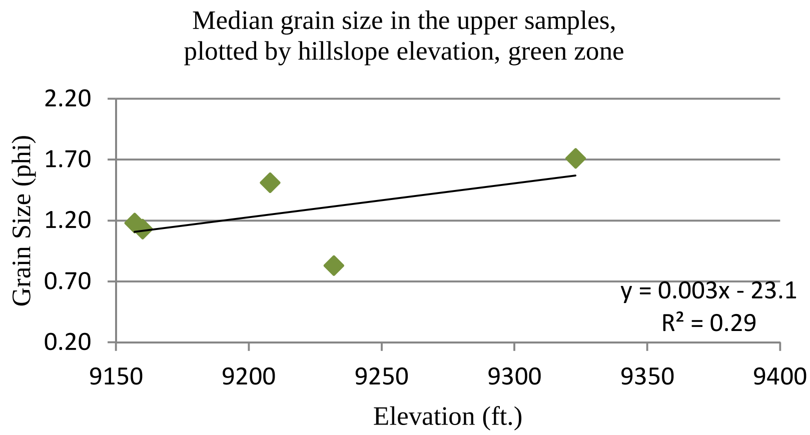
Table 4b: Composite grain size percentiles for intermediate to deep samples.

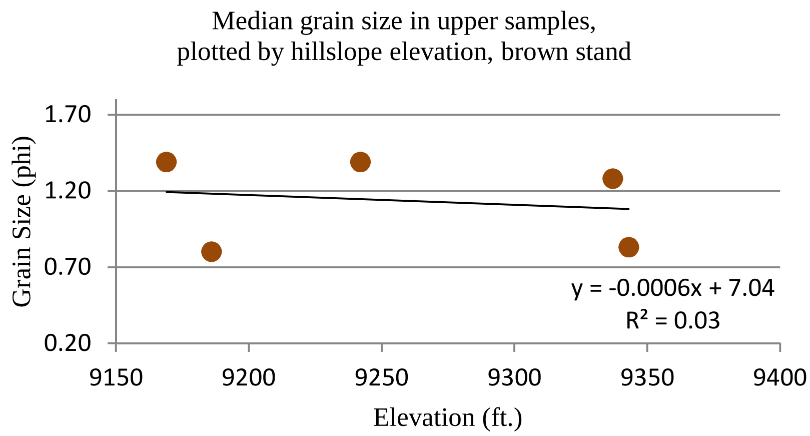
Pine Stand Type	**5th (Φ)**	**16th (Φ)**	**25th (Φ)**	**50th (Φ)**	**75th (Φ)**	**84th (Φ)**	**95th (Φ)**	**Mean (Φ)**	**Std. Dev. (Φ)**	**Std. Error (Φ**
Green	-0.97	-0.53	-0.08	1.06	2.36	2.93	3.87	1.23	1.86	0.7
Brown	-0.88	-0.46	-0.03	1.03	2.24	2.71	3.47	1.15	1.69	0.64
Gray	-0.94	-0.59	-0.27	0.61	1.83	2.35	3.46	0.92	1.66	0.63

To further assess downslope migration of regolith on the hillslope the 50th and 95th percentiles of the grain size data were plotted as a function of hillslope position in each of the three pine stand types, and fit with a best fit line to test correlation (Fig. 10 & 11). Results show low R^2 values and varying slopes of the best fit line. The 50th percentile data has a positive slope in the samples of the green stand, negative slope in the brown stand, and positive slope in the gray stand. The 95th percentile data have a negative slope in the samples of the green stand, positive slope in the brown stand, and negative slope in the gray stand.

4.3 Geochemistry

Geochemical data (Table 5) were obtained to allow comparison of the soils to rock samples thought to represent parent material for the soils and to compare concentrations of the major oxide compounds and selected trace elements in the soil profiles beneath each of the three





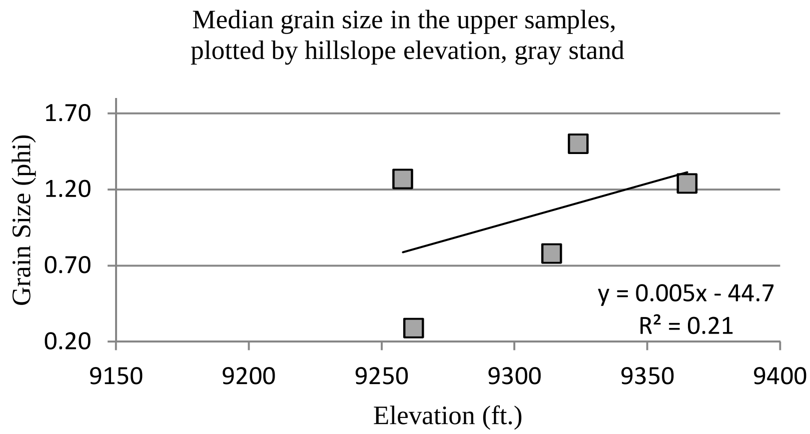
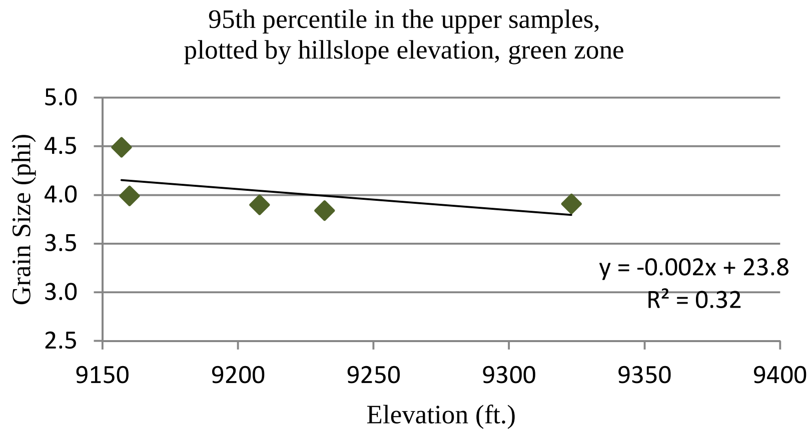
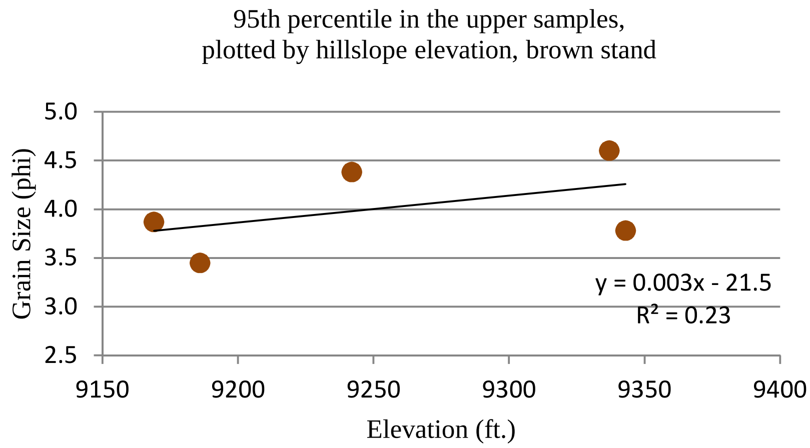


Figure 10. Median grain size diameter in the upper samples of each pine stand type.





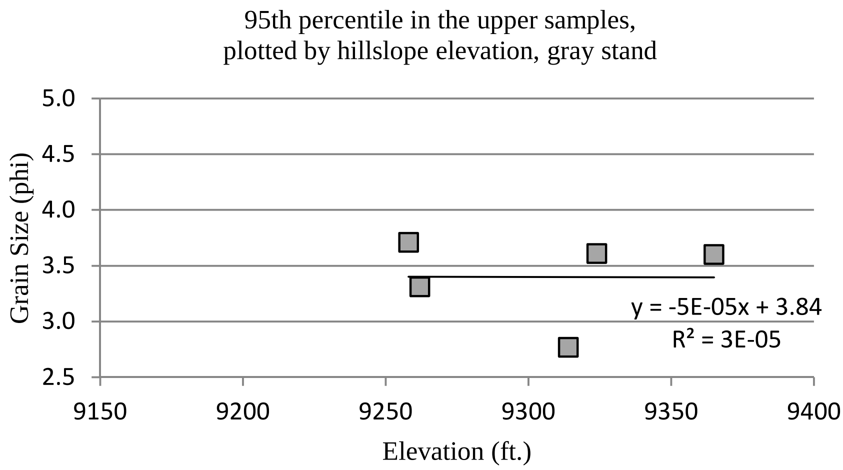


Figure 11. 95th percentile (fines) in the upper samples of each pine stand type.

Table 5: Soil and whole-rock geochemistry.

Analyte Symbol	SiO2	Al2O3	Fe2O3(T)	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	LOI	Total	Ba	Sr	Y	Sc	Zr	Be	V
Unit Symbol	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
Gn 1.1	72.2	12.3	3.75	0.04	0.70	0.83	1.96	4.01	0.54	0.22	3.66	100.2	744	567	56	7	319	2	62
Gn 1.2	72.7	12.6	3.36	0.03	0.56	0.68	1.88	3.88	0.56	0.16	2.91	99.27	760	241	23	5	322	2	60
Gn 1.3	71.3	12.8	3.71	0.06	0.68	0.74	1.79	3.64	0.63	0.17	3.50	99.09	802	269	23	6	361	2	70
Gn 1.5	67.9	13.9	4.24	0.05	0.89	0.80	1.72	3.76	0.61	0.17	4.66	98.71	800	278	24	8	313	2	82
Gn 1.7	67.7	14.3	4.46	0.05	1.01	0.86	1.64	3.45	0.64	0.18	5.18	99.42	818	300	29	9	331	2	87
Average	70.4	13.2	3.90	0.05	0.77	0.78	1.80	3.75	0.59	0.18			785	331	31	7	329	2	72
Standard Error	1.07	0.39	0.20	0.01	0.08	0.03	0.06	0.10	0.02	0.01			14.0	59.8	6.3	0.7	8.46	0	5.4
Gn 3.1	69.0	12.8	3.53	0.04	0.57	0.73	1.91	4.13	0.53	0.19	4.94	98.40	688	225	26	5	309	2	61
Gn 3.2	69.5	12.8	3.72	0.04	0.62	0.72	1.84	4.02	0.54	0.18	4.80	98.69	700	233	25	6	292	2	67
Gn 3.3	68.8	14.3	4.14	0.05	0.96	0.80	1.66	3.65	0.58	0.16	5.01	100.1	720	266	28	8	316	2	85
Gn 3.4	70.2	13.6	4.05	0.06	0.71	0.76	1.78	4.03	0.52	0.16	3.72	99.57	696	232	28	6	300	2	73
Average	69.4	13.4	3.86	0.05	0.72	0.75	1.80	3.96	0.54	0.17			701	239	27	6	304	2	72
Standard Error	0.32	0.37	0.14	0.005	0.09	0.02	0.05	0.11	0.01	0.01			6.81	9.17	0.75	0.6	5.23	0	5.1
Gn 5.1	71.6	12.9	2.65	0.03	0.45	0.61	2.24	4.73	0.46	0.17	4.44	100.3	675	183	20	4	243	1	42
Gn 5.2	72.8	12.9	2.85	0.03	0.44	0.62	2.12	4.48	0.46	0.17	3.14	99.98	670	185	20	4	267	1	44
Gn 5.3	72.9	13.2	2.89	0.03	0.45	0.60	2.25	4.64	0.45	0.17	2.67	100.2	650	175	20	4	282	1	43
Gn 5.4	71.6	13.5	3.68	0.03	0.50	0.63	2.32	4.78	0.50	0.18	2.63	100.3	653	185	24	4	296	2	55
Gn 5.5	71.5	13.2	3.85	0.04	0.51	0.70	2.15	4.44	0.53	0.19	2.66	99.68	630	193	29	4	319	1	59
Average	72.1	13.1	3.18	0.03	0.47	0.63	2.22	4.61	0.48	0.18			656	184	23	4	281	1	49
Standard Error	0.31	0.11	0.24	0.003	0.01	0.02	0.04	0.07	0.01	0.004			7.99	2.87	1.8	0	12.9	0.2	3.5
Gn 7.1	72.4	12.8	3.46	0.03	0.47	0.67	1.99	4.27	0.50	0.17	3.97	100.8	642	199	27	4	306	2	55
Gn 7.2	71.8	12.9	3.85	0.03	0.45	0.63	2.01	4.52	0.49	0.18	2.60	99.50	617	175	28	5	315	2	58
Gn 7.3	71.5	13.1	3.99	0.03	0.47	0.63	2.03	4.67	0.48	0.20	2.65	99.77	610	171	30	5	297	2	58
Gn 7.4	71.4	13.3	3.64	0.03	0.45	0.62	1.99	4.52	0.45	0.19	2.42	98.99	607	160	29	5	284	2	53
Average	71.8	13.0	3.74	0.03	0.46	0.64	2.01	4.50	0.48	0.19			619	176	29	5	301	2	56
Standard Deviation	0.23	0.11	0.12	0.001	0.006	0.01	0.01	0.08	0.01	0.006			7.95	8.22	0.65	0.3	6.61	0.0	1.2

Table 5 con't: Soil and whole-rock geochemistry.

Analyte Symbol	**SiO2**	**Al2O3**	**Fe2O3(T)**	**MnO**	**MgO**	**CaO**	**Na2O**	**K2O**	**TiO2**	**P2O5**	**LOI**	**Total**	**Ba**	**Sr**	**Y**	**Sc**	**Zr**	**Be**	**V**
Unit Symbol	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
Bn 4.1	71.7	12.2	4.35	0.06	0.39	0.65	2.08	4.12	0.56	0.15	2.77	98.93	660	223	27	4	326	2	76
Bn 4.2	72.4	13.2	3.42	0.04	0.39	0.64	2.30	4.87	0.46	0.17	2.42	100.3	686	233	23	4	246	2	56
Bn 4.3	72.7	13.2	3.24	0.04	0.42	0.66	2.24	4.48	0.43	0.17	2.11	99.72	737	257	19	4	230	2	51
Bn 4.6	70.6	13.3	3.82	0.05	0.59	0.66	2.03	4.20	0.52	0.13	3.05	98.96	729	252	23	6	273	2	66
Average	71.9	12.9	3.71	0.05	0.45	0.65	2.16	4.42	0.49	0.16			703	241	23	5	269	2	62
Standard Error	0.47	0.27	0.25	0.006	0.05	0.005	0.06	0.17	0.03	0.01			18.2	7.98	1.6	0.5	21.0	0	5.5
Bn 5.1	71.7	12.5	2.97	0.03	0.43	0.60	1.95	4.15	0.48	0.17	3.68	98.70	642	194	22	4	279	2	46
Bn 5.2	72.4	12.6	2.96	0.03	0.44	0.60	1.97	4.17	0.46	0.16	2.72	98.53	668	200	21	4	255	2	45
Bn 5.3	72.8	12.8	3.12	0.03	0.48	0.63	2.12	4.72	0.45	0.17	2.76	100.1	693	208	18	5	236	2	50
Bn 5.4	74.3	12.8	3.09	0.04	0.50	0.63	2.02	4.39	0.47	0.15	2.45	100.9	713	213	18	5	231	2	50
Bn 5.5	72.7	12.7	3.24	0.04	0.51	0.57	2.10	4.53	0.45	0.14	2.32	99.29	670	207	19	5	232	2	50
Average	72.8	12.7	3.08	0.03	0.47	0.61	2.03	4.39	0.46	0.16			677	204	20	5	247	2	48
Standard Error	0.43	0.053	0.052	0.002	0.02	0.01	0.03	0.11	0.006	0.006			12.1	3.33	0.81	0.2	9.2	0	1.1
Bn 7.1	73.5	12.1	2.20	0.02	0.33	0.52	1.95	4.68	0.36	0.12	2.88	98.64	599	106	18	4	203	2	29
Bn 7.2	74.7	12.3	2.32	0.02	0.32	0.50	2.04	4.95	0.36	0.12	2.26	99.87	589	103	18	4	214	2	30
Bn 7.3	74.4	12.7	2.26	0.01	0.32	0.46	2.17	5.46	0.33	0.13	1.99	100.2	573	94	16	4	197	2	27
Bn 7.5	74.9	12.5	2.51	0.01	0.34	0.45	2.10	5.33	0.33	0.14	2.32	101.0	572	91	16	4	189	2	29
Average	74.4	12.4	2.32	0.02	0.33	0.48	2.07	5.11	0.34	0.13			583	99	17	4	201	2	29
Standard Error	0.32	0.12	0.067	0.001	0.005	0.02	0.05	0.18	0.008	0.005			6.54	3.6	0.58	0	5.27	0	0.63
Bn 8.1	72.9	12.3	2.63	0.02	0.39	0.49	1.82	4.59	0.42	0.15	3.29	98.98	619	125	20	4	243	2	38
Bn 8.2	73.7	12.5	2.65	0.02	0.36	0.45	1.85	4.84	0.34	0.13	2.5	99.3	603	106	16	4	191	2	33
Bn 8.3	72.7	13.6	2.68	0.01	0.38	0.44	1.82	4.87	0.32	0.12	2.5	99.48	583	97	18	4	211	2	34
Bn 8.5	73.9	13.7	2.56	0.02	0.36	0.39	1.84	5.18	0.30	0.15	2.57	101	578	86	17	4	162	2	31
Average	73.3	13.0	2.63	0.02	0.37	0.44	1.83	4.87	0.34	0.14			596	104	18	4	202	2	34
Standard Error	0.29	0.38	0.025	0.00	0.01	0.02	0.01	0.12	0.03	0.01			9.45	8.25	0.85	0	17.0	0	1.5

Table 5 con't: Sand and whole-rock geochemistry.

Analyte Symbol	**SiO2**	**Al2O3**	**Fe2O3(T)**	**MnO**	**MgO**	**CaO**	**Na2O**	**K2O**	**TiO2**	**P2O5**	**LOI**	**Total**	**Ba**	**Sr**	**Y**	**Sc**	**Zr**	**Be**	**V**
Unit Symbol	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
Gy 3.1	71.5	13.1	3.06	0.03	0.37	0.60	2.42	4.68	0.41	0.13	3.13	99.39	732	250	18	4	232	2	52
Gy 3.2	72.7	13.4	2.93	0.02	0.36	0.54	2.42	5.05	0.33	0.14	2.50	100.3	658	193	14	4	195	2	42
Gy 3.3	70.3	14.0	3.59	0.03	0.47	0.64	2.36	4.91	0.39	0.17	2.86	99.72	727	228	17	5	193	2	58
Gy 3.5	71.8	13.7	3.81	0.04	0.50	0.71	2.18	4.60	0.40	0.18	3.04	100.9	711	229	20	5	206	2	57
Average	71.6	13.5	3.35	0.03	0.43	0.62	2.35	4.81	0.38	0.16			707	225	17	5	207	2	52
Standard Error	0.48	0.19	0.21	0.002	0.04	0.04	0.06	0.10	0.02	0.01			16.9	11.8	1.3	0.3	8.97	0	3.7
Gy 4.1	65.5	14.3	4.95	0.04	0.69	0.94	2.18	4.34	0.53	0.22	5.67	99.35	911	335	20	8	187	2	85
Gy 4.2	68.9	13.7	4.12	0.04	0.58	0.73	2.19	4.41	0.46	0.16	4.44	99.70	813	310	15	5	181	2	66
Gy 4.3	68.7	13.9	3.92	0.04	0.58	0.76	2.21	4.43	0.42	0.15	4.30	99.37	869	354	15	6	185	2	63
Gy 4.4	70.2	13.8	3.82	0.03	0.56	0.75	2.18	4.44	0.42	0.16	3.94	100.4	799	312	18	6	208	2	60
Average	68.3	13.9	4.20	0.04	0.60	0.80	2.19	4.41	0.46	0.17			848	328	17	6	190	2	69
Standard Error	0.99	0.12	0.26	0.002	0.03	0.05	0.01	0.02	0.03	0.02			25.9	10.4	1.2	0.6	6.05	0	5.6
Gy 6.1	72.2	12.8	3.02	0.02	0.39	0.63	2.21	4.55	0.45	0.15	3.55	100	744	212	20	4	261	2	47
Gy 6.2	70.5	13.3	3.39	0.02	0.44	0.65	2.23	4.73	0.40	0.17	3.20	99.04	802	237	17	5	190	2	50
Gy 6.3	71.0	13.6	3.45	0.02	0.47	0.67	2.20	4.65	0.39	0.17	2.95	99.57	772	227	17	5	203	2	50
Gy 6.5	67.9	14.6	4.55	0.04	0.63	0.86	2.38	4.69	0.46	0.19	3.56	99.86	908	353	17	6	215	2	72
Average	70.4	13.6	3.60	0.03	0.48	0.70	2.26	4.66	0.43	0.17			807	257	18	5	217	2	55
Standard Error	0.91	0.37	0.33	0.005	0.05	0.05	0.04	0.04	0.02	0.008			35.8	32.3	0.75	0.4	15.5	0	5.8
Gy 7.1	71.5	13.1	3.03	0.02	0.39	0.67	2.49	4.94	0.43	0.15	3.51	100.1	792	240	17	4	223	2	46
Gy 7.2	72.9	13.3	3.03	0.02	0.45	0.62	2.20	4.72	0.40	0.15	2.48	100.2	796	235	15	5	202	2	44
Gy 7.3	73.6	13.1	2.91	0.02	0.39	0.62	2.30	4.80	0.38	0.17	2.57	100.8	784	229	17	4	214	2	42
Gy 7.4	72.8	13.4	3.00	0.02	0.46	0.63	2.20	4.65	0.40	0.15	2.60	100.3	780	227	17	5	217	2	44
Gy 7.5	71.6	13.3	3.03	0.03	0.46	0.67	2.17	4.54	0.38	0.15	3.34	99.62	785	241	18	5	197	2	45
Average	72.4	13.2	3.00	0.02	0.43	0.64	2.27	4.73	0.40	0.15			787	234	17	5	211	2	44
Standard Error	0.45	0.074	0.026	0.001	0.02	0.01	0.07	0.08	0.01	0.004			3.23	3.15	0.55	0.3	5.39	0	0.74
Outcrop 1	65.1	12.7	3.11	0.06	1.28	4.52	1.00	1.58	0.44	0.30	9.75	99.88	1580	1706	19	6	175	1	46
Outcrop 2.1	62.7	15.5	4.85	0.13	1.27	4.51	2.41	2.74	0.49	0.28	5.11	99.88	1774	1510	22	9	191	2	69
Outcrop 2.2	61.8	16.8	5.5	0.12	1.19	4.03	3.57	3.17	0.57	0.25	2.75	99.73	1637	1664	20	9	182	2	104

pine stand types. Variation in soil and whole-rock geochemistry is illustrated here in plots of selected oxide compounds (i.e. SiO_2, Al_2O_3, $Fe_2O_{3(T)}$, MnO, MgO, CaO, Na_2O, K_2O, TiO_2) and a few trace elements (i.e. Ba, Sr, and Zr) versus sample depth in each of the pine stand types. In addition, a composite plot for each of the compounds and trace elements compares the average and standard error of geochemical data from samples collected from similar depths in each of the three pine stand types. The data plotted in the composite plots is according to approximate depth, indicating that not all soils were collected from the same sampling depth, but the data plotted includes samples collected from similar depths from the various pine stand types. In addition, the soil pits within each of the pine stand types are ordered by hillslope elevation.

The geochemical make-up of the majority of soils is fairly uniform with only modest variations in geochemistry among the soil pits. Table 6 compares the average and standard error of major and trace elements in the upper soils as well as from intermediate to deep depths and illustrates that the majority of the major and trace element averages do not record strong relationships between pine stand type and average element concentration. MnO, MgO and Zr show a slight decrease in average concentration from the green to brown and gray sampling sites. Average K_2O is greater in the soils of the brown and gray stands than in the green stand. The data indicate that there is more Al_2O_3 (~ 0.6 – 1.0 wt. %) in the upper soils beneath the trees in the gray stand than in the soils beneath the trees in the brown and green stands (Table 6).

Vertical variations in chemical composition of soils on the hillslope were interpreted by plotting selected major and trace elements as a function of sampling depth. The concentrations of SiO_2 in soils are similar within the soil sampling sites, but are variable with the depth of sampling, and there is not a consistent relationship apparent between SiO_2 concentration and the sampling locations (Table 5; Fig. 12a,b,c). The composite plot shows that there are greater and

Table 6a: Average and standard deviation of element concentrations in the upper samples.

	SiO_2	Al_2O_3	Fe_2O_3(T)	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Ba	Sr	Y	Sc	Zr	Be	V
	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Upper samples in green stand (n=4).																	
Average	71.3	12.7	3.35	0.03	0.55	0.71	2.03	4.29	0.50	0.19	687	293	32	5	294	2	55
Standard Error	0.78	0.14	0.24	0.003	0.06	0.05	0.07	0.16	0.02	0.01	21.3	91.5	8.0	0.7	17.3	0.3	4.6
Upper samples in brown stand (n=4).																	
Average	72.4	12.3	3.04	0.03	0.39	0.57	1.95	4.39	0.45	0.15	630	162	22	4	263	2	47
Standard Error	0.45	0.09	0.46	0.009	0.02	0.04	0.05	0.15	0.04	0.01	13.3	27.8	2.0	0	26.2	0	10
Upper samples in the gray stand (n=4).																	
Average	70.2	13.3	3.52	0.03	0.46	0.71	2.33	4.63	0.45	0.16	795	259	19	5	226	2	58
Standard Error	1.56	0.32	0.48	0.005	0.08	0.08	0.08	0.13	0.03	0.02	40.9	26.5	0.75	1	15.3	0	9.5

Table 6b: Mean and standard deviation of element concentrations in intermediate to deep samples.

	SiO_2	Al_2O_3	Fe_2O_3(T)	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Ba	Sr	Y	Sc	Zr	Be	V
	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Intermediate to deep samples in the green stand (n=4).																	
Average	70.3	13.6	3.90	0.04	0.64	0.70	1.95	4.27	0.52	0.18	689	214	26	6	298	2	66
Standard Error	0.85	0.13	0.15	0.007	0.10	0.05	0.14	0.23	0.03	0.01	41.2	26.1	1.3	0.85	5.98	0	7.0
Intermediate to deep samples in the brown stand (n=4).																	
Average	74.0	13.0	2.85	0.03	0.41	0.53	2.05	4.85	0.38	0.15	650	162	18	4	203	2	40
Standard Error	0.46	0.25	0.18	0.006	0.04	0.07	0.08	0.24	0.04	0.006	43.5	42.9	0.65	0.3	16.4	0	6.5
Intermediate to deep samples in the gray stand (n=4).																	
Average	70.9	13.8	3.77	0.03	0.52	0.74	2.26	4.63	0.42	0.18	801	281	18	5	211	2	58
Standard Error	1.20	0.31	0.34	0.004	0.05	0.05	0.05	0.08	0.02	0.006	40.7	31.1	0.70	0.5	2.22	0	6.0

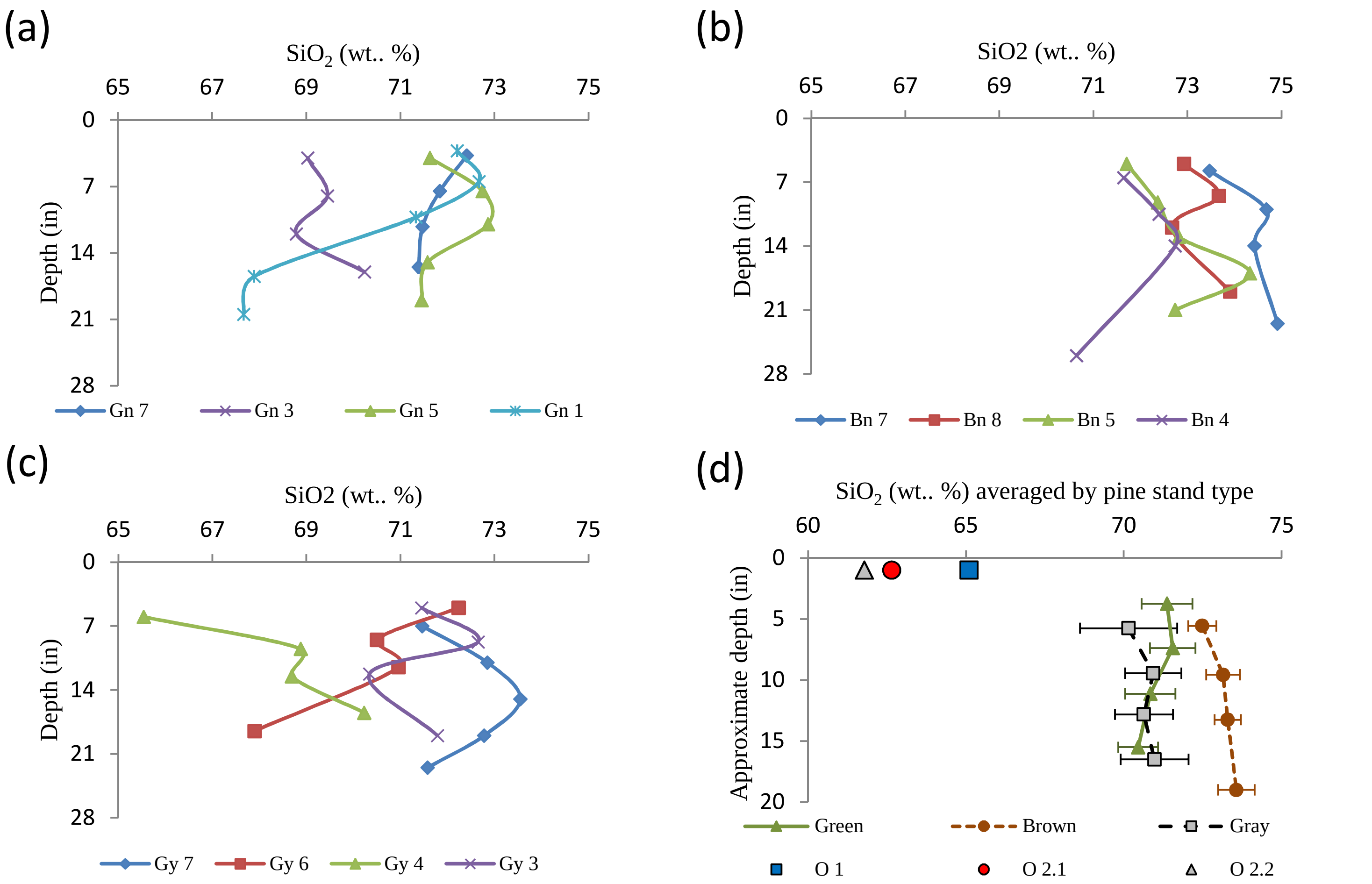


Figure 12. SiO_2 (wt.. %) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of SiO_2 with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

less variable concentrations of SiO_2 in the soils of the brown stand than in the green and gray stands (Fig. 12d). With a few outliers, Al_2O_3 generally increases with depth in the majority of the soil pits in the green, brown, and gray stands, and values range between approximately 12 and 14 wt. % (Fig. 13). Concentration of Fe_2O_3(T) generally increases with depth in the soil pits in the green stand (Fig. 14a), except for pit Gn 7. In pits Bn 7, Bn 8, and Bn 5 of brown stand Fe_2O_3(T) does not vary much with depth, but in pit Bn 4 Fe_2O_3(T) is lower in the middle depths of sampling. Overall, there is an increase in Fe_2O_3(T) in the samples of the four brown stand pits moving down the hillslope (Fig. 14b). The concentration of Fe_2O_3(T) in the soils of the gray stand is variable by pit and depth (Fig. 14c). In the composite plot, average concentrations of Fe_2O_3(T) slightly increase with depth in the samples of the green stand, while in the brown and gray stands the concentrations show little variation (Fig. 14d). Concentrations of MnO and MgO are variable by pit and depth in the green, brown and gray stands, but the composite plots shows that the average concentrations are lower in the brown and gray stands than in the green stand (Fig. 15 & 16). In the soil of the brown stand the concentrations of MnO increase moving down the hillslope, and possibly in the gray stand (Fig 15).

In the individual pits of the green stand, the depth-based concentrations of CaO, Na_2O, K_2O, and TiO_2 are variable, in some pits these elements decrease with depth and in others they increase with depth (Fig. 17a, 18a, 19a, 20a). In the brown pine stand CaO shows little variation with depth, but is higher in the lower elevation pits than in the ones uphill (Fig. 17b). Average concentrations of CaO are similar between the three pine stand types, but are lowest in the samples of the brown pine stand type (Table 6; Fig. 17d). In the brown stand Na_2O and K_2O increase to intermediate depths and in all pits except Bn 8 the concentrations decrease from intermediate to the deeper samples (Fig. 18b & 19b). The Na_2O and K_2O composite plots from

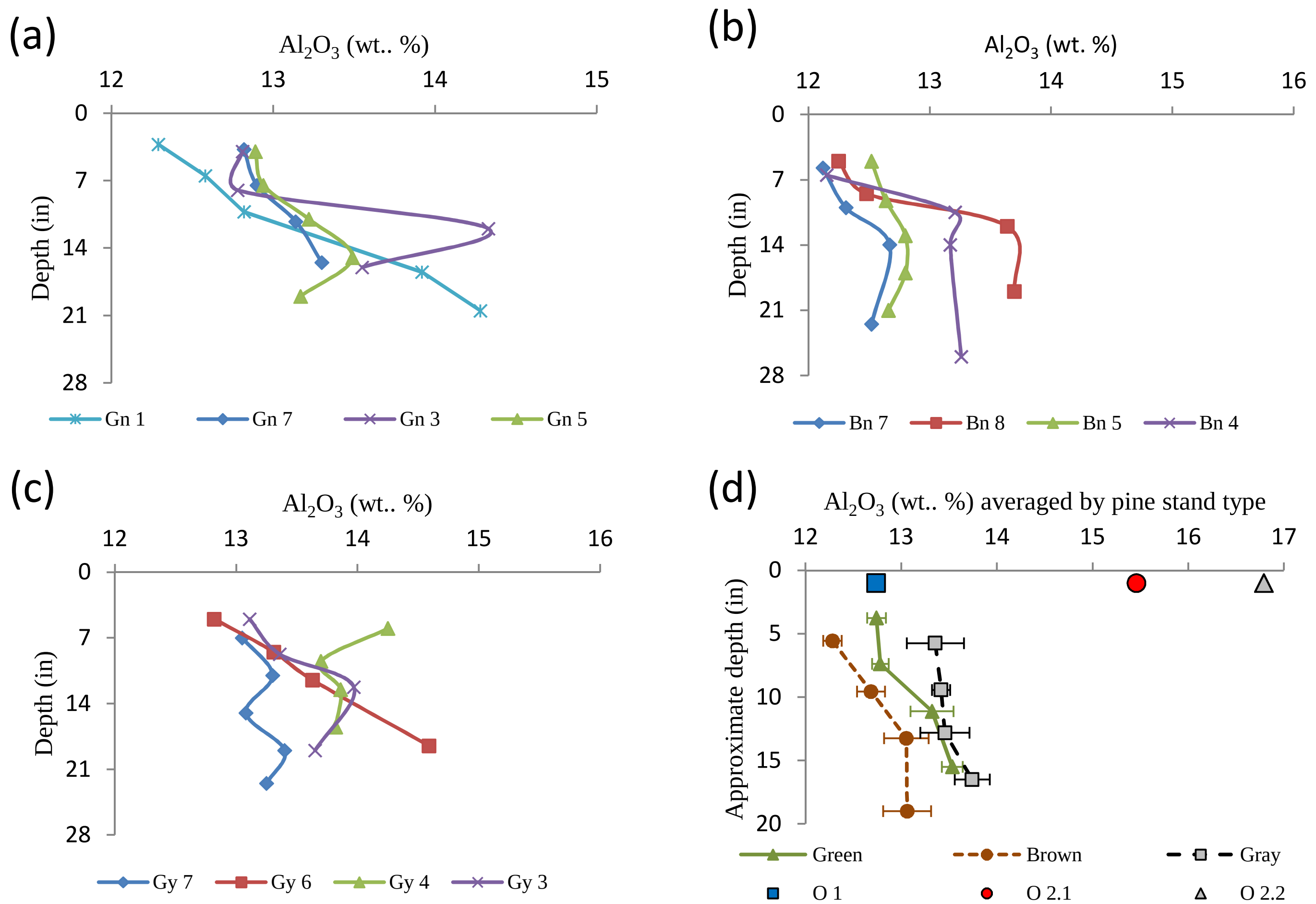


Figure 13. Al_2O_3 (wt.. %) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of Al_2O_3 with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

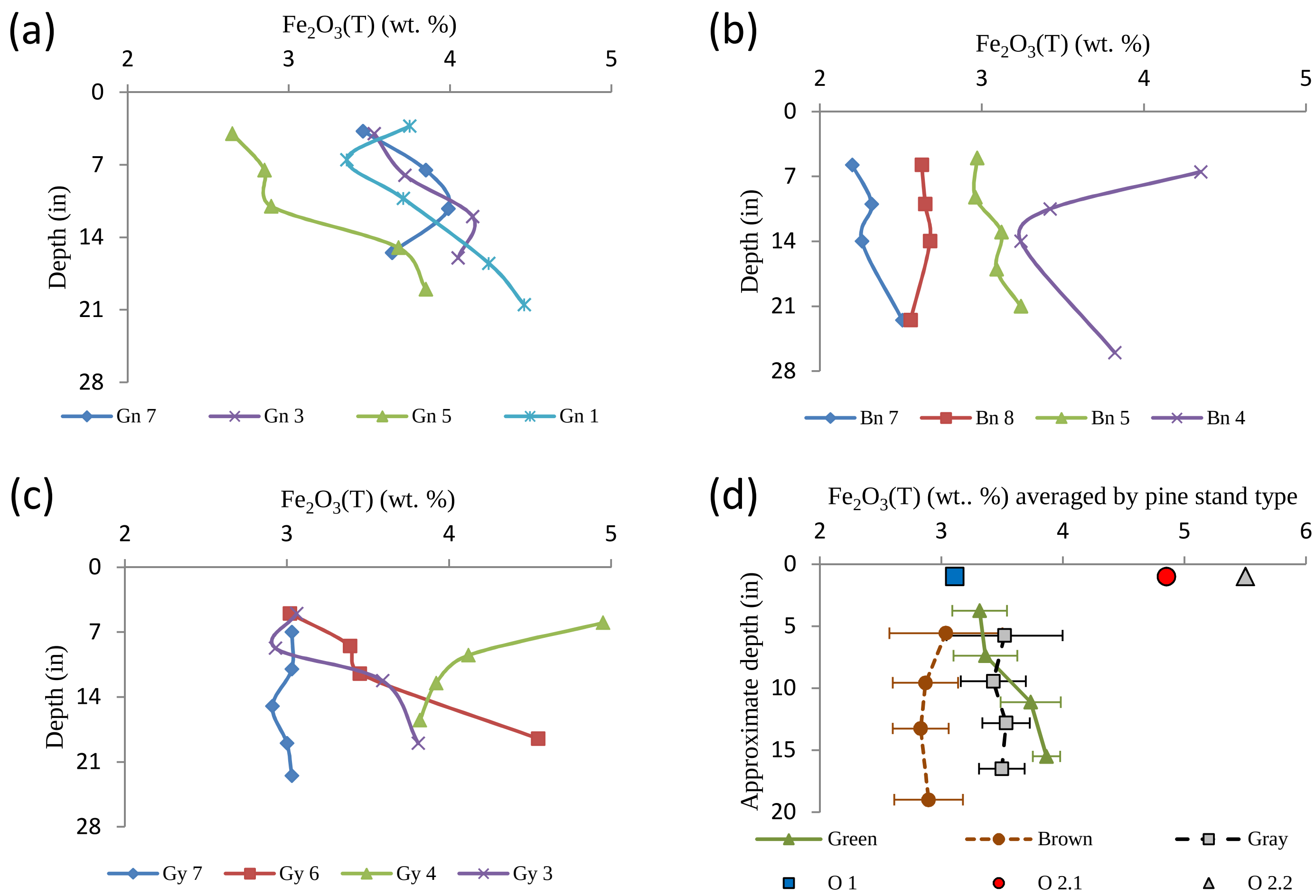


Figure 14. Fe_2O_3(T) (wt.. %) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of Fe_2O_3 (T) with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

