University of Alberta

FOLIC DEBRIS SLIDES NEAR PRINCE RUPERT, BRITISH COLUMBIA

by

HEATHER KRISTEN NAGLE ©

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

in

SOIL SCIENCE

Department of Renewable Resources

Edmonton, Alberta

Fall, 2000

0-612-59856-X

University of Alberta

Library Release Form

Name of Author: Heather Kristen Nagle

Title of Thesis: Folic Debris Slides near Prince Rupert, British Columbia.

Degree: Master of Science

Year this Degree Granted: 2000

H. N.

Box 560
Golden, B.C.
VOA 1HO

26/7/00

Date

ABSTRACT

The purpose of this study was to determine the soil and landscape attributes that contribute towards folic debris slides in the maritime climate of Prince Rupert, British Columbia. The folic debris slides were shallow (< 1 m) and composed predominantly of organic material overlying steep bedrock surfaces. Folic debris slides were investigated through several approaches: characterization of the physical and chemical properties of folic soils; principal components analysis (PCA) of soil and landscape level attributes of 30 debris slide sites; paired comparison of debris slide and non-debris slide sites; determination of shear strength values and physical soil properties at the folic soil - bedrock contact; examination of folic debris slide attributes within the infinite slope model using 'Deterministic Level 1 Stability Analysis' (DLISA). PCA results indicated that the geologic attributes of slope angle, surface configuration and bedrock structure and patterns in folic soil horizonation influenced slope instability primarily though hydrologic means. Saturated conditions, and hence loss of soil adhesion, likely occurred. Soil adhesion values ranged from 12 to 93 N with a mean value of 32 N. Results suggested that slope angle, soil cohesion, groundwater ratio and root cohesion most influenced the stability of folic soils.

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *Folic debris slides near Prince Rupert, British Columbia* submitted by *Heather K. Nagle* in partial fulfillment of the requirements for the degree of *Master of Science* in *Soil Science*.

Donald J. Pluth
Dr. D.J. Pluth

Dr. D.M. Cruden

Dr. D.S. Chanasyk

J.W. Schwab

Y. Feng
Dr. Y. Feng

25 July 2000
Date

For my family

ACKNOWLEDGEMENTS

Thank you to my parents without whose support, financial and otherwise, this document would not be possible. Thanks to Mom who at least tried to read and edit my thesis. It was a good effort anyway! Thanks to Dad for attempting to keep me on track while I was writing from home. I could not have done it without you. I love you both so much.

Thanks to Danielle Bailey, my partner in commiserating and procrastination. I would be crazy right now if you hadn't been around.

Thanks to Greg Pope and Reiko Graham for their friendship and their help with statistics. I for one, hope never again to attend a PCA party!

Thank you to Jim Schwab, Marten Geertsema and the B.C. Ministry of Forests for the financial support, advice and expertise.

Thank you to David Cruden for his advice and expertise.

Finally, thanks to Don Pluth for his advice, support and encouragement throughout my time at the University of Alberta.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 LITERATURE REVIEW

1.1 Folisols

Folisolic soils are formed primarily of folic material, defined as upland organic materials, chiefly of forest origin. Organic materials are defined as those containing $\geq$17 % organic carbon by weight. Folic materials qualify as Folisols under the Canadian System of Soil Classification (Soil Classification Working Group, 1998) in several profile situations. The folic material must be either $\geq$ 40 cm thick or $\geq$ 10 cm thick if it is directly overlying a lithic contact or fragmental material. Folic materials are also classified as Folisols if the folic material is twice the thickness of a mineral soil layer if the mineral layer $\leq$ 20 cm thick. Green et al. (1993) further classified upland organic material as humus forms. A humus form is defined as a group of soil horizons that have formed from organic residues, either separate from or intermixed with mineral materials. The three orders of humus forms are Mor, Moder and Mull.

Folisols vary from other soils of the Organic order in several significant ways. Folisols are very seldom saturated in the sense of having a high permanent water table, but rather tend to be well to imperfectly drained. Folic material is formed principally of upland organic material as opposed to the peat materials of wetland origin. Finally, folic materials are subject to upland accumulation and decomposition processes rather than peat-forming processes associated with wetland conditions (Trowbridge et al., 1985; Soil Classification Working Group, 1998).

The genesis and morphology of Folisols is principally dependent upon climate acting through vegetation. The cool, humid climate of northern coastal British Columbia allows the development of highly productive coniferous forests. Climatic conditions in this area do not favor decomposition or forest fires hence litter layers can become quite deep (Lewis and Lavkulich, 1972; Trowbridge et al., 1985). Extremely acid pH values also likely contribute to low decomposition rates in Folisolic soils (Fox et al, 1987). Essentially, in this region, litter biomass production exceeds decomposition (Fox et al, 1994). Even bedrock outcrops are ultimately colonized by coniferous forest because of the accumulation of significant litter layers from neighboring vegetation growing on thicker soils and the amelioration effect of microclimate by the encroaching forest (Lewis and Lavkulich, 1972).

For the purpose of this study, the term 'folic soil' will be used to describe both Folisolic soils and some Orthic Regosols that contain at least one horizon of folic material.

1.2 Debris Slides

Slope movements are named based on the type of movement that occurs and the type of materials that are displaced. The slope movements dealt with in this study may be classified as debris slides. Debris particles are defined as inorganic material containing a significant amount of coarse material, that is 20 to 80 % $\geq$ 2 mm in diameter. A slide is defined as a downslope movement consisting of shear strain and displacement along one or more surfaces that are visible or may be reasonably inferred. Slide movement does not occur concurrently over the whole of what ultimately becomes the surface of rupture; instead it propagates from a zone of local failure (Cruden and Varnes, 1996).

The debris slides in the Prince Rupert region may be further classified as translational slides. Wherein the debris mass progresses on a planar or gently undulating surface. This type of slide differs from a slump in that it has no rotary movement or backward tilting characteristics. A translational slide may advance indefinitely if the plane on which it rests is adequately inclined and as long as the shear resistance remains lower than the relatively constant driving force. The movement of translational slides is commonly controlled structurally by surfaces of weakness such as the interface between the bedrock and overlying material (Cruden and Varnes, 1996). For the purpose of this study, the term 'folic debris slide' refers to a translational movement of debris composed predominantly of folic debris.

1.3 Natural Factors Influencing Slope Stability

The natural factors influencing the stability of forested slopes can be grouped into five process-related categories, including geologic, soil, hydrologic and biotic properties (Schroeder and Alto, 1983). Sidle (1985) included seismicity in the above list; however siesmicity is unlikely to be an influential factor affecting slope stability in the Prince Rupert region. Clague (1984) stated that the Prince Rupert area is a zone of potential major earthquake damage, although reported earthquakes have not been considered in this thesis to be significant factors in slope failures.

1.3.1 Geologic Properties Influencing Slope Stability

Shallow slope failures are common in regions where mountains have undergone natural steepening by tectonic uplift and glaciation (Varnes, 1978; Sidle, 1985). Slope angle can be closely related to shallow slope failures in some areas but it is difficult to generalize because of other confounding elements (Sidle, 1985; Swanston and Howes, 1994). However, many slopes > 25 ° are prone to rapid slope failure and most slopes > 35 ° are prone to rapid slope failure (Sidle, 1985).

Bedrock structure can be a significant factor in slope stability. Jointed or fractured bedrock slopes with principal joints and fracture surfaces parallel to the slope often provide little mechanical support for overburden. However, joints and fractures perpendicular to the slope may permit better attachment of the soil to the underlying bedrock than is often found with more massive igneous and metamorphic bedrock. Jointing may also create avenues for deep subsurface water flow resulting in the development of springs and hydrostatic pressure excesses (Sidle, 1985; Swanston and Howes, 1994).

Slope shape is an important factor in determining the distribution of subsurface water flow on slopes. Convex slopes tend to disperse subsurface water and tend to be more stable than concave slopes that concentrate subsurface water into small areas of the slope (Sidle, 1985; Swanston and Howes, 1994). Slopes with mid to upper slope concave depressions are thought to be particularly susceptible to slope failure. These depressions accumulate subsurface water and develop positive pore water pressure, thus decreasing slope stability (Sidle and Swanston, 1981; Sidle, 1985; Schroeder and Swanston, 1987).

1.3.2 Physical Soil Properties Influencing Slope Stability

Soil shear strength can be defined as a quantitative measure of the resistance of a soil to failure, shear strength is a function of normal stress on a slip surface, cohesion and internal angle of friction (Sidle, 1985; Gray and Sotir, 1996).

Normal stress is influenced by the unit weight or density of the soil at field moisture content as well as by soil depth and slope angle. Pore water pressure at the failure plane decreases the normal stress to an effective normal stress by behaving as a buoyant force. However, infiltrating water can encourage slope failure by increasing the weight of the soil profile (Sidle, 1985).

Soil cohesion is a function of water content, increasing slightly with increasing water content from air dryness and then decreasing rapidly as water content is increased further. Generally, the point at which cohesive forces are the strongest corresponds to the minimum water content at which a soil can be deformed without rupture. In field soils, cohesion is complemented by the contribution of rooting strength. The sum of soil and root cohesion is called total cohesion (Sidle, 1985).

Internal angle of friction can be defined as the degree of interlocking between individual organic and inorganic grains or aggregates. It is influenced by the shape, roundness, size and packing arrangement of these particles. Angular particles have a larger internal angle of friction than rounded particles because of their greater interlocking capabilities. In addition, soil aggregation may increase interlocking and therefore the internal angle of friction (Sidle, 1985).

Little published information exists regarding the physical properties of folic horizons. However, information concerning peat may be relevant because many of the physical properties of both folic materials and peat are strongly influenced by degree of decomposition.

Boelter (1968) discussed physical properties of peat in relationship to degree of decomposition. Some physical properties of any soil are dependent upon porosity and pore-size distribution that in turn are related to particle-size distribution and the arrangement of particles. In peat materials, both particle size and structure and the resulting porosity are principally controlled by degree of decomposition. With increasing decomposition, the size of the organic particles decreases, resulting in smaller pores and higher bulk density. Low bulk density, fibric peats contain many large pores that allow them to drain easily and permit rapid water movement. With increasing decomposition, bulk density increases and a greater proportion of small pores exist, increasing water retention and slowing water movement rates (Boelter, 1968).

Saturated water content is higher in less decomposed fibric peat than more strongly decomposed humic peats. Total porosity decreases gradually with increased decomposition, but is large for all peat materials. Walmsley (1977) reported porosity values ranging from 80.7 to 95.2 %, with an average of about 92 %. However there are significant differences in the amount of water retained under unsaturated conditions, indicating that pore size distribution is more important than total porosity in water desorption. As mentioned, there is a small decrease in total porosity as decomposition progresses but a significant decrease in pore diameter. As a result, desorption curves indicate that undecomposed peat loses water at much higher matric potentials than decomposed peats. Therefore, water content is higher in decomposed peats under unsaturated conditions (Boelter, 1968; Walmsley, 1977).

Saturated hydraulic conductivity is very high in the surface or near-surface horizons of undecomposed peats whereas denser, more decomposed peats permit only very slow water movement. Boelter (1968) reports hydraulic conductivities ranging from 3.8×10^{-2} cm/sec in undecomposed mosses to 4.5×10^{-6} cm/sec in well-decomposed peat. Different pore size distributions, found in varying stages of decomposition, create large differences in the behavior of soil water (Boelter, 1968; Walmsley, 1977).

Shear strength of peat is derived from both the tensile strength of the peat fiber and the particle-to-particle strength of the peat matrix. Factors that affect the shear strength of peat include variations in peat structure, water content and ash content (MacFarlane and Williams, 1974). MacFarlane (1969) reports that the shear strength of peat varies inversely with its water content and directly with its ash content.

MacFarlane (1969) reports relative values for some peat engineering properties. Amorphous granular peat has the smallest water content, natural permeability, tensile strength and shear strength, whereas fibrous peat has greatest values. The relative water content values reported by MacFarlane (1969) pertain to the saturated condition because the low water retention values of fibrous peat would not allow high water content in an unsaturated condition.

1.3.3 Hydrologic Properties Influencing Slope Stability

Hydrologic properties influencing the stability of slopes are largely dependent upon the precipitation regime, the rate of infiltration into the solum, the transmission rate of water within the solum and evapotranspiration (Sidle, 1985).

Transmission within the solum may be the dominant mechanism of downslope water movement (Sidle, 1985). Soil water recharge can be strongly affected by soil horizonation or the presence of a shallow water table. Downward progress of the wetting front may be hampered when the front encounters a layer of considerably lower permeability. The same effect occurs when infiltrating water reaches a perched water table. Tension cracks, which develop around the headwalls and flanks in unstable terrain, can provide a rapid recharge route into the solum. The discharge rate of water from the solum is probably the most critical hydrologic factor influencing slope stability because if the subsurface flow rate is less than the infiltration rate for an extended amount of time, a perched water table may form (Sidle, 1985; Swanston and Howes, 1994). Perched water tables above a potential failure plane can significantly reduce shear strength by reducing soil effective stresses and hence soil cohesion (Sidle, 1985; Schroeder and Swanston, 1987; Swanston and Howes, 1994). Buoyancy in a saturated state decreases effective intergranular pressure and friction. In addition, intergranular pressure due to capillary tension in a moist soil is destroyed upon saturation, thereby reducing soil shear strength (Cruden and Varnes, 1996). The formation of perched water tables or zones of high hydrostatic pressures in unstable soils are believed to be a major triggering mechanism of shallow translational slides in steep terrain (Sidle, 1985). Some mineral forest soils have high infiltration rates because of their thick, permeable, organic surface horizons. As a result, the infiltration rate often does not limit the recharge of unstable slopes and the subsurface flow rate becomes the principal hydrologic variable during many periods of precipitation (Sidle, 1985).

Evapotranspiration may influence slope stability through transpiration, canopy interception and timing of transpiration relative to the seasonal distribution of precipitation. Since most shallow rapid slope failures occur during prolonged periods of rainfall (Sidle, 1985; Swanston and Howes, 1994), evapotranspiration is unlikely to be a major controlling factor in this study because the amount of rainfall the area receives likely far outweighs potential evapotranspiration.

1.3.4 Vegetation Properties Influencing Slope Stability

Plant roots affect slope stability in several ways. Large roots add strength to the soil by vertically anchoring through the solum into fractured bedrock, although this mechanism is only effective in stabilizing relatively thin soils, less than 1 m thick. Root anchoring may be the dominant factor in maintaining slope stability in extremely steep areas. Thick networks of medium and small-sized roots reinforce the upper soil layer acting as a membrane to provide lateral support and increased stability (Sidle, 1985; Swanston and Howes, 1994). Larger structural roots in the area of individual trees can provide buttressing depending upon tree spacing. This buttressing mechanism is only significant in stabilizing thin soil mantles prone to debris slides (Sidle, 1985; Gray and Sotir, 1996). Root strength and anchoring effects may be particularly important influences in regards to debris slide stability because they tend to occur on shallow soils (Swanston and Swanson, 1976).

O"Loughlin (1974) examined some mineral debris slides near Vancouver, British Columbia. He states that the condition of partly exposed roots at the mainscarps and lateral scarps indicate that a high percentage of roots, both large and small, at debris slide margins fail in tension. Broken roots extended some distance from the head and lateral scarps suggesting that they had been subject to considerable pull. This examination suggests that the tensile strength of tree roots may be a critical contributor to slope stability. The ability of roots to lengthen without rupturing in response to tensile stress may allow the soil mantle on steep slopes to undergo small, differential movements or creep without serious loss of strength.

Gray and Sotir (1996) report some mean tensile strength values for some common tree and shrub species of the Prince Rupert area: *Picea sitchensis* - 16 MPa, *Pseudotsuga mensieii* - 55 MPa, *Tsuga heterophylla* - 20 MPa and *Vaccinium* spp. - 16 MPa. Generally, the tensile strength of individual roots decreases with increasing root diameter (Gray and Sotir, 1996).

1.4 Mechanics of Slope Movement

The infinite slope model is a common framework for describing the mechanisms and complex relationships between elements that are active in the development of shallow translational slope failures (Wu and Swanston, 1980; Swanston and Howes. 1994; Gray and Sotir, 1996). An infinite slope is considered to be infinite in extent with no top or toe (Al-Khafaji and Andersland, 1992). In regards to folic debris slides in the Prince Rupert area, the length of slope divided by the depth of soil is very large (Appendix 3) and the infinite slope model therefore defines the subject best. In addition, folic soils can be considered to be cohesive soils and therefore the infinite slope model for cohesive soils, rather than the model for cohesionless soils, better describes debris slides in this area.

Because of the geometry of an infinite slope, overall stability can be determined by analyzing the stability of a block of overburden as a ratio between its shear strength or resistance to sliding along the failure surface, and the downslope gravity or shear force. The factor of safety of the block is defined by this ratio. If the shear strength exceeds the shear force, the factor of safety remains greater than 1 and the block of overburden will not fail. By analogy, the block becomes a surrogate of the materials and terrain conditions prevailing in an area (Sidle, 1985; Al-Khafaji and Andersland, 1992; Hammond et al., 1992; Swanston and Howes, 1994; Gray and Sotir, 1996).

The factor of safety, FS, is defined as (Hammond et al., 1992):

$$FS = \frac{C_r + C'_s + \cos^2\alpha\,[q_0 + \gamma\,(D - D_w) + (\gamma_{sat} - \gamma_w)\,D_w]\tan\phi'}{\sin\alpha\cos\alpha\,[q_0 + \gamma(D - Dw) + \gamma_{sat}\,D_w]}$$

where FS = factor of safety

- α = slope angle
- D = total soil thickness
- D_w = saturated soil thickness
- Cr = tree root strength expressed as cohesion
- q_0 = tree surcharge
- C'_s = soil cohesion
- ϕ' = effective internal angle of friction
- γ = moist soil unit weight
- γ_{sat} = saturated soil unit weight
- γ_w = water unit weight

1.5 Research Justification

Folic soils occur extensively on the outer coast of British Columbia, near the Prince Rupert area. Many of these folic soils occur on very steep terrain ranging up to 60 °. This region is dominated by several economically valuable conifer species and is of interest from a timber harvesting perspective.

Terrain stability has become an important aspect of forestry in British Columbia. Under the terms of the British Columbia Forest Practices Code (1995) forestry operations must be conducted to protect, maintain, or enhance the long-term productivity of forest soils and minimize the impacts on water quality. As a result, areas that are to be harvested or modified must undergo some level of terrain stability assessment. Areas that are thought to be unstable or to have a moderate to high likelihood of slope failure following timber harvesting, road construction or modification, or those having a slope angle over 60 percent must be assessed for terrain stability.

There has been very little research regarding the physical properties of folic soils and the failure of organic soils, in general. As a result, little is known regarding factors that contribute towards the failure of folic soils in this region. In an area with such potentially high debris slide risk, it is important to understand the factors contributing towards folic debris slides to make a knowledgeable and accurate terrain stability assessment.

The general purpose of this study is to determine the soil and landscape attributes that contribute significantly towards the occurrence of folic debris slides in the Prince Rupert region. The study approaches taken are direct examination of folic debris slides, comparison of folic debris slides to similar non-debris slide sites and through characterizing the physical and chemical properties of folic soils.

1.6 Hypotheses

Through review of the literature, some factors have been identified as having the potential to be particularly significant in influencing folic debris slides in the Prince

Rupert area. Slope angle is likely a primary factor influencing the stability of folic soils in this region. Slope angles tend to be very steep in the Prince Rupert area and slope angle is often strongly related to shallow slope failures (Appendix 4). A thin, poorly decomposed upper horizon and a thick, well-decomposed lower horizon characterize the general pattern of soil horizonation found in the folic debris slides of this area (Appendix 5). This pattern of soil horizonation may cause the formation of a water table during periods of heavy rainfall due to high infiltration rates in surface horizons and lower percolation rates in lower horizons. In addition, lower soil horizons may be weaker due to decomposition and lack of root mass. Shallow hillslope depressions or particular bedrock structures may concentrate subsurface water and cause high pore water pressures. Finally, rooting strength and its contribution to cohesion is likely a very important aspect in maintaining the stability of folic soils in this region because they are shallow soils that may be poorly attached to the underlying bedrock.

1.7 References Cited

Al-Khafaji, A and Andersland, O. 1992. Geotechnical engineering and soil testing. Saunders College Publishing, Fort Worth, TX. 695 pp.

Boelter, D.H. 1968. Important physical properties of peat materials. Proc. Third International Peat Congress. Quebec, Canada. Energy, Mines and Resources and National Research Council of Canada, Ottawa, Ontario.

British Columbia Forest Practices Code of British Columbia Act. 1995. Forest development plan guidebook. Province of British Columbia. Victoria, B.C.

Clague, John J. 1984. Quaternary geology and geomorphology Smithers - Terrace - Prince Rupert Area, British Columbia. Geological Survey of Canada, Memoir 413, Ottawa, Ontario.

Cruden, D.M. and Varnes, D.J. 1996. Landslide types and processes. Pages 36 - 75 *in* Transportation Research Board Special Report 247.

Fox, C.A., Preston, C.M. and Fyfe, C.A. 1994. Micromorphological and 13C NMR characterization of a Humic, Lignic, and Histic Folisol from British Columbia. Can. J. Soil Sci. **74**: 1 – 15.

Fox, C.A., Trowbridge, R. and Tarnocai, C. 1987. Classification, macromorphology and chemical characteristics of Folisols from British Columbia. Can. J. Soil Sci. **67**: 765 - 778.

Gray, D.H. and Sotir, R.B. 1996. Biotechnical and soil bioengineering slope stabilization: a practical guide for erosion control. John Wiley and Sons Inc., Toronto, Ontario. 378 pp.

Green, R.N., Trowbridge, R.L. and Klinka, K. 1993. Towards a taxonomic classification of humus forms. Forest Sci. Monograph 29.

Hammond, C., Hall, D., Miller, S. and Swetik, P. 1992. Level 1 stability analysis (LISA) documentation for version 2.0. USDA Forest Service, Gen. Tech. Rep. INT-285, Ogden, UT.

Lewis, T. and Lavkulich, L.M. 1972. Some Folisols in the Vancouver area, British Columbia. Can. J. Soil. Sci. **52**: 91 – 98.

MacFarlane, I.C. 1969. Engineering characteristics of peat. Pages 78 – 130 *in* I.C. MacFarlane, ed. Muskeg engineering handbook. University of Toronto Press, Toronto, Ontario.

MacFarlane, I.C. and Williams, G.P. 1974. Some engineering aspects of peat soils. Pages 79 - 93 *in* A.R. Aandahl, ed. Histosols: their characteristics, classification, and use. SSSA Special Publication Series. Soil Science Society of America Inc., Madison, WI.

O'Loughlin, C.L. 1974. A study of tree root strength deterioration following clearfelling. Can. J. For. Res. **4**: 107 – 113.

Schroeder, W.L. and Alto, J.V. 1983. Soil properties for slope stability analysis: Oregon and Washington coastal mountains. Forest Sci. **29**: 823-833.

Schroeder, W.L. and Swanston, D.N. 1987. Application of geotechnical data to resource planning in southeast Alaska. USDA Forest Service, Gen. Tech. Rep. PNW-198, Portland, OR.

Sidle, R.C. 1985. Factors influencing the stability of slopes. Pages 17 – 25 *in* D.N. Swanston, ed. Proc. of a workshop on slope stability: problems and solutions in forest management. USDA Forest Service, Gen. Tech. Rep. PNW-180, Portland, OR.

Sidle, R.C. and Swanston, D.N. 1981. Storm characteristics affecting piezometric rise in unstable hillslopes of southeast Alaska. Transactions of the American Geophysical Union **62**: 856 (Abstr.)

Soil Classification Working Group. 1998. The Canadian system of soil classification. Third ed. Agric. and Agri-Food Can. Publ. 1646. National Research Council of Canada, Ottawa, Ontario.

Swanston, D.N. and Howes, D.E. 1994. Slope movement processes and characteristics. Pages 1 – 17 *in* S.C. Chatwin, D.E. Howes, J.W. Schwab and D.N. Swanston, eds. A guide for management of landslide-prone terrain in the Pacific Northwest. Second Ed. Land Management Handbook No. 18. British Columbia Ministry of Forests. Victoria, British Columbia.

Swanston, D.N. and Swanson, F.J. 1976. Timber harvesting, mass erosion and steepland forest geomorphology in the Pacific Northwest. Pages 199 – 221 *in* D.R. Coates, ed. Geomorphology and engineering. Dowden, Hutchinson and Ross Inc., New York, NY.

Trowbridge, R., Luttmerding, H. and Tarnocai, C. 1985. Report on Folisolic soil classification in Canada. Expert committee on soil survey proceedings of the sixth annual meeting, Guelph, Ontario. Research Branch, Agriculture Canada. Ottawa, Ontario.

Walmsley, M.E. 1977. Physical and chemical properties of peat. Pages 82 - 132 *in* N.W. Radforth and C.O. Brawner, eds. Muskeg and the northern environment. University of Toronto Press, Toronto, Ontario.

Wu, T.H. and Swanston, D.N. 1980. Risk of landslides in shallow soils and its relation to clearcutting in southeastern Alaska. Forest Sci. **26**: 495 – 510.

2.0 STUDY AREA

This study was conducted within a 50 km radius of the city of Prince Rupert, British Columbia (Figure 2-1). Prince Rupert is located on the northern coast of British Columbia at about 54.3° N and 130.5 ° W.

2.1 Geology

The Prince Rupert area is composed mostly of steep mountainous terrain with narrow valleys and undulating lowlands on the outer coast (Clague, 1984; Banner et al., 1993). The Prince Rupert area is underlain by the Ecstall Pluton, west of the Work Channel and the Quottoon Pluton, east of the channel. The area directly around Prince Rupert is composed of thinly bedded metasedimentary rocks with individual beds ranging from 5 - 15 cm in thickness. Quartz diorite forms the greater part of the Quottoon Pluton. Granodiorite forms large parts of the Ecstall Pluton but some parts are composed of homogeneous, massive and generally inclusion-free quartz monzonite (Hutchinson, 1967). The majority of sites examined directly in this study were underlain by diorite, quartz diorite or gneiss (Appendices 4 and 13).

2.2 Climate

The climate of the Prince Rupert area is mostly maritime or oceanic climate with relatively mild temperatures and very heavy rainfall. The summer months tend to be cool and cloudy. The winter months are extremely wet and quite mild, except when frigid Arctic weather systems cover the region. In addition, low elevation coastal areas tend to

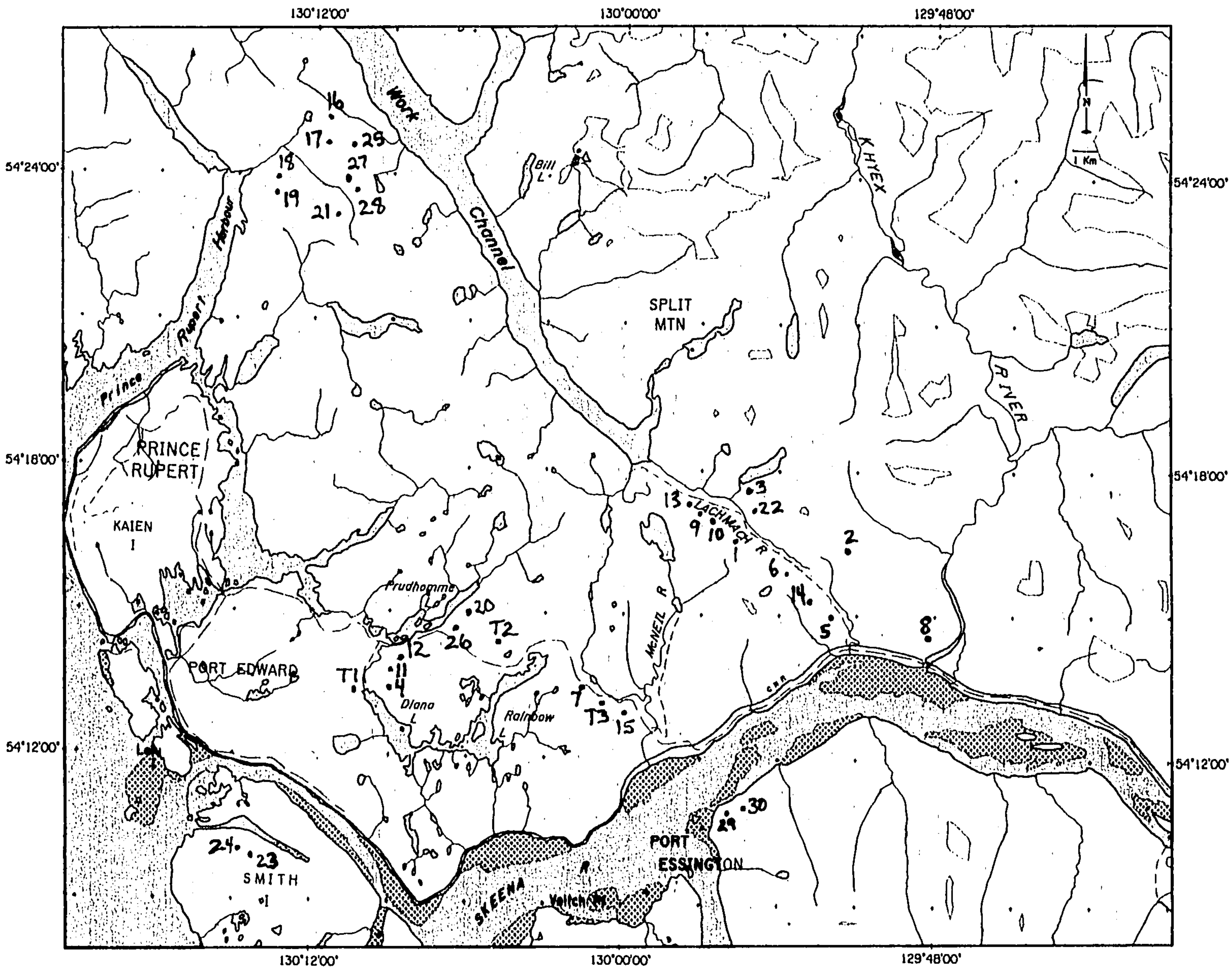
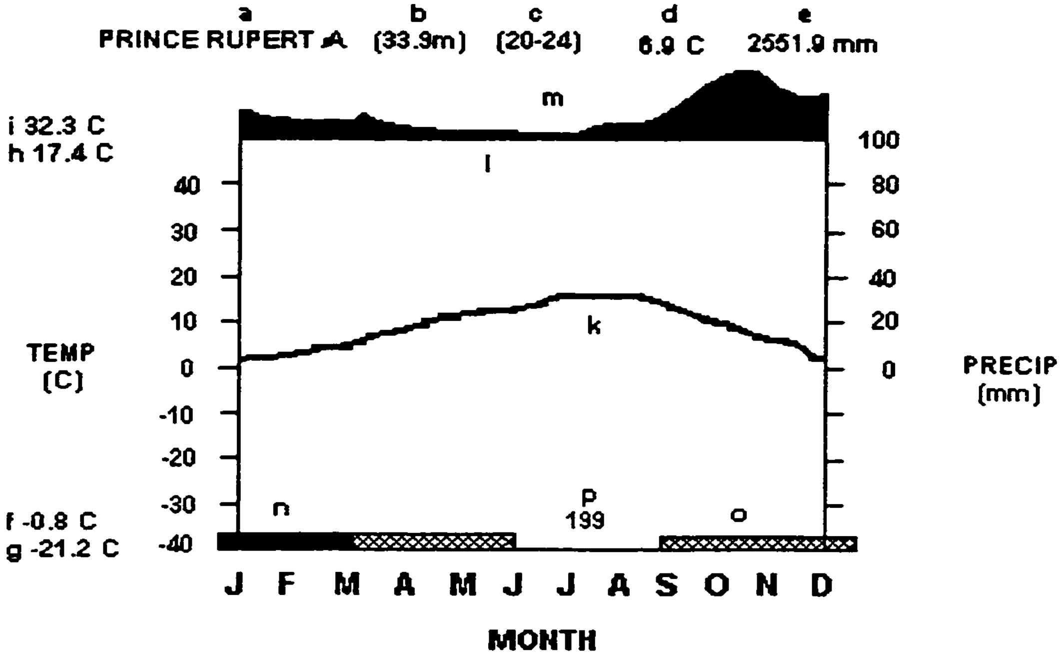


Figure 2-1. Map illustrating the locations of debris slide sites and non-debris slide transects

receive very little snow and soils do not freeze significantly during a normal winter (Banner et al, 1993).

Environment Canada (1998) reports climate normals at the Prince Rupert A station from 1961 to 1990. The mean daily temperature is 6.9 °C annually, 12.4 °C in the summer months (June – August) and 1.7 °C in the winter months (December – February). The mean annual precipitation is 2551.9 mm, with 2409.1 mm falling as rain and 142.6 falling as snow. The mean monthly precipitation is 131.7 mm for the summer months that all falls as rain. The mean monthly precipitation is 245.7 mm for the winter months with 211.3 falling as rain and 34.4 mm falling as snow. Annually, on average there are 236 days with measurable precipitation. For the summer months there are 17 days of measurable precipitation per month and in the winter months there are 21 days of measurable precipitation per month. Potential evapotranspiration can be calculated using the Thornthwaite method (Washburne, 1999). The mean monthly potential evapotranspiration is 102 mm for the summer months, 25 mm for the winter months and 696 mm annually.

Banner (1983) illustrated some climatic information for the Prince Rupert A station in the form of a climatic diagram (Figure 2-2).



a – station
b – height above sea level
c – duration (yrs.) of observations
d – mean annual temperature
e – mean annual precipitation
f – mean daily minimum temperature of the coldest month
g – lowest temperature recorded
h – mean daily maximum temperature of the warmest month
i – highest temperature recorded
k – curve of mean monthly temperature
l – curve of mean monthly precipitation
m – mean monthly rain > 100 mm (black scale reduced by 1/10th)
n – months with mean daily minimum temperature < 0 C (black)
o – months with absolute temperature < 0 C (frosts occur)
p – mean duration (days) of frost free period

Figure 2-2. Climatic diagram for the Prince Rupert A station (Banner, 1983)

Recurrence intervals are used to express the probability a particular storm event will occur in a specified number of years to equal or exceed some given value (Figure 2-3). It refers to the interval between particular events over a large number of years.

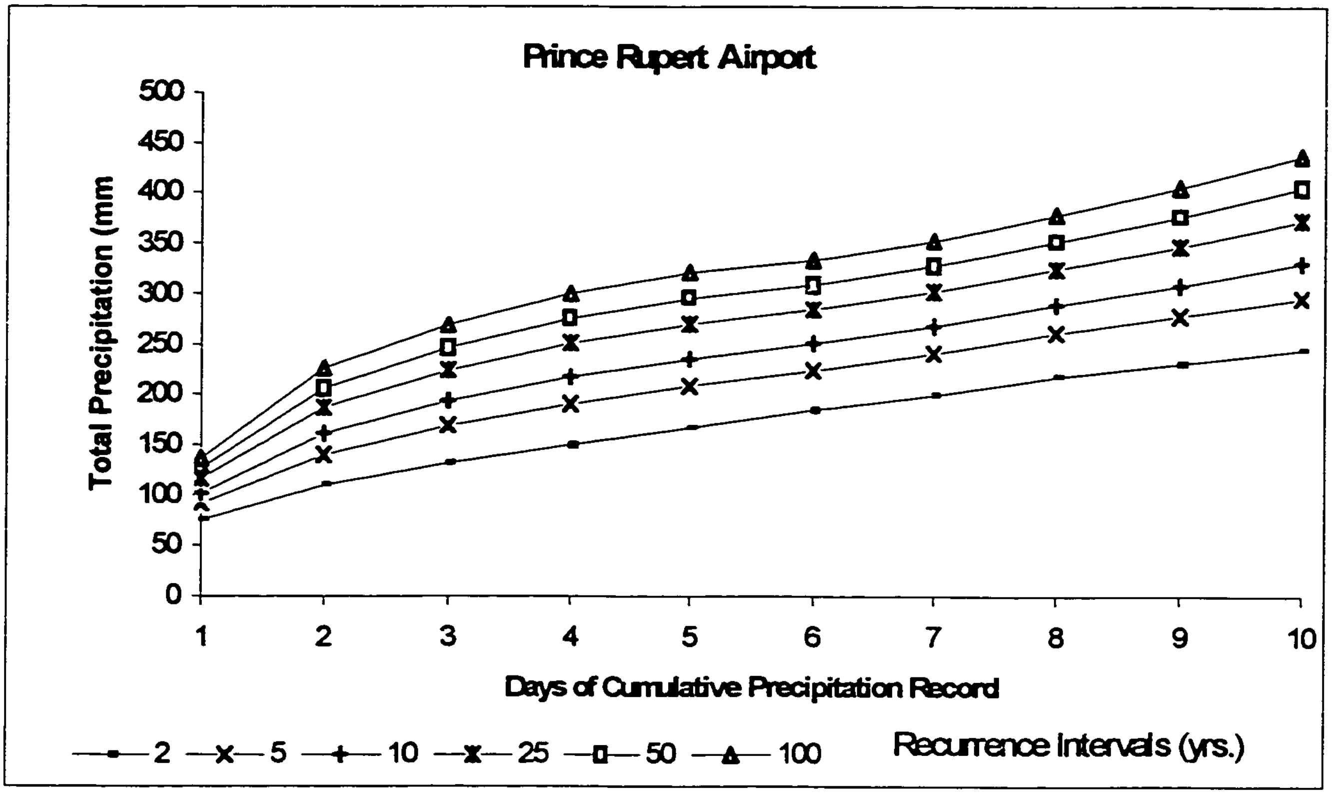


Figure 2-3. Intensity-duration frequency graph for Prince Rupert A station (J.Schwab, British Columbia Ministry of Forests, Smithers, B.C., 1999).

2.3 Vegetation

The natural vegetation of the Prince Rupert area is dominated by old-growth conifer stands of western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*). Sitka spruce (*Picea sitchensis*) is common but never dominant and shore pine (*Pinus contorta* var. *contorta*) and yellow-cedar (*Chamaecyparis nootkatensis*) are abundant on the outer coast in scrub forest form. Deciduous trees such as red alder (*Alnus rubra*) are uncommon, naturally occurring primarily on floodplains and debris slide scars where disturbance exposes mineral soil. Understory vegetation is often dominated by various blueberries and huckleberries (*Vaccinium* spp.) and scattered throughout with small herbs (Banner et al., 1993).

2.4 Soils

Cool, wet weather and granitic parent materials are the two dominant features in shaping the soils of the Prince Rupert area, and combine to create strongly leached, nutrient-deficient mineral soils with thick folic accumulations. Plant roots are located mainly within the folic layers likely because this is where most nutrient cycling occurs. Folic phases of Ferro-Humic and Humic Podzols are common in areas with thicker mineral soils whereas Folisols are dominant where mineral layers are shallow or non-existent over bedrock. Other common soils include Regosols or Brunisols on floodplains and Gleysols on wet sites (Banner et al., 1993).

2.5 References Cited

Banner, A. 1983. Classification and successional relationships of some bog and forest ecosystems near Prince Rupert, British Columbia. M.Sc. Thesis, University of British Columbia, Vancouver, B.C. 233 pp.

Banner, A., MacKenzie, W., Haeussler, S., Thompson, S. and Pojar, J. 1993. A field guide to site identification and interpretation for the Prince Rupert forest region. Land Management Handbook. Ministry of Forests. Crown Publications Inc., Victoria, B.C.

Clague, J.J. 1984. Quaternary geology and geomorphology Smithers - Terrace Prince Rupert area, British Columbia. Geological Survey of Canada. Memoir 413. Ottawa, Ontario. 71 pp.

Environment Canada. 1998. Canadian climate normals 1961 – 1990. Prince Rupert A, British Columbia. 54°18-N 130°26-W/O 34 m.

Hutchison, W.W. 1967. Prince Rupert and Skeena map-area, British Columbia. Geological Survey Of Canada. Paper 66-33. Ottawa, Ontario.

Washburne, J. 1999. Calculation of Potential Evapotranspiration Worksheet. [Online] Available: http://www.hwr.arizona.edu/globe/Hydro/G3/Potential_Evapotranspiration_ Worksheet.html [13 April 2000]

3.0 CHARACTERIZATION OF FOLIC SOILS

3.1 Introduction

North American folic soils are limited in extent and as a result there has been only a small amount of research done regarding even the most basic chemical and physical description. The research that does exist tends to be relatively confined in sample size and extent. Lewis and Lavkulich (1972) described three sites near Vancouver, British Columbia and attempted to characterize the environment in which the Folisols formed. The relationship between Folisol thickness and decomposition and elevation was examined, and it was determined that the thickness of L-F horizons decreases with elevation whereas the thickness of the H horizon increases. The relationship between Folisol chemistry and elevation was also examined although Folisol chemistry appeared to be more related to seepage and bedrock chemistry than elevation. Witty and Arnold (1970) described two Folists occupying steep mountain slopes in New York State. The purpose of this paper was descriptive, discussing the morphology, distribution and classification of these soils. It appears that the distribution and thickness of Folists in New York State are related to slope angle, debris slides and water erosion and deposition. The macromorphology and chemical characteristics of all four Folisol subgroups at nine sites in north coastal British Columbia were described in an effort to improve folic horizon designations (Fox et al., 1987). Fox et al. (1994) considered the chemical and micromorphological description of all four Folisol subgroups at nine sites in north coastal British Columbia. Three main types of horizons were identified: horizons derived from accumulated residues, horizons with advanced decomposition and horizons derived from ligneous material. The chemical characteristics, physical characteristics and spatial variability of twelve pedons in north coastal British Columbia were described in order to understand the occurrence of Folisols in the landscape. The occurrence of Folisolic soils in this region was related to topographic relationship, amount of ligneous material present and the amount of accumulated plant residues (Fox, 1985). Some attempt has been made to discover and explain relationships and trends among folic soil characteristics; however; more research is needed in order to make conclusive statements regarding folic soils.

The main objective of this chapter was to contribute to the further description and understanding of folic soils found in high relief terrain. More specific chapter objectives were to discover and express spatial trends in folic soils both horizontally and vertically.

3.2 Methods and Materials

3.2.1 Site Description and Sampling Design

The pedons selected for the characterization of chemical and physical properties of folic soils were not sampled expressly for purpose of characterization. Folic characterization pedons were sampled both at the upper slope and at the upper-mid slope contours on both sides of a debris slide (Figure 3-1.) Properties of the pre-slide soil are assumed to be the mean of the two replicate pedons sampled at a contour. As a result, the mean of the two values at a given contour is the value used in data analysis for this chapter, with the exception of humus-form summary statistics. The upper slope pedon samples used for folic soil characterization were collected based on the systematic site description and sampling design created for debris slide sites that is described in more detail in section 4.2.1. Therefore, the criteria and constraints used in selecting debris slide pedons also apply to folic characterization pedons. However, only the upper slope pedons are used in Chapter 4 whereas both the upper and upper-mid slope pedons are used for folic characterization.

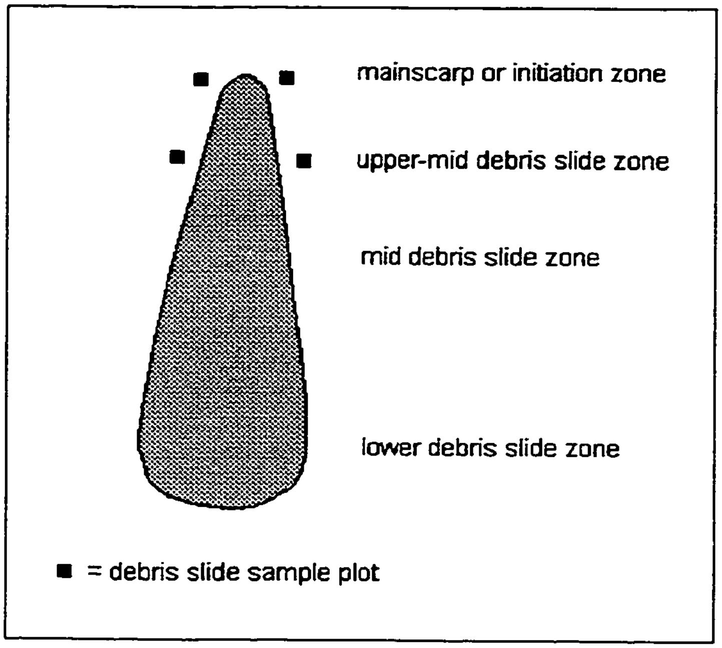


Figure 3-1. Sample plot locations on a typical debris slide

3.2.2 Field Sampling

At each sample site, data were collected regarding geologic, biotic, hydrologic, and soil characteristics. Geologic data collected included slope angle, slope shape, surface configuration, bedrock type, bedrock structure, bedrock exposure, as well as a description of the local setting. Descriptions of these attributes follow guidelines set out by Swanston and Howes (1994). Biotic data included the presence or absence of water tolerant vegetation, root attachment to bedrock, evidence of windthrow, root size and abundance within the soil profile, as well as a percent cover estimate of the tree, shrub, herb and moss and lichen layers. Descriptions of these attributes follow guidelines set out by Green et al. (1993), Swanston and Howes (1994) and B.C Ministry of Forests and B.C. Ministry of Environment Land and Parks (1998). The hydrologic data collected included only a description of field moisture status, following guidelines set out by Green et al. (1993). Soil data noted included horizon nomenclature, horizon depth, von Post humification, soil color, structure, character, consistence, horizon boundary description, and coarse fragment content. Descriptions of these attributes follow guidelines set out by the Soil Classification Working Group (1998) and Green et al. (1993).

3.2.3 Laboratory Analysis

In preparation for laboratory analysis, samples were air-dried and homogenized by hand to pass through a 4-mm sieve. Samples were not sieved through the standard 2-mm because preservation of soil structure was deemed important for some laboratory analyses.

Bulk density was determined by the core method, using aluminum cylinders with volumes of 271.9 cm^3 and 182.5 cm^3, inserted horizontally into the soil. The samples were oven dried at 105 °C until their mass became constant (Day et al., 1979). Particle density was determined using the pycnometer method (Blake, 1965). The standard pycnometer method requires a 10-g sample size. Because of the low bulk density of organic soil materials, the sample size used was often smaller, ranging from 1.5 to 10 g. Porosity (%) was calculated using the equation: (1-(bulk density/particle density)) x 100.

Sand to ash content ratios were approximated on selected samples using a several part procedure. Initially, samples ranging from 7.4 to 70 g were combusted in a muffle furnace at a temperature of 550 °C for 20 hours. The remaining ash was then passed through a nest of 125 μm and 50 μm sieves with the aid of a weak stream of water. The material that did not pass through the sieves was collected and oven-dried at 105 °C until its mass became constant. The mass of sand (> 50 μm) could then be compared with the mass of total ash. Ash content (i.e. the soil mineral content) was determined using the dry-ashing method. A soil sample was combusted in a muffle furnace at a temperature of 550 °C for 20 hours. The oven-dry weight of the sample after combustion is expressed as ash content (Carter, 1993). Organic matter content (g/kg) was defined by the equation: (1000 – Ash Content, g/kg). Organic carbon content (g/kg) was assumed equal to: organic matter content (g/kg) x 0.58.

Water retention properties were determined on the disturbed, 4-mm sieved, air-dried soil samples using pressure plate apparatus at matric potentials of -5, -10, -33 and -1500 kPa (Day et al., 1979). The samples were initially saturated by filling the ceramic plate with water and letting the samples wet from the bottom up overnight ensuring full saturation of the sample. However, some soil samples were hydrophobic and those samples had to be pre-wetted by mixing the sample with water in a beaker. These samples were then placed with the rest of the samples on the ceramic plate filled with water and left to saturate overnight. Detention storage capacity describes the amount of water between saturation and field capacity. It was calculated using the equation: (porosity – volumetric water content at –10 kPa).

The pH was determined using 0.01 M $CaCl_2$ (Day et al., 1979). This procedure requires a 3 g sample size for a constant $CaCl_2$ solution to soil ratio (w/v). However, because of the highly varying ash contents and bulk densities of folic material, soil samples varying from 1 to 9 g were used. The volume of 0.01 M $CaCl_2$ also varied between 40 and 50 mL. Ratios (w/v) between folic material and $CaCl_2$ solution ranged from 1:50 in low bulk density material to 9:40 in higher bulk density material.

Total nitrogen was determined using micro-Kjeldahl digestion (Carter, 1993) followed by quantification of solution NH_4^+ using a Technicon AutoAnalyzer II, Industrial Method No. 334-74W/B^+ (Technicon Industrial Systems, 1977). Exchangeable bases were extracted using 1 M NH_4OAc at pH 7.0 (Carter, 1993) and quantified by atomic absorption spectrophotometry. Total exchange capacity (TEC) was further determined by replacement of $NH4^+$ using the Technicon AutoAnalyzer II, Industrial Method No. 334-74W/B^+ (Technicon Industrial Systems, 1977). Exchangeable bases are expressed both on a whole-soil basis and as a percentage of the TEC. TEC is expressed both on a whole-soil basis and on an ash-free basis. Base saturation was calculated by dividing the sum of exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ by TEC.

3.2.4 Data Analysis

Paired-samples t-tests were employed in order to determine any differences between soil properties at upper vs. upper-mid debris slide positions. The mean distance between upper and upper-mid debris slide sites is 92 m with a standard deviation of 58 m ($n = 30$). The minimum distance is 25 m and the maximum is 225 m. Paired-samples t-tests were also used to determine any differences between horizons denoted by vertical position within a pedon, (i.e. horizon sequence). Paired-samples t-tests were performed using the Paired-Samples T-Test procedure in SPSS (SPSS Inc., 1995). A two-tailed significance level ≤ 0.05 was accepted as significant.

Simple correlations were employed in order to pursue relationships between physical and chemical soil characteristics. Simple correlations were performed using the Bivariate Correlation procedure in SPSS and were executed using a Pearson correlation and a two-tailed test of significance (SPSS Inc., 1995). Only $r \geq 0.5$ and α levels ≤ 0.05 were accepted as significant (Cohen, 1992).

Bivariate regression was employed to describe the relationship between i) gravimetric water content at different matric potentials and ash content, ii) TEC and ash content. Bivariate regression was performed using the Linear Regression procedure in SPSS (SPSS Inc., 1995). Only r^2 values ≥ 0.8 were accepted as significant.

3.3 Results

Summary statistics are presented according to horizon sequence that is, horizon 1, horizon 2 and horizon 3. Non-continuous variables are summarized by frequencies and continuous variables are presented as descriptive summary statistics. Summary desorption curves are presented illustrating mean volumetric and gravimetric water content by horizon sequence at -5, -10, -33 and -1500 kPa. Summary statistics of continuous variables were also completed for any humus-form horizon designation with 5 or more occurrences in the sample.

Particle density values were not separated by horizon because too few measurements were obtained. On a whole-soil basis, particle density had a median of 1.7 Mg/m^3, a mean of 1.8 Mg/m^3 (n = 16), a standard deviation of 0.3 Mg/m^3, a coefficient of variation of 17%, a minimum of 1.5 Mg/m^3 and a maximum of 2.3 Mg/m^3.

3.3.1 Summary Statistics by Horizon Sequence

Table 3-1. Summary frequencies of morphological soil characteristics
horizon 1: n = 116, horizon 2: n = 98, horizon 3: n = 10

Soil Consistence

Value Label	Horizon 1 (%)	Horizon 2(%)	Horizon 3(%)
Tenacious	82.8	5.1	0.0
Pliable	6.0	38.8	40.0
Loose	9.5	56.1	60.0
Resilient	1.7	0.0	0.0

Soil Character

Value Label	Horizon 1 (%)	Horizon 2(%)	Horizon 3(%)
Fibrous	56.9	2.0	0.0
Greasy	4.3	23.5	0.0
Gritty	7.8	54.1	90.0
Mossy	7.8	3.1	0.0
Mushy	1.7	3.1	0.0
Ligneous	4.3	2.0	0.0
Fibrous / Gritty	6.0	0.0	0.0
Fibrous / Ligneous	0.9	0.0	0.0
Felty / Fibrous	3.4	0.0	0.0
Fibrous / Mossy	2.6	0.0	0.0
Greasy / Gritty	0.9	8.2	10.0
Felty / Fibrous / Gritty	0.9	0.0	0.0
Mossy / Gritty	1.7	0.0	0.0
Mossy / Mushy	0.9	0.0	0.0
Fibrous / Mushy	0.0	1.0	0.0
Mushy / Gritty	0.0	3.1	0.0

• '/' represents a sample containing two morphological soil characteristics.

Soil Structure

Value Label	Horizon 1 (%)	Horizon 2(%)	Horizon 3(%)
Non-Compact Matted	81.0	4.1	0.0
Massive	5.2	30.6	60.0
Granular	6.9	26.5	10.0
Blocky	3.4	36.7	30.0
Erect	3.4	1.0	0.0
Wood	0.0	1.0	0.0

Soil Color

Value Label	Horizon 1 (%)	Horizon 2(%)	Horizon 3(%)
2.5YR 2.5/1	1.7	2.0	0.0
2.5YR 3/3	0.0	1.0	0.0
5YR 2.5/1	25.9	8.2	20.0
5YR 2.5/2	13.8	4.1	0.0
5YR 3/2	0.9	0.0	10.0
7.5YR 2.5/1	21.6	39.8	20.0
7.5YR 2.5/2	6.0	7.1	10.0
7.5YR 2.5/3	0.0	1.0	0.0
7.5YR 3/1	2.6	0.0	0.0
7.5YR 3/2	0.0	1.0	0.0
7.5YR 4/4	0.9	0.0	0.0
7.5YR 5/3	0.9	0.0	0.0
10YR 2/1	10.3	27.6	40.0
10YR 2/2	7.8	4.1	0.0
10YR 3/1	0.9	0.0	0.0
10YR 3/2	0.0	2.0	0.0
10YR 3/3	0.0	2.0	0.0
10YR 4/2	0.9	0.0	0.0
10YR 4/4	0.9	0.0	0.0
10YR 4/6	0.9	0.0	0.0
2.5Y 5/3	0.9	0.0	0.0
2.5Y 6/4	1.7	0.0	0.0
2.5Y 6/6	0.9	0.0	0.0
5Y 3/7	0.9	0.0	0.0

Horizon Designation

Value Label	Horizon 1 (%)	Horizon 2(%)	Horizon 3(%)
Ln	1.7	0.0	0.0
Lni	0.9	0.0	0.0
Lv	2.6	0.0	0.0
Lvw	0.0	1.0	0.0
Fm	1.7	0.0	0.0
Fz	1.7	0.0	0.0
Fa	69.0	3.1	0.0
Fai	5.2	1.0	0.0
Faw	2.6	0.0	0.0
Hh	1.7	17.3	0.0
Hhi	3.4	18.4	20.0
Hz	0.0	4.1	0.0
Hzi	0.0	1.0	20.0
Hr	2.6	7.1	0.0
Hri	2.6	3.1	10.0
C	4.3	43.9	50.0

The master upland organic horizons of L, F and H are familiar and commonly used (Soil Classification Working Group, 1998). However, codes for subordinate upland organic horizon, described by Green et al. (1993), are less well known. A Ln horizon is composed of newly accreted, unfragmented plant residues whereas an Lv horizon exhibits initial decay and discoloration. The Fm horizon is composed mainly of fungal mycelia and has a matted structure and tenacious consistence. An Fz horizon is composed primarily of faunal droppings and is weakly aggregated with a loose consistence. A Fa horizon is an intergrade between the Fm and Fz horizons with weak to moderate, non-compact matted structure. Fine substances with very few recognizable plant residues dominate an Hh horizon. The fabric of a Hz horizon is composed mainly of faunal droppings and there are very few recognizable plant residues. An Hr horizon is dominated by fine substances but contains recognizable plant residues. The lowercase modifier 'i' describes an organic horizon that contains intermixed mineral particles finer than 2 mm, with 17 to 35 % organic carbon by mass. The lowercase modifier 'w' describes an organic horizon where > 35 % of the volume of solids is composed of coarse woody debris.

The modal pedon in this study has two horizons. The modal morphology of the upper horizon is fibrous soil character, tenacious soil consistence and a non-compact matted structure. The modal horizon designation for the uppermost horizon is Fa. The modal thickness of a Fa horizon is 9.0 cm, with a tenth percentile of 5.4 cm and a ninetieth percentile of 18.0 cm. The modal morphology of the lower horizon is less clear than the upper horizon, however, some generalizations can be made. Gritty and greasy soil character, pliable and loose consistence and massive, granular or blocky structure are modal for the lower horizon. The modal horizon designations for the lower horizon are Hh, Hhi and C. The modal thickness of the lower horizon is 20.0 cm with a tenth percentile of 10.0 cm and a ninetieth percentile of 48.0 cm.

Table 3-2. Summary statistics for physical and chemical properties of folic soils

horizon 1: n = 60, horizon 2: n = 59, horizon 3: n = 8

Variable	Median	Mean	Std. Dev.	CV (%)	Min.	Max.
Von Post Humification 1	4	4	1	34	2	8
2	8	8	1	13	4	9
3	8	8	1	8	7	9
Ash Content 1 (g kg^{-1})	88	164	169	103	21	653
2	560	583	221	38	80	931
3	844	760	181	24	420	940
Organic Carbon 1 (g kg^{-1})	527	484	98	20	200	570
2	253	239	129	54	40	534
3	91	140	110	75	40	330
Total Nitrogen 1 (g kg^{-1})	10.7	10.7	2.2	20	5.5	16.5
2	7.3	7.3	4.1	56	1.3	19.9
3	4.4	3.4	3.2	73	1.3	9.6
Total N ash-free 1 (g kg^{-1}OM)	12.8	13.2	2.7	14	7.8	22.2
2	17.6	19.8	13.2	67	5.2	87.1
3	19.6	18.5	3.8	21	10.7	23.5
Carbon : Nitrogen Ratio 1	45	46	9	20	26	74
2	33	36	17	48	7	111
3	30	33	9	28	25	54
Bulk Density 1 (Mg m^{-3})	0.08	0.12	0.11	91	0.04	0.69
2	0.26	0.29	0.16	57	0.06	0.83
3	0.29	0.38	0.23	60	0.15	0.71
Porosity 1 (%)	95	94	3	3	82	98
2	88	88	6	7	69	96
3	87	85	8	9	73	93
Detention Storage Capacity 1 (%)	77	76	7	9	46	86
2	73	70	12	17	41	90
3	66	67	12	17	52	83
Gravimetric Water @ -5 kPa 1 (%)	260	266	82	31	80	447
2	119	121	67	55	24	280
3	57	73	38	52	30	129
Gravimetric Water @ -10 kPa 1 (%)	231	230	72	31	65	435
2	85	99	57	58	21	241
3	51	59	31	53	25	111
Gravimetric Water @ -33 kPa 1 (%)	167	166	53	32	53	346
2	67	73	43	59	12	169
3	36	47	32	59	15	106
Gravimetric Water @ -1500 kPa 1 (%)	140	139	45	32	31	280
2	49	54	37	69	12	169
3	15	28	24	86	6	75
Volumetric Water @ -5 kPa 1 (%)	22	26	14	54	12	81
2	24	30	18	61	7	98
3	22	22	7	31	11	33
Volumetric Water @ -10 kPa 1 (%)	19	23	12	54	10	70
2	19	24	17	63	6	86
3	18	18	6	35	8	26
Volumetric Water @ -33 kPa 1 (%)	14	17	9	55	8	51
2	14	17	12	67	6	65
3	12	13	5	37	6	20
Volumetric Water @ -1500 kPa 1 (%)	11	14	7	54	5	42
2	11	13	9	70	3	46
3	7	7	3	46	3	12
pH ($CaCl_2$) 1	3.5	3.5	0.3	7	3.1	4.3
2	3.7	3.6	0.2	6	3.1	4.1
3	3.9	3.8	0.4	9	3.2	4.4
TEC 1 (cmol (+) kg^{-1})	195	199	51	26	73	293

Variable	Median	Mean	Std. Dev.	CV (%)	Min.	Max.
2	81	91	53	58	18	227
3	34	59	51	87	13	145
TEC ash-free 1 (cmol (+) kg^{-1}OM)	238	239	47	20	141	435
2	224	232	136	59	63	1216
3	227	232	56	24	160	322
Exchangeable Ca 1 (cmol (+) kg^{-1})	17.0	18.7	11.0	59	1.4	49.8
2	3.1	4.7	4.7	99	0.5	19.7
3	1.6	2.5	2.6	103	0.5	7.0
Exchangeable Ca / TEC 1 (%)	8.6	9.5	5.4	57	0.9	22.2
2	4.6	5.6	4.2	75	0.5	17.9
3	5.0	4.9	3.5	71	1.1	11.4
Exchangeable Mg 1 (cmol (+) kg^{-1})	3.2	3.3	1.1	35	0.7	5.7
2	0.7	1.0	0.7	68	0.2	2.9
3	0.2	0.5	0.5	98	0.1	1.4
Exchangeable Mg / TEC 1 (%)	1.6	1.7	0.6	37	0.6	4.4
2	1.1	1.1	0.5	44	0.3	2.6
3	0.8	0.8	0.2	26	0.5	1.1
Exchangeable K 1 (cmol (+) kg^{-1})	2.8	2.8	1.2	43	0.5	5.7
2	0.6	0.8	0.4	53	0.3	2.0
3	0.3	0.5	0.3	65	0.2	1.1
Exchangeable K / TEC 1 (%)	1.4	1.4	0.5	36	0.5	2.6
2	1.0	1.0	0.5	49	0.3	2.5
3	0.9	1.0	0.5	44	0.6	2.0
Exchangeable Na 1 (cmol (+) kg^{-1})	0.4	0.4	0.1	33	0.1	0.7
2	0.2	0.2	0.1	54	0.1	0.6
3	0.2	0.2	0.1	59	0.03	0.3
Exchangeable Na / TEC 1 (%)	0.2	0.2	0.6	30	0.07	0.3
2	0.2	0.3	0.2	68	0.1	0.9
3	0.2	0.3	0.2	51	0.2	0.6
Base Saturation 1 (%)	12	13	6	45	4	26
2	7	8	5	60	2	23
3	7	7	4	55	3	14

• OM = Organic Matter

When the physical and chemical properties of folic soils are compared by horizon sequence, variability among the means is large. In Table 3-2, values for coefficient of variation are often large, indicating a large amount of variation in chemical and physical soil characteristics, even within a particular horizon.

The volumetric mean water desorption curves (Figure 3-2) illustrate that there is only a small difference between the water content values when examined on the basis of horizon sequence. The gravimetric mean water desorption curves (Figure 3-3) depict larger differences in water content values when examined on the basis of horizon sequence, than the mean volumetric desorption curves. The significance of the differences in volumetric water content between horizons and gravimetric water content between horizons will be examined further in section 3.3.3. These desorption curves also demonstrate that the largest amount of water desorption occurs at very high matric potentials. In fact, at only Ψ_m = -5 kPa approximately 60 % to 70 % of the saturated water content has drained, as porosity ranges from 85 % to 94 % (Table 3-2).

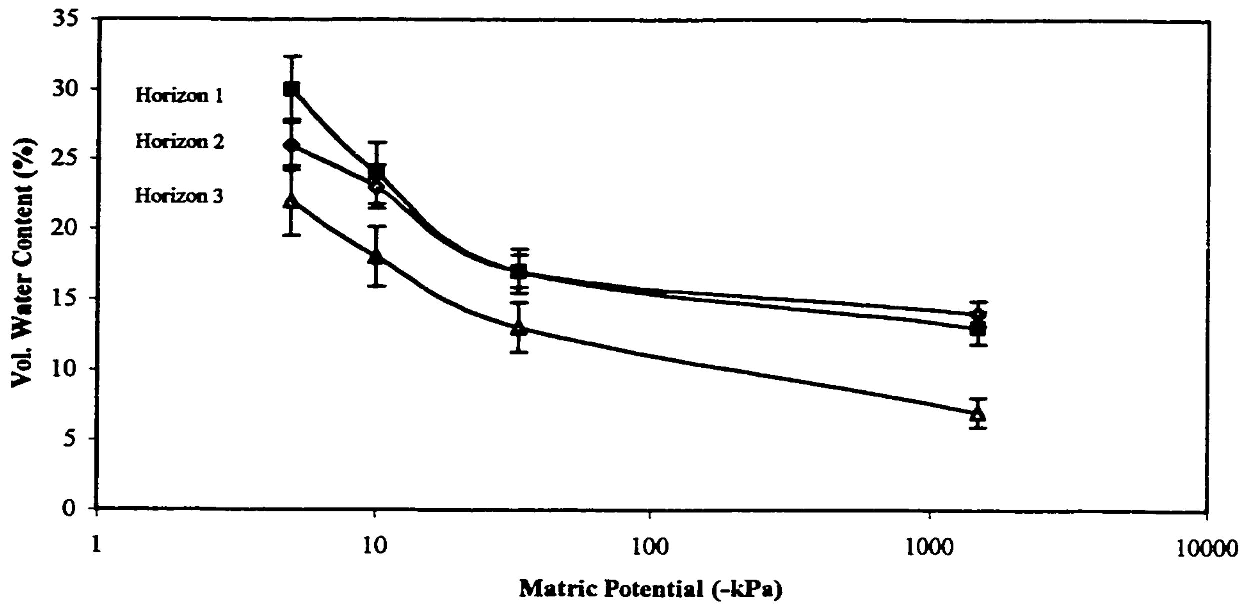


Figure 3-2. Mean volumetric water desorption curves for horizons by vertical sequence in folic pedons (error bars ± 1 SE)

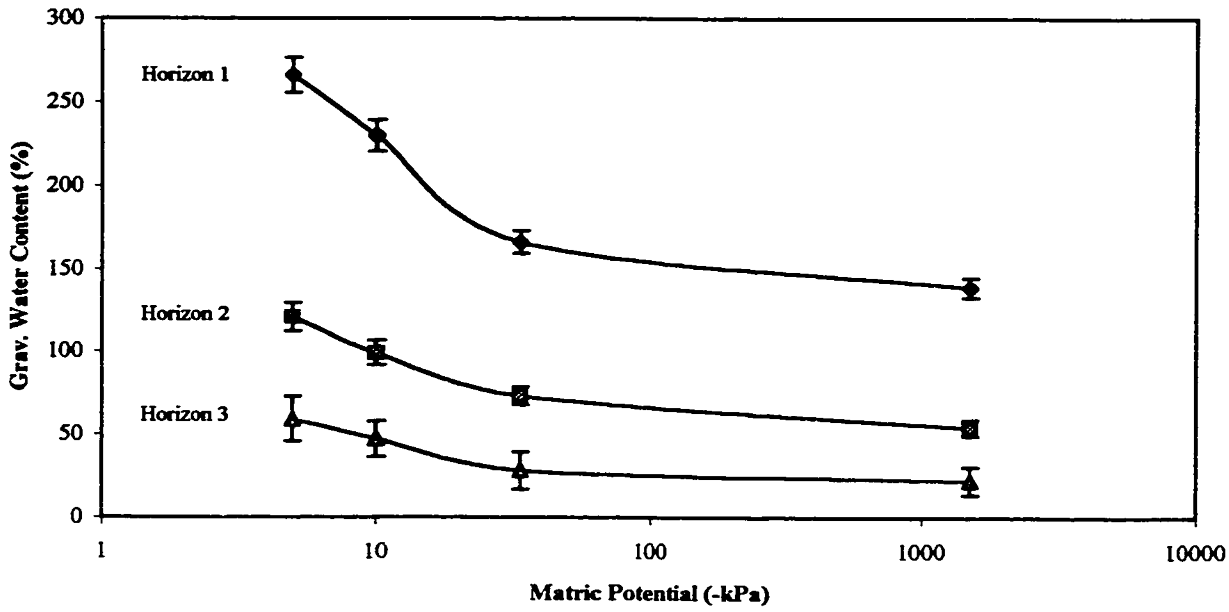


Figure 3-3. Mean gravimetric water desorption curves for horizons by vertical sequence in folic pedons (error bars ± 1 SE)

3.3.2 Summary Statistics for Humus-Form Horizon Designations

In section 3.3.1, morphological soil characteristics are related to common humus-form horizon designations. Summary statistics of chemical and physical soil characteristics were completed for common horizon designations in order to establish a range of values for different folic horizon designations. (Table 3-3 to 3-9).

Table 3-3. Physical and chemical characteristics of horizon Fa **n = 83**

Variable	Median	Mean	Std. Dev.	CV(%)	Min.	Max.
Von Post Humification	3	3.4	0.5	17	3.0	5.0
Ash Content (g kg^{-1})	55	71	53	75	15	295
Organic Carbon (g kg^{-1})	548	539	31	6	409	571
Total Nitrogen (g kg^{-1})	12	12	2	19	7.5	20
Carbon : Nitrogen Ratio	47	47	9	19	27	73
Bulk Density (Mg m^{-3})	0.07	0.07	0.02	32	0.04	0.2
Porosity (%)	96	96	1	2	91	97
Detention Storage (%)	79	78	7	9	50	89
Volumetric Water @ -5 kPa (%)	20	20	6	29	10	47
Volumetric Water @ -10 kPa (%)	18	18	5	29	9	41
Volumetric Water @ -33 kPa (%)	13	13	4	28	7	27
Volumetric Water @ -1500 kPa (%)	11	11	3	30	6	24
pH ($CaCl_2$)	3.5	3.5	0.3	9	2.8	5.0
TEC (cmol (+) kg^{-1})	204	219	45	21	117	349
Exchangeable Ca (cmol (+) kg^{-1})	19.1	20.4	13.5	66	1.4	70.7
Exchangeable Mg (cmol (+) kg^{-1})	3.5	3.6	1.3	36	0.9	6.6
Exchangeable K (cmol (+) kg^{-1})	3.0	3.2	1.4	44	0.8	8.0
Exchangeable Na (cmol (+) kg^{-1})	0.41	0.46	0.17	38	0.23	1.4
Base Saturation (%)	12	13	6	50	2	33

- Frequency Fa = 24 %

Table 3-4. Physical and chemical characteristics of horizon Fai **n = 7**

Variable	Median	Mean	Std. Dev.	CV(%)	Min.	Max.
Von Post Humification	5	4.6	1	21	3.0	6.0
Ash Content (g kg^{-1})	474	428	125	29	170	565
Organic Carbon (g kg^{-1})	305	332	70	22	252	481
Total Nitrogen (g kg^{-1})	8	9	1	14	7	11
Carbon : Nitrogen Ratio	40	39	6	15	28	45
Bulk Density (Mg m^{-3})	0.21	0.23	0.17	77	0.09	0.6
Porosity (%)	90	89	9	10	70	96
Detention Storage (%)	69	72	8	11	64	86
Volumetric Water @ -5 kPa (%)	27	36	33	92	11	109
Volumetric Water @ -10 kPa (%)	20	32	32	102	10	103
Volumetric Water @ -33 kPa (%)	18	23	21	90	6	69
Volumetric Water @ -1500 kPa (%)	12	15	8	54	8	41
pH ($CaCl_2$)	3.6	3.6	0.3	8	2.8	3.9
TEC (cmol (+) kg^{-1})	153	163	35	21	113	225
Exchangeable Ca (cmol (+) kg^{-1})	3.0	5.1	5.4	104	0.7	20.2
Exchangeable Mg (cmol (+) kg^{-1})	1.0	1.3	0.9	70	0.4	4.5
Exchangeable K (cmol (+) kg^{-1})	1.7	1.8	0.5	27	1.1	2.5
Exchangeable Na (cmol (+) kg^{-1})	0.37	0.36	0.12	34	0.19	0.5
Base Saturation (%)	7	8	5	62	5	19

- Frequency Fai = 2 %

Table 3-5. Physical and chemical characteristics of horizon Hh n = 19

Variable	Median	Mean	Std. Dev.	CV(%)	Min.	Max.
Von Post Humification	8.0	8.1	0.8	10	7.0	9.0
Ash Content (g kg^{-1})	276	259	96	37	102	390
Organic Carbon (g kg^{-1})	420	430	56	13	354	521
Total Nitrogen (g kg^{-1})	14	14	4	29	6	24
Carbon : Nitrogen Ratio	30	32	9	29	21	59
Bulk Density (Mg m^{-3})	0.13	0.16	0.10	60	0.08	0.5
Porosity (%)	93	91	5	6	73	96
Detention Storage (%)	72	70	8	11	54	81
Volumetric Water @ -5 kPa (%)	26	31	17	55	16	87
Volumetric Water @ -10 kPa (%)	23	27	15	56	13	73
Volumetric Water @ -33 kPa (%)	17	20	11	56	10	54
Volumetric Water @ -1500 kPa (%)	12	15	8	54	8	41
pH ($CaCl_2$)	3.6	3.6	0.3	8	2.8	3.9
TEC (cmol (+) kg^{-1})	153	163	35	21	113	225
Exchangeable Ca (cmol (+) kg^{-1})	3.0	5.1	5.4	104	0.7	20.2
Exchangeable Mg (cmol (+) kg^{-1})	1.0	1.3	0.9	70	0.4	4.5
Exchangeable K (cmol (+) kg^{-1})	0.8	1.0	0.6	53	0.3	2.6
Exchangeable Na (cmol (+) kg^{-1})	0.2	0.3	0.1	47	0.1	0.6
Base Saturation (%)	3	5	3.7	76	1	15

- Frequency Hh = 6 %

Table 3-6. Physical and chemical characteristics of horizon Hhi n = 25

Variable	Median	Mean	Std. Dev.	CV(%)	Min.	Max.
Von Post Humification	8.0	8.1	0.5	6	7.0	9.0
Ash Content (g kg^{-1})	607	594	76	13	424	688
Organic Carbon (g kg^{-1})	228	235	44	19	181	334
Total Nitrogen (g kg^{-1})	7	7	2	34	5	16
Carbon : Nitrogen Ratio	35	35	8	24	21	55
Bulk Density (Mg m^{-3})	0.22	0.31	0.21	68	0.11	0.6
Porosity (%)	90	86	9	11	69	95
Detention Storage (%)	75	69	17	24	30	27
Volumetric Water @ -5 kPa (%)	22	27	17	64	10	72
Volumetric Water @ -10 kPa (%)	18	23	17	73	8	69
Volumetric Water @ -33 kPa (%)	13	18	14	78	6	58
Volumetric Water @ -1500 kPa (%)	8	12	11	88	4	45
pH ($CaCl_2$)	3.6	3.6	0.2	7	3.2	4.1
TEC (cmol (+) kg^{-1})	88	89	25	28	53	157
Exchangeable Ca (cmol (+) kg^{-1})	2.2	3.1	2.4	77	0.8	10.7
Exchangeable Mg (cmol (+) kg^{-1})	0.9	1.0	0.5	48	0.3	2.1
Exchangeable K (cmol (+) kg^{-1})	0.7	0.7	0.3	35	0.4	1.5
Exchangeable Na (cmol (+) kg^{-1})	0.17	0.19	0.09	50	0.11	0.6
Base Saturation (%)	4	6	3	45	3	14

- Frequency Hhi = 14 %

Table 3-7. Physical and chemical characteristics of horizon Hr n = 10

Variable	Median	Mean	Std. Dev.	CV(%)	Min.	Max.
Von Post Humification	7.0	6.9	0.7	11	6.0	8.0
Ash Content (g kg^{-1})	140	152	77	51	40	336
Organic Carbon (g kg^{-1})	498	492	45	9	385	557
Total Nitrogen (g kg^{-1})	14	13	3	27	4	15
Carbon : Nitrogen Ratio	36	45	30	66	31	131
Bulk Density (Mg m^{-3})	0.09	0.08	0.04	45	0.05	0.2
Porosity (%)	95	94	3	3	89	97
Detention Storage (%)	79	75	12	16	51	87
Volumetric Water @ -5 kPa (%)	20	22	10	45	10	43
Volumetric Water @ -10 kPa (%)	16	20	9	49	10	38
Volumetric Water @ -33 kPa (%)	13	15	6	43	7	27
Volumetric Water @ -1500 kPa (%)	11	12	4	36	7	19
pH ($CaCl_2$)	3.5	3.5	0.4	10	3.1	4.2
TEC (cmol (+) kg^{-1})	176	186	37	20	132	241
Exchangeable Ca (cmol (+) kg^{-1})	14	15	8	51	5	31
Exchangeable Mg (cmol (+) kg^{-1})	2.3	2.6	0.9	34	1.6	4.5
Exchangeable K (cmol (+) kg^{-1})	1.9	1.8	0.4	22	1.2	2.4
Exchangeable Na (cmol (+) kg^{-1})	0.37	0.39	0.14	34	0.21	0.6
Base Saturation (%)	10	11	5	48	5	22

- Frequency Hr = 3 %

Table 3-8. Physical and chemical characteristics of horizon Hri n = 6

Variable	Median	Mean	Std. Dev.	CV(%)	Min.	Max.
Von Post Humification	8.0	7.3	0.8	11	6.0	8.0
Ash Content (g kg^{-1})	563	537	61	11	430	585
Organic Carbon (g kg^{-1})	254	268	36	13	241	331
Total Nitrogen (g kg^{-1})	8	8	2	22	7	12
Carbon : Nitrogen Ratio	31	33	5	16	28	41
Bulk Density (Mg m^{-3})	0.17	0.17	0.06	36	0.09	0.3
Porosity (%)	92	92	3	3	88	96
Detention Storage (%)	78	74	13	17	58	90
Volumetric Water @ -5 kPa (%)	16	21	12	58	7	38
Volumetric Water @ -10 kPa (%)	14	18	10	54	6	30
Volumetric Water @ -33 kPa (%)	11	13	6	47	6	21
Volumetric Water @ -1500 kPa (%)	11	11	5	49	4	20
pH ($CaCl_2$)	3.7	3.6	0.2	6	3.3	3.9
TEC (cmol (+) kg^{-1})	109	103	34	33	60	137
Exchangeable Ca (cmol (+) kg^{-1})	9.0	10.3	8.4	81	1.4	22.3
Exchangeable Mg (cmol (+) kg^{-1})	1.6	1.6	1.0	71	0.2	2.9
Exchangeable K (cmol (+) kg^{-1})	1.0	0.9	0.5	61	0.1	1.4
Exchangeable Na (cmol (+) kg^{-1})	0.20	0.20	0.15	73	0.02	0.5
Base Saturation (%)	15	12	8	61	1	20

- Frequency Hri = 5 %

Table 3-9. Physical and chemical characteristics of horizon C						n = 53
Variable	Median	Mean	Std. Dev.	CV(%)	Min.	Max.
Von Post Humification	8.0	7.6	0.7	9	5.0	9.0
Ash Content (g kg^{-1})	837	835	75	9	710	971
Organic Carbon (g kg^{-1})	95	96	44	45	17	168
Total Nitrogen (g kg^{-1})	3	3	2	67	1	15
Carbon : Nitrogen Ratio	30	31	10	32	6	54
Bulk Density (Mg m^{-3})	0.38	0.41	0.18	45	0.10	0.8
Porosity (%)	85	84	7	8	69	96
Detention Storage (%)	69	67	14	21	34	90
Volumetric Water @ -5 kPa (%)	20	21	11	51	7	49
Volumetric Water @ -10 kPa (%)	15	17	9	53	5	46
Volumetric Water @ -33 kPa (%)	10	11	6	51	4	25
Volumetric Water @ -1500 kPa (%)	6	6	3	50	2	18
pH ($CaCl_2$)	3.8	3.8	0.3	7	3.3	4.4
TEC (cmol (+) kg^{-1})	37	39	20	50	11	103
Exchangeable Ca (cmol (+) kg^{-1})	1.6	2.3	2.1	91	0.3	8.4
Exchangeable Mg (cmol (+) kg^{-1})	0.4	0.5	0.9	159	0.1	6.4
Exchangeable K (cmol (+) kg^{-1}g)	0.4	0.5	0.2	50	0.2	1.2
Exchangeable Na (cmol (+) kg^{-1})	0.13	0.14	0.07	54	0.03	0.5
Base Saturation (%)	7	10	6	65	1	32

- Frequency C = 33 %

Mean volumetric water desorption curves are given for horizon Fa, Fai, Hh and Hhi in order to compare the desorption of folic soils with varying degree of decomposition and varying ash content (Figure 3-4)

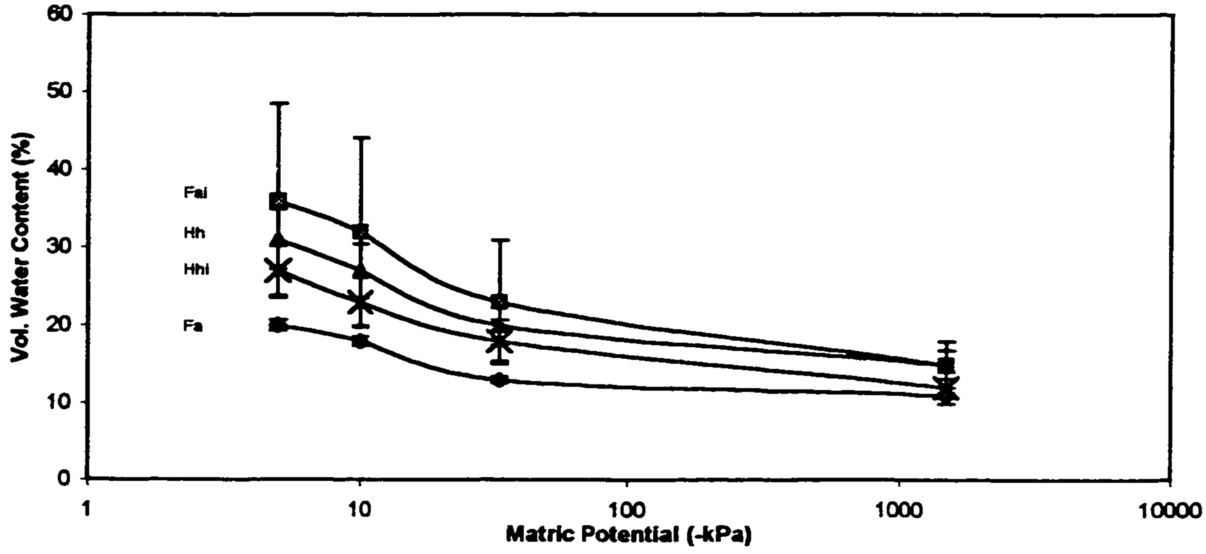


Figure 3-4. Mean volumetric water desorption curves for folic horizons with varying degree of decomposition and ash content (error bars ± 1 SE)

3.3.3 Spatial Comparison of Folic Soil Properties

The soil characteristics of upper debris slide pedons are not significantly different from the characteristics of upper-mid debris side pedons because paired sample t-test results by slope position (not shown) were not significant. However, there are significant differences in soil characteristics vertically within the pedon when pedons for the two slope positions are pooled (Table 3-10). The soil characteristics of horizon 1 were compared with both horizon 2 and horizon 3. In addition, horizon 2 and 3 were also compared.

Table 3-10. Statistical comparison of physical and chemical soil properties by horizon sequence

	Hor. 1 vs. Hor. 2 (n = 59, df = 58)		Hor. 1 vs. Hor. 3 (n = 8, df = 7)		Hor 2 vs. Hor 3 (n = 8, df = 7)	
Variable	t-value	2-Tailed Sig.	t-value	2-Tailed Sig.	t-value	2-Tailed Sig.
Von Post Humification	15.16	**0.00**	-3.75	**0.00**	-0.68	0.52
Ash Content	-11.14	**0.00**	-5.50	**0.00**	-2.67	**0.03**
Organic Carbon	11.24	**0.00**	5.50	**0.00**	2.67	**0.03**
Total Nitrogen	5.82	**0.00**	4.76	**0.00**	2.65	**0.03**
Total Nitrogen ash-free	-3.89	**0.00**	-3.00	**0.02**	0.22	0.83
Carbon:Nitrogen Ratio	3.77	**0.00**	2.29	0.06	0.92	0.39
Bulk Density	-6.58	**0.00**	-2.12	0.10	-0.64	0.55
Porosity	7.70	**0.00**	3.33	**0.01**	1.09	0.31
Detention Storage	3.49	**0.00**	2.07	0.08	1.07	0.32
Grav. Water Content @ -5 kPa	9.99	**0.00**	5.43	**0.00**	2.28	0.06
Grav. Water Content @ -10 kPa	10.34	**0.00**	5.33	**0.00**	2.22	0.06
Grav. Water Content @ -33 kPa	10.26	**0.00**	4.49	**0.00**	1.89	0.10
Grav. Water Content @ -1500 kPa	10.97	**0.00**	4.73	**0.00**	2.19	0.07
Vol. Water Content @ -5 kPa	-1.34	0.18	-0.01	0.99	1.04	0.33
Vol. Water Content @ -10 kPa	-0.80	0.43	0.11	0.91	0.93	0.38
Vol. Water Content @ -33 kPa	-0.57	0.57	-0.06	0.95	0.83	0.43
Vol. Water Content @ -1500 kPa	0.59	0.56	2.11	0.07	1.67	0.14
pH ($CaCl_2$)	-2.53	**0.01**	-2.06	0.08	-1.03	0.39
TEC	10.49	**0.00**	6.92	**0.00**	1.98	0.09
TEC ash-free	0.37	0.71	1.39	0.08	0.14	0.89
Exch. Ca	9.12	**0.00**	3.19	**0.02**	1.85	0.11
Exch. Ca / TEC	4.96	**0.00**	2.07	0.22	1.36	0.22
Exch. Mg	12.31	**0.00**	3.48	**0.01**	1.68	0.14
Exch. Mg/ TEC	6.36	**0.00**	6.36	**0.00**	0.75	0.48
Exch. K	11.51	**0.00**	3.24	**0.01**	3.19	**0.02**
Exch. K / TEC	4.44	**0.00**	0.28	0.79	0.54	0.60
Exch. Na	9.32	**0.00**	3.91	**0.01**	2.52	**0.04**
Exch. Na / TEC	-3.14	**0.00**	-1.19	0.27	-0.12	0.91
Base Saturation	5.57	**0.00**	1.97	0.09	1.31	0.23

• 2-Tailed Significance levels in boldface are significant.

Horizon 1 is significantly different from horizon 2 for all soil variables, except volumetric water content at all matric potentials and TEC on an ash-free basis (Table 3-10). Horizon 1 is significantly different from horizon 3 for only 17 of 30 soil variables. While horizon 2 is significantly different from horizon 3 for only 6 of 30 soil variables. The lack of significant difference between horizon 1 and 3, where one would expect to see the largest difference between variables, may be due to the small sample size of 8 pairs.

3.3.4 Relationships between Chemical and Physical Properties of Folic Soils

Simple correlation and bivariate regression were employed in order to pursue relationships between the physical and chemical properties of folic soils (Appendix 10). Ash content and degree of decomposition appear to be influential soil attributes affecting several folic soil properties.

Ash content correlated significantly with total nitrogen, where $r = -0.77$, $p = 0.00$ and $n = 126$. However, when total nitrogen was expressed on an ash-free basis the correlation was no longer significant.

Bivariate regression was used to characterize the relationship between ash content and TEC. The relationship between ash content (x) and TEC (y) was significant with an r^2 value of 0.85 and a sig. F value of 0.00. The relationship is characterized by the equation: $y = 233.84 - 2.37x$. Relationships also exist between ash content and the exchangeable basic cations (Table 3-11). These relationships are not strong enough to be significant bivariate regressions, but they are strong enough to be significant simple correlations.

Table 3-11. Simple correlation between ash content and exchangeable cations

Variable	r	p	n
Exchangeable Ca (cmol(+) kg^{-1})	**-0.68**	0.00	127
Exchangeable Mg (cmol(+) kg^{-1})	**-0.80**	0.00	127
Exchangeable K (cmol(+) kg^{-1})	**-0.79**	0.00	127
Exchangeable Na (cmol(+) kg^{-1})	**-0.74**	0.00	127
Exchangeable Ca/TEC (%)	-0.28	0.00	127
Exchangeable Mg/TEC (%)	-0.26	0.00	127
Exchangeable K/TEC (%)	-0.15	0.09	127
Exchangeable Na/TEC (%)	0.47	0.00	127

• Correlation coefficients in boldface are significant.

The inverse relationships between ash content and concentration of exchangeable cations (cmol(+)/kg) are significant, however, when exchangeable cations are expressed as a percentage of the TEC the relationships are no longer significant. Significant relationships also exist between von Post humification and TEC and von Post humification and concentration of exchangeable cations (Table 3-12).

Table 3-12. Simple correlation between von Post and exchangeable cations and TEC

Variable	r	p	n
TEC (cmol(+) kg^{-1})	**-0.77**	0.00	127
Exchangeable Ca (cmol(+) kg^{-1})	**-0.65**	0.00	127
Exchangeable Mg (cmol(+) kg^{-1})	**-0.77**	0.00	127
Exchangeable K (cmol(+) kg^{-1})	**-0.81**	0.00	127
Exchangeable Na (cmol(+) kg^{-1})	**-0.70**	0.00	127
TEC ash-free (cmol(+) kg^{-1} OM)	-0.08	0.37	127
Exchangeable Ca/TEC (%)	-0.36	0.00	127
Exchangeable Mg/TEC (%)	-0.38	0.00	127
Exchangeable K/TEC (%)	-0.38	0.00	127
Exchangeable Na/TEC (%)	0.24	0.01	127

• Correlation coefficients in boldface are significant. • OM = Organic Matter

Von Post humification correlates significantly with TEC and all exchangeable basic cations when expressed on a whole-soil basis. However, they do not correlate significantly when expressed on an ash-free basis or as a percentage of the TEC.

Table 3-13. Relationship between ash and gravimetric water content at different matric potentials

Matric Potential	r^2	Sig. F	Equation
-5 kPa	**0.84**	0.00	y = 315.13 – 3.25x
-10 kPa	**0.85**	0.00	y = 273.17 – 2.89x
-33 kPa	**0.84**	0.00	y = 201.03 – 2.13x
-1500 kPa	**0.85**	0.00	y = 165.91 – 1.86x

• r^2 values in boldface are significant.

Gravimetric water content at all matric potentials is significantly dependent upon the ash content of the soil (Table 3-13). All of the relationships are vary slightly, however the relationship between ash content and gravimetric water content at different matric potentials is always negative. On the other hand, the relationship between volumetric water content at different matric potentials and ash content is not significant.

Table 3-14. Simple correlation between gravimetric and volumetric water content at all matric potentials and von Post humification

Variable	r	p	n
Gravimetric Water Content @-5 kPa	**-0.82**	0.00	127
Gravimetric Water Content @-10 kPa	**-0.82**	0.00	127
Gravimetric Water Content @-33 kPa	**-0.80**	0.00	127
Gravimetric Water Content @-1500 kPa	**-0.81**	0.00	127
Volumetric Water Content @-5 kPa	0.11	0.23	126
Volumetric Water Content @-10 kPa	0.06	0.50	126
Volumetric Water Content @-33 kPa	0.06	0.48	126
Volumetric Water Content @-1500 kPa	-0.06	0.54	126

• Correlation coefficients in boldface are significant

Similarly, gravimetric water content at all matric potentials is negatively correlated with von Post humification while volumetric water content is not (Table 3-14).

3.4 Discussion

3.4.1 Ash Content, Degree of Decomposition and Bulk Density of Folic Soils

Ash content is an influential property of folic soils, affecting the values and trends in other physical folic soil properties and chemical properties. Degree of decomposition also affects many other folic soils properties although its influence is often overridden by the more dominant influence of ash content. Ash content and degree of decomposition both influence folic soil properties by affecting bulk density. Ash content also influences folic soil properties via particle size and through replacement of organic matter.

The ash content of folic soils tends to increase with soil depth. The ash content of Folisols found in comparable coastal study sites with relatively high relief terrain illustrates a similar trend (Lewis and Lavkulich 1972; Fox, 1985; Fox et al. 1987). In this study, horizons located nearest the lithic contact are the horizons that tend to be highest in ash content. Mean ash content value was 164 g/kg in horizon 1 and 760 g/kg in horizon 3. The sand-sized material of the ash content (Appendix 25) and its increasing abundance with proximity to the lithic contact seem to point toward the underlying bedrock as the primary source of ash content, although Lewis and Lavkulich (1972) stated that transport from upslope may also be a factor.

Degree of decomposition of folic soils tends to increase with soil depth, from a mean value of 4 for horizon 1 to 8 for horizon 3. The degree of decomposition of Folisols found in comparable high relief, coastal study sites illustrate a similar trend (Lewis and Lavkulich 1972; Fox, 1985; Fox et al. 1987). This trend exists because the genesis of folic horizons is a result of the buildup of litter from surrounding vegetation (Lewis and Lavkulich, 1972). Undecomposed parent material is added to the top of the soil profile. As a result, the lower horizons are the oldest horizons and have had the most time to undergo decomposition processes.