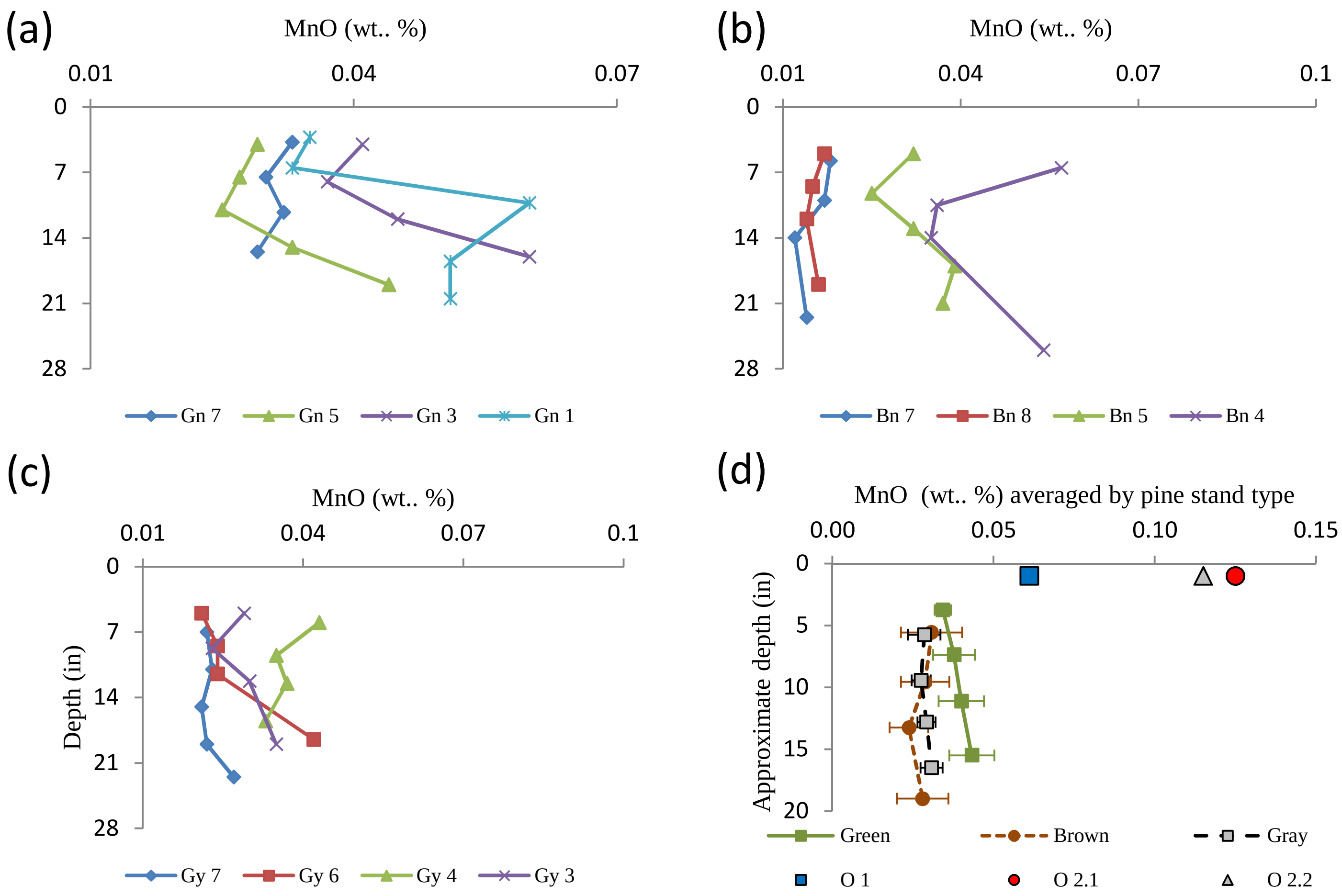


Figure 15. MnO (wt.. %) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of MnO with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

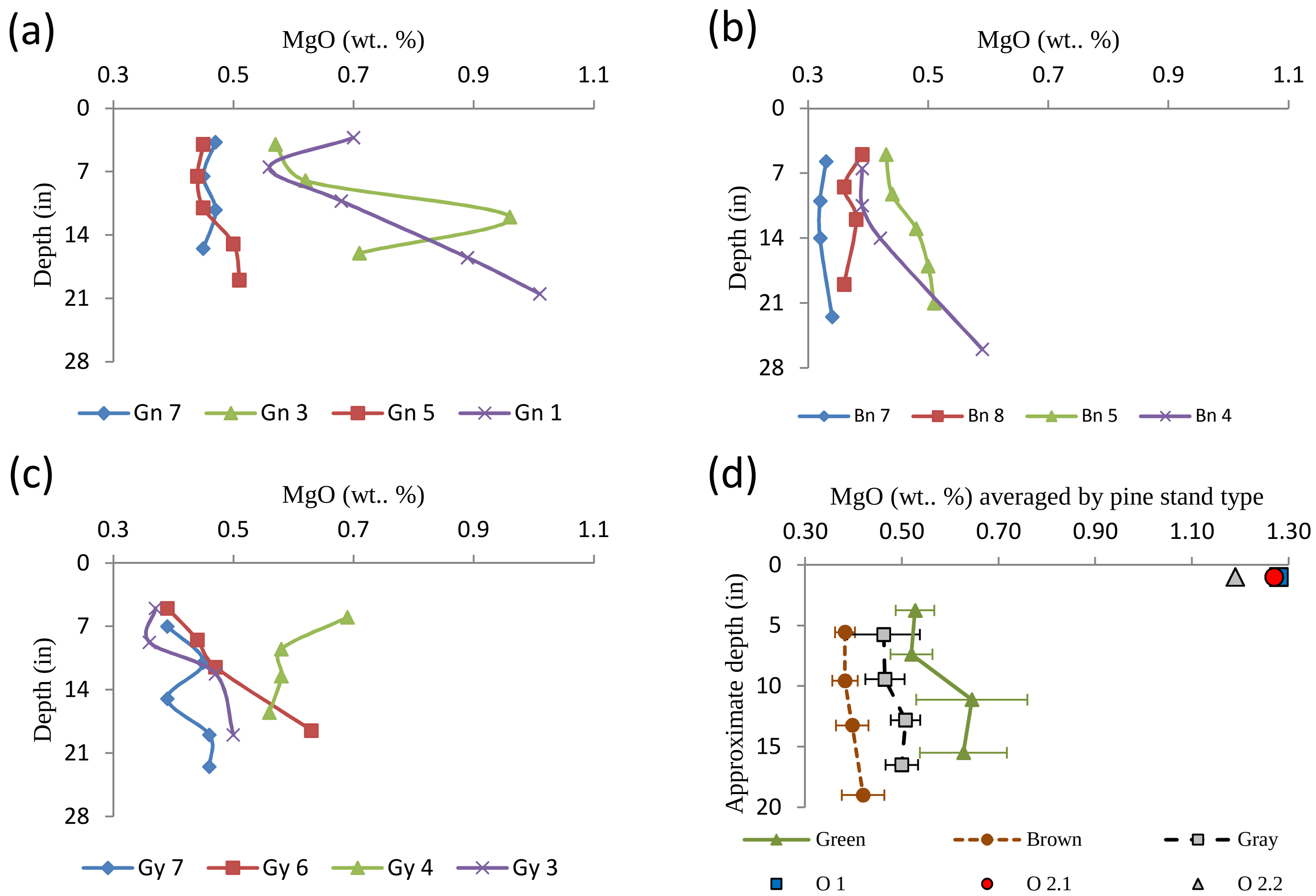


Figure 16. MgO (wt.. %) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of MgO with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

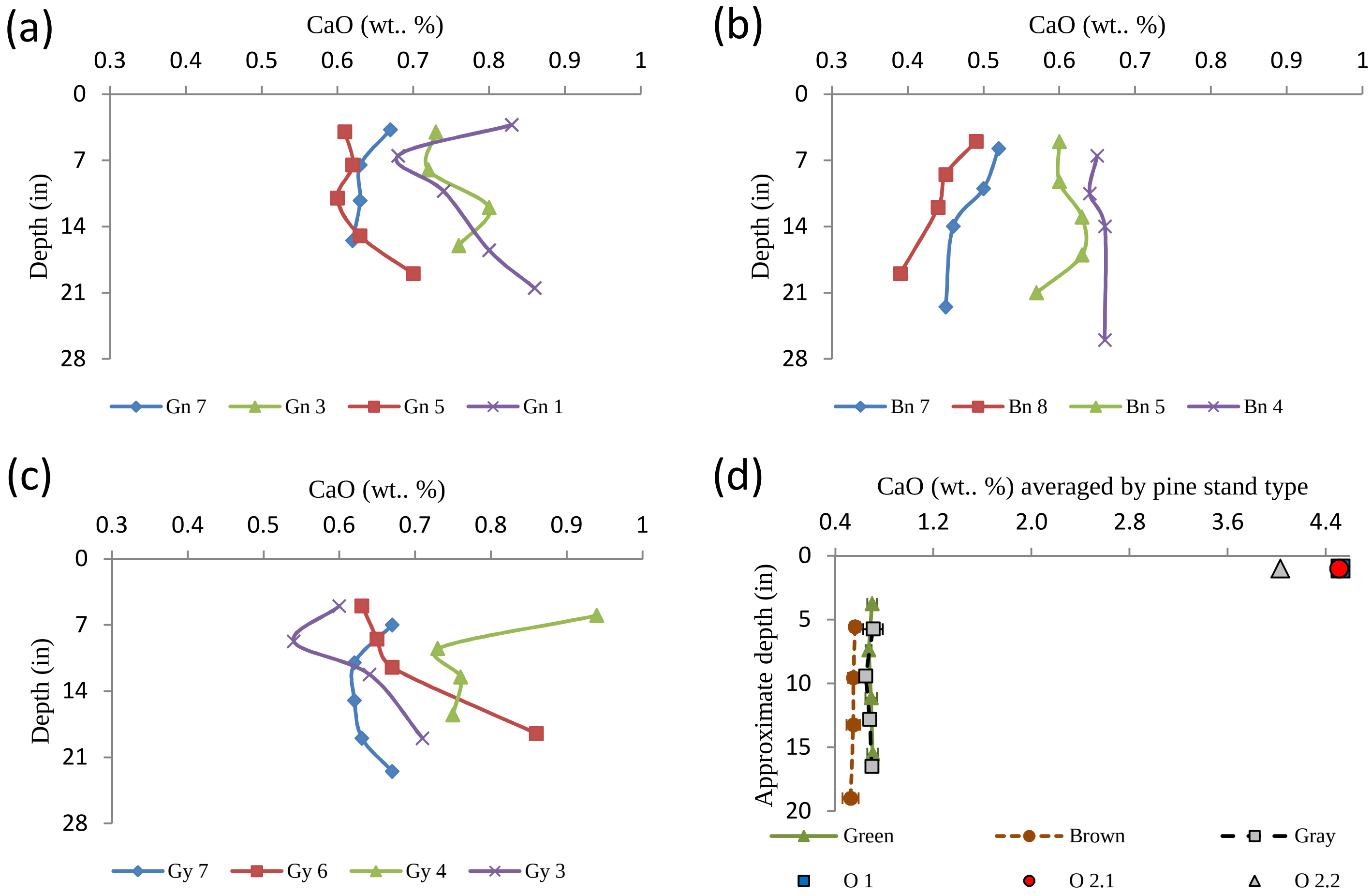


Figure 17. CaO (wt.. %) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of CaO with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

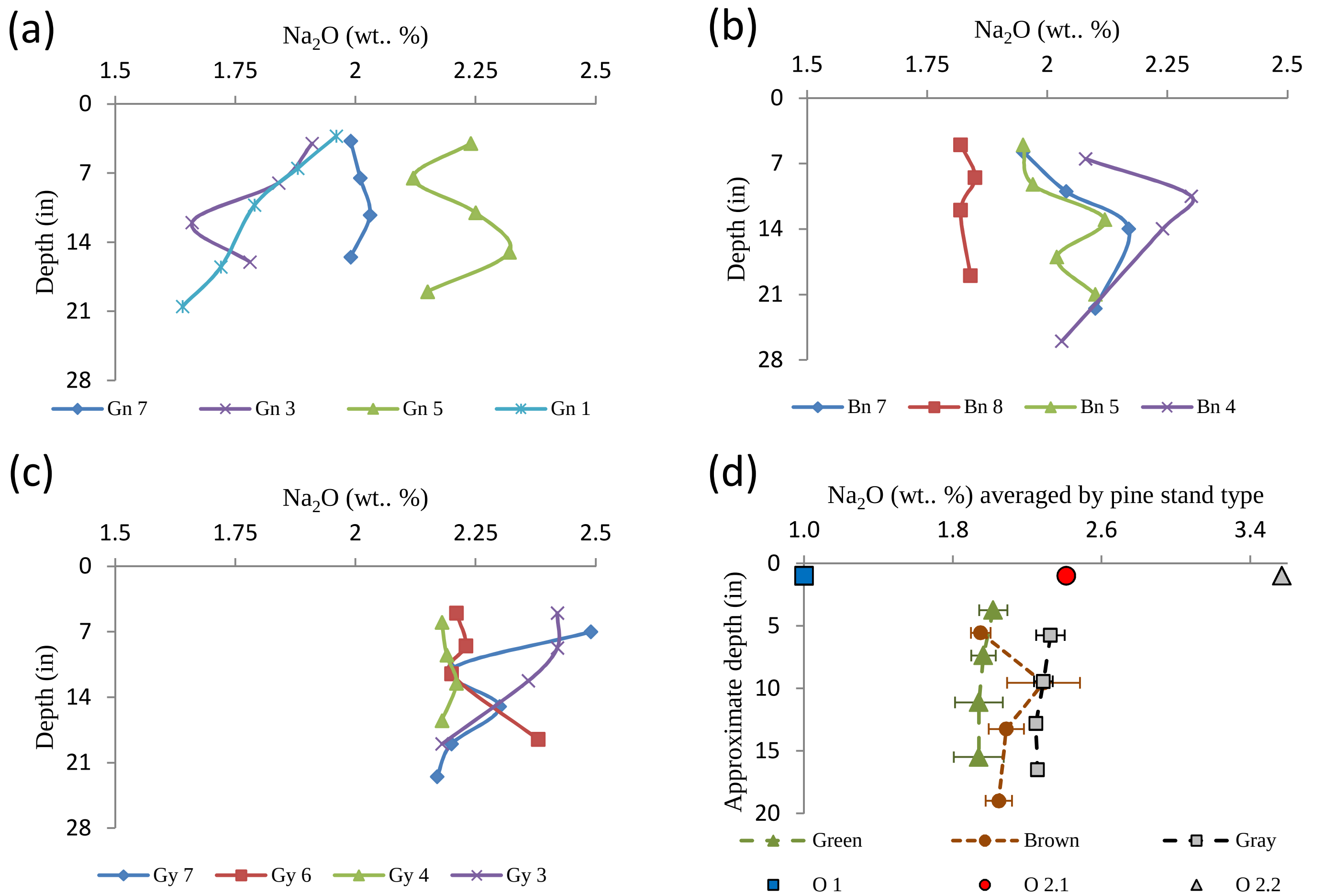


Figure 18. Na_2O (wt.. %) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of Na_2O with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

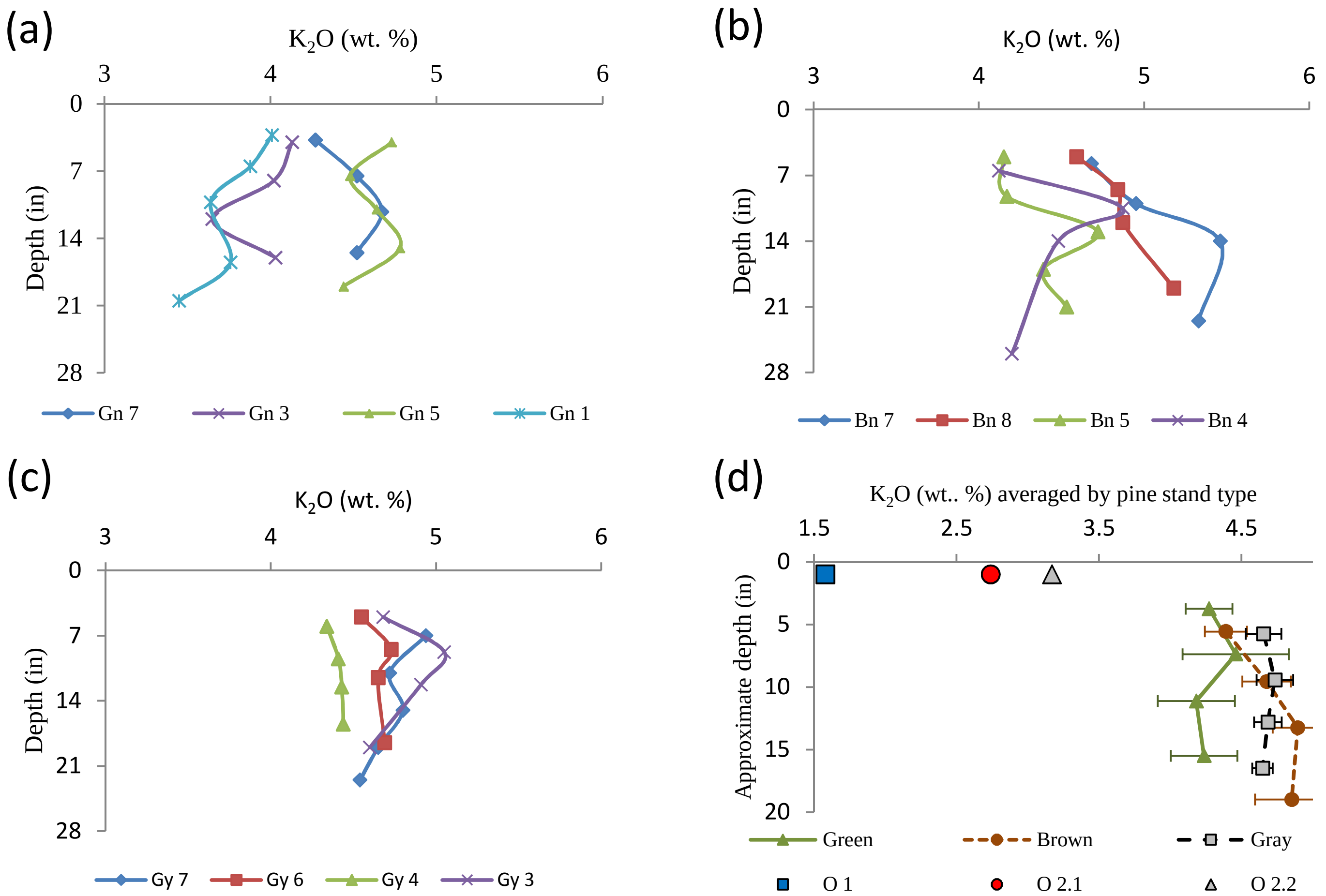


Figure 19. K_2O (wt.. %) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of K_2O with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

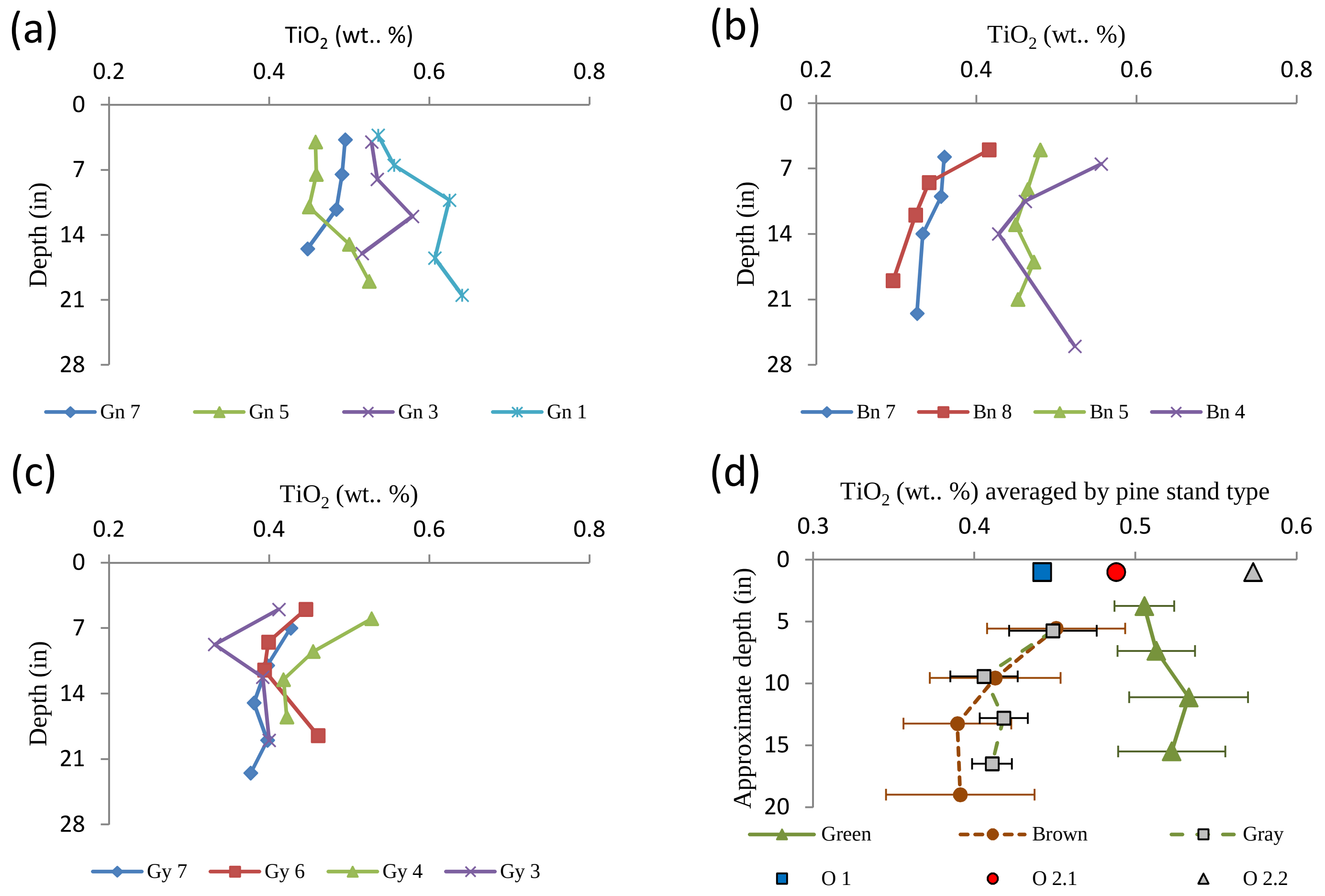


Figure 20. TiO_2 (wt.. %) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of TiO_2 with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

the brown stand show a similar relationship. In the soil pits of the gray stand, there is a bit of scatter in Na_2O with depth among individual pits, and K_2O plots as a fairly tight group with not much variance between ~4.2-5 wt. % (Fig. 18c & 19c). The average concentration of Na_2O and K_2O is slightly higher in the brown and gray stands than in the green stand (Fig. 18d & 19d). The concentration of TiO_2 ranges from approximately $0.3 \leq TiO_2 \leq 0.6$ in each of the pine stand types, but the average concentration of TiO_2 is slightly higher (~0.1 wt. %) in the green stand than in the brown and gray stands (Fig. 20). Average concentrations of TiO_2 decrease from the upper samples to the intermediate to deep samples in the brown and gray stands and slightly increase to intermediate to deep depths in the green stand (Fig. 20d).

The concentrations of Ba and Sr are lowest in the brown stand type and greatest in the gray pine stand type (Fig. 21 & 22). The concentration of Zr is variable with depth in the individual soil pits, but generally decreases to intermediate to deep depths in the brown and gray stands (Fig. 23). The composite plot shows that there is more Zr in the green stand than in the brown and gray stands (Fig. 23d).

The composite plots with average major and trace element concentrations also include the rock sample major oxide and trace element concentrations. Comparing the rock and soil samples, rock samples O 2.1 and O 2.2 record higher weight percent Al_2O_3, $Fe_2O_{3(T)}$, and MnO than the soil samples (Figs. 13, 14, 15). All three rock samples record higher weight percent MgO and CaO, and lower weight percent SiO_2 and K_2O than the soils (Figs. 12, 16, 17, and 19). Na_2O is lower in rock sample O 1 and higher in rock sample O 2.2 than in the soil samples (Fig. 18). The rock and soil samples have similar concentrations of TiO_2 (Fig. 20). Ba and Sr concentrations are greater in the rock samples than the soil samples, and Zr content is lower in the rock samples than it is in most of the soil samples (Fig. 21, 22, 23).

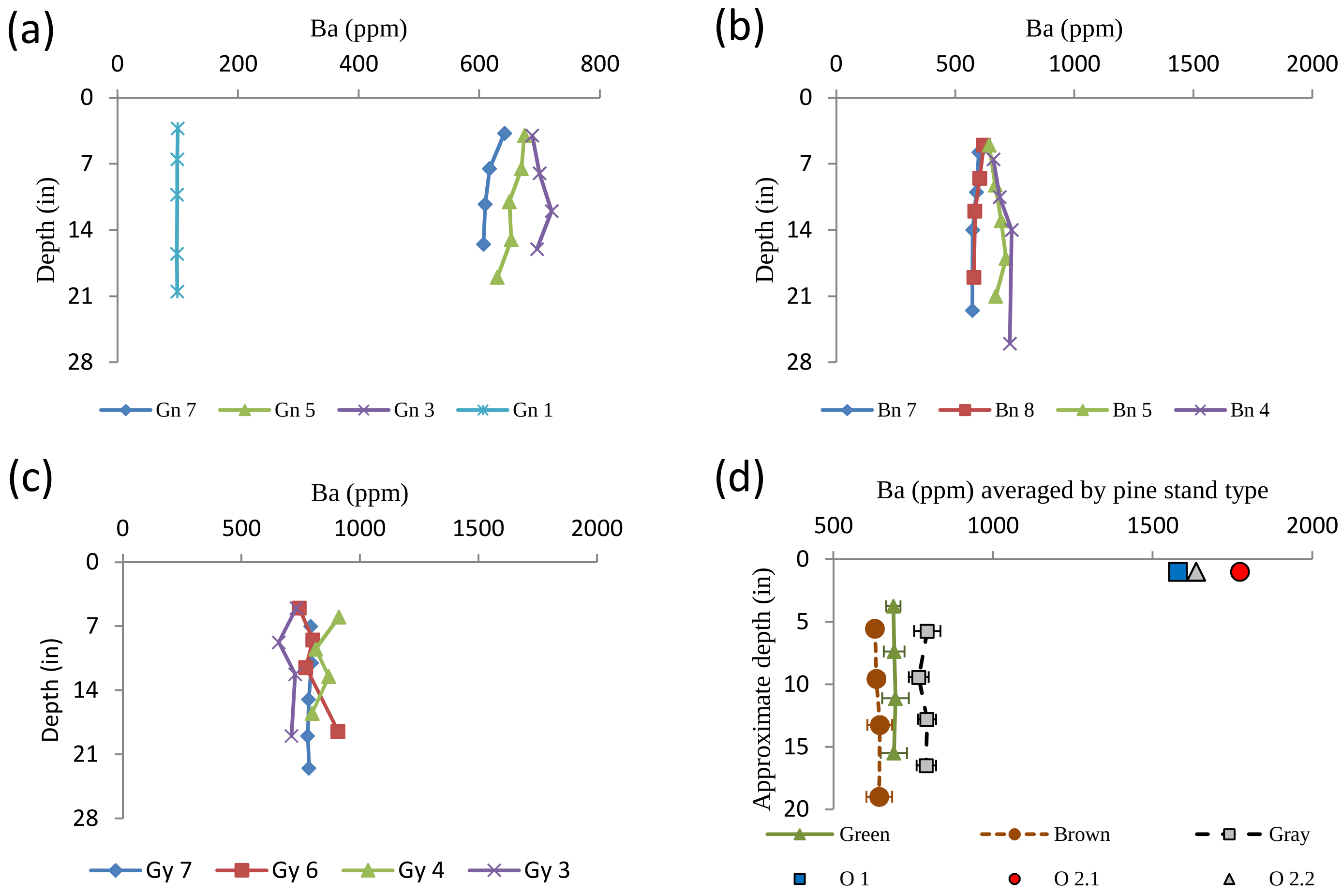


Figure 21. Ba (ppm) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of Ba with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

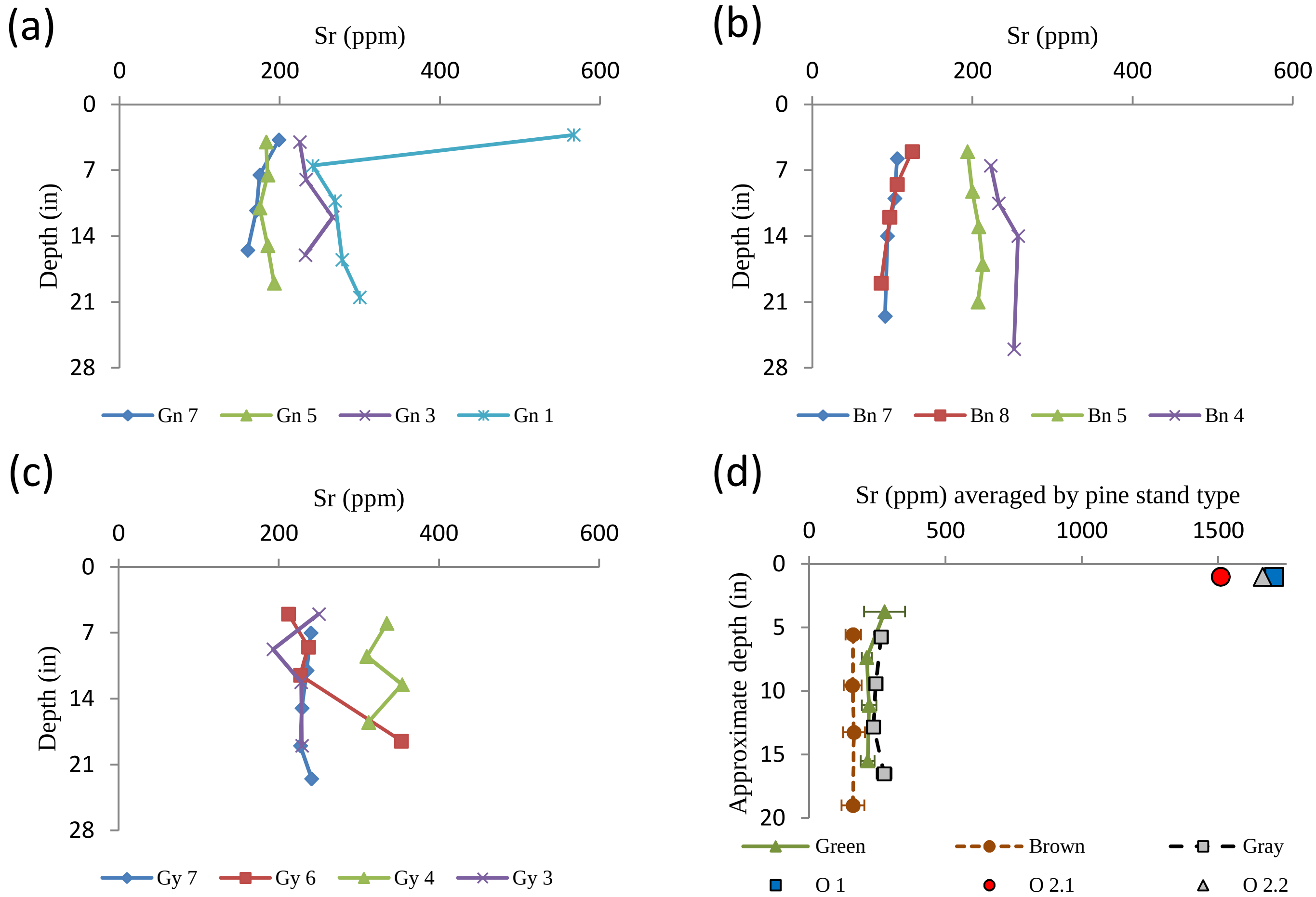


Figure 22. Sr (ppm) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of Sr with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

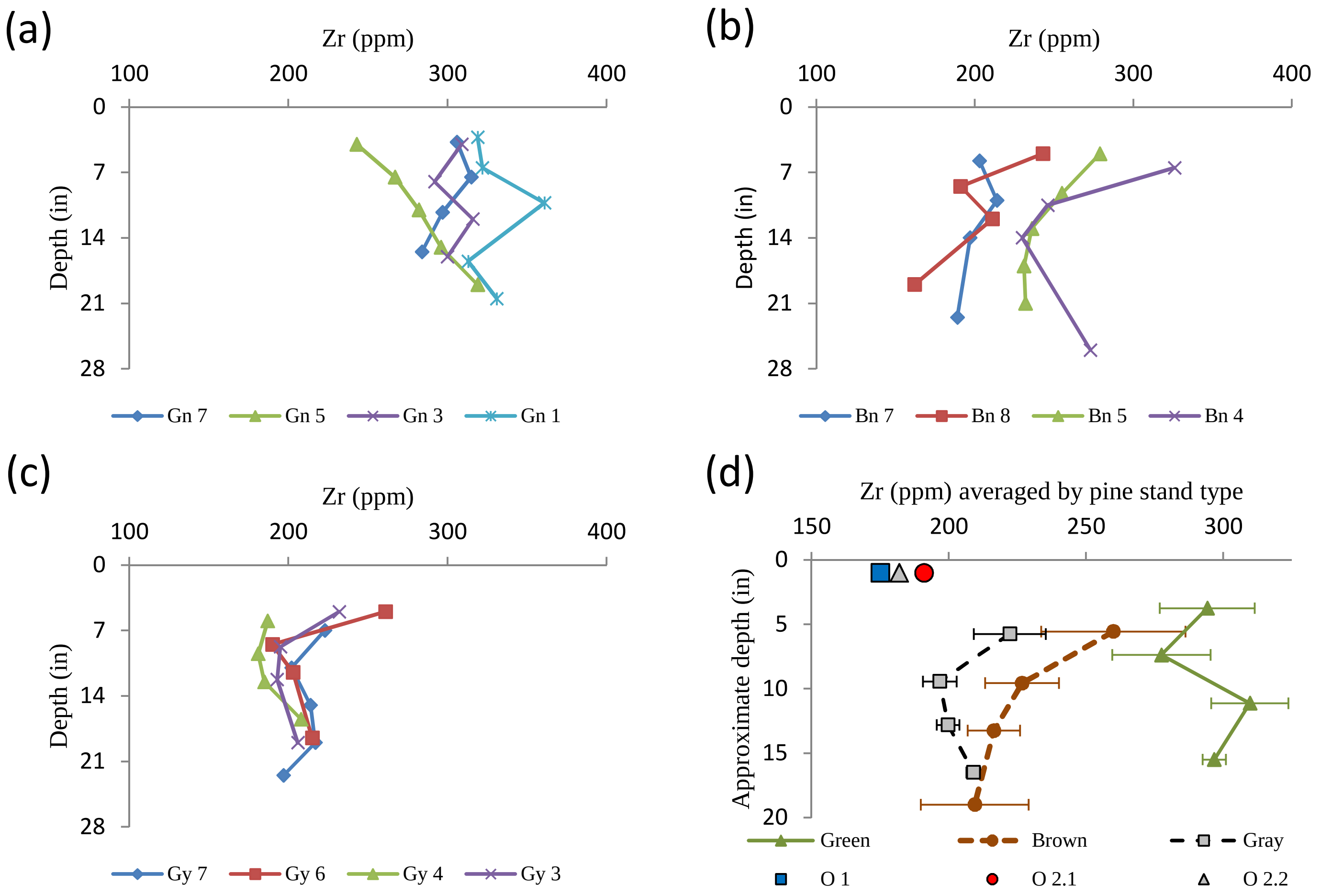


Figure 23. Zr (ppm) plotted by the sampling depth and listed in legend by decreasing elevation for soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of Zr with error bars depicting the standard error of data in each site type and includes the data for the rock samples (i.e. O 1, O 2.1 and O 2.2).

Gains or losses of elements were also studied by comparing the ratios of concentrations of mobile elements to relatively immobile elements. Similar methods have been used in many geochemical investigations of weathering trends, and are often based on Ti, Zr, or Al, which are relatively immobile (Egli and Fitze, 2000; Maynard, 1992). In this study variations in soil weathering were studied by dividing the other oxide compounds by TiO_2 which serves as a means of assessing the progression of chemical weathering in the soil profiles beneath each of the three pine stand types. The geochemical data are organized by pine stand type and plotted according to soil depth and hillslope elevation.

The geochemical data analyzed by the various oxide ratios, soil depths, and pine stand types can be summarized as follows:

SiO_2/TiO_2: The ratio of SiO_2/TiO_2 varies as much as 50% by pit and soil depth in the green stand (Fig. 24a). Among the green stand sampling sites there is no consistent change in the ratio with increasing depth. In the soils of the brown stand, pits Bn 7 and Bn 8 have ratios that steadily increase with depth, increasing about 10% and 40%, respectively (Fig 24b). In soil pit Bn 4 the ratio increases with depth for the first 3 samples, but the deepest sample is similar to the top. In pit Bn 5 the ratio shows little variation. The variations in ratio of SiO_2/TiO_2 with depth in the soils of the gray stand are fairly similar from one pit to another with the uppermost samples showing the lowest values (Fig. 24c). In the composite plot the ratio of SiO_2/TiO_2 in the soils of the green stand show little variation, while the ratio in the soils of the brown and gray stands behave more similarly to one another. In the gray stand the ratio increases from the top to the intermediate depth samples and then decreases in the deepest samples, and in the brown stand the ratio increases from the upper to deeper samples (Fig. 24d).

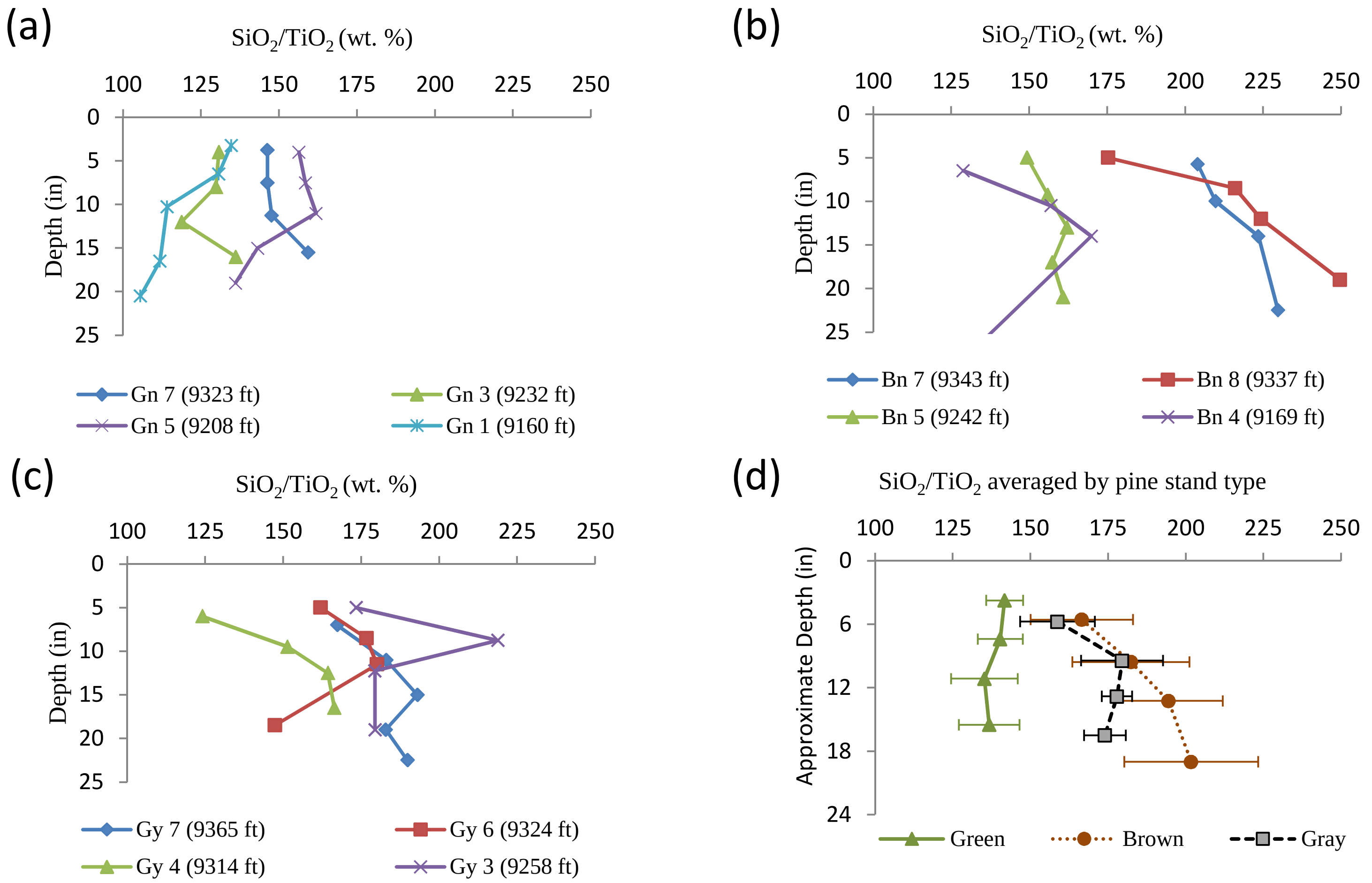


Figure 24. SiO_2/TiO_2 ratio plots, each sample is plotted according to the sampling depth and the representative elevations are shown for each soil pit in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of the oxide ratios with error bars depicting the standard error of data in each pine stand type.

Al_2O_3/TiO_2: The Al_2O_3/TiO_2 ratio in the soil pits of the green stand shows only modest variation with depth (Fig. 25a). In soil pits Gn 7 and Gn 3 the depth-based ratios of Al_2O_3/TiO_2 are very similar and increase slightly with depth. The ratio in pit Gn 5 changes little to intermediate depths and then decreases deeper, while in pit Gn 1 there is little variation. The values of the Al_2O_3/TiO_2 ratio in the soils beneath the brown trees are variable, but in all 4 of the brown pits the ratio rises between the top and middle depths of the profile. Sampling sites Bn 4 and Bn 5, from the lowest elevations, have the lowest magnitude of values. The higher elevation sites, Bn 7 and Bn 8, have higher overall ratios and increase with depth (Fig. 25b). The Al_2O_3/TiO_2 ratios in the soil pits beneath the gray trees are similar from pit to pit; the ratio in all of these pits increases downward to intermediate depths, and below these depths stabilizes or decreases slightly (Fig. 25c). The depth-based ratios of Al_2O_3/TiO_2 in some of the pits in the brown stand (i.e. Bn 4 and Bn 5) are similar to the soil pits in the gray stand. The behavior of the average Al_2O_3/TiO_2 ratios for each of the three stands is similar to the average SiO_2/TiO_2 ratios. While there is large variability in the samples of the brown stand, the average ratios in the samples of the brown and gray stands increase to intermediate depths and decrease deeper (Fig. 25d). The average Al_2O_3/TiO_2 ratio for the samples in the green stand shows little variation with depth.

$Fe_2O_{3(T)}$/ TiO_2: With the exception of a few outliers, the ratio of $Fe_2O_{3(T)}/TiO_2$ increases with depth in the profiles in the three stands and values range from approximately 6 to 10 (Fig. 26). The ratio in soil pits Gy 6, Gy 4, and Gy 3 reaches the greatest values (Fig. 26c). Similar relationships are shown in the composite plot. The green, brown and gray pine stand types having ratios that generally increase with depth, but the samples in the gray

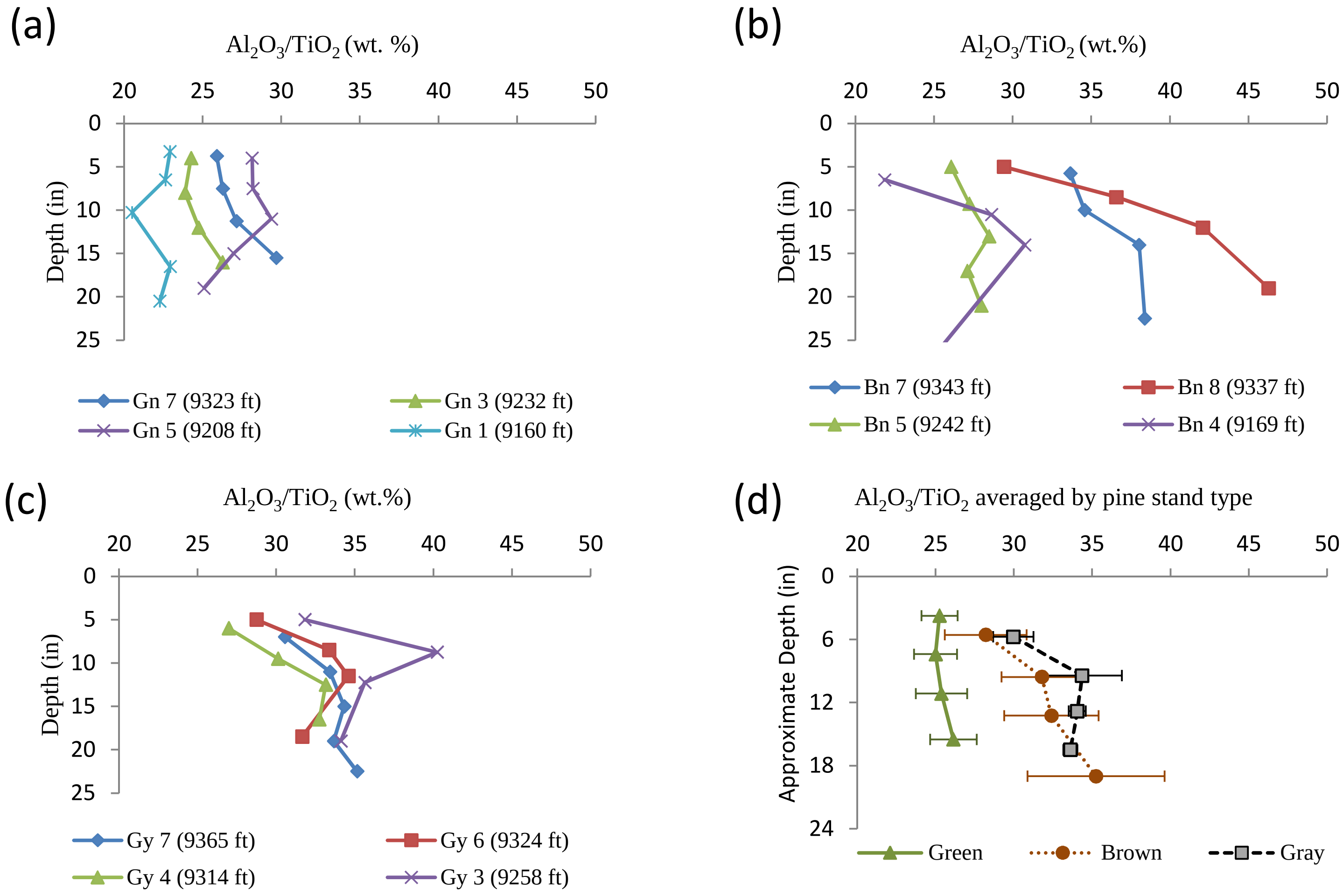


Figure 25. Al_2O_3/TiO_2 ratio plots, each sample is plotted according to the sampling depth and the representative elevations are shown for each soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of the oxide ratios with error bars depicting the standard error of data in each pine stand type.

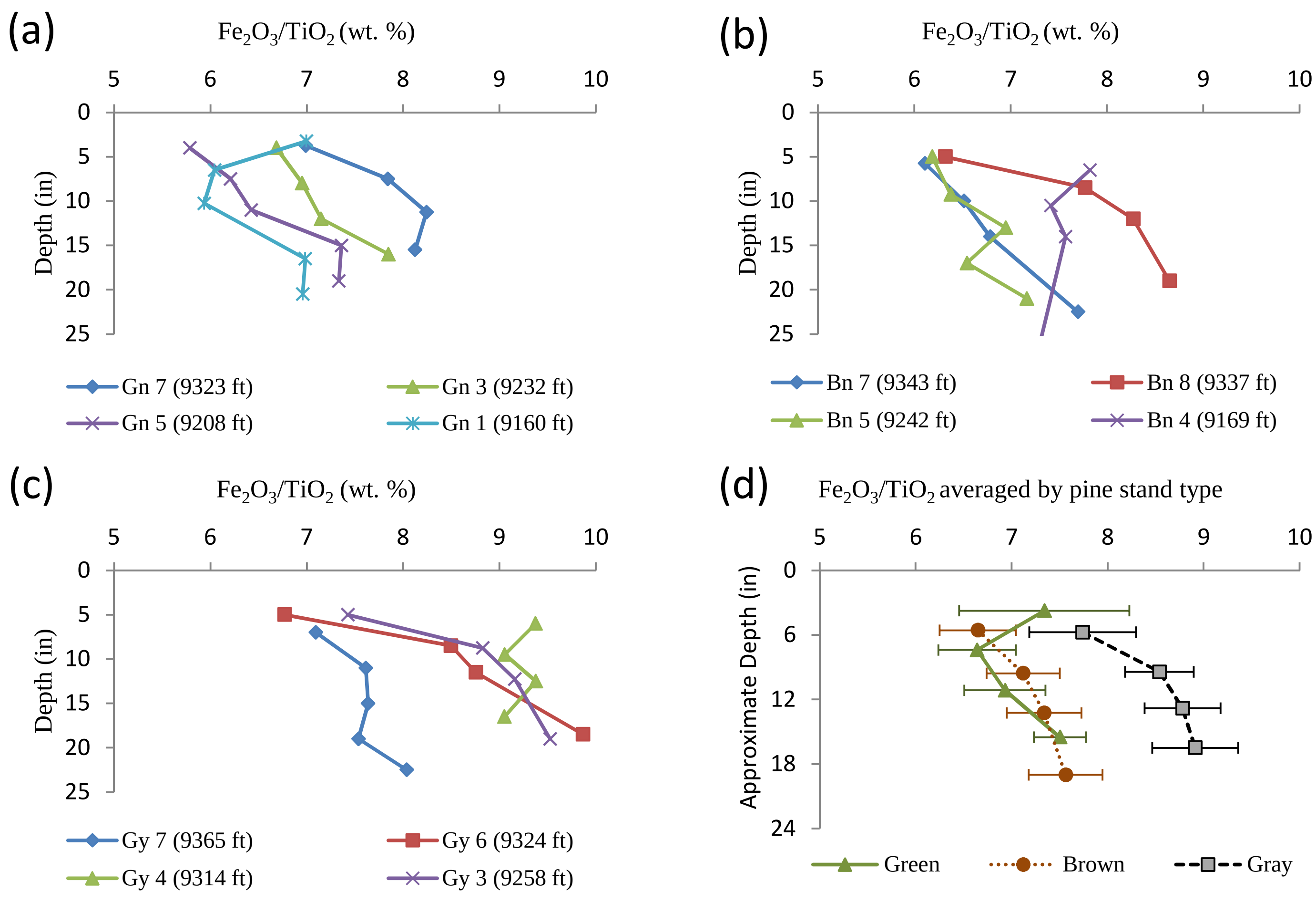


Figure 26. $Fe_2O_{3(T)}/TiO_2$ ratio plots, each sample is plotted according to the sampling depth and the representative elevations are shown for each soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of the oxide ratios with error bars depicting the standard error of data in each pine stand type.

stand have the greatest ratios. The ratios in the green pine stand type decrease from the upper samples to shallow depths and then increase to the deeper samples in 3 of the 4 sampling depths (Fig. 26d).

MnO/TiO_2: The values of the MnO/TiO_2 vary by 100% or more in each of the three pine stands, and there are no major differences in the ratio of MnO/TiO_2 between hillslope locations (Fig. 27). The samples from lower elevations in the brown (Bn 4 & 5) and gray (Gn 3 & 4) stands show higher MnO/TiO_2 than the samples from the higher elevations. In the composite plots, MnO/TiO_2 initially decreases from the top sample to the second sample in the green and brown stands and then increases deeper (Fig. 27d). In the gray stand the average ratio increases with depth.

MgO/TiO_2: Among the green stand sampling sites there are no consistent changes in the ratio of MgO/TiO_2 with increasing depth (Fig. 28a). With a few exceptions, the soil pits in the brown and gray stands have ratios of MgO/TiO_2 that slightly increase with depth (Fig. 28c, d). Similar relationships are shown in the composite plots. The average ratios steadily increase within the depths of sampling.

CaO/TiO_2: The values of the CaO/TiO_2 ratio in the soils beneath the trees in the green, brown and gray stands vary up to 50%, but the changes in the ratio with depth are different between the pine stand types (Fig. 29). In the green stand, the ratio of CaO/TiO_2 in pits Gn 1, Gn 7, and Gn 3 decreases to intermediate depths and then increases to the deeper samples (Fig. 29a). In the brown stand, the ratio of CaO/TiO_2 in pits Bn 8, Bn 5, and Bn 4 increases to intermediate depths, and then decreases to deeper samples (Fig. 29b). In the gray stand, samples Gy 7, Gy 6 and Gy 3 record CaO/TiO_2 ratios that increase fairly

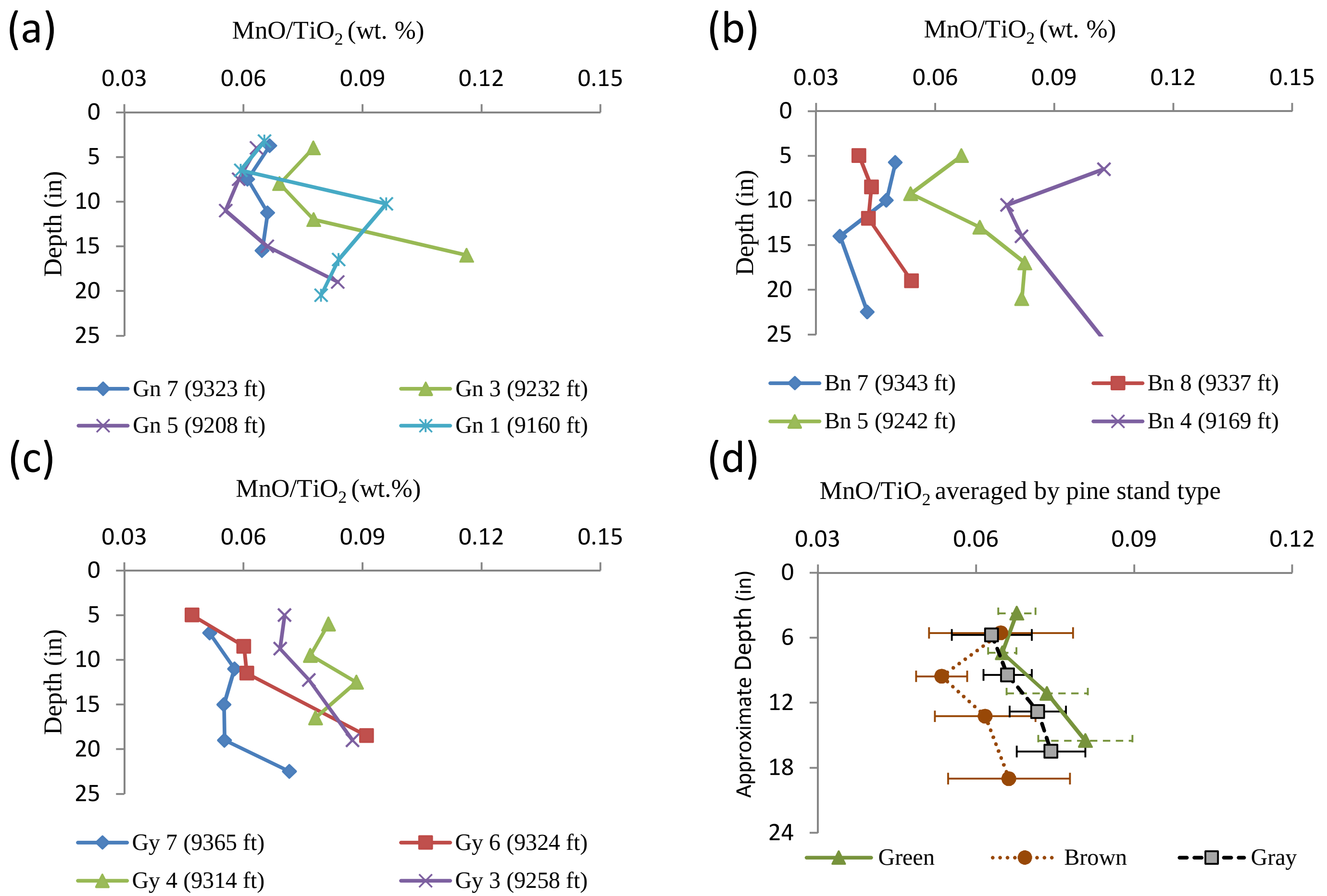


Figure 27. MnO/TiO_2 ratio plots, each sample is plotted according to the sampling depth and the representative elevations are shown for each soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of the oxide ratios with error bars depicting the standard error of data in each pine stand type.

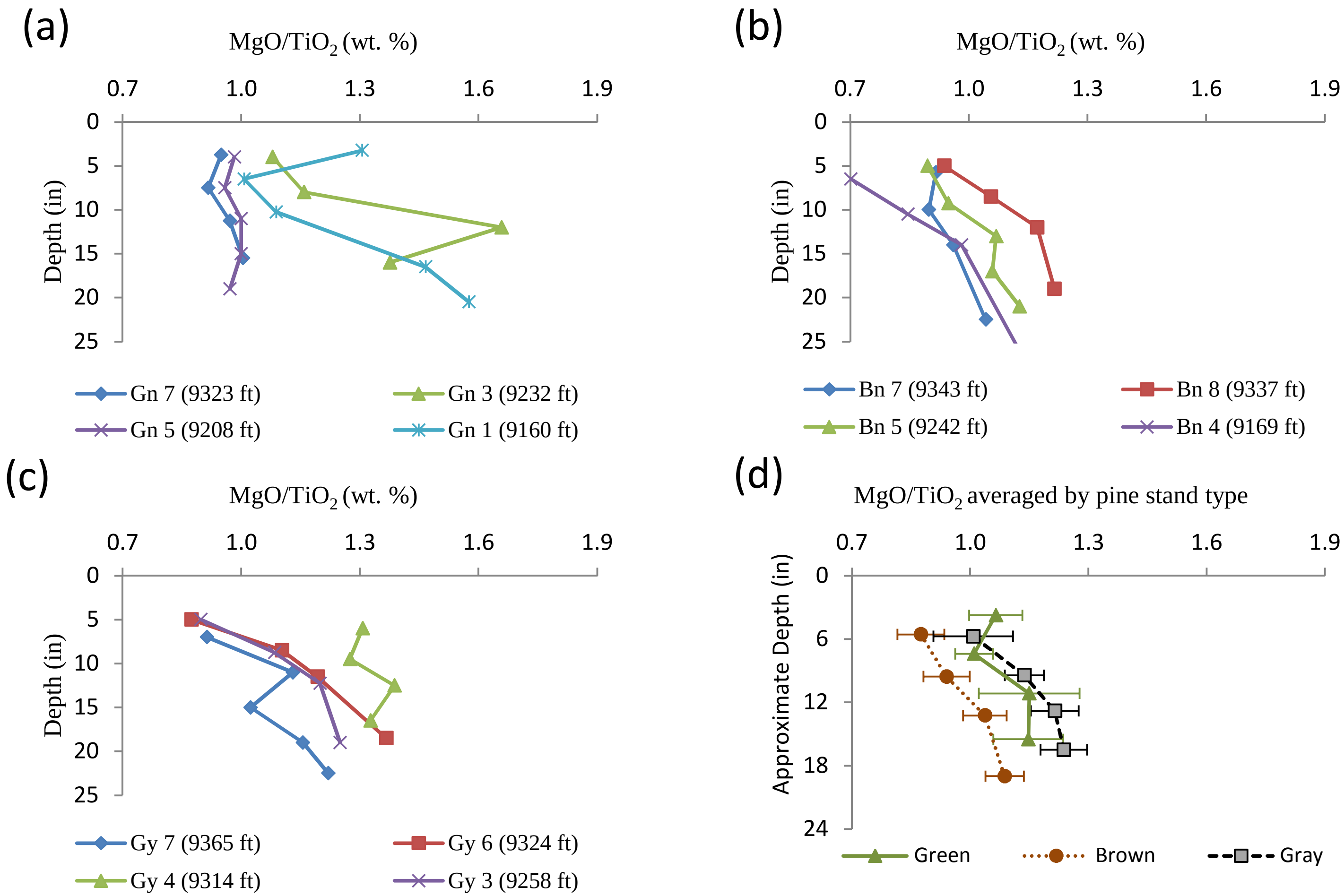


Figure 28. MgO/TiO_2 ratio plots, each sample is plotted according to the sampling depth and the representative elevations are shown for each soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of the oxide ratios with error bars depicting the standard error of data in each pine stand type.

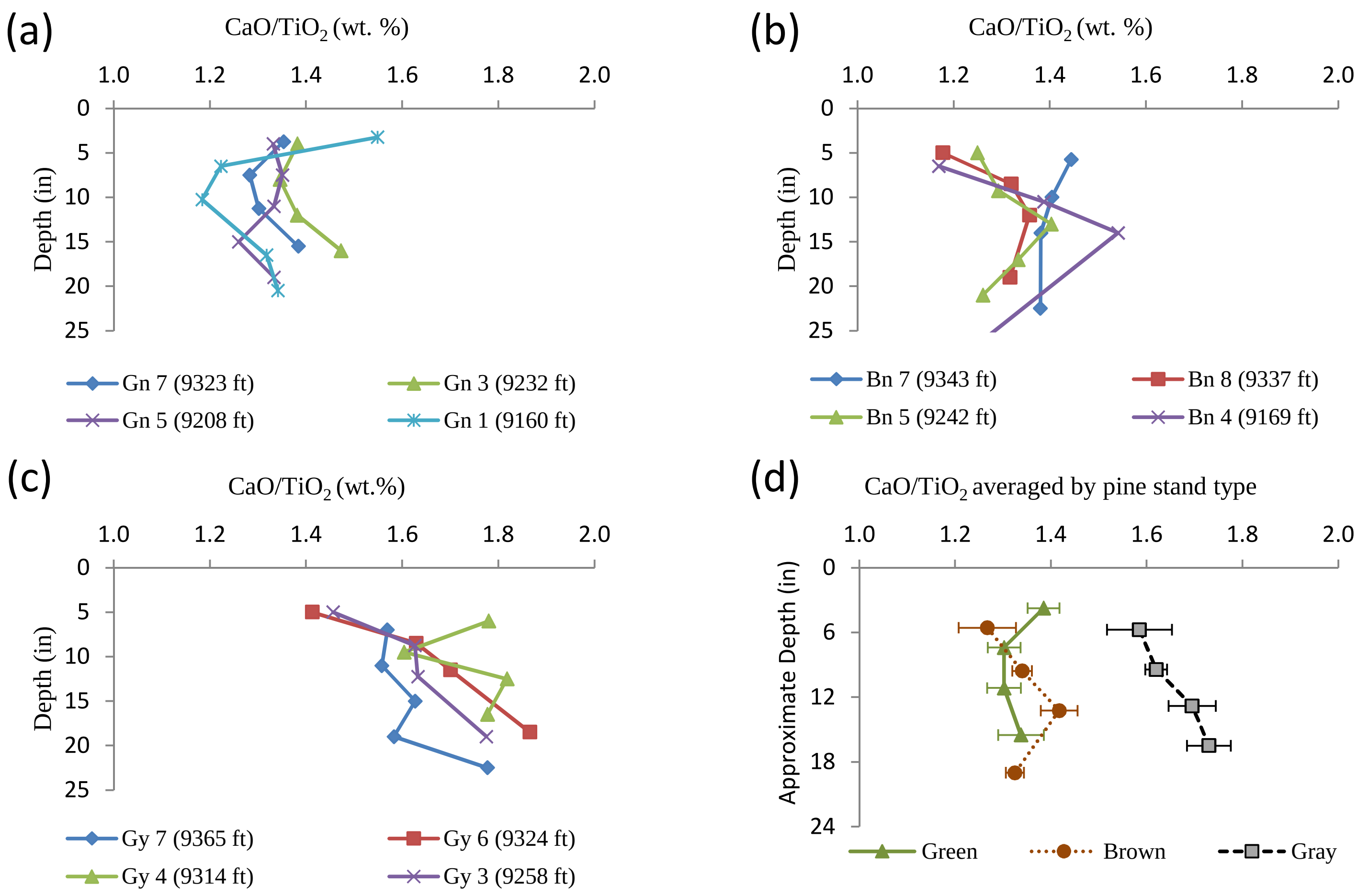


Figure 29. CaO/TiO_2 ratio plots, each sample is plotted according to the sampling depth and the representative elevations are shown for each soil pits in the (a) green pine stand (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of the oxide ratios with error bars depicting the standard error of data in each pine stand type.

steadily in the depths of sampling and reach values of approximately 1.8 (Fig. 29c). The averages for each pine stand type show only modest variation at depth. The green and brown pits have similar average values with slightly higher values in the gray pits (Fig. 29d).

Na_2O/TiO_2: In the soils of the green stand the ratio of Na_2O/TiO_2 varies considerably from pit to pit, and there is no consistent change in the ratio of Na_2O/TiO_2 with increasing depth (Fig. 30a). The ratio of Na_2O/TiO_2 is lowest in the upper samples of most of the brown and gray pits and shows variable concentration deeper (Fig. 30b, c). In the composite plot, the average ratios of Na_2O/TiO_2 in the green stand's samples show little variation and average Na_2O/TiO_2 is lower in the green pits than in the brown and gray pits. The average ratios in the soil samples of the brown and gray stand increase to intermediate depths and then decrease deeper (Fig. 30d).

K_2O/ TiO_2: The variability of K_2O/TiO_2 in the soils is very similar to Na_2O/TiO_2, except that there is more K_2O than Na_2O in the soils (Fig. 30 & 31). In the soils of the green stand the ratio of K_2O/TiO_2 varies considerably from pit to pit, and there is no consistent change with increasing depth (Fig. 31a). In the brown and gray stands the ratio of K_2O/TiO_2 increases to intermediate depths and then decreases to deeper samples (Fig. 31b, c). In the composite plot, the average ratio of K_2O/TiO_2 in the green stand shows little variation, while the average ratio in the samples of the brown and gray stand increases to intermediate/ deeper depths (Fig. 31d). In addition, there is a higher average concentration of K_2O/TiO_2 in the brown and gray pits than in the green pits (Fig 31d).

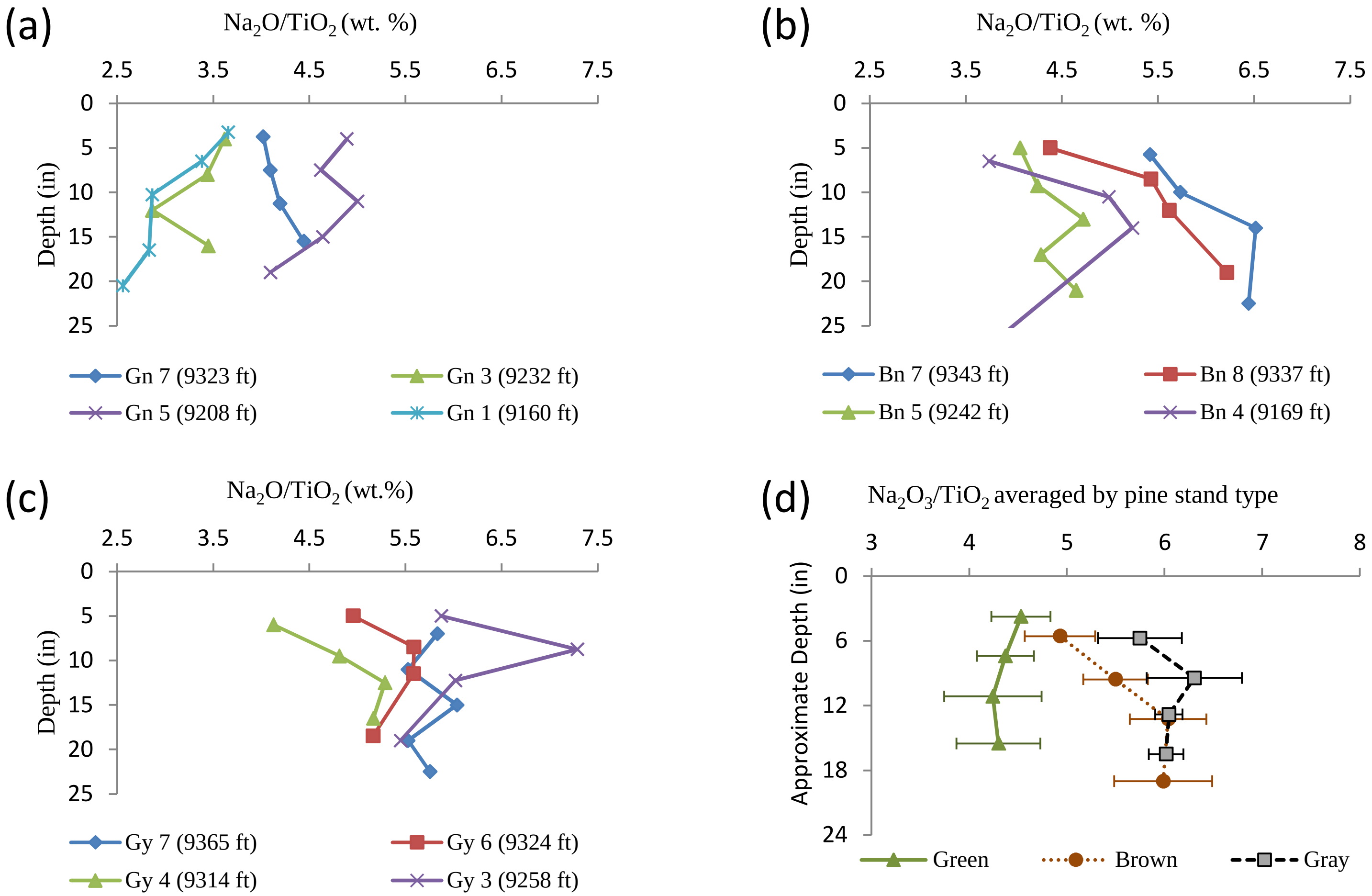


Figure 30. Na_2O/TiO_2 ratio plots, each sample is plotted according to the sampling depth and the representative elevations are shown for each soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of the oxide ratios with error bars depicting the standard error of data in each pine stand type.

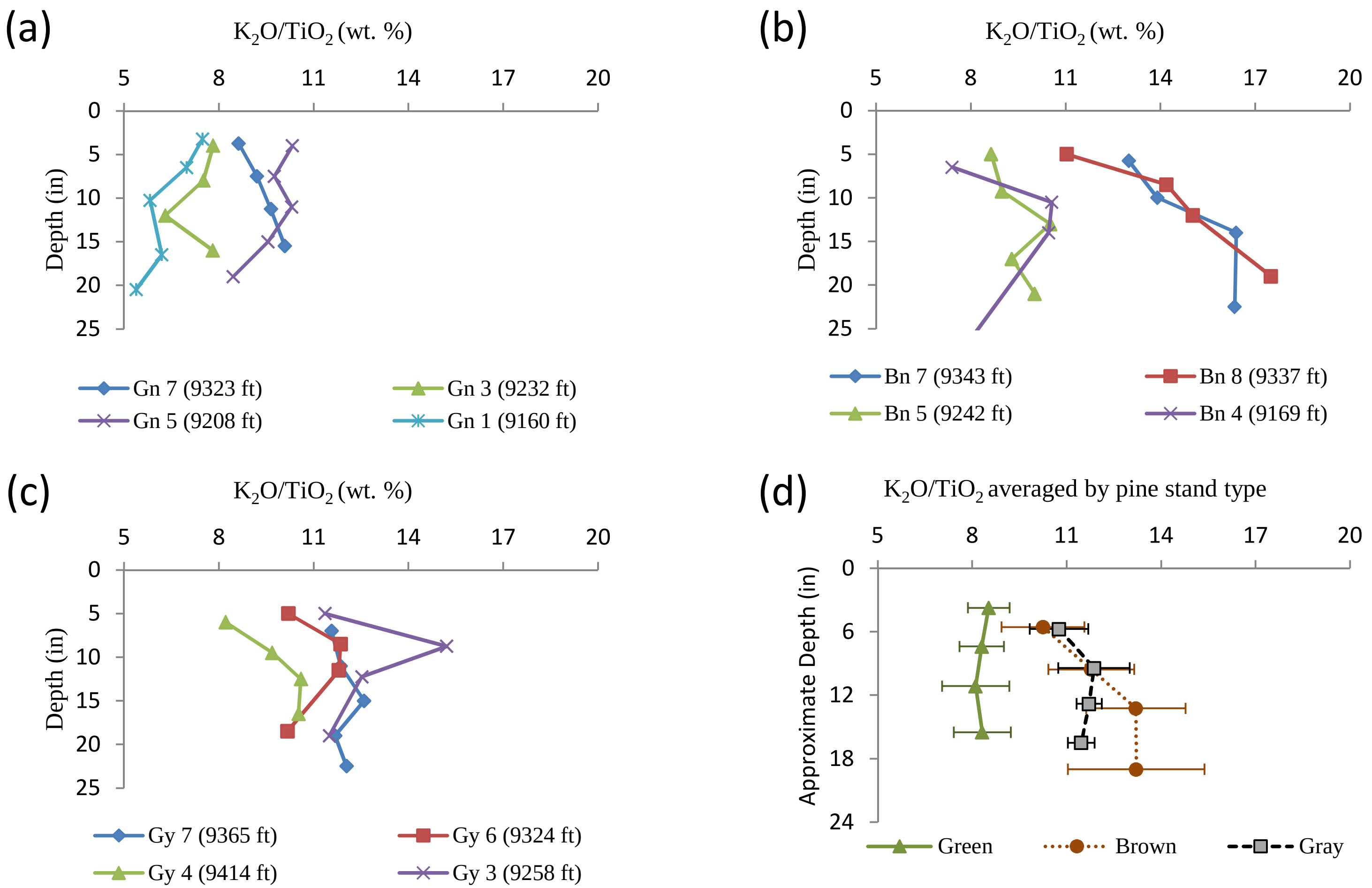


Figure 31. K_2O/TiO_2 ratio plots, each sample is plotted according to the sampling depth and the representative elevations are shown for each soil pits in the (a) green pine stand, (b) brown pine stand, and (c) gray pine stand. Composite plot (d) compares the average concentration of the oxide ratios with error bars depicting the standard error of data in each pine stand type.

4.4 Thin section petrography

Modal analysis of soils was accomplished by point counting (approximately 250 points per thin section) clasts present in thin sections from the green and gray stands. The modal abundances of clasts in thin sections are shown in Appendix D. The goal of point counting soils was to determine differences in mineralogy and mineral alterations, as well as non-mineral constituents through the soil profiles from the green and gray pine stand types and with hillslope position. The major constituents identified and counted include: quartz, plagioclase feldspar, potassium feldspar, soil aggregates, plutonic rock fragments (PRF), sedimentary rock fragments (SRF) volcanic rock fragments (VRF), metamorphic rock fragments (MRF), biotite, muscovite, hornblende, opaque minerals, undifferentiated clay- and silt-sized material (identified as matrix material), and organic matter. There are also pieces of wood and other tree debris in the thin sections; however, these constituents were not included in the point count results. Biotite and muscovite are not very prevalent in the soil pits, so the sum of these minerals was calculated and plotted as total micas.

Photomicrographs of representative soil samples from the green and gray pine stand types were taken to show the mineralogical composition of soils and are shown in Figures 32 and 33, respectively. Figures 34, 35, and 36 are of scanned thin sections and photomicrographs from rock samples and illustrate the heterogeneity of possible parent material for the soils. Rock sample O 1 is poorly sorted and is classified as a biotite quartz wacke with an abundance of organic ribbons (Appendix D; Fig. 34). Modal analyses and rock sample descriptions show that samples O 2.1 and O 2.2 are feldspathic wacke, but sample O 2.1 has coarser mineral grains than sample O 2.2 (Appendix D; Fig. 35, 36).