The bulk density of folic soils tends to increase with soil depth. Bulk density was as low as 0.04 Mg/m^3 for horizon 1 and as high as 0.83 Mg/m^3 for horizon 3. The primary reason for this increase with depth is because ash content also tends to increase with depth and mineral material has higher particle density than organic material (Walmsley, 1977). Another important but less influential factor is degree of decomposition. An increase in the degree of decomposition of an organic soil results in an increase in bulk density because strongly decomposed soil contains more solids and less airspace than poorly decomposed soil (Farnham and Finney, 1965; Boelter, 1969).

Witty and Arnold (1970) illustrate similar trends in the bulk density, ash content and degree of decomposition of Folists.

3.4.2 Hydrologic Properties of Folic Soils

The hydrologic properties of folic soils are influenced primarily by two physical soil properties: ash content and degree of decomposition. Ash content is likely the more important of the two due to its effect on soil bulk density and the coarse texture of the ash content of folic soils in the Prince Rupert area.

The porosity of folic soils tends to decrease with increasing soil depth. Mean porosity decreases from 94 % in horizon 1 to 85 % in horizon 3. For the purposes of this study, porosity was calculated using the equation: (1-(bulk density/particle density))*100. As a result, the porosity of a folic soil is influenced by the same properties that affect bulk density values; namely ash content and degree of decomposition, with ash content having a more important influence. Both ash content and degree of decomposition are positively correlated to porosity. Ash content correlates significantly to porosity where, $r = -0.73$, $p = 0.00$ and $n = 126$. Degree of decomposition correlates significantly to porosity where, $r = 0.57$, $p = 0.00$ and $n = 126$.

Gravimetric water contents at -5, -10, -33 and -1500 kPa all tended to decrease with soil depth. This is likely a result of both increasing ash content and increasing decomposition that occurs with depth. It is difficult to discern between the two influences because ash content and von Post humification correlate significantly where, $r = 0.80$, $p = 0.00$ and $n = 127$. Gravimetric water contents at -5, -10, -33 and -1500 kPa are significantly and negatively related to the ash content of folic soils, with r^2 values of

0.84 and 0.85. The implication of this statement is that water retention in folic soils comes primarily from the organic portion of the soil. The ash content of folic soils in this region is primarily composed relatively large, sand-sized particles. Large particles create large pores that drain easily at relatively low matric potentials whereas small particles create small pores that are not easily drained at high matric potentials (Juma, 1999). Therefore, folic soils with high ash contents have poorer gravimetric water retention capabilities than folic soils with low ash content. Degree of decomposition and gravimetric water content at all matric potentials has a significant negative relationship. Poorly decomposed peat has a high total porosity consisting chiefly of large pores that drain easily at relatively high matric potentials whereas strongly decomposed soil is composed primarily of small pores which do not drain at high matric potentials (Boelter, 1964).

Volumetric water contents at -5, -10, -33 and -1500 kPa portray no significant difference with soil depth and hence horizon type. It appears that poorly decomposed, low ash content folic soils drain at similar volumetric water content values as highly decomposed, high ash content folic soils (Figure 3-1). Therefore, kind of material is not important in the volumetric desorption of folic soils, likely due to the highly variable bulk densities between the upper and lower horizons. For instance, the mean bulk density value for horizon 1 is 0.12 Mg/m^3 and horizon 3 is 0.38 Mg/m^3. Moskal (1999) found that highly varying bulk densities, due to differing ash content, had a similar effect upon the volumetric water content of peat : sand mixtures. This trend in the volumetric desorption is very different from that of peat soils. Poorly decomposed fibric peat and low ash content (< 150 g/kg) has a high total porosity consisting chiefly of large pores that drain easily at relatively high matric potentials whereas strongly decomposed humic peat and low ash content is composed primarily of small pores that are not drained at high matric potentials (Boelter, 1964). However, peat profiles tend not to have highly variable ash content like the folic profiles of the Prince Rupert region.

3.4.3 Carbon and Nitrogen in Folic Soils

The organic carbon content of folic soils tends to decrease with increasing soil depth. The mean organic carbon value for horizon 1 samples is 484 g/kg and 140 g/kg for horizon 3. The decrease in organic carbon with depth in folic soils is related to ash content increasing with soil depth. For the purposes of this study, it cannot be discerned whether or not organic carbon is influenced by the degree of decomposition because organic carbon is calculated as a fixed percentage of soil organic matter. Theoretically organic carbon content should decrease with increasing decomposition because the microbial activity that creates decomposition causes a release of carbon in the form of carbon dioxide through microbial respiration (McGill, 1997).

The total nitrogen content of folic soils tends to decrease with soil depth because ash content increases with soil depth and consequently the organic portion of the soil decreases with depth. The mean total nitrogen value for horizon 1 is 11 g/kg and 4 g/kg for horizon 3. In fact, total nitrogen and ash content in folic soils have a significant negative correlation. The implication of this statement is that the total nitrogen found in folic soils comes primarily from the organic portion of the soil (Walmsley, 1977).

If total nitrogen is examined on an ash-free basis the trend is reversed. Total nitrogen on an ash-free basis increases with soil depth. On an ash-free basis, the mean total nitrogen value is 13 g/kg for horizon 1 and 19 g/kg for horizon 3. This trend is likely a result of degree of decomposition increasing as soil depth increases. Total nitrogen on an ash-free basis correlates negatively with degree of decomposition, although correlation coefficient is not considered significant for this study. Accumulations of organic nitrogen are believed to occur where decomposition has progressed the furthest (Frazier and Lee, 1971; Walmsley, 1977). Fox et al. (1994) observed that the net release of nitrogen is related to the onset of decomposition and the disappearance of acid-insoluble organic substances, such as lignin.

The carbon to nitrogen ratio of folic soils tends to decrease with soil depth. The mean carbon to nitrogen ratio is 46:1 for horizon 1 and 33:1 for horizon 3. Both organic carbon and total nitrogen content decrease with soil depth however, it must be that total carbon content decreases more quickly than total nitrogen content with depth. This occurrence is likely a result of loss of carbon through microbial respiration.

3.4.4 Total Exchange Capacity, Exchangeable Basic Cations and pH of Folic Soils

The trends and values for TEC and exchangeable basic cations in folic soils are influenced primarily by two physical soil properties: ash content and degree of decomposition. Ash content is the most influential property and degree of decomposition is less influential but important in terms of the chemical changes that accompany decomposition of organic matter.

The TEC of folic soils tends to decrease with increasing soil depth. The mean value for TEC is 199 (cmol(+)/kg) for horizon 1 and 59 (cmol(+)/kg) for horizon 3. This trend is likely a result of decreasing organic matter content with soil depth. TEC is significantly and negatively correlated with the ash content of folic soils, although the sand-sized ash particles are likely not sources of TEC. The implication of this statement is that the TEC of folic soils comes primarily from the organic portion of the soil. The capacity of a soil to adsorb cations is positively related to its humus content (Walmsley, 1977). There are several theories as to the source of high total exchange capacities in organic matter. Cation exchange may be a result of the substitution of dissociable hydrogen ions in certain organic groups by other ions or may also be a result of carboxyl and hydroxyl groups associated with humic acid and hemicellulose. Regardless of the source, soil organic matter has a high TEC (Walmsley, 1977; Bohn et al., 1979) whereas sand-sized mineral material has relatively low TEC values (Cornell Cooperative Extension, 1997). Therefore, folic soils with a high content of sand-sized ash have low total exchange capacities. The TEC of folic soils is not related to degree of decomposition since t-test results for TEC on an ash-free basis were not significant. In addition, the relationship between degree of decomposition and TEC expressed on an ash-free basis was not significant.

Exchangeable basic cations tended to decrease with soil depth. Fox et al. (1987) reported similar trends with exchangeable Ca^{2+}, Mg^{2+} and K+ and Lewis and Lavkulich (1972) reported some similar trends with exchangeable Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} in Folisols. This trend is likely a result of increasing ash content and decreasing organic matter content with soil depth. The relationships between ash content and exchangeable Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} are significantly negative. The implication of this statement is that the exchangeable basic cations found in folic soils come primarily from the organic portion of the soil. When the exchangeable cations are expressed as a percentage of the

TEC, the trend was still to decrease with soil depth with the exception of Na^+, which then increases with soil depth. However, the relationship between degree of decomposition and exchangeable basic cations expressed as a percentage of the TEC was not significant. Therefore, degree of decomposition does not appear to influence the level of exchangeable basic cations found in folic soils.

The increase in exchangeable Na^+ values when expressed as a percentage of TEC with soil depth is likely a result of a lithic sodium source. Diorite is a common bedrock in the Prince Rupert area, with a frequency of 75 % at study sites. Diorite often contains a proportion of sodium-rich plagioclase feldspar (Ambos, 1997). The relationship between Na^+ expressed as a percentage of TEC and ash content was not significant ($r = 0.47$, where $p = 0.00$ and $n = 126$), although the results a very close to being significant and are worth examination. Exchangeable cation values may be a result of other influences such as seepage of cations from upslope, weathering of bedrock and biological cycling.

Base saturation in folic soils tends to decrease with soil depth. The mean base saturation value decreases from 13 % in horizon 1 to 7 % in horizon 3. Lewis and Lavkulich (1972) discovered similar trends in the base saturation of Folisols of coastal British Columbia. The decrease in base saturation with depth may be a result of disassociable acidic H^+ from carboxyl and hydroxyl groups that are associated with an increase in degree of decomposition (Walmsley, 1977). Base saturation and degree of decomposition are negatively related in a correlation that is near to being significant ($r = -0.40$, where $p = 0.00$ and $n = 126$).

Folic soils tend to become very slightly more basic with increasing soil depth: the mean pH value for horizon 1 samples is 3.5 and 3.8 in horizon 3 samples. Walmsley (1977) and Fox et al. (1987) reported similar trends in peat and Folisols, respectively. This trend is likely a result of increasing ash content and decreasing organic matter content with increasing soil depth. The strong acidity of folic soils is a result of the organic matter portion of the soil therefore, as ash content increases and the source of acidity becomes diluted, soil becomes more basic. Peat soils tend towards more acidic conditions as organic content increases, however, this relationship breaks down at about 80 percent organic matter content (Walmsley, 1977).

3.5 Conclusions

The physical properties of ash and degree of decomposition play a vital role in determining the vertical distribution of values for other physical and chemical properties in folic pedons. Both ash content and degree of decomposition increase with soil depth in the folic soils studied, indicating that the chemical and physical properties of folic soils tend to change along a vertical continuum within the pedon.

Ash content is a very influential physical property of folic soils because the chemical and physical properties of organic matter and mineral material are very different. Ash content influences the bulk density, carbon content, nitrogen content, hydrology and chemistry of folic soils. Farnham and Finney (1965) suggested that when the ash content of an organic soil exceeds 50 percent by mass that it displays properties more characteristic of mineral material than organic material.

Degree of decomposition is also an important physico-chemical property of folic soils because with the decomposition of plant material causes both physical disintegration and biochemical alteration (Farnham and Finney, 1965). As a result, degree of decomposition influences the bulk density, total nitrogen content, hydrology and chemistry of folic soils.

3.6 References Cited

Ambos, E.L. 1997. General geology. [Online] Available: http://seis.natsci.csulb.edu/basicgeol [17 March 2000].

B.C. Ministry of Forests and B.C. Ministry of Environment, Land and Parks. 1998. Field manual for describing terrestrial ecosystems. Land Management Handbook Number 25. Province of British Columbia. Victoria, B.C.

Blake, G.R. 1965. Particle Density. Pages 371 - 373 *in* C.A. Black, ed. Methods of soil analysis, part 1. Agronomy no. 9. American Society of Agronomy. Madison, WI.

Boelter, D.H. 1964. Water storage characteristics of peats in situ. Soil Sci. Soc. Amer. Proc. **28**: 433 – 435.

Boelter, D.H. 1968. Important physical properties of peat materials. Proc. Third International Peat Congress. Quebec, Canada. Energy, Mines and Resources and National Research Council of Canada, Ottawa, Ontario.

Boelter, D.H. 1969. Physical properties of peats as related to degree of decomposition. Soil Sci. Soc. Amer. Proc. **33**: 606 – 609.

Bohn, H.L., McNeal, B.L., O'Connor, G.A. 1979. Soil chemistry. John Wiley & Sons Inc., New York, NY. 329 pp.

Carter, M.R. (Ed.) 1993. Soil sampling and methods of analysis. Canadian Lewis Publishers, Boca Raton, FL. 823 pp.

Cohen, J. 1992. Quantitative methods in psychology: a power primer. Psychological Bulletin. **112**: 155-159.

Cornell Cooperative Extension. 1997. Something to grow on: nutrient management the key to successful nursery crop management. [Online] Available: http://dept/flori/growon/index.html [18 March 2000].

Day, J.H., Rennie, P.J., Stanek, W., Raymond, G.P. 1979. Peat testing manual. National Research Council of Canada, Technical Memorandum No. 125, Ottawa, Ontario. 193 pp.

Farnham, R.S. and Finney, H.R. 1965. Classification and properties of organic soils. Adv. Agron. **17**: 115 – 139.

Fox, C.A. 1985. Characteristics of the Folisolic soils of British Columbia. Pages 180 – 185 *in* J.A. Shields and D.J. Kroetsch, eds. Expert committee on soil survey: proceedings of the sixth annual meeting, Agriculture Canada, Ottawa, Ontario.

Fox, C.A., Preston, C.M. and Fyfe, C.A. 1994. Micromorphological and 13C NMR characterization of a Humic, Lignic, and Histic Folisol from British Columbia. Can. J. Soil Sci. **74**: 1 – 15.

Fox, C.A., Trowbridge, R. and Tarnocai, C. 1987. Classification, macromorphology and chemical characteristics of Folisols from British Columbia. Can. J. Soil Sci. **67**: 765 - 778.

Frazier, B.E. and Lee, G.B. 1971. Soil genesis, morphology, and classification of three Wisconsin Histosols. Soil Sci. Soc. Amer. Proc. **35**: 776 – 780.

Green, R.N., Trowbridge, R.L. and Klinka, K. 1993. Towards a taxonomic classification of humus forms. For. Sci. Monograph 29.

Juma, N. 1999. The pedosphere and its dynamics: a systems approach to soil science. Volume 1. Salman Designs, Edmonton, Alberta. 315 pp.

Lewis, T. and Lavkulich, L.M. 1972. Some Folisols in the Vancouver area, British Columbia. Can. J. Soil. Sci. **52**: 91 – 98.

McGill, W.B. 1997. Soil Environmental Microbiology & Biochemistry – Lecture Guide 1997. Department of Renewable Resources. University of Alberta. Edmonton, Alberta.

Moskal, T.D. 1999. Moisture characteristics of coarse textured soils and peat : mineral mixes. M.Sc. Thesis, University of Alberta, Edmonton, Alberta. 139 pp.

Soil Classification Working Group. 1998. The Canadian system of soil classification. Third Ed. Agric. and Agri-Food Can. Publ. 1646. National Research Council of Canada, Ottawa, Ontario.

SPSS Inc. 1995. SPSS for windows. Release 6.1.3. Standard Version. SPSS Inc. 1989 – 1995.

Swanston, D.N. and Howes, D.E. 1994. Slope movement processes and characteristics. Pages 1 – 17 *in* S.C. Chatwin, D.E. Howes, J.W. Schwab and D.N. Swanston, eds. A guide for management of landslide-prone terrain in the Pacific Northwest. Second Ed. Land Management Handbook No. 18. British Columbia Ministry of Forests. Victoria, British Columbia.

Technicon Industrial Systems. 1977. Technicon autoanalyzer II individual / simultaneous determination of nitrogen and/or phosphorous in BD acid digests. Tarrytown, N.Y.

Walmsley, M.E. 1977. Physical and chemical properties of peat. Pages 82 - 132 *in* N.W. Radforth and C.O. Brawner, eds. Muskeg and the northern environment. University of Toronto Press, Toronto, Ontario.

Witty, J.E. and Arnold, R.W. 1970. Some Folists on Whiteface Mountain, New York. Soil Sci. Soc. Amer. Proc. **34**: 653 – 657.

4.0 FACTORS CONTRIBUTING TOWARDS FOLIC DEBRIS SLIDES

4.1 Introduction

Swanston and Swanson (1976) discussed shallow debris slides in the steep competent bedrock of the Coast Mountain Ranges of Oregon, Washington, British Columbia and Alaska. The stability of these areas can be heavily impacted by timber harvesting operations, particularly through the alteration of hydrology. Sidle and Swanston (1982) and Sidle (1985b) considered coastal Alaskan debris slides. They state that high intensity rainfall events, a permeable forest mantle and geologic concave depressions that collect groundwater are key debris slide triggers. Four natural, process-related categories that can influence the stability of forested slopes in the coastal ranges of Oregon and Washington are geologic factors, biotic factors, hydrologic factors and soil properties (Schroeder and Alto, 1983). Contributions to debris slides may appear as landscape-level characteristics such as geologic features, or they may appear as smaller-scale, pedon-level characteristics such as soil attributes.

It is important to determine the factors that contribute toward slope failure in the Prince Rupert region as it has such a high debris slide risk. By identifying and understanding the possible causes of debris slides, there can be more confidence in minimizing the risk of debris slides that occur through timber harvesting activities. There has been little investigation regarding folic debris slides in the Prince Rupert area. However, there have been several investigations of shallow debris slides in the Coast Ranges of the Pacific Northwest.

The following hypotheses were formed concerning contributions to slope failure in this region: i) Slope angle is a primary factor influencing the stability of folic soils in this region, ii) soil characteristics and bedrock characteristics are closely related to slope hydrology and have an important effect on slope stability.

The objectives of this chapter were to determine the factors and relationships that contribute toward folic debris slides in the Prince Rupert area, on both a landscape and a pedon scale.

4.2 Methods and Materials

4.2.1 Site Description and Sampling Design

Thirty sampling sites were chosen within an approximately 50 km radius surrounding the city of Prince Rupert, British Columbia. Folic debris slides were identified by several methods: debris slide scar recognition, debris slide sidewall recognition in older sites and by the fact that they tended to occur more often in western redcedar – western hemlock forests than mineral debris slides that were more often located in Sitka spruce forests. The apparent age of folic debris slides in this study range between approximately 1 to 300 years.

There were two criteria used in selecting sample debris slide sites. The debris slides must occur on open slopes, outside of a confining drainage, in order to avoid well-documented indicators of slope instability, such as gullies (Swanston and Howes, 1994). In addition, the soil profile of a sample debris slide site should contain only folic material over bedrock, with little or no mineral soil component. The failure of organic soil that was of interest therefore soils with thick mineral horizons were excluded from the study.

Some mineral soils were unknowingly sampled. At the time of field sampling, the samples in question were thought to be Folisols, but upon laboratory investigation they were discovered to be otherwise. However, these soils tend to have a strong folic influence and were therefore included in the study regardless.

Sample collection on the folic debris slides was further divided into two sample plots per slide. These plots were located, in most cases, within 5 m of the path of damage, outside of the debris slide scar on opposite sides of the initiation zone or mainscarp (Figure 4-1). Situations in which this was not the case are due to accessibility problems, when the terrain was too steep for safe travel.

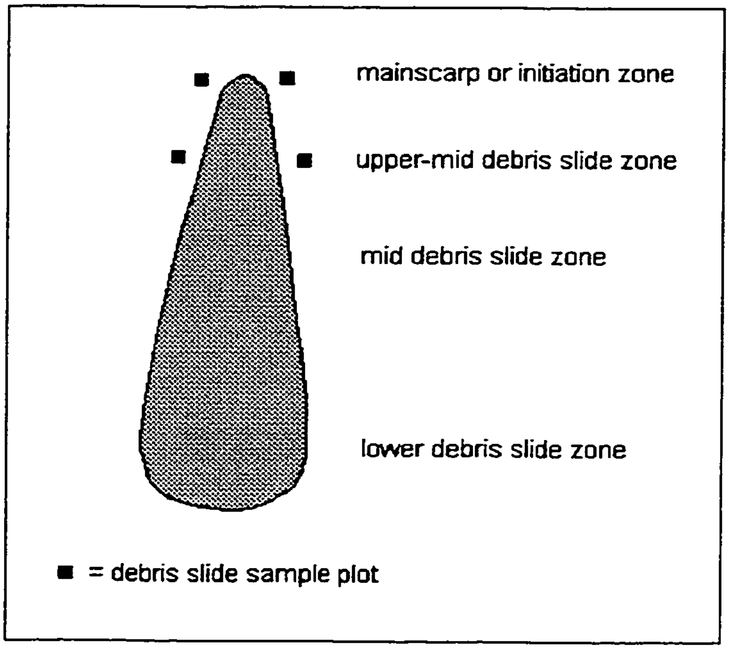


Figure 4-1. Sample plot locations on a typical debris slide.

4.2.2 Field Sampling

Field sampling methods for debris slide sites are the same as those used at folic soil characterization sites. Refer to section 3.2.2 for a detailed description of the field sampling methods used at these sites.

4.2.3 Laboratory Analysis

In preparation for laboratory analysis, samples were air-dried and homogenized by hand to pass through a 4-mm sieve. Samples were not sieved through the standard 2-mm because preservation of soil structure was deemed important for some laboratory analyses. Bulk density was determined by the core method, using cylinders with volumes of 271.9 cm^3 and 182.5 cm^3, inserted horizontally into the soil. The samples were oven dried at 105 °C until their mass became constant (Day et al., 1979). Particle density was determined using the pycnometer method (Blake, 1965). The standard pycnometer method requires a 10-g sample size. Because of the low bulk density of organic soil materials, the sample size used was often smaller, ranging from 1.5 to 10 g. Ash content was determined using the dry-ashing method, also commonly referred to as loss-on-ignition. The organic matter was combusted in a muffle furnace at a temperature of 550 °C for 20 hours (Carter, 1993).

4.2.4 Data Analysis

Principal components analysis (PCA) was performed separately on both landscape and pedon-level variables using the Principal Components procedure in SPSS (SPSS Inc., 1995). The PCA was executed using a varimax rotation and extracting eigenvalues >1 only. By conducting the PCA on landscape and pedon-level variables separately, the guideline of at least five cases for each observed variable was satisfied (Tabachnick and Fidell, 1989). For both PCAs, only a loading ≥ 0.5 was accepted as being significant in the formation of the principal component or factor. A loading ≥ 0.5 is the traditional cutoff point in PCA procedure (Sharma, 1996). In regards to summary statistics, continuous data are presented as descriptive summary statistics and non-continuous data are summarized by frequencies.

Two duplicate samples were taken at the mainscarp on either side of the debris slide for both landscape and pedon-level variables. What lies between the two sample locations is assumed to be the mean of the two replicates. The mean of the two replicates was the value used in the PCA. Non-continuous data were merged creating additional ranked categories as a substitution for a mean value. In addition, for the pedon-level, the data used in analysis were obtained from the soil horizon in contact with bedrock because it is that horizon which fails initially. For all PCA and summary statistics in this chapter $n = 30$. For simple correlations in this chapter $n = 126$ or 216 because upper-mid slope position data were included to allow for a stronger correlation and / or duplicate samples were unable to merged.

Landscape-level variables can be defined as those variables that vary over larger distances than the pedon-level, that is, approximately > 50 m. The landscape-level variables utilized in the PCA include bedrock structure, slope shape, slope angle, surface configuration, weighted vegetation cover and the presence or absence of water-tolerant vegetation (Appendix 11). These variables are non-continuous with the exception of slope angle and weighted vegetation cover. A ranking system was devised to code non-continuous data. The system was based upon whether a particular landscape attribute was more or less likely to contribute towards debris slide occurrence. A rationale based on debris slide theory and literature exists for all non-continuous variables (Sidle, 1985a; Al-Khafaji and Andersland, 1992; Swanston and Howes, 1994; Gray and Sotir, 1996).

The bedrock structure variable is ranked according to the idea that jointed and fractured bedrock is more likely to contribute towards folic debris sliding than massive bedrock structure. Joints and fractures are often ready-made zones of weakness and avenues for deep penetration of groundwater or groundwater discharge. It was observed that bedrock jointing in the study area was primarily parallel to the slope, providing little mechanical support for the overburden. Overburden can also be poorly attached to massive bedrock but it does not include planes of weakness nor excess hydrostatic pressure (Sidle, 1985a; Swanston and Howes, 1994).

The slope shape variable is ranked according to the idea that convex slopes are least likely to contribute toward slope failure, followed by straight slopes and finally concave slopes are most likely to contribute towards slope failure. Concave slopes tend to concentrate subsurface water flow and convex slopes tend to disperse subsurface water flow (Sidle, 1985a; Swanston and Howes, 1994). The concentration of water flow results in a situation where saturated soil conditions are more likely and coincident instability is more likely. The surface configuration variable is ranked according to the idea that uniform and smooth slopes are less stable than irregular and benchy slopes. Irregular slopes may have flat segments that serve to support the overburden through a buttressing mechanism. This makes slope failure less likely. However, irregular and benchy slopes may have more seeps and springs as a result of breaks in the slope, allowing groundwater an exit point.

The water-tolerant vegetation variable is ranked according to the idea that the presence of water-tolerant vegetation indicates high groundwater levels and impeded soil drainage (Swanston and Howes, 1994), in turn indicating an increased probability of saturated soil conditions and therefore reduced slope stability. Weighted vegetation cover is a variable that has combined tree, shrub and herb cover percentages into a single new variable, created by multiplying the individual cover percentages by a factor of 1 for trees, 0.3 for shrubs and 0.1 for herbs then obtaining the sum. The factors are simply estimated in an attempt to account for the variable root volume found amongst these strata of vegetation.

Pedon-level variables can be defined as those variables that vary over a distance $<$ 10 m. The pedon-level variables utilized in the PCA include: ash content, mass of saturated soil per unit surface area, porosity, root abundance class, soil structure and von Post humification (Appendix 12). These variables are continuous with the exception of root abundance class and soil structure. As with the landscape-level variables, non-continuous data were ranked and coded. The root abundance class variable was ranked on the basis of estimated root volume. The classes that include the largest volume of roots are less likely to create unstable conditions than the classes with the smallest volume of roots. Root content in a soil can increase the stability of a slope by the contribution of root cohesion to soil cohesion (Sidle, 1985a; Al-Khafaji and Andersland, 1992; Gray and Sotir, 1996). The soil structure variable is ranked based on the idea that soil structure with higher porosity is less likely to contribute towards slope instability.

Better soil drainage is less likely to result in saturated soil conditions. This rationale is based upon the significant linear relationship that exists between the soil structure and porosity values. The correlation between soil structure and porosity is significant, where $r = 0.53$, where $p = 0.00$ and $n = 216$.

4.3 Results

4.3.1 Landscape-Level Summary Statistics

Table 4-1. Descriptive summary statistics for landscape-level variables

Variable	Median	Mean	Std. Dev.	CV (%)	Min.	Max.
Slope Angle (°)	44	43	7	16	30	60
Weighted Vegetation Cover (%)	72	71	11	16	41	96

For landscape-level summary statistics both continuous (Table 4-1) and non-continuous data (Table 4-2) are presented. The sample sites chosen for this study have a relatively large range in slope angle, although the coefficient of variation is small. It is important to note the distribution of values because slope angle has traditionally been thought to have a direct and primary influence on slope stability (Sidle, 1985a; Swanston and Howes, 1994).

Table 4-2. Summary frequencies for landscape-level variables

Bedrock Structure

Value Label	Frequency (%)
Jointed / Fractured	77
Massive	23

Slope Shape

Value Label	Frequency (%)
Convex	47
Straight	23
Convex / Straight	13
Concave	10
Concave / Straight	7

Surface Configuration

Value Label	Frequency (%)
Irregular / Benchy	67
Uniform / Smooth	33

Water-Tolerant Vegetation

Value Label	Frequency (%)
Present	63
Absent	37

The frequency distribution for bedrock structure supports the hypothesis that jointed and fractured bedrock is less stable than massive bedrock. The frequency distribution for slope shape runs contrary to published data by Sidle (1985a) and Swanston and Howes (1994) that state that concave slopes are the most likely to create unstable conditions. However, Krag (1986) illustrated that debris slides on the Queen Charlotte Islands had a similar distribution of slope shapes as this study, with dominantly convex slopes. He noted that convex initiation zones were usually associated with seepage zones.

The frequency distribution for surface configuration also runs contrary to the hypothesis that uniform and smooth slopes are more likely to contribute toward instability. Water-tolerant vegetation frequencies agree with published data that state that the presence of water-tolerant vegetation is more likely to be characterized by slope instability than its absence (Swanston and Howes, 1994).

4.3.2 Landscape- Level PCA Results

The landscape-level PCA resulted in the extraction of three factors that accounted for 73.6 % of variation (Table 4-3). Factor 1 had an eigenvalue of 1.79 and accounted for 29.8 % of variation. Factor 2 had an eigenvalue of 1.60 and accounted for 26.6 percent of variation. Factor 3 had an eigenvalue of 1.03 and accounted for 17.2 percent of variation.

Table 4-3. Rotated factor loading matrix of landscape-level PCA

Variable	Factor 1	Factor 2	Factor 3
Bedrock Structure	**0.72**	0.41	0.07
Slope Shape	-0.03	0.05	**-0.94**
Slope Angle	**-0.82**	0.23	0.17
Surface Configuration	-0.12	**0.70**	**0.53**
Weighted Vegetation Cover	**0.73**	0.03	0.07
Water-Tolerant Vegetation	-0.09	**-0.86**	0.16

• Factor loadings in boldface are significant.

Variables considered significant in the formation of Factor 1 include bedrock structure, slope angle and weighted vegetation cover. Surface configuration and water-tolerant vegetation are considered significant in the formation of Factor 2. Slope shape and surface configuration are considered significant in the formation of Factor 3.

In Factor 1, bedrock structure loads in the direction of massive structure, slope angle decreases and weighted vegetation cover increases. The variables that load on Factor 1 describe a landscape that is resistant to failure primarily though geologic means. As previously discussed, massive bedrock is less likely to contribute towards slope instability than jointed and fractured bedrock. Obviously, a decrease in slope angle also decreases the likelihood of slope failure. Vegetation cover may be related to slope angle; the steeper the slope, the less vegetation that thrives. Therefore, a consequence of decreasing slope angle in this factor is an increase in vegetation cover and increased vegetation cover also increases the likelihood of slope stability. Factor 1 will be named 'Geologic Resistance to Failure' Factor.

In Factor 2, surface configuration loads in the direction of irregularity and the presence of water-tolerant vegetation increases. The variables that load on this factor are primarily hydrologic in influence. An irregular and benchy slope may have more seeps and springs as a result of breaks in the slope that allow groundwater an exit point. As mentioned previously, water-tolerant vegetation thrives in areas containing springs because of relatively permanent high groundwater levels. As a result of the above discussion, Factor 2 will be named 'Geologic / Hydrologic Instability 1' Factor.

In Factor 3 slope shape loads in the direction of concavity and surface configuration loads in the direction of irregularity. The variables that load on Factor 3, like Factor 2, are primarily hydrologic in influence. A concave slope shape tends to concentrate water on a slope and as mentioned previously, an irregular and benchy slope may allow the formation of springs and seeps. As a result of the above discussion, Factor 3 will be named 'Geologic / Hydrologic Instability 2' Factor.

4.3.3 Pedon-Level Summary Statistics

Table 4-4. Descriptive summary statistics for pedon-level variables in lowest horizon at upper slope position, n= 30

Variable	Median	Mean	Std. Dev.	CV (%)	Min.	Max.
Ash Content (g kg^{-1})	553	557	18	3	102	860
Saturated Soil Mass (kg m^{-2})	461	454	206	45	168	1024
Porosity (%)	88	87	7	8	69	96
Von Post Humification	8	8	1	13	5	9

For pedon-level summary statistics both continuous (Table 4-4) and non-continuous data are presented (Table 4-5). All of the variables in Table 4-4 have very low coefficient of variation values with the exception of saturated soil mass. A higher level of variation is expected in saturated soil mass because it is a secondary measurement composed of several primary variable including coarse fragment content, bulk density and porosity.

Table 4-5. Summary frequencies for pedon-level variables in lowest horizon at upper slope position, n = 30

Root Content Class

Value Label	Frequency (%)
Few, Fine to Very Fine	53
Common, Fine to very Fine	33
Few, Medium to Very Fine	10
Common, Medium / Abundant, Fine to Very Fine	3

Soil Structure

Value Label	Frequency (%)
Medium	23
Massive / Medium	23
Massive	13
Fine	13
Medium / Fine	10
Non-Compact Matted	7
Non-Compact Matted / Medium	7
Massive / Fine	3

The frequency distribution of root content class is in accordance with literature that networks of medium and small-sized roots may provide lateral support and therefore increase slope stability (Sidle, 1985a; Swanston and Howes, 1994). The soil structure frequency distribution illustrates that soil structure at debris slide sites have no strongly dominant type, although the lowest soil horizon has a very low frequency of well drained, non-compact matted structure.

4.3.4 Pedon-Level PCA Results

The pedon-level PCA resulted in the extraction of three factors that accounted 74.6 % of variation (Table 4-6). Factor 1 had an eigenvalue of 2.17 and accounted for 36.1 % of variation. Factor 2 had an eigenvalue of 1.27 and accounted for 21.1 percent of variation. Factor 3 had an eigenvalue of 1.04 and accounted for 17.4 percent of variation.

Table 4-6. Rotated factor loading matrix of pedon-level PCA

Variable	Factor 1	Factor 2	Factor3
Ash Content	0.15	**0.86**	0.07
Saturated Soil Mass	0.01	0.10	**0.94**
Porosity	**0.54**	**-0.64**	-0.04
Root Content	**0.80**	0.26	-0.04
Soil Structure	**0.62**	0.07	**-0.51**
Von Post Humification	**-0.80**	0.35	-0.05

• Factor loadings in boldface are significant.

Variables considered significant in the formation of Factor 1 include porosity, root content, soil structure and von Post humification. Ash content and porosity are considered significant in the formation of factor 2. Variables considered significant in the formation of Factor 3 include saturated soil mass and soil structure.

In Factor 1, soil structure loads in the direction of non-compact matted structure, porosity and root content are increasing, and von Post humification is decreasing in value. The variables that load on Factor 1 describe a soil condition that is resistant to failure. A non-compact matted structure tends towards being less likely to become saturated. Soil structure with high porosity makes saturated conditions less likely to occur because more water is required to fill pores. Porosity and soil structure are significantly correlated. Increased root volume in soil increases root cohesion values, therefore increasing soil shear strength. Pedons with lower von Post values tend to be higher in porosity and retain less water than soils with higher von Post values, making the saturated soil conditions less likely to occur. Because saturated conditions decrease soil shear strength and root cohesion increases shear strength, Factor 1 will be named the 'Increased Shear Strength' Factor.

In Factor 2, ash content values are increasing and porosity values are decreasing. The variables that load on Factor 2 describe a soil that has an increased risk of failure. An increase in the ash content of the soil increases soil bulk density, therefore decreasing soil porosity. In addition, an increase in the ash content of a soil decreases its organic matter content, therefore reducing the extra porosity that can sometimes be found in plant cellular structure. The above variables combine to create a situation in which saturated soil conditions are more likely to occur and as a result, soil shear strength is more likely to be reduced. As a result, Factor 2 will be named the 'Soil / Hydrologic Instability' Factor.

In Factor 3 soil structure loads in the direction of massive structure and saturated soil mass increases in value. The variables that load on Factor 3 describe a soil with an increased risk of failure primarily due to increased normal load. The structure of this soil tends toward being less porous and less likely to drain freely. Soil with poor drainage creates saturated conditions more easily, reducing shear strength, and increases the mass of water present in the soil. An increase in the saturated soil mass per unit area increases the normal load upon the failure surface. As a result of the above discussion Factor 3 will be named the 'Increased Normal Load' Factor.

4.4. Discussion

4.4.1 Landscape-Level Factors

The dominant variables among landscape-level factors are primarily geologic in origin. Bedrock structure, slope shape, surface configuration and slope angle variables appear to be influential in determining slope stability of folic soils in the Prince Rupert region because they load significantly upon the factors in the landscape-level PCA. Weighted vegetation cover and water-tolerant vegetation variables are secondary variables that occur as a result of the geologic properties.

Geologic conditions affect slope stability primarily through their influence upon slope hydrology. It is important to note that the hydrologic and hence, geologic conditions are important primarily because of the large amount of rainfall the Prince Rupert area receives. The amount of precipitation the area receives is larger in winter months, when evapotranspiration is low, therefore creating ideal conditions for saturation of the soil profile and hence loss of soil cohesion.

Bedrock structure is a significant variable within the 'Geologic Resistance to Failure' Factor, with a factor loading of 0.72. It is a geologic variable that influences slope stability through its effect on slope hydrology. The influence of bedrock structure upon slope stability can be significant, particularly in areas prone to steep shallow debris slides. Joints and fractures impede vertical infiltration and root penetration in many cases, decreasing slope stability (Sidle, 1985a). In addition, Swanston and Howes (1994) stated that joints and fractures can create avenues for deep groundwater penetration, with subsequent porewater pressure development along the planes. Massive structure is also poor, often permitting poor attachment of the solum (Sidle, 1985a).

Slope shape is a significant variable within the 'Geologic / Hydrologic Instability 2' Factor, with a factor loading of –0.94. Like bedrock structure, slope shape is a geologic variable that influences slope stability through its effect on slope hydrology. Convex slopes tend to disperse subsurface water and tend to be more stable than concave slopes that concentrate subsurface water into smaller areas of the slope (Sidle, 1985a; Swanston and Howes, 1994). Slopes with mid to upper slope concave depressions are thought to be particularly susceptible to slope failure. These depressions accumulate subsurface water and develop positive pore water pressure, thus decreasing slope stability (Sidle and Swanston, 1981; Sidle, 1985a; Schroeder and Swanston, 1987; Swanston and Howes, 1994). However, as mentioned previously, debris slides on the Queen Charlotte Islands had a similar distribution of slope shapes as this study, with dominantly convex slopes (Krag, 1986). Although, it is noted that convex initiation zones were usually associated with seepage zones.

Surface configuration is a significant variable within the 'Geologic / Hydrologic Instability 1 and 2' Factors, with factor loadings of 0.70 and 0.53, respectively. Like bedrock structure and slope shape, surface configuration is a geologic variable that influences slope stability through its effect on slope hydrology. Uniform slopes may be less stable because they tend to contain fewer steep segments that act to buttress the overburden. However, 67 % of debris slides in this study had irregular slopes. Irregular slopes contain many breaks in slope that can serve to allow groundwater an exit point as springs or seeps. Therefore, an irregular configuration may have more of an influence on slope instability via hydrology than a uniform configuration has through lack of physical buttressing.

Slope angle is a significant variable within the 'Geologic Resistance to Failure' Factor, with a factor loading of –0.82. In this study, slope angle has an unknown effect upon slope hydrology but it influences slope stability by its effect upon normal stress. Slope angle is very closely related to shallow debris slides and is a key factor in controlling slope stability (Sidle, 1985a; Swanston and Howes, 1994).

4.4.2 Pedon-Level Factors

The dominant variables among pedon-level factors are primarily a result of physical soil properties. Soil porosity, ash content and degree of decomposition variables appear to be influential in determining slope stability in the Prince Rupert region since they load significantly upon the factors in the pedon-level PCA. Soil structure and saturated soil mass variables are secondary variables that are influenced by more primary soil physical measurements.

Porosity is a significant variable within the 'Increased Shear Strength' and the 'Soil / Hydrologic Instability 1' Factors, with factor loadings of 0.54 and –0.64, respectively. It influences slope stability through its effect on soil hydrology. The porosity of a soil determines the amount of water required to achieve saturation. The amount of water required to achieve saturation is important because of the reduction in soil shear strength that comes with saturation and a decline in intergranular pressure (Sidle, 1985a; Gray and Sotir, 1996). Porosity also determines the contribution of water to normal load in a saturated soil. The porosity of folic soils is influenced by degree of decomposition (correlation coefficient = 0.57, where p = 0.00 and n = 126) and ash content (correlation coefficient = -0.73, where p = 0.00 and n = 126).

Ash content is a significant variable within the 'Soil / Hydrologic Instability 1' Factor, with a factor loading of 0.86. It influences slope stability through its effect on soil hydrology and normal load. An increase in the ash content of a folic soil decreases its total porosity, making saturated conditions more likely to occur because there is a smaller volume of pores to fill. Although it is a relatively small contribution, an increase in the ash content of a soil increases normal load because mineral material is denser than organic material. Saturated conditions and an increased normal load are both conditions that serve to decrease soil shear strength and make slope failure more likely (Sidle, 1985a; Gray and Sotir, 1996).

Degree of decomposition is a significant variable within the 'Increased Shear Strength' Factor, with a factor loading of –0.80. It influences slope stability through its effect on soil hydrology. Degree of decomposition influences total porosity through the decrease in organic particle size that comes with decomposition processes. The size of the organic particles decrease with increasing decomposition, resulting in smaller pores and higher bulk density (Boelter, 1968). A decrease in total porosity increases the likelihood of saturated conditions by reducing soil shear strength and increasing the likelihood of slope failure.

4.5 Conclusions

Swanston and Dyrness (1973) state that both geologic and soil considerations are equally important in influencing the stability of slopes. This statement is valid with regards to folic debris slides in the Prince Rupert area. Both the underlying geology and folic soils of the region serve to influence slope stability primarily through hydrologic means but also through influencing normal stress.

Slope angle is a highly loading variable in the landscape-level PCA, likely acting through its influence on normal stress. Therefore, slope angle appears to have an important influence on the stability of folic soils in the Prince Rupert region.

The hydrologic processes influencing the stability of slopes in the Prince Rupert area are initially dependent upon the large amount of rainfall the area receives. Rainfall is particularly high during the winter months with a mean monthly rainfall of 211.3 mm (Environment Canada, 1998). The amount and seasonal distribution of precipitation received in the Prince Rupert area is a driving hydrologic variable with regards to slope stability. However, slope stability is ultimately determined by how the water is transmitted once it reaches the ground surface.

Geologic variables are important in influencing slope stability in the Prince Rupert region, primarily through their effect upon groundwater. Any geologic circumstance that creates locations of high hydrostatic pressure, in turn creates the potential for slope instability through reduction of soil shear strength.

4.6 References Cited

Al-Khafaji, A and Andersland, O. 1992. Geotechnical engineering and soil testing. Saunders College Publishing, Fort Worth, TX. 695 pp.

Blake, G.R. 1965. Particle Density. Pages 371 - 373 *in* C.A. Black, ed. Methods of soil analysis, part 1. Agronomy no. 9. American Society of Agronomy. Madison, Wisconsin.

Boelter, D.H. 1964. Water storage characteristics of peats in situ. Soil Sci. Soc. Amer. Proc. **28**: 433 – 435.

Boelter, D.H. 1968. Important physical properties of peat materials. Proc. Third International Peat Congress. Quebec, Canada. Energy, Mines and Resources and National Research Council of Canada, Ottawa, Ontario.

Carter, M.R. (Ed.) 1993. Soil sampling and methods of analysis. Canadian Lewis Publishers, Boca Raton, FL. 823 pp.

Day, J.H., Rennie, P.J., Stanek, W., Raymond, G.P. 1979. Peat testing manual. National Research Council of Canada, Technical Memorandum No. 125, Ottawa, Ontario. 193 pp.

Environment Canada. 1998. Canadian climate normals 1961 – 1990. Prince Rupert A, British Columbia. 54°18-N 130°26-W/O 34 m.

Gray, D.H. and Sotir, R.B. 1996. Biotechnical and soil bioengineering slope stabilization: a practical guide for erosion control. John Wiley and Sons Inc., Toronto, Ontario. 378 pp.

Krag, R.K. 1986. A forest engineering analysis of landslides in logged areas on the Queen Charlotte Islands, British Columbia. Land Management Report No. 43. Province of British Columbia. Victoria, B.C.

Schroeder, W.L. and Alto, J.V. 1983. Soil properties for slope stability analysis: Oregon and Washington coastal mountains. Forest Sci. **29**: 823-833.

Schroeder, W.L. and Swanston, D.N. 1987. Application of geotechnical data to resource planning in southeast Alaska. USDA Forest Service, Gen. Tech. Rep. PNW-198, Portland, OR.

Sharma, S. 1996. Applied multivariate techniques. John Wiley & Sons Inc., New York, NY. 493 pp.

Sidle, R.C. 1985a. Factors influencing the stability of slopes. Pages 17 – 25 *in* D.N. Swanston, ed. Proc. of a workshop on slope stability: problems and solutions in forest management. USDA Forest Service, Gen. Tech. Rep. PNW-180, Portland, OR.

Sidle, R.C. 1985b. Shallow groundwater fluctuations in unstable hillslopes of coastal Alaska. Zietschrift für Gletscherkunde und Glazialgeologie **20**: 79 – 95.

Sidle, R.C. and Swanston, D.N. 1981. Storm characteristics affecting piezometric rise in unstable hillslopes of southeast Alaska. Transactions of the American Geophysical Union 62: 856 (Abstr.) .

Sidle, R.C. and Swanston, D.N. 1982. Analysis of a small debris slide in coastal Alaska. Can. Geotech. J. **19**: 167 – 174.

SPSS Inc. 1995. SPSS for windows. Release 6.1.3. Standard Version. SPSS Inc. 1989 – 1995.

Swanston, D.N. and Dyrness, C.T. 1973. Stability of steep land. J. For. **71**: 264 – 274.

Swanston, D.N. and Howes, D.E. 1994. Slope movement processes and characteristics. Pages 1 – 17 *in* S.C. Chatwin, D.E. Howes, J.W. Schwab and D.N. Swanston, eds. A guide for management of landslide-prone terrain in the Pacific Northwest. Second Ed. Land Management Handbook No. 18. British Columbia Ministry of Forests. Victoria, British Columbia.

Swanston, D.N. and Swanson, F.J. 1976. Timber harvesting, mass erosion and steepland forest geomorphology in the Pacific Northwest. Pages 199 – 221 *in* D.R. Coates, ed. Geomorphology and engineering. Dowden, Hutchinson and Ross Inc., New York, NY.

Tabachnick, B.G. and Fidell, L.S. 1989. Using multivariate statistics. Second Ed. HarperCollins Publishers Inc., New York, NY. 509 pp.

5.0 COMPARING FOLIC DEBRIS SLIDES TO NON-DEBRIS SLIDE SITES

5.1 Introduction

One way of attempting to understand the factors causing folic debris slides is to compare their characteristics with those of folic non-debris slide transects. Comparison of the continuous soil and terrain variables between debris slide sites and non-debris slide sites may allow the determination of key differences and properties sensitive to slope failure.