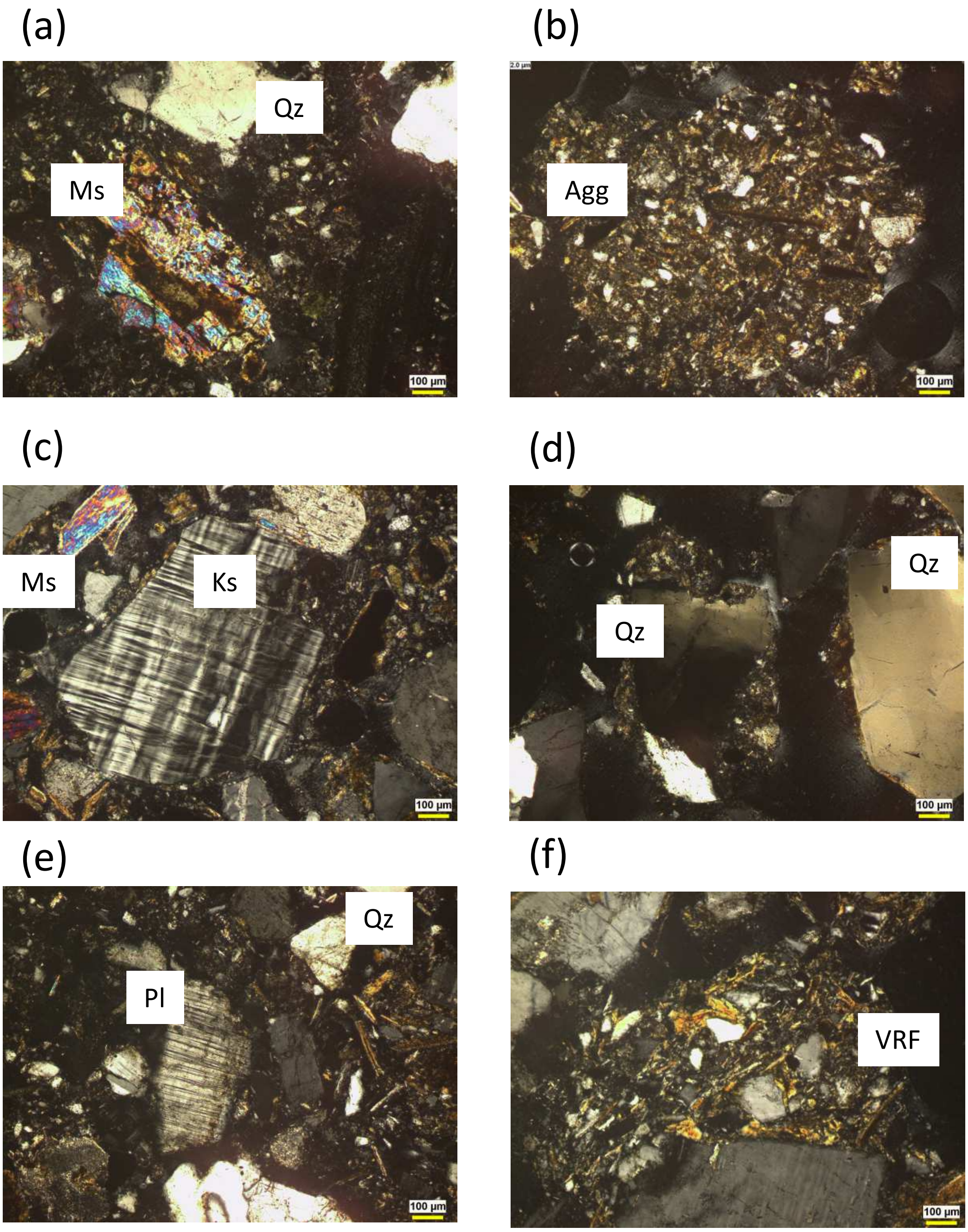


Figure 32. Cross polarized light. Representative mineralogy from samples from the green pine stand type (a) Green 1.1 (b) Green 3.1 (c) Green 5.5 (d) Green 7.1 (e) Green 7.1 (f) Green 7.4. Muscovite (Ms), Quartz (Qz), Aggregate (Agg), Potassium feldspar (Ks), Plagioclase feldspar (Pl) Volcanic Rock fragment (VRF).

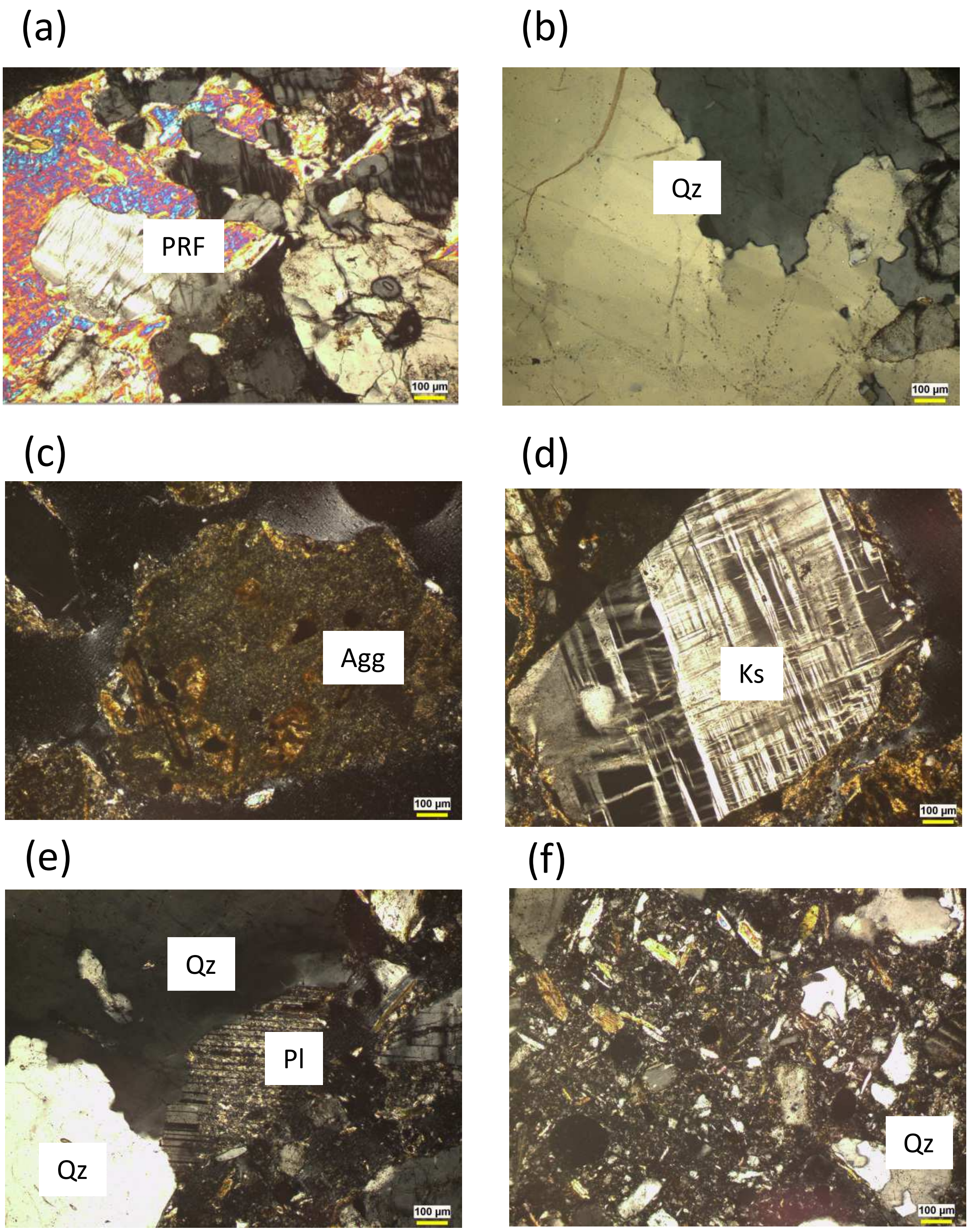


Figure 33. Cross polarized light. Representative mineralogy from samples from the gray pine stand type (a) Gray 4.1 (b) Gray 3.1 (c) Gray 4.1 (d) Gray 6.5 (f) Gray 7.1 (f) Gray 7.1. Muscovite (Ms), Quartz (Qz), Aggregate (Agg), Potassium feldspar (Ks), Plagioclase feldspar (Pl), Plutonic Rock Fragment (PRF).

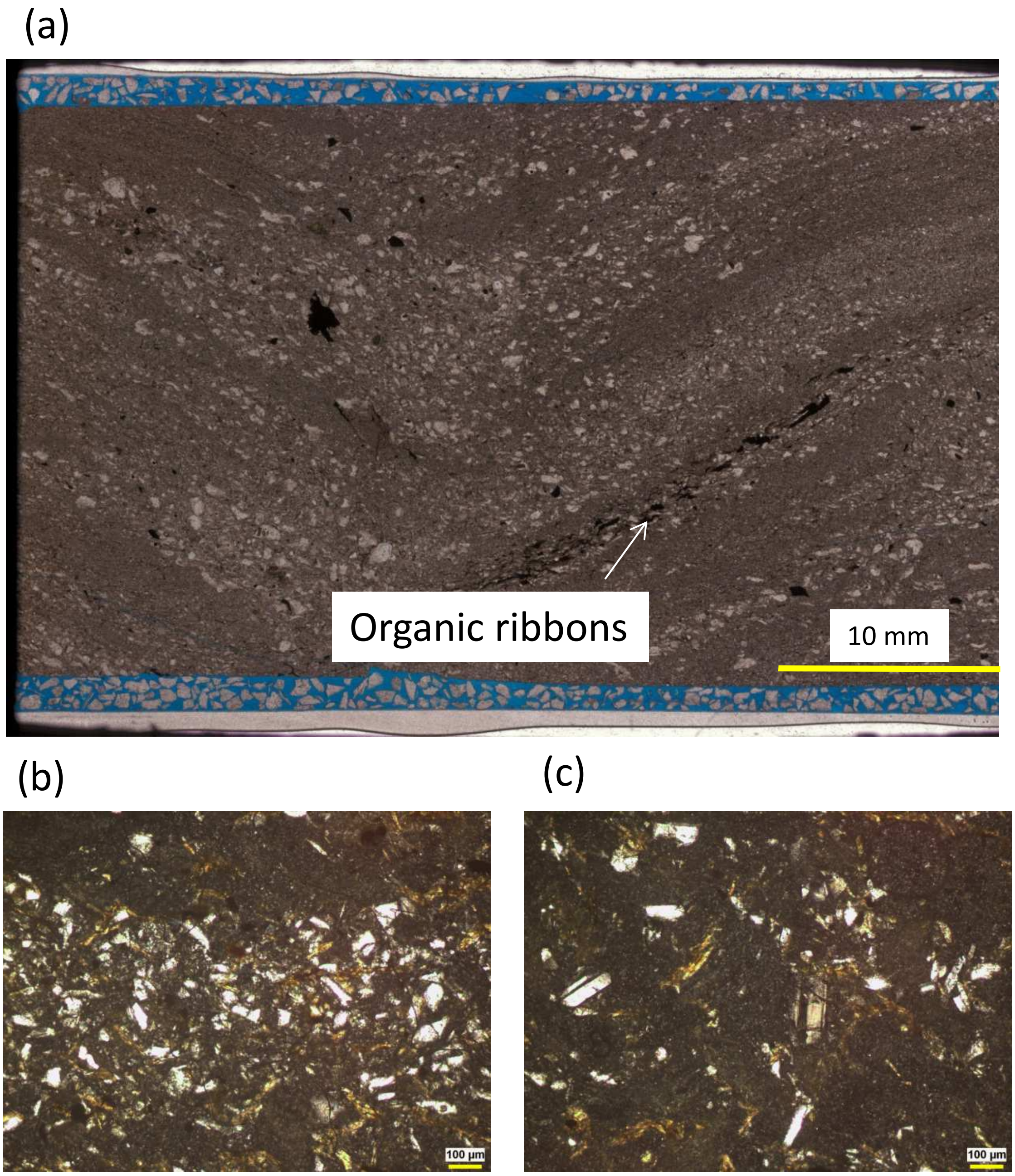


Figure 34. Cross polarized light. Sample O 1. (a) Scanned thinned section, (b and c) Photomicrographs from sample O 1, mostly quartz and biotite grains in a wacke matrix.

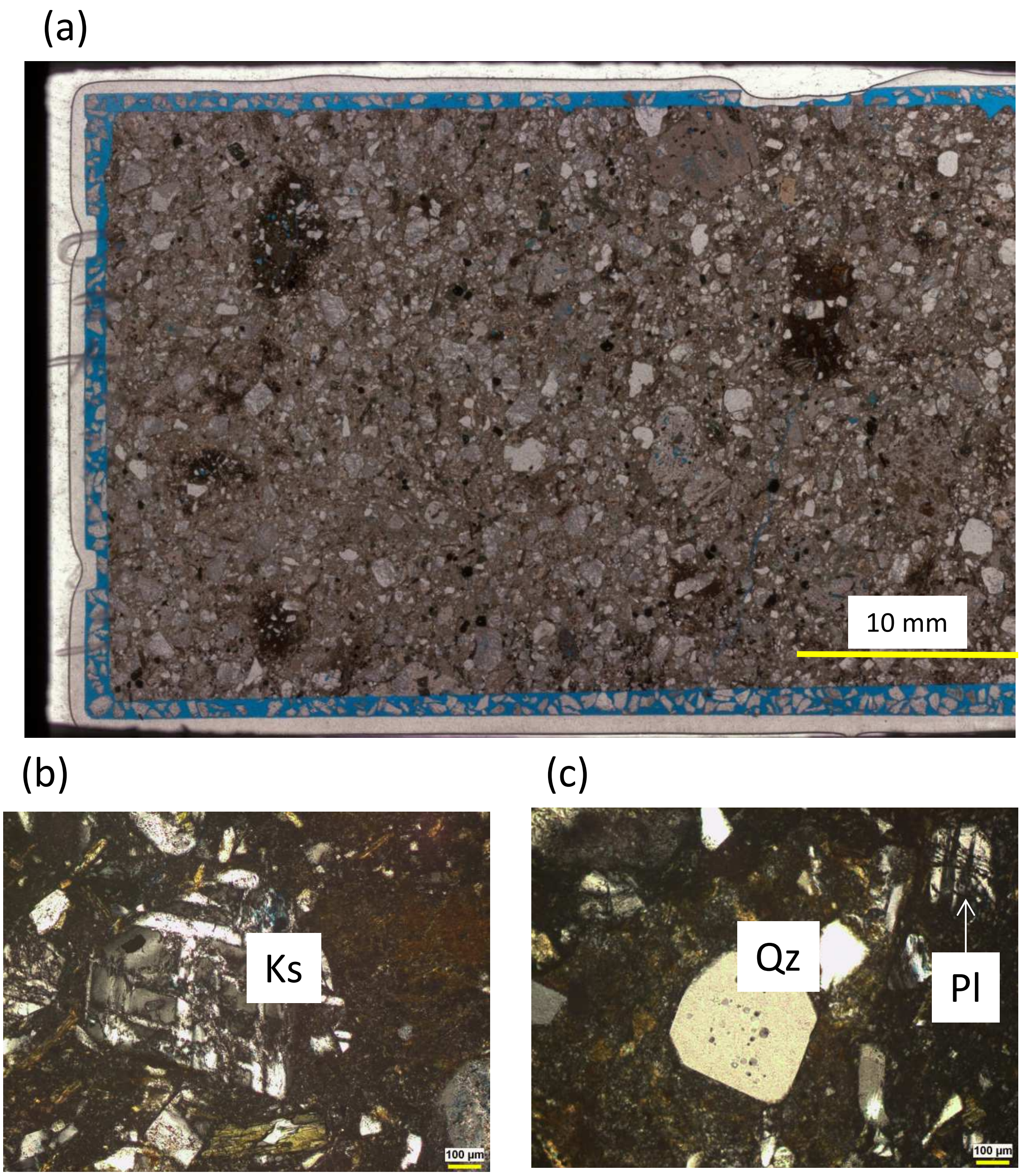


Figure 35. Cross polarized light. Sample O 2.1. (a) Scanned thin section. (b and c) Photomicrographs from sample O 2.1. Potassium feldspar (Ks), Quartz (Qz), Plagioclase feldspar (Pl).

(a)

(b)

(c)

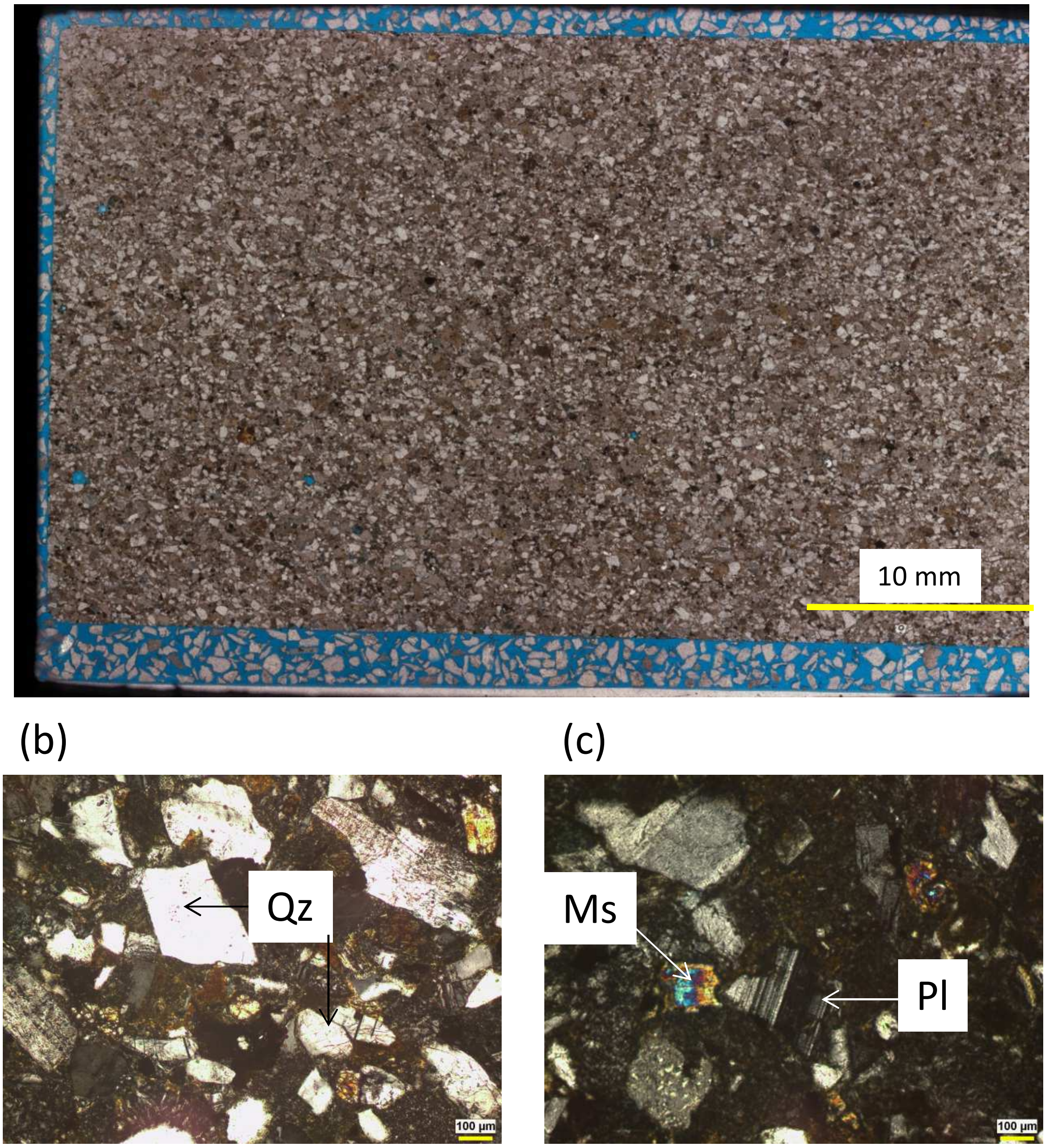


Figure 36. Cross polarized light. Sample O 2.2. (a) Scanned thin section. (b and c) Photomicrographs from sample O 2.2. Quartz (Qz), Muscovite (Ms), Plagioclase feldspar (Pl).

Modal abundances of minerals in the soil samples are variable, so to simplify the point counted mineralogy the mineral constituents within individual soil pits were reported with averages and standard error values (Table 7). The point count data were categorized by pine stand type and ordered by hillslope elevation. Modal abundances of quartz, and aggregates are plotted in Figure 37; plagioclase and potassium feldspars are plotted in Figure 38; plutonic rock fragments (PRF) and volcanic rock fragments (VRF) are plotted in Figure 39; and undifferentiated clay- and silt-sized material (matrix) and the sum of the modal percentages of biotite and muscovite (micas) are plotted in Figure 40.

The petrographic results are compared between samples collected from the upper depths (approximately 2- to 8-inches below ground surface) and samples collected from the deeper depths (approximately 13- to 20-inches below ground surface) and also between the green and gray pine stand types. Results show that the average modal quartz is slightly greater in the soils beneath the trees in the gray stand than in the green stand (Fig. 37; Table 7). The average modal percentage of soil aggregates in the green stand is approximately 3-times greater than in the gray stand (Fig. 37; Table 7). Modal quartz slightly decreases from the shallow samples to the deeper samples in both the green and gray pine stand types. Modal aggregates slightly increase from the shallow to the deeper samples in the green stand, and in the gray stand modal aggregates slightly decrease from the shallow to the deeper samples (Table 7). The petrographic data for plagioclase and potassium feldspars show that the soils beneath the gray stand contain approximately 1.5-times the average modal plagioclase and potassium feldspar of the green stand (Table 7; Fig. 38).

There are greater average modal percentages of PRF and VRF in the gray stand than in the green stand (Table 7; Fig. 39). The soil samples from pit Gy 4 contained the greatest amount of VRF for the samples of the gray pine stand, and the average modal content of PRF and VRF

Table 7a: Modal composition of the upper samples.

Sample	Elevation (ft.)	Top / Bottom Depth (in)		Qz	Agg	KF	PF	PRF	VRF	MRF	SRF	Mx	Bt	Ms	Total Mica	Hb	Op	Qz / Agg + Total Micas
Gn 7.1	9323	2.0	5.5	34.1	26.4	6.9	4.6	10.0	0.8	0.4	0	11.1	1.9	1.9	3.8	0.4	1.5	1.1
Gn 3.1	9232	2.0	6.0	7.3	72.9	3.7	1.5	9.2	0.4	0.7	0	2.6	0	1.1	1.1	0	0.7	0.10
Gn 5.1	9208	2.0	6.0	23.0	43.8	6.3	3.9	10.2	0.4	0.8	0	7.8	0.8	1.2	2	0	2	0.50
Gn 1.1	9160	2.0	4.5	26.6	51.0	6.5	4.6	4.6	0.0	0.8	0	4.2	0.4	0.8	1.2	0	0.8	0.51
Average				22.8	48.5	5.9	3.7	8.5	0.4	0.7	0	6.4	0.8	1.3	2.0	0.1	1.3	0.6
Standard Error				5.65	9.63	0.73	0.7	1.3	0.2	0.1	0	1.9	0.4	0.23	0.63	0.1	0.3	0.2
Gy 7.1	9365	5.0	9.0	30.3	10.6	10.9	5.1	26.3	5.1	1.1	0.7	8.8	0.7	0	0.7	0	0.4	2.7
Gy 6.1	9324	3.0	7.0	28.2	17.2	18.7	11.1	11.5	2.7	0.0	0	6.1	1.9	1.5	3.4	0	1.1	1.4
Gy 4.1	9314	4.0	8.0	18.6	15.3	12.8	6.2	19.0	24.8	0.7	0.4	2.2	0	0	0	0	0	1.2
Gy 3.1	9258	3.0	7.0	36.2	14.3	11.5	6.5	19.0	3.2	0.7	0.4	6.5	0.4	1.1	1.5	0	0.4	2.3
Average				28.3	14.4	13.5	7.2	19.0	9.0	0.6	0.4	5.9	0.8	0.7	1.4	0	0.5	1.9
Standard Error				3.66	1.39	1.79	1.3	3.0	5.31	0.2	0.1	1.4	0.4	0.4	0.73	0	0.2	0.4

Qz = Quartz
Agg = Aggregates
KF = Potassium Feldspar
PF = Plagioclase Feldspar
PRF = Plutonic Rock Fragments
VRF = Volcanic Rock Fragments
MRF = Metamorphic Rock Fragments
SRF = Sedimentary Rock Fragments

Mx = Matrix
Bt = Biotite
Ms = Muscovite
Hb = Hornblende
Op = Opaque

Table 7b: Modal composition of the intermediate to deep samples.

Sample	Elevation (ft.)	Top / Bottom Depth (in)		Qz	Agg	KF	PF	PRF	VRF	MRF	SRF	Mx	Bt	Ms	Total Micas	Hb	Op	Qz / Agg + Total Micas
Gn 7.4	9323	13.0	18.0	33.8	15.4	11.7	8.6	16.9	1.5	0.8	0	5.3	2.3	2.6	4.9	0.4	0.8	1.7
Gn 3.4	9232	14.0	18.0	15.5	51.8	7.2	2.4	12.7	1.6	0.4	0	6	0.4	1.6	2	0	0.4	0.29
Gn 5.4	9208	13.0	17.0	18.4	57.6	4.2	1.8	9.2	1.4	1.4	0	4.2	0.7	0.7	1.4	0	0.4	0.31
Gn 1.5	9160	15.0	18.0	4.6	86.1	2.1	1.8	1.4	0.0	0.0	0	2.1	0.4	0.7	1.1	0	0.7	0.05
Average				18.1	52.7	6.3	3.7	10.1	1.1	0.7	0	4.4	1.0	1.4	2.4	0.1	0.6	0.58
Standard Error				6.02	14.5	2.1	1.7	3.3	0.38	0.3	0	0.85	0.46	0.45	0.87	0.1	0.1	0.37
Gy 7.3	9365	13.0	17.0	28.2	8.9	12.5	6.1	28.2	5.7	0.4	0	7.5	0.7	1.4	2.1	0	0.4	2.6
Gy 6.5	9324	17.0	20.0	26.2	9.7	11.7	8.1	29.8	10.5	0.0	1.6	2.4	0	0	0	0	0	2.7
Gy 4.4	9314	14.0	19.0	23.8	13.1	8.7	3.2	31.0	15.9	0.8	0	2.4	0.4	0.8	1.2	0	0	1.7
Gy 3.5	9258	17.0	21.0	23.7	12.9	11.6	5.2	32.1	7.6	0.4	0	4.4	0.4	0.8	1.2	0	0.8	1.7
Average				25.5	11.2	11.1	5.7	30.3	9.9	0.4	0	4.2	0.4	0.8	1.1	0	0.3	2.2
Standard Error				1.08	1.08	0.8	1.0	0.84	2.2	0.2	0	1.2	0.1	0.3	0.43	0	0.2	0.28

Qz = Quartz
Agg = Aggregates
KF = Potassium Feldspar
PF = Plagioclase Feldspar
PRF = Plutonic Rock Fragments
VRF = Volcanic Rock Fragments
MRF = Metamorphic Rock Fragments
SRF = Sedimentary Rock Fragments

Mx = Matrix
Bt = Biotite
Ms = Muscovite
Hb = Hornblende
Op = Opaque

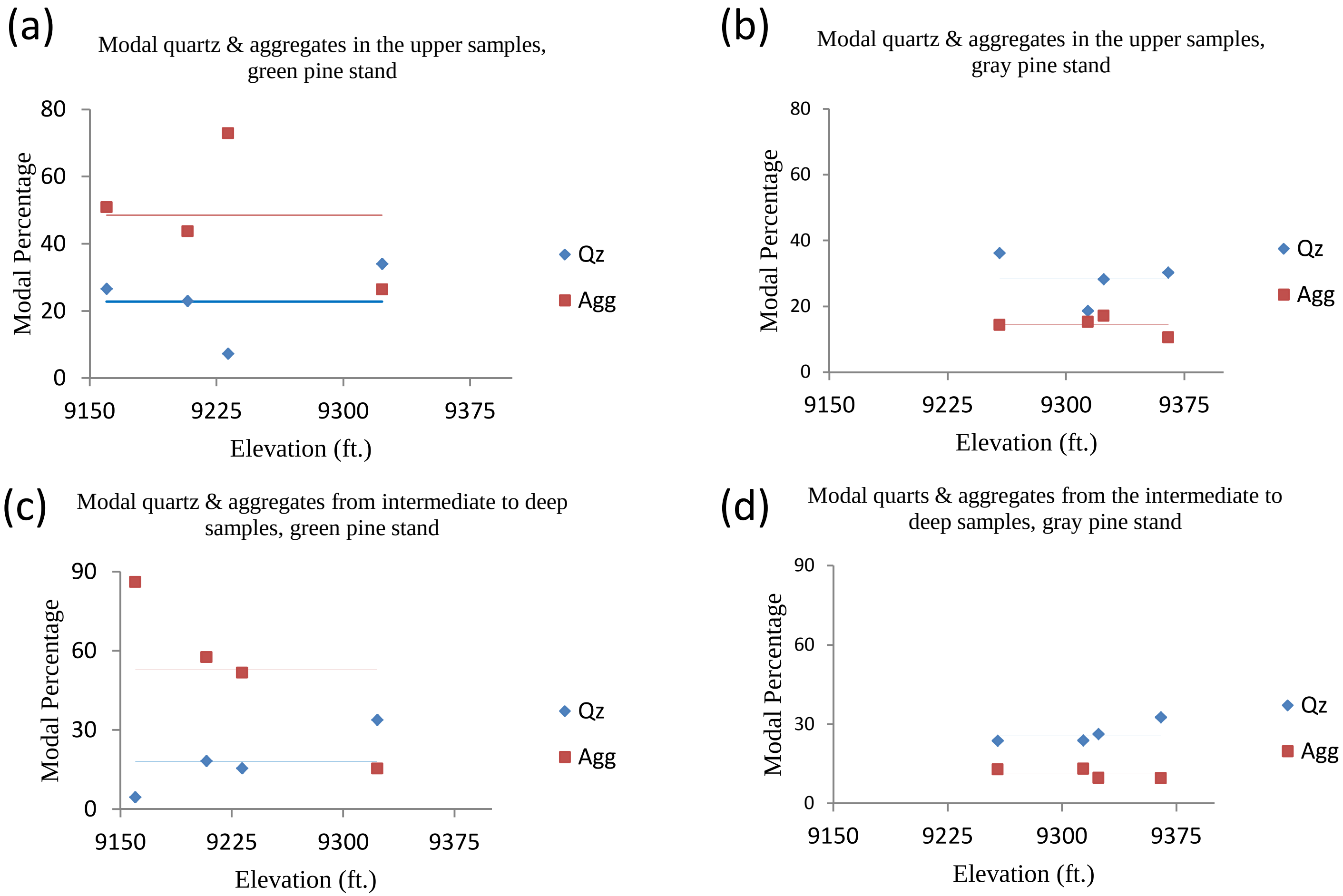


Figure 37. Modal percentages of quartz and aggregates counted from thin sections in the upper samples of the (a) green and (b) gray pine stand types, as well as from the intermediate to deep samples of the (c) green and (d) gray pine stand types. The horizontal lines represent the average modal composition.

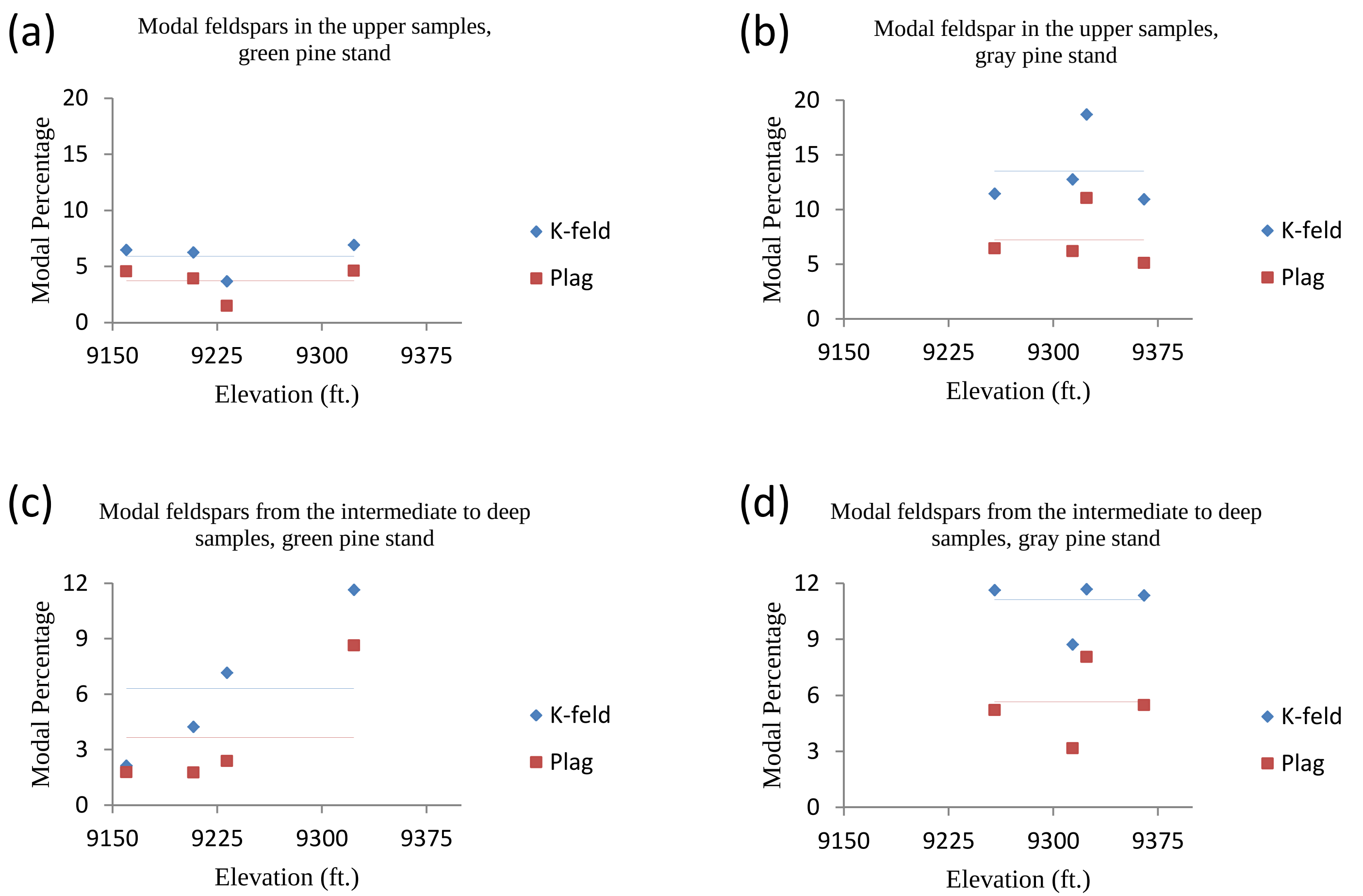


Figure 38. Modal percentages of plagioclase and potassium feldspars counted from thin sections in the upper samples of the (a) green and (b) gray pine stand types, as well as from the intermediate to deep samples of the (c) green and (d) gray pine stand types. The horizontal lines represent the average modal composition.

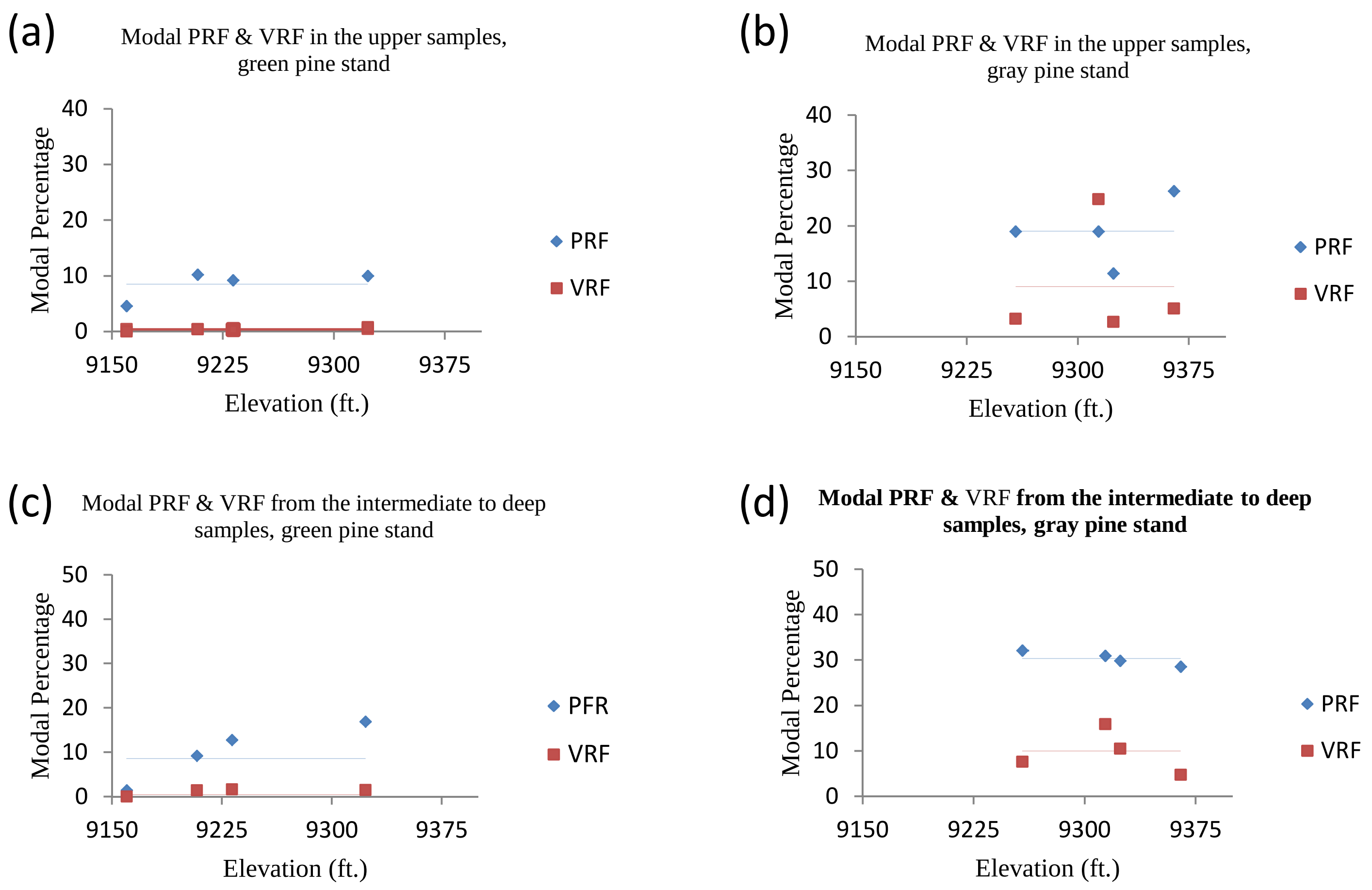


Figure 39. Modal percentages of plutonic and volcanic rock fragments counted from thin sections in the upper samples of the (a) green and (b) gray pine stand types, as well as from the intermediate to deep samples of the (c) green and (d) gray pine stand types. The horizontal lines represent the average modal composition.

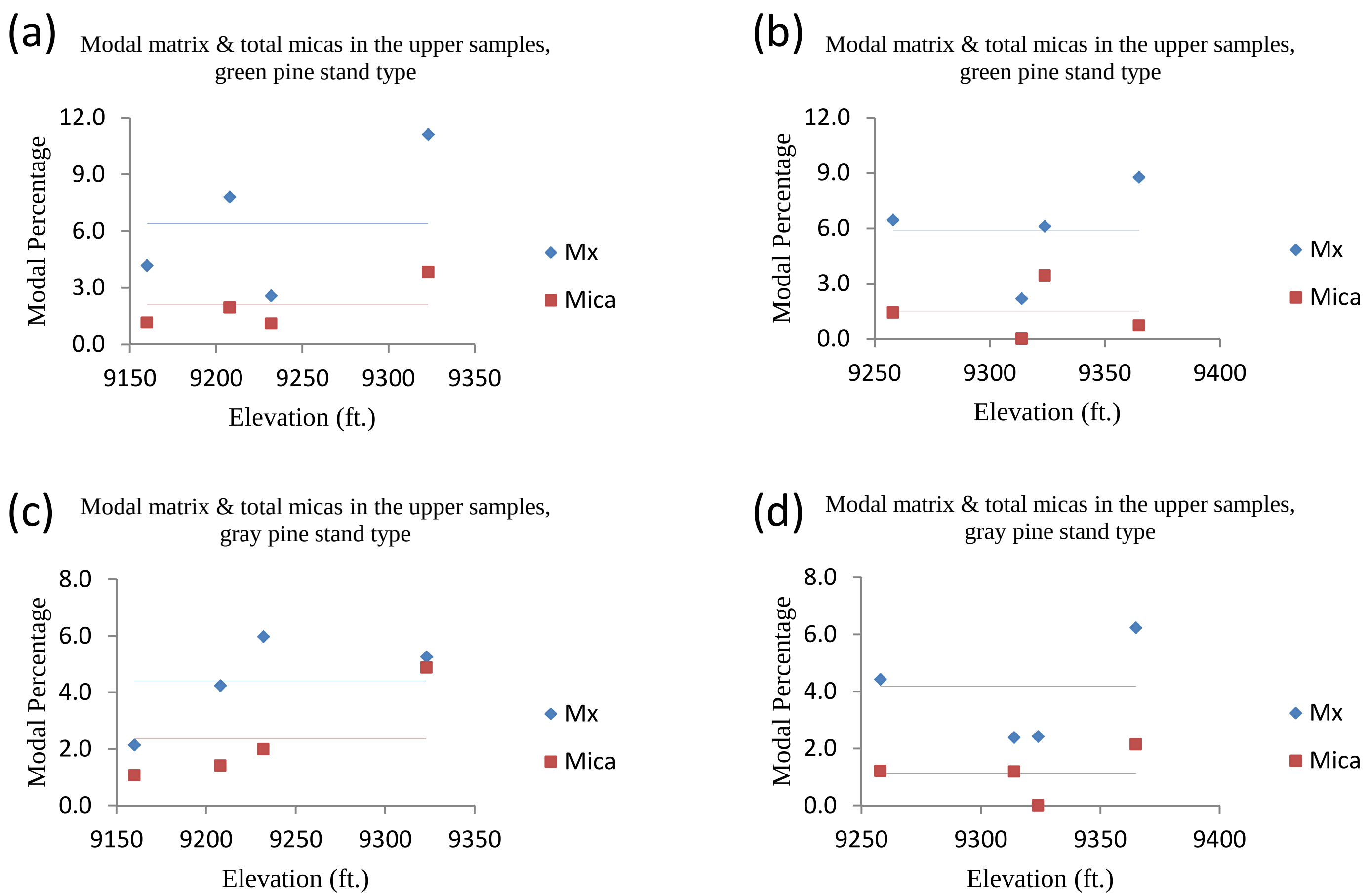


Figure 40. Modal percentages of matrix and total micas counted from thin sections in the upper samples of the (a) green and (b) gray pine stand types, as well as from the intermediate to deep samples of the (c) green and (d) gray pine stand types. The horizontal lines represent the average modal composition.

in soil of the gray stand generally increases from the upper samples to the deeper samples (Table 7; Fig. 39). The presence of VRF in the soil samples was generally low compared to PRF in the soil samples. There were minimal amounts of MRF and SRF counted within the soil samples of both the green and gray pine stand types (Table 7). The modal percentage of matrix constituents identified within the soils of the green and gray pine stand types is similar and there is a slightly higher modal composition of matrix in the upper samples than in the deeper samples. The total mica is slightly greater in the soils of the green pine stand type than in the gray pine stand type (Table 7; Fig. 40).

Photomicrographs of representative soil aggregates present in soil samples from the green and gray pine stand types are shown in Figure 41. Aggregates are primarily comprised of clays, with lesser amounts of quartz, feldspar, biotite, muscovite, as well as iron oxide cement.

The modal abundance of quartz slightly increases from the green to gray pine stands, and the abundances of aggregates and micas decreases from the green to gray pine stands, so a plot comparing the ratio of Quartz / (Aggregates + Micas) was constructed to compare the relationship of this ratio in the shallow and deeper soils from each of the pine stand types (Table 7; Fig. 42). The ratio is illustrated with the average values for each of the pine stand types (Fig. 42). Depth-based ratios are variable, but the averages of this ratio are shown to slightly increase from the green to gray stands (Table 7; Fig. 42). The samples in the green pine stand primarily reside around 0.5 in the plot of Quartz / (Aggregates + Micas), while the samples in the gray pine stands have ratios that primarily reside around 2 (Table 7; Fig. 42).

Petrographic observations show that there are lower abundances of soil aggregates at the gray sites than in the green sites, but there are also physical differences in the aggregates from

(a)

(b)

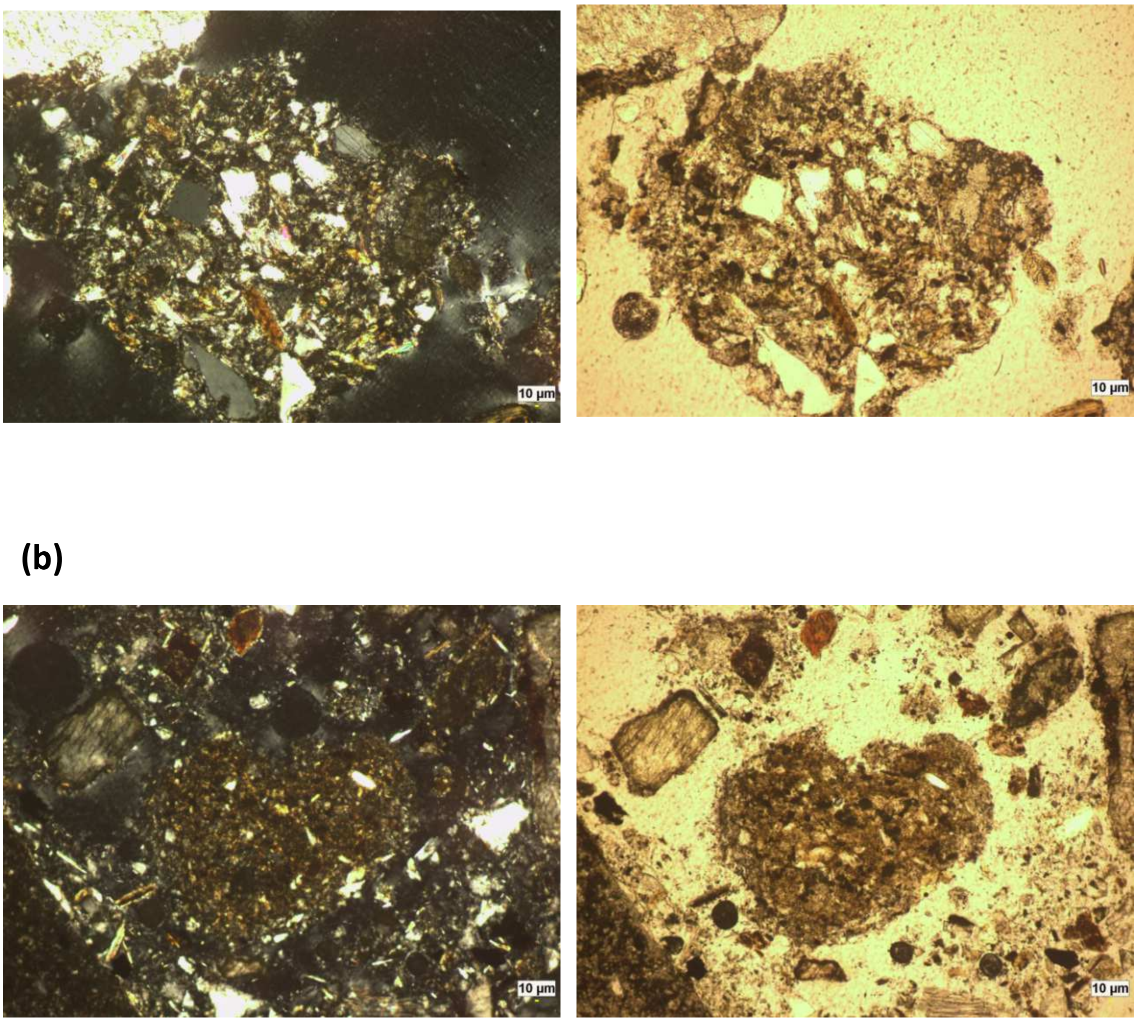


Figure 41: Photomicrographs of representative soil aggregates present in soil samples from the (a) green and (b) gray pine stand types. Soil aggregates in the gray pine stand type generally contained finer mineral components than the soil aggregates from the green pine stand type. *Left:* Cross polarized light, *Right:* Plane polarized light. Photomicrographs from samples (a) Gn 5 and (b) Gy 7.

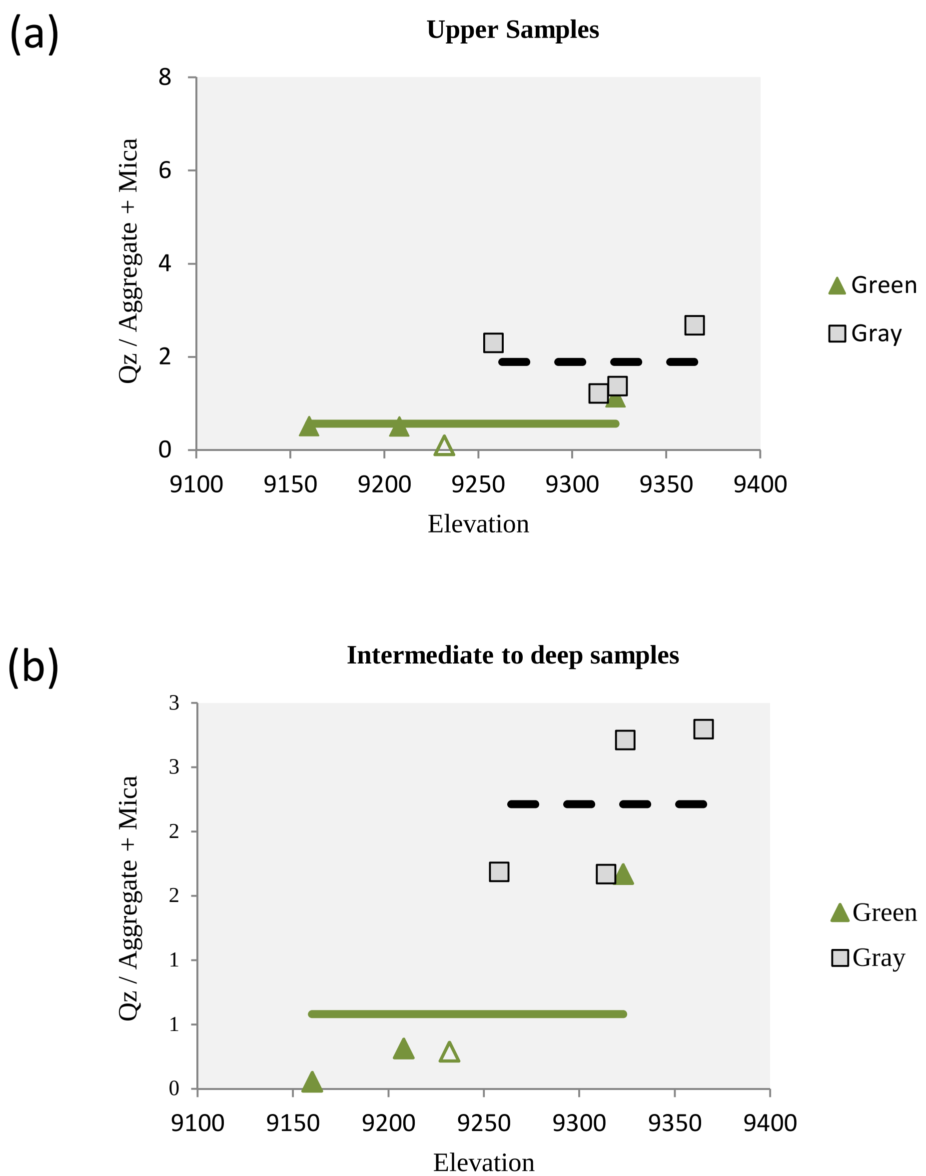


Figure 42: Modal ratios of quartz / (aggregates + micas) in the (a) upper soils and (b) intermediate to deep samples. The green line and black stippled line represents the composite data for the samples in the green and gray pine stand types.

the green and gray sites. Soil aggregates from the green stands have well-defined grain boundaries and abundant coarse mineral fragments inside of them (Table 7; Fig. 37 & 41). In the soils of the gray stand, there are fewer aggregates present, and many of the soil aggregate grain boundaries are not as well defined. Some of the aggregates from gray sites have more clay inside of them than the typical aggregates in the green sites have (Fig. 41b). In the soils of the gray stands there are aggregates comprised almost entirely of clays, and these types of aggregates are rare in the soils of the green stand.

4.5 Soil pH and saturated paste electric conductivity testing

Appendix E is a record of soil pH and electric conductivity (EC) from each of the 119 soil samples analyzed. Variations in soil pH are illustrated in Figure 43, and soil electric conductivity in Figure 44. Soil pH and EC readings are averaged, ordered by hillslope elevation and are plotted in composite plots according to approximate depth, indicating that not all soils were collected from the same sampling depth, but the data plotted include samples collected from similar depths from each of the three pine stand types. The composite plots also include error bars representing the standard error of values. The average pH of the organic topsoils was calculated for each of the three pine stand types. The average topsoil pH is 5.53, 5.42, and 5.34 for the green, brown, and gray stands respectively; below the topsoils, average pH is greatest in the many of the gray soil samples and lowest in many of the brown soil samples (Fig. 43). Soil pH is shown to increase with depth in the composite plots and reaches values of up to 6.5 for the deepest samples. Soil conductivity varies with depth and is primarily dependent on clay content, soil moisture and metal composition in the soil profile. The averaged data record a narrow range of readings, ranging between approximately 130 µS/cm and 150 µS/cm, with depth in the green and brown pine stand type. Results in the gray stand record lower EC readings, ranging

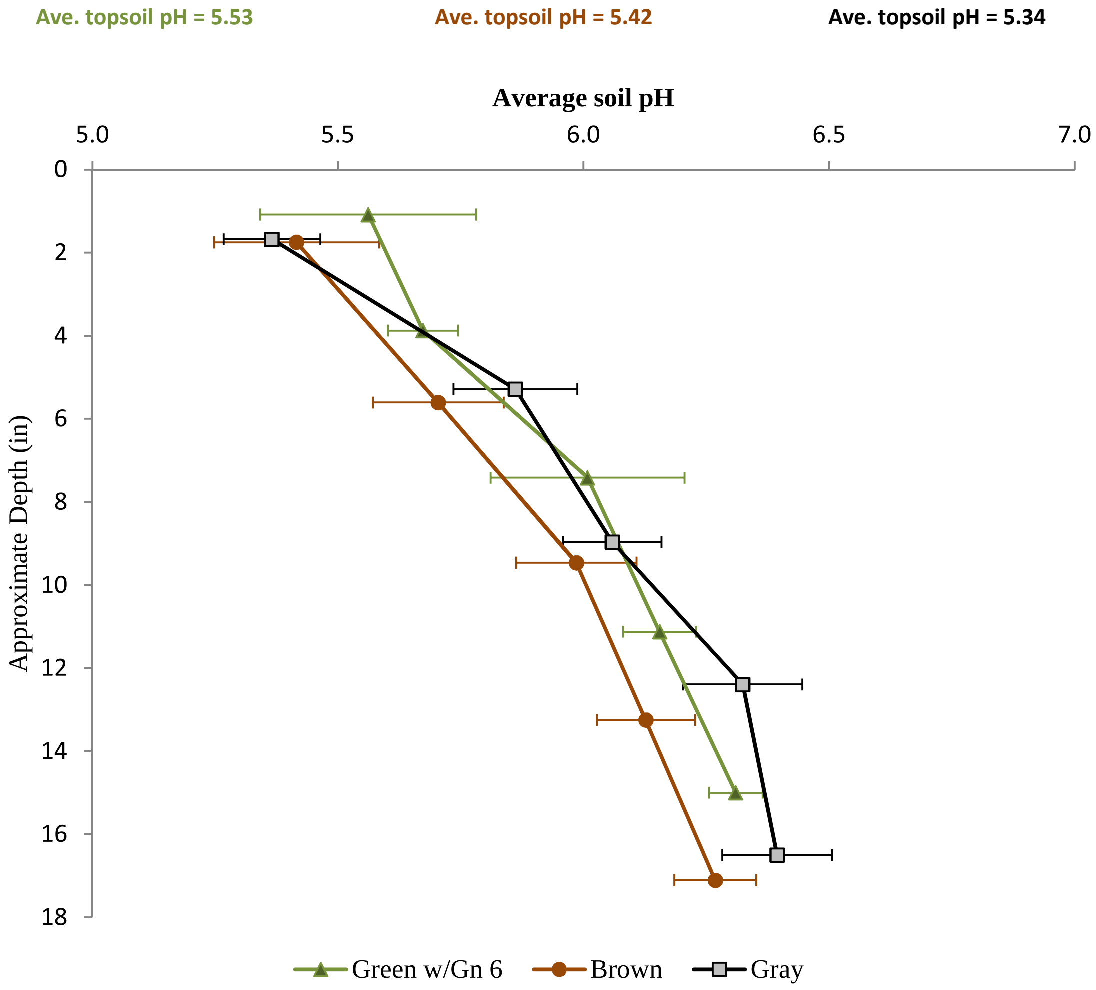


Figure 43: Composite soil pH plotted by approximate sampling depth. The error bars represent the standard error of data.

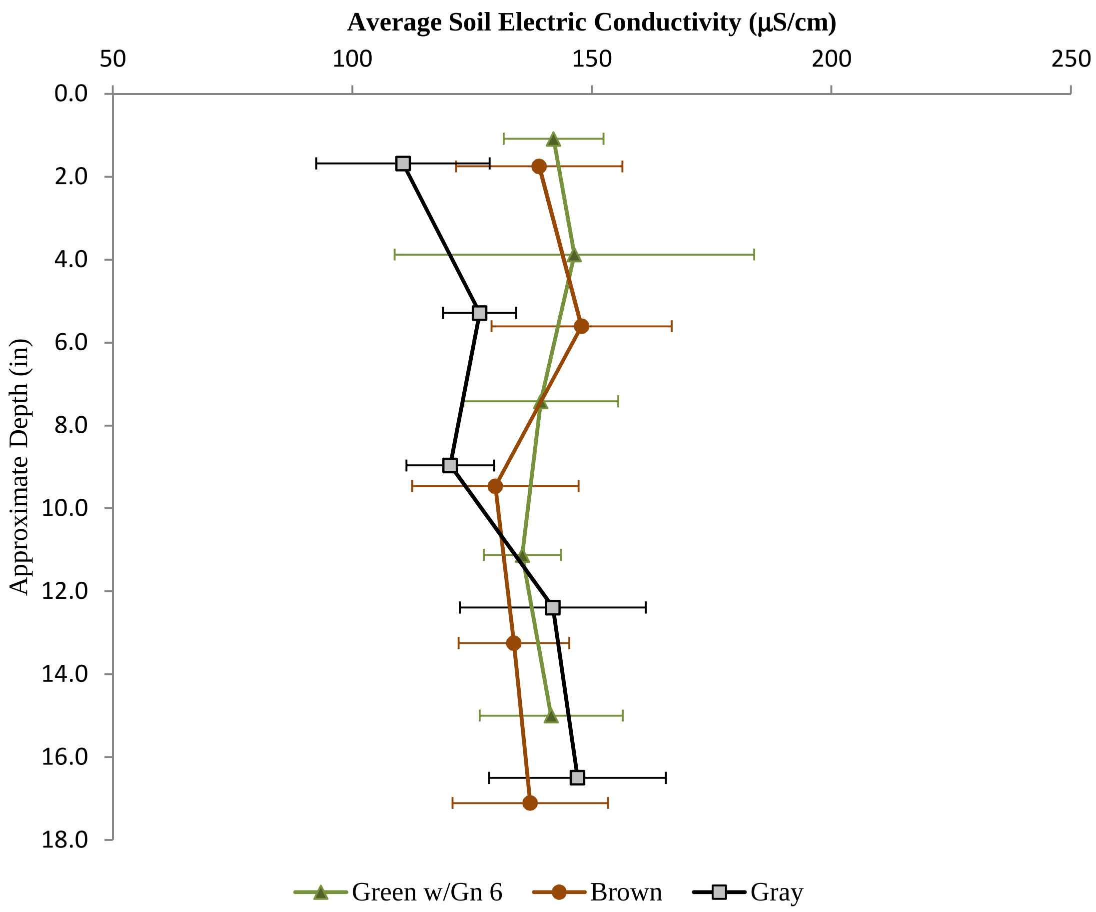


Figure 44. Composite soil electric conductivity (EC) plotted by approximate sampling depth. The error bars represent the standard error of data.

between approximately 110 μS/cm and 125 μS/cm, in the upper to intermediate depth samples, while the upper to intermediate depth samples of the brown and green stands record higher readings (Fig. 44). The average EC data in the deeper samples of the gray stand are similar to the average data of the brown and gray samples.

CHAPTER 5

Discussion

5.1 Soil characterization

The soil types observed and identified were generally comprised of coarse sandy loam with variable abundances of cobbles and boulder sized materials. The soils within the soil pits are interpreted to be predominantly comprised of *in situ* weathered rock, while the cobble and boulder sized material are derived from slope colluvium. The abundance cobble and boulder sized material was variable between the sampling sites, but not necessarily between the three pine stand types. The soils within the brown and gray sampling sites contained deeper depths of organic litter/ pine needles than what was observed in the green sampling sites. In addition, soil leaching and bleaching was observed in a few of the sampling sites (Gy 3, 5, 6 and 7) within the gray pine stand type. The upper soils within the brown and gray sampling sites were generally darker in color than what was observed in the green pine stand type. The differences observed within the soils of the green stand and pine beetle-killed pine stands are interpreted to be a result of increased weathering resulting from pine needle degradation.

5.2 Grain size analysis

The samples from the gray pine stand record a fine skewed grain size distribution, and the mean of the grain size distribution records coarser soils beneath the gray pine stand than in the brown and green pine stands (Table 3 & 4; Fig. 9). Two potential explanations for the grain size distributions observed among the different pine stand types are proposed: 1) the slight differences are caused by changes in weathering of soils related to beetle-kill, or 2) the differences are due to original variability in grain size in the parent sedimentary rock. Most of the samples in the green (20/23) and brown (25/25) pine stand types record platykurtic kurtosis values, 5/25 samples in gray stand record mesokurtic kurtosis values and remainder record a platykurtic distribution (Table 3).

Coarsening of the mean of soil grains from the green to brown to gray stands is likely due to increased weathering in soils beneath the beetle-killed pines. Modal analyses show that the abundance of aggregates and micas decreases from the green to gray stands, and that there are slightly greater abundances of quartz grains beneath the gray pines than in the soil pits of the green stand (Fig. 37; Table 7). The coarser soils beneath the gray pines may be a result of increased chemical weathering of aggregates and micas, thereby increasing the modal abundance of quartz grains, which is fairly resistant to weathering. In other words, at some time there may have been more soil aggregates in the soils beneath the gray pines, and perhaps the decomposing litter is weathering the cements holding the aggregates together; weathered material may be physically transported deeper into the profile or down the hillslope. Once the cements are broken down and fines are removed, the coarser quartz and feldspar fragments inside the aggregates are left behind, skewing the data toward a coarser grain size distribution. Results from the gray stand indicate that there are less of the finest fractions (i.e. silt and clay) in the soils when compared to the soils from the green stand (Fig. 9). The apparent coarsening of the grain size distribution may be attributed to weathering and removal of the finer fractions within the beetle-killed pine stands.

Sampled soils are likely derived from sandstones of the underlying Coalmont Formation. Given the sedimentary nature of the parent material and variability within the Coalmont Formation (Hendrix, 1978 Roberts and Rossi, 1999; Tweto, 1975), there is likely original heterogeneity in the grain size distribution within the study area. All three of the rock samples collected in this study are from the Coalmont Formation and each has a different grain size distribution (Fig. 34, 35, 36). Therefore, the differing soil grain size distributions observed could be due to original variability of grain sizes in parent material. The lateral distribution of the soil sampling sites increases the possibility that there are primary differences in the grain size distribution. In particular the brown sampling sites are grouped into two different areas on the hillslope; there is a group on the far western side of the hillslope and another near the middle-eastern portion of the study area (Fig. 5a). In addition, the soil samples from the gray stand are generally collected from higher elevations than the brown and green stands.

There is no apparent relationship between the grain size data and hillslope position. This interpretation is based on the scatter associated with the data, low R^2 values, and varying slopes of the best fit line. Therefore, the second hypothesis of increased downslope migration of weathered material due to increased weathering is unsupported (Fig. 10 & 11). The lateral distribution of sampling sites may not provide a good means of evaluating the downslope movement of physical products of weathering.

5.3 Geochemistry

The geochemical make-up of the majority of soil samples is fairly uniform and some of the heterogeneity observed may reflect heterogeneity in the parent sedimentary rock (Hendrix, 1978 Roberts and Rossi, 1999; Tweto, 1975) (Fig. 12 to 23). All three rock samples record slightly lower weight percent SiO_2, K_2O and Zr (Fig. 12d, 19d, 23d), and higher concentrations of MgO, CaO, Sr and Ba than seen in soils (Fig. 16d, 17d, 22d, 21d). Rock samples O 2.1 and O 2.2 record higher weight percent Al_2O_3, $Fe_2O_{3(T)}$, and MnO than soil samples (Fig. 13d, 14d, and 15d). Na_2O is lower in rock sample O 1 and higher in rock sample O 2.2 than seen in the soil samples (Fig. 18d). The rock samples have similar concentrations of TiO_2 to the soil samples, but rock sample O 2.2 has slightly higher concentrations than the soils (Fig. 20d). Lower percentages of MgO and CaO in the soils may be due to leaching and weathering of parent material. Higher weight percent SiO_2 in the soil profiles is likely due to passive quartz enrichment, as less resistant minerals are weathered. Some of the geochemical variability between rock and soil samples may be attributed to the breakdown of cements within the parent sedimentary rock during weathering. Despite the geochemical differences between rocks and soils, petrographic results confirm that rock samples O 2.1 and O 2.2 are the closest likely parent for soils, so these samples will be used in comparison of soil geochemistry.

Soil pits contained an abundance of granitic cobble- and boulder-sized colluvium; some soil pits contained more than others (Appendix A). As mentioned in section 3.1, any rocks larger than an inch in diameter were discarded from the collected sample, and in general the larger rocks present in the soil pits were granitic in composition. These granitic constituents appeared to be competent and minimally weathered; however, weathering of these cobbles could alter the chemistry of soils on the hillslope. The soils on the hillslope are likely from a sedimentary sandstone source that may have been derived from a prior granitic source, but the presence of the Tertiary dikes and granitic cobbles suggest that there are additional sources contributing to soil mineral composition (Hendrix, 1978; Roberts and Rossi, 1999; Tweto, 1975). In addition, there is the potential that soil samples were cross contaminated during collection. Soil material from the upper soil samples may have been knocked into the sampling pits during shoveling and sample collection. These potential sources of error are probably not affecting the majority of the soil pits in this study, but should be considered.

The chemistry of the soils did not change much with increased depths of sampling (Table 5). This suggests that the soil profiles were either not much influenced by element leaching and/or eluviation processes, or the pits were not deep enough to sample depth-related changes. In all the soil pits of the three pine stands the concentrations of SiO_2 vary modestly at various depths in most of the soil pits (Fig. 12a,b,c). Concentrations of SiO_2 are likely influenced by quartz content in samples from various depths. Comparison of changes in other major elements with depth under the various pine stand types and of differing hillslope locations suggests modest differences in soil weathering. The soils from the green pine stand type record greater geochemical variability among individual soil pits when compared to the soil geochemistry of the soils from the brown and gray pine stand types. In the soil pits of the brown stand the greater Al_2O_3 concentration in intermediate to deep samples likely indicates that either Al has been leached from the upper samples or that eluviation has increased the Al content of the deeper samples (Fig. 13b). The fact that the Al_2O_3 concentration is essentially constant from depths of 11 inches downward in the brown pits suggests leaching of the upper samples was more important than eluviation. A few of the soil pits in the gray stand (i.e. Gy 6 and Gy 3) show similar depth-based behavior of Al_2O_3 to the samples in the brown stand, but the other two gray samples (i.e. Gy 7 and Gy 4) do not (Fig. 13c). The higher average concentrations of Al_2O_3 in the upper soils beneath the gray pines also have a high standard error, so the higher average is not statistically significant (Table 6; Fig. 13d). Concentrations of Fe_2O_3(T) do not change much with depth in the majority of soil pits in the brown or gray stands (Fig. 14b,c). However, similar to Al_2O_3, soil pits Gy 6 and Gy 3 of the gray stand show an increase in Fe_2O_3(T) with depth suggesting that Al_2O_3 and Fe_2O_3(T) is removed from the upper samples and reprecipitated to lower depths (Fig. 14c & 14c).

Concentrations of MnO and MgO are variable with depth in the majority of the individual soil pits, but the data show that average MnO and MgO is higher in the soil pits of the green stand than in the brown and gray stands (Table 6; Fig. 15d & 16d). The lower average concentrations of MnO and MgO in the brown and gray stands could be due to leaching in the depths of sampling, or the lower averages could be due to original heterogeneity of parent material. Concentrations of CaO are variable with depth among the individual soil pits, but appear to be more alike in the soil pits of the green and gray stands than in the brown stand (Fig. 17a,b,c). In the pits of the green and gray stands some of the upper soil samples have higher concentrations of CaO than the samples immediately below, and in the brown stand CaO does not change much with depth (Fig. 17). Higher concentrations of CaO in upper soils of the green and gray stands may be from decomposing pine needles, as well as from additional plant materials (Preston et al., 2009; Berg and Laskowski, 1997). Berg & Laskowski (1997) showed the addition of Ca to soils from litter during pine needle degradation was greatest out of the nutrients analyzed. Concentrations of Na_2O and K_2O vary modestly with depth in the soil pits of the brown and gray stands, but average Na_2O and K_2O is greatest in the soils of the brown and gray stands, and lowest in the green stand (Fig. 18 & 19). Concentrations of K_2O are greater in all of the soil samples than in the likely parent rocks, so it is difficult to make an argument for leaching of K. (Fig. 19d). However, the geochemical data show that K_2O is greatest in the soils of the gray stand, followed by the brown and lowest in the green stand (Table 6; Fig. 18d & 19d). Preston et al. (2009) and Berg and Laskowski (1997) showed that K is released quickly from decomposing litter. Therefore, added potassium in soils from the brown and gray stands is likely from decomposing pine needles.

The ratio of more mobile elements to TiO_2 was used to assess weathering in the soils of the hillslope. Maynard (1993) suggested that less mobile elements (i.e. Al, Ti and Zr) used as a denominator may serve as a means of assessing the in situ nature of altered material from supposed parent rock in igneous rock types. Maynard (1993) also indicated that this method is difficult to use in sedimentary rocks due to primary heterogeneity within the parent rock. Ti was chosen over Al and Zr because the concentration of TiO_2 is more similar between the rock and soil samples than the others. However, variability in the average distribution of TiO_2 in the soil profiles must be considered (Fig. 20d). Average concentration of TiO_2 is slightly greater in the soils beneath the green stand than in the brown and gray stands, and the average concentrations of TiO_2 in the composite plots show that TiO_2 slightly increases to intermediate to deep depths in the soils of the green stand, whereas TiO_2 slightly decreases to intermediate to deep depths in the soils of the brown and gray stands (Table 6; Fig. 20).

Assuming Ti is relatively immobile, the difference in the ratios of SiO_2, Al_2O_3, CaO, Na_2O, and K_2O to TiO_2 suggests differences in weathering of soils beneath the various pine stand types. In the soils of the green stands these ratios are variable with no apparent relationship between pits, in some pits the ratios decrease with depth and in others the ratios increase with depth (Fig. 24, 25, 29, 31, and 31). Similar relationships for samples from the green stand were identified in the plots of individual geochemical components (Fig. 12a, 13a, 17a, 18a, 19a). The ratios of the oxides listed above in the soils beneath the brown and gray stands appear to be more similar to one another than in the soils in the green stand and generally increase to intermediate to deep depths, which may suggest leaching of weathered material. Therefore the potential for increased chemical weathering of materials beneath the brown and gray stands is possible. However, average TiO_2 is slightly lower in the brown and gray stands than in the green stand (Table 6; Fig. 20d); therefore, if the more mobile element concentrations are similar between the pine stand types (i.e. green, brown and gray) one would expect the ratios to be higher in the brown and gray than in the green stands. Variability in the distribution of TiO_2 in the soil profiles may have skewed the results of this test (Maynard, 1993). The average concentrations of TiO_2 were similar within the rock and soils samples; however, there is slight variability and likely a result of primary heterogeneity within the parent sedimentary rock.

5.4 Thin section petrography

Based on the three whole rock samples analyzed, rock samples O 2.1 and O 2.2 are the closest likely parent material for soils, but O 2.1 is the best fit. This interpretation was made based on the mineralogy and texture of rock samples. Rock sample O 1 does not have enough feldspar or mica minerals and the grain sizes are too fine to fit descriptions for soil samples. The mineralogy of rock sample O 2.2 is fairly similar to O 2.1, but grain sizes are finer in sample O 2.2. Sample O 2.1 has the coarsest mineral grains, and the modal mineralogy is closest to descriptions in soil samples (Appendix D). Soil texture is classified as sandy, and minerals in soils were generally coarser than minerals in samples O 1 and O 2.1 (Fig. 34, 35, 36).

In general, approximately 70% of the modal components of samples from the green stand are comprised of quartz and aggregates, while the same components in the gray stand account for approximately 40% of the total composition (Table 7: Fig. 37). Samples from the gray stands contain fewer aggregates and more quartz components than the samples from the green stand. The slight increase in quartz content from samples of the green to gray pine stands likely reflects weathering and/or removal of clays, micas and feldspars (Table 7: Fig. 37). The mineralogical data does not record less feldspar or clay minerals in the gray stands than in the green stands; however, there is a modal decrease in micas and soil aggregates from the green to gray stands (Table 7). The decrease in modal percentage of aggregates from the green to gray sampling locations could be caused by the breakdown of aggregates. The decomposition of the pine needles and the production of CO_2 and organic acids (White and Brantley, 1995) may break down the cements holding the soil aggregates together, and could explain why there are not as many aggregates in the soils beneath the gray pine stand than in the green stand.

Plagioclase feldspar, potassium feldspar and plutonic rock fragments (PRF) increase as the soil aggregates decrease in soils from the gray stand. There are approximately 2-times more plagioclase and potassium feldspars in the soils from the gray stand than in the green stand. The upper samples collected from the gray stand contain approximately 2-times more PRFs, and 3-times more PRFs in the intermediate to deep samples, than the samples collected from the green stand.

It was fairly difficult to differentiate the various rock fragments and soil aggregates in the soil samples; one potential source of error in the mineralogical results is that some of the rock fragments may have been misidentified as soil aggregates, and vice versa. Therefore, there is a potential for the mineralogical results to be variable depending on the analyst studying the mineral components. However, the same methods of identification were used in studying all of the mineral components of the soil samples, and in general, the rock fragments held their boundaries better than the soil aggregates and the rock fragments generally contained coarser mineral components inside of them than in the soil aggregates.

5.5 Soil pH and saturated paste electric conductivity testing

In the composite plots of soil pH versus depth, standard error values range from approximately 0.25 to 0.5, hence there is reasonable scatter among the averaged data representative of each of the pine stand types. The soils from the brown pine stand type record the overall lowest pH readings. The average upper samples record a slight decrease in soil pH going away from green to brown to gray sampling sites, suggesting beetle damage correlates with lowered topsoil pH (Fig. 43). Decomposing coniferous tree litter has the potential to intensify soil acidity (Certini et al., 1998); therefore, the decrease in upper soil pH may be due to pine needle decomposition. The increased litter depths observed in the brown and gray sites could result in increased acidity from pine needle decomposition, as well as changes in temperature or moisture content under the litter (White and Brantley, 1995).

There is considerable scatter in plots of EC versus depth among the samples representative of the three pine stand types, but the lower EC values in the upper to intermediate depth samples of the gray stand suggests an increase in associated soil moisture in these soils compared to the brown and green stands. The deeper samples of the gray stand record EC values that are more similar to the readings in the brown and green stands (Fig 44). MPB induced tree-kill is likely increasing litter depths, which may increase soil moisture and soil insulation (Barnes et al, 1998; Clow et al., 2011 and Sariyildiz et al., 2005). Perhaps the lower conductivity readings in the upper samples of the gray stand are due to higher associated moisture in soils, giving the soils lower conductivity readings.

CHAPTER 6

Conclusions

This study compared the degree and nature of weathering in soils beneath green colored, healthy-appearing pine trees, brown colored dead or dying pines that are still holding most of their needles, and gray colored dead pines that have dropped their needles. The greater average thicknesses of organic litter observed under the brown and gray stands are a result of increased needle drop and appear to affect weathering conditions in the soil. Based on the timescale of beetle-kill in the area (since approximately 1996) and the amount of time it takes for lodgepole pine needles to decompose (i.e. 4 years for 70% decomposition), there likely have been organic acids or other decomposition products affecting soil beneath the brown and gray pine stands..

Using the soil characteristics (i.e. grain size distribution, bulk geochemistry, mineralogy, soil pH, and saturated paste electric conductivity) to evaluate the study hypotheses, the data suggest that the soils beneath the various stages of beetle-killed trees in Arapahoe National Forest Lands, Grand County, CO have variable soil weathering conditions. The findings of this study can be summarized as follows:

- Characterization of soils within the sampling locations reveals that there were greater thicknesses of organic material in the brown and gray stands than in the green stands. Color observations observed within a few the soil pits of the gray stands (Gy 5, 6 & 7) indicate that the upper approximately 12-inches of soil depth were lighter in color when compared to the other soil pits and record evidence of soil leaching.
- The grain size distribution on the hillslope records that the soils within the gray stands are approximately 1.3 times coarser as compared to the soils within the green stands.

Coarser soils could be from soil weathering of the finer materials under the gray stands due to increased organic acid production during pine needle decomposition.

- The geochemical data record differences in soil chemistry beneath the brown and gray pine stands as compared to the green pine stands. The average concentration of K_2O and Na_2O_3 is greater, and the average concentration of MnO and MgO is smaller, in soils of the brown and gray stands than in the green stand. The similarities between the average concentrations of these compounds within the soil profiles in brown and gray pine stands and their differences from the green stands suggest that they are more weathered than the soils in the green stands.
- Mineralogical investigation of soils records that there is more quartz and less aggregate and mica in the soils beneath the gray stand than in the green stand. These results suggest increased weathering beneath the gray stands versus the green stands. Soil weathering is likely breaking down the aggregates and mica under gray stands.
- Soil pH in the upper soils slightly decreases from the green to brown to gray stands, which suggests that increased needle cover and decomposition is lowering soil pH. At depth, below the upper horizon, lower pH readings were observed in soils beneath the brown stands as compared to soils at the same depths under the green and gray stands.
- Lower conductivity readings in the upper to intermediate depth samples of the gray stands suggest an increase in soil moisture in these soils compared to the soils of the brown and green stands.
- Downslope physical migration of regolith was not evident in the results of this study.