During initial field survey only two features differed noticeably between debris slide and non-debris slide sites; slope angle and pedon thickness. Because slope angle is often closely related to shallow debris slides (Sidle, 1985; Swanston and Howes, 1994) and pedon thickness appeared to be related to slope angle upon initial examination, the following hypotheses were formed regarding the differences between folic debris slide sites and non-debris slide transects: i) Folic pedon thickness is dependent upon slope angle, ii) slope angle and pedon thickness are likely the only significant differences between folic debris slide sites and non-debris slide transects.

One objective of this chapter was to examine and better define the relationship between folic pedon thickness and slope angle. Another objective of this chapter was to compare folic debris slide sites with non-debris slide transects in an attempt to discern any significant difference between their characteristics. Both of these objectives may aid in the identification of stable versus unstable terrain and may lead to a better understanding of soil and terrain conditions that create debris slides.

5.2 Methods and Materials

5.2.1 Site Description and Sampling Design

In order to investigate the soil properties that contribute towards the occurrence of folic debris slides in the Prince Rupert area, four transects were established on terrain not containing debris slides. These transects were sampled for comparison with those samples taken adjacent to debris slides. Transects were all located within an approximately 50 km radius surrounding the city of Prince Rupert, British Columbia.

Two criteria were used in selecting non-debris slide transects: i) Sample transects were to be located in areas underlain with quartz diorite, diorite or gneiss rock, corresponding to rock types found at debris slide sites. This criterion was used in order to focus upon folic soil characteristics that may contribute towards slope failure, rather than geologic characteristics which have been well documented by Sidle and Swanston (1981), Sidle (1985), Schroeder and Swanston (1987) and Swanston and Howes (1994). ii) Transects were also to be located on large open slopes with no gullies and no debris slides in or nearby the chosen transect. This criterion was employed in order to more closely duplicate the geologic conditions of debris slide sample sites and in order to ensure that the transect sites were located on terrain that could be considered to be reasonably stable.

Sample collection on non-debris slide transects was divided into 5 sites per transect. These sites were based upon the following slope-angle classes: $\leq$ 19 °, 20 to 24 °, 25 to 29 °, 30 to 34 °and $\geq$ 35 °. Lower slope angle classes tended to be located in lower slope positions and higher slope angle classes tended to be located in mid slope positions.

5.2.2 Field Sampling

Field sampling methods used on non-debris slide transects are the same as those used at debris slide sites (Section 3.2.2)

5.2.3 Laboratory Analysis

The methods of laboratory analysis used for non-debris slide transect samples were the same as those employed for debris slide sample sites (Section 4.2.3).

5.2.4 Data Analysis

Paired samples t-tests were performed to compare continuous data collected at folic debris slide sites to data collected at non-debris slide transects in order to discern any significant differences between the two data sets. The Paired Samples T-Test procedure in SPSS was used (SPSS Inc., 1995). A two-tailed significance level ≤ 0.05 was accepted as significant.

Simple correlation was employed in order to examine the relationship between slope angle and folic pedon thickness. Simple correlation was performed using the Bivariate Correlation procedure in SPSS and the results were expressed as a Pearson correlation coefficient with a two-tailed test of significance (SPSS Inc., 1995). Only a correlation with $r \geq 0.5$ and an alpha level ≤ 0.05 was accepted as significant (Cohen, 1992).

Only continuous variables used in the principal components analysis are presented in this chapter. In addition, all data represent the horizon nearest the lithic contact (horizon 2 or 3), with the exception of saturated soil mass and pedon thickness, which represent the entire soil profile.

5.3 Results

5.3.1 Summary Statistics

Both the debris slide and non-debris slide summary statistics are presented for comparison because the main purpose of this chapter is to determine differences between the two data sets (Table 5-1).

Table 5-1. Descriptive summary statistics for non-debris slide transects and debris slide sites

Non-Debris Slide Sites						n = 20
Variable	Median	Mean	Std. Dev.	CV (%)	Min.	Max.
Ash Content (g kg^{-1})*	772	617	321	52	23	952
Von Post Humification*	8	8	1	13	4	9
Porosity (%)*	88	87	5	6	73	94
Saturated Soil Mass (kg m^{-2})	415	561	333	59	208	1538
Pedon Thickness (cm)	35	47	23	49	19	96
Slope Angle (°)	28	28	9	32	15	49

Debris Slide Sites						n = 30
Variable	Median	Mean	Std. Dev.	CV (%)	Min.	Max.
Ash Content (g kg^{-1})*	553	557	181	33	10	860
Von Post Humification*	8	8	1	13	5	9
Porosity (%)*	88	87	7	8	69	96
Saturated Soil Mass (kg m^{-2})	461	454	206	45	168	1024
Pedon Thickness (cm)	31	34	41	14	10	69
Slope Angle (°)	44	43	7	16	30	60

* Values for the lowest horizon in contact with the bedrock surface

Upon initial inspection these two data sets appear very similar. The mean slope angle is much higher in debris slide sites (43°) than in non-debris slide transects (28°).

However, this may be an artifact of a non-debris slide transect sampling design which was biased toward relatively shallow slope classes.

5.3.2 Slope Angle and Pedon Thickness

The relationship between slope angle and pedon thickness is negative. Non-debris slide data were initially used for comparing these two variables because the sample sites were chosen based on slope angle. The non-debris slide data illustrate the negative relationship but not significantly. A simple correlation between the two variables resulted in a r of –0.31, where p = 0.18 and n = 20. The lack of significance is likely due to the small sample size. The same correlation was run using both non-debris slide transects and debris slide sites resulting in a r of -0.40, where p = 0.00 and n = 136. A significant negative relationship still did not exist between slope angle and folic pedon thickness, but the relationship is very close to being significant and is therefore worth noting.

5.3.3 Comparing Folic Debris Slide Sites with Non-Debris Slide Transects

Table 5-2. Paired samples t-test: debris slide vs. non-debris slide sites **n = 20, df = 19**

Variable	t-value	2-Tailed Sig.
Ash Content	-0.76	0.46
Von Post Humification	0.00	1.00
Porosity	-1.24	0.23
Saturated Soil Mass	1.23	0.23
Pedon Thickness	-2.11	**0.05**
Slope Angle	5.09	**0.00**

• 2-Tailed Significance levels in boldface are significant.

Paired samples t-tests were performed in order to determine if any significant difference exists between the characteristics of debris slide sites and non-debris slide transects (Table 5-2). The only two variables in Table 5-2 that had means that differed significantly from debris slide sites to non-debris slide transects were pedon thickness and slope angle. It was expected that slope angle of debris slide sites would be significantly greater because of differing sampling designs. It was also expected that pedon thickness is significantly greater along non-debris slide transects because pedon thickness and slope angle are inversely related.

5.4 Discussion

5.4.1 Slope Angle and Pedon Thickness

The relationship between slope angle and pedon thickness is near to being significant ($r = -0.40$, where $p = 0.00$ and $n = 136$). The relationship that exists between these two variables is likely a result of the fact that folic soils require vegetation to supply parent material in the form of litter (Lewis and Lavkulich, 1972) and field obervation indicated that aboveground biomass tends to grow less densely on steeper slopes. The trend between slope angle and weighted vegetation cover is negative ($r = -0.36$, where $p = 0.05$ and $n = 30$). The variation in the relationship between slope angle and pedon thickness is likely a result of small-scale topography creating pockets of thinner or thicker soil, unrelated to the slope of the larger angle. In addition, pedon thickness may also be related to degree of decomposition, pedon thickness decreasing as decomposition and hence bulk density increases.

5.4.2 Comparing Folic Debris Slide Sites with Non-Debris Slide Transects

The variable of slope angle differed significantly between debris slide sites and non-debris slide transects (t-value = 5.09, two-tailed sig. = 0.00). This difference is likely an artifact of the sampling design. The sampling design for non-debris slide sites was based on examining different slope angle classes whereas the design for debris slide sites was based only upon the presence of an accessible debris slide. As a result, many of the non-debris slide transect sites are much less steep than the debris slide sites. However, one would generally expect debris slides sites to be steeper than stable sites because slope angle is a well-documented predictor of debris slides. Sidle (1985) reports that many slopes over 25 ° and most slopes over 35 ° are prone to rapid slope failure. However, it is difficult to determine if the significant difference in slope angle is a real phenomenon or if it is a result of study design.

Because of the negative trend between slope angle and pedon thickness it is not surprising that the pedon thickness of debris slide sites and non-debris slide transects is also significantly different (t-value = -2.11, two-tailed sig. = 0.05). Again, it is difficult to determine if the significant difference in pedon thickness is a real phenomenon or if it is a result of study design.

Non-debris slide transects tend to have thicker soil that debris slide sites. These areas likely have thicker soils because they have never failed and therefore deep folic material has had a chance to develop over time. One might expect a thicker soil mantle to be more indicative of unstable conditions than a thinner soil mantle due to the increase in normal load and friction a thicker soil places upon the failure surface. Therefore it is likely that pedon thickness, and its contribution to normal load, is a less sensitive variable in slope stability analyses than slope angle. Sidle (1985) and Swanston and Howes (1994) state that slope angle can often be closely related to shallow slope failures such as those found in the study area.

5.5 Conclusions

Results do not support the hypothesis that pedon thickness is dependent upon slope angle because the negative correlation between pedon thickness and slope angle is not significant however, the relationship between the two variables is near to being significant and therefore worth noting.

Results support the hypothesis that slope angle and pedon thickness are the only apparent differences between debris slide sites and non-debris slide transects. It is not clear whether these relationships are a result of differing sampling designs or whether it is a real phenomenon.

Slope angle may be a sensitive, primary indicator of shallow debris slide stability. However, the difference in the sampling design of debris slide sites and non-debris slide transects makes this question more difficult to answer. Clearly, more examination of this parameter is needed. This may be better accomplished through sampling non-debris slide areas that have more similar slope angles (i.e. steeper) to debris slide sites.

5.6 References Cited

Cohen, J. 1992. Quantitative methods in psychology: a power primer. Psychological Bulletin **112**: 155-159.

Lewis, T. and Lavkulich, L.M. 1972. Some Folisols in the Vancouver area, British Columbia. Can. J. Soil. Sci. **52**: 91 – 98.

Schroeder, W.L. and Swanston, D.N. 1987. Application of geotechnical data to resource planning in southeast Alaska. USDA Forest Service, Gen. Tech. Rep. PNW-198, Portland, Oregon.

Sidle, R.C. 1985. Factors influencing the stability of slopes. Pages 17 – 25 *in* D.N. Swanston, ed. Proc. of a workshop on slope stability: problems and solutions in forest management. USDA Forest Service, Gen. Tech.Rep. PNW-180, Portland, OR.

Sidle, R.C. and Swanston, D.N. 1981. Storm characteristics affecting piezometric rise in unstable hillslopes of southeast Alaska. Transactions of the American Geophysical Union **62**: 856 (Abstr.)

Swanston, D.N. and Howes, D.E. 1994. Slope movement processes and characteristics. Pages 1 – 17 *in* S.C. Chatwin, D.E. Howes, J.W. Schwab and D.N. Swanston, eds. A guide for management of landslide-prone terrain in the Pacific Northwest. Second Edition. Land Management Handbook No. 18, British Columbia Ministry of Forests, Victoria, British Columbia.

SPSS Inc. 1995. SPSS for windows. Release 6.1.3. Standard Version. SPSS Inc. 1989 – 1995.

6.0 SHEAR STRENGTH AT FOLIC SOIL – BEDROCK INTERFACES

6.1 Introduction

An infinite slope model is a common framework used in assessing debris slide risk. Soil shear strength is a central concept and measurement used in these models. It can be defined as a quantitative measure of the resistance of a soil to failure, as a function of normal stress on a slip surface, cohesion and internal angle of friction (Sidle, 1985; Al-Khafaji and Andersland, 1992; Gray and Sotir, 1996). There has been no past research regarding shear strength of folic soils in British Columbia. In addition, no attempt has been made to discover relationships between folic soil shear strength and other physical characteristics.

Folic soils in the Prince Rupert area fail at the folic soil – bedrock interface. Therefore, shear strength and its components of adhesion and friction are a result of the relationship between folic soil properties and the bedrock, rather than folic soil properties alone. The term 'adhesion' is used in place of the more usual term 'cohesion' and the term 'angle of friction' is used in place of the more common term 'internal angle of friction' because the materials in question are different (i.e. soil and bedrock).

Sidle (1985) found soil cohesion to be negatively related to soil water content, cohesion being weakest when a soil is saturated. Effective internal angle of friction was also negatively related to water content, increased water content reduced friction between individual particles or aggregates (Sidle, 1985). Thus the following hypothesis was formed regarding the relationship between shear strength parameters and soil water content: shear strength, adhesion and friction at the folic soil-bedrock interface decreases as soil water content increases.

An increase in von Post humification is hypothesized as having a positive influence on both shear strength and adhesion at the folic soil – bedrock interface because of the decreasing particle size that accompanies the decomposition of organic materials. Sidle et al. (1985) stated that smaller soil particles tend to have better cohesive properties than larger particles through stronger interparticle bonding.

Values for shear strength and friction at the folic soil – bedrock interface are hypothesized to increase as the ash content of a folic soil increases. This hypothesis is based upon the idea that an increase in bulk density and hence normal load can be primarily related to ash content because the particle density of soil mineral matter is much higher than that of soil organic matter. Based upon the same idea of increased bulk density and normal load is the hypothesis that states that shear strength and friction at the folic soil – bedrock interface increase as coarse fragment content increases. Finally, shear strength, friction and adhesion at folic soil – bedrock interface are hypothesized as increasing as bulk density increases. Friction is related to bulk density through the increase in normal load that is created through the presence of denser soil materials (i.e. ash). Adhesion is related to bulk density through degree of decomposition. A strongly decomposed soil has smaller particles that are able to pack into a denser arrangement than poorly decomposed soil, increasing soil bulk density (Boelter, 1969).

The objectives of this chapter were to obtain some preliminary values for the shear strength, adhesion and friction at the folic soil – bedrock interfaces for use with the infinite slope model. Objectives of also included discovering and examining the relationships between shear strength parameters and other soil properties.

6.2 Methods and Materials

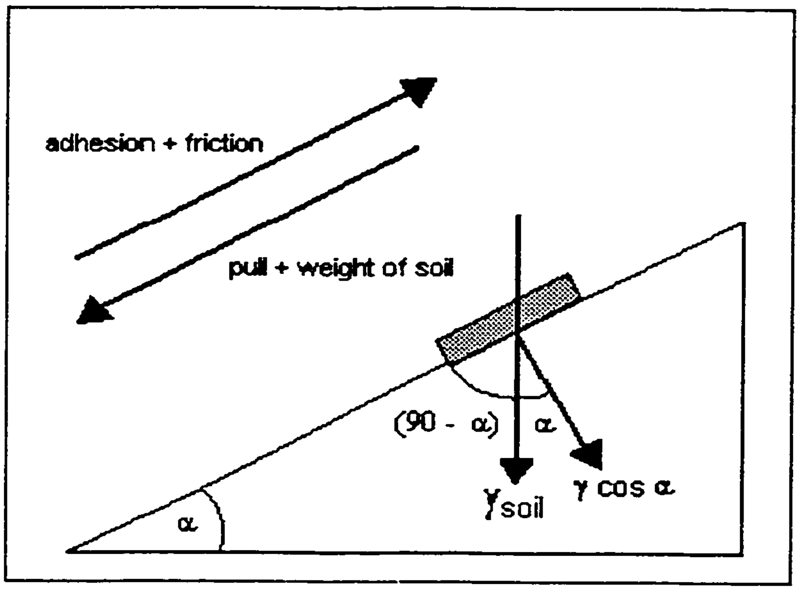
6.2.1 Site Description and Sampling Design

Nine sampling sites, located within about a 50-km radius of the city of Prince Rupert, were chosen for examining the shear strength of the folic soil – bedrock interface. Selection of sampling locations was based upon three criteria: i) The sample sites must include folic soils with varying ash contents, ii) the sample sites must include terrain with varying slope angles and, iii) the sample sites should overlie a relatively smooth, planar bedrock surface.

Sample sites were located within 10 m of the path of damage of four different folic debris slides and different slope positions along the debris slides (Appendix 18). The number of replicates of shear strength measurements ranged between 3 and 8 at each site location (Appendix 21).

6.2.2 Infinite Slope Model

An infinite slope model describes the stability of a block of material in terms of a ratio between its shear strength or resistance to sliding along a failure surface, and its shear stress or force promoting failure. This ratio is called the factor of safety (Hammond et al., 1992). For the purpose of this study, shear strength parameters were measured using a shear frame apparatus similar to that used in snow avalanche studies (McClung and Schaerer, 1993). The shear frame apparatus used in this study is described in more detail in Section 6.2.3. The volume of soil within the shear frame represents the 'block of material' in the infinite slope theory. The shear strength of the block of soil may be divided into two components: the adhesion of the soil block to the underlying bedrock and the friction between the soil block and the underlying bedrock. The shear stress components on the 'block of material' include the force of the pull on the soil block used to achieve failure and the component weight of the soil acting downslope. Figure 6-1 illustrates the infinite slope model as applied to the shear frame apparatus and gives equations for shear strength or forces resisting failure and shear stress or forces promoting failure.



shear strength / forces resistant to failure = $C'_s A + \gamma_{soil} \cos \alpha \tan \phi'$
shear stress / forces promoting failure = $P + \gamma_{soil} \sin \alpha$

where: C'_s = adhesion (N)
A = area of specimen pulled (m^2)
P = pull used to achieve failure (N)
γ_{soil} = unit weight of soil (N)
α = slope angle (°)
ϕ' = effective angle of friction (°)
$\gamma_{soil} \cos \alpha \tan \phi'$ = friction (N)
$\gamma_{soil} \sin \alpha$ = weight of soil block acting downslope (N)

Figure 6-1. Infinite slope model applied to shear frame apparatus (D.M. Cruden, University of Alberta, Edmonton, AB.)

6.2.3 Field Sampling

For the purposes of this study, shear strength was measured at the folic soil - bedrock interface (i.e. the failure surface). Shear strength was further broken down into two components: adhesion and friction. Adhesion replaces cohesion in this instance because the two interacting materials are different (i.e. soil and bedrock).

Shear strength measurements were taken using a shear frame apparatus. The shear frame used in this study was a square wooden frame with an internal area of 625 cm^2 and a height of 5 cm. The frame was fit around a previously excavated pedestal of soil with the same dimensions as the shear frame. The soil was excavated to bedrock level in the area surrounding the soil pedestal. Two wires attached the frame to a Chatillon IN-50NRP torsion scale that was in turn attached to a Canadian Tire 1 Ton winch, model no. 61-8153-2. (Figure 6-2) The winch was then used to pull the frame downslope with a controlled speed of about 5 cm of winch cable per second. In cases where colluvial rock fragments were present in the soil pedestal, it was more difficult to obtain a satisfactory measurement. The amount of pull needed to create soil failure was recorded from the torsion scale in kilograms (Equation 1). The detached soil pedestal and frame were then put back into their original location at time = 0. The soil block and frame were then pulled as before until failure again occurred. A measurement of the friction created by the soil and frame was then recorded from the scale (Equation 2). Finally, the soil pedestal was removed from the frame and the frame apparatus was put back into its original position at time = 0. The frame alone was then pulled as before until failure occurred. A measurement of the friction created by the frame alone was then recorded from the scale (Equation 3). By subtracting the third pull from the first pull the components of the weight and friction of the frame are removed from the value for shear strength (Equation 4). By subtracting the second pull from the first pull the value for the component of adhesion is derived (Equation 5).

By subtracting the third pull from the second pull the value for the component of friction is derived (Equation 6). The equations below describe forces involved in the three different pulls of the shear frame apparatus and the derivation of shear strength and its components of adhesion and friction:

Pull 1 = $C'_s A + (\gamma_{soil} + \gamma_{frame}) \cos\alpha \tan\phi'$ (Eq.1)
Pull 2 = $(\gamma_{soil} + \gamma_{frame}) \cos\alpha \tan\phi'$ (Eq.2)
Pull 3 = $\gamma_{frame} \cos\alpha \tan\phi'$ (Eq.3)

Shear Strength = Pull 1 – Pull 3 = $C'_s A + \gamma_{soil} \cos\alpha \tan\phi'$ (Eq.4)
Adhesion = Pull 1 – Pull 2 = $C'_s A$ (Eq.5)
Friction = Pull 2 – Pull 3 = $\gamma_{soil} \cos\alpha \tan\phi'$ (Eq.6)
$\phi' = \tan^{-1}$ (friction / $\gamma_{soil} \cos\alpha$), where friction and γ_{soil} are given in N. (Eq. 7)

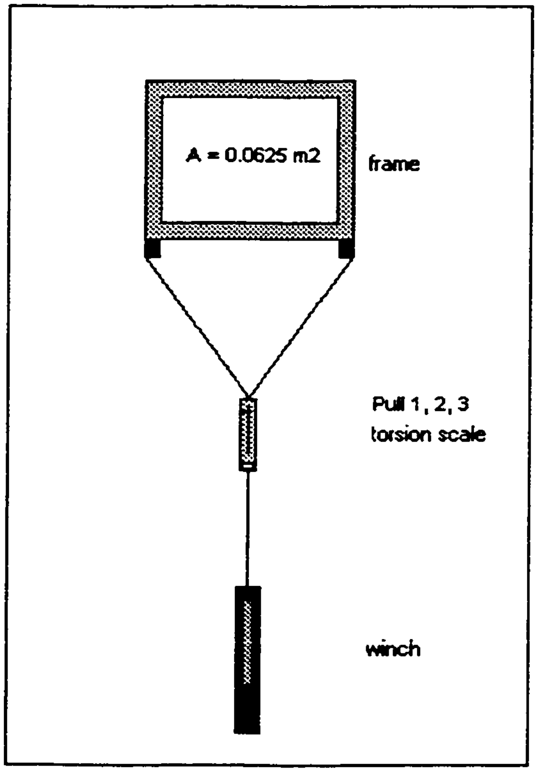


Figure 6-2. Diagram of the shear frame apparatus.

In addition to shear frame measurements, data were collected regarding the geologic, biotic, hydrologic, and soil characteristics present at the sample sites. Field sampling methods used in collecting the above data are similar to those employed at debris slide sites (Section 3.2.2). Soil samples were taken within 10 cm of the folic soil-bedrock interface (i.e. lowest horizon)

6.2.4 Laboratory Analysis

In preparation for laboratory analysis, soil samples were air-dried and homogenized by hand to pass through a 4-mm sieve. Samples were not sieved to the standard 2-mm because soil structure was to be preserved for further laboratory analysis. Bulk density was determined using the core method, utilizing cylinders with volumes of 271.9 cm^3 and 182.5 cm^3, inserted horizontally into the soil. The samples were oven dried at 105 °C until their mass became constant (Day et al., 1979). Gravimetric field water content was determined by measuring the water lost upon oven-drying the core at 105 °C. Volumetric field water content was calculated by multiplying bulk specific gravity and gravimetric field water content. Ash content was determined using the dry-ashing method, also commonly referred to as loss-on-ignition. The organic matter was combusted in a muffle furnace at a temperature of 550 °C for 20 hours (Carter, 1993). Oven-dry root density of the sample was obtained by separating the root mass from the soil mass found inside the volume of the shear frame, i.e. the pedestal. Flushing the soil through a 2-mm sieve using a constant stream of water flow separated the roots. Once separated from the soil the roots were oven-dried at 60 °C and weighed. Six segments of oven-dried roots from each size class was measured and weighed. Oven-dry root length density is calculated by multiplying oven-dry root density and a conversion factor. The conversion factor is based upon the mean density to length ratios of oven-dried root samples for different root size classes. Oven-dry root density was further manipulated in order to calculate oven-dry root length density because oven-dry root length density may be a better indication of the area of roots in contact with the bedrock. See Appendix 24 for conversion factors and results.

6.2.5 Data Analysis

Three to eight replicates of shear strength measurements and associated soil samples were taken at each of the nine sample site locations within an area of 5 m^2. The mean values of each of these replicate sites were used for data analysis.

Simple correlations were used in order to pursue relationships between soil properties and shear strength parameters. Simple correlations were performed using the Bivariate Correlation procedure in SPSS and were executed using a Pearson correlation coefficient and a two-tailed test of significance (SPSS Inc., 1995). Only correlations with $r \geq 0.5$ and alpha levels ≤ 0.10 were accepted as significant. A larger alpha level was accepted as significant because the sample size ranges from only 6 to 9.

Bivariate regression was employed to describe the relationship between soil-bedrock friction and slope angle. Bivariate regression was performed using the Linear Regression procedure in SPSS (SPSS Inc., 1995). Only r^2 values ≥ 0.8 were accepted as significant.

6.3 Results and Discussion

6.3.1 Summary Statistics

Non-continuous variables are summarized by frequencies whereas continuous variables are presented as descriptive summary statistics (Table 6-1). Non-continuous data are not used directly in either simple correlation or linear regression. However the frequencies give some indication of the condition of the pedons examined in this study. Gritty character is the dominant soil character of 44 % of all samples (n = 9). Soils with greasy character comprise 22 % of samples. A mixture of greasy and gritty character constitutes 22 % of samples. A combination of fibrous and gritty character accounts for only 11 % of samples. The dominance of samples with a gritty character indicates that sample sites are often relatively high in mineral content. Pliable consistency is the dominant soil consistency accounting for 67 % of sample sites. Loose consistence constitutes 22 % of sites and a mixture of tenacious and pliable consistence comprises only 11 % of sample sites. Granular structure is the dominant soil structure accounting for 63 % of sample sites. Blocky structure constitutes 25 % of sites and massive structure comprises 13 % of sample sites.

Table 6-1. Descriptive summary statistics for the lowest horizon in contact with bedrock n = 6 to 9

Variable	Median	Mean	Std. Dev.	CV(%)	Min.	Max.
Shear Strength (kPa)	928	992	608	61	352	2210
Friction (kPa)	240	256	128	50	80	448
Adhesion (kPa)	512	720	480	67	192	1490
Angle of Friction (°)	41	41	6	15	34	49
Ash Content (g kg^{-1})	813	668	262	39	295	885
Bulk Density (Mg m^{-3})	0.39	0.41	0.21	51	0.14	0.66
Von Post Humification	8	8.5	0.5	6	8	9
Coarse Fragment Content (%)	0	8	11	138	0	30
Gravimetric Water Content (%)	295	260	160	62	91	456
Volumetric Water Content (%)	68	67	10	15	48	76
Oven-Dry Root Density (kg m^{-3})	4	8	7	88	0.7	22
Oven-Dry Root Length Density(cm cm^{-3})	0.5	35	93	266	0.1	281
Slope Angle(°)	27	29	8	28	15	40

Some of the continuous variables have very high coefficients of variation, particularly oven-dry root length density, oven-dry root density and coarse fragment content. The variation is likely common in coarse fragment content and oven-dry root density because the high variation was apparent prior to analysis. However, the very high coefficient of variation of oven-dry root length density may be a result of the conversion factor used in calculation of this variable (Appendix 24). The large ranges in ash content and slope angle were expected, addressing the criteria of sample locations with varying amounts of mineral material and varying slope angles. Friction angle is summarized in Table 6-1 in order to establish a range of friction values at the folic soil-bedrock contact. It is also important to note that field gravimetric water content values in Table 6-1 correspond to matric potential greater than –5 kPa (Appendix 23), indicating the soils were wet but not saturated at the time of testing.

6.3.2 Relationships between Shear Strength Parameters and Physical Properties

Of all of the relationships between physical soil variables and friction, adhesion, and shear strength, only the relationship between friction and slope angle can be characterized significantly through bivariate regression with an r^2 value of 0.83 and a significant F value of 0.00. The dependence of friction upon slope angle is characterized by the equation: y = 63.60-1.28x.

Simple correlation was employed in order to determine the effect of primary, physical variables upon the values of friction, adhesion and shear strength (Table 6-2). There are no significant relationships between friction angle and the variables in Table 6-2 (correlation not shown).

Table 6-2. Pearson correlation coefficients **n = 6 to 9**

Variable	Friction	Adhesion	Shear Strength
Ash Content	**0.73 (p = 0.06)**	**0.72 (p = 0.07)**	**0.69 (p = 0.07)**
Bulk Density	**0.78 (p = 0.07)**	**0.89 (p = 0.02)**	**0.85 (p = 0.02)**
Von Post Humification	0.30 (p = 0.51)	**0.71 (p = 0.07)**	0.52 (p = 0.17)
Coarse Fragment Content	**0.68 (p = 0.09)**	**0.77 (p = 0.04)**	0.45 (p = 0.27)
Gravimetric Water Content	-0.67 (p = 0.15)	**-0.81 (p = 0.05)**	**-0.70 (p = 0.08)**
Volumetric Water Content	-0.14 (p = 0.79)	-0.13 (p = 0.81)	-0.06 (p = 0.89)
Oven-Dry Root Density	**-0.79 (p = 0.04)**	-0.55 (p = 0.20)	-0.55 (p = 0.16)
Oven-Dry Root Length Density	-0.18 (p = 0.71)	-0.35 (p = 0.44)	-0.36 (p = 0.38)
Slope Angle	**-0.91 (p =0.00)**	**-0.72 (p = 0.07)**	**-0.82 (p = 0.01)**

• Correlation coefficients in boldface are significant at $r > 0.5$ and $p \leq 0.10$

6.3.3 Relationships between Friction and Physical Properties

The fact that friction and slope angle are strongly negatively related is expected because friction is a function of the cosine of slope angle (Equation 6). Slope angle and the component weight of the soil combine to become the normal stress on the bedrock surface or the component weight of soil acting downslope.

The positive correlation between friction and ash content is likely a result of sand-sized soil mineral matter creating more friction on the bedrock surface than softer, smoother soil organic matter. The positive correlation between friction and bulk density is likely a result of the strong influence of ash content has upon bulk density. Sand-sized ash particles create more friction than organic particles because they have a rougher texture and a greater influence upon normal load. The positive relationship between friction and coarse fragment content is also a result of the rough texture of mineral material in comparison with organic matter and the influence of heavy coarse fragments in increasing normal load.

The inverse relationship between friction and oven-dry root density can be explained though reasoning similar to ash content. As oven dry root mass per unit area increases, folic soil material in contact with the bedrock, including the mineral component, decreases. Softer, smoother organic material likely creates less friction than sand-sized mineral material. Therefore, friction decreases as the soil mass, including the mineral component, decreases.

6.3.4 Relationships between Adhesion and Physical Properties

There is a positive correlation between adhesion and von Post humification. Degree of decomposition relates to adhesion because the smaller particles found in strongly decomposed soil, likely have better adhesive properties than the larger particles found in poorly decomposed soil because fine-grained particles tend to be more strongly bonded than coarse-grained particles (Sidle et al., 1985). The positive correlation between adhesion and bulk density may also be explained by degree of decomposition.

An increase in the degree of decomposition of a soil creates higher bulk densities because soil particles in strongly decomposed soil being smaller and more densely packed than larger, poorly decomposed particles (Farnham and Finney, 1965; Boelter, 1969). The positive correlation between bulk density and von Post humification is significant, where $r = 0.56$, $p = 0.00$ and $n = 120$. However, ash content is also positively correlated to adhesion and ash content has a far stronger effect on the bulk density of folic soils than degree of decomposition. One would expect the sand-sized ash found in the folic soils of this region to have few adhesive properties. The reason behind the existence of a positive correlation between coarse fragment content and adhesion is not clear. It seems that like ash content, the opposite should be true because large mineral fragments have few adhesive properties.

The inverse relationship between gravimetric water content and adhesion can be explained by effective soil stresses, the portion of total soil stress that is supported by grain-to-grain contact. When a soil becomes saturated, its effective stresses are reduced, therefore reducing a soil's adhesive properties (Sidle, 1985; Schroeder and Swanston, 1987; Swanston and Howes, 1994). Shear strength and volumetric water content were not significantly related.

The inverse relationship between adhesion and slope angle is more difficult to explain. Mathematically, slope angle is not a function of adhesion. However, the two variables may be related by an unexplored secondary relationship that slope angle has upon folic soil characteristics.

6.3.5 Relationships between Shear Strength and Physical Properties

The inverse relationship between shear strength and slope can be explained as a function of normal stress. Recall that normal stress is a component of friction and friction is a component of shear strength (Equation 4 and 6). The positive correlation between shear strength and ash content can be explained by the influence that ash content has upon the component friction. The positive correlation between shear strength and bulk density can explained though the influence of bulk density upon both friction and adhesion components. The inverse relationship between shear strength and gravimetric water content is likely a result of the negative influence gravimetric water content has upon adhesion.

6.4 Conclusions

Both shear strength and adhesion are inversely related to gravimetric water content therefore fulfilling two parts of the hypothesis that states that shear strength, adhesion and friction decrease as water content increases. Adhesion and von Post humification are positively related, however von Post humification does not correlate significantly with shear strength. These results support part of the hypotheses that the shear strength and adhesion of the folic soil – bedrock interface decrease as von Post humification increases. Both friction and shear strength correlate positively with ash content therefore supporting the hypothesis that the friction and shear strength of the folic soil – bedrock interface increase as ash content increases. However, adhesion also correlates positively with ash content, which was not hypothesized. Friction correlates positively with coarse fragment content as hypothesized; however, shear strength does not correlate significantly with it. Also, there is a positive correlation between adhesion and coarse fragment content, which was not hypothesized. Bulk density is positively correlated to friction, adhesion and shear strength thereby supporting the hypothesis that states that shear strength, friction and adhesion at the folic soil – bedrock interface increase as bulk density increases.

6.5 References Cited

Boelter, D.H. 1969. Physical properties of peats as related to degree of decomposition. Soil Sci. Soc. Amer. Proc. **33**: 606 – 609.

Carter, M.R. (Ed.) 1993. Soil sampling and methods of analysis. Canadian Lewis Publishers, Boca Raton, FL. 823 pp.

Cohen, J. 1992. Quantitative methods in psychology: a power primer. Psychological Bulletin **112**: 155-159.

Day, J.H., Rennie, P.J., Stanek, W., Raymond, G.P. 1979. Peat testing manual. National Research Council of Canada, Technical Memorandum No. 125, Ottawa, Ontario. 193 pp.

Farnham, R.S. and Finney, H.R. 1965. Classification and properties of organic soils. Adv. Agron. **17**: 115 – 139.

Gray, D.H. and Sotir, R.B. 1996. Biotechnical and soil bioengineering slope stabilization: a practical guide for erosion control. John Wiley and Sons Inc., Toronto, Ontario. 378 pp.

Hammond, C., Hall, D., Miller, S. and Swetik, P. 1992. Level 1 stability analysis (LISA) documentation for version 2.0. USDA Forest Service, Gen. Tech. Rep. INT-285, Ogden, UT.

MacFarlane, I.C. 1969. Engineering characteristics of peat. Pages 78 – 130 *in* I.C. MacFarlane, ed. Muskeg engineering handbook. University of Toronto Press, Toronto, Ontario.

McClung, D. and Schaerer, P. 1993. The avalanche handbook. The Mountaineers. Seattle, WA. 271 pp.

Sidle, R.C. 1985. Factors influencing the stability of slopes. Pages 17 – 25 *in* D.N. Swanston, ed. Proc. of a workshop on slope stability: problems and solutions in forest management. USDA Forest Service, Gen. Tech. Rep. PNW-180, Portland, OR.

Sidle, R.C., Pearce, A.J. and O'Loughlin, C.L. 1985. Hill slope stability and land use. American Geophysical Union, Water Resources Monograph 11, Washington, DC. 140 pp.

Schroeder, W.L. and Alto, J.V. 1983. Soil properties for slope stability analysis; Oregon and Washington coastal mountains. Forest Sci. **29**: 823-833.

Schroeder, W.L. and Swanston, D.N. 1987. Application of geotechnical data to resource planning in southeast Alaska. USDA Forest Service, Gen. Tech. Rep. PNW-198, Portland, Oregon.

Swanston, D.N. and Howes, D.E. 1994. Slope movement processes and characteristics. Pages 1 – 17 *in* S.C. Chatwin, D.E. Howes, J.W. Schwab and D.N. Swanston, eds. A guide for management of landslide-prone terrain in the Pacific Northwest. Second Ed. Land Management Handbook No. 18. British Columbia Ministry of Forests. Victoria, British Columbia.

SPSS Inc. 1995. SPSS for windows. Release 6.1.3. Standard Version. SPSS Inc. 1989 – 1995.

7.0 SYNTHESIS

This study examined folic debris slides through several approaches: direct examination of folic debris slide sites, comparison of folic debris slide sites to similar non-debris slide sites and through characterization of the physical and chemical properties of folic soils. The purpose of this chapter is to synthesize the information obtained through these different approaches to more clearly determine the soil and landscape attributes that contribute to the occurrence of folic debris slides in the Prince Rupert region.

7.1 Factors Influencing Slope Stability and the Infinite Slope Model

The natural factors influencing the stability of forested slopes in the Prince Rupert area fall into four process-related categories: geologic properties, soil properties, hydrologic properties and vegetation properties (Schroeder and Alto, 1983). All four of these factors are addressed within an infinite slope model of slope stability (Section 1.4). An infinite slope model provided an excellent framework for describing the mechanisms and complex relationships between elements that are active in the development of shallow, translational debris slides (Wu and Swanston, 1980; Swanston and Howes, 1994; Gray and Sotir, 1996). Folic debris slides in the Prince Rupert area are both shallow and translational, and are therefore candidates for characterization via an infinite slope model.

7.1.1 Geologic Properties Influencing Slope Stability

In the principal components analyses described in chapter 4, the geologic variables of bedrock structure, slope shape, surface configuration and slope angle are portrayed as key variables in influencing the spatial occurrence of folic debris slides. Bedrock structure, slope shape and surface configuration influence slope stability primarily through their influence upon groundwater. Any geologic circumstance that creates locations of high hydrostatic pressure, in turn creates the potential for slope instability through reduction of soil adhesion and in turn, soil shear strength. In fact, in Chapter 6, adhesion was shown to be significantly related to gravimetric water content where $r = -0.81$, $p = 0.05$ and $n = 7$.

Slope angle influences slope stability via shear stress, which is defined as the component of the weight of the soil acting downslope. It is a stress that promotes slope failure (Figure 6-1). Normal stress is a component of friction, and friction in turn, is a component of soil shear strength (Equations 4 and 6, Chapter 6). Any increase in slope angle decreases normal stress, decreases friction and decreases shear strength, therefore making slope stability less likely. Significant negative correlations were found between slope angle and friction ($r = -0.91$, where $p = 0.00$ and $n = 8$) and between friction and shear strength ($r = -0.82$, where $p = 0.01$ and $n = 8$). The examination of non-debris slide terrain indicated that slope angle is significantly lower in non-debris slide sites when compared with debris slide sites. However, it is likely that this difference is a result of the non-debris slide site sampling design being biased against very steep slope angles. The selection of non-debris slide transect sites was based upon slope angle classes, most of which were very shallow in comparison to studied debris slide sites.

In general, the bedrock surface underlying debris slides in the Prince Rupert area is steep with an irregular surface configuration and jointing and fracturing parallel to the slope aspect. All of these geologic features are indicative of unstable terrain. However, debris slide sites in this area contained a high frequency (47 %) of convex mainscarps (Chapter 4), and convexity is a more stable feature than concavity.

7.1.2 Soil Properties Influencing Slope Stability

In the principal components analyses described in chapter 4, the physical soil variables of ash content, saturated soil mass per unit area, porosity, soil structure and von Post humification are portrayed as key variables in influencing the stability of folic debris slides. Ash content, porosity, soil structure and von Post humification primarily influence slope stability through their effect upon water movement within the soil profile.

The modal folic soil of the Prince Rupert region has two horizons. The upper horizon had a mean thickness of 14 cm; a von Post humification index of 4, non-compact matted structure, a mean ash content of 164 g/kg and mean porosity of 94 %. The lower horizon had a mean thickness of 24 cm, a von Post humification index of 8, massive, granular or blocky structure, a mean ash content of 583 g/kg and mean porosity of 88%. Modal folic soils of the Prince Rupert region have a particular horizon sequence and physical soil properties that would allow a water table to form. Poor decomposition and low ash content produce high porosity in the upper horizon. Advanced decomposition, higher ash content and the weight of the overlying soil produce lower porosity in the lower horizon. Porosity correlated with type of soil structure, where $r = 0.53$, $p = 0.00$ and $n = 216$. Non-compact matted soil structure had a higher porosity than massive, granular and blocky structure.

The modal folic soil should allow water to infiltrate quickly into the soil however, the water is impeded by the presence of relatively impermeable bedrock therefore allowing a water table to form (Figure 7-1). Any soil properties that create high hydrostatic pressure, in turn create the potential for slope instability through loss of soil-bedrock adhesion and in turn, reduction of shear strength at that interface.

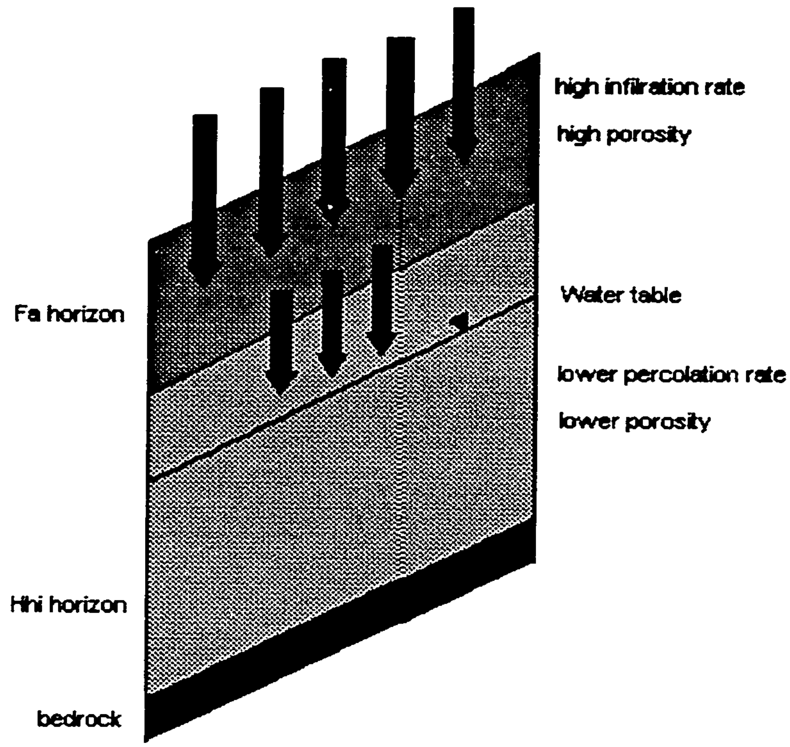


Figure 7-1. Schematic of the vertical dimension of water table formation in a modal folic soil (≈ 0.4 m thick) overlying bedrock on a hillslope

Ash content, von Post humification, porosity and saturated soil mass per unit area, influence slope stability through their effect upon normal load. Both ash content ($r = 0.74$, $p = 0.00$, $n = 120$) and von Post humification ($r = 0.56$, $p = 0.00$, $n = 120$) were positively correlated with bulk density, and bulk density was negatively correlated with porosity ($r = -0.93$, where $p = 0.00$ and $n = 120$), through the equation Porosity (%) = (1 - (Bulk Density /Particle Density)) x 100. In addition, bulk density and porosity are used in the equation to calculate saturated soil mass per unit area using the equation: Saturated Soil Mass, kg/m2 = ((Coarse Fragment Content, v/v x Particle Density, kg/m3 + Bulk Density, kg/m3 + Porosity, v/v)(Soil Depth, m). An increase in normal load upon the failure surface causes an increase in shear strength of folic material and an increase in shear stress at the folic-bedrock interface (Equation 4, Chapter 6).

7.1.3 Hydrologic Properties Influencing Slope Stability

In the principal components analyses described in chapter 4, the hydrologic variable of water-tolerant vegetation is portrayed as a key variable in influencing the stability of folic debris slides. Water-tolerant vegetation indicates continuously high groundwater levels and impeded soil drainage (Swanston and Howes, 1994). The presence of water-tolerant vegetation indicates a greater likelihood of saturated soil conditions and therefore reduced slope stability.

Adhesion and gravimetric water content were negatively correlated ($r = -0.81$, $p = 0.05$, $n = 8$). This relationship may be explained by effective soil stresses, the portion of total soil stress that is supported by grain-to-grain contact. When a soil becomes saturated its effective stresses are reduced, by reducing a soil's adhesive properties. (Sidle, 1985; Schroeder and Swanston, 1987; Swanston and Howes, 1994)

There are several influences in the Prince Rupert region that may aid in the creation of saturated soil conditions. Some geologic (Section 7.1.1) and physical soil properties (Section 7.1.2) that facilitate the creation of saturated conditions have been discussed previously. A primary reason for the periodic saturated conditions in folic soils of the Prince Rupert region that has yet to be discussed is climate. Banner et al. (1993)

describes the climate of the Prince Rupert area as a mostly maritime or oceanic climate with relatively mild temperatures and large rainfall amounts. In fact on average, about 10 modal folic profile-pore volumes of precipitation are received annually. However, on average, only about 3 modal folic profile-pore volumes of water are lost via evapotranspiration annually. The winter months are extremely wet (Section 2.2) which is important because most debris slides in this region occur during winter storm events (Sidle and Swanston, 1982).

7.1.4 Vegetation Properties Influencing Slope Stability

Vegetation can influence the stability of slopes in three prevalent ways. Roots may add strength to the soil by vertically anchoring through the solum to the bedrock or they may provide lateral support (Sidle, 1985; Swanston and Howes, 1994). Vegetation also influences slope stability through its influence on tree surcharge (Hammond et al., 1992). Both tree root strength (Cr') and tree surcharge (q0) are a part of the infinite slope equation for factor of safety (Section 1.4). An increase in tree root strength aids in maintaining slope stability through increasing total soil cohesion (Cs' + Cr'). An increase in tree surcharge aids in decreasing slope stability through adding to the component weight of the theoretical 'block of material' acting downslope. In other words, shear stress increases. Another unexpected way in which vegetation influences the stability of folic soils is through the frictional component of shear strength. The correlation between friction and oven dry root density was significant ($r = -0.79$, where $p = 0.04$ and $n = 8$). This relationship can be explained by the fact that as oven dry root mass increases, folic soil material in contact with the bedrock, including the mineral component, decreases.

Soft, smooth organic material may create less friction than comparatively rough-textured, sand-sized mineral material. If this is the case then friction should decrease as the root mass increases and the mineral soil mass decreases.