In conclusion, the results of this study have shown that the death of the pine trees and decomposition of pine litter likely resulted in increased soil weathering on the hillslope.

CHAPTER 7

Future Studies

Future investigations in relation to soil weathering may include: a better soil sampling distribution, better quantification of properties and timing of needle decomposition, and continual monitoring of changes in litter thickness, soil moisture and temperature associated with increased pine needle cover. A smaller lateral spread between sampling locations could reduce heterogeneity within parent material for soils, and a tighter sample gradient would serve as a better means of assessing physical downslope migration of weathered regolith. One may also study the soil characteristics after beetle activity has run its course and all the infected trees have subsequently fallen over and dropped all their needles. In addition to soil weathering, a study of weathering characteristics occurring within the bedrock/ parent material for soils in the region would allow for greater insight into the weathering processes taking place beneath the MPB-killed pine stands. Geochemical analysis of the bedrock would also allow for a better constraint on the heterogeneity of the parent material.

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Appendix A: Sample site and soil classification

Site & sample #	Coordinates (Lat, Lon; WGS 84)	Elevation (ft)	Depth (in)	Munsell (naturally wet)	Description
Green 1	N40.26036, W106.05578	9160	0		Young tree stand with lodgepole and ponderosa pines. There are no MPB infected trees, but there was some down trees and debris. The soil profile consisted of sandy loam soils, the soils contain more clay as you move down in sequence. All the soils where wet. Contact between A- and B-horizon is gradational.
OH			2	10YR - 3/3 - Dark Brown	
1.1			4.5	10YR - 4/3 - Brown	
1.2			8.5	10YR - 5/3 - Brown	
1.3			12	10YR - 5/4 Yellowish brown	
1.4			15	10YR - 5/3 - Brown	
1.5			18	10YR - 5/3 - Brown	
1.6 & 1.7			23	10YR - 4/3 - Brown	
Green 2	N40.26013, W106.05619	9157	0		Young tree stand with lodgepole and ponderosa pine. There are no MPB infected trees, but there was some down trees and debris. The soils had an abundance of cobbles and contain less clay than Grn 1. Contact between A- and B-horizon is gradational.
OH			2	10YR - 3/3 - Dark Brown	
2.1			6	10YR - 4/3 - Brown	
2.2			9	10YR - 4/4 - Dark yellow Brown	
2.3			13	10YR - 4/4 - Dark yellow Brown	
2.4			17	10YR - 4/4 - Dark yellow Brown	
Green 3	N40.26048, W106.05613	9232	0		Trees are mostly ponderosa and lodgepole with no dead MPB infected trees in 10m radius. The soil pit is clay rich with an abundance of clay peds. Hole was difficult to dig b/c of wet clays. Distinguishable contact between A- and B horizon, defined by color/grain size.
Oh			2	10YR - 3/3 - dark brown	
3.1			6	10YR - 4/3 - brown	
3.2			10	10YR - 4/4 - dark yellow brown	
3.3			14	10YR - 4/4 - dark yellow brown	
3.4			18	10YR - 4/6 - dark yellow brown	
Green 4	N40.26051, W106.05520	9252	0		Ponderosa and lodgepole pines with a few MPB infected trees in 10m radius. The soils in this pit are a sandy loam with the clays forming ~2cm peds. The and soil is loose, similar to beach sand. Contact between A- and B-horizon is gradational.
Oh			3	10YR - 4/4 - dark yellow brown	
4.1			6	10YR - 5/3 - brown	
4.2			9	10YR - 5/3 - brown	
4.3			13	10YR - 5/4 - yellowish brown	
4.4			17	10YR - 5/4 - yellowish brown	

Appendix A con't: Sample site and soil classification

Site & sample #	Coordinates (Lat, Lon; WGS 84)	Elevation (ft)	Depth (in)	Munsell (naturally wet)	Description
Green 5	N40.26020, W106.05656	9208	0		The soils dug are mostly light yellow loose sands with little compaction and some cobbles. The trees in the area are mostly ponderosa, with a few lodgepoles. All trees are in a healthy condition. There were not a lot of tree roots or cobbles in soil pit. Contact between A- and B-horizon is gradational.
Oh			2	10YR - 4/2 - d. grayish brown	
5.1			6	10YR - 4/3 - brown	
5.2			9	10YR - 4/3 - brown	
5.3			13	10YR - 5/4 - yellowish brown	
5.4			17	10YR - 5/4 - yellowish brown	
5.5			21	10YR - 5/4 - yellowish brown	
Green 6	N40.26070, W106.05434	9255	0		Young healthy pines, some clear cut. Sandy loam soil, with little clays. The pit has lots of tree roots and cobbles. The ground is hard making it difficult to dig, Soils are red and possiblly from granitic parent, there is a dike about 30 feet away from the pit. Aggregates well cemented. Contact between A- and B-horizon is gradational.
OH			2	10YR - 2/2 - v. dark brown	
6.1			5.5	10YR - 4/4 - d. yellowish brown	
6.2			9.5	10YR - 4/4 - d. yellowish brown	
6.3			13	10YR - 5/4 - yellowish brown	
6.4			17	10YR - 5/4 - yellowish brown	
Green 7	N40.26117, W106.05645	9323	0		Mostly poderosa with some lodgepole pines. All trees within a 30 ft. radius are green and healthy, but there are browns to the east and west. The pine stand is thin and the hole is difficult to dig b/c of all the roots and boulders. Sandy loam soil - gradational contact.
OH			2	10YR - 2/2 - v. dark brown	
7.1			5.5	10YR - 3/3 - dark brown	
7.2			9.5	10YR - 4/4 - d. yellowish brown	
7.3			13	10YR - 5/4 - yellowish brown	
7.4			18	10YR - 5/4 - yellowish brown	

Appendix A con't: Sample site and soil classification

Site & sample #	Coordinates (Lat, Lon; WGS 84)	Elevation (ft)	Depth (in)	Munsell (naturally wet)	Description
Brown 1	N40.25970, W106.05500	9170	0		Mostly brown lodgepole pines missing most of their needles. There were 6 healthy trees and 7 brown trees within a 10m radius. There is a thicker O-horizon than in grn stands and an abundance of needles on forest floor. The soils are a sandy loam. Contact between A- and B-horizon is gradational.
OH			3	10YR - 3/3 - Dark brown	
1.1			7	10YR - 4/3 - Brown	
1.2			10	10YR - 4/6 - Dark yellowish brown	
1.3			14	10YR - 4/4 - Dark yellow Brown	
1.4			17	10YR - 5/4 - Yellowish Brown	
1.5			21	10YR - 4/3 - Brown	
Brown 2	N40.25997, W106.05505	9186	0		The area has more brown lodgepole pines trees than Brn 1 with 14 brown trees and 1 green tree. The forest floor has an abundance of dead pine needles. The soils are wet and consist of mostly sand with some clays. Contact between A- and B-horizon is gradational.
OH			3	10YR - 2/1 - Black	
2.1			7	10YR - 3/3 - Dark Brown	
2.2			11	10YR - 4/3 - Brown	
2.3			14	10YR - 4/3 - Brown	
2.4			18	10YR - 4/3 - Brown	
2.5			21	10YR - 4/4 - Dark yellowish brown	
Brown 3	N40.25990, W106.05397	9200	0		Lots of recently (within days) cut LP pines up slope. The trees are all LP and MPB infested missing ~ half of their needles. The Oh is thick and the soils are darker than in most other areas. Sandy Loam with granitic pebbles and boulders.Contact btw A- and B-horizon is gradational.
Oh			4.5	10YR - 2/2 - v. dark brown	
3.1			7.5	10YR - 4/3 - brown	
3.2			12.5	10YR - 4/3 - brown	
3.3			17.5	10YR - 4/4 - dark yellow brown	
3.4			20	10YR - 4/4 - dark yellow brown	
Brown 4	N40.25974, W106.05342	9169	0		Approximately 90% of mature LP trees are dead with at least 50% of needles shed. 10 trees are somewhat green and 21 dead within a 30 foot radius. This soil pit a is a fine-grained sandy loam and there are a few boulders in pit. Soils are light in color and mostly fine grained. Change in soil horizon is not easily noticeable.
Oh			4	10YR - 2/2 - v. dark brown	
4.1			9	10YR - 3/3 - dark brown	
4.2			12	10YR - 3/3 - dark brown	
4.3			16	10YR - 4/4 - dark yellow brown	
4.4			20	10YR - 4/4 - dark yellow brown	
4.5			24	10YR - 4/4 - dark yellow brown	
4.6			28	10YR - 4/4 - dark yellow brown	

Appendix A con't: Sample site and soil classification

Site & sample #	Coordinates (Lat, Lon; WGS 84)	Elevation (ft)	Depth (in)	Munsell (naturally wet)	Description
Brown 5	N40.26014, W106.05782	9242	0		Sample site is further west than other Brown spots. 18 MPB lodgepoles and 8 green younger trees. The soils from the area are sandy loam, with an abundance of soil peds. The soil pit contained roots, boulders and cobbles. Again not a clear change in horizon.
OH			2.5	10YR - 3/2 - v.d. grayish brown	
5.1			7.5	10YR - 3/4 - d. yellowish brown	
5.2			11	10YR - 4/4 - d. yellowish brown	
5.3			15	10YR - 4/4 - d. yellowish brown	
5.4			19	10YR - 4/4 - d. yellowish brown	
5.5			23	10YR - 5/4 - yellowish brown	
Brown 6	N40.25985, W106.05895	9244	0		Another western MPB spot. The trees immediately around pit are lodgepole and missing more than half of their needles. Within 30 ft. there are 20 brown lodgepoles and 13 that are mostly green, but are in beginning stages of infection. The soils are loamy, well compacted with some alluvial cobbles/boulders.
OH			4	10YR - 2/2 - v. dark brown	
6.1			8	10YR - 3/2 - v.d. grayish brown	
6.2			11	10YR - 4/3 - brown	
6.3			14.5	10YR - 4/4 - d. yellowish brown	
6.4			18.5	10YR - 4/4 - d. yellowish brown	
6.5			22	10YR - 4/4 - d. yellowish brown	
6.6			26	10YR - 5/4 - yellowish brown	
Brown 7	N40.26112, W106.05779	9343	0		This site is further up slope from brown 5.The trees in the area and lodgepole with 28 browns missing most of their needles. There are 10 trees that are green, but they also are missing needles. The soil is a organic rich sandy loam with an abundance of cobbles and boulders. Contact is gradational.
OH			3.5	10YR - 2/1 - Black	
7.1			8	10YR - 3/3 - dark brown	
7.2			12	10YR - 3/3 - dark brown	
7.3			16	10YR - 4/3 - brown	
7.4			20	10YR - 4/3 - brown	
7.5			25	10YR - 4/3 - brown	
Brown 8	N40.26085, W106.05843	9337	0		This site is similar to brown 7 in terms of MPB-killed trees, but the soils are a bit different in terms of color. The soils are sandy with an abundance of cobbles, boulders, and roots in pit. There are 20 MPB-killed and 11 green lodgepole pines, but the green are younger than brown.
OH			3	10YR - 2/2 - v. dark brown	
8.1			7	10YR - 4/4 - d. yellowish brown	
8.2			10	10YR - 5/4 - yellowish brown	
8.3			14	10YR - 5/4 - yellowish brown	
8.4			18	10YR - 5/4 - yellowish brown	
8.5			20	10YR - 5/4 - yellowish brown	

Appendix A con't: Sample site and soil classification

Site & sample #	Coordinates (Lat, Lon; WGS 84)	Elevation (ft)	Depth (in)	Munsell (naturally wet)	Description
Gray 1	N40.26042, W106.05366	9262	0		This location is right on the edge of the brown and gray zones. There are 11 dead (standing) lodgepoles in area with only 1 tall standing green lodgepole and 5 younger lodgepoles. The soils seem sandier than other pits, but soils appear more clay-rich deeper into the pit defining the B-horizon.
OH			2.5	10YR - 2/1 - Black	
1.1			6.5	10YR - 4/3 - Brown	
1.2			10.5	10YR - 4/4 - Dark yellow Brown	
1.3			14.5	10YR - 4/4 - Dark yellow Brown	
1.4			18.5	10YR - 4/4 - Dark yellow Brown	
1.5			21.5	10YR - 4/6 - Dark yellow brown	
1.6			24	10YR - 4/6 - Dark yellow brown	
Gray 2	N40.26051, W106.05275	9259	0		This location is deeper into the dead lodgepole pines with 18 dead (standing) lodgepoles. There are no tall standing healthy lodgepoles, but there are 13 small/young lodgepoles in area. The soils are mostly sandy with an abundance of cobbles. Contact between A- and B-horizon is gradational.
OH			3	10YR - 2/1 - Black	
2.1			6	10YR - 3/3 - Dark brown	
2.2			9	10YR - 4/3 - Brown	
2.3			12	10YR - 4/3 - Brown	
2.4			16	10YR - 4/4 - Dark yellow Brown	
2.5			19	10YR - 4/4 - Dark yellow Brown	
2.6			23	10YR - 4/4 - Dark yellow Brown	
Gray 3	N40.26052, W106.05266	9258	0		This area has been logged in past few days. The soil is a sandy loam with a lot of boulders in pit. The trees left standing are small young pines. The trees cut down have not been removed, so there is a lot of logs. Approximately 14 inches into pit is the start of Bh, but contact is gradational.
Oh			3	10YR - 2/2 - v. dark brown	
3.1			7	10YR - 5/3 - brown	
3.2			10.5	10YR - 5/4 - yellowish brown	
3.3			14	10YR - 5/4 - yellowish brown	
3.4			17	10YR - 5/4 - yellowish brown	
3.5			21	10YR - 4/4 - dark yellow brown	
Gray 4	N40.26100, W106.05218	9314	0		Area is clear cut, but there are still 8 dead and 20 live (younger ≤ 15 ft trees) standing pines. The hole is difficult to dig b/c of the abundance of boulders. The soils are still a sandy loam and are pretty consistent throughout pit. Ah/ Bh contact gradational.
Oh			4	10YR - 2/2 - v. dark brown	
4.1			8	10YR - 4/3 - brown	
4.2			11	10YR - 4/3 - brown	
4.3			14	10YR - 4/3 - brown	
4.4			19	10YR - 4/3 - brown	

Appendix A con't: Sample site and soil classification

Site & sample #	Coordinates (Lat, Lon; WGS 84)	Elevation (ft)	Depth (in)	Munsell (naturally wet)	Description
Gray 5	N40.26119, W106.05313	9353	0		This spot is in the gray zone, but most of the trees have been clear cut in last week. The soils are a sandy loam with cobbles. There is evidence of leaching given by the whitish soils. About 1ft into the hole soils get darker and grade into the Bh.
OH			3	10YR - 2/2 - v. dark brown	
5.1			7	10YR - 5/4 - yellowish brown	
5.2			11	10YR - 5/4 - yellowish brown	
5.3			14	10YR - 5/4 - yellowish brown	
5.4			18	10YR - 5/4 - yellowish brown	
5.5			22	10YR - 4/3 - brown	
Gray 6	N40.26106, W106.05243	9324	0		This location is directly under 4 dead lodgepole pines, and there are 10 dead and 8 green trees within 10m radius. The soils are bleached similar to pit gray 5. The soils are mostly sand with some clay content. Leaching of the upper ~16in of hole. Below 16in the soils get darker in color.
OH			3	10YR - 3/2 - v.d. grayish brown	
6.1			7	10YR - 6/3 - l. yellowish brown	
6.2			10	10YR - 6/3 - l. yellowish brown	
6.3			13	10YR - 6/3 - l. yellowish brown	
6.4			17	10YR - 5/4 - yellowish brown	
6.5			20	10YR - 4/3 - brown	
Gray 7	N40.26132, W106.05248	9365	0		This site is at a higher elevation than most other gray spots. The trees in the area were recently (weeks) logged. There are 6 dead and dozens of young-green lodgepole pines, with no mature-green lodgepole pines. The soils are sandy with an abundance on cobbles/boulders. Soils appear to have experienced some leaching in the top 5 in of soil depth.
OH			5	10YR - 2/2 - v. dark brown	
7.1			9	10YR - 5/3 - brown	
7.2			13	10YR - 5/4 - yellowish brown	
7.3			17	10YR - 5/4 - yellowish brown	
7.4			21	10YR - 5/4 - yellowish brown	
7.5			24	10YR - 5/4 - yellowish brown	

Appendix B: Shows which samples were used for various procedures. Soil pit Gn 6 was sampled and analysed, but the results are not dicussed in the results of this study.

Sample	Location	Top Depth (in)	Sieved	Geochemistry	Petrography	pH & EC
Gn 1 Oh	N40.26036, W106.05578	0				x
Gn 1.1		2	x	x	x	x
Gn 1.2		4.5	x	x	x	x
Gn 1.3		8.5	x	x	x	x
Gn 1.4		12	x			x
Gn 1.5		15	x	x	x	x
Gn 1.6		18	x			x
Gn 1.7		23		x	x	x
Gn 2 Oh	N40.26013, W106.05619	0				
Gn 2.1		2	x			
Gn 2.2		6	x			
Gn 2.3		9	x			
Gn 2.4		13	x			
Gn 3 Oh	N40.26048, W106.05613	0				x
Gn 3.1		2	x	x	x	x
Gn 3.2		6	x	x	x	x
Gn 3.3		10	x	x	x	x
Gn 3.4		14	x	x	x	x
Gn 4 Oh	N40.26051, W106.05520	0				x
Gn 4.1		3				x
Gn 4.2		6				x
Gn 4.3		9				x
Gn 4.4		13				x
Gn 5 Oh	N40.26020, W106.05656	0				x
Gn 5.1		2	x	x	x	x
Gn 5.2		6	x	x	x	x
Gn 5.3		9	x	x	x	x
Gn 5.4		13	x	x	x	x
Gn 5.5		17	x	x	x	x
Gn 6 Oh	N40.26070, W106.05434	0				x
Gn 6.1		2	x	x	x	x
Gn 6.2		5.5	x	x	x	x
Gn 6.3		9.5	x	x	x	x
Gn 6.4		13	x	x	x	x
Gn 7 Oh	N40.26117, W106.05645	0				x
Gn 7.1		2	x	x	x	x
Gn 7.2		5.5	x	x	x	x
Gn 7.3		9.5	x	x	x	x
Gn 7.4		13	x	x	x	x

Appendix B con't: Shows which samples were used for various procedures.

Sample	Location	Top Depth (in)	Sieved	Geochemistry	Petrography	pH & EC
Bn 1 Oh	N40.25970, W106.05500	0				x
Bn 1.1		3				x
Bn 1.2		7				x
Bn 1.3		10				x
Bn 1.4		14				x
Bn 1.5		17				x
Bn 2 Oh	N40.25997, W106.05505	0				
Bn 2.1		3	x			
Bn 2.2		7	x			
Bn 2.3		11	x			
Bn 2.4		14	x			
Bn 2.5		18				
Bn 3 Oh	N40.25990, W106.05397	0				x
Bn 3.1		4.5				x
Bn 3.2		7.5				x
Bn 3.3		12.5				x
Bn 3.4		17.5				x
Bn 4 Oh	N40.25974, W106.05342	0				x
Bn 4.1		4	x	x		x
Bn 4.2		9	x	x		x
Bn 4.3		12	x	x		x
Bn 4.4		16	x			x
Bn 4.5		20	x			x
Bn 4.6		24	x	x		x
Bn 5 Oh	N40.26014, W106.05782	0				x
Bn 5.1		2.5	x	x		x
Bn 5.2		7.5	x	x		x
Bn 5.3		11	x	x		x
Bn 5.4		15	x	x		x
Bn 5.5		19	x	x		x
Bn 6 Oh	N40.25985, W106.05895	0				x
Bn 6.1		4				x
Bn 6.2		8				x
Bn 6.3		11				x
Bn 6.4		14.5				x
Bn 6.5		18.5				x
Bn 6.6		22				x
Bn 7 Oh	N40.26112, W106.05779	0				x
Bn 7.1		3.5	x	x		x
Bn 7.2		8	x	x		x
Bn 7.3		12	x	x		x
Bn 7.4		16	x			x
Bn 7.5		20	x	x		x
Bn 8 Oh	N40.26085, W106.05843	0				x
Bn 8.1		3	x	x		x
Bn 8.2		7	x	x		x
Bn 8.3		10	x	x		x
Bn 8.4		14	x			x
Bn 8.5		18	x	x		x

Appendix B con't: Shows which samples were used for various procedures.

Sample	Location	Top Depth (in)	Sieved	Geochemistry	Petrography	pH & EC
Gy 1 Oh	N40.26042, W106.05366	0				x
Gy 1.1		2.5	x			x
Gy 1.2		6.5	x			x
Gy 1.3		10.5	x			x
Gy 1.4		14.5	x			x
Gy 1.5		18.5	x			x
Gy 1.6		21.5	x			x
Gy 2 Oh	N40.26051, W106.05275	0				x
Gy 2.1		3				x
Gy 2.2		6				x
Gy 2.3		9				x
Gy 2.4		12				x
Gy 2.5		16				x
Gy 2.6		19				x
Gy 3 Oh	N40.26052, W106.05266	0				x
Gy 3.1		3	x	x	x	x
Gy 3.2		7	x	x	x	x
Gy 3.3		10.5	x	x	x	x
Gy 3.4		14	x			x
Gy 3.5		17	x	x	x	x
Gy 4 Oh	N40.26100, W106.05218	0				x
Gy 4.1		4	x	x	x	x
Gy 4.2		8	x	x	x	x
Gy 4.3		11	x	x	x	x
Gy 4.4		14	x	x	x	x
Gy 5 Oh	N40.26119, W106.05313	0				x
Gy 5.1		3				x
Gy 5.2		7				x
Gy 5.3		11				x
Gy 5.4		14				x
Gy 5.5		18				x
Gy 6 Oh	N40.26106, W106.05243	0				x
Gy 6.1		3	x	x	x	x
Gy 6.2		7	x	x	x	x
Gy 6.3		10	x	x	x	x
Gy 6.4		13	x			x
Gy 6.5		17	x	x	x	x
Gy 7 Oh	N40.26132, W106.05248	0				x
Gy 7.1		5	x	x	x	x
Gy 7.2		9	x	x	x	x
Gy 7.3		13	x	x	x	x
Gy 7.4		17	x	x	x	x
Gy 7.5		21	x	x	x	x
O 1	N40.27222, W106.08478	N/A	N/A	x	x	N/A
O 2.1	N40.26969, W106.07863	N/A	N/A	x	x	N/A
O 2.2	N40.26969, W106.07863	N/A	N/A	x	x	N/A

Appendix C: sieve data

Sample / Size description	USSS No.	Grain Size mm	Grain Size phi	Raw Weight (g)	Cumulative Weight (g)	Cumulative %	Individual %
Gn 1.1							
V. coarse sand	12	1.78	-0.75	14.41	14.41	10.72	10.72
	18	1	0	21.72	36.13	26.88	16.16
C. Sand	30	0.59	0.75	22.96	59.09	43.97	17.08
Medium sand	40	0.42	1.25	10.56	69.65	51.82	7.86
	60	0.25	2	19.96	89.61	66.67	14.85
F. Sand	100	0.15	2.75	19.76	109.37	81.38	14.70
V. Fine Sand	170	0.09	3.5	9.57	118.94	88.50	7.12
	230	0.063	4	8.22	127.16	94.61	6.12
Silt and Clay	325	0.044	4.5	3.56	130.72	97.26	2.65
	>325	0.037	4.75	3.68	134.4	100.00	2.74
			Total	134.4			
			Original Wt.	135.76			
			Sieve loss/gain	1.36			
Gn 1.2							
V. coarse sand	12	1.78	-0.75	27.26	27.26	12.93	12.93
	18	1	0	37.79	65.05	30.85	17.92
C. Sand	30	0.59	0.75	37.35	102.4	48.57	17.72
Medium sand	40	0.42	1.25	17.13	119.53	56.69	8.13
	60	0.25	2	29.09	148.62	70.49	13.80
F. Sand	100	0.15	2.75	18.96	167.58	79.49	8.99
V. Fine Sand	170	0.09	3.5	17.46	185.04	87.77	8.28
	230	0.063	4	10.76	195.8	92.87	5.10
Silt and Clay	325	0.044	4.5	7.5	203.3	96.43	3.56
	>325	0.037	4.75	7.53	210.83	100.00	3.57
			Total	210.83			
			Original Wt.	212.99			
			Sieve loss/gain	2.16			
Gn 1.3							
V. coarse sand	12	1.78	-0.75	23.73	23.73	12.09	12.09
	18	1	0	34.91	58.64	29.88	17.79
C. Sand	30	0.59	0.75	34.33	92.97	47.38	17.49
Medium sand	40	0.42	1.25	15.41	108.38	55.23	7.85
	60	0.25	2	23.11	131.49	67.01	11.78
F. Sand	100	0.15	2.75	41.31	172.8	88.06	21.05
V. Fine Sand	170	0.09	3.5	11.91	184.71	94.13	6.07
	230	0.063	4	8.47	193.18	98.45	4.32
Silt and Clay	325	0.044	4.5	2.28	195.46	99.61	1.16
	>325	0.037	4.75	0.77	196.23	100.00	0.39
			Total	196.23			
			Original Wt.	197.46			
			Sieve loss/gain	1.23			
Gn 1.4							
V. coarse sand	12	1.78	-0.75	7.09	7.09	10.02	10.02
	18	1	0	11.11	18.2	25.72	15.70
C. Sand	30	0.59	0.75	11.87	30.07	42.50	16.78
Medium sand	40	0.42	1.25	6.51	36.58	51.70	9.20
	60	0.25	2	8.81	45.39	64.16	12.45
F. Sand	100	0.15	2.75	8.59	53.98	76.30	12.14
V. Fine Sand	170	0.09	3.5	5.52	59.5	84.10	7.80
	230	0.063	4	5.35	64.85	91.66	7.56
Silt and Clay	325	0.044	4.5	2.33	67.18	94.95	3.29
	>325	0.037	4.75	3.57	70.75	100.00	5.05
			Total	70.75			
			Original Wt.	71.18			
			Sieve loss/gain	0.43			

Gn 1.5							
V. coarse sand	12	1.78	-0.75	7.82	7.82	13.76	13.76
	18	1	0	10.07	17.89	31.48	17.72
C. Sand	30	0.59	0.75	9.36	27.25	47.95	16.47
Medium sand	40	0.42	1.25	4.52	31.77	55.90	7.95
	60	0.25	2	6.43	38.2	67.22	11.31
F. Sand	100	0.15	2.75	8.16	46.36	81.58	14.36
V. Fine Sand	170	0.09	3.5	3.45	49.81	87.65	6.07
	230	0.063	4	5.65	55.46	97.59	9.94
Silt and Clay	325	0.044	4.5	0.78	56.24	98.96	1.37
	>325	0.037	4.75	0.59	56.83	100.00	1.04
			Total	56.83			
			Original Wt.	57.48			
			Sieve loss/gain	0.65			
Gn 1.6							
V. coarse sand	12	1.78	-0.75	20.92	20.92	14.53	14.53
	18	1	0	27.33	48.25	33.52	18.99
C. Sand	30	0.59	0.75	23.64	71.89	49.94	16.42
Medium sand	40	0.42	1.25	12.64	84.53	58.72	8.78
	60	0.25	2	15.79	100.32	69.69	10.97
F. Sand	100	0.15	2.75	13.96	114.28	79.39	9.70
V. Fine Sand	170	0.09	3.5	15.73	130.01	90.32	10.93
	230	0.063	4	11.04	141.05	97.99	7.67
Silt and Clay	325	0.044	4.5	1.88	142.93	99.29	1.31
	>325	0.037	4.75	1.02	143.95	100.00	0.71
			Total	143.95			
			Original Wt.	144.63			
			Sieve loss/gain	0.68			
Gn 2.1							
	12	1.78	-0.75	5.48	5.48	3.39	3.39
	14	1.41	-0.5	6.92	12.4	7.67	4.28
V. coarse sand	16	1.19	-0.25	13.84	26.24	16.23	8.56
	18	1	0	10.6	36.84	22.79	6.56
	20	0.84	0.25	13.4	50.24	31.08	8.29
Coarse sand	25	0.71	0.5	9.12	59.36	36.72	5.64
	30	0.59	0.75	10.63	69.99	43.29	6.58
	35	0.5	1	3.16	73.15	45.25	1.95
	40	0.42	1.25	6.37	79.52	49.19	3.94
Medium sand	45	0.35	1.5	8.57	88.09	54.49	5.30
	50	0.3	1.75	8.76	96.85	59.91	5.42
	60	0.25	2	6.26	103.11	63.78	3.87
	70	0.21	2.25	5.22	108.33	67.01	3.23
Fine Sand	80	0.18	2.5	4.71	113.04	69.92	2.91
	100	0.15	2.75	5.64	118.68	73.41	3.49
	120	0.13	3	1.13	119.81	74.11	0.70
	140	0.11	3.25	5.86	125.67	77.73	3.62
V. fine sand	170	0.09	3.5	4.41	130.08	80.46	2.73
	200	0.074	3.75	4.37	134.45	83.16	2.70
	230	0.063	4	1.78	136.23	84.26	1.10
	270	0.053	4.25	2.72	138.95	85.95	1.68
	325	0.044	4.5	6.16	145.11	89.76	3.81
Silt and clay	>325	0.037	4.75	16.56	161.67	100.00	10.24
			Total	161.67			
			Original Wt.	158.95			
			Wt. loss/gain	-2.72			

Gn 2.2							
	12	1.78	-0.75	9.48	9.48	6.30	6.30
V. coarse sand	14	1.41	-0.5	8.9	18.38	12.22	5.92
	16	1.19	-0.25	11.78	30.16	20.05	7.83
	18	1	0	9.06	39.22	26.07	6.02
	20	0.84	0.25	11.35	50.57	33.61	7.54
Coarse sand	25	0.71	0.5	8.12	58.69	39.01	5.40
	30	0.59	0.75	10.4	69.09	45.92	6.91
	35	0.5	1	17.96	87.05	57.86	11.94
	40	0.42	1.25	13.63	100.68	66.92	9.06
Medium sand	45	0.35	1.5	13.72	114.4	76.04	9.12
	50	0.3	1.75	0	114.4	76.04	0.00
	60	0.25	2	6.21	120.61	80.17	4.13
	70	0.21	2.25	4.59	125.2	83.22	3.05
Fine Sand	80	0.18	2.5	3.83	129.03	85.76	2.55
	100	0.15	2.75	5.64	134.67	89.51	3.75
	120	0.13	3	2.47	137.14	91.15	1.64
	140	0.11	3.25	2.21	139.35	92.62	1.47
V. fine sand	170	0.09	3.5	2.01	141.36	93.96	1.34
	200	0.074	3.75	1.65	143.01	95.05	1.10
	230	0.063	4	0.79	143.8	95.58	0.53
	270	0.053	4.25	0.97	144.77	96.22	0.64
Silt and clay	325	0.044	4.5	1.94	146.71	97.51	1.29
	>325	0.037	4.75	3.74	150.45	100.00	2.49
			Total	150.45			
			Original Wt.	151.46			
			Sieve loss/gain	1.01			
Gn 2.3							
	12	1.78	-0.75	8.12	8.12	5.25	5.25
V. coarse sand	14	1.41	-0.5	7.37	15.49	10.02	4.77
	16	1.19	-0.25	9.91	25.4	16.43	6.41
	18	1	0	9.81	35.21	22.77	6.34
	20	0.84	0.25	13.23	48.44	31.33	8.56
Coarse sand	25	0.71	0.5	9.88	58.32	37.72	6.39
	30	0.59	0.75	11.88	70.2	45.40	7.68
	35	0.5	1	2.87	73.07	47.25	1.86
	40	0.42	1.25	8.21	81.28	52.56	5.31
Medium sand	45	0.35	1.5	10.35	91.63	59.26	6.69
	50	0.3	1.75	11.27	102.9	66.55	7.29
	60	0.25	2	7.91	110.81	71.66	5.12
	70	0.21	2.25	6.34	117.15	75.76	4.10
Fine Sand	80	0.18	2.5	5.27	122.42	79.17	3.41
	100	0.15	2.75	5.82	128.24	82.93	3.76
	120	0.13	3	5.05	133.29	86.20	3.27
	140	0.11	3.25	16.46	149.75	96.84	10.64
V. fine sand	170	0.09	3.5	0.59	150.34	97.23	0.38
	200	0.074	3.75	2.6	152.94	98.91	1.68
	230	0.063	4	0.25	153.19	99.07	0.16
	270	0.053	4.25	0.26	153.45	99.24	0.17
Silt and clay	325	0.044	4.5	0.73	154.18	99.71	0.47
	>325	0.037	4.75	0.45	154.63	100.00	0.29
			Total	154.63			
			Original Wt.	159.02			
			Sieve loss/gain	4.39			

Gn 2.4							
	12	1.78	-0.75	12.61	12.61	4.41	4.41
V. coarse sand	14	1.41	-0.5	22.01	34.62	12.09	7.69
	16	1.19	-0.25	23.53	58.15	20.31	8.22
	18	1	0	19.7	77.85	27.20	6.88
	20	0.84	0.25	26.28	104.13	36.38	9.18
Coarse sand	25	0.71	0.5	16.9	121.03	42.28	5.90
	30	0.59	0.75	23.9	144.93	50.63	8.35
	35	0.5	1	7.55	152.48	53.27	2.64
	40	0.42	1.25	14.22	166.7	58.24	4.97
Medium sand	45	0.35	1.5	18.19	184.89	64.59	6.35
	50	0.3	1.75	17.88	202.77	70.84	6.25
	60	0.25	2	16.86	219.63	76.73	5.89
	70	0.21	2.25	9.19	228.82	79.94	3.21
Fine Sand	80	0.18	2.5	7.89	236.71	82.69	2.76
	100	0.15	2.75	9.01	245.72	85.84	3.15
	120	0.13	3	4.97	250.69	87.58	1.74
	140	0.11	3.25	5.39	256.08	89.46	1.88
V. fine sand	170	0.09	3.5	4.95	261.03	91.19	1.73
	200	0.074	3.75	4.71	265.74	92.83	1.65
	230	0.063	4	1.74	267.48	93.44	0.61
	270	0.053	4.25	3.02	270.5	94.50	1.06
Silt and clay	325	0.044	4.5	5.63	276.13	96.46	1.97
	>325	0.037	4.75	10.12	286.25	100.00	3.54
			Total	286.25	286.25		
			Original Wt.	287.38			
			Sieve loss/gain	1.13			
Gn 3.1							
V. coarse sand	12	1.78	-0.75	21.14	21.14	11.80	11.80
	18	1	0	33.69	54.83	30.60	18.80
C. Sand	30	0.59	0.75	31.27	86.1	48.06	17.45
Medium sand	40	0.42	1.25	16.05	102.15	57.02	8.96
	60	0.25	2	24.13	126.28	70.48	13.47
F. Sand	100	0.15	2.75	19.64	145.92	81.45	10.96
V. Fine Sand	170	0.09	3.5	14.84	160.76	89.73	8.28
	230	0.063	4	12.4	173.16	96.65	6.92
Silt and Clay	325	0.044	4.5	1.74	174.9	97.62	0.97
	>325	0.037	4.75	4.26	179.16	100.00	2.38
			Total	179.16			
			Original Wt.	179.71			
			Sieve loss/gain	0.55			
Gn 3.2							
V. coarse sand	12	1.78	-0.75	12.36	12.36	15.17	15.17
	18	1	0	15.78	28.14	34.53	19.36
C. Sand	30	0.59	0.75	13.67	41.81	51.31	16.78
Medium sand	40	0.42	1.25	6.79	48.6	59.64	8.33
	60	0.25	2	9.61	58.21	71.43	11.79
F. Sand	100	0.15	2.75	7.45	65.66	80.57	9.14
V. Fine Sand	170	0.09	3.5	5.63	71.29	87.48	6.91
	230	0.063	4	7.75	79.04	96.99	9.51
Silt and Clay	325	0.044	4.5	0.87	79.91	98.06	1.07
	>325	0.037	4.75	1.58	81.49	100.00	1.94
			Total	81.49			
			Original Wt.	82.33			
			Sieve loss/gain	0.84			

Gn 3.3							
V. coarse sand	12	1.78	-0.75	15.61	15.61	18.80	18.80
	18	1	0	16.98	32.59	39.25	20.45
C. Sand	30	0.59	0.75	12.88	45.47	54.76	15.51
Medium sand	40	0.42	1.25	6.52	51.99	62.62	7.85
	60	0.25	2	9.09	61.08	73.56	10.95
F. Sand	100	0.15	2.75	7.78	68.86	82.93	9.37
V. Fine Sand	170	0.09	3.5	5.61	74.47	89.69	6.76
	230	0.063	4	6.71	81.18	97.77	8.08
Silt and Clay	325	0.044	4.5	0.63	81.81	98.53	0.76
	>325	0.037	4.75	1.22	83.03	100.00	1.47
			Total	83.03			
			Original Wt.	83.88			
			Sieve loss/gain	0.85			
Gn 3.4							
V. coarse sand	12	1.78	-0.75	11.19	11.19	13.44	13.44
	18	1	0	15.84	27.03	32.48	19.03
C. Sand	30	0.59	0.75	13.65	40.68	48.88	16.40
Medium sand	40	0.42	1.25	8.34	49.02	58.90	10.02
	60	0.25	2	11.41	60.43	72.61	13.71
F. Sand	100	0.15	2.75	8.71	69.14	83.07	10.46
V. Fine Sand	170	0.09	3.5	5.82	74.96	90.06	6.99
	230	0.063	4	4.6	79.56	95.59	5.53
Silt and Clay	325	0.044	4.5	1.7	81.26	97.63	2.04
	>325	0.037	4.75	1.97	83.23	100.00	2.37
			Total	83.23			
			Original Wt.	83.94			
			Sieve loss/gain	0.71			
Gn 5.1							
V. coarse sand	12	1.78	-0.75	25.96	25.96	8.51	8.51
	18	1	0	47.55	73.51	24.11	15.60
C. Sand	30	0.59	0.75	40.56	114.07	37.41	13.30
Medium sand	40	0.42	1.25	26.05	140.12	45.96	8.54
	60	0.25	2	38.22	178.34	58.49	12.54
F. Sand	100	0.15	2.75	44.82	223.16	73.19	14.70
V. Fine Sand	170	0.09	3.5	38.39	261.55	85.79	12.59
	230	0.063	4	34.33	295.88	97.04	11.26
Silt and Clay	325	0.044	4.5	4.98	300.86	98.68	1.63
	>325	0.037	4.75	4.03	304.89	100.00	1.32
			Total	304.89			
			Original Wt.	306.04			
			Sieve loss/gain	1.15			
Gn 5.2							
V. coarse sand	12	1.78	-0.75	18.74	18.74	7.29	7.29
	18	1	0	32.91	51.65	20.09	12.80
C. Sand	30	0.59	0.75	36.79	88.44	34.41	14.31
Medium sand	40	0.42	1.25	21.34	109.78	42.71	8.30
	60	0.25	2	36.36	146.14	56.85	14.15
F. Sand	100	0.15	2.75	36.89	183.03	71.21	14.35
V. Fine Sand	170	0.09	3.5	23.6	206.63	80.39	9.18
	230	0.063	4	37.38	244.01	94.93	14.54
Silt and Clay	325	0.044	4.5	6.55	250.56	97.48	2.55
	>325	0.037	4.75	6.48	257.04	100.00	2.11
			Total	257.04			
			Original Wt.	258.53			
			Sieve loss/gain	1.49			