This study did not focus upon the measurement of vegetation properties influencing slope stability. Therefore, there is little to remark upon regarding root strength or tree surcharge. No comment can be made upon the lateral tensile strength component of roots because during the shear frame test (Section 6.2.3), all lateral roots were severed in order to place the shear frame upon the soil block. In addition, through general field observation, there were no tree roots anchored into joints and fractures in the bedrock. Hammond et al. (1992) described this type of soil-root morphology as type A. Type A morphology consists of shallow soils overlying competent rocks that roots cannot easily penetrate. The failure plane in type A morphology generally lies below the root zone at the soil-bedrock contact. Folic soils found adjacently to debris slide mainscarps in the Prince Rupert area have a mean thickness of 34 cm. The bedrock in this area is relatively competent diorite or gneiss, generally with some joints and fractures. In addition, the observed failure plane of folic debris slides was consistently at the soil-bedrock contact.

7.2 Deterministic Level 1 Stability Analysis (DLISA)

DLISA v. 1.02 is a deterministic slope stability computer program that can solve the infinite slope equation for the factor of safety (Section 1.4). A single value must be supplied for each of soil depth (ft), surface slope angle (%), tree surcharge (psf), root cohesion (psf), groundwater ratio, friction angle (°), soil cohesion (psf), dry unit weight (pcf), moisture content (%) and specific gravity. Note that all variables used in this program are specified in Imperial units. The infinite slope model that DLISA is based on is the same as that described in Section 1.4. The purpose of DLISA in this study is as a tool for integrating the different approaches used in gathering folic slope stability data. It also serves to synthesize the geologic, soil, hydrologic and vegetation factors influencing slope stability through the framework of the infinite slope model.

7.2.1 DLISA Variables

Values for soil depth and surface slope angle were gathered directly from actual debris slide site data. Tree surcharge is an estimated variable that was calculated using timber volume and wood densities from forested areas in the Prince Rupert Forest Region that contained similar tree species to those found in this study (N. Nesting, unpublished data). The value of the root cohesion variable was estimated using laboratory root strength values from the literature for tree species found in the study area (Hammond et al., 1992). The laboratory root strength values were then altered to 'apparent' root cohesion values through the use of the three-dimensional block model (Hammond et al., 1992). This model states that root strength acts only along the perimeter of the failure in the case of type A root morphology. Basically, as the size of the failure mass increases, the side and headwall resisting forces, and therefore root strength, have proportionally less influence on the stability of the soil mass (Hammond et al., 1992). For failure blocks approximately 12 m or wider, 'apparent' root strength values should be approximately 5 % of laboratory root strength values. The groundwater ratio is the ratio between the vertical height of the phreatic surface and the soil depth. For the purposes of this study, the groundwater ratio is assumed to be 1 because on the North Coast, slope failures often occur during high intensity rainfall events (Sidle and Swanston, 1982). Soil cohesion values were obtained using soil adhesion values from the shear frame experiment in chapter 6. Friction angle is a variable that was calculated using the shear frame measurements of chapter 6. Equation 7 in chapter 6 specifies how friction angle was derived. Dry unit weight (pcf) was calculated using the equation: ((Bulk density, kg/m3) + (coarse fragment content, v/v * 2650, kg/m3))* 0.062. Moisture content was calculated using the equation: ((Bulk density, kg/m3) + (coarse fragment content, v/v * 2650, kg/m3) + (water content - 10 kPa, v/v)* 0.062. Finally, specific gravity values were obtained as direct laboratory measurements (Section 3.2.3). Table 7-1 illustrates the summary statistics for variables to be used in the DLISA program, with the exception of root cohesion (6 psf) because only one value was computed. Groundwater ratio is also excluded because its value (1) is assumed in order to mimic a worst-case, storm event condition that increases the likelihood of slope failure. Note that the values used in the DLISA model are the mean of two replicate values from samples taken on both sides of the mainscarp (Section 4.2.1).

Table 7-1. Descriptive summary statistics for parameterizing the DLISA model n = 30

Variable	Median	Mean	Std. Dev.	CV(%)	Min.	Max.
Soil depth (ft)	0.9	1.0	0.4	42	0.3	2.1
Slope angle (%)	95	97	27	28	57	173
Tree surcharge (psf)	12	11	3	23	7	17
Friction angle (°)	41	41	6	15	34	49
Soil cohesion (psf)	16	19	14	74	4	44
Dry Unit Weight (pcf)	17	16	9	56	4	37
Moisture Content (%)	48	47	9	19	17	56
Specific Gravity	1.8	1.6	0.3	14	1.5	2.3

7.2.2 Investigating Debris Slide Factor of Safety using DLISA

Slope angle is a well-documented contributor to slope instability. Slope angle is often considered to be closely related to shallow slope failures (Sidle, 1985; Swanston and Howes, 1994), such as the folic debris slides of the Prince Rupert area. Therefore, data from two sample debris slides sites, one with the shallowest slope angle and one with the steepest slope angle, are input to the DLISA program for an examination of the result upon factor of safety. Slide 15, from the Harrison Lake area, represents the lowest slope angle and slide 29 from the Skeena River / Ecstall River confluence represents the steepest slope angle (Appendix 2). Observations from the individual slide sites are be used where possible and substitute values (from literature and shear frame test) are used where no real data are available.

Soil depth, slope angle, dry unit weight and moisture content values are all values specific to each individual slide site (Figure 7-2). In the case of tree surcharge, the maximum value was used for slide 15 and the minimum value was used for slide 29. The assumed values for tree surcharge are based upon the negative relationship between slope angle and vegetation cover ($r = -0.36$, where $p = .05$ and $n = 30$). For specific gravity, maximum (slide 15) and minimum (slide 29) values were also used. The assignment of values for specific gravity is based upon the fact that slide 15 contains denser materials than slide 29. Root cohesion and groundwater ratio values were common to slides 15 and 29. Friction angle and soil cohesion values are common because there was not enough information to vary the values meaningfully. The friction angle value used is a mean value calculated from shear frame measurements (Chapter 6). The soil cohesion (adhesion in folic debris slides) value is lower than the mean to account for the fact that the groundwater ratio is 1 (profile saturation). The original soil adhesion data from chapter 6 were taken at field moisture content (less than saturation) and soil adhesion decreases with increasing water content. Therefore, a lower soil cohesion value was used in DILSA in order to mimic saturated soil conditions.

Table 7-2. DLISA parameters

Variable	Slide 15	Slide 29
Soil Depth (ft.)	1	0.8
Slope Angle (%)	57	173
Tree Surcharge (psf)	17	7
Root Cohesion (psf)	6	6
Groundwater Ratio	1	1
Friction Angle (°)	41	41
Soil Cohesion (psf)	15	15
Dry Unit Weight (pcf)	12	30
Moisture Content (%)	45	17
Specific Gravity	1.5	2.3
Factor of Safety	**0.97**	**0.83**

The factor of safety is larger in the debris slide site with the shallowest slope angle (slide 15), illustrating that slide 15 either has more forces resistant to failure or fewer forces promoting failure than slide 29. However, which variables are most important in determining factor of safety have yet to be determined. The sensitivity of the variables may be determined through varying the values of a variable and examining their effect upon factor of safety.

7.2.3 Sensitivity Analyses

All the DLISA variables have been varied between their maximum and minimum values in order to determine the influence of each variable upon factor of safety (Figure 7-

2 to 7-11). Soil depth, slope angle, dry unit weight, moisture content and specific gravity variables contain actual maximum and minimum values as they range from slide 15 to 29. The maximum and minimum values for the tree surcharge variable were derived from timber volume and wood densities from a forested area of the Prince Rupert Forest Region that contained similar tree species to those found in the study area. The minimum tree density value was input with slide 29 and the maximum value with slide 15 because there was a negative trend between vegetation cover and slope angle ($r = -0.36$ where $p = 0.05$ and $n = 30$). Root cohesion, friction angle and soil cohesion variables were varied between the maximum and minimum values from Table 7-1. Root cohesion was varied between 3 and 30 psf, friction angle was varied between 34 and 49 ° and soil cohesion variables were varied between 4 and 44 psf. Groundwater ratio was varied over the entire possible range of values, from 0 to 1. Note the use of different scales on the x-axis (Factor of Safety) for Figures 7-2 to 7-11. Also, note that the apparent 'wobble' in the values for Figure 7-2, 7-4, 7-7, 7-9 and 7-11 are a result of too few significant digits in relation to the scale of the x-axis, rather than any real pattern in the data.

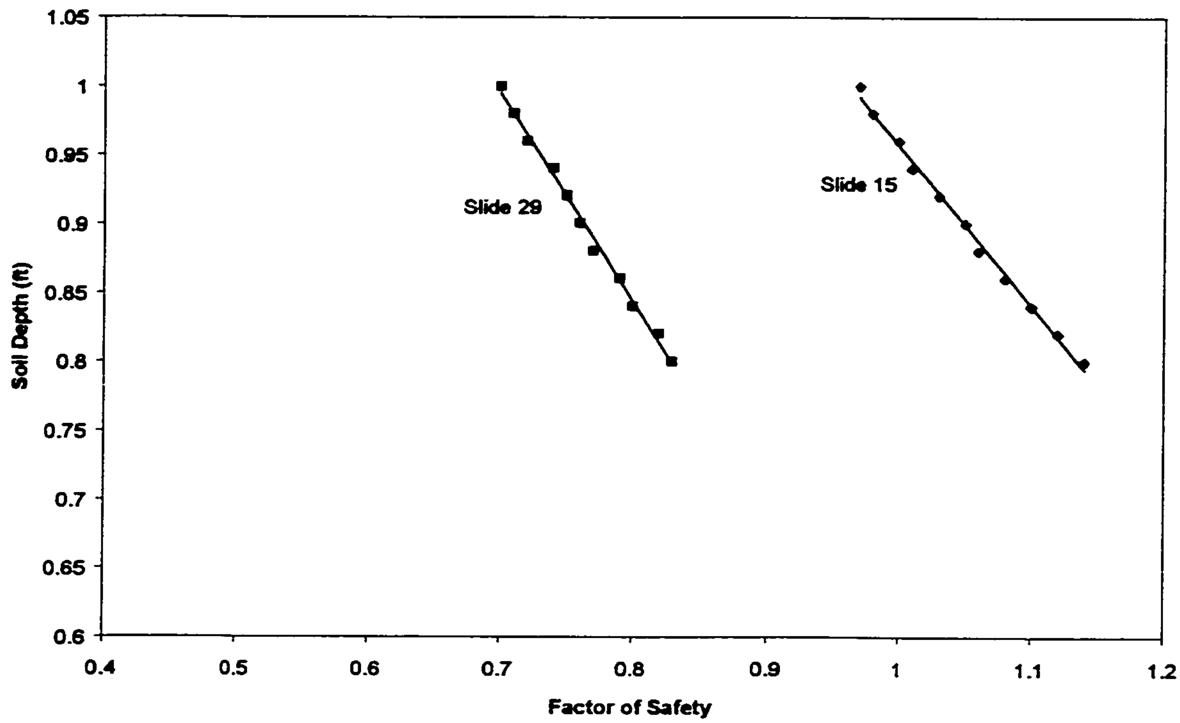


Figure 7-2. Sensitivity of soil depth variable upon factor of safety for slides 15 and 29

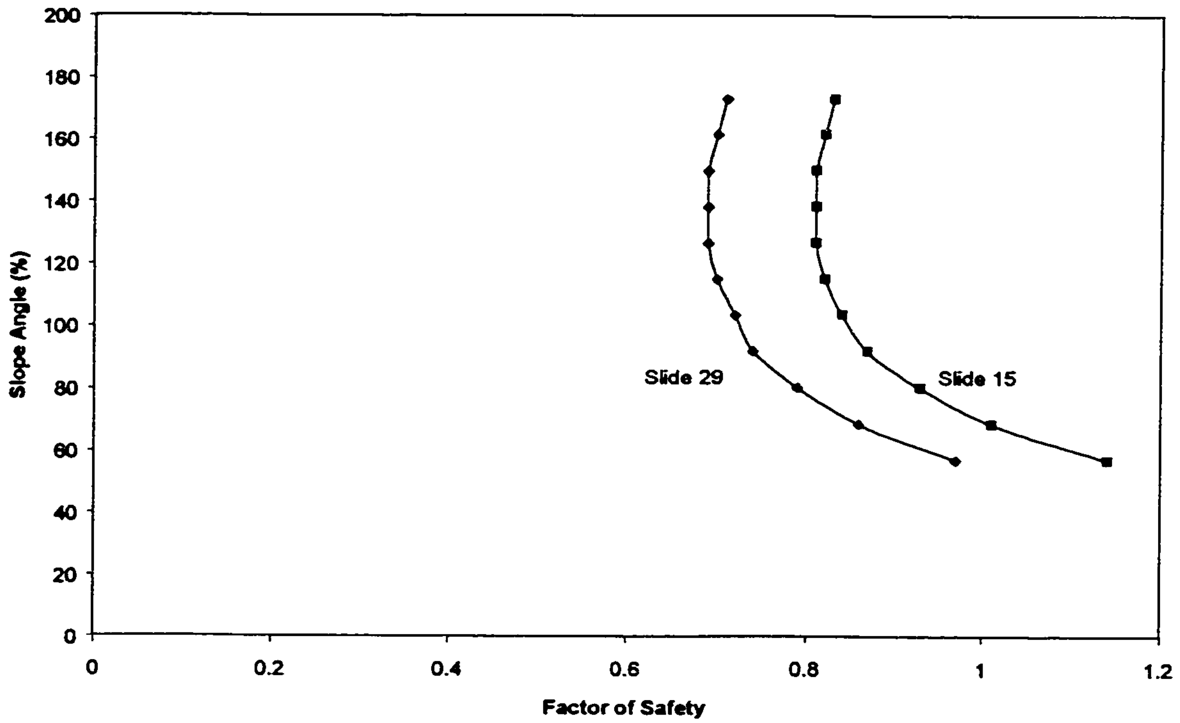


Figure 7-3. Sensitivity of slope angle variable upon factor of safety for slides 15 and 29

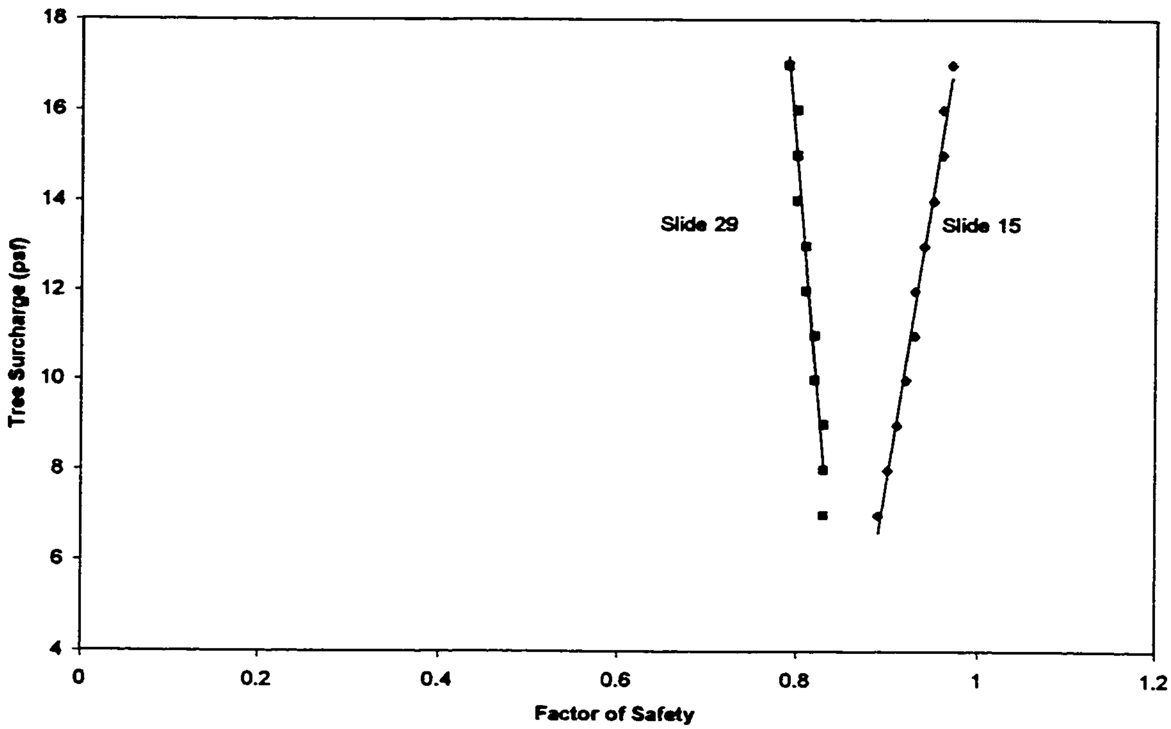


Figure 7-4. Sensitivity of tree surcharge variable upon factor of safety for slides 15 and 29

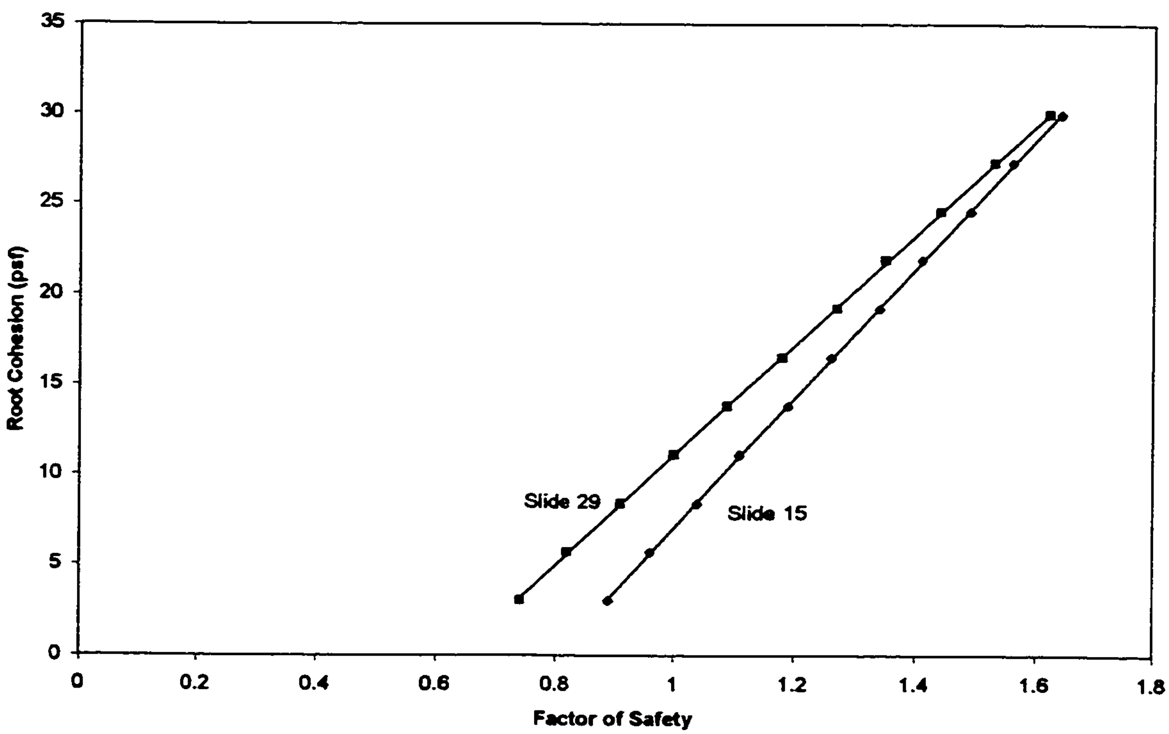


Figure 7-5. Sensitivity of root cohesion variable upon factor of safety for slides 15 and 29

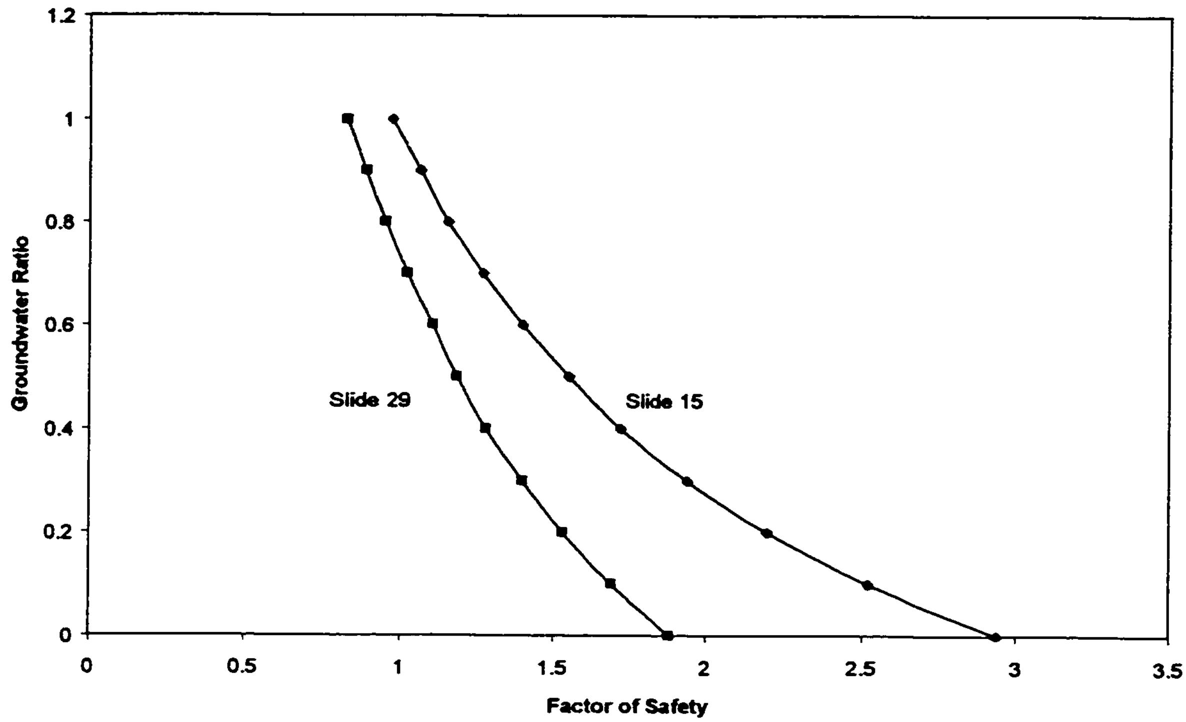


Figure 7-6. Sensitivity of groundwater ratio variable upon factor of safety for slides 15 and 29

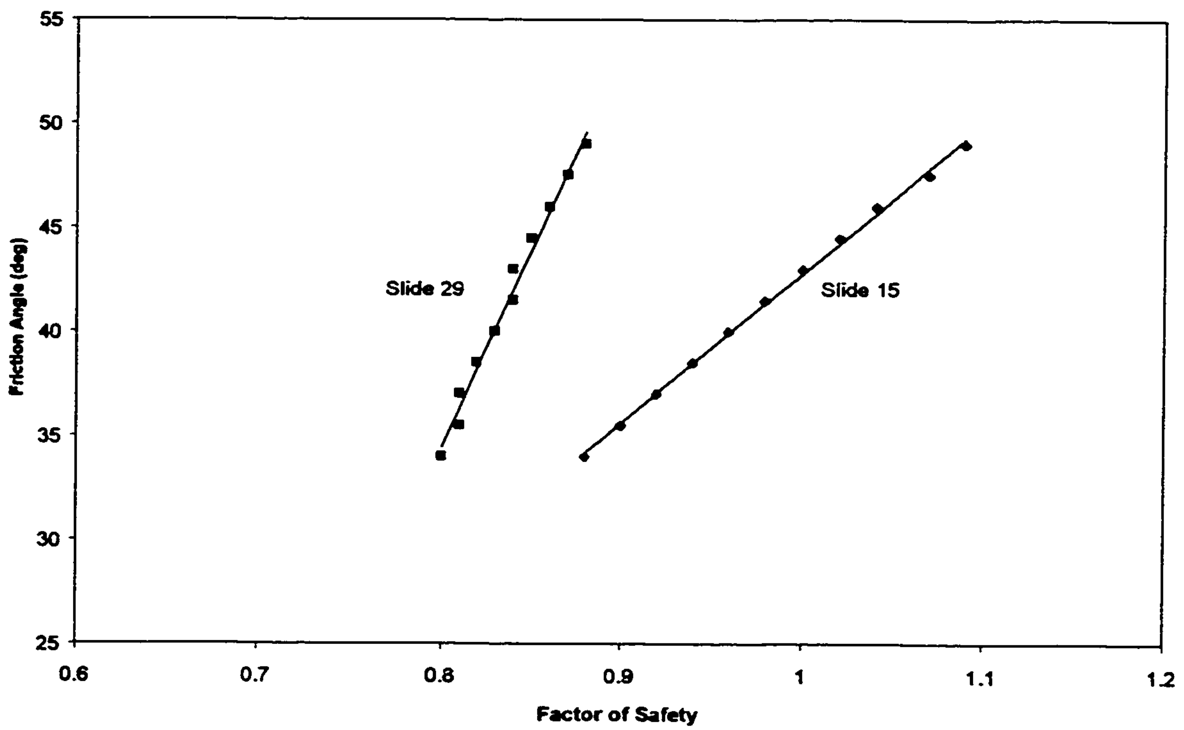


Figure 7-7. Sensitivity of friction angle variable upon factor of safety for slides 15 and 29

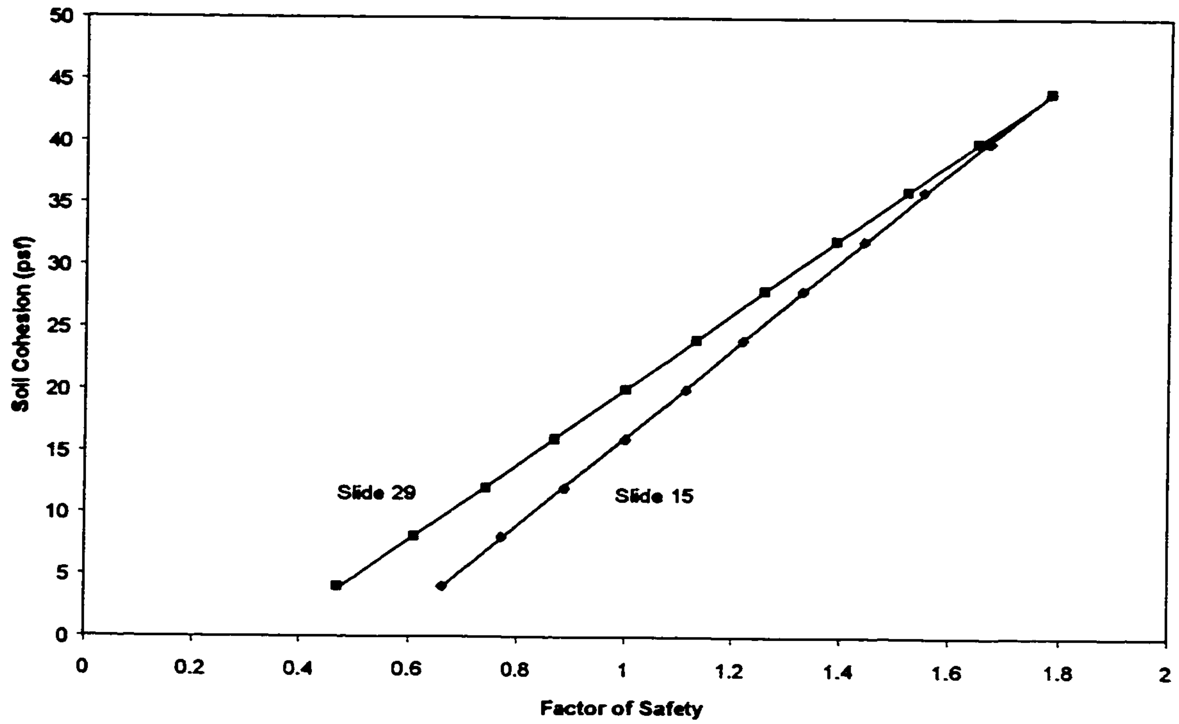


Figure 7-8. Sensitivity of soil cohesion variable upon factor of safety for slides 15 and 29

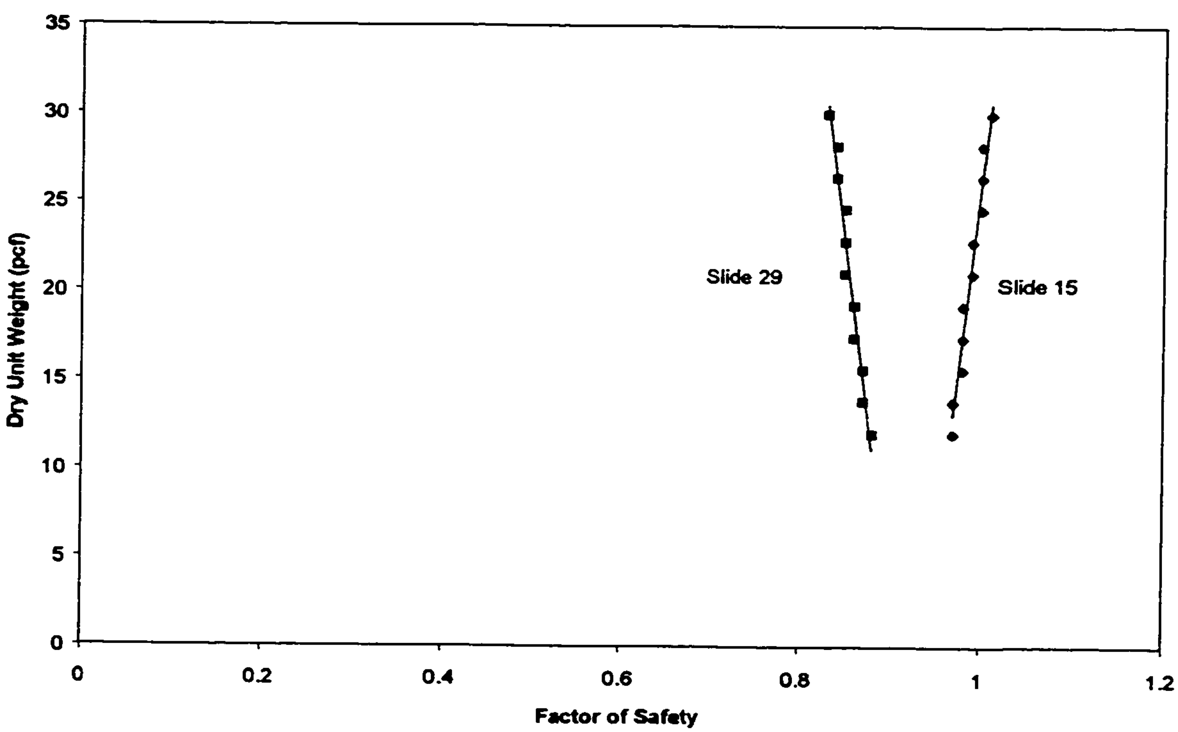


Figure 7-9. Sensitivity of dry unit weight variable upon factor of safety for slides 15 and 29

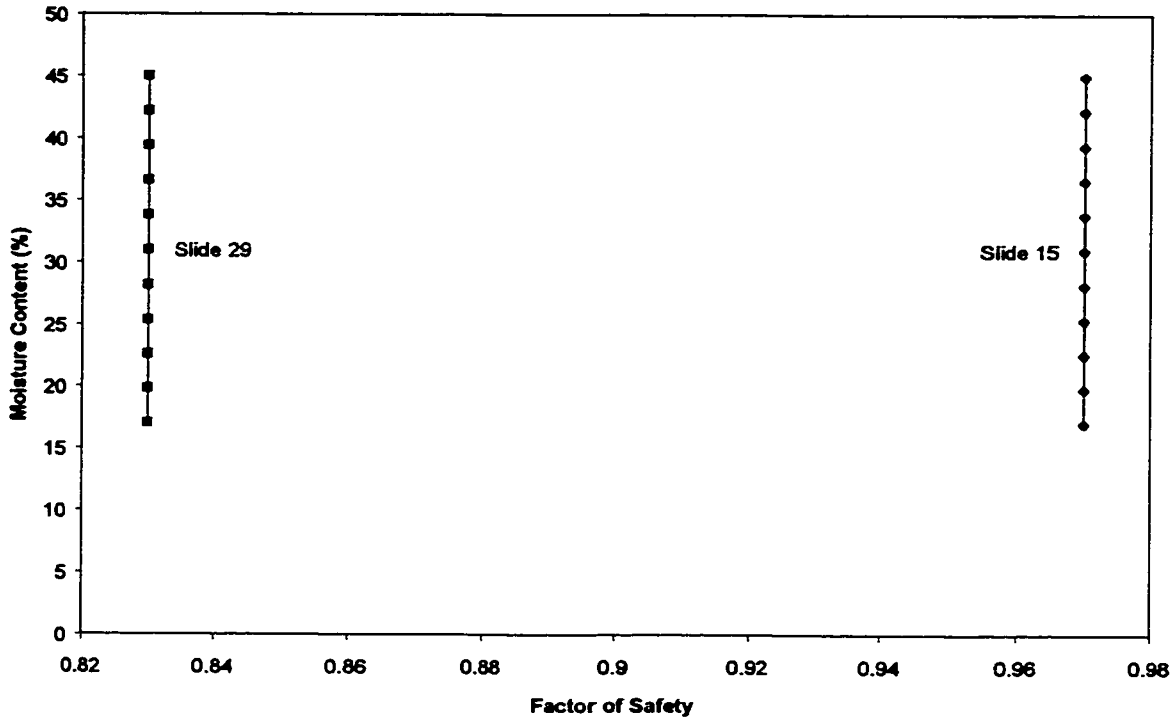


Figure 7-10. Sensitivity of moisture content variable upon factor of safety for slides 15 and 29

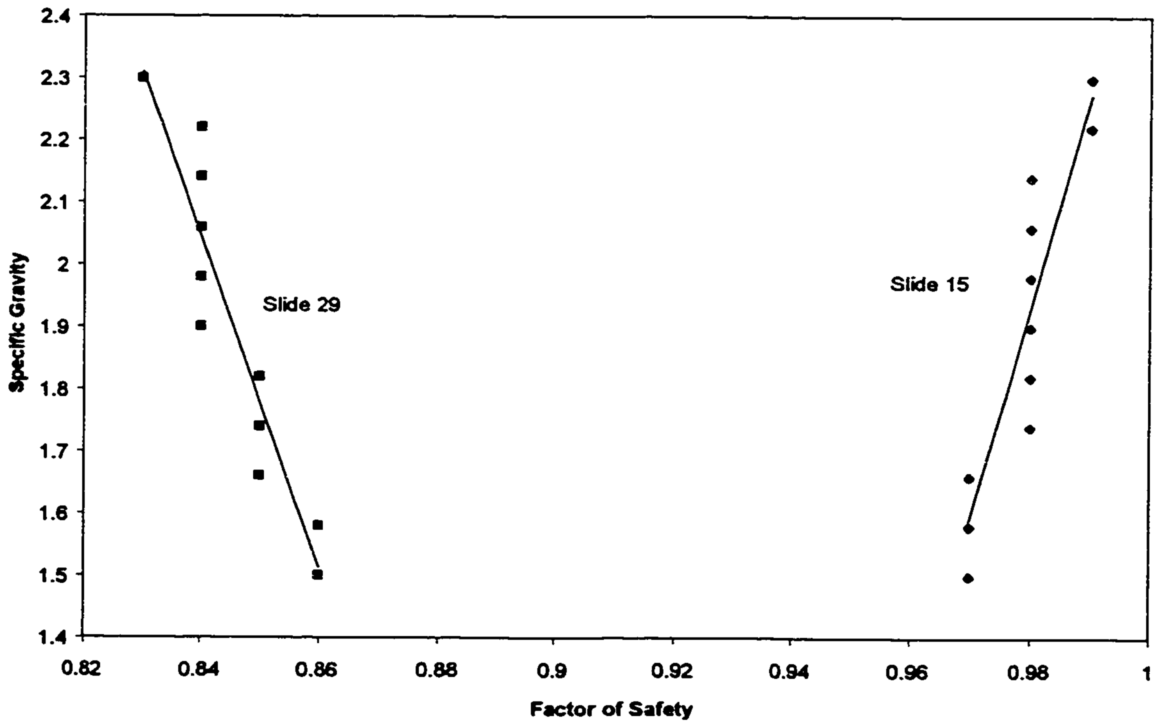


Figure 7-11. Sensitivity of specific gravity variable upon factor of safety for slides 15 and 29.

For ranges in the DLISA variables, factor of safety is relatively insensitive to differences in extremes in measured tree surcharge (Fig. 7-4), dry unit weight (Fig. 7-9), moisture content (Fig. 7-10) and specific gravity (Fig. 7-11). Throughout the range of extreme values for these variables, the influence upon factor of safety was very small. For tree surcharge, dry unit weight and specific gravity the factor of safety was altered by only about 0.05 units and for moisture content the factor of safety was not altered at all. Tree surcharge, dry unit weight and specific gravity are all variables that influence the normal load upon the failure surface. These variables all have a similar influence upon factor of safety: for slide 15 they have a negative relationship with factor of safety and for slide 29 they have a positive relationship with factor of safety. Therefore, steeper slides become less unstable with increased normal load and shallower slides become more unstable with increased normal load. Moisture content likely has no influence upon factor of safety because the groundwater ratio used in the DLISA model is 1. Through examining the infinite slope equation in Section 1.4 it is apparent that the term for moisture content (γ) is negated by the fact that the soil thickness (D) and the saturated soil thickness (Dw) have the same value. If the groundwater ratio were less than 1, the moisture content variable would then exert some influence.

For ranges in the DLISA variables factor of safety is moderately sensitive to differences in extremes in measured soil depth (Fig. 7-2), slope angle (Fig. 7-3) and friction angle (Fig. 7-7). Throughout the range of extreme values for these variables the influence upon factor of safety was relatively moderate. For the soil depth and friction angle variable the factor of safety changed by about 0.25 units. For the slope angle variable the factor of safety changed by about 0.40 units. The friction angle variable has a larger effect upon the factor of safety of slide 15 (0.05 units) than slide 29 (0.25 units) illustrating that friction may be a more important factor at shallower slope angles. The relationship between slope angle and factor of safety is not linear. At about 115 % factor of safety reaches its minimum point and increases slightly. However, below 115 % factor of safety follows a pattern of decrease with slope angle increase. The mechanism behind this trend is unclear.

For ranges in the DLISA variables, factor of safety is relatively sensitive to differences in extremes in measured root cohesion (Fig. 7-5), groundwater ratio (Fig. 7-6) and soil cohesion (Fig. 7-8). Throughout the range of extreme values for these variables the influence upon factor of safety was high. For the root cohesion variable factor of safety changed by about 0.90 units; for the groundwater ratio variable, factor of safety changed by about 1.90 units and for the soil cohesion variable, factor of safety changed by about 1.30 units. The root cohesion variable had a larger effect upon the factor of safety of slide 29 (0.90 units) than of slide 15 (0.70 units), illustrating that soil adhesion may be a more important factor at steeper slope angles. The groundwater ratio variable has a larger effect upon the factor of safety of slide 15 (1.90 units) than slide 29 (0.90 units) illustrating that groundwater ratio may be a more important factor at shallower slope angles. This is likely the case because slope angle negatively related to soil depth. A groundwater ratio of 1 in a deeper soil translates to an increase in normal load and hence a reduced factor of safety. The soil cohesion variable has a larger effect upon the factor of safety of slide 29 (1.30 units) than of slide 15 (1.10 units), illustrating that soil adhesion may be more important at steeper slope angles. Recall that the root cohesion variable also has a larger influence upon that factor of safety of steeper slopes than shallower slopes.

This indicates that the total cohesive forces (C's + C r) may be more important on steeper slopes.

7.3 Conclusions

Slope angle is an important factor influencing the stability of folic soils in the Prince Rupert region. The sensitivity analysis illustrated in Figure 7-3 depicts considerable differences in the factor of safety of debris slide sites between the minimum and maximum slope angles in this study. The relationship between factor of safety and slope angle is not linear. In this model, at very high slope angle values (115% +) factor of safety begins to rise with increasing slope angle.

It is likely that the modal pattern of horizonation in folic soils in the Prince Rupert region aids in causing the formation of a water table due to high infiltration rates and low percolation rates. This is a result of the thin, poorly decomposed upper horizon having a significantly higher porosity than the thicker, well-decomposed lower horizon. The differences in porosity likely result in differences in saturated conductivity allowing water to infiltrate quickly into the upper horizon and percolate slowly into the lower horizon, therefore allowing a water table to form. Boelter (1969) reported similar differences in the saturated conductivity of poorly decomposed and well-decomposed peat.

Shallow hillslope depressions do not appear to be as important in the stability of slopes in the Prince Rupert area as originally hypothesized. The majority of folic debris slides in this study have convex headscarps, illustrating that slope failure often occurs without the influence of shallow hillslope depressions. However, gullied areas were avoided in this study because they have been a previously well-documented cause of slope failure. The principal components analyses in Chapter 4 isolated slope shape as an important variable in the slope stability of this region. Convex slope shape may negatively influence slope stability in several ways, not previously considered. The very steep angle of many of convex slopes in this study may have created conditions of failure without the influence of concave depressions. In addition, a change in slope from a concave or straight segment to a steeper convex segment downslope may create a break in the slope that allows groundwater an exit point, therefore creating unstable conditions. Shallow hillslope depressions may be a more critical factor in the failure of areas with lower slope angles.

Root cohesion is unlikely to have a major contribution towards slope stability in the Prince Rupert area in spite of the factor of safety being sensitive to root cohesion. Field observation indicated that there were few tree roots anchored vertically into the bedrock. However there were thick networks of small and medium-sized roots in the upper soil layers that may provide lateral support and increased stability. The width of the slides also serves to reduce the root cohesion. According to the three-dimensional block model, as the size of the failure mass increases, the side and headwall resisting forces and therefore root cohesion, have proportionally less influence on the stability of the soil mass. For failure blocks 12 m or wider, 'apparent' root strength should be approximately 5 % of laboratory values (Hammond et al., 1992). The studied folic debris slides have a mean width of 27 m, a standard deviation of 36 m, a minimum of 5 m and a maximum of 190 m. The sensitivity analysis in Figure 7-5 indicates that root cohesion is a highly influential variable with regard to factor of safety. Examination using DLISA indicates that root cohesion values must be low in order to obtain a factor of safety below 1 on even the maximum slope angle example, site 29.

Soil adhesion appears to be the most influential variable regarding slope stability in the Prince Rupert area. Soil adhesion correlated positively with bulk density and negatively with gravimetric water content. Therefore, any process that contributes toward a decrease in bulk density or an increase in soil water content of the lowest soil horizon also serves to decrease soil adhesion and therefore increase slope instability.

Any activity, natural or human-induced, that serves to increase soil bulk density or water content may have a detrimental effect on slope stability. Sidecast from road building is likely to increase soil bulk density, decreasing soil porosity and creating conditions in which a soil is more likely to become saturated. Soil saturation causes a reduction in effective soil stresses, reducing soil adhesion and hence slope stability. The addition of sidecast to a surface also serves to create unstable conditions through increase in normal load. Clearcut logging practices may also contribute toward folic soil instability because of the loss in vegetation canopy that serves to reduce soil water content through interception of rainfall and transpiration.

Groundwater ratio is negatively related to factor of safety and is a very influential factor in determining slope stability. As a water table develops within a soil, adhesion is reduced and normal load is increased therefore making slope instability more likely for two reasons.

7.4 References Cited

Banner, A., MacKenzie, W., Haeussler, S., Thompson, S and Pojar, J. 1993. A field guide to site identification and interpretation for the Prince Rupert forest region. Land Management Handbook. Ministry of Forests, Crown Publications Inc.,Victoria, B.C.

Boelter, D.H. 1969. Physical properties of peats as related to degree of decomposition. Soil Sci. Soc. Amer. Proc. **33**: 606 - 609.

Cruden, D.M. and Varnes, D.J. 1996. Landslide types and processes. Pages 36 - 75 *in* Transportation Research Board Special Report 247.

Farnham, R.S. and Finney, H.R. 1965. Classification and properties of organic soils. Advance. Agron. **17**: 115 - 139.

Gray, D.H. and Sotir, R.B. 1996. Biotechnical and soil bioengineering slope stabilization: a practical guide for erosion control. John Wiley and Sons Inc., Toronto, Ontario. 378 pp.

Hammond, C., Hall, D., Miller, S. and Swetik, P. 1992. Level 1 stability analysis (LISA) documentation for version 2.0. USDA Forest Service, Gen. Tech. Rep. INT-285, Ogden, UT.

Hammond, C., Hall, D., Swetik, P. 1991. DLISA version 1.02. Deterministic level 1 stability analysis of natural slopes using infinite slope equation. USDA Forest Service. Intermountain Research Center. Moscow, ID.

Schroeder, W.L. and Alto, J.V. 1983. Soil properties for slope stability analysis: Oregon and Washington coastal mountains. Forest Sci. **29**: 823-833.

Schroeder, W.L. and Swanston, D.N. 1987. Application of geotechnical data to resource planning in southeast Alaska. USDA Forest Service, Gen. Tech. Rep. PNW-198, Portland, OR.

Sidle, R.C. 1985. Factors influencing the stability of slopes. Pages 17 - 25 *in* D.N. Swanston, ed. Proc. of a workshop on slope stability: problems and solutions in forest management. USDA Forest Service, Gen. Tech. Rep. PNW-180, Portland, OR.

Sidle, R.C. and Swanston, D.N. 1982. Analysis of a small debris slide in coastal Alaska. Can. Geotech. J. 19: 167 - 174.

Soil Classification Working Group. 1998. The Canadian system of soil classification. Third Ed. Agric. and Agri-Food Can. Publ. 1646. National Research Council of Canada, Ottawa, Ontario.

Swanston, D.N. and Howes, D.E. 1994. Slope movement processes and characteristics. Pages 1 - 17 *in* S.C. Chatwin, D.E. Howes, J.W. Schwab and D.N. Swanston, eds. A guide for management of landslide-prone terrain in the Pacific Northwest. Second Ed. Land Management Handbook No. 18. British Columbia Ministry of Forests. Victoria, British Columbia.

Trowbridge, R., Luttmerding, H. and Tarnocai, C. 1985. Report on Folisolic soil classification in Canada. Expert committee on soil survey proceedings of the sixth annual meeting. Guelph, Ontario. Research Branch, Agriculture Canada. Ottawa, Ontario.

Wu, T.H. and Swanston, D.N. 1980. Risk of landslides in shallow soils and its relation to clearcutting in southeastern Alaska. Forest Sci. **26**: 495 - 510.

Appendices

Codes used in Appendices

1. Debris Slide Codes

Example: 1312

Slide number: 13
Pedon number: 1
Horizon number: 2

There are 30 slides, 3 or 4 pedons per slide and from 1 to 3 horizons per pedon. Pedon number 1 and 2 are generally located adjacent to the mainscarp, whereas pedon 3 and 4 are located at the upper-mid slide location.

2. Non-Debris Slide Transect Codes

Example: G32

Transect Location: Green River
Slope Class: 25 to 29 °
Horizon Number: 2

There are 4 non-debris slide transect locations: Green River, Prudhomme Lake, Diana Lake and Harrison Lake. There are 5 slope classes: $\leq$ 19 °, 20 to 24 °, 25 to 29 °, 30 to 34 °and $\geq$ 35 °. There are from 1 to 3 horizons per slope class pedon.

3. Shear Frame Codes

Example: P3R4

Plot Number: 3
Replicate: 4

There are 9 shear frame plot locations and the number of replicates per plot varies.

4. General

n/d: not determined

Appendix 1 - Location of Debris Slides and Non-Debris Slide Transects

1) Debris Slides

Slide	Description	Latitude	Longitude	UTM
1	Lachmach Road 7.5 km - west of road - new	n/d	n/d	n/d
2	Lachmach Road 4.55 km - east of road - L47	54 16.2'	130 52.9'	VL425139
3	Lachmach Road 8.5 km - east of road - L24	54 17.6'	130 55.9'	VL392164
4	Diana Lake 1 - P22a	54 13.4'	130 9.4'	VL245089
5	Lachmach Road 1.95 km - west of road	54 15.2'	130 52.2'	VL433119
6	Lachmach Road 4.5 km - west of road	54 15.8'	130 53.2'	VL422131
7	Harrison Lake 1 - Hwy 16 - west	54 13.6'	130 1.8'	VL329090
8	Boatlaunch - Hwy 16 at 45 km sign	n/d	n/d	n/d
9	Lachmach Road 7.9 km - west of road	54 17.4'	130 56.9'	VL383159
10	Lachmach Road 7.6 km - west of road	54 17.2'	130 56.5'	VL385157
11	Diana Lake 2 - P22b	54 13.7'	130 9.3'	VL248091
12	Diana Lake 3 - P22c	54 13.7'	130 9.2'	VL249092
13	Lachmach Road 6.7 km - west of road	54 17.0'	130 55.9'	VL395153
14	Lachmach Road 3.6 km - west of road	54 15.8'	130 53.1'	VL423131
15	Harrison Lake 2 - Hwy 16 - east	54 13.0'	130 0.5'	VL343079
16	Silver Creek 1 - road initiated - north	54 25.5'	130 11.4'	VL230305
17	Silver Creek 2 - road initiated south	54 25.2'	130 11.5'	VL228303
18	Osbourn Cove 1 - north	54 23.7'	130 13.5'	VL206277
19	Osbourn Cove 2 - south	54 23.6'	130 13.5'	VL206275
20	Prodhomme Lake 1 - unnamed - west	54 14.9'	130 6.3'	VL280115
21	Woodward Lake watershed - W01	54 23.0'	130 12.6'	VL214265
22	Lachmach Road - Helisite - east of road	54 16.2'	130 55.8'	VL396167
23	Smith Island Inlet 1 - upper	54 9.7'	130 15.8'	VL177022
24	Smith Island Inlet 2 - lower	54 9.8'	130 15.9'	VL176024
25	Silver Creek - Blasting Initiated	54 24.9'	130 11.7'	VL225298
26	Prodhomme Lake 2 - east - P17	54 14.9'	130 5.9'	VL285115
27	Silver Creek - west - S10b	54 23.9'	130 10.9'	VL235280
28	Silver Creek - east - S10c	54 23.9'	130 10.9'	VL234280
29	Skeena/Ecstall 1 - west	54 10.8'	130 55.9'	VL393038
30	Skeena/Ecstall 2 - east	54 10.8'	130 55.8'	VL393038

2) Non-Debris Slide Transects

Transect	Description	Latitude	Longitude	UTM
1	Diana Lk. - Mt. MacDonald Lookout Trail	54 13.2'	130 11.0'	VL229087
2	Prodhomme Lake area - north side of Hwy 16	54 14.2'	130 5.6'	VL287100
3	Harrison Lake - between Harrison Lk. 1 & 2 slides	54 13.3'	130 1.1'	VL337083
4	Green River - after 2nd Cutblock on Green Rvr. Rd.	n/d	n/d	n/d

Appendix 2 - Slope Position of Debris Slide Initiation Zone

Slide	Slope Position
1	upper mid
2	lower mid
3	lower mid
4	mid
5	mid
6	mid
7	lower
8	mid
9	mid
10	mid
11	upper mid
12	upper mid
13	mid
14	mid
15	lower
16	mid
17	mid
18	upper
19	upper
20	mid
21	lower
22	mid
23	upper mid
24	mid
25	mid
26	mid
27	upper
28	upper
29	upper
30	upper

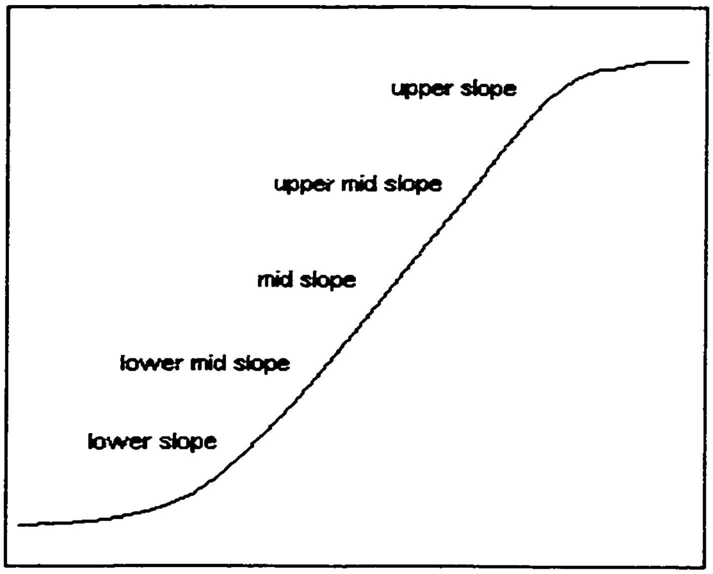


Figure A-1. Approximate slope positions on an idealized slope

Appendix 3 - Mean Debris Slide Parameters

Slide	Depth (m)	Width (m)	Length (m)
1	0.5	19	750
2	0.8	22	300
3	0.5	17	400
4	0.8	13	150
5	0.5	16	300
6	0.5	13	400
7	0.5	25	250
8	0.5	33	300
9	0.5	10	350
10	0.5	13	200
11	0.5	13	100
12	0.5	13	100
13	0.4	25	150
14	0.5	10	200
15	0.5	100	400
16	0.5	18	900
17	0.5	20	100
18	0.4	13	300
19	0.2	12	150
20	0.2	190	210
21	0.5	13	200
22	0.4	20	500
23	0.5	20	900
24	0.5	20	700
25	0.5	n/d	400
26	0.5	63	400
27	0.5	15	300
28	0.5	15	250
29	0.5	8	700
30	0.5	5	700

Appendix 4 - Landscape Characteristics for Debris Slide Sites

Slide	Elev. (m)	Aspect	Slope Shape	Surface Config.	Slope Angle (deg)	Bedrock Exposure	Bedrock Type	Bedrock Structure	Local Setting
1	450	E	straight	uniform/smooth	42	subsurface	diorite	jointed/fractured	n/d
1	440	E	straight	uniform/smooth	42	subsurface	diorite	jointed/fractured	n/d
1	250	NE	straight	uniform/smooth	37	subsurface	diorite	jointed/fractured	n/d
1	240	NE	straight	uniform/smooth	35	subsurface	diorite	jointed/fractured	n/d
2	270	NWW	straight	irregular/benchy	80	exposed	diorite	jointed/fractured	cliffs
2	220	NWW	concave	irregular/benchy	40	exposed	diorite	jointed/fractured	cliffs
2	130	NWW	convex	irregular/benchy	32	subsurface	diorite	jointed/fractured	n/d
3	220	SSE	convex	irregular/benchy	45	exposed	diorite	jointed/fractured	n/d
3	220	SSE	straight	irregular/benchy	38	exposed	diorite	massive	n/d
3	175	SSE	concave	irregular/benchy	38	exposed	diorite	massive	n/d
4	160	NW	concave	irregular/benchy	50	exposed	gneiss	jointed/fractured	talus at cliff base
4	150	NW	straight	irregular/benchy	56	exposed	gneiss	jointed/fractured	talus at cliff base
4	110	NW	straight	uniform/smooth	39	subsurface	gneiss	jointed/fractured	talus at cliff base
4	110	NW	convex	uniform/smooth	47	subsurface	gneiss	jointed/fractured	talus at cliff base
5	308	E	convex	irregular/benchy	42	exposed	diorite	massive	cliffs
5	300	E	straight	irregular/benchy	45	exposed	diorite	massive	cliffs
5	240	E	concave	irregular/benchy	45	exposed	diorite	massive	cliffs
5	210	E	concave	irregular/benchy	45	subsurface	diorite	massive	n/d
6	280	NE	straight	uniform/smooth	45	exposed	diorite	massive	cliffs
6	260	NE	straight	uniform/smooth	45	subsurface	diorite	massive	n/d
6	210	NE	straight	uniform/smooth	40	subsurface	diorite	massive	n/d
6	208	NE	straight	uniform/smooth	42	subsurface	diorite	massive	n/d
7	250	NE	straight	uniform/smooth	44	subsurface	quartz diorite	massive	n/d
7	260	NE	straight	uniform/smooth	46	subsurface	quartz diorite	massive	n/d
7	200	NE	straight	uniform/smooth	38	subsurface	quartz diorite	massive	n/d
7	200	NE	straight	uniform/smooth	38	subsurface	quartz diorite	massive	n/d
8	150	SE	convex	irregular/benchy	50	exposed	quartz diorite	massive	cliffs
8	140	SE	convex	irregular/benchy	50	exposed	quartz diorite	massive	cliffs
8	50	SE	concave	irregular/benchy	35	exposed	quartz diorite	massive	talus at cliff base
9	210	NE	concave	irregular/benchy	39	exposed	diorite	massive	cliffs
9	210	NE	concave	irregular/benchy	39	exposed	diorite	massive	cliffs

Slide	Elevation (m)	Aspect	Slope Shape	Surface Configuation	Slope Angle (deg)	Bedrock Exposure	Bedrock Type	Bedrock Structure	Local Setting
9	190	NE	concave	irregular/benchy	42	exposed	diorite	massive	cliffs
9	190	NE	concave	irregular/benchy	39	exposed	diorite	massive	cliffs
10	275	NE	straight	irregular/benchy	50	exposed	diorite	massive	cliffs
10	290	NE	straight	irregular/benchy	49	subsurface	diorite	massive	n/d
10	235	NE	straight	irregular/benchy	48	exposed	diorite	massive	cliffs
10	230	NE	straight	irregular/benchy	45	exposed	diorite	massive	cliffs
11	200	NW	convex	irregular/benchy	55	exposed	gneiss	jointed/fractured	cliffs
11	170	NW	convex	irregular/benchy	52	exposed	gneiss	jointed/fractured	talus at cliff base
11	170	NW	convex	irregular/benchy	52	subsurface	gneiss	jointed/fractured	n/d
12	200	NW	concave	irregular/benchy	48	subsurface	gneiss	jointed/fractured	n/d
12	200	NW	concave	irregular/benchy	42	subsurface	gneiss	jointed/fractured	n/d
12	180	NW	concave	irregular/benchy	33	subsurface	gneiss	jointed/fractured	n/d
12	180	NW	concave	irregular/benchy	37	subsurface	gneiss	jointed/fractured	cliffs
13	260	NNE	convex	irregular/benchy	48	subsurface	diorite	massive	cliffs
13	240	NNE	convex	irregular/benchy	48	subsurface	diorite	massive	cliffs
13	205	NNE	straight	irregular/benchy	42	subsurface	diorite	massive	n/d
13	195	NNE	concave	irregular/benchy	39	subsurface	diorite	massive	cliffs
14	260	NNE	straight	irregular/benchy	48	exposed	diorite	massive	cliffs
14	265	NNE	straight	irregular/benchy	44	exposed	diorite	massive	cliffs
14	200	NNE	concave	irregular/benchy	42	subsurface	diorite	massive	n/d
14	200	NNE	concave	irregular/benchy	37	subsurface	diorite	massive	n/d
15	340	NE	convex	irregular/benchy	39	exposed	quartz diorite	massive	cliffs
15	345	NE	straight	irregular/benchy	42	exposed	quartz diorite	massive	n/d
15	290	NE	concave	uniform/smooth	42	subsurface	quartz diorite	massive	n/d
15	285	NE	concave	uniform/smooth	39	subsurface	quartz diorite	massive	n/d
16	350	W	convex	uniform/smooth	28	subsurface	gneiss	jointed/fractured	n/d
16	350	W	convex	uniform/smooth	26	subsurface	gneiss	jointed/fractured	n/d
16	325	W	straight	uniform/smooth	22	subsurface	gneiss	jointed/fractured	n/d
16	325	W	straight	uniform/smooth	22	subsurface	gneiss	jointed/fractured	n/d
17	330	NW	convex	uniform/smooth	20	subsurface	gneiss	jointed/fractured	n/d
17	330	NW	convex	uniform/smooth	20	subsurface	gneiss	jointed/fractured	n/d
17	310	NW	straight	uniform/smooth	20	subsurface	gneiss	jointed/fractured	n/d
17	310	NW	straight	uniform/smooth	20	subsurface	gneiss	jointed/fractured	n/d

Slide	Elevation (m)	Aspect	Slope Shape	Surface Configuration	Slope Angle (deg)	Bedrock Exposure	Bedrock Type	Bedrock Structure	Local Setting
18	580	SW	convex	uniform/smooth	45	exposed	gneiss	jointed/fractured	n/d
18	575	SW	convex	uniform/smooth	62	exposed	gneiss	jointed/fractured	cliffs
18	550	SW	convex	uniform/smooth	48	subsurface	gneiss	jointed/fractured	n/d
18	540	SW	concave	uniform/smooth	45	subsurface	gneiss	jointed/fractured	n/d
19	535	W	convex	uniform/smooth	42	subsurface	gneiss	jointed/fractured	n/d
19	530	W	convex	uniform/smooth	42	subsurface	gneiss	jointed/fractured	n/d
19	515	W	concave	uniform/smooth	42	subsurface	gneiss	jointed/fractured	n/d
19	520	W	concave	uniform/smooth	35	subsurface	gneiss	jointed/fractured	n/d
20	145	NW	concave	irregular/benchy	39	exposed	diorite	massive	cliffs
20	150	NW	straight	irregular/benchy	29	subsurface	diorite	massive	n/d
20	120	NW	straight	irregular/benchy	44	subsurface	diorite	massive	n/d
20	110	NW	straight	irregular/benchy	42	subsurface	diorite	massive	blocks at cliff base
21	260	E	convex	uniform/smooth	31.5	subsurface	gneiss	jointed/fractured	n/d
21	260	E	convex	uniform/smooth	31.5	subsurface	gneiss	jointed/fractured	n/d
21	225	E	concave	uniform/smooth	29	subsurface	gneiss	jointed/fractured	n/d
21	220	E	concave	uniform/smooth	31	subsurface	gneiss	jointed/fractured	n/d
22	325	SE	convex	irregular/benchy	42	subsurface	diorite	massive	n/d
22	325	SE	convex	irregular/benchy	43	subsurface	diorite	massive	n/d
22	275	SE	concave	irregular/benchy	33	subsurface	diorite	massive	n/d
22	270	SE	concave	irregular/benchy	33	subsurface	diorite	massive	n/d
23	470	NNE	straight	irregular/benchy	33	subsurface	quartz diorite	massive	n/d
23	470	NNE	straight	irregular/benchy	29	subsurface	quartz diorite	massive	n/d
23	405	NNE	concave	irregular/benchy	38	subsurface	quartz diorite	massive	n/d
23	405	NNE	concave	irregular/benchy	28	subsurface	quartz diorite	massive	n/d
24	390	NNE	convex	irregular/benchy	39	subsurface	quartz diorite	massive	n/d
24	385	NNE	straight	irregular/benchy	33	subsurface	quartz diorite	massive	n/d
24	310	NNE	concave	irregular/benchy	33	subsurface	quartz diorite	massive	n/d
24	310	NNE	convex	irregular/benchy	29	subsurface	quartz diorite	massive	n/d
25	325	W	concave	irregular/benchy	42	subsurface	gneiss	jointed/fractured	n/d
25	325	W	concave	irregular/benchy	42	subsurface	gneiss	jointed/fractured	n/d
25	310	W	concave	irregular/benchy	29	subsurface	gneiss	jointed/fractured	n/d
25	310	W	concave	irregular/benchy	31	subsurface	gneiss	jointed/fractured	n/d
26	215	NW	convex	irregular/benchy	37	exposed	quartz diorite	massive	cliffs

Slide	Elevation (m)	Aspect	Slope Shape	Surface Configuation	Slope Angle (deg)	Bedrock Exposure	Bedrock Type	Bedrock Structure	Local Setting
26	215	NW	convex	irregular/benchy	37	exposed	quartz diorite	massive	n/d
26	200	NW	convex	irregular/benchy	40	exposed	quartz diorite	massive	cliffs
26	180	NW	convex	irregular/benchy	42	subsurface	quartz diorite	massive	n/d
27	410	SW	convex	uniform/smooth	45	subsurface	gneiss	jointed/fractured	n/d
27	410	SW	convex	uniform/smooth	42	subsurface	gneiss	jointed/fractured	n/d
27	400	SW	convex	uniform/smooth	39	subsurface	gneiss	jointed/fractured	n/d
27	390	SW	convex	uniform/smooth	35	subsurface	gneiss	jointed/fractured	n/d
28	415	SW	convex	uniform/smooth	42	subsurface	gneiss	jointed/fractured	n/d
28	410	SW	convex	uniform/smooth	42	subsurface	gneiss	jointed/fractured	n/d
28	390	SW	convex	uniform/smooth	48	subsurface	gneiss	jointed/fractured	n/d
28	390	SW	convex	uniform/smooth	35	subsurface	gneiss	jointed/fractured	n/d
29	430	N	convex	irregular/benchy	60	exposed	quartz diorite	massive	cliffs
29	430	N	convex	irregular/benchy	50	subsurface	quartz diorite	massive	n/d
29	380	N	convex	irregular/benchy	48	subsurface	quartz diorite	massive	n/d
29	390	N	convex	irregular/benchy	45	subsurface	quartz diorite	massive	n/d
30	430	N	convex	irregular/benchy	48	subsurface	quartz diorite	massive	n/d
30	430	N	convex	irregular/benchy	50	subsurface	quartz diorite	massive	n/d
30	390	N	convex	irregular/benchy	39	subsurface	quartz diorite	massive	n/d
30	390	N	convex	irregular/benchy	45	subsurface	quartz diorite	massive	n/d

Appendix 5 - Morphological Characteristics for Debris Slide Soil Samples

Sample	Horizon Thickness (cm)	Horizon Designation	Character	Structure	Consistence (Moist)	Coarse Fragment (%)
111	0-7	Fa	fibrous	nc-matted	tenacious	0
112	7-43	Hh	greasy	massive	pliable	0
121	0-12	Fa	fibrous	nc-matted	tenacious	0
122	12-37	C	gritty	granular	pliable	5 angular cobbles
131	0-18	Fa	fibrous	nc-matted	tenacious	0
132	18-50	Hhi	mushy/gritty	massive	pliable	5 angular cobbles
141	0-30	Hh	mushy	massive	pliable	0
211	0-3	Fai	felty/fibrous/gritty	nc-matted	tenacious	0
212	3-13	Hr	fibrous	nc-matted	tenacious	0
213	13-30	Hzi	gritty	granular	loose	0
221	0-5	Fa	fibrous	nc-matted	tenacious	0
222	5-35	Lvw	ligneous	wood	tenacious	0
223	35-50	Hzi	gritty	massive	loose	0
231	0-5	Hhi	gritty	granular	loose	0
311	0-2	Fa	fibrous	nc-matted	tenacious	0
312	2-10	Hz	fibrous	nc-matted	tenacious	0
313	10-27	Hhi	gritty	blocky	pliable	30 angular cobbles
321	0-3	Fai	fibrous/gritty	nc-matted	tenacious	0
322	3-27	C	gritty	blocky	pliable	0
323	27-46	Hhi	gritty	massive	pliable	0
331	0-9	Fa	fibrous	nc-matted	tenacious	0
332	9-29	C	gritty	massive	pliable	0
411	0-4	Ln	felty/fibrous	nc-matted	tenacious	0
412	4-13	Hri	gritty	blocky	pliable	0
421	0-6	Fa	felty/fibrous	nc-matted	tenacious	0
431	0-5	C	gritty	granular	loose	10 angular cobbles
432	5-25	C	gritty	massive	loose	20 angular cobbles
441	0-30	Hri	gritty	massive	loose	50 angular cobbles
511	0-8	Fa	fibrous	nc-matted	tenacious	0
512	8-29	Hr	mushy	granular	loose	0
513	29-52	Hhi	greasy/gritty	massive	pliable	0

Sample	Horizon Thickness (cm)	Horizon Designation	Character	Structure	Consistence (Moist)	Coarse Fragment (%)
521	0-9	Fa	mossy	erect	tenacious	0
522	9-41	Fa	mossy	erect	tenacious	0
531	0-14	Fa	fibrous	nc-matted	tenacious	0
532	14-28	C	gritty	massive	loose	0
541	0-10	Fa	fibrous	nc-matted	tenacious	0
542	10-35	C	gritty	blocky	pliable	0
611	0-18	Fa	fibrous	nc-matted	tenacious	0
621	0-10	Faw	fibrous/ligneous	nc-matted	tenacious	0
622	10-32	Hr	greasy	blocky	loose	90 angular cobbles
631	0-7	Fa	fibrous	nc-matted	tenacious	0
632	7-30	Hhi	gritty	blocky	loose	5 angular cobbles
641	0-6	Fa	fibrous	nc-matted	tenacious	0
642	6-40	Hhi	greasy/gritty	blocky	loose	5 angular cobbles
643	40-55	C	gritty	blocky	loose	90 angular cobbles
711	0-18	Fa	fibrous	nc-matted	tenacious	0
712	18-35	C	gritty	massive	loose	0
721	0-9	Fa	fibrous	nc-matted	tenacious	0
722	9-35	Hhi	gritty	massive	loose	0
731	0-9	Faw	ligneous	nc-matted	tenacious	0
732	9-32	Hr	greasy	granular	loose	0
733	32-50	C	gritty	massive	loose	20 angular cobbles
741	0-30	Fa	greasy	granular	loose	10 angular cobbles
742	30-65	C	gritty	massive	loose	10 angular cobbles
811	0-16	Fm	felty/fibrous	nc-matted	tenacious	0
821	0-18	Fa	fibrous	nc-matted	tenacious	0
822	18-38	C	gritty	blocky	loose	0
831	0-8	Fz	gritty	granular	loose	0
832	8-41	C	gritty	blocky	loose	20 angular cobbles
911	0-10	Fa	fibrous	nc-matted	tenacious	0
912	10-15	Hh	greasy	blocky	loose	0
921	0-10	Fa	fibrous	nc-matted	tenacious	0
922	10-22	C	gritty	massive	loose	0
931	0-11	Fa	fibrous	nc-matted	tenacious	0

Sample	Horizon Thickness (cm)	Horizon Designation	Character	Structure	Consistence (Moist)	Coarse Fragment (%)
932	11-21	Hr	mossy	massive	loose	10 angular cobbles
941	0-3	Fa	fibrous	nc-matted	tenacious	0
942	3-13	Hh	greasy	massive	loose	0
1011	0-9	Fa	fibrous	nc-matted	tenacious	0
1012	9-36	Hhi	greasy/gritty	granular	loose	0
1021	0-6	Fa	fibrous	nc-matted	tenacious	0
1022	6-16	C	gritty	granular	loose	60 angular cobbles
1031	0-7	Fa	fibrous	nc-matted	tenacious	0
1032	7-15	Hri	greasy/gritty	blocky	loose	20 angular cobbles
1041	0-24	Hr	greasy	granular	loose	0
1111	0-30	Hri	gritty	blocky	loose	30 angular cobbles
1121	0-10	Hr	fibrous	blocky	loose	0
1122	10-25	C	gritty	massive	loose	35 angular cobbles
1131	0-10	Hhi	greasy/gritty	nc-matted	tenacious	0
1132	10-30	C	gritty	blocky	loose	70 angular cobbles
1211	0-40	Hh	greasy	granular	pliable	40 angular cobbles
1221	0-9	Fa	fibrous	nc-matted	tenacious	0
1222	9-29	C	gritty	granular	loose	30 angular cobbles
1231	0-12	Hr	greasy	granular	loose	0
1232	12-24	C	gritty	massive	loose	5 angular cobbles
1233	24-34	C	gritty	massive	loose	20 angular cobbles
1241	0-32	Fa	greasy	blocky	loose	0
1311	0-8	Fa	ligneous	nc-matted	tenacious	0
1312	8-31	Hh	ligneous	blocky	loose	0
1321	0-4	Fa	fibrous	nc-matted	tenacious	0
1322	4-17	Hhi	gritty	granular	loose	0
1331	0-13	Fa	fibrous	nc-matted	tenacious	0
1332	13-24	C	gritty	massive	pliable	0
1341	0-9	Fa	fibrous	nc-matted	tenacious	0
1342	9-20	Hz	greasy	granular	pliable	0
1411	0-14	Fa	fibrous	nc-matted	tenacious	0
1412	14-26	C	gritty	granular	pliable	5 angular cobbles
1421	0-16	Fa	fibrous	nc-matted	tenacious	0

Sample	Horizon Thickness (cm)	Horizon Designation	Character	Structure	Consistence (Moist)	Coarse Fragment (%)
1422	16-27	C	gritty	blocky	pliable	30 angular cobbles
1431	0-9	Fa	fibrous	nc-matted	tenacious	0
1432	9-35	C	gritty	blocky	pliable	20 angular cobbles
1441	0-8	Fa	fibrous	nc-matted	tenacious	0
1442	8-36	Hz	greasy	blocky	pliable	10 angular cobbles
1511	0-8	Fa	fibrous	nc-matted	tenacious	0
1512	8-35	Hzi	greasy/gritty	granular	loose	10 angular cobbles
1521	0-7	Fa	fibrous	nc-matted	tenacious	0
1522	7-32	C	gritty	granular	loose	15 angular cobbles
1531	0-11	Fa	ligneous	nc-matted	tenacious	0
1532	11-30	Hh	greasy	granular	pliable	0
1541	0-5	Fa	fibrous	nc-matted	tenacious	0
1542	5-24	Hh	greasy	blocky	pliable	0
1611	0-13	Fa	fibrous	nc-matted	tenacious	0
1612	13-43	Hh	greasy	massive	pliable	0
1621	0-12	Fa	fibrous	nc-matted	tenacious	0
1622	12-48	Hhi	greasy/gritty	massive	pliable	0
1631	0-10	Fa	mossy	nc-matted	tenacious	0
1632	10-48	Hh	greasy	massive	pliable	0
1641	0-59	C	gritty	massive	pliable	25 angular cobbles
1711	0-7	Lni	fibrous/gritty	nc-matted	tenacious	0
1712	7-82	Hri	gritty	blocky	pliable	10 angular cobbles
1721	0-56	C	gritty	massive	pliable	15 angular cobbles
1731	0-5	Fa	fibrous	nc-matted	tenacious	0
1732	5-80	Fa	greasy	massive	pliable	0
1741	0-61	C	gritty	granular	pliable	0
1811	0-6	Fa	fibrous	nc-matted	tenacious	0
1812	6-16	C	gritty	granular	loose	0
1821	0-7	Fm	felty/fibrous	nc-matted	tenacious	0
1822	7-23	C	gritty	blocky	pliable	0
1831	0-10	Fa	fibrous	nc-matted	tenacious	0
1832	10-44	C	gritty	blocky	pliable	10 angular cobbles
1841	0-7	Fz	mushy	nc-matted	tenacious	0

Sample	Horizon Thickness (cm)	Horizon Designation	Character	Structure	Consistence (Moist)	Coarse Fragment (%)
1842	7-36	C	gritty	granular	loose	5 angular cobbles
1911	0-7	Fa	fibrous	nc-matted	tenacious	0
1912	7-20	C	gritty	granular	loose	10 angular cobbles
1921	0-8	Fa	fibrous	nc-matted	tenacious	0
1922	8-42	C	gritty	granular	loose	15 angular cobbles
1931	0-7	Fa	fibrous	nc-matted	tenacious	0
1932	7-14	C	gritty	blocky	pliable	0
1941	0-12	Fai	fibrous/gritty	nc-matted	tenacious	0
2011	0-4	Hri	fibrous/gritty	nc-matted	tenacious	0
2012	4-11	C	gritty	granular	loose	0
2021	0-16	Fa	fibrous	nc-matted	tenacious	0
2022	16-33	Hh	greasy	massive	loose	0
2031	0-6	Fa	fibrous	nc-matted	tenacious	0
2032	6-23	Hh	greasy	blocky	loose	5 angular cobbles
2041	0-8	Fa	fibrous	nc-matted	tenacious	0
2042	8-28	C	gritty	granular	loose	0
2111	0-9	Fa	ligneous	nc-matted	tenacious	0
2112	9-14	Hh	greasy	massive	loose	0
2121	0-20	Faw	ligneous	nc-matted	tenacious	0
2122	20-56	C	gritty	blocky	loose	10 angular cobbles
2131	0-5	Fa	fibrous	nc-matted	tenacious	0
2132	5-10	Hr	greasy	massive	pliable	0
2133	10-36	C	gritty	blocky	loose	50 angular cobbles
2141	0-11	Fa	fibrous	nc-matted	tenacious	0
2142	11-59	C	gritty	granular	loose	5 angular cobbles
2211	0-6	Fa	fibrous	nc-matted	tenacious	0
2212	6-51	Hhi	gritty	granular	loose	0
2221	0-18	Fa	fibrous	nc-matted	tenacious	0
2222	18-61	Hz	greasy	granular	loose	0
2231	0-16	Ln	mossy	erect	tenacious	0
2241	0-7	Fa	fibrous	nc-matted	tenacious	0
2242	7-58	Hhi	greasy/gritty	granular	loose	0
2311	0-10	Fa	fibrous	nc-matted	tenacious	0

Sample	Horizon Thickness (cm)	Horizon Designation	Character	Structure	Consistence (Moist)	Coarse Fragment (%)
2312	10-49	C	gritty	massive	pliable	0
2321	0-9	Fa	fibrous	nc-matted	tenacious	0
2322	9-23	Hh	greasy	massive	pliable	0
2323	23-40	C	gritty	massive	pliable	0
2331	0-50	Fa	mossy	nc-matted	tenacious	0
2332	50-70	C	gritty	massive	pliable	0
2341	0-12	Fa	fibrous	nc-matted	tenacious	0
2342	12-50	Hh	mushy	massive	pliable	0
2411	0-12	Fai	fibrous/gritty	nc-matted	tenacious	0
2412	12-30	C	gritty	granular	loose	0
2421	0-9	Fa	fibrous	nc-matted	tenacious	0
2422	9-86	Hhi	greasy/gritty	blocky	pliable	0
2431	0-10	Fa	fibrous/mossy	nc-matted	tenacious	0
2432	10-40	C	gritty	massive	pliable	0
2441	0-11	Lv	mossy	nc-matted	tenacious	0
2442	11-35	Hr	mossy	massive	tenacious	0
2511	0-13	Fa	fibrous	nc-matted	tenacious	0
2512	13-55	Hh	greasy	blocky	pliable	0
2521	0-12	Fa	fibrous	nc-matted	tenacious	0
2522	12-60	Hhi	gritty	blocky	pliable	10 angular cobbles
2531	0-14	Fa	fibrous	nc-matted	tenacious	0
2532	14-40	C	gritty	blocky	pliable	0
2541	0-13	Fa	fibrous	nc-matted	tenacious	0
2542	13-50	Hhi	greasy/gritty	massive	pliable	0
2611	0-9	Lv	mossy	erect	resilient	0
2612	9-19	Fai	mushy/gritty	nc-matted	pliable	10 angular cobbles
2621	0-9	Fa	fibrous	nc-matted	tenacious	0
2622	9-30	Hh	mushy	massive	pliable	0
2631	0-8	Fa	mossy/mushy	nc-matted	tenacious	0
2632	8-27	Hhi	mushy/gritty	massive	pliable	0
2641	0-9	Lv	mossy	erect	resilient	0
2642	9-20	Fa	fibrous/mushy	nc-matted	pliable	0
2711	0-5	Fa	fibrous	nc-matted	tenacious	0

Sample	Horizon Thickness (cm)	Horizon Designation	Character	Structure	Consistence (Moist)	Coarse Fragment (%)
2712	5-35	C	gritty	blocky	loose	10 angular cobbles
2721	0-48	Hhi	mossy/gritty	massive	pliable	0
2731	0-9	Fa	fibrous	nc-matted	tenacious	0
2732	9-40	C	gritty	blocky	loose	0
2741	0-9	Fai	fibrous/gritty	nc-matted	tenacious	0
2742	9-42	C	gritty	granular	loose	0
2811	0-8	Fa	fibrous	nc-matted	tenacious	0
2812	8-30	C	gritty	blocky	loose	0
2821	0-48	Hhi	mossy/gritty	massive	pliable	0
2831	0-71	C	gritty	blocky	loose	10 angular cobbles
2841	0-9	Fai	fibrous/gritty	nc-matted	tenacious	0
2842	9-42	C	gritty	granular	loose	0
2911	0-10	Fa	fibrous/mossy	nc-matted	tenacious	10 angular cobbles
2912	10-25	Hh	greasy	blocky	loose	0
2921	0-9	Fa	fibrous	nc-matted	tenacious	0
2922	9-29	Hhi	gritty	blocky	loose	0
2931	0-9	Fa	fibrous	nc-matted	tenacious	0
2932	9-70	Hh	greasy	blocky	loose	0
2941	0-7	Fa	mossy	nc-matted	tenacious	0
2942	7-17	Hhi	gritty	blocky	loose	0
3011	0-8	Fa	fibrous/mossy	nc-matted	tenacious	0
3012	8-20	C	gritty	granular	loose	0
3021	0-9	Fa	fibrous	nc-matted	tenacious	0
3022	9-29	Hhi	gritty	blocky	loose	0
3031	0-9	Fa	fibrous	nc-matted	tenacious	0
3032	9-30	Hhi	gritty	blocky	loose	0
3041	0-7	Fa	mossy	nc-matted	tenacious	0
3042	7-17	Hhi	gritty	blocky	loose	0

Appendix 6 - Physical Characteristics for Debris Slide Soil Samples

Sample	Db (Mg m-3)	Dp (Mg m-3)	von Post	Ash (g kg-1)	5 kPa Grav. Water (%)	10 kPa Grav. Water (%)	33 kPa Grav. Water (%)	1500 kPa Grav. Water (%)	Field Grav. Water Content (%)
111	n/d	n/d	4	70.0	279.91	241.02	175.58	134.17	n/d
112	0.52	n/d	9	360.0	167.89	140.20	104.25	78.19	119.11
121	0.09	n/d	5	225.0	255.87	215.94	151.45	115.58	507.76
122	0.35	n/d	8	710.0	65.48	48.19	33.52	24.71	210.28
131	n/d	n/d	4	35.0	316.85	267.34	189.90	137.93	n/d
132	0.50	n/d	8	630.0	96.82	74.32	55.56	24.31	53.35
141	n/d	n/d	8	345.0	185.99	185.28	120.96	90.65	n/d
211	n/d	n/d	3	170.0	211.92	169.51	129.20	126.06	n/d
212	0.12	n/d	7	165.0	197.01	169.57	120.66	113.06	231.64
213	0.12	n/d	8	447.5	135.52	118.09	117.89	87.58	283.51
221	0.07	n/d	3	20.0	280.72	233.33	161.63	153.08	341.40
222	n/d	n/d	1	15.0	363.74	312.99	139.44	123.87	n/d
223	0.19	n/d	8	400.0	122.96	105.67	94.48	62.09	299.46
231	0.22	n/d	8	640.0	99.62	85.12	53.22	31.11	249.20
311	0.05	n/d	3	45.0	325.00	271.82	185.62	151.75	599.82
312	n/d	n/d	7	40.0	303.03	255.72	179.28	151.20	n/d
313	n/d	n/d	8	590.0	108.35	82.75	69.37	38.88	n/d
321	0.21	n/d	4	565.0	109.07	96.88	66.94	59.97	136.81
322	0.26	n/d	8	745.0	79.93	55.17	43.00	22.76	136.07
324	0.29	n/d	8	637.5	121.82	96.02	67.57	41.04	130.15
331	0.07	n/d	3	50.0	305.66	267.07	167.39	141.18	522.20
332	0.19	n/d	9	740.0	81.94	59.48	42.47	34.10	324.55
411	n/d	n/d	1	70.0	279.41	214.08	263.50	175.39	n/d
412	0.09	n/d	8	555.0	79.47	69.56	62.05	48.71	406.24
421	n/d	n/d	4	210.0	225.50	191.01	121.76	115.12	n/d
431	n/d	n/d	7	720.0	75.18	52.17	44.21	28.57	n/d
432	n/d	n/d	8	865.0	55.95	42.73	27.59	15.50	n/d
441	0.19	n/d	7	585.0	93.16	76.74	62.50	42.37	170.97
511	0.05	n/d	3	35.0	257.24	231.15	165.73	137.01	355.11
512	n/d	n/d	6	107.3	199.22	190.05	143.32	132.46	n/d
513	0.15	n/d	9	640.0	106.47	77.03	73.26	46.95	509.46

Sample	Db (Mg m-3)	Dp (Mg m-3)	von Post	Ash (g kg-1)	5 kPa Grav. Water (%)	10 kPa Grav. Water (%)	33 kPa Grav. Water (%)	1500 kPa Grav. Water (%)	Field Grav. Water Content (%)
521	0.04	n/d	3	55.0	440.85	340.74	303.95	170.45	1413.38
522	0.06	n/d	4	295.0	344.23	214.09	171.32	98.64	1218.05
531	0.08	n/d	3	15.0	299.37	250.09	167.06	137.04	461.47
532	0.13	n/d	8	796.7	64.33	52.78	36.99	26.83	468.44
541	0.07	n/d	3	100.0	255.19	204.76	157.98	135.85	439.27
542	0.60	n/d	8	853.3	46.94	28.30	22.73	16.69	71.44
611	0.07	n/d	3	130.0	259.40	210.40	153.33	152.51	492.32
621	0.06	n/d	3	45.0	349.63	275.73	202.01	150.72	579.37
622	0.07	n/d	6	335.8	229.08	168.21	144.95	117.18	523.04
631	0.08	n/d	3	35.0	298.05	244.94	181.38	170.00	450.10
632	0.11	n/d	8	530.0	92.42	74.31	56.53	38.08	478.74
641	n/d	n/d	3	230.0	273.23	223.39	121.19	110.22	n/d
642	0.12	n/d	9	424.0	176.96	146.39	108.97	68.75	531.30
643	0.23	n/d	8	840.0	49.65	36.07	24.88	13.28	211.07
711	0.05	n/d	3	125.0	282.22	223.68	163.92	157.72	639.27
712	n/d	n/d	8	925.0	28.48	20.33	13.02	6.84	n/d
721	0.07	n/d	3	75.0	308.11	253.30	186.31	163.08	556.75
722	n/d	n/d	7	606.7	68.00	49.93	36.69	27.53	n/d
731	n/d	n/d	3	37.5	311.60	258.49	181.29	142.82	n/d
732	0.09	n/d	7	145.0	217.99	187.71	146.40	111.92	488.49
733	0.71	n/d	8	927.5	30.47	24.48	14.73	9.28	47.60
741	0.08	n/d	4	90.0	262.76	243.85	181.96	153.92	387.04
742	0.49	n/d	8	906.7	21.69	21.40	14.85	9.70	84.20
811	0.11	n/d	3	380.0	180.00	138.38	127.60	66.31	139.67
821	0.09	n/d	3	85.0	230.86	202.16	148.78	125.63	286.29
822	0.33	n/d	7	720.0	54.34	47.50	33.64	24.23	69.18
831	0.13	n/d	3	325.0	155.60	142.08	131.79	104.55	230.80
832	0.37	n/d	7	750.0	54.20	49.74	36.93	28.37	68.94
911	0.04	n/d	3	50.0	336.64	286.49	198.39	185.37	724.56
912	0.13	n/d	8	335.0	177.30	148.33	108.24	94.67	470.10
921	0.05	n/d	3	20.0	364.00	304.35	204.39	146.74	552.50
922	0.11	n/d	8	785.0	67.18	49.86	38.47	25.36	642.03
931	0.04	n/d	3	30.0	400.00	352.11	280.00	183.10	1079.67

Sample	Db (Mg m-3)	Dp (Mg m-3)	von Post	Ash (g kg-1)	5 kPa Grav. Water (%)	10 kPa Grav. Water (%)	33 kPa Grav. Water (%)	1500 kPa Grav. Water (%)	Field Grav. Water Content (%)
932	0.06	n/d	6	120.0	325.20	243.90	200.00	146.94	1072.02
941	0.05	n/d	3	60.0	384.90	317.63	199.82	165.16	662.00
942	0.12	n/d	9	250.0	205.56	187.74	138.87	136.65	514.89
1011	0.05	n/d	3	30.0	310.79	283.33	208.47	171.43	479.31
1012	0.11	n/d	8	465.3	98.56	82.72	63.41	50.10	463.91
1021	0.07	n/d	4	22.5	327.21	290.96	216.55	160.78	504.23
1022	0.38	n/d	8	970.7	50.65	40.07	20.57	17.08	130.90
1031	0.06	n/d	3	40.0	273.86	253.42	199.35	177.12	334.40
1032	0.22	n/d	8	430.0	155.98	131.31	95.87	92.52	136.60
1041	0.07	n/d	8	145.0	212.82	209.72	141.15	116.96	425.46
1111	0.15	2.24	8	582.9	98.94	94.04	63.18	61.63	186.16
1121	0.09	n/d	7	135.0	230.28	212.39	164.62	156.68	323.24
1122	0.21	n/d	8	775.0	62.55	46.95	31.96	21.41	177.01
1131	0.13	n/d	8	447.8	119.17	95.30	72.01	53.13	159.99
1132	n/d	n/d	8	815.0	49.72	40.08	25.89	18.29	n/d
1211	0.20	n/d	7	265.0	180.30	172.58	137.22	105.28	274.46
1221	0.08	n/d	3	45.0	300.00	266.84	190.29	157.22	457.99
1222	0.33	n/d	6	915.0	141.45	138.89	64.19	53.58	159.98
1231	0.13	n/d	7	40.0	279.68	261.74	182.56	144.36	374.55
1232	0.64	n/d	8	805.0	72.02	50.79	38.43	19.26	93.15
1233	n/d	n/d	8	850.0	61.02	51.83	35.29	14.48	n/d
1241	0.07	n/d	3	170.0	205.19	194.61	150.00	115.95	408.38
1311	0.09	n/d	3	110.0	263.00	238.35	170.47	121.18	432.35
1312	0.08	n/d	7	150.0	202.78	182.69	136.66	130.61	411.00
1321	n/d	n/d	4	70.0	286.39	249.68	175.69	151.18	n/d
1322	0.21	n/d	8	577.5	98.68	85.04	64.17	56.02	242.88
1331	0.05	n/d	4	25.0	281.56	270.75	169.11	140.67	428.76
1332	0.17	n/d	8	755.0	65.70	55.53	29.11	22.83	358.26
1341	0.08	n/d	3	40.0	280.57	262.43	167.07	166.30	478.60
1342	0.13	n/d	9	360.0	204.88	114.67	84.46	73.96	428.43
1411	0.09	n/d	3	35.0	273.51	265.68	176.84	141.48	552.11
1412	0.21	n/d	7	735.0	60.79	58.91	34.20	27.13	330.21
1421	0.07	n/d	4	75.0	258.49	238.84	172.30	132.75	467.37

Sample	Db (Mg m-3)	Dp (Mg m-3)	von Post	Ash (g kg-1)	5 kPa Grav. Water (%)	10 kPa Grav. Water (%)	33 kPa Grav. Water (%)	1500 kPa Grav. Water (%)	Field Grav. Water Content (%)
1422	0.29	n/d	8	810.0	54.26	45.62	30.25	17.58	79.18
1431	0.09	n/d	4	60.0	261.63	248.52	168.98	136.18	439.69
1432	0.24	n/d	8	747.5	55.11	47.38	32.36	21.69	191.57
1441	0.07	n/d	3	40.0	260.00	257.30	179.26	138.80	376.69
1442	0.11	n/d	8	105.0	278.01	230.35	184.36	133.80	456.23
1511	0.08	n/d	3	55.0	243.12	233.57	163.37	160.40	467.26
1512	0.15	2.27	7	690.0	56.30	54.88	38.95	27.80	299.25
1521	0.07	n/d	4	55.0	259.01	240.91	168.35	157.14	479.78
1522	0.23	n/d	8	870.0	34.64	31.70	24.26	11.80	225.92
1531	0.08	n/d	3	55.0	274.31	250.93	161.31	133.64	523.99
1532	0.11	n/d	8	265.0	221.31	184.03	102.05	94.74	760.84
1541	0.08	n/d	3	55.0	265.13	252.99	185.43	162.41	791.15
1542	0.11	n/d	8	317.5	228.70	187.76	111.81	108.52	774.65
1611	0.05	n/d	3	75.0	272.03	218.55	169.84	168.57	665.96
1612	0.13	n/d	7	115.0	203.21	188.23	144.45	136.18	627.24
1621	0.07	n/d	3	95.0	333.04	303.85	231.37	180.00	672.68
1622	0.44	n/d	8	685.0	81.93	66.61	51.61	33.77	141.13
1631	0.04	n/d	3	35.0	321.50	272.79	186.36	175.63	556.04
1632	0.17	n/d	9	390.0	174.30	161.48	116.94	70.56	434.42
1641	0.63	n/d	8	780.0	78.25	62.64	40.30	20.49	104.26
1711	n/d	1.87	2	400.0	313.83	256.19	201.65	178.82	n/d
1712	0.25	n/d	6	500.0	151.54	120.89	74.56	48.49	165.34
1721	0.41	n/d	8	737.5	83.38	68.47	44.55	23.74	127.01
1731	0.04	n/d	3	55.0	368.31	272.41	235.48	190.24	565.56
1732	0.13	n/d	4	80.0	227.92	188.69	169.73	115.97	585.46
1741	0.38	n/d	8	755.0	95.90	85.17	61.91	23.79	153.83
1811	n/d	n/d	3	50.0	244.44	213.38	178.21	140.52	n/d
1812	0.13	n/d	8	790.0	50.25	40.20	26.93	21.65	310.66
1821	0.14	1.53	3	105.0	221.58	194.23	153.93	137.04	188.97
1822	0.72	n/d	9	885.6	56.55	42.04	22.48	11.52	82.39
1831	0.07	n/d	3	81.6	248.70	223.45	178.68	124.07	544.71
1832	0.24	n/d	7	906.4	31.30	27.04	16.65	9.26	176.87
1841	0.07	1.54	4	42.1	254.31	211.89	163.73	121.75	419.13