Gn 5.3							
V. coarse sand	12	1.78	-0.75	16.96	16.96	8.50	8.50
	18	1	0	31.46	48.42	24.27	15.77
C. Sand	30	0.59	0.75	23.97	72.39	36.28	12.01
Medium sand	40	0.42	1.25	16.81	89.2	44.71	8.42
	60	0.25	2	35.87	125.07	62.68	17.98
F. Sand	100	0.15	2.75	40.52	165.59	82.99	20.31
V. Fine Sand	170	0.09	3.5	12.29	177.88	89.15	6.16
	230	0.063	4	19.23	197.11	98.79	9.64
Silt and Clay	325	0.044	4.5	1.28	198.39	99.43	0.64
	>325	0.037	4.75	1.14	199.53	100.00	0.57
			Total	199.53			
			Original Wt.	200.03			
			Sieve loss/gain	0.5			
Gn 5.4							
V. coarse sand	12	1.78	-0.75	12.85	12.85	8.70	8.70
	18	1	0	18.79	31.64	21.41	12.72
C. Sand	30	0.59	0.75	19.61	51.25	34.68	13.27
Medium sand	40	0.42	1.25	11.31	62.56	42.34	7.65
	60	0.25	2	20.22	82.78	56.02	13.68
F. Sand	100	0.15	2.75	22.61	105.39	71.33	15.30
V. Fine Sand	170	0.09	3.5	23.85	129.24	87.47	16.14
	230	0.063	4	15.13	144.37	97.71	10.24
Silt and Clay	325	0.044	4.5	2.11	146.48	99.13	1.43
	>325	0.037	4.75	1.28	147.76	100.00	0.87
			Total	147.76			
			Original Wt.	148.31			
			Sieve loss/gain	0.55			
Gn 5.5							
V. coarse sand	12	1.78	-0.75	11.26	11.26	9.51	9.51
	18	1	0	15.63	26.89	22.72	13.21
C. Sand	30	0.59	0.75	15.43	42.32	35.76	13.04
Medium sand	40	0.42	1.25	9.83	52.15	44.06	8.31
	60	0.25	2	16.52	68.67	58.02	13.96
F. Sand	100	0.15	2.75	26.63	95.3	80.52	22.50
V. Fine Sand	170	0.09	3.5	8.48	103.78	87.68	7.16
	230	0.063	4	12.37	116.15	98.13	10.45
Silt and Clay	325	0.044	4.5	1.19	117.34	99.14	1.01
	>325	0.037	4.75	1.02	118.36	100.00	0.86
			Total	118.36			
			Original Wt.	118.88			
			Sieve loss/gain	0.52			
Gn 6.1							
V. coarse sand	12	1.78	-0.75	10.55	10.55	4.38	4.38
	18	1	0	28.41	38.96	16.19	11.81
C. Sand	30	0.59	0.75	48.04	87	36.16	19.96
Medium sand	40	0.42	1.25	29.94	116.94	48.60	12.44
	60	0.25	2	40.24	157.18	65.32	16.72
F. Sand	100	0.15	2.75	32.37	189.55	78.77	13.45
V. Fine Sand	170	0.09	3.5	22.13	211.68	87.97	9.20
	230	0.063	4	17.92	229.6	95.42	7.45
Silt and Clay	325	0.044	4.5	4.96	234.56	97.48	2.06
	>325	0.037	4.75	6.07	240.63	100.00	2.52
			Total	240.63			
			Original Wt.	243.21			
			Sieve loss/gain	2.58			

Gn 6.2							
V. coarse sand	12	1.78	-0.75	23.11	23.11	11.97	11.97
	18	1	0	40.56	63.67	32.97	21.00
C. Sand	30	0.59	0.75	49.71	113.38	58.71	25.74
Medium sand	40	0.42	1.25	22.34	135.72	70.28	11.57
	60	0.25	2	25.73	161.45	83.60	13.32
F. Sand	100	0.15	2.75	13.99	175.44	90.85	7.24
V. Fine Sand	170	0.09	3.5	7.17	182.61	94.56	3.71
	230	0.063	4	6.39	189	97.87	3.31
Silt and Clay	325	0.044	4.5	1.4	190.4	98.59	0.72
	>325	0.037	4.75	2.72	193.12	100.00	1.41
			Total	193.12			
			Original Wt.	193.22			
			Sieve loss/gain	0.1			
Gn 6.3							
V. coarse sand	12	1.78	-0.75	15.35	15.35	9.80	9.80
	18	1	0	30.58	45.93	29.32	19.52
C. Sand	30	0.59	0.75	37.6	83.53	53.32	24.00
Medium sand	40	0.42	1.25	22.54	106.07	67.71	14.39
	60	0.25	2	21.34	127.41	81.33	13.62
F. Sand	100	0.15	2.75	12.01	139.42	89.00	7.67
V. Fine Sand	170	0.09	3.5	7.87	147.29	94.02	5.02
	230	0.063	4	5.95	153.24	97.82	3.80
Silt and Clay	325	0.044	4.5	1.63	154.87	98.86	1.04
	>325	0.037	4.75	1.78	156.65	100.00	1.14
			Total	156.65			
			Original Wt.	157.55			
			Sieve loss/gain	0.9			
Gn 6.4							
V. coarse sand	12	1.78	-0.75	23.57	23.57	7.08	7.08
	18	1	0	46.31	69.88	21.00	13.92
C. Sand	30	0.59	0.75	75.67	145.55	43.74	22.74
Medium sand	40	0.42	1.25	48.61	194.16	58.35	14.61
	60	0.25	2	62.41	256.57	77.11	18.76
F. Sand	100	0.15	2.75	34.16	290.73	87.37	10.27
V. Fine Sand	170	0.09	3.5	18.04	308.77	92.79	5.42
	230	0.063	4	14.86	323.63	97.26	4.47
Silt and Clay	325	0.044	4.5	3.06	326.69	98.18	0.92
	>325	0.037	4.75	6.06	332.75	100.00	1.82
			Total	332.75			
			Original Wt.	334.13			
			Sieve loss/gain	1.38			
Gn 7.1							
V. coarse sand	12	1.78	-0.75	14.33	14.33	6.69	6.69
	18	1	0	26.76	41.09	19.19	12.50
C. Sand	30	0.59	0.75	30.56	71.65	33.47	14.27
Medium sand	40	0.42	1.25	18.53	90.18	42.12	8.66
	60	0.25	2	31.19	121.37	56.69	14.57
F. Sand	100	0.15	2.75	36.04	157.41	73.53	16.83
V. Fine Sand	170	0.09	3.5	26.13	183.54	85.73	12.21
	230	0.063	4	23.84	207.38	96.87	11.14
Silt and Clay	325	0.044	4.5	3.82	211.2	98.65	1.78
	>325	0.037	4.75	2.89	214.09	100.00	1.35
			Total	214.09			
			Original Wt.	216.18			
			Sieve loss/gain	2.09			

Gn 7.2							
V. coarse sand	12	1.78	-0.75	18.24	18.24	9.21	9.21
	18	1	0	31.33	49.57	25.02	15.82
C. Sand	30	0.59	0.75	31.12	80.69	40.73	15.71
Medium sand	40	0.42	1.25	18.58	99.27	50.11	9.38
	60	0.25	2	28.34	127.61	64.42	14.31
F. Sand	100	0.15	2.75	31.66	159.27	80.40	15.98
V. Fine Sand	170	0.09	3.5	26.98	186.25	94.02	13.62
	230	0.063	4	9.65	195.9	98.89	4.87
Silt and Clay	325	0.044	4.5	1.31	197.21	99.56	0.66
	>325	0.037	4.75	0.88	198.09	100.00	0.44
			Total	198.09			
			Original Wt.	198.77			
			Sieve loss/gain	0.68			
Gn 7.3							
V. coarse sand	12	1.78	-0.75	27.42	27.42	9.54	9.54
	18	1	0	39.91	67.33	23.43	13.89
C. Sand	30	0.59	0.75	41.97	109.3	38.03	14.60
Medium sand	40	0.42	1.25	24.25	133.55	46.47	8.44
	60	0.25	2	46.13	179.68	62.52	16.05
F. Sand	100	0.15	2.75	51.24	230.92	80.35	17.83
V. Fine Sand	170	0.09	3.5	34.49	265.41	92.35	12.00
	230	0.063	4	18.4	283.81	98.75	6.40
Silt and Clay	325	0.044	4.5	1.99	285.8	99.44	0.69
	>325	0.037	4.75	1.6	287.4	100.00	0.56
			Total	287.4			
			Original Wt.	287.61			
			Sieve loss/gain	0.21			
Gn 7.4							
V. coarse sand	12	1.78	-0.75	21.74	21.74	8.99	8.99
	18	1	0	32.91	54.65	22.61	13.62
C. Sand	30	0.59	0.75	35.29	89.94	37.21	14.60
Medium sand	40	0.42	1.25	23.23	113.17	46.82	9.61
	60	0.25	2	36.94	150.11	62.11	15.28
F. Sand	100	0.15	2.75	44.15	194.26	80.37	18.27
V. Fine Sand	170	0.09	3.5	32.83	227.09	93.96	13.58
	230	0.063	4	12.09	239.18	98.96	5.00
Silt and Clay	325		4.5	1.54	240.72	99.59	0.64
	>325		4.75	0.98	241.7	100.00	0.41
			Total	241.7			
			Original Wt.	243.07			
			Sieve loss/gain	1.37			

Bn 2.1							
	12	1.78	-0.75	11.32	11.32	4.52	4.52
V. coarse sand	14	1.41	-0.5	15.11	26.43	10.56	6.04
	16	1.19	-0.25	15.74	42.17	16.85	6.29
	18	1	0	17.43	59.6	23.81	6.96
	20	0.84	0.25	18.65	78.25	31.27	7.45
Coarse sand	25	0.71	0.5	17.86	96.11	38.40	7.14
	30	0.59	0.75	15.46	111.57	44.58	6.18
	35	0.5	1	16.11	127.68	51.02	6.44
	40	0.42	1.25	12.66	140.34	56.08	5.06
Medium sand	45	0.35	1.5	3.67	144.01	57.54	1.47
	50	0.3	1.75	22.97	166.98	66.72	9.18
	60	0.25	2	14.13	181.11	72.37	5.65
	70	0.21	2.25	8.85	189.96	75.90	3.54
Fine Sand	80	0.18	2.5	14.56	204.52	81.72	5.82
	100	0.15	2.75	14.88	219.4	87.67	5.95
	120	0.13	3	2.92	222.32	88.83	1.17
	140	0.11	3.25	12.17	234.49	93.69	4.86
V. fine sand	170	0.09	3.5	1.83	236.32	94.43	0.73
	200	0.074	3.75	6.57	242.89	97.05	2.63
	230	0.063	4	3.34	246.23	98.39	1.33
	270	0.053	4.25	0.31	246.54	98.51	0.12
Silt and clay	325	0.044	4.5	1.15	247.69	98.97	0.46
	>325	0.037	4.75	2.58	250.27	100.00	1.03
			Total	250.27			
			Original Wt.	253.66			
			Sieve loss/gain	3.39			
Bn 2.2							
	12	1.78	-0.75	8.46	8.46	5.88	5.88
Very coarse sand	14	1.41	-0.5	10.6	19.06	13.24	7.36
	16	1.19	-0.25	10.57	29.63	20.58	7.34
	18	1	0	10.92	40.55	28.16	7.58
	20	0.84	0.25	12.01	52.56	36.50	8.34
Coarse sand	25	0.71	0.5	8.84	61.4	42.64	6.14
	30	0.59	0.75	11.09	72.49	50.34	7.70
	35	0.5	1	7.87	80.36	55.81	5.47
	40	0.42	1.25	6.55	86.91	60.36	4.55
Medium sand	45	0.35	1.5	1.91	88.82	61.68	1.33
	50	0.3	1.75	12.71	101.53	70.51	8.83
	60	0.25	2	7.9	109.43	76.00	5.49
	70	0.21	2.25	4.64	114.07	79.22	3.22
Fine Sand	80	0.18	2.5	7.55	121.62	84.46	5.24
	100	0.15	2.75	6.83	128.45	89.21	4.74
	120	0.13	3	0.53	128.98	89.58	0.37
	140	0.11	3.25	7.47	136.45	94.76	5.19
Very fine sand	170	0.09	3.5	1.19	137.64	95.59	0.83
	200	0.074	3.75	4.08	141.72	98.42	2.83
	230	0.063	4	1.33	143.05	99.35	0.92
	270	0.053	4.25	0.17	143.22	99.47	0.12
Silt and clay	325	0.044	4.5	0.33	143.55	99.69	0.23
	>325	0.037	4.75	0.44	143.99	100.00	0.31
			Total	143.99			
			Original Wt.	144.91			
			Sieve loss/gain	0.92			

Bn 2.3							
	12	1.78	-0.75	17.11	17.11	7.38	7.38
Very coarse sand	14	1.41	-0.5	17.81	34.92	15.07	7.68
	16	1.19	-0.25	19.86	54.78	23.63	8.57
	18	1	0	18.06	72.84	31.43	7.79
	20	0.84	0.25	20.84	93.68	40.42	8.99
Coarse sand	25	0.71	0.5	17.35	111.03	47.90	7.49
	30	0.59	0.75	19.52	130.55	56.32	8.42
	35	0.5	1	12.47	143.02	61.71	5.38
	40	0.42	1.25	9.05	152.07	65.61	3.90
Medium sand	45	0.35	1.5	12.85	164.92	71.15	5.54
	50	0.3	1.75	6.34	171.26	73.89	2.74
	60	0.25	2	12.41	183.67	79.24	5.35
	70	0.21	2.25	7.31	190.98	82.40	3.15
Fine Sand	80	0.18	2.5	15.07	206.05	88.90	6.50
	100	0.15	2.75	9.06	215.11	92.81	3.91
	120	0.13	3	0.23	215.34	92.91	0.10
	140	0.11	3.25	7.26	222.6	96.04	3.13
Very fine sand	170	0.09	3.5	1.15	223.75	96.54	0.50
	200	0.074	3.75	3.87	227.62	98.21	1.67
	230	0.063	4	1.83	229.45	98.99	0.79
	270	0.053	4.25	0.16	229.61	99.06	0.07
Silt and clay	325	0.044	4.5	0.93	230.54	99.47	0.40
	>325	0.037	4.75	1.24	231.78	100.00	0.53
			Total	231.78			
			Original Wt.	233.04			
			Sieve loss/gain	1.26			
Bn 2.4							
	12	1.78	-0.75	16.87	16.87	6.84	6.84
Very coarse sand	14	1.41	-0.5	20.85	37.72	15.29	8.45
	16	1.19	-0.25	18.26	55.98	22.69	7.40
	18	1	0	19.18	75.16	30.46	7.77
	20	0.84	0.25	20.58	95.74	38.80	8.34
Coarse sand	25	0.71	0.5	14.69	110.43	44.75	5.95
	30	0.59	0.75	18.81	129.24	52.37	7.62
	35	0.5	1	12.93	142.17	57.61	5.24
	40	0.42	1.25	11.46	153.63	62.26	4.64
Medium sand	45	0.35	1.5	8.04	161.67	65.52	3.26
	50	0.3	1.75	14.61	176.28	71.44	5.92
	60	0.25	2	13.21	189.49	76.79	5.35
	70	0.21	2.25	7.53	197.02	79.84	3.05
Fine Sand	80	0.18	2.5	10.21	207.23	83.98	4.14
	100	0.15	2.75	12.89	220.12	89.20	5.22
	120	0.13	3	3.11	223.23	90.46	1.26
	140	0.11	3.25	6.76	229.99	93.20	2.74
Very fine sand	170	0.09	3.5	3.56	233.55	94.65	1.44
	200	0.074	3.75	7.18	240.73	97.56	2.91
	230	0.063	4	3.33	244.06	98.91	1.35
	270	0.053	4.25	0.25	244.31	99.01	0.10
Silt and clay	325	0.044	4.5	0.87	245.18	99.36	0.35
	>325	0.037	4.75	1.58	246.76	100.00	0.64
			Total	246.76			
			Original Wt.	249.72			
			Sieve loss/gain	2.96			

Bn 4.1							
V. coarse sand	12	1.78	-0.75	15.34	15.34	7.31	7.31
	18	1	0	30.04	45.38	21.62	14.31
C. Sand	30	0.59	0.75	34.09	79.47	37.86	16.24
Medium sand	40	0.42	1.25	17.99	97.46	46.44	8.57
	60	0.25	2	33.84	131.3	62.56	16.12
Fine Sand	100	0.15	2.75	43.19	174.49	83.14	20.58
V. Fine Sand	170	0.09	3.5	11.52	186.01	88.63	5.49
	230	0.063	4	14.33	200.34	95.45	6.83
Silt and Clay	325	0.044	4.5	2.42	202.76	96.61	1.15
	>325	0.037	4.75	7.12	209.88	100.00	3.39
			Total	209.88			
			Original Wt.	211.45			
			Sieve loss/gain	1.57			
Bn 4.2							
V. coarse sand	12	1.78	-0.75	25.22	25.22	8.76	8.76
	18	1	0	46.36	71.58	24.86	13.32
C. Sand	30	0.59	0.75	45.54	117.12	40.67	13.09
Medium sand	40	0.42	1.25	27.11	144.23	50.08	7.79
	60	0.25	2	39.1	183.33	63.66	11.23
F. Sand	100	0.15	2.75	42.09	225.42	78.28	12.09
V. Fine Sand	170	0.09	3.5	30.39	255.81	88.83	8.73
	230	0.063	4	25.23	281.04	97.59	7.25
Silt and Clay	325	0.044	4.5	3.78	284.82	98.90	1.09
	>325	0.037	4.75	3.16	287.98	100.00	0.91
			Total	287.98			
			Original Wt.	289.87			
			Sieve loss/gain	1.89			
Bn 4.3							
V. coarse sand	12	1.78	-0.75	15.34	15.34	8.17	8.17
	18	1	0	27.52	42.86	22.84	14.66
C. Sand	30	0.59	0.75	30.32	73.18	38.99	16.15
Medium sand	40	0.42	1.25	15.68	88.86	47.34	8.35
	60	0.25	2	29.71	118.57	63.17	15.83
F. Sand	100	0.15	2.75	33.87	152.44	81.22	18.05
V. Fine Sand	170	0.09	3.5	19.22	171.66	91.46	10.24
	230	0.063	4	12.16	183.82	97.94	6.48
Silt and Clay	325	0.044	4.5	1.93	185.75	98.97	1.03
	>325	0.037	4.75	1.94	187.69	100.00	1.03
			Total	187.69			
			Original Wt.	188.95			
			Sieve loss/gain	1.26			
Bn 4.4							
V. coarse sand	12	1.78	-0.75	26.28	26.28	7.26	7.26
	18	1	0	50.04	76.32	21.09	13.83
C. Sand	30	0.59	0.75	57.98	134.3	37.12	16.02
Medium sand	40	0.42	1.25	30.21	164.51	45.47	8.35
	60	0.25	2	50.59	215.1	59.45	13.98
F. Sand	100	0.15	2.75	60.37	275.47	76.13	16.69
V. Fine Sand	170	0.09	3.5	44.23	319.7	88.36	12.22
	230	0.063	4	36.21	355.91	98.37	10.01
Silt and Clay	325	0.044	4.5	2.05	357.96	98.93	0.57
	>325	0.037	4.75	3.86	361.82	100.00	1.07
			Total	361.82			
			Original Wt.	363.24			
			Sieve loss/gain	1.42			

Bn 4.5							
V. coarse sand	12	1.78	-0.75	15.77	15.77	5.58	5.58
	18	1	0	37.11	52.88	18.71	13.13
C. Sand	30	0.59	0.75	46.12	99	35.03	16.32
Medium sand	40	0.42	1.25	25.72	124.72	44.13	9.10
	60	0.25	2	36.77	161.49	57.14	13.01
F. Sand	100	0.15	2.75	47.44	208.93	73.92	16.79
V. Fine Sand	170	0.09	3.5	44.71	253.64	89.74	15.82
	230	0.063	4	24.66	278.3	98.47	8.73
Silt and Clay	325	0.044	4.5	3.02	281.32	99.54	1.07
	>325	0.037	4.75	1.31	282.63	100.00	0.46
			Total	282.63			
			Original Wt.	283.71			
			Sieve loss/gain	1.08			
Bn 4.6							
V. coarse sand	12	1.78	-0.75	21.37	21.37	7.82	7.82
	18	1	0	43.99	65.36	23.92	16.10
C. Sand	30	0.59	0.75	46.52	111.88	40.94	17.02
Medium sand	40	0.42	1.25	25.25	137.13	50.18	9.24
	60	0.25	2	42.13	179.26	65.60	15.42
F. Sand	100	0.15	2.75	51.31	230.57	84.38	18.78
V. Fine Sand	170	0.09	3.5	27.81	258.38	94.55	10.18
	230	0.063	4	12.25	270.63	99.04	4.48
Silt and Clay	325	0.044	4.5	1.81	272.44	99.70	0.66
	>325	0.037	4.75	0.82	273.26	100.00	0.30
			Total	273.26			
			Original Wt.	273.83			
			Sieve loss/gain	0.57			
Bn 5.1							
V. coarse sand	12	1.78	-0.75	17.7	17.7	6.72	6.72
	18	1	0	37.76	55.46	21.04	14.33
C. Sand	30	0.59	0.75	40.73	96.19	36.50	15.45
Medium sand	40	0.42	1.25	25.52	121.71	46.18	9.68
	60	0.25	2	34.91	156.62	59.42	13.25
F. Sand	100	0.15	2.75	28.72	185.34	70.32	10.90
V. Fine Sand	170	0.09	3.5	29.02	214.36	81.33	11.01
	230	0.063	4	25.36	239.72	90.95	9.62
Silt and Clay	325	0.044	4.5	11.94	251.66	95.48	4.53
	>325	0.037	4.75	11.91	263.57	100.00	4.52
			Total	263.57			
			Original Wt.	265.76			
			Sieve loss/gain	2.19			
Bn 5.2							
V. coarse sand	12	1.78	-0.75	15.68	15.68	9.44	9.44
	18	1	0	27.85	43.53	26.20	16.76
C. Sand	30	0.59	0.75	28.87	72.4	43.58	17.38
Medium sand	40	0.42	1.25	13.91	86.31	51.95	8.37
	60	0.25	2	22.41	108.72	65.43	13.49
F. Sand	100	0.15	2.75	17.81	126.53	76.15	10.72
V. Fine Sand	170	0.09	3.5	14.42	140.95	84.83	8.68
	230	0.063	4	15.15	156.1	93.95	9.12
Silt and Clay	325	0.044	4.5	6.36	162.46	97.78	3.83
	>325	0.037	4.75	3.69	166.15	100.00	2.22
			Total	166.15			
			Original Wt.	167.53			
			Sieve loss/gain	1.38			

Bn 5.3							
V. coarse sand	12	1.78	-0.75	20.26	20.26	9.73	9.73
	18	1	0	35.59	55.85	26.81	17.09
C. Sand	30	0.59	0.75	36.11	91.96	44.15	17.34
Medium sand	40	0.42	1.25	20.22	112.18	53.86	9.71
	60	0.25	2	24.5	136.68	65.62	11.76
F. Sand	100	0.15	2.75	22.02	158.7	76.19	10.57
V. Fine Sand	170	0.09	3.5	19.63	178.33	85.62	9.42
	230	0.063	4	21.95	200.28	96.15	10.54
Silt and Clay	325	0.044	4.5	5.87	206.15	98.97	2.82
	>325	0.037	4.75	2.14	208.29	100.00	1.03
			Total	208.29			
			Original Wt.	209.13			
			Sieve loss/gain	0.84			
Bn 5.4							
V. coarse sand	12	1.78	-0.75	25.05	25.05	8.50	8.50
	18	1	0	45.67	70.72	24.01	15.51
C. Sand	30	0.59	0.75	52.67	123.39	41.89	17.88
Medium sand	40	0.42	1.25	24.08	147.47	50.07	8.18
	60	0.25	2	40.37	187.84	63.77	13.71
F. Sand	100	0.15	2.75	33.23	221.07	75.06	11.28
V. Fine Sand	170	0.09	3.5	34.38	255.45	86.73	11.67
	230	0.063	4	30.11	285.56	96.95	10.22
Silt and Clay	325	0.044	4.5	5.95	291.51	98.97	2.02
	>325	0.037	4.75	3.03	294.54	100.00	1.03
			Total	294.54			
			Original Wt.	295.91			
			Sieve loss/gain	1.37			
Bn 5.5							
V. coarse sand	12	1.78	-0.75	20.13	20.13	5.80	5.80
	18	1	0	46.68	66.81	19.27	13.46
C. Sand	30	0.59	0.75	63.98	130.79	37.72	18.45
Medium sand	40	0.42	1.25	34.65	165.44	47.71	9.99
	60	0.25	2	45.85	211.29	60.93	13.22
F. Sand	100	0.15	2.75	61.86	273.15	78.77	17.84
V. Fine Sand	170	0.09	3.5	38.46	311.61	89.86	11.09
	230	0.063	4	18.83	330.44	95.29	5.43
Silt and Clay	325	0.044	4.5	11.22	341.66	98.52	3.24
	>325	0.037	4.75	5.12	346.78	100.00	1.48
			Total	346.78			
			Original Wt.	347.97			
			Sieve loss/gain	1.19			
Bn 7.1							
V. coarse sand	12	1.78	-0.75	29.92	29.92	10.47	10.47
	18	1	0	53.57	83.49	29.22	18.75
C. Sand	30	0.59	0.75	51.71	135.2	47.32	18.10
Medium sand	40	0.42	1.25	32.77	167.97	58.79	11.47
	60	0.25	2	41.55	209.52	73.33	14.54
F. Sand	100	0.15	2.75	34.27	243.79	85.32	11.99
V. Fine Sand	170	0.09	3.5	20.95	264.74	92.66	7.33
	230	0.063	4	16.77	281.51	98.53	5.87
Silt and Clay	325	0.044	4.5	1.8	283.31	99.16	0.63
	>325	0.037	4.75	2.41	285.72	100.00	0.84
			Total	285.72			
			Original Wt.	288.02			
			Sieve loss/gain	2.3			

Bn 7.2							
V. coarse sand	12	1.78	-0.75	25.85	25.85	8.83	8.83
	18	1	0	46.43	72.28	24.69	15.86
C. Sand	30	0.59	0.75	55.98	128.26	43.82	19.12
Medium sand	40	0.42	1.25	30.63	158.89	54.28	10.46
	60	0.25	2	50.01	208.9	71.36	17.08
F. Sand	100	0.15	2.75	49.96	258.86	88.43	17.07
V. Fine Sand	170	0.09	3.5	19.1	277.96	94.95	6.52
	230	0.063	4	12.43	290.39	99.20	4.25
Silt and Clay	325	0.044	4.5	0.75	291.14	99.46	0.26
	>325	0.037	4.75	1.59	292.73	100.00	0.54
			Total	292.73			
			Original Wt.	294.6			
			Sieve loss/gain	1.87			
Bn 7.3							
V. coarse sand	12	1.78	-0.75	26.82	26.82	9.48	9.48
	18	1	0	48.71	75.53	26.69	17.21
C. Sand	30	0.59	0.75	50.62	126.15	44.58	17.89
Medium sand	40	0.42	1.25	28.73	154.88	54.73	10.15
	60	0.25	2	51.72	206.6	73.00	18.28
F. Sand	100	0.15	2.75	56.53	263.13	92.98	19.98
V. Fine Sand	170	0.09	3.5	11.82	274.95	97.16	4.18
	230	0.063	4	7.23	282.18	99.71	2.55
Silt and Clay	325	0.044	4.5	0.53	282.71	99.90	0.19
	>325	0.037	4.75	0.29	283	100.00	0.10
			Total	283			
			Original Wt.	283.74			
			Sieve loss/gain	0.74			
Bn 7.4							
V. coarse sand	12	1.78	-0.75	44.21	44.21	9.95	9.95
	18	1	0	74.71	118.92	26.77	16.82
C. Sand	30	0.59	0.75	85.39	204.31	45.99	19.22
Medium sand	40	0.42	1.25	52.93	257.24	57.91	11.91
	60	0.25	2	68.96	326.2	73.43	15.52
F. Sand	100	0.15	2.75	62.97	389.17	87.61	14.18
V. Fine Sand	170	0.09	3.5	33.01	422.18	95.04	7.43
	230	0.063	4	19.35	441.53	99.39	4.36
Silt and Clay	325	0.044	4.5	1.34	442.87	99.69	0.30
	>325	0.037	4.75	1.36	444.23	100.00	0.31
			Total	444.23			
			Original Wt.	444.96			
			Sieve loss/gain	0.73			
Bn 7.5							
V. coarse sand	12	1.78	-0.75	31.99	31.99	10.44	10.44
	18	1	0	53.13	85.12	27.77	17.33
C. Sand	30	0.59	0.75	56.49	141.61	46.20	18.43
Medium sand	40	0.42	1.25	31.41	173.02	56.44	10.25
	60	0.25	2	47.95	220.97	72.09	15.64
F. Sand	100	0.15	2.75	49.81	270.78	88.34	16.25
V. Fine Sand	170	0.09	3.5	19.49	290.27	94.70	6.36
	230	0.063	4	12.76	303.03	98.86	4.16
Silt and Clay	325	0.044	4.5	1.35	304.38	99.30	0.44
	>325	0.037	4.75	2.15	306.53	100.00	0.70
			Total	306.53			
			Original Wt.	309.26			
			Sieve loss/gain	2.73			

Bn 8.1							
V. coarse sand	12	1.78	-0.75	22.56	22.56	9.26	9.26
	18	1	0	38.64	61.2	25.13	15.87
C. Sand	30	0.59	0.75	39.57	100.77	41.38	16.25
Medium sand	40	0.42	1.25	19.54	120.31	49.40	8.02
	60	0.25	2	33.4	153.71	63.11	13.71
F. Sand	100	0.15	2.75	24.15	177.86	73.03	9.92
V. Fine Sand	170	0.09	3.5	19.16	197.02	80.90	7.87
	230	0.063	4	16.89	213.91	87.83	6.94
Silt and Clay	325	0.044	4.5	13.65	227.56	93.44	5.60
	>325	0.037	4.75	15.98	243.54	100.00	6.56
			Total	243.54			
			Original Wt.	246.34			
			Sieve loss/gain	2.8			
Bn 8.2							
V. coarse sand	12	1.78	-0.75	29.53	29.53	8.40	8.40
	18	1	0	55.91	85.44	24.31	15.91
C. Sand	30	0.59	0.75	61.97	147.41	41.95	17.63
Medium sand	40	0.42	1.25	33.77	181.18	51.56	9.61
	60	0.25	2	60.07	241.25	68.65	17.09
F. Sand	100	0.15	2.75	72.53	313.78	89.29	20.64
V. Fine Sand	170	0.09	3.5	24.3	338.08	96.20	6.91
	230	0.063	4	11.19	349.27	99.39	3.18
Silt and Clay	325	0.044	4.5	0.69	349.96	99.58	0.20
	>325	0.037	4.75	1.47	351.43	100.00	0.42
			Total	351.43			
			Original Wt.	353.15			
			Sieve loss/gain	1.72			
Bn 8.3							
V. coarse sand	12	1.78	-0.75	32.98	32.98	11.13	11.13
	18	1	0	50.59	83.57	28.20	17.07
C. Sand	30	0.59	0.75	52.13	135.7	45.78	17.59
Medium sand	40	0.42	1.25	29.98	165.68	55.90	10.11
	60	0.25	2	46.24	211.92	71.50	15.60
F. Sand	100	0.15	2.75	48.62	260.54	87.90	16.40
V. Fine Sand	170	0.09	3.5	15.81	276.35	93.24	5.33
	230	0.063	4	17.98	294.33	99.30	6.07
Silt and Clay	325	0.044	4.5	1.14	295.47	99.69	0.38
	>325	0.037	4.75	0.93	296.4	100.00	0.31
			Total	296.4			
			Original Wt.	298.91			
			Sieve loss/gain	2.51			
Bn 8.4							
V. coarse sand	12	1.78	-0.75	40.27	40.27	12.21	12.21
	18	1	0	59.76	100.03	30.34	18.13
C. Sand	30	0.59	0.75	61.77	161.8	49.08	18.74
Medium sand	40	0.42	1.25	31.82	193.62	58.73	9.65
	60	0.25	2	49.2	242.82	73.65	14.92
F. Sand	100	0.15	2.75	42.93	285.75	86.67	13.02
V. Fine Sand	170	0.09	3.5	23.82	309.57	93.90	7.22
	230	0.063	4	14.88	324.45	98.41	4.51
Silt and Clay	325	0.044	4.5	1.87	326.32	98.98	0.57
	>325	0.037	4.75	3.37	329.69	100.00	1.02
			Total	329.69			
			Original Wt.	330.96			
			Sieve loss/gain	1.27			

Bn 8.5							
V. coarse sand	12	1.78	-0.75	27.52	27.52	8.52	8.52
	18	1	0	53.42	80.94	25.07	16.54
C. Sand	30	0.59	0.75	64.82	145.76	45.14	20.07
Medium sand	40	0.42	1.25	34.86	180.62	55.94	10.80
	60	0.25	2	54.32	234.94	72.76	16.82
F. Sand	100	0.15	2.75	50.27	285.21	88.33	15.57
V. Fine Sand	170	0.09	3.5	22.64	307.85	95.34	7.01
	230	0.063	4	11.73	319.58	98.97	3.63
Silt and Clay	325	0.044	4.5	1.2	320.78	99.35	0.37
	>325	0.037	4.75	2.11	322.89	100.00	0.65
			Total	322.89			
			Original Wt.	323.72			
			Sieve loss/gain	0.83			

Gy 1.1							
V. coarse sand	12	1.78	-0.75	20.99	20.99	8.43	8.43
	14	1.41	-0.5	19.92	40.91	16.42	8.00
	16	1.19	-0.25	23.99	64.9	26.05	9.63
	18	1	0	24.34	89.24	35.82	9.77
Coarse sand	20	0.84	0.25	23.95	113.19	45.44	9.61
	25	0.71	0.5	16.65	129.84	52.12	6.68
	30	0.59	0.75	16.53	146.37	58.75	6.64
	35	0.5	1	12.92	159.29	63.94	5.19
Medium sand	40	0.42	1.25	7.33	166.62	66.88	2.94
	45	0.35	1.5	11.84	178.46	71.64	4.75
	50	0.3	1.75	14.12	192.58	77.30	5.67
	60	0.25	2	7.05	199.63	80.13	2.83
Fine Sand	70	0.21	2.25	7.81	207.44	83.27	3.14
	80	0.18	2.5	11.22	218.66	87.77	4.50
	100	0.15	2.75	4.02	222.68	89.39	1.61
	120	0.13	3	4.36	227.04	91.14	1.75
V. fine sand	140	0.11	3.25	6.12	233.16	93.59	2.46
	170	0.09	3.5	4.65	237.81	95.46	1.87
	200	0.074	3.75	3.64	241.45	96.92	1.46
	230	0.063	4	1.35	242.8	97.46	0.54
Silt and clay	270	0.053	4.25	2.31	245.11	98.39	0.93
	325	0.044	4.5	2.68	247.79	99.47	1.08
	>325	0.037	4.75	1.33	249.12	100.00	0.53
			Total	249.12			
			Original Wt.	247.88			
			Sieve loss/gain	-1.24			

Gy 1.2							
	12	1.78	-0.75	10.52	10.52	5.46	5.46
V. coarse sand	14	1.41	-0.5	15.79	26.31	13.65	8.19
	16	1.19	-0.25	15.12	41.43	21.50	7.85
	18	1	0	14.88	56.31	29.22	7.72
	20	0.84	0.25	17.02	73.33	38.05	8.83
Coarse sand	25	0.71	0.5	11.95	85.28	44.25	6.20
	30	0.59	0.75	14.26	99.54	51.65	7.40
	35	0.5	1	10.99	110.53	57.35	5.70
	40	0.42	1.25	9.76	120.29	62.41	5.06
Medium sand	45	0.35	1.5	10.7	130.99	67.97	5.55
	50	0.3	1.75	10.39	141.38	73.36	5.39
	60	0.25	2	7.64	149.02	77.32	3.96
	70	0.21	2.25	6.54	155.56	80.71	3.39
Fine Sand	80	0.18	2.5	8.46	164.02	85.10	4.39
	100	0.15	2.75	7.21	171.23	88.84	3.74
	120	0.13	3	3.73	174.96	90.78	1.94
	140	0.11	3.25	7.32	182.28	94.58	3.80
V. fine sand	170	0.09	3.5	2.71	184.99	95.98	1.41
	200	0.074	3.75	4.52	189.51	98.33	2.35
	230	0.063	4	0.76	190.27	98.72	0.39
	270	0.053	4.25	0.34	190.61	98.90	0.18
Silt and clay	325	0.044	4.5	1.21	191.82	99.53	0.63
	>325	0.037	4.75	0.91	192.73	100.00	0.47
			Total	192.73			
			Original Wt.	195.02			
			Sieve loss/gain	2.29			

Gy 1.3							
	12	1.78	-0.75	25.5	25.5	7.03	7.03
V. coarse sand	14	1.41	-0.5	34.96	60.46	16.68	9.64
	16	1.19	-0.25	33.23	93.69	25.84	9.17
	18	1	0	29.4	123.09	33.95	8.11
	20	0.84	0.25	34.78	157.87	43.54	9.59
Coarse sand	25	0.71	0.5	26.39	184.26	50.82	7.28
	30	0.59	0.75	27.11	211.37	58.30	7.48
	35	0.5	1	18.85	230.22	63.50	5.20
	40	0.42	1.25	18.22	248.44	68.53	5.03
Medium sand	45	0.35	1.5	19.67	268.11	73.95	5.43
	50	0.3	1.75	18.43	286.54	79.03	5.08
	60	0.25	2	11.41	297.95	82.18	3.15
	70	0.21	2.25	11.12	309.07	85.25	3.07
Fine Sand	80	0.18	2.5	19.46	328.53	90.62	5.37
	100	0.15	2.75	13.51	342.04	94.34	3.73
	120	0.13	3	3.09	345.13	95.20	0.85
	140	0.11	3.25	8.81	353.94	97.63	2.43
V. fine sand	170	0.09	3.5	1.71	355.65	98.10	0.47
	200	0.074	3.75	4.09	359.74	99.22	1.13
	230	0.063	4	0.55	360.29	99.38	0.15
	270	0.053	4.25	0.34	360.63	99.47	0.09
Silt and clay	325	0.044	4.5	1.18	361.81	99.80	0.33
	>325	0.037	4.75	0.74	362.55	100.00	0.20
			Total	362.55			
			Original Wt.	366.9			
			Sieve loss/gain	4.35			