Sample	Db (Mg m-3)	Dp (Mg m-3)	von Post	Ash (g kg-1)	5 kPa Grav. Water (%)	10 kPa Grav. Water (%)	33 kPa Grav. Water (%)	1500 kPa Grav. Water (%)	Field Grav. Water Content (%)
1842	0.53	n/d	8	836.6	52.41	35.77	24.46	13.27	86.32
1911	0.09	n/d	3	19.1	253.74	231.51	184.00	145.37	603.21
1912	0.47	n/d	7	730.0	71.33	59.07	24.88	21.30	137.64
1921	0.07	n/d	3	23.4	257.26	236.84	175.41	147.06	490.32
1922	0.72	n/d	7	952.9	32.55	24.18	12.15	4.51	61.14
1931	0.06	n/d	4	57.4	243.20	234.76	163.58	143.45	543.00
1932	0.21	n/d	8	829.4	74.05	52.64	32.75	20.27	313.98
1941	0.09	n/d	5	483.3	125.18	110.24	65.18	59.24	551.04
2011	0.12	n/d	7	570.7	120.92	106.08	76.96	99.06	194.08
2012	0.49	n/d	7	894.3	24.85	23.78	16.92	12.60	53.16
2021	0.05	n/d	3	29.6	353.85	307.26	199.02	159.41	697.25
2022	0.13	n/d	9	275.9	221.05	164.11	122.02	90.97	574.13
2031	0.06	n/d	3	35.0	295.83	262.28	185.23	162.41	451.17
2032	0.12	n/d	9	331.7	196.36	173.88	111.90	93.17	575.83
2041	0.07	n/d	3	19.9	223.53	200.00	154.82	139.20	227.84
2042	0.29	n/d	7	797.0	46.19	43.85	28.90	21.12	163.80
2111	0.09	n/d	4	84.2	226.01	208.26	159.32	158.88	356.87
2112	n/d	n/d	7	339.5	118.25	79.82	69.14	52.71	n/d
2121	0.12	1.50	4	14.8	255.70	241.21	170.35	138.32	372.45
2122	n/d	n/d	8	875.6	56.33	35.21	26.95	8.50	n/d
2131	n/d	n/d	3	37.4	313.74	266.09	198.53	172.90	n/d
2132	0.19	1.75	8	201.9	227.82	202.16	142.86	95.38	334.72
2133	0.60	n/d	7	934.8	40.36	29.68	18.80	6.04	60.57
2141	0.10	n/d	4	39.8	268.99	243.15	183.72	166.14	398.91
2142	0.51	n/d	8	762.5	74.10	63.84	48.58	19.85	105.46
2211	0.05	n/d	3	33.2	260.16	239.26	171.13	144.36	928.26
2212	0.26	n/d	7	537.3	92.55	81.74	58.33	43.32	146.53
2221	0.08	n/d	3	19.2	247.30	222.95	171.33	128.85	342.58
2222	0.16	1.70	7	120.0	230.37	221.24	175.60	135.42	419.86
2231	n/d	n/d	1	28.5	668.63	639.06	304.23	218.18	n/d
2241	0.07	n/d	3	34.1	217.12	230.05	178.65	149.01	406.71
2242	0.13	2.05	8	509.9	94.66	84.93	62.71	35.02	345.16
2311	0.08	n/d	3	37.2	365.29	295.79	224.07	200.00	520.53

Sample	Db (Mg m-3)	Dp (Mg m-3)	von Post	Ash (g kg-1)	5 kPa Grav. Water (%)	10 kPa Grav. Water (%)	33 kPa Grav. Water (%)	1500 kPa Grav. Water (%)	Field Grav. Water Content (%)
2312	0.75	n/d	7	929.2	48.04	32.10	21.41	7.18	71.60
2321	0.10	n/d	4	69.0	310.53	272.14	220.81	211.31	748.39
2322	0.15	1.55	7	104.8	219.03	184.58	154.49	128.35	524.10
2323	0.53	n/d	7	846.9	53.85	49.53	36.43	16.14	118.27
2331	0.12	n/d	4	83.3	253.10	223.33	161.03	133.12	660.58
2332	0.62	n/d	7	860.0	40.97	28.17	20.92	11.66	98.99
2341	0.09	n/d	3	83.1	259.23	229.57	158.52	114.29	626.74
2342	0.21	n/d	8	356.1	158.31	138.78	112.45	70.83	389.37
2411	0.60	n/d	4	432.0	182.05	171.33	114.88	90.18	96.77
2412	0.70	n/d	7	920.8	44.96	33.26	21.48	7.48	74.15
2421	0.10	1.60	3	98.2	282.12	260.17	184.34	137.09	601.98
2422	0.22	n/d	8	617.1	102.56	74.73	54.80	36.55	316.62
2431	0.09	n/d	3	99.0	321.52	282.61	215.65	192.74	757.32
2432	0.53	n/d	8	902.0	50.43	40.87	32.83	14.59	103.16
2441	0.04	n/d	2	75.7	396.83	311.84	217.24	181.97	1641.36
2442	n/d	n/d	7	120.4	275.96	215.87	172.82	159.23	n/d
2511	0.08	n/d	4	120.7	229.71	220.71	154.00	126.21	568.21
2512	0.12	n/d	8	296.7	149.53	142.44	120.55	71.19	619.66
2521	0.15	n/d	4	127.9	315.57	270.97	177.10	157.58	284.85
2522	0.13	1.98	8	581.0	97.37	81.09	66.90	45.77	671.01
2531	0.10	n/d	4	142.9	228.07	191.72	143.79	140.56	607.61
2532	0.48	n/d	8	801.0	52.13	47.48	34.77	18.83	124.91
2541	0.07	n/d	4	81.3	313.27	265.26	194.63	157.41	1022.40
2542	0.19	n/d	8	542.3	101.06	82.17	75.42	48.38	394.13
2611	0.03	n/d	2	34.1	500.00	423.88	365.96	309.52	1493.78
2612	0.13	n/d	6	400.0	264.48	228.16	188.76	157.14	554.33
2621	0.05	n/d	3	48.2	367.92	292.59	218.03	209.65	1056.33
2622	0.08	n/d	9	180.0	221.82	183.72	126.97	95.35	1195.37
2631	0.04	n/d	3	58.4	412.50	367.47	326.39	282.28	1322.22
2632	0.13	n/d	8	641.8	79.74	77.73	64.13	52.15	608.26
2641	0.04	1.70	2	54.5	480.65	427.03	365.79	276.81	1534.72
2642	0.06	n/d	5	200.0	317.95	252.22	227.13	173.89	1099.74
2711	n/d	n/d	4	63.7	262.18	229.27	191.47	171.79	n/d

Sample	Db (Mg m-3)	Dp (Mg m-3)	von Post	Ash (g kg-1)	5 kPa Grav. Water (%)	10 kPa Grav. Water (%)	33 kPa Grav. Water (%)	1500 kPa Grav. Water (%)	Field Grav. Water Content (%)
2712	0.83	n/d	8	922.3	23.93	20.92	11.77	7.46	44.27
2721	0.69	n/d	8	586.6	104.51	99.73	83.58	65.01	79.53
2731	0.09	n/d	5	67.3	252.68	233.13	166.07	147.34	516.56
2732	0.38	n/d	7	914.3	27.27	21.00	13.72	7.49	187.38
2741	0.23	n/d	5	473.7	115.99	88.31	78.35	53.80	197.42
2742	0.51	n/d	8	931.2	33.37	27.35	15.42	7.15	117.07
2811	0.10	n/d	3	50.8	228.30	200.00	166.18	130.08	436.18
2812	0.37	n/d	8	901.4	32.40	27.18	17.24	7.53	185.25
2821	0.69	n/d	8	586.6	104.51	99.73	83.58	65.01	79.53
2831	0.42	n/d	5	830.4	44.39	42.55	30.34	16.49	125.44
2841	0.23	n/d	5	473.7	115.99	88.31	78.35	53.80	197.42
2842	0.51	n/d	8	931.2	33.37	27.35	15.42	7.15	117.07
2911	0.04	n/d	3	23.9	327.82	276.19	208.67	162.22	1044.38
2912	0.26	n/d	9	102.4	233.77	238.62	157.30	123.85	212.68
2921	0.06	1.59	3	74.5	335.82	303.17	239.23	196.90	789.70
2922	0.72	n/d	9	687.8	167.19	111.23	106.71	53.42	120.51
2931	0.06	n/d	3	19.0	343.51	284.43	251.97	161.74	542.56
2932	0.12	n/d	8	149.3	237.79	217.72	151.90	96.10	284.21
2941	0.05	n/d	3	54.5	430.86	362.96	258.75	227.47	1071.58
2942	0.51	n/d	8	668.3	66.60	59.87	43.87	35.70	92.76
3011	0.07	n/d	3	148.8	427.38	395.51	279.83	175.27	409.37
3012	0.10	n/d	6	741.3	65.33	58.66	42.99	27.48	505.25
3021	0.06	1.59	3	74.5	335.82	303.17	239.23	196.90	789.70
3022	0.72	n/d	9	687.8	167.19	111.23	106.71	53.42	120.51
3031	0.08	n/d	4	28.4	286.00	278.83	193.13	150.36	494.30
3032	0.18	n/d	8	663.4	144.50	81.45	61.28	43.40	248.25
3041	0.05	n/d	3	54.5	430.86	362.96	258.75	227.47	1071.58
3042	0.51	n/d	8	668.3	66.60	59.87	43.87	35.70	92.76

Appendix 7 - Chemical Characteristics for Debris Slide Soil Samples

Sample	pH	Org. C (kg m-2)	Total N (kg m-2)	C:N Ratio	TEC (cmol(+) m-2)	Exch. Ca (cmol (+) kg-1)	Exch. Mg (cmol (+) kg-1)	Exch. K (cmol (+) kg-1)	Exch. Na (cmol (+) kg-1)	Base Sat. (%)
111	3.22	2.64	0.05	57.38:1	16.62	12.54	1.47	1.45	0.85	4.81
112	3.87	69.49	2.38	29.23:1	250.92	0.65	0.46	0.72	0.17	1.49
121	3.40	4.96	0.14	36.25:1	21.66	11.29	1.93	1.34	0.60	7.73
122	3.73	14.72	0.35	42.05:1	56.50	0.92	0.22	0.41	0.19	2.71
131	3.17	4.03	0.08	49.53:1	20.04	27.33	5.59	2.07	0.54	12.76
132	3.88	34.34	0.90	38.32:1	123.53	1.27	0.54	0.49	0.19	3.23
141	3.68	19.37	0.77	25.33:1	105.13	2.99	0.87	1.57	0.41	2.83
211	3.28	1.44	0.03	44.99:1	6.08	11.54	1.64	2.11	0.52	7.80
212	3.25	5.81	0.16	36.14:1	24.94	9.67	1.81	2.40	0.63	6.98
213	3.23	6.54	0.21	31.12:1	25.85	5.47	1.12	1.14	0.26	6.29
221	3.30	1.99	0.04	45.47:1	7.03	22.41	2.30	2.98	0.55	14.05
222	2.96	5.14	0.03	184.29:1	22.14	8.87	1.77	1.09	0.44	4.94
223	3.08	9.92	0.25	39.55:1	46.63	7.36	1.60	1.00	0.33	6.29
231	3.89	2.30	0.06	36.63:1	8.07	2.21	0.65	0.51	0.16	4.81
311	4.03	0.55	0.01	45.40:1	2.60	47.98	4.72	3.78	0.50	21.87
312	3.70	1.78	0.04	41.55:1	7.53	28.32	4.36	2.32	0.47	15.07
313	3.84	11.32	0.36	31.71:1	74.84	7.73	1.17	0.73	0.24	6.28
321	4.24	1.59	0.06	28.35:1	9.06	23.75	1.80	1.83	0.25	19.21
322	4.00	9.23	0.31	29.58:1	42.96	5.92	0.72	0.57	0.15	10.69
324	3.85	11.59	0.31	36.89:1	50.38	6.21	0.97	0.77	0.17	8.87
331	3.63	3.47	0.08	43.05:1	11.41	19.14	2.63	4.43	0.62	14.81
332	3.86	5.73	0.17	34.27:1	23.96	1.04	0.38	0.35	0.14	3.03
411	4.20	1.29	0.03	48.59:1	5.98	51.47	5.42	2.73	0.69	24.21
412	3.82	2.09	0.05	38.52:1	5.67	9.77	1.41	1.30	0.45	18.48
421	3.41	3.30	0.09	36.95:1	11.91	21.64	4.12	2.12	0.63	17.24
431	3.36	2.60	0.12	22.25:1	11.43	6.22	1.18	1.19	0.17	12.26
432	3.78	5.95	0.26	23.03:1	33.24	5.91	0.40	1.10	0.22	17.46
441	3.68	13.72	0.46	29.72:1	75.25	1.35	0.20	0.14	0.02	1.29
511	3.83	2.24	0.04	52.31:1	7.90	55.70	3.20	5.29	0.43	32.72
512	3.05	8.70	0.22	40.14:1	30.19	13.50	1.59	1.36	0.34	9.34
513	3.66	7.20	0.26	27.84:1	24.55	1.22	0.56	0.65	0.18	3.66

Sample	pH	Org. C (kg m-2)	Total N (kg m-2)	C:N Ratio	TEC (cmol(+) m-2)	Exch. Ca (cmol (+) kg-1)	Exch. Mg (cmol (+) kg-1)	Exch. K (cmol (+) kg-1)	Exch. Na (cmol (+) kg-1)	Base Sat. (%)
521	3.67	1.97	0.03	73.08:1	7.22	8.25	3.79	4.34	0.58	8.46
522	3.78	7.85	0.29	27.26:1	39.34	4.79	2.03	1.80	0.40	4.40
531	3.46	6.40	0.12	52.90:1	22.06	16.12	2.29	3.10	0.46	11.15
532	3.59	2.15	0.09	23.59:1	7.75	1.81	0.55	0.40	0.14	6.81
541	3.28	3.65	0.08	44.24:1	12.81	12.10	2.66	2.61	0.37	9.69
542	3.73	12.76	0.41	31.51:1	41.51	1.87	0.30	0.42	0.11	9.77
611	4.11	6.36	0.15	42.76:1	21.20	45.08	2.68	3.01	0.38	30.40
621	3.73	3.32	0.07	50.35:1	10.46	30.41	3.74	2.27	0.34	21.10
622	3.62	5.93	0.17	35.02:1	24.97	15.08	2.36	1.28	0.21	11.67
631	3.24	3.13	0.07	44.07:1	10.92	16.88	2.46	3.06	0.34	11.66
632	3.48	6.90	0.19	35.40:1	21.86	1.56	0.61	0.54	0.18	3.35
641	3.71	3.48	0.09	40.97:1	12.19	12.68	2.54	2.58	0.44	11.67
642	4.03	13.63	0.64	21.42:1	63.16	3.91	1.10	1.13	0.23	4.11
643	4.06	3.20	0.11	29.00:1	8.84	1.89	0.25	0.32	0.16	10.21
711	3.44	4.57	0.10	46.56:1	13.51	6.54	1.69	3.14	0.43	7.86
712	3.79	2.96	0.12	25.59:1	11.51	1.07	0.14	0.22	0.12	9.18
721	3.60	3.38	0.09	37.26:1	11.76	22.77	6.12	2.68	0.40	17.12
722	3.38	16.61	0.35	47.53:1	38.26	3.18	0.84	0.66	0.19	9.26
731	3.49	2.01	0.03	64.17:1	6.42	40.32	2.12	2.32	0.38	25.30
732	3.43	10.27	0.08	130.50:1	31.30	7.21	2.14	2.24	0.36	7.90
733	3.88	5.37	0.18	30.04:1	17.15	0.79	0.15	0.27	0.03	9.23
741	3.21	12.67	0.26	48.42:1	50.62	27.98	3.06	1.61	0.24	15.60
742	3.72	9.28	0.24	38.67:1	30.18	0.63	0.15	0.29	0.06	6.41
811	3.46	6.33	0.15	42.31:1	20.93	1.46	1.43	2.25	0.32	4.59
821	3.32	8.60	0.16	52.54:1	30.97	1.39	2.02	2.47	0.50	3.34
822	3.43	10.72	n/d	n/d	30.69	0.45	0.54	0.56	0.10	3.55
831	3.84	4.07	0.11	37.64:1	9.95	21.18	2.41	1.31	0.31	26.37
832	3.44	17.70	0.60	29.59:1	57.24	4.17	0.62	0.46	0.09	11.39
911	3.43	2.20	0.06	39.93:1	10.54	19.73	3.57	3.13	0.28	10.13
912	3.47	2.51	0.09	27.16:1	9.81	1.88	0.93	1.54	0.13	2.97
921	3.02	2.84	0.06	44.06:1	10.03	19.05	3.06	2.36	0.30	12.34
922	3.65	1.65	0.06	26.53:1	6.04	1.32	0.28	0.42	0.14	4.74
931	3.64	2.48	0.05	51.15:1	10.10	19.65	4.74	4.22	0.29	12.59

Sample	pH	Org. C (kg m-2)	Total N (kg m-2)	C:N Ratio	TEC (cmol(+) m-2)	Exch. Ca (cmol (+) kg-1)	Exch. Mg (cmol (+) kg-1)	Exch. K (cmol (+) kg-1)	Exch. Na (cmol (+) kg-1)	Base Sat. (%)
932	3.67	3.06	0.08	40.51:1	14.44	10.05	2.14	2.12	0.26	6.05
941	3.72	0.82	0.02	42.93:1	4.67	29.40	3.59	3.38	0.31	11.79
942	3.64	5.22	0.24	21.53:1`	17.36	4.36	1.31	1.80	0.17	5.28
1011	3.66	2.53	0.06	44.30:1	8.30	25.01	5.56	4.91	0.28	19.40
1012	3.78	9.21	0.20	46.28:1	27.19	2.48	0.72	1.29	0.20	5.12
1021	3.26	2.38	0.06	41.09:1	8.45	21.99	4.50	2.84	0.32	14.74
1022	3.77	0.65	0.10	6.29:1	10.45	1.10	0.36	0.32	0.11	6.85
1031	3.66	2.34	0.05	43.16:1	8.58	37.01	5.29	7.98	0.53	24.89
1032	3.26	5.82	0.21	28.26:1	22.55	17.93	1.91	0.93	0.21	16.38
1041	3.18	8.33	0.25	33.06:1	29.09	30.74	4.47	1.92	0.41	21.68
1111	3.58	10.89	0.36	30.24:1	40.31	8.17	1.79	1.07	0.19	12.52
1121	3.54	4.52	0.13	34.60:1	14.68	20.66	3.62	1.24	0.37	15.88
1122	3.66	4.11	0.48	8.64:1	13.96	4.56	0.62	0.44	0.21	13.17
1131	3.43	4.16	0.14	28.86:1	13.97	10.73	2.07	1.46	0.29	13.54
1132	3.52	7.73	0.24	32.52:1	32.45	5.68	0.96	0.73	0.32	17.08
1211	3.55	34.10	1.15	29.60:1	124.86	20.17	2.44	0.77	0.33	15.19
1221	3.39	3.99	0.08	47.14:1	16.32	26.60	2.77	2.23	0.54	14.18
1222	3.29	3.25	0.49	6.66:1	68.26	8.35	1.29	0.57	0.25	10.11
1231	3.20	8.69	0.22	38.94:1	36.54	21.09	2.36	1.74	0.56	10.99
1232	3.47	8.69	0.24	36.48:1	35.43	1.12	0.40	0.29	0.12	4.19
1233	3.80	3.31	0.06	54.38:1	11.51	0.54	0.15	0.21	0.07	3.24
1241	2.92	10.78	0.25	43.76:1	26.09	6.29	1.66	1.29	0.32	8.21
1311	2.75	3.72	0.09	42.31:1	12.23	6.18	2.79	1.71	0.38	6.51
1312	2.77	9.07	0.36	25.28:1	31.92	1.17	1.61	1.02	0.25	2.33
1321	3.46	1.29	0.03	37.20:1	3.81	20.18	4.04	2.57	0.33	17.08
1322	3.41	6.69	0.30	22.49:1	20.31	4.61	1.20	0.78	0.14	9.04
1331	3.19	3.68	0.08	45.98:1	11.24	16.35	2.88	1.86	0.30	12.37
1332	3.30	2.66	0.06	43.06:1	4.69	7.11	0.50	0.29	0.09	31.88
1341	3.46	4.01	0.11	37.37:1	13.48	24.37	2.68	1.72	0.23	15.50
1342	3.26	5.31	0.18	29.94:1	22.61	5.77	2.20	0.64	0.17	5.55
1411	3.16	7.05	0.15	46.64:1	22.80	20.90	3.32	1.85	0.32	14.59
1412	3.42	3.87	0.11	35.74:1	9.91	1.49	0.44	0.37	0.12	6.18
1421	3.21	6.01	0.13	45.08:1	20.94	16.45	2.53	2.54	0.35	11.69

Sample	pH	Org. C (kg m-2)	Total N (kg m-2)	C:N Ratio	TEC (cmol(+) m-2)	Exch. Ca (cmol (+) kg-1)	Exch. Mg (cmol (+) kg-1)	Exch. K (cmol (+) kg-1)	Exch. Na (cmol (+) kg-1)	Base Sat. (%)
1422	3.66	3.52	0.10	34.44:1	17.73	4.70	0.56	0.48	0.22	10.73
1431	3.14	4.42	0.12	38.13:1	17.64	15.67	5.50	2.76	0.34	11.14
1432	3.59	9.14	0.19	48.83:1	31.50	1.97	0.62	0.52	0.18	6.49
1441	3.44	3.12	0.08	37.88:1	16.63	47.02	5.79	3.21	0.40	19.00
1442	3.05	15.99	0.47	34.38:1	93.53	37.48	2.86	1.11	0.28	13.74
1511	3.87	3.51	0.09	41.21:1	11.00	29.07	2.90	3.29	0.35	20.72
1512	3.56	7.28	0.21	34.58:1	27.52	5.25	0.79	0.62	0.11	9.96
1521	4.74	2.69	0.07	40.30:1	17.11	70.67	2.89	2.87	0.29	21.97
1522	4.02	4.34	0.18	24.32:1	18.76	2.56	0.29	0.37	0.07	10.11
1531	3.61	4.82	0.09	54.81:1	20.01	29.15	3.29	4.37	0.40	16.37
1532	3.91	8.91	0.26	34.38:1	40.77	11.93	1.73	0.65	0.22	7.45
1541	3.74	2.19	0.05	40.60:1	11.65	22.85	3.97	3.42	0.43	10.53
1542	3.82	8.27	0.33	25.06:1	31.88	7.64	1.47	0.47	0.20	6.41
1611	3.25	3.49	0.07	50.14:1	12.78	17.70	4.09	3.06	0.46	12.88
1612	3.26	20.02	0.59	33.99:1	78.87	3.45	0.99	0.84	0.35	2.78
1621	3.55	4.41	0.09	48.16:1	18.09	23.75	4.24	2.73	0.39	14.44
1622	3.75	28.94	0.71	40.60:1	101.70	2.73	0.44	0.51	0.11	5.91
1631	3.48	2.24	0.05	46.64:1	8.41	29.27	4.44	2.45	0.32	17.36
1632	3.51	22.86	0.39	58.97:1	86.94	1.05	0.38	0.51	0.13	1.54
1641	3.76	47.43	1.19	39.88:1	292.26	0.54	0.14	0.17	0.07	1.17
1711	3.84	4.87	0.12	39.55:1	29.42	9.44	2.80	2.46	0.34	7.16
1712	3.64	54.38	1.31	41.43:1	112.92	2.43	0.36	0.31	0.10	5.31
1721	4.19	34.97	1.01	34.61:1	153.91	6.78	0.23	0.27	0.07	10.96
1731	3.52	1.10	0.04	30.03:1	5.18	13.99	3.53	2.63	0.26	7.89
1732	3.47	52.03	1.94	26.81:1	197.20	2.62	0.87	1.02	0.25	2.35
1741	3.96	32.94	0.95	34.66:1	181.00	1.02	0.21	0.22	0.11	1.98
1811	3.22	1.65	0.03	60.55:1	6.05	15.75	4.30	3.23	0.50	11.79
1812	3.35	1.58	0.03	46.85:1	4.79	0.88	0.55	0.70	0.13	6.13
1821	3.46	5.09	0.09	57.68:1	19.01	23.24	4.79	4.28	0.55	16.94
1822	4.03	7.65	0.21	36.87:1	35.45	0.56	0.25	0.45	0.13	4.53
1831	3.48	3.73	0.07	57.27:1	22.26	22.57	4.78	4.26	0.40	10.07
1832	3.92	4.43	0.14	31.93:1	15.89	1.71	0.61	0.46	0.08	14.67
1841	3.06	2.72	0.06	46.30:1	10.24	26.34	4.63	3.02	0.54	16.51

Sample	pH	Org. C (kg m-2)	Total N (kg m-2)	C:N Ratio	TEC (cmol(+) m-2)	Exch. Ca (cmol (+) kg-1)	Exch. Mg (cmol (+) kg-1)	Exch. K (cmol (+) kg-1)	Exch. Na (cmol (+) kg-1)	Base Sat. (%)
1842	3.61	14.56	0.32	45.12:1	61.78	1.69	0.52	0.63	0.14	7.41
1911	3.63	3.58	0.06	60.52:1	11.01	25.94	4.19	5.06	0.57	20.46
1912	3.84	9.57	0.34	28.47:1	22.70	4.34	0.90	0.41	0.14	15.57
1921	3.38	3.17	0.06	49.26:1	10.08	30.89	5.64	4.06	0.50	22.82
1922	4.08	6.69	0.29	22.76:1	26.25	0.48	0.14	0.35	0.09	9.88
1931	3.26	2.30	0.05	50.16:1	8.13	13.96	3.17	2.86	0.43	10.55
1932	3.99	1.45	0.07	21.99:1	4.40	5.36	0.77	0.51	0.13	22.61
1941	4.14	3.24	0.07	44.73:1	8.05	2.73	0.81	1.09	0.19	6.47
2011	3.88	1.20	0.04	31.92:1	6.59	22.29	2.90	1.44	0.23	19.55
2012	3.86	2.10	0.08	25.54:1	8.26	2.03	0.44	0.21	0.06	11.37
2021	3.44	4.50	0.07	63.24:1	20.01	18.35	6.64	2.73	0.26	11.18
2022	3.61	9.28	0.31	29.58:1	30.33	1.99	0.96	0.84	0.14	2.87
2031	3.29	2.01	0.03	58.30:1	9.25	17.04	2.64	3.56	0.45	9.21
2032	3.85	7.91	0.26	30.28:1	24.33	1.72	0.95	0.94	0.20	3.19
2041	3.22	3.18	0.06	53.13:1	18.44	38.48	2.75	2.83	0.45	13.52
2042	3.64	6.83	0.21	31.82:1	26.79	1.64	0.45	0.99	0.14	6.97
2111	3.15	4.30	0.10	43.54:1	16.30	23.73	2.81	2.09	0.41	14.43
2112	3.38	3.26	0.08	39.49:1	9.58	8.77	1.27	0.73	0.27	9.79
2121	2.96	13.71	0.19	71.43:1	60.99	13.83	3.30	2.59	0.51	7.96
2122	4.20	10.14	0.24	42.47:1	42.89	1.05	0.20	0.35	0.09	5.52
2131	3.80	1.67	0.04	46.14:1	6.86	31.19	3.21	3.10	0.38	16.56
2132	4.22	4.40	0.14	30.86:1	12.56	17.99	2.12	1.91	0.28	16.86
2133	4.40	5.90	0.20	29.10:1	29.35	2.15	0.14	0.23	0.09	13.87
2141	3.46	6.13	0.13	48.01:1	27.76	24.83	2.75	2.07	0.39	11.90
2142	3.90	33.73	0.71	47.51:1	134.71	0.33	0.29	0.51	0.07	2.18
2211	3.39	1.68	0.03	53.92:1	8.75	24.38	3.38	3.28	0.30	10.74
2212	3.28	31.40	0.73	43.28:1	121.46	1.73	0.87	0.76	0.14	3.38
2221	3.21	8.19	0.17	48.21:1	31.16	21.29	1.41	2.52	0.28	11.79
2222	3.35	35.12	0.83	42.18:1	91.97	9.38	3.39	0.79	0.22	10.31
2231	3.39	3.61	0.04	81.67:1	22.07	18.48	3.55	2.49	0.45	7.24
2241	3.07	2.74	0.06	46.68:1	9.27	15.59	4.34	7.81	1.37	15.39
2242	3.23	18.85	0.34	54.66:1	58.27	1.88	0.69	0.47	0.59	4.13
2311	3.45	4.47	0.07	63.46:1	19.37	9.64	5.13	3.27	0.74	7.76

Sample	pH	Org. C (kg m-2)	Total N (kg m-2)	C:N Ratio	TEC (cmol(+) m-2)	Exch. Ca (cmol (+) kg-1)	Exch. Mg (cmol (+) kg-1)	Exch. K (cmol (+) kg-1)	Exch. Na (cmol (+) kg-1)	Base Sat. (%)
2312	3.82	12.02	0.47	25.68:1	46.46	0.29	0.18	0.23	0.13	5.20
2321	3.55	4.86	0.12	39.13:1	18.38	4.10	3.54	3.07	0.58	5.53
2322	3.57	10.90	0.51	21.37:1	37.76	1.24	0.71	0.70	0.26	1.62
2323	3.89	8.00	0.32	24.67:1	34.69	0.42	0.22	0.33	0.13	2.87
2331	3.57	31.90	1.16	27.41:1	112.84	2.77	1.69	0.80	0.47	3.05
2332	3.89	10.07	0.33	30.07:1	30.00	1.96	0.38	0.38	0.51	13.32
2341	3.53	5.74	0.15	39.39:1	18.69	4.33	2.11	1.69	0.68	5.09
2342	3.60	29.80	1.00	29.88:1	103.65	5.06	0.82	0.34	0.64	5.28
2411	3.51	23.72	0.59	40.17:1	105.98	6.35	3.47	2.53	0.49	8.72
2412	3.94	5.79	0.20	28.71:1	26.66	0.93	0.32	0.68	0.16	9.88
2421	3.47	4.71	0.11	41.84:1	19.95	4.97	3.32	6.60	0.58	6.97
2422	3.78	37.62	1.22	30.84:1	159.25	1.61	0.80	0.53	0.16	3.30
2431	3.66	4.70	0.09	52.26:1	26.11	8.48	4.38	6.98	0.63	7.06
2432	3.72	9.04	0.51	17.77:1	55.27	1.06	0.70	0.57	0.16	7.14
2441	3.73	2.36	0.03	74.46:1	8.58	5.40	4.31	4.40	0.79	7.64
2442	3.79	9.80	0.28	34.47:1	41.03	5.03	2.94	1.79	0.50	4.80
2511	3.67	5.30	0.11	50.50:1	19.82	36.80	5.27	5.39	0.55	25.18
2512	3.65	20.56	0.52	39.61:1	71.74	5.38	1.11	1.06	0.21	5.45
2521	3.91	9.11	0.18	49.59:1	51.70	48.71	3.92	4.93	0.45	20.20
2522	3.70	15.17	0.38	39.84:1	57.62	3.55	0.49	0.42	0.14	4.99
2531	3.56	6.96	0.20	35.26:1	26.59	14.18	3.54	3.02	0.65	11.26
2532	3.83	14.40	0.39	37.23:1	60.73	0.78	0.26	0.26	0.10	2.87
2541	4.98	4.85	0.12	38.89:1	18.15	55.74	2.50	3.43	0.37	31.11
2542	4.07	18.66	0.49	37.92:1	70.66	5.35	0.28	0.50	0.11	6.21
2611	3.38	1.51	0.01	114.33:1	6.68	10.06	5.95	3.51	0.70	8.18
2612	3.45	4.52	0.11	40.47:1	17.75	3.86	1.87	1.37	0.30	5.43
2621	3.51	2.48	0.05	54.65:1	10.89	5.06	3.65	4.20	0.50	5.53
2622	3.67	7.99	0.29	27.98:1	30.52	2.61	1.24	1.29	0.33	3.01
2631	3.54	1.75	0.03	61.36:1	8.09	5.68	5.70	4.18	0.78	6.46
2632	3.49	5.13	0.21	23.88:1	20.91	1.28	1.38	0.69	0.15	4.13
2641	3.36	1.97	0.03	72.15:1	10.47	8.49	4.54	3.36	0.57	5.83
2642	3.41	3.06	0.08	39.66:1	12.63	5.43	2.87	1.69	0.35	5.40
2711	3.73	1.90	0.04	44.51:1	8.64	30.27	6.53	5.08	0.70	17.25

Sample	pH	Org. C (kg m-2)	Total N (kg m-2)	C:N Ratio	TEC (cmol(+) m-2)	Exch. Ca (cmol (+) kg-1)	Exch. Mg (cmol (+) kg-1)	Exch. K (cmol (+) kg-1)	Exch. Na (cmol (+) kg-1)	Base Sat. (%)
2712	3.88	11.22	0.32	34.67:1	47.35	2.80	0.28	0.39	0.13	18.94
2721	3.38	78.76	2.55	30.88:1	333.95	4.67	2.01	0.76	0.21	7.59
2731	3.91	4.38	0.09	50.09:1	18.00	24.95	5.76	2.72	0.51	15.27
2732	4.13	5.86	0.20	29.24:1	22.11	2.16	0.30	0.33	0.20	15.94
2741	3.40	6.32	0.17	36.34:1	27.62	3.07	1.30	1.70	0.37	4.82
2742	3.75	6.72	0.29	23.48:1	30.08	0.63	0.24	0.31	0.14	7.36
2811	3.44	4.40	0.08	53.45:1	16.48	20.29	4.10	4.71	0.66	14.45
2812	3.74	4.65	0.12	38.12:1	18.37	0.76	0.24	0.38	0.10	6.56
2821	3.38	78.76	2.55	30.88:1	333.95	4.67	2.01	0.76	0.21	7.59
2831	3.78	29.34	0.78	37.84:1	119.28	3.48	6.40	0.87	0.14	27.22
2841	3.40	6.32	0.17	36.34:1	27.62	3.07	1.30	1.70	0.37	4.82
2842	3.75	6.72	0.29	23.48:1	30.08	0.63	0.24	0.31	0.14	7.36
2911	3.16	2.26	0.04	61.54:1	7.65	16.07	4.10	4.91	0.38	13.32
2912	2.93	20.30	0.43	49.90:1	87.62	14.68	4.54	2.60	0.37	9.88
2921	3.49	2.90	0.06	47.93:1	13.67	10.65	3.47	2.37	0.38	6.66
2922	3.59	26.07	0.92	28.29:1	107.42	1.29	1.19	0.64	0.12	4.34
2931	3.39	3.07	0.05	64.66:1	13.30	14.82	3.69	3.92	0.39	9.27
2932	3.69	36.12	0.97	37.38:1	164.74	0.76	0.95	1.15	0.22	1.37
2941	3.28	1.92	0.04	54.29:1	7.72	2.45	2.54	2.22	0.41	3.46
2942	3.45	9.81	0.26	38.48:1	30.95	0.77	0.94	0.74	0.16	4.30
3011	3.33	2.76	0.05	55.47:1	13.45	7.59	4.80	4.32	0.53	7.18
3012	3.31	1.80	0.06	28.86:1	6.92	1.83	1.12	0.89	0.13	6.88
3021	3.49	2.90	0.06	47.93:1	13.67	10.65	3.47	2.37	0.38	6.66
3022	3.59	26.07	0.92	28.29:1	107.42	1.29	1.19	0.64	0.12	4.34
3031	3.23	4.06	0.08	49.87:1	15.95	22.17	5.46	4.24	0.80	14.74
3032	3.44	7.38	0.29	25.03:1	36.13	1.73	1.25	0.82	0.19	4.18
3041	3.28	1.92	0.04	54.29:1	7.72	2.45	2.54	2.22	0.41	3.46
3042	3.45	9.81	0.26	38.48:1	30.95	0.77	0.94	0.74	0.16	4.30

Appendix 8 - Volumetric Chemical Characteristics for Debris Slide Soil Horizons

Sample	Organic Carbon (kg m-2)	Total Nitrogen (kg m-2)	TEC (cmol(+) m-2)
111	2.64	0.05	16.62
112	69.49	2.38	250.92
121	4.96	0.14	21.66
122	14.72	0.35	56.50
131	4.03	0.08	20.04
132	34.34	0.90	123.53
141	19.37	0.77	105.13
211	1.44	0.03	6.08
212	5.81	0.16	24.94
213	6.54	0.21	25.85
221	1.99	0.04	7.03
222	5.14	0.03	22.14
223	9.92	0.25	46.63
231	2.30	0.06	8.07
311	0.55	0.01	2.60
312	1.78	0.04	7.53
313	11.32	0.36	74.84
321	1.59	0.06	9.06
322	9.23	0.31	42.96
324	11.59	0.31	50.38
331	3.47	0.08	11.41
332	5.73	0.17	23.96
411	1.29	0.03	5.98
412	2.09	0.05	5.67
421	3.30	0.09	11.91
431	2.60	0.12	11.43
432	5.95	0.26	33.24
441	13.72	0.46	75.25
511	2.24	0.04	7.90
512	8.70	0.22	30.19
513	7.20	0.26	24.55
521	1.97	0.03	7.22
522	7.85	0.29	39.34
531	6.40	0.12	22.06
532	2.15	0.09	7.75
541	3.65	0.08	12.81
542	12.76	0.41	41.51
611	6.36	0.15	21.20
621	3.32	0.07	10.46
622	5.93	0.17	24.97
631	3.13	0.07	10.92
632	6.90	0.19	21.86
641	3.48	0.09	12.19
642	13.63	0.64	63.16
643	3.20	0.11	8.84
711	4.57	0.10	13.51
712	2.96	0.12	11.51
721	3.38	0.09	11.76

Sample	Organic Carbon (kg m-2)	Total Nitrogen (kg m-2)	TEC (cmol(+) m-2)
722	16.61	0.35	38.26
731	2.01	0.03	6.42
732	10.27	0.08	31.30
733	5.37	0.18	17.15
741	12.67	0.26	50.62
742	9.28	0.24	30.18
811	6.33	0.15	20.93
821	8.60	0.16	30.97
822	10.72	n/d	30.69
831	4.07	0.11	9.95
832	17.70	0.60	57.24
911	2.20	0.06	10.54
912	2.51	0.09	9.81
921	2.84	0.06	10.03
922	1.65	0.06	6.04
931	2.48	0.05	10.10
932	3.06	0.08	14.44
941	0.82	0.02	4.67
942	5.22	0.24	17.36
1011	2.53	0.06	8.30
1012	9.21	0.20	27.19
1021	2.38	0.06	8.45
1022	0.65	0.10	10.45
1031	2.34	0.05	8.58
1032	5.82	0.21	22.55
1041	8.33	0.25	29.09
1111	10.89	0.36	40.31
1121	4.52	0.13	14.68
1122	4.11	0.48	13.96
1131	4.16	0.14	13.97
1132	7.73	0.24	32.45
1211	34.10	1.15	124.86
1221	3.99	0.08	16.32
1222	3.25	0.49	68.26
1231	8.69	0.22	36.54
1232	8.69	0.24	35.43
1233	3.31	0.06	11.51
1241	10.78	0.25	26.09
1311	3.72	0.09	12.23
1312	9.07	0.36	31.92
1321	1.29	0.03	3.81
1322	6.69	0.30	20.31
1331	3.68	0.08	11.24
1332	2.66	0.06	4.69
1341	4.01	0.11	13.48
1342	5.31	0.18	22.61
1411	7.05	0.15	22.80
1412	3.87	0.11	9.91
1421	6.01	0.13	20.94
1422	3.52	0.10	17.73

Sample	Organic Carbon (kg m-2)	Total Nitrogen (kg m-2)	TEC (cmol(+) m-2)
1431	4.42	0.12	17.64
1432	9.14	0.19	31.50
1441	3.12	0.08	16.63
1442	15.99	0.47	93.53
1511	3.51	0.09	11.00
1512	7.28	0.21	27.52
1521	2.69	0.07	17.1i
1522	4.34	0.18	18.76
1531	4.82	0.09	20.01
1532	8.91	0.26	40.77
1541	2.19	0.05	11.65
1542	8.27	0.33	31.88
1611	3.49	0.07	12.78
1612	20.02	0.59	78.87
1621	4.41	0.09	18.09
1622	28.94	0.71	101.70
1631	2.24	0.05	8.41
1632	22.86	0.39	86.94
1641	47.43	1.19	292.26
1711	4.87	0.12	29.42
1712	54.38	1.31	112.92
1721	34.97	1.01	153.91
1731	1.10	0.04	5.18
1732	52.03	1.94	197.20
1741	32.94	0.95	181.00
1811	1.65	0.03	6.05
1812	1.58	0.03	4.79
1821	5.09	0.09	19.01
1822	7.65	0.21	35.45
1831	3.73	0.07	22.26
1832	4.43	0.14	15.89
1841	2.72	0.06	10.24
1842	14.56	0.32	61.78
1911	3.58	0.06	11.01
1912	9.57	0.34	22.70
1921	3.17	0.06	10.08
1922	6.69	0.29	26.25
1931	2.30	0.05	8.13
1932	1.45	0.07	4.40
1941	3.24	0.07	8.05
2011	1.20	0.04	6.59
2012	2.10	0.08	8.26
2021	4.50	0.07	20.01
2022	9.28	0.31	30.33
2031	2.01	0.03	9.25
2032	7.91	0.26	24.33
2041	3.18	0.06	18.44
2042	6.83	0.21	26.79
2111	4.30	0.10	16.30
2112	3.26	0.08	9.58

Sample	Organic Carbon (kg m-2)	Total Nitrogen (kg m-2)	TEC (cmol(+) m-2)
2121	13.71	0.19	60.99
2122	10.14	0.24	42.89
2131	1.67	0.04	6.86
2132	4.40	0.14	12.56
2133	5.90	0.20	29.35
2141	6.13	0.13	27.76
2142	33.73	0.71	134.71
2211	1.68	0.03	8.75
2212	31.40	0.73	121.46
2221	8.19	0.17	31.16
2222	35.12	0.83	91.97
2231	3.61	0.04	22.07
2241	2.74	0.06	9.27
2242	18.85	0.34	58.27
2311	4.47	0.07	19.37
2312	12.02	0.47	46.46
2321	4.86	0.12	18.38
2322	10.90	0.51	37.76
2323	8.00	0.32	34.69
2331	31.90	1.16	112.84
2332	10.07	0.33	30.00
2341	5.74	0.15	18.69
2342	29.80	1.00	103.65
2411	23.72	0.59	105.98
2412	5.79	0.20	26.66
2421	4.71	0.11	19.95
2422	37.62	1.22	159.25
2431	4.70	0.09	26.11
2432	9.04	0.51	55.27
2441	2.36	0.03	8.58
2442	9.80	0.28	41.03
2511	5.30	0.11	19.82
2512	20.56	0.52	71.74
2521	9.11	0.18	51.70
2522	15.17	0.38	57.62
2531	6.96	0.20	26.59
2532	14.40	0.39	60.73
2541	4.85	0.12	18.15
2542	18.66	0.49	70.66
2611	1.51	0.01	6.68
2612	4.52	0.11	17.75
2621	2.48	0.05	10.89
2622	7.99	0.29	30.52
2631	1.75	0.03	8.09
2632	5.13	0.21	20.91
2641	1.97	0.03	10.47
2642	3.06	0.08	12.63
2711	1.90	0.04	8.64
2712	11.22	0.32	47.35
2721	78.76	2.55	333.95

Sample	Organic Carbon (kg m-2)	Total Nitrogen (kg m-2)	TEC (cmol(+) m-2)
2731	4.38	0.09	18.00
2732	5.86	0.20	22.11
2741	6.32	0.17	27.62
2742	6.72	0.29	30.08
2811	4.40	0.08	16.48
2812	4.65	0.12	18.37
2821	78.76	2.55	333.95
2831	29.34	0.78	119.28
2841	6.32	0.17	27.62
2842	6.72	0.29	30.08
2911	2.26	0.04	7.65
2912	20.30	0.43	87.62
2921	2.90	0.06	13.67
2922	26.07	0.92	107.42
2931	3.07	0.05	13.30
2932	36.12	0.97	164.74
2941	1.92	0.04	7.72
2942	9.81	0.26	30.95
3011	2.76	0.05	13.45
3012	1.80	0.06	6.92
3021	2.90	0.06	13.67
3022	26.07	0.92	107.42
3031	4.06	0.08	15.95
3032	7.38	0.29	36.13
3041	1.92	0.04	7.72
3042	9.81	0.26	30.95

Appendix 9 - Soil Clasification for Debris Slide Pedons

	Canadian System			Humus Form		Soil Taxonomy			
Pedon	Order	Great Group	Subgroup	Order	Group	Order	Suborder	Great Group	Subgroup
11	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
12	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
13	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
14	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
21	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
22	Organic	Folisol	Lignic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
23	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Orthent	Udorthent	Lithic Udorthents
31	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
32	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
33	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
41	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
42	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Orthent	Udorthent	Lithic Udorthents
43	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
44	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
51	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
52	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
53	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
54	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
61	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
62	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
63	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
64	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
71	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
72	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
73	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
74	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Oxyaquic Udipsamment
81	Organic	Folisol	Hemic Folisol	Mor	Hemimor	Histosol	Folist	UdiFolist	Lithic Udifolist
82	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
83	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
91	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist

	Canadian System			Humus Form		Soil Taxonomy			
Pedon	Order	Great Group	Subgroup	Order	Group	Order	Suborder	Great Group	Subgroup
92	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
93	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
94	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
101	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
102	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Orthent	Udorthent	Lithic Udorthents
103	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
104	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
111	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
112	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Orthent	Udorthent	Lithic Udorthents
113	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Orthent	Udorthent	Lithic Udorthents
121	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
122	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
123	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
124	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
131	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
132	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
133	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
134	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
141	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
142	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
143	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
144	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
151	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
152	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
153	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
154	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
161	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
162	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
163	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
164	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Oxyaquic Udipsamment
171	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
172	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Oxyaquic Udipsamment