Gy 1.4							
	12	1.78	-0.75	12.75	12.75	7.54	7.54
V. coarse sand	14	1.41	-0.5	17.02	29.77	17.59	10.06
	16	1.19	-0.25	15.97	45.74	27.03	9.44
	18	1	0	15.15	60.89	35.99	8.95
	20	0.84	0.25	17.28	78.17	46.20	10.21
Coarse sand	25	0.71	0.5	12.01	90.18	53.30	7.10
	30	0.59	0.75	13.26	103.44	61.13	7.84
	35	0.5	1	8.14	111.58	65.95	4.81
	40	0.42	1.25	8.11	119.69	70.74	4.79
Medium sand	45	0.35	1.5	1.99	121.68	71.91	1.18
	50	0.3	1.75	13.99	135.67	80.18	8.27
	60	0.25	2	4.46	140.13	82.82	2.64
	70	0.21	2.25	3.71	143.84	85.01	2.19
Fine Sand	80	0.18	2.5	4.47	148.31	87.65	2.64
	100	0.15	2.75	4.43	152.74	90.27	2.62
	120	0.13	3	0.96	153.7	90.84	0.57
	140	0.11	3.25	5.36	159.06	94.01	3.17
V. fine sand	170	0.09	3.5	2.03	161.09	95.21	1.20
	200	0.074	3.75	4.17	165.26	97.67	2.46
	230	0.063	4	0.63	165.89	98.04	0.37
	270	0.053	4.25	0.74	166.63	98.48	0.44
Silt and clay	325	0.044	4.5	1.63	168.26	99.44	0.96
	>325	0.037	4.75	0.94	169.2	100.00	0.56
			Total	169.2			
			Original Wt.	172.71			
			Sieve loss/gain	3.51			
Gy 1.5							
	12	1.78	-0.75	14.07	14.07	5.84	5.84
V. coarse sand	14	1.41	-0.5	19.33	33.40	13.86	8.02
	16	1.19	-0.25	20.35	53.75	22.30	8.44
	18	1	0	21.87	75.62	31.38	9.08
	20	0.84	0.25	21.85	97.47	40.45	9.07
Coarse sand	25	0.71	0.5	18.31	115.78	48.04	7.60
	30	0.59	0.75	22.33	138.11	57.31	9.27
	35	0.5	1	15.33	153.44	63.67	6.36
	40	0.42	1.25	11.78	165.22	68.56	4.89
Medium sand	45	0.35	1.5	3.22	168.44	69.90	1.34
	50	0.3	1.75	26.18	194.62	80.76	10.86
	60	0.25	2	7.52	202.14	83.88	3.12
	70	0.21	2.25	6.76	208.90	86.68	2.81
Fine Sand	80	0.18	2.5	6.79	215.69	89.50	2.82
	100	0.15	2.75	6.05	221.74	92.01	2.51
	120	0.13	3	2.53	224.27	93.06	1.05
	140	0.11	3.25	7.01	231.28	95.97	2.91
V. fine sand	170	0.09	3.5	1.89	233.17	96.76	0.78
	200	0.074	3.75	4.51	237.68	98.63	1.87
	230	0.063	4	0.49	238.17	98.83	0.20
	270	0.053	4.25	0.55	238.72	99.06	0.23
Silt and clay	325	0.044	4.5	1.39	240.11	99.63	0.58
	>325	0.037	4.75	0.88	240.99	100.00	0.37
			Total	240.99			
			Original Wt.	243.49			
			Sieve loss/gain	2.5			

Gy 1.6							
	12	1.78	-0.75	33.57	33.57	6.73	6.73
V. coarse sand	14	1.41	-0.5	52.17	85.74	17.18	10.45
	16	1.19	-0.25	59.16	144.90	29.04	11.86
	18	1	0	50.38	195.28	39.13	10.10
	20	0.84	0.25	56.17	251.45	50.39	11.26
Coarse sand	25	0.71	0.5	34.54	285.99	57.31	6.92
	30	0.59	0.75	41.48	327.47	65.63	8.31
	35	0.5	1	26.21	353.68	70.88	5.25
	40	0.42	1.25	22.87	376.55	75.46	4.58
Medium sand	45	0.35	1.5	4.79	381.34	76.42	0.96
	50	0.3	1.75	43.33	424.67	85.10	8.68
	60	0.25	2	11.04	435.71	87.32	2.21
	70	0.21	2.25	10.55	446.26	89.43	2.11
Fine Sand	80	0.18	2.5	21.95	468.21	93.83	4.40
	100	0.15	2.75	11.15	479.36	96.06	2.23
	120	0.13	3	2.45	481.81	96.56	0.49
	140	0.11	3.25	6.24	488.05	97.81	1.25
V. fine sand	170	0.09	3.5	2.29	490.34	98.26	0.46
	200	0.074	3.75	4.48	494.82	99.16	0.90
	230	0.063	4	0.96	495.78	99.35	0.19
	270	0.053	4.25	0.44	496.22	99.44	0.09
Silt and clay	325	0.044	4.5	1.63	497.85	99.77	0.33
	>325	0.037	4.75	1.15	499.00	100.00	0.23
			Total	499			
			Original Wt.	502.5			
			Sieve loss/gain	3.5			
Gy 3.1							
V. coarse sand	12	1.78	-0.75	23.87	23.87	8.27	8.27
	18	1	0	42.81	66.68	23.09	14.83
C. Sand	30	0.59	0.75	49.04	115.72	40.07	16.98
Medium sand	40	0.42	1.25	27.01	142.73	49.43	9.35
	60	0.25	2	41.37	184.10	63.76	14.33
F. Sand	100	0.15	2.75	60.94	245.04	84.86	21.10
V. Fine Sand	170	0.09	3.5	25.33	270.37	93.63	8.77
	230	0.063	4	14.19	284.56	98.55	4.91
Silt and Clay	325	0.044	4.5	1.75	286.31	99.15	0.61
	>325	0.037	4.75	2.45	288.76	100.00	0.85
			Total	288.76			
			Original Wt.	290.75			
			Sieve loss/gain	1.99			
Gy 3.2							
V. coarse sand	12	1.78	-0.75	12.71	12.71	9.30	9.30
	18	1	0	24.45	37.16	27.19	17.89
C. Sand	30	0.59	0.75	25.26	62.42	45.68	18.49
Medium sand	40	0.42	1.25	14.19	76.61	56.06	10.38
	60	0.25	2	18.01	94.62	69.24	13.18
F. Sand	100	0.15	2.75	14.93	109.55	80.17	10.93
V. Fine Sand	170	0.09	3.5	11.51	121.06	88.59	8.42
	230	0.063	4	11.03	132.09	96.66	8.07
Silt and Clay	325	0.044	4.5	2.43	134.52	98.44	1.78
	>325	0.037	4.75	2.13	136.65	100.00	1.56
			Total	136.65			
			Original Wt.	137.7			
			Sieve loss/gain	1.05			

Gy 3.3							
V. coarse sand	12	1.78	-0.75	22.35	22.35	10.83	10.83
	18	1	0	36.29	58.64	28.41	17.58
C. Sand	30	0.59	0.75	40.27	98.91	47.91	19.51
Medium sand	40	0.42	1.25	19.57	118.48	57.39	9.48
	60	0.25	2	30.52	149.00	72.18	14.78
F. Sand	100	0.15	2.75	27.66	176.66	85.57	13.40
V. Fine Sand	170	0.09	3.5	16.46	193.12	93.55	7.97
	230	0.063	4	9.51	202.63	98.15	4.61
Silt and Clay	325	0.044	4.5	1.67	204.30	98.96	0.81
	>325	0.037	4.75	2.14	206.44	100.00	1.04
			Total	206.44			
			Original Wt.	207.11			
			Sieve loss/gain	0.67			
Gy 3.4							
V. coarse sand	12	1.78	-0.75	34.21	34.21	14.52	14.52
	18	1	0	49.45	83.66	35.51	20.99
C. Sand	30	0.59	0.75	46.96	130.62	55.44	19.93
Medium sand	40	0.42	1.25	22.32	152.94	64.91	9.47
	60	0.25	2	30.76	183.70	77.97	13.06
F. Sand	100	0.15	2.75	21.84	205.54	87.24	9.27
V. Fine Sand	170	0.09	3.5	12.76	218.30	92.65	5.42
	230	0.063	4	10.51	228.81	97.11	4.46
Silt and Clay	325	0.044	4.5	2.52	231.33	98.18	1.07
	>325	0.037	4.75	4.28	235.61	100.00	1.82
			Total	235.61			
			Original Wt.	236.12			
			Sieve loss/gain	0.51			
Gy 3.5							
V. coarse sand	12	1.78	-0.75	20.89	20.89	10.67	10.67
	18	1	0	34.76	55.65	28.41	17.75
C. Sand	30	0.59	0.75	39.71	95.36	48.69	20.27
Medium sand	40	0.42	1.25	21.96	117.32	59.90	11.21
	60	0.25	2	27.54	144.86	73.96	14.06
F. Sand	100	0.15	2.75	21.21	166.07	84.79	10.83
V. Fine Sand	170	0.09	3.5	13.95	180.02	91.91	7.12
	230	0.063	4	10.41	190.43	97.22	5.31
Silt and Clay	325	0.044	4.5	3.03	193.46	98.77	1.55
	>325	0.037	4.75	2.41	195.87	100.00	1.23
			Total	195.87			
			Original Wt.	196.48			
			Sieve loss/gain	0.61			
Gy 4.1							
V. coarse sand	12	1.78	-0.75	20.74	20.74	9.73	9.73
	18	1	0	40.49	61.23	28.72	18.99
C. Sand	30	0.59	0.75	44.69	105.92	49.68	20.96
Medium sand	40	0.42	1.25	23.47	129.39	60.69	11.01
	60	0.25	2	33.59	162.98	76.44	15.75
F. Sand	100	0.15	2.75	37.65	200.63	94.10	17.66
V. Fine Sand	170	0.09	3.5	8.27	208.90	97.98	3.88
	230	0.063	4	3.31	212.21	99.53	1.55
Silt and Clay	325	0.044	4.5	0.39	212.60	99.71	0.18
	>325	0.037	4.75	0.61	213.21	100.00	0.29
			Total	213.21			
			Original Wt.	214.94			
			Sieve loss/gain	1.73			

Gy 4.2							
V. coarse sand	12	1.78	-0.75	20.06	20.06	10.40	10.40
	18	1	0	43.84	63.90	33.11	22.72
C. Sand	30	0.59	0.75	43.09	106.99	55.44	22.33
Medium sand	40	0.42	1.25	22.2	129.19	66.95	11.50
	60	0.25	2	25.03	154.22	79.92	12.97
F. Sand	100	0.15	2.75	22.21	176.43	91.43	11.51
V. Fine Sand	170	0.09	3.5	12.48	188.91	97.90	6.47
	230	0.063	4	3.09	192.00	99.50	1.60
Silt and Clay	325	0.044	4.5	0.44	192.44	99.73	0.23
	>325	0.037	4.75	0.53	192.97	100.00	0.27
			Total	192.97			
			Original Wt.	194.07			
			Sieve loss/gain	1.1			
Gy 4.3							
V. coarse sand	12	1.78	-0.75	22.59	22.59	11.84	11.84
	18	1	0	41.96	64.55	33.84	22.00
C. Sand	30	0.59	0.75	41.71	106.26	55.70	21.87
Medium sand	40	0.42	1.25	20.06	126.32	66.22	10.52
	60	0.25	2	27.47	153.79	80.62	14.40
F. Sand	100	0.15	2.75	19.09	172.88	90.63	10.01
V. Fine Sand	170	0.09	3.5	8.26	181.14	94.96	4.33
	230	0.063	4	6.92	188.06	98.58	3.63
Silt and Clay	325	0.044	4.5	1.13	189.19	99.18	0.59
	>325	0.037	4.75	1.57	190.76	100.00	0.82
			Total	190.76			
			Original Wt.	191.48			
			Sieve loss/gain	0.72			
Gy 4.4							
V. coarse sand	12	1.78	-0.75	33.07	33.07	13.81	13.81
	18	1	0	58.52	91.59	38.24	24.44
C. Sand	30	0.59	0.75	54.85	146.44	61.15	22.90
Medium sand	40	0.42	1.25	25.97	172.41	71.99	10.84
	60	0.25	2	27.42	199.83	83.44	11.45
F. Sand	100	0.15	2.75	17.89	217.72	90.91	7.47
V. Fine Sand	170	0.09	3.5	10.46	228.18	95.28	4.37
	230	0.063	4	7.35	235.53	98.35	3.07
Silt and Clay	325	0.044	4.5	2.03	237.56	99.19	0.85
	>325	0.037	4.75	1.93	239.49	100.00	0.81
			Total	239.49			
			Original Wt.	240.1			
			Sieve loss/gain	0.61			
Gy 6.1							
V. coarse sand	12	1.78	-0.75	17.67	17.67	7.82	7.82
	18	1	0	30.87	48.54	21.49	13.67
C. Sand	30	0.59	0.75	35.64	84.18	37.27	15.78
Medium sand	40	0.42	1.25	19.23	103.41	45.78	8.51
	60	0.25	2	31.88	135.29	59.90	14.11
F. Sand	100	0.15	2.75	45.61	180.90	80.09	20.19
V. Fine Sand	170	0.09	3.5	28.83	209.73	92.86	12.76
	230	0.063	4	13.15	222.88	98.68	5.82
Silt and Clay	325	0.044	4.5	1.46	224.34	99.33	0.65
	>325	0.037	4.75	1.52	225.86	100.00	0.67
			Total	225.86			
			Original Wt.	226.98			
			Sieve loss/gain	1.12			

Gy 6.2							
V. coarse sand	12	1.78	-0.75	24.16	24.16	10.70	10.70
	18	1	0	39.51	63.67	28.21	17.50
C. Sand	30	0.59	0.75	40.92	104.59	46.33	18.13
Medium sand	40	0.42	1.25	22.48	127.07	56.29	9.96
	60	0.25	2	29.78	156.85	69.48	13.19
F. Sand	100	0.15	2.75	40.85	197.70	87.58	18.10
V. Fine Sand	170	0.09	3.5	14.38	212.08	93.95	6.37
	230	0.063	4	11.62	223.70	99.10	5.15
Silt and Clay	325	0.044	4.5	1.06	224.76	99.57	0.47
	>325	0.037	4.75	0.98	225.74	100.00	0.43
			Total	225.74			
			Original Wt.	226.84			
			Sieve loss/gain	1.1			
Gy 6.3							
V. coarse sand	12	1.78	-0.75	14.84	14.84	10.30	10.30
	18	1	0	25.65	40.49	28.10	17.80
C. Sand	30	0.59	0.75	25.82	66.31	46.02	17.92
Medium sand	40	0.42	1.25	13.34	79.65	55.27	9.26
	60	0.25	2	19.73	99.38	68.97	13.69
F. Sand	100	0.15	2.75	18.08	117.46	81.51	12.55
V. Fine Sand	170	0.09	3.5	9.52	126.98	88.12	6.61
	230	0.063	4	14.53	141.51	98.20	10.08
Silt and Clay	325	0.044	4.5	1.03	142.54	98.92	0.71
	>325	0.037	4.75	1.56	144.10	100.00	1.08
			Total	144.1			
			Original Wt.	144.86			
			Sieve loss/gain	0.76			
Gy 6.4							
V. coarse sand	12	1.78	-0.75	30.04	30.04	12.22	12.22
	18	1	0	47.2	77.24	31.43	19.20
C. Sand	30	0.59	0.75	46.84	124.08	50.48	19.06
Medium sand	40	0.42	1.25	25.22	149.30	60.75	10.26
	60	0.25	2	33.41	182.71	74.34	13.59
F. Sand	100	0.15	2.75	25.23	207.94	84.60	10.27
V. Fine Sand	170	0.09	3.5	19.21	227.15	92.42	7.82
	230	0.063	4	15.26	242.41	98.63	6.21
Silt and Clay	325	0.044	4.5	1.92	244.33	99.41	0.78
	>325	0.037	4.75	1.45	245.78	100.00	0.59
			Total	245.78			
			Original Wt.	248.11			
			Sieve loss/gain	2.33			
Gy 6.5							
V. coarse sand	12	1.78	-0.75	37.58	37.58	12.53	12.53
	18	1	0	54.86	92.44	30.82	18.29
C. Sand	30	0.59	0.75	55.07	147.51	49.18	18.36
Medium sand	40	0.42	1.25	26.99	174.50	58.18	9.00
	60	0.25	2	41.89	216.39	72.15	13.97
F. Sand	100	0.15	2.75	43.78	260.17	86.74	14.60
V. Fine Sand	170	0.09	3.5	16.16	276.33	92.13	5.39
	230	0.063	4	17.86	294.19	98.09	5.95
Silt and Clay	325	0.044	4.5	2.03	296.22	98.76	0.68
	>325	0.037	4.75	3.71	299.93	100.00	1.24
			Total	299.93			
			Original Wt.	300.63			
			Sieve loss/gain	0.7			

Gy 7.1							
V. coarse sand	12	1.78	-0.75	20.99	20.99	8.84	8.84
	18	1	0	37.05	58.04	24.43	15.60
C. Sand	30	0.59	0.75	40.68	98.72	41.56	17.13
Medium sand	40	0.42	1.25	20.32	119.04	50.11	8.55
	60	0.25	2	32.82	151.86	63.93	13.82
F. Sand	100	0.15	2.75	45.73	197.59	83.18	19.25
V. Fine Sand	170	0.09	3.5	25.45	223.04	93.90	10.71
	230	0.063	4	12.25	235.29	99.05	5.16
Silt and Clay	325	0.044	4.5	1.49	236.78	99.68	0.63
	>325	0.037	4.75	0.76	237.54	100.00	0.32
			Total	237.54			
			Original Wt.	239.81			
			Sieve loss/gain	2.27			
Gy 7.2							
V. coarse sand	12	1.78	-0.75	18.59	18.59	8.86	8.86
	18	1	0	36.6	55.19	26.29	17.44
C. Sand	30	0.59	0.75	40.32	95.51	45.50	19.21
Medium sand	40	0.42	1.25	20.75	116.26	55.39	9.89
	60	0.25	2	24.99	141.25	67.29	11.91
F. Sand	100	0.15	2.75	34.34	175.59	83.65	16.36
V. Fine Sand	170	0.09	3.5	20.41	196.00	93.38	9.72
	230	0.063	4	11.26	207.26	98.74	5.36
Silt and Clay	325	0.044	4.5	1.55	208.81	99.48	0.74
	>325	0.037	4.75	1.09	209.90	100.00	0.52
			Total	209.9			
			Original Wt.	211.53			
			Sieve loss/gain	1.63			
Gy 7.3							
V. coarse sand	12	1.78	-0.75	23.19	23.19	9.92	9.92
	18	1	0	41.82	65.01	27.81	17.89
C. Sand	30	0.59	0.75	44.42	109.43	46.82	19.00
Medium sand	40	0.42	1.25	20.48	129.91	55.58	8.76
	60	0.25	2	38.22	168.13	71.93	16.35
F. Sand	100	0.15	2.75	33.6	201.73	86.31	14.38
V. Fine Sand	170	0.09	3.5	20.08	221.81	94.90	8.59
	230	0.063	4	9.13	230.94	98.81	3.91
Silt and Clay	325	0.044	4.5	1.26	232.20	99.35	0.54
	>325	0.037	4.75	1.53	233.73	100.00	0.65
			Total	233.73			
			Original Wt.	236.87			
			Sieve loss/gain	3.14			
Gy 7.4							
V. coarse sand	12	1.78	-0.75	18.68	18.68	8.19	8.19
	18	1	0	39.01	57.69	25.28	17.09
C. Sand	30	0.59	0.75	40.17	97.86	42.88	17.60
Medium sand	40	0.42	1.25	22.42	120.28	52.71	9.82
	60	0.25	2	29.84	150.12	65.78	13.08
F. Sand	100	0.15	2.75	25.2	175.32	76.83	11.04
V. Fine Sand	170	0.09	3.5	28.74	204.06	89.42	12.59
	230	0.063	4	17.99	222.05	97.30	7.88
Silt and Clay	325	0.044	4.5	4.67	226.72	99.35	2.05
	>325	0.037	4.75	1.48	228.20	100.00	0.65
			Total	228.2			
			Original Wt.	229.63			
			Sieve loss/gain	1.43			

Gy 7.5							
V. coarse sand	12	1.78	-0.75	27.13	27.13	8.50	8.50
	18	1	0	61.07	88.20	27.62	19.12
C. Sand	30	0.59	0.75	64.38	152.58	47.78	20.16
Medium sand	40	0.42	1.25	34.18	186.76	58.48	10.70
	60	0.25	2	45.61	232.37	72.76	14.28
F. Sand	100	0.15	2.75	35.38	267.75	83.84	11.08
V. Fine Sand	170	0.09	3.5	24.56	292.31	91.53	7.69
	230	0.063	4	20.37	312.68	97.91	6.38
Silt and Clay	325	0.044	4.5	4.52	317.20	99.32	1.42
	>325	0.037	4.75	2.16	319.36	100.00	0.68
			Total	319.36			
			Original Wt.	320.72			
			Sieve loss/gain	1.36			

Appedix D: Thin section petrography. Soil pit Gn 6 was sampled and analysed, but the results are not dicussed in the results of this study.

Sample	Top Depth (in)	Quartz	Aggregate	Pottasium Feldspar	Plagioclase Feldspar	Plutonic Rock Fragments	Volcanic Rock Fragments	Metamorphic Rock Fragments	Sedimentary Rock Fragments	Matrix	Biotite	Muscovite	Hornblende	Opaque
Gn 7.1	2	89	69	18	12	26	2	1	0	29	5	5	1	4
%		34.1	26.4	6.9	4.6	10.0	0.8	0.4	0.0	11.1	1.9	1.9	0.4	1.5
Gn 7.2	5.5	83	66	34	12	28	5	1	0	27	5	7	0	5
%		30.4	24.2	12.5	4.4	10.3	1.8	0.4	0.0	9.9	1.8	2.6	0.0	1.8
Gn 7.3	9.5	87	46	27	20	29	2	2	0	16	4	6	1	3
%		35.8	18.9	11.1	8.2	11.9	0.8	0.8	0.0	6.6	1.6	2.5	0.4	1.2
Gn 7.4	13	90	41	31	23	45	4	2	0	14	6	7	1	2
%		33.8	15.4	11.7	8.6	16.9	1.5	0.8	0.0	5.3	2.3	2.6	0.4	0.8
Gn 3.1	2	20	199	10	4	25	1	2	0	7		3	0	2
%		7.3	72.9	3.7	1.5	9.2	0.4	0.7	0.0	2.6	0.0	1.1	0.0	0.7
Gn 3.2	6	21	191	11	4	24	4	0	0	9	1	2	0	3
%		7.8	70.7	4.1	1.5	8.9	1.5	0.0	0.0	3.3	0.4	0.7	0.0	1.1
Gn 3.3	10	13	221	4	2	14	0	2	0	13	1	4	0	2
%		4.7	80.1	1.4	0.7	5.1	0.0	0.7	0.0	4.7	0.4	1.4	0.0	0.7
Gn 3.4	14	39	130	18	6	32	4	1	0	15	1	4	0	1
%		15.5	51.8	7.2	2.4	12.7	1.6	0.4	0.0	6.0	0.4	1.6	0.0	0.4
Gn 5.1	2	59	112	16	10	26	1	2	0	20	2	3	0	5
%		23.0	43.8	6.3	3.9	10.2	0.4	0.8	0.0	7.8	0.8	1.2	0.0	2.0
Gn 5.2	6	40	191	13	5	19	2	1	0	6	2	6	0	2
%		13.9	66.6	4.5	1.7	6.6	0.7	0.3	0.0	2.1	0.7	2.1	0.0	0.7
Gn 5.3	9	79	95	16	7	23	0	0	0	21	1	4	0	3
%		31.7	38.2	6.4	2.8	9.2	0.0	0.0	0.0	8.4	0.4	1.6	0.0	1.2
Gn 5.4	13	52	163	12	5	26	4	4	0	12	2	2	0	1
%		18.4	57.6	4.2	1.8	9.2	1.4	1.4	0.0	4.2	0.7	0.7	0.0	0.4
Gn 5.5	17	71	67	33	11	50	9	2	0	22	4	5	0	3
%		25.6	24.2	11.9	4.0	18.1	3.2	0.7	0.0	7.9	1.4	1.8	0.0	1.1
Gn 6.1	2	81	11	20	11	27	97	0	0	6	0	0	8	2
%		30.8	4.2	7.6	4.2	10.3	36.9	0.0	0.0	2.3	0.0	0.0	3.0	0.8
Gn 6.2	5.5	53	16	16	9	26	112	0	1	2	0	0	12	1
%		21.4	6.5	6.5	3.6	10.5	45.2	0.0	0.4	0.8	0.0	0.0	4.8	0.4
Gn 6.3	9.5	54	3	14	4	31	125	2	1	7	0	0	5	4
%		21.6	1.2	5.6	1.6	12.4	50.0	0.8	0.4	2.8	0.0	0.0	2.0	1.6
Gn 6.4	13	44	4	12	3	64	121	2	3	3	0	0	2	3
%		16.9	1.5	4.6	1.1	24.5	46.4	0.8	1.1	1.1	0.0	0.0	0.8	1.1
Gn 1.1	2	70	134	17	12	12	0	2	0	11	1	2	0	2
%		26.6	51.0	6.5	4.6	4.6	0.0	0.8	0.0	4.2	0.4	0.8	0.0	0.8
Gn1.2	4.5	31	181	12	8	10	0	1	0	18	1	4	0	1
%		11.6	67.8	4.5	3.0	3.7	0.0	0.4	0.0	6.7	0.4	1.5	0.0	0.4
Gn 1.3	8.5	24	201	10	6	16	0	0	0	15	2	3	0	1
%		8.6	72.3	3.6	2.2	5.8	0.0	0.0	0.0	5.4	0.7	1.1	0.0	0.4
Gn 1.5	15	13	242	6	5	4	0	0	0	6	1	2	0	2
%		4.6	86.1	2.1	1.8	1.4	0.0	0.0	0.0	2.1	0.4	0.7	0.0	0.7
Gn 1.7	18	10	233	4	4	8	0	2	0	7	1	1	0	1
%		3.7	86.0	1.5	1.5	3.0	0.0	0.7	0.0	2.6	0.4	0.4	0.0	0.4

Appedix D: Thin section petrography.

Sample	Top Depth (in)	Quartz	Aggregate	Pottasium Feldspar	Plagioclase Feldspar	Plutonic Rock Fragments	Volcanic Rock Fragments	Metamorphic Rock Fragments	Sedimentary Rock Fragments	Matrix	Biotite	Muscovite	Hornblende	Opaque
Gy 7.1	5	83	29	30	14	72	14	3	2	24	2	0	0	1
%		30.3	10.6	10.9	5.1	26.3	5.1	1.1	0.7	8.8	0.7	0.0	0.0	0.4
Gy 7.2	9	81	24	40	12	86	20	2	1	26	1	2	0	0
%		27.5	8.1	13.6	4.1	29.2	6.8	0.7	0.3	8.8	0.3	0.7	0.0	0.0
Gy 7.3	13	79	25	35	17	79	16	1	0	21	2	4	0	1
%		28.2	8.9	12.5	6.1	28.2	5.7	0.4	0.0	7.5	0.7	1.4	0.0	0.4
Gy 7.4	17	89	26	31	15	78	13	0	0	17	1	2	0	1
%		32.6	9.5	11.4	5.5	28.6	4.8	0.0	0.0	6.2	0.4	0.7	0.0	0.4
Gy 7.5	21	73	24	30	15	73	15	3	2	21	3	5	0	0
%		27.7	9.1	11.4	5.7	27.7	5.7	1.1	0.8	8.0	1.1	1.9	0.0	0.0
Gy 6.1	3	74	45	49	29	30	7	0	0	16	5	4	0	3
%		28.2	17.2	18.7	11.1	11.5	2.7	0.0	0.0	6.1	1.9	1.5	0.0	1.1
Gy 6.2	7	74	41	37	42	46	6	0	0	7	1	6	0	1
%		28.4	15.7	14.2	16.1	17.6	2.3	0.0	0.0	2.7	0.4	2.3	0.0	0.4
Gy 6.3	10	81	34	40	35	56	8	0	0	8	0	6	0	3
%		29.9	12.5	14.8	12.9	20.7	3.0	0.0	0.0	3.0	0.0	2.2	0.0	1.1
Gy 6.5	17	65	24	29	20	74	26	0	4	6	0	0	0	0
%		26.2	9.7	11.7	8.1	29.8	10.5	0.0	1.6	2.4	0.0	0.0	0.0	0.0
Gy 4.1	4	51	42	35	17	52	68	2	1	6	0	0	0	0
%		18.6	15.3	12.8	6.2	19.0	24.8	0.7	0.4	2.2	0.0	0.0	0.0	0.0
Gy 4.2	8	69	18	43	19	33	49	0	7	15	5	3	0	0
%		26.4	6.9	16.5	7.3	12.6	18.8	0.0	2.7	5.7	1.9	1.1	0.0	0.0
Gy 4.3	11	54	36	20	12	55	71	0	2	8	2	7	0	2
%		20.1	13.4	7.4	4.5	20.4	26.4	0.0	0.7	3.0	0.7	2.6	0.0	0.7
Gy 4.4	14	60	33	22	8	78	40	2	0	6	1	2	0	0
%		23.8	13.1	8.7	3.2	31.0	15.9	0.8	0.0	2.4	0.4	0.8	0.0	0.0
Gy 3.1	3	101	40	32	18	53	9	2	1	18	1	3	0	1
%		36.2	14.3	11.5	6.5	19.0	3.2	0.7	0.4	6.5	0.4	1.1	0.0	0.4
Gy 3.2	7	106	31	39	16	39	22	3	1	15	3	4	0	0
%		38.0	11.1	14.0	5.7	14.0	7.9	1.1	0.4	5.4	1.1	1.4	0.0	0.0
Gy 3.3	10.5	60	35	28	27	66	14	1	2	15	4	4	0	1
%		23.3	13.6	10.9	10.5	25.7	5.4	0.4	0.8	5.8	1.6	1.6	0.0	0.4
Gy 3.5	17	59	32	29	13	80	19	1	0	11	1	2	0	2
%		23.7	12.9	11.6	5.2	32.1	7.6	0.4	0.0	4.4	0.4	0.8	0.0	0.8

Appendix E: Soil pH and EC

Sample	soil/solution ratio	Coordinates (Lat, Lon; WGS 84)	Sample Depth (in)		pH	Electric Conductivity (μs)	Temp. (°C)
			Top	Bottom			
Gn 1 Oh	1 to 1	N40.26036, W106.05578	0	2	5.37	156	21.4
Gn 1.1	1 to 1		2	4.5	5.44	332	20.7
Gn 1.2	1 to 1		4.5	8.5	5.81	134	20.3
Gn 1.3	1 to 1		8.5	12	5.9	148	20.4
Gn 1.4	1 to 1		12	15	6.08	183	19.5
Gn 1.5	1 to 1		15	18	6.14	176	20.1
Gn 1.6	1 to 1		18	23	6.15	235	20.3
Gn 3 Oh	1 to 1	N40.26048, W106.05613	0	2	5.37	155	20.7
Gn 3.1	1 to 1		2	6	5.66	164	19.6
Gn 3.2	1 to 1		6	10	5.81	174	19.9
Gn 3.3	1 to 1		10	14	6.11	156	20.5
Gn 3.4	1 to 1		14	18	6.30	183	20.7
Gn 4 Oh	1 to 2	N40.26051, W106.05520	0	3	5.79	145	21.1
Gn 4.1	1 to 1		3	6	5.90	92	20.4
Gn 4.2	1 to 1		6	9	5.89	95	20.2
Gn 4.3	1 to 1		9	13	6.11	114	19.8
Gn 4.4	1 to 1		13	17	6.41	126	19.5
Gn 5 Oh	1 to 2	N40.26020, W106.05656	0	2	5.07	140	21.3
Gn 5.1	1 to 1		2	6	5.66	169	20.3
Gn 5.2	1 to 1		6	9	5.86	190	20.8
Gn 5.3	1 to 1		9	13	6.02	139	20.4
Gn 5.4	1 to 1		13	17	6.35	107	21.1
Gn 5.5	1 to 1		17	21	6.35	157	20.6
Gn 6 Oh	1 to 2	N40.26070, W106.05434	0	2	5.16	143	21.7
Gn 6.1	1 to 1		2	5.5	5.52	180	19.9
Gn 6.2	1 to 1		5.5	9.5	6.94	114	21.0
Gn 6.3	1 to 1		9.5	13	6.30	139	20.1
Gn 6.4	1 to 1		13	17	6.33	128	20.8
Gn 7 Oh	1 to 1	N40.26117, W106.05645	0	2	6.39	93	21.0
Gn 7.1	1 to 1		2	5.5	5.71	116	20.4
Gn 7.2	1 to 1		5.5	9.5	5.98	128	20.1
Gn 7.3	1 to 1		9.5	13	6.34	112	19.9
Gn 7.4	1 to 1		13	18	6.41	119	20.3

Appendix E con't: Soil pH and EC

Sample	soil/solution ratio	Coordinates (Lat, Lon; WGS 84)	Sample Depth (in)		pH	Electric Conductivity (µs)	Temp. (°C)
			Top	Bottom			
Bn 1 Oh	1 to 1	N40.25970, W106.05500	0	3	5.57	197	20.9
Bn 1.1	1 to 1		3	7	5.61	168	20.7
Bn 1.2	1 to 1		7	10	5.90	115	20.2
Bn 1.3	1 to 1		10	14	6.12	114	19.9
Bn 1.4	1 to 1		14	17	6.37	126	19.8
Bn 1.5	1 to 1		17	21	6.07	107	20.0
Bn 3 Oh	1 to 1	N40.25990, W106.05397	0	4.5	4.95	141	20.7
Bn 3.1	1 to 1		4.5	7.5	5.26	106	19.9
Bn 3.2	1 to 1		7.5	12.5	5.77	92	20.6
Bn 3.3	1 to 1		12.5	17.5	5.96	96	20.2
Bn 3.4	1 to 1		17.5	20	6.28	96	19.8
Bn 4 Oh	1 to 2	N40.25974, W106.05342	0	4	4.65	102	22.0
Bn 4.1	1 to 1		4	9	6.24	91	20.8
Bn 4.2	1 to 1		9	12	6.53	84	19.9
Bn 4.3	1 to 1		12	16	6.56	104	20.3
Bn 4.4	1 to 1		16	20	6.61	112	19.7
Bn 4.5	1 to 1		20	24	6.68	118	19.6
Bn 4.6	1 to 1		24	28	6.58	116	20.1
Bn 5 Oh	1 to 1	N40.26014, W106.05782	0	2.5	5.63	78	19.8
Bn 5.1	1 to 1		2.5	7.5	5.45	185	20.9
Bn 5.2	1 to 1		7.5	11	5.93	125	20.7
Bn 5.3	1 to 1		11	15	5.86	122	20.5
Bn 5.4	1 to 1		15	19	6.23	159	20.5
Bn 5.5	1 to 1		19	23	6.45	171	20.0
Bn 6 Oh	1 to 1	N40.25985, W106.05895	0	4	5.63	98	19.9
Bn 6.1	1 to 1		4	8	5.96	109	20.3
Bn 6.2	1 to 1		8	11	6.14	120	20.1
Bn 6.3	1 to 1		11	14.5	6.27	133	20.3
Bn 6.4	1 to 1		14.5	18.5	6.33	96	20.3
Bn 6.5	1 to 1		18.5	22	6.50	105	20.4
Bn 6.6	1 to 1		22	26	6.62	118	19.9
Bn 7 Oh	1 to 2	N40.26112, W106.05779	0	3.5	5.65	186	20.6
Bn 7.1	1 to 1		3.5	8	6.05	161	20.1
Bn 7.2	1 to 1		8	12	6.18	222	19.8
Bn 7.3	1 to 1		12	16	6.33	172	19.8
Bn 7.4	1 to 1		16	20	6.46	190	20.0
Bn 7.5	1 to 1		20	25	6.47	139	20.0
Bn 8 Oh	1 to 1.5	N40.26085, W106.05843	0	3	5.88	157	21.1
Bn 8.1	1 to 1		3	7	5.59	228	20.6
Bn 8.2	1 to 1		7	10	5.52	148	19.8
Bn 8.3	1 to 1		10	14	5.86	171	19.4
Bn 8.4	1 to 1		14	18	5.90	198	19.9
Bn 8.5	1 to 1		18	20	5.95	184	19.4

Appendix E con't: Soil pH and EC

Sample	soil/solution ratio	Coordinates (Lat, Lon; WGS 84)	Sample Depth (in)		pH	Electric Conductivity (µs)	Temp. (°C)
			Top	Bottom			
Gy 1 Oh	1 to 1	N40.26042, W106.05366	0	2.5	5.45	191	21.1
Gy 1.1	1 to 1		2.5	6.5	5.95	151	20.3
Gy 1.2	1 to 1		6.5	10.5	6.00	154	19.4
Gy 1.3	1 to 1		10.5	14.5	6.05	154	20.3
Gy 1.4	1 to 1		14.5	18.5	6.21	207	20.6
Gy 1.5	1 to 1		18.5	21.5	6.28	217	20.5
Gy 1.6	1 to 1		21.5	24	6.26	385	20.9
Gy 2 Oh	1 to 1	N40.26051, W106.05275	0	3	5.11	172	21.0
Gy 2.1	1 to 1		3	6	5.83	127	19.8
Gy 2.2	1 to 1		6	9	6.34	100	19.7
Gy 2.3	1 to 1		9	12	6.52	111	19.3
Gy 2.4	1 to 1		12	16	6.55	130	19.4
Gy 2.5	1 to 1		16	19	5.97	108	20.4
Gy 2.6	1 to 1		19	23	6.48	106	19.8
Gy 3 Oh	1 to 3	N40.26052, W106.05266	0	3	4.96	87	21.9
Gy 3.1	1 to 1		3	7	5.40	93	19.5
Gy 3.2	1 to 1		7	10.5	5.71	93	19.8
Gy 3.3	1 to 1		10.5	14	6.02	117	20.1
Gy 3.4	1 to 1		14	17	6.05	121	20.7
Gy 3.5	1 to 1		17	21	6.41	138	20.8
Gy 4 Oh	1 to 2	N40.26100, W106.05218	0	4	5.25	83	21.5
Gy 4.1	1 to 1		4	8	5.88	136	19.7
Gy 4.2	1 to 1		8	11	5.94	120	20.1
Gy 4.3	1 to 1		11	14	5.98	120	19.9
Gy 4.4	1 to 1		14	19	6.52	119	20.1
Gy 5 Oh	1 to 1.5	N40.26119, W106.05313	0	3	5.36	84	21.1
Gy 5.1	1 to 1		3	7	6.35	117	19.9
Gy 5.2	1 to 1		7	11	6.27	101	19.1
Gy 5.3	1 to 1		11	14	6.81	250	19.1
Gy 5.4	1 to 1		14	18	6.96	146	19.5
Gy 5.5	1 to 1		18	22	6.62	141	19.7
Gy 6 Oh	1 to 2	N40.26106, W106.05243	0	3	5.58	83	21.0
Gy 6.1	1 to 1		3	7	5.71	147	22.4
Gy 6.2	1 to 1		7	10	5.82	145	21.5
Gy 6.3	1 to 1		10	13	6.57	123	21.6
Gy 6.4	1 to 1		13	17	6.64	234	20.6
Gy 6.5	1 to 1		17	20	6.84	159	20.4
Gy 7 Oh	1 to 2	N40.26132, W106.05248	0	5	5.70	83	21.6
Gy 7.1	1 to 1		5	9	6.32	142	19.6
Gy 7.2	1 to 1		9	13	6.38	102	19.9
Gy 7.3	1 to 1		13	17	6.32	102	19.5
Gy 7.4	1 to 1		17	21	6.41	107	19.9
Gy 7.5	1 to 1		21	24	6.54	116	20.1