	Canadian System			Humus Form		Soil Taxonomy			
Pedon	Order	Great Group	Subgroup	Order	Group	Order	Suborder	Great Group	Subgroup
173	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
174	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Oxyaquic Udipsamment
181	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
182	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
183	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
184	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
191	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
192	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
193	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
194	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
201	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
202	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
203	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
204	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
211	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
212	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Oxyaquic Udipsamment
213	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Orthent	Udorthent	Lithic Udorthents
214	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Oxyaquic Udipsamment
221	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
222	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
223	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
224	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
231	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
232	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
233	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
234	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
241	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
242	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
243	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
244	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
251	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
252	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist

	Canadian System			Humus Form		Soil Taxonomy			
Pedon	Order	Great Group	Subgroup	Order	Group	Order	Suborder	Great Group	Subgroup
253	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
254	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
261	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
262	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
263	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
264	Organic	Folisol	Hemic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
271	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
272	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
273	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
274	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
281	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
282	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
283	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Oxyaquic Udipsamment
284	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
291	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
292	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
293	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Typic Udifolist
294	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
301	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
302	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
303	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist
304	Organic	Folisol	Humic Folisol	Moder	Mormoder	Histosol	Folist	UdiFolist	Lithic Udifolist

Appendix 10 - Folic Soil Characterization Pearson Correlation Matrix

	Ash	Base Sat.	Exch. Ca	Ca/TEC	C:N Ratio	Db	Detention	Exch. K	K/TEC	Grav. 5	Grav. 10	Grav. 1500	Grav. 33	Exch. Mg	Mg/TEC
Ash															
Base Sat.	-.27, .00														
Exch Ca	-.68, .00	.78, .00													
Ca/TEC	-.28, .00	.99, .00	.80, .00												
C:N Ratio	.51, .00	.01, .93	.24, .01	-.02, .87											
Db	.74, .00	.22, .01	-.50, .00	-.24, .01	-.36, .00										
Detention	-.41, .00	.22, .01	.30, .00	.21, .02	.24, .01	-.65, .00									
Exch. K	.79, .00	.43, .00	.69, .00	.37, .00	.47, .00	-.53, .00	.35, .00								
K/TEC	-.15, .00	.54, .00	.32, .00	.42, .00	.17, .06	-.02, .82	.17, .06	.62, .00							
Grav. 5	-.92, .00	.22, .02	.60, .00	.20, .02	.51, .00	-.68, .00	.37, .00	.82, .00	.19, .03						
Grav. 10	-.92, .00	.23, .01	.60, .00	.21, .02	.51, .00	-.67, .00	.34, .00	.83, .00	.21, .02	.99, .00					
Grav. 1500	-.92, .00	.26, .00	.61, .00	.24, .01	.49, .00	-.67, .00	.37, .00	.82, .00	.21, .02	.97, .00	.96, .00				
Grav. 33	.92, .00	.21, .02	.58, .00	.19, .03	.52, .00	-.66, .00	.36, .00	.81, .00	.20, .03	.97, .00	.98, .00	.98, .00			
Exch. Mg	-.80, .00	.46, .00	.70, .00	.40, .00	.41, .00	-.55, .00	.36, .00	.87, .00	.42, .00	.81, .00	.82, .00	.85, .00	.83, .00		
Mg/TEC	-.26, .00	.59, .00	.39, .00	.45, .00	.11, .24	-.18, .05	.24, .01	.47, .00	.57, .00	.25, .00	.27, .00	.32, .00	.29, .00	.67, .00	
Exch. Na	-.74, .00	.29, .00	.51, .00	.25, .01	.42, .00	-.52, .00	.32, .00	.75, .00	.33, .00	.71, .00	.73, .00	.74, .00	.74, .00	.72, .00	.35, .00
Na/TEC	.47, .00	.16, .08	-.26, .00	.10, .27	.21, .02	.37, .00	-.07, .42	.24, .01	.33, .00	.45, .00	-.44, .00	-.43, .00	.43, .00	.30, .00	.12, .17
Org. C	-.99, .00	.28, .00	.68, .00	.28, .00	.50, .00	-.74, .00	.40, .00	.80, .00	.15, .10	.92, .00	.93, .00	.93, .00	.92, .00	.81, .00	.26, .00
pH	.45, .00	.19, .03	-.04, .69	.21, .02	-.27, .00	.38, .00	-.23, .01	-.24, .01	.12, .17	-.40, .00	-.42, .00	.40, .00	.40, .00	-.33, .00	.11, .21
Porosity	-.73, .00	.25, .01	.52, .00	.26, .00	.36, .00	-.93, .00	.67, .00	.55, .00	.02, .83	.70, .00	.69, .00	.70, .00	.69, .00	.59, .00	.19, .03
TEC	-.92, .00	.20, .02	.67, .00	.21, .02	.46, .00	-.67, .00	.35, .00	.79, .00	.09, .34	.92, .00	.92, .00	.91, .00	.91, .00	.81, .00	.19, .03
TEC/OM	.08, .36	-.03, .73	.06, .49	-.01, .91	-.18, .04	.05, .61	-.25, .00	.04, .67	-.13, .15	.09, .32	.10, .27	.06, .50	.06, .00	.08, .39	.06, .51
Total N	-.77, .00	.21, .02	.54, .00	.24, .01	-.05, .58	-.61, .00	.28, .00	.49, .00	-.07, .45	.65, .00	.66, .00	.68, .00	.66, .00	.55, .00	.13, .14
Total N/OM	.46, .00	-.00, .98	.22, .01	.02, .84	-.67, .00	.24, .01	-.26, .00	-.35, .00	-.11, .24	-.36, .00	.35, .00	.37, .00	-.39, .00	.33, .00	.12, .17
Vol.10	-.03, .00	-.19, .03	.08, .41	-.18, .04	-.02, .87	.42, .00	-.49, .00	.02, .86	-.14, .12	.06, .52	.08, .40	.04, .67	.06, .50	.02, .80	.08, .36
Vol. 1500	-.20, .02	-.11, .20	.05, .55	.11, .24	.04, .64	.24, .01	-.32, .00	.13, .15	-.14, .12	.19, .03	.20, .02	.22, .01	.22, .02	.17, .05	.00, .96
Vol. 33	-.06, .50	-.21, .02	-.07, .43	-.20, .02	.01, .93	.38, .00	-.42, .00	.02, .81	.16, .08	.07, .46	.08, .40	.07, .45	.10, .28	.05, .60	.07, .43
Vol. 5	.03, .75	-22, .01	-.11, .21	-.21, .02	-.05, .59	.47, .00	-.49, .00	-.04, .68	-.16, .07	.02, .86	.01, .88	-.02, .87	.01, .93	-.03, .73	-.11, .22
von Post	.80, .00	-.40, .00	-.65, .00	-.36, .00	-.42, .00	.56, .00	-.26, .00	-.81, .00	-.39, .00	-.82, .00	-.82, .00	.81, .00	-.80, .00	-.77, .00	-.38, .00

Example .56, .00
.56 = correlation coefficient
.00 = alpha level

Exch. Na	Na/TEC	Org. C	pH	Porosity	TEC	TEC/OM	Total N	Total N/OM	Vol. 10	Vol. 1500	Vol. 33	Vol. 5	
													Ash
													Base Sat.
													Exch Ca
													Ca/TEC
													C:N Ratio
													Db
													Detention
													Exch. K
													K/TEC
													Grav. 5
													Grav. 10
													Grav. 1500
													Grav. 33
													Exch. Mg
													Mg/TEC
													Exch. Na
.05, .61													Na/TEC
.74, .00	.48, .00												Org. C
.34, .00	.27, .00	.45, .00											pH
.53, .00	.37, .00	.73, .00	.35, .00										Porosity
.73, .00	.51, .00	.93, .00	-.42, .00	0.70, .00									TEC
.06, .53	.11, .22	.07, .46	.09, .32	.01, .90	.17, .05								TEC/OM
.49, .00	-.47, .00	.78, .00	.35, .00	.60, .00	.71, .00	.02, .81							Total N
.29, .00	.20, .03	-.45, .00	.11, .22	.24, .01	.35, .00	.60, .00	.02, .84						Total N/OM
.02, .81	-.22, .01	.04, .70	.03, .74	-.31, .00	.09, .31	.21, .02	.08, .37	.04, .65					Vol.10
.15, .09	.31, .00	.21, .02	.11, .23	.09, .32	.25, .01	.14, .12	.25, .01	.06, .54	.94, .00				Vol. 1500
.04, .64	-.25, .01	.07, .45	.04, .70	.26, .00	.11, .22	.12, .19	.11, .21	.04, .70	.98, .00	.96, .00			Vol. 33
.03, .71	-.22, .02	-.02, .81	.02, .84	.34, .00	.04, .65	.18, .04	.04, .69	.04, .67	.99, .00	.93, .00	.97, .00		Vol. 5
-.70, .00	.24, .01	-80, .00	.28, .00	.57, .00	.77, .00	.08, .37	.51, .00	.31, .00	.06, .50	.06, .54	.0, .48	.10, .23	von Post

Appendix 11 - Landscape Level Data for Principal Components Analysis

Slide	Bedrock Structure	Slope Shape	Slope Angle (deg)	Surface Configuration	Vegetation Cover (%)	Water Tolerant Vegetation
1	jointed/fractured	straight	42.0	irregular/benchy	67.0	absent
2	jointed/fractured	straight	57.8	uniform/smooth	69.0	absent
3	jointed/fractured	convex/straight	50.5	uniform/smooth	40.5	present
4	jointed/fractured	concave/straight	47.5	uniform/smooth	61.5	present
5	jointed/fractured	convex/straight	43.5	uniform/smooth	62.5	present
6	jointed/fractured	straight	45.5	irregular/benchy	60.0	absent
7	massive	straight	41.5	irregular/benchy	71.5	absent
8	jointed/fractured	convex	49.5	uniform/smooth	55.0	absent
9	jointed/fractured	concave	45.5	uniform/smooth	74.5	present
10	jointed/fractured	straight	46.0	uniform/smooth	60.5	present
11	jointed/fractured	convex	51.5	uniform/smooth	62.0	absent
12	jointed/fractured	concave	46.0	uniform/smooth	77.5	present
13	jointed/fractured	convex	45.0	uniform/smooth	79.5	present
14	jointed/fractured	straight	37.0	uniform/smooth	83.0	absent
15	massive	convex/straight	29.5	uniform/smooth	74.0	present
16	jointed/fractured	convex	45.0	irregular/benchy	73.0	present
17	jointed/fractured	convex	31.0	irregular/benchy	68.5	present
18	jointed/fractured	convex	37.0	irregular/benchy	74.5	absent
19	jointed/fractured	convex	36.8	irregular/benchy	77.5	absent
20	massive	concave/straight	41.0	uniform/smooth	82.0	present
21	jointed/fractured	convex	30.3	irregular/benchy	78.0	absent
22	massive	convex	37.5	uniform/smooth	88.5	present
23	massive	straight	37.5	uniform/smooth	95.5	present
24	massive	convex/straight	38.0	uniform/smooth	65.0	present
25	jointed/fractured	concave	42.0	uniform/smooth	68.5	absent
26	massive	convex	39.5	uniform/smooth	63.5	present
27	jointed/fractured	convex	47.5	irregular/benchy	66.0	present
28	jointed/fractured	convex	46.0	irregular/benchy	76.0	present
29	jointed/fractured	convex	60.0	uniform/smooth	75.0	present
30	jointed/fractured	convex	48.0	uniform/smooth	80.0	present

Appendix 12 - Pedon Level Data for Principal Components Analysis

Slide	Ash Content (g kg-1)	Soil Mass (kg m-2)	Porosity (%)	Root Content*	Soil Structure	von Post
1	535.00	488.84	78.71	f/f-vf	massive/medium	9
2	401.30	317.29	92.13	f/f-vf	medium	8
3	400.00	511.39	87.60	f/m-vf	massive/medium	6
4	425.00	210.42	95.71	f/m-vf	non-compact matted/medium	6
5	221.60	488.57	93.18	f/f-vf	massive	8
6	368.40	519.68	96.13	f/f-vf	non-compact matted/medium	5
7	855.00	381.30	86.59	f/f-vf	massive	8
8	675.40	168.34	85.65	c/a, m/f-vf	non-compact matted	6
9	555.00	191.86	94.20	f/f-vf	massive/medium	8
10	690.20	360.21	90.08	c/f-vf	fine	7
11	580.20	916.63	91.25	c/f-vf	medium	8
12	537.50	675.82	87.31	f/f-vf	fine	8
13	510.00	252.79	92.69	c/f-vf	medium/fine	8
14	710.00	337.40	89.49	c/f-vf	medium/fine	8
15	713.80	441.13	92.11	c/f-vf	medium	8
16	500.30	509.24	86.21	c/f-vf	massive	8
17	726.50	1024.07	87.80	f/m-vf	massive/medium	7
18	533.00	236.27	83.05	f/f-vf	medium/fine	9
19	802.80	489.90	76.33	f/f-vf	fine	8
20	507.20	238.02	86.90	f/f-vf	massive/fine	7
21	222.20	464.84	88.69	f/f-vf	massive/medium	7
22	577.20	607.68	89.09	c/f-vf	fine	8
23	755.10	456.73	81.01	f/f-vf	massive	8
24	550.40	684.38	81.79	c/f-vf	medium	8
25	441.70	670.57	93.38	f/f-vf	medium	8
26	650.70	266.29	94.39	c/f-vf	non-compact matted	7
27	805.10	624.50	68.68	f/f-vf	massive/medium	9
28	664.00	488.35	85.77	f/f-vf	massive/medium	7
29	102.40	332.91	76.22	f/f-vf	medium	9
30	687.80	277.26	82.22	c/f-vf	medium	9

* **Root Content**

Example: c/f-vf
common abundance class
fine to very fine size class

Abundance Class	Size Class
f = few	vf = very fine
c = common	f = fine
p = plentiful	m = medium
a = abundant	c = coarse
	k = very coarse

Appendix 13 - Landscape Characteristics for Non-Debris Slide Transect Sites

Site	Elev. (m)	Aspect	Slope Shape	Surface Config.	Slope Angle (deg)	Bedrock Exposure	Bedrock Type	Bedrock Structure	Local Setting
D1	260	NNW	straight	uniform/smooth	15	subsurface	gneiss	jointed/fractured	n/d
D2	215	NNW	concave	irregular/benchy	24	subsurface	gneiss	jointed/fractured	n/d
D3	285	NNW	concave	uniform/smooth	28	exposed	gneiss	jointed/fractured	n/d
D4	230	NNW	concave	irregular/benchy	33	subsurface	gneiss	jointed/fractured	n/d
D5	245	NNW	convex	uniform/smooth	45	subsurface	gneiss	jointed/fractured	n/d
G1	45	W	concave	irregular/benchy	17	subsurface	diorite	jointed/fractured	n/d
G2	55	W	concave	irregular/benchy	22	subsurface	diorite	masssive	n/d
G3	75	W	concave	irregular/benchy	28	subsurface	diorite	masssive	n/d
G4	90	W	concave	irregular/benchy	32	subsurface	diorite	masssive	n/d
G5	105	W	concave	irregular/benchy	37	exposed	diorite	masssive	n/d
H1	180	NNE	straight	uniform/smooth	15	subsurface	quartz diorite	masssive	n/d
H2	220	NNE	concave	irregular/benchy	23	subsurface	quartz diorite	masssive	n/d
H3	190	NNE	concave	irregular/benchy	27	subsurface	quartz diorite	masssive	n/d
H4	220	NNE	convex	irregular/benchy	32	subsurface	quartz diorite	masssive	n/d
H5	210	NNE	convex	irregular/benchy	49	exposed	quartz diorite	masssive	n/d
P1	130	SW	straight	irregular/benchy	17	subsurface	quartz diorite	masssive	n/d
P2	90	SW	concave	irregular/benchy	22	subsurface	quartz diorite	masssive	n/d
P3	120	SW	concave	irregular/benchy	29	subsurface	quartz diorite	masssive	n/d
P4	145	SW	concave	irregular/benchy	32	subsurface	quartz diorite	masssive	n/d
P5	150	SW	convex	irregular/benchy	37	subsurface	quartz diorite	masssive	n/d

Appendix 14 - Morphological Characteristics for Non-Debris Slide Transect Soil Samples

Sample	Horizon Thickness (cm)	Horizon Designation	Character	Structure	Consistence (Moist)	Coarse Fragment (%)
D11	0-13	Fa	fibrous	nc-matted	tenacious	0
D12	13-56	Hz	greasy	blocky	loose	0
D13	56-85	Hh	greasy	massive	pliable	0
D21	0-20	Hrw	ligneous	wood	loose	0
D22	20-55	Hz	greasy	blocky	loose	0
D23	55+	C	gritty	blocky	loose	0
D31	0-10	Fawi	ligneous/gritty	nc-matted	tenacious	0
D32	10-41	Hhi	greasy/gritty	blocky	pliable	0
D41	0-23	Fa	fibrous	nc-matted	tenacious	0
D42	23-96	C	gritty	blocky	loose	20 angular cobbles
D51	0-11	Fa	fibrous	nc-matted	tenacious	0
D52	11-29	Hhi	greasy/gritty	blocky	loose	0
G11	0-4	Fa	mossy	erect	tenacious	0
G12	4-31	Hh	greasy	massive	pliable	0
G21	0-7	Fa	fibrous	nc-matted	tenacious	0
G22	7-29	Hr	greasy	blocky	loose	0
G31	0-9	Fa	fibrous	nc-matted	tenacious	0
G32	9-56	Hhi	greasy/gritty	blocky	pliable	0
G41	0-35	Fz	ligneous/greasy	granular	loose	0
G51	0-8	Ln	mossy	erect	tenacious	0
G52	8-20	C	gritty	massive	pliable	15 angular cobbles
H11	0-13	Fa	fibrous	nc-matted	tenacious	0
H12	13-30	Hh	greasy	massive	pliable	0
H13	30-75	C	gritty	blocky	pliable	0
H21	0-7	Fa	fibrous	nc-matted	tenacious	0
H22	7-50	Hhi	greasy/gritty	blocky	pliable	0
H31	0-6	Hh	fibrous	nc-matted	tenacious	0
H32	6-18	Hh	greasy	massive	pliable	0
H33	18-72	C	gritty	blocky	loose	0
H41	0-9	Fa	fibrous	nc-matted	tenacious	0
H42	9-35	C	gritty	blocky	loose	0

Sample	Horizon Thickness (cm)	Horizon Designation	Character	Structure	Consistence (Moist)	Coarse Fragment (%)
H51	0-7	Fa	fibrous	nc-matted	tenacious	0
H52	7-27	Hhi	greasy/gritty	blocky	loose	0
P11	0-9	Fa	fibrous	nc-matted	tenacious	0
P12	9-30	C	gritty	granular	loose	0
P21	0-20	C	gritty	blocky	pliable	0
P31	0-6	Fz	fibrous	nc-matted	tenacious	0
P32	6-19	Hh	greasy	blocky	pliable	0
P41	0-45	C	gritty	granular	loose	0
P51	0-4	Fa	fibrous	nc-matted	tenacious	0
P52	4-20	Hr	greasy	granular	loose	0
P53	20-30	C	gritty	granular	loose	0

Appendix 15 - Physical Characteristics for Non-Debris Slide Transect Soil Samples

Sample	Db (Mg m-3)	Dp (Mg m-3)	von Post	Ash (g kg-1)	5 kPa Grav. Water (%)	10 kPa Grav. Water (%)	33 kPa Grav. Water (%)	1500 kPa Grav. Water (%)	Field Grav. Water Content (%)
G11	n/d	n/d	3	36.46	323.02	292.42	217.36	190.51	n/d
G12	0.17	n/d	9	252.48	169.94	164.21	117.00	99.25	412.92
G21	0.08	n/d	4	34.40	249.48	233.54	158.29	129.48	461.45
G22	0.11	n/d	8	352.11	130.33	115.18	99.65	79.13	556.47
G31	0.06	n/d	4	173.71	270.45	262.42	173.64	129.75	556.48
G32	0.20	n/d	9	510.00	167.55	118.13	91.65	65.78	418.77
G41	0.09	n/d	4	63.41	195.29	188.16	146.31	126.82	379.56
G51	0.04	n/d	2	59.11	461.29	420.19	325.33	250.57	1096.89
G52	0.25	n/d	8	899.04	32.00	30.29	16.97	11.06	275.34
D11	0.08	n/d	4	30.00	252.56	233.53	162.68	142.78	498.57
D12	0.16	n/d	9	148.33	156.30	154.60	121.24	98.72	534.35
D13	0.15	n/d	7	140.91	224.15	216.27	157.51	103.45	442.39
D21	0.12	n/d	6	62.10	259.70	257.43	183.25	137.33	498.49
D22	0.15	n/d	8	124.46	221.11	223.23	173.58	116.50	450.48
D23	n/d	n/d	8	872.73	56.35	52.02	33.54	9.88	n/d
D31	0.09	n/d	3	573.53	69.57	68.59	48.02	24.41	506.50
D32	0.15	n/d	8	23.26	282.38	268.26	150.00	98.93	446.55
D41	n/d	n/d	3	60.19	227.88	221.33	159.44	134.43	n/d
D42	0.43	n/d	8	848.59	69.77	49.29	30.05	13.79	138.89
D51	0.10	n/d	4	103.90	246.88	231.03	158.38	128.75	481.12
D52	0.44	n/d	8	440.37	119.34	111.99	75.31	64.60	107.18
H11	0.09	n/d	3	39.13	240.00	217.06	167.06	152.57	552.64
H12	0.12	n/d	7	298.90	153.59	132.72	88.98	77.45	560.49
H13	0.25	n/d	8	875.52	44.26	36.26	23.53	10.82	260.12
H21	0.07	n/d	3	201.97	229.23	208.23	148.07	120.96	659.67
H22	0.30	n/d	7	572.12	69.00	64.13	44.58	30.62	265.46
H31	0.06	n/d	7	113.12	251.23	238.01	143.68	115.25	834.87
H32	0.12	n/d	9	278.03	192.20	169.91	143.88	93.18	622.67
H33	0.42	n/d	7	909.91	33.69	27.60	21.14	10.88	134.78
H41	0.07	n/d	5	61.32	251.23	229.65	176.30	151.17	614.09
H42	0.31	n/d	7	852.52	34.65	33.49	22.61	12.68	201.24
H51	0.08	n/d	3	100.00	279.12	243.85	163.04	125.11	554.48
H52	0.25	n/d	7	795.40	39.49	41.98	27.89	24.27	258.50

Sample	Db (Mg m-3)	Dp (Mg m-3)	von Post	Ash (g kg-1)	5 KPa Grav. Water (%)	10 Kpa Grav. Water (%)	33 KPa Grav. Water (%)	1500 KPa Grav. Water (%)	Field Grav. Water Content (%)
P11	0.07	n/d	3	48.08	237.36	231.30	172.25	127.35	422.05
P12	0.71	n/d	8	942.31	33.89	20.40	16.00	4.71	53.59
P21	0.26	n/d	7	747.86	80.18	71.49	37.11	19.29	324.33
P31	0.11	n/d	3	129.63	235.56	212.04	152.82	135.68	524.25
P32	0.26	n/d	8	370.89	138.92	113.38	91.17	65.54	300.25
P41	0.49	n/d	7	915.61	37.80	25.50	18.16	7.73	121.37
P51	0.15	1.60	4	233.33	224.26	205.59	153.85	128.30	430.77
P52	0.52	n/d	7	199.07	173.31	161.62	136.22	116.10	46.16
P53	n/d	n/d	7	951.85	29.26	18.02	12.60	5.43	n/d

Appendix 16 - Chemical Characteristics for Non-Debris Slide Transect Soil Samples

Sample	pH	Org. C (kg m-2)	Total N (kg m-2)	C:N Ratio	TEC NH4+ (cmol(+) m-2)	Exch. Ca (cmol(+) kg-1)	Exch. Mg (cmol(+) kg-1)	Exch. K (cmol(+) kg-1)	Exch. Na (cmol(+) kg-1)	Base Sat.(%)
G11	3.36	2.91	0.05	53.74:1	10.95	15.02	2.66	2.44	0.41	9.75
G12	3.54	31.69	1.31	24.22:1	124.44	2.23	1.68	1.34	0.32	3.27
G21	2.85	12.99	0.28	46.29:1	49.19	12.94	4.27	1.97	0.72	8.81
G22	3.17	8.27	0.17	48.80:1	31.68	9.73	2.03	0.88	0.16	2.44
G31	3.98	10.06	0.29	34.23:1	42.70	8.51	2.00	3.29	0.58	1.85
G32	3.94	8.53	0.49	17.44:1	40.62	4.73	1.33	1.25	0.23	23.80
G41	2.89	4.89	0.12	42.11:1	16.95	18.74	2.65	2.10	0.54	1.74
G51	3.69	6.77	0.11	63.46:1	31.60	13.11	4.39	2.48	0.62	0.30
G52	3.87	3.37	0.14	23.42:1	12.97	1.22	0.32	0.84	0.23	80.13
D11	2.84	32.86	0.64	51.15:1	115.42	12.23	3.32	2.54	0.59	0.74
D12	2.88	8.69	0.22	39.20:1	34.83	1.79	1.16	0.34	0.22	9.59
D13	3.10	13.45	0.39	34.60:1	61.03	1.98	0.80	0.62	0.35	5.67
D21	2.99	2.61	0.06	46.50:1	10.99	10.14	3.67	0.71	0.36	6.50
D22	3.81	20.57	0.47	43.78:1	81.67	0.99	0.40	0.38	0.23	1.00
D23	4.16	2.02	0.04	49.21:1	9.82	0.45	0.14	0.17	0.12	2.44
D31	3.15	4.90	0.07	68.71:1	13.74	2.45	1.57	0.85	0.15	18.55
D32	2.92	7.65	0.14	55.54:1	27.68	15.59	4.18	1.21	0.47	0.77
D41	2.97	17.93	0.41	43.61:1	70.12	7.10	3.85	2.08	0.45	4.88
D42	3.79	13.22	0.35	38.18:1	52.45	0.39	0.24	0.37	0.14	41.24
D51	3.26	4.16	0.10	39.98:1	17.55	11.71	3.13	2.58	0.52	2.29
D52	3.54	17.14	0.55	30.91:1	80.53	4.79	1.14	0.81	0.26	14.07
H11	3.22	6.52	0.14	46.44:1	23.56	24.77	2.99	4.01	0.46	11.37
H12	3.44	8.29	0.31	26.75:1	30.00	1.68	0.81	0.63	0.16	2.70
H13	3.86	8.12	0.23	36.10:1	34.24	0.44	0.12	0.13	0.07	3.91
H21	3.36	2.27	0.07	31.92:1	10.57	1.66	1.87	2.80	0.27	17.06
H22	3.52	32.01	0.70	45.96:1	73.71	0.34	0.40	0.27	0.09	12.41
H31	3.59	1.85	0.04	43.59:1	7.27	16.98	2.17	3.06	0.67	3.74
H32	3.73	6.03	0.21	28.68:1	28.10	1.82	0.98	0.92	0.24	12.31
H33	3.99	11.85	0.45	26.13:1	63.83	0.52	0.15	0.35	0.17	47.90
H41	3.25	3.43	0.09	37.55:1	13.62	14.84	3.29	2.76	0.62	0.53
H42	3.63	6.89	0.31	22.51:1	24.17	0.15	0.21	0.15	0.06	71.72

Sample	pH	Org. C (kg m-2)	Total N (kg m-2)	C:N Ratio	TEC NH4+ (cmol(+) m-2)	Exch. Ca (cmol(+) kg-1)	Exch. Mg (cmol(+) kg-1)	Exch. K (cmol(+) kg-1)	Exch. Na (cmol(+) kg-1)	Base Sat.(%)
H51	3.49	2.92	0.11	27.62:1	10.48	35.64	3.48	4.01	0.51	0.38
H52	3.35	11.54	0.19	62.35:1	23.63	2.49	0.46	0.23	0.11	1.88
P11	3.10	3.48	0.08	45.82:1	9.63	12.53	2.75	2.42	0.37	13.48
P12	3.77	4.99	0.15	33.46:1	30.65	0.86	0.15	0.26	0.19	12.69
P21	4.39	7.60	0.27	28.12:1	32.37	7.04	0.99	2.06	0.32	28.82
P31	3.61	3.33	0.08	43.52:1	11.55	29.19	3.17	4.03	0.42	4.00
P32	3.28	12.33	0.37	33.48:1	46.50	3.72	1.05	2.01	0.30	31.72
P41	3.95	10.79	0.46	23.31:1	45.37	0.45	0.20	0.15	0.09	15.99
P51	3.36	2.67	0.06	44.47:1	7.92	15.29	2.39	16.75	0.77	26.67
P52	3.24	38.65	1.58	24.45:1	150.62	4.96	1.53	1.32	0.25	4.45
P53	3.58	1.23	0.07	17.45:1	6.52	0.29	0.15	0.39	0.06	5.47

Appendix 17 - Soil Classification for Non-Debris Slide Transect Pedons

	Canadian System			Humus Form		Soil Taxonomy			
Pedon	Order	Great Group	Subgroup	Order	Group	Order	Suborder	Great Group	Subgroup
D1	Organic	Folisol	Humic Folisol	Moders	Mormoder	Histosol	Folist	Udifolist	Typic Udifolist
D2	Organic	Folisol	Humic Folisol	Moders	Mormoder	Histosol	Folist	Udifolist	Typic Udifolist
D3	Organic	Folisol	Humic Folisol	Moders	Mormoder	Histosol	Folist	Udifolist	Lithic Udifolist
D4	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Typic Udipsamment
D5	Organic	Folisol	Humic Folisol	Moders	Mormoder	Histosol	Folist	Udifolist	Lithic Udifolist
G1	Organic	Folisol	Humic Folisol	Moders	Mormoder	Histosol	Folist	Udifolist	Lithic Udifolist
G2	Organic	Folisol	Humic Folisol	Moders	Mormoder	Histosol	Folist	Udifolist	Lithic Udifolist
G3	Organic	Folisol	Humic Folisol	Moders	Mormoder	Histosol	Folist	Udifolist	Typic Udifolist
G4	Organic	Folisol	Hemic Folisol	Moders	Leptomoder	Histosol	Folist	Udifolist	Lithic Udifolist
G5	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
H1	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Typic Udipsamment
H2	Organic	Folisol	Humic Folisol	Moders	Mormoder	Histosol	Folist	Udifolist	Lithic Udifolist
H3	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Typic Udipsamment
H4	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
H5	Organic	Folisol	Humic Folisol	Moders	Mormoder	Histosol	Folist	Udifolist	Lithic Udifolist
P1	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
P2	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
P3	Organic	Folisol	Humic Folisol	Moders	Leptomoder	Histosol	Folist	Udifolist	Lithic Udifolist
P4	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment
P5	Regosol	Regosol	Orthic Regosol	n/d	n/d	Entisol	Psamment	Udipsamment	Lithic Udipsamment

Appendix 18 - Location of Shear Frame Plots

Plot	Slide	Location
P1	1	Lachmach Road 7.5 km
P2	1	Lachmach Road 7.5 km
P3	7	Harrison Lake - west
P4	1	Lachmach Road 7.5 km
P5	1	Lachmach Road 7.5 km
P6	16	Silver Creek 1 - road initiated - north
P7	23	Smith Island Inlet 1 - upper
P8	23	Smith Island Inlet 1 - upper
P9	1	Lachmach Road 7.5 km

Appendix 19 - Landscape Characteristics for Shear Frame Plots

Plot	Elev. (m)	Aspect	Slope Shape	Surface Config.	Slope Angle (deg)	Bedrock Exposure	Bedrock Type	Bedrock Structure	Local Setting
P1	140	NE	straight	uniform/smooth	37	subsurface	quartz diorite	jointed/fractured	n/d
P2	260	NE	concave	uniform/smooth	21	subsurface	quartz diorite	jointed/fractured	n/d
P3	210	NE	convex	uniform/smooth	31	subsurface	quartz diorite	massive	n/d
P4	190	NE	convex	uniform/smooth	26.5	subsurface	quartz diorite	jointed/fractured	n/d
P5	180	NE	convex	uniform/smooth	34	subsurface	quartz diorite	jointed/fractured	n/d
P6	330	NW	convex	uniform/smooth	15	subsurface	gneiss	jointed/fractured	n/d
P7	430	NNE	straight	uniform/smooth	15	subsurface	quartz diorite	massive	n/d
P8	430	NNE	straight	uniform/smooth	25	subsurface	quartz diorite	massive	n/d
P9	135	NE	convex	uniform/smooth	40	subsurface	quartz diorite	jointed/fractured	n/d

Appendix 20 - Morphological Characteristics of Shear Frame Soil Samples

Plot	Horizon	Depth (cm)	von Post	Structure	Character	Consistence	Coarse Fragments (%)	Water Content
P1	1	0-8	3	non compact matted	fibrous	tenacious	0	saturated
P1	2	8-20	8	too wet	greasy	loose	5 angular cobbles	saturated
P2	1	0-6	2	non compact matted	fibrous	tenacious	0	saturated
P2	2	6-20	9	granular	gritty	pliable	30 angular cobbles	saturated
P3	1	0-6	3/4	non compact matted	fibrous	tenacious	0	saturated
P3	2	6-30	9	granular	greasy/gritty	pliable	0	saturated
P4	1	0-10	4	non compact matted	fibrous	tenacious	0	saturated
P4	2	10-20	8	granular	greasy/gritty	pliable	5 angular cobbles	saturated
P4	3	20-28	9	massive	gritty	loose	15 angular cobbles	saturated
P5	1	0-7	3/4	non compact matted	fibrous	tenacious	0	wet
P5	2	7-13	8	granular	greasy/gritty	pliable	0	saturated
P6	1	0-9	4	non compact matted	fibrous	tenacious	0	wet
P6	2	9-55	7	blocky	greasy	pliable	0	wet
P7	1	0-10	4	non compact matted	fibrous	tenacious	0	wet
P7	2	10-30	9	granular	gritty	pliable	10 angular cobbles	saturated
P8	1	0-20	4	non compact matted	fibrous	tenacious	0	saturated
P8	2	20-37	8	granular	gritty	pliable	0	saturated
P9	1	0-8	3	non compact matted	fibrous	tenacious	0	wet
P9	2	8-17	9	blocky	fibrous/gritty	tenacious/pliable	0	wet

Appendix 21 - Shear Frame Shear Strength Measurements and Notes

Sample	Pull 1 (kPa)	Pull 2 (kPa)	Pull 3 (kPa)	Notes
P1R1	627	431	39	n/d
P1R2	627	353	118	n/d
P1R3	549	353	78	n/d
P1R4	470	274	78	35 deg slope angle
P1R5	196	118	78	40 deg slope angle
P1R6	314	118	wt. of scale	40 deg slope angle
P2R1	1098	broke	78	part of pedon atop angular cobble/ pedon broke apart
P2R2	1098	broke	78	part of pedon atop angular cobble/ pedon broke apart
P2R3	1960	470	78	n/d
P3R1	1254	314	78	n/d
P3R2	1215	314	78	n/d
P3R3	1372	314	78	n/d
P4R1	784	broke	118	pedon broke
P4R2	862	broke	118	pedon broke
P4R3	2038	broke	157	part of pedon atop angular cobble/ pedon broke apart
P5R1	448	157	78	steepest area
P5R2	627	157	78	deeper soil in one area due to uneven bedrock/less steep
P5R3	1568	624	78	deeper soil in one area due to uneven bedrock/large area
P6R1	3200	666	157	n/d
P6R2	3920	1568	314	pedestal butressed by rise in bedrock/did not fail at max reading
P6R3	3920	1568	78	deeper soil in one area due to uneven bedrock/possible butressing
P6R4	3920	1568	235	pedestal butressed by rise in bedrock/did not fail at max reading
P7R1	2509	broke	39	15 deg slope angle/high amounts of colluvium near bottom of profile
P7R2	1254	510	157	25 deg slope angle/less colluvium than rep 1
P7R3	3920	broke	wt. of scale	5 deg slope angle
P7R4	1725	510	wt. of scale	24 deg slope angle/water running at soil-bedrock contact
P7R5	1882	510	wt. of scale	5 deg slope angle
P8R1	627	353	78	25 deg slope angle/water running at soil-bedrock contact
P8R2	666	196	wt. of scale	35 deg slope angle/water running at soil-bedrock contact
P8R3	196	196	wt. of scale	40 deg slope angle/water running at soil-bedrock contact
P9R1	1024	78	wt. of scale	40 deg slope angle/smooth impermeable bedrock
P9R2	wt. of scale	wt. of scale	wt. of scale	50 deg slope angle/smooth impermeable bedrock
P9R3	235	wt. of scale	wt. of scale	40 deg slope angle/smooth impermeable bedrock

wt. of scale = 323 g

Appendix 22 - Physical Characteristics for Shear Frame Soil Samples

Sample	Ash Content (g kg-1)	Organic Carbon (g kg-1)
P1R1	402.99	346.27
P1R2	169.15	481.89
P1R3	155.00	490.10
P1R4	710.00	168.20
P1R5	273.63	421.29
P1R6	305.00	403.10
P2R2	850.00	87.00
P2R3	860.00	81.20
P3R1	760.00	139.20
P3R2	805.00	113.10
P3R3	875.00	72.50
P4R2	885.00	66.70
P5R1	400.00	348.00
P5R2	660.00	197.20
P5R3	258.71	429.95
P6R1	611.94	225.07
P6R2	280.00	417.60
P6R3	770.00	133.40
P6R4	330.00	388.60
P7R1	890.00	63.80
P7R2	825.00	101.50
P7R3	977.50	13.05
P7R4	854.50	84.39
P7R5	870.00	75.40
P8R1	755.00	142.10
P8R2	885.00	66.70
P8R3	880.00	69.60
P9R1	80.00	533.60
P9R2	490.00	295.80
P9R3	315.00	397.30

Sample	Bulk Density (Mg cm-3)
P1	0.14
P2	0.60
P3	0.56
P4	0.43
P5	0.17
P6	0.17
P7	0.66
P8	0.34
P9	n/d

Appendix 23 - Hydrologic Characteristics for Shear Frame Soil Samples

Sample	Field Grav. Water Cont. (%)	Field Vol. Water Cont. (%)
P1	456.07	48.29
P2	112.14	66.77
P3	123.18	68.23
P4	363.55	72.58
P5	446.75	75.63
P6	451.80	57.83
P7	90.85	59.51
P8	226.14	74.53
P9	n/a	n/a

Sample	5 kPa Grav. Water Cont. (%)	10 kPa Grav. Water Cont. (%)	33 kPa Grav. Water Cont. (%)	1500 kPa Grav. Water Cont. (%)
P1R1	176.26	161.86	125.25	113.78
P1R2	168.60	156.27	134.73	132.39
P1R3	152.28	144.44	130.83	127.71
P1R4	65.76	63.80	51.49	24.65
P1R5	159.40	145.39	133.72	129.15
P1R6	168.67	159.15	128.85	117.91
P2R2	44.87	34.91	24.07	12.67
P2R3	35.98	29.83	18.55	10.55
P3R1	36.24	32.18	22.78	21.87
P3R2	51.24	32.13	25.63	24.53
P3R3	25.97	23.32	14.58	13.03
P4R2	28.51	23.11	18.54	9.34
P5R1	150.00	137.37	121.34	113.18
P5R2	109.01	100.00	84.18	61.87
P5R3	150.76	136.06	105.72	101.28
P6R1	131.99	94.84	72.06	66.09
P6R2	203.08	195.57	150.00	72.57
P6R3	83.81	57.63	51.56	40.01
P6R4	110.67	131.75	119.81	117.84
P7R1	42.27	27.34	17.93	9.86

Sample	5 kPa Grav. Water Cont. (%)	10 kPa Grav. Water Cont. (%)	33 kPa Grav. Water Cont. (%)	1500 kPa Grav. Water Cont. (%)
P7R2	55.14	42.72	32.08	15.19
P7R3	61.27	36.83	27.04	11.01
P7R4	35.90	28.09	18.65	10.25
P7R5	50.60	34.35	25.26	11.59
P8R1	40.36	33.09	27.71	18.32
P8R2	36.45	24.41	17.58	10.54
P8R3	30.75	23.67	15.65	10.45
P9R1	225.88	208.59	197.72	169.11
P9R2	129.07	127.00	121.54	112.98
P9R3	164.23	146.18	134.90	110.04

Appendix 24 - Root Mass and Root Length Conversion for Shear Frame Soil Samples

Sample	Root Size Class	Moist Root Mass (g)	Oven Dry Root Mass (g)
P1R1	very fine	97.24	9.16
P1R1	fine	31.17	4.34
P1R1	medium	38.70	4.05
P1R1	total	167.11	17.55
P1R2	very fine	78.23	6.96
P1R2	fine	22.16	2.79
P1R2	medium	100.56	14.68
P1R2	total	200.95	24.43
P1R3	very fine	84.39	10.20
P1R3	fine	79.37	12.78
P1R3	medium	54.64	10.03
P1R3	total	218.40	33.01
P1R4	very fine	61.57	8.17
P1R4	fine	38.95	5.85
P1R4	medium	17.39	4.09
P1R4	coarse	14.86	3.65
P1R4	total	132.77	21.76
P1R5	very fine	59.92	8.82
P1R5	fine	73.62	14.02
P1R5	medium	49.61	12.29
P1R5	coarse	16.72	4.36
P1R5	total	199.87	39.49
P1R6	very fine	42.13	6.68
P1R6	fine	46.23	8.44
P1R6	medium	60.70	15.70
P1R6	coarse	15.49	7.37
P1R6	total	164.55	38.19
P2R2	very fine	0.78	0.10
P2R2	fine	1.29	0.22
P2R2	medium	7.12	1.21
P2R2	coarse	11.27	2.11

Moist Root Length to Moist Mass

Sample	< 0.1 mm Micro (cm g-1 ww)	0.1-1 mm Very Fine (cm g-1 ww)	1-2 mm Fine (cm g-1 ww)	2.1-5 mm Medium (cm g-1 ww)	5.1-15 mm Coarse (cm g-1 ww)	> 15 mm Very Coarse (cm g-1 ww)
composite	4137.93	131.72	63.46	3.49	0.63	0.30
P4R2	n/d	161.90	40.12	4.93	1.12	0.36
P5R3	3571.43	141.36	44.10	n/d	n/d	n/d
P9R1	3695.65	146.43	n/d	n/d	n/d	n/d
P9R3	4318.18	170.50	n/d	n/d	n/d	n/d
P10R1	n/d	160.53	39.10	3.42	0.98	0.22
P10R2	n/d	141.18	63.91	3.33	0.78	0.29
Mean	**3930.80**	**150.52**	**50.14**	**3.79**	**0.88**	**0.29**

Oven Dry Root Length to Oven Dry Mass

Sample	< 0.1 mm Micro (cm g-1 dw)	0.1-1 mm Very Fine (cm g-1 dw)	1-2 mm Fine (cm g-1 dw)	2.1-5 mm Medium (cm g-1 dw)	5.1-15 mm Coarse (cm g-1 dw)	> 15 mm Very Coarse (cm g-1 dw)
P4R2	n/d	944.44	235.37	29.73	3.33	1.63
P5R3	51373.57	964.30	214.71	n/d	n/d	n/d
P9R1	46522.35	1301.28	n/d	n/d	n/d	n/d
P9R3	38677.09	1123.19	n/d	n/d	n/d	n/d
P10R1	n/d	1265.01	253.80	13.22	4.84	0.93
P10R2	n/d	887.76	388.69	10.92	3.08	0.80
Mean	**45524.34**	**1081.00**	**273.14**	**17.96**	**3.75**	**1.12**

Sample	Root Size Class	Moist Root Mass (g)	Oven Dry Root Mass (g)
P2R2	total	20.46	3.64
P2R3	very fine	11.85	1.91
P2R3	fine	14.89	3.46
P2R3	medium	24.53	5.62
P2R3	coarse	52.64	12.01
P2R3	total	103.91	23.00
P3R1	very fine	8.09	0.76
P3R1	fine	3.00	0.29
P3R1	medium	4.59	0.67
P3R1	coarse	26.83	11.30
P3R1	total	42.51	13.02
P3R3	very fine	5.96	1.01
P3R3	fine	1.28	0.25
P3R3	medium	6.51	0.80
P3R3	total	13.75	2.06
P4R2	very fine	2.45	0.42
P4R2	fine	12.32	2.10
P4R2	medium	32.68	5.42
P4R2	coarse	19.96	6.69
P4R2	very coarse	167.05	37.07
P4R2	total	234.46	51.70
P5R1	very fine	7.79	1.22
P5R1	fine	10.07	1.76
P5R1	medium	1.44	0.29
P5R1	total	19.30	3.27
P5R2	very fine	6.18	0.98
P5R2	fine	17.57	3.38
P5R2	medium	17.52	5.11
P5R2	coarse	12.03	3.45
P5R2	total	53.30	12.92
P5R3	micro	61.71	4.29
P5R3	very fine	3.82	0.56
P5R3	fine	27.12	5.57
Sample	Root Size Class	Moist Root Mass (g)	Oven Dry Root Mass (g)

P5R3	medium	35.48	7.85
P5R3	total	128.13	18.27
P6R1	fine	4.95	0.43
P6R1	medium	61.92	5.28
P6R1	total	66.87	5.71
P6R2	fine	10.23	1.01
P6R2	medium	34.07	3.67
P6R2	total	44.30	4.68
P6R3	very fine	0.36	0.02
P6R3	fine	1.49	0.20
P6R3	medium	10.91	0.88
P6R3	total	12.76	1.10
P6R4	very fine	6.17	0.84
P6R4	fine	3.35	0.28
P6R4	medium	27.98	2.22
P6R4	total	37.50	3.34
P7R1	very fine	4.08	1.45
P7R1	fine	6.54	1.77
P7R1	medium	1.10	0.10
P7R1	total	11.72	3.32
P7R2	very fine	19.63	2.24
P7R2	fine	8.74	1.02
P7R2	total	28.37	3.26
P7R3	very fine	10.00	1.72
P7R3	fine	4.22	0.70
P7R3	total	14.22	2.42
P7R4	very fine	1.74	0.30
P7R4	fine	6.46	0.62
P7R4	medium	2.99	0.16
P7R4	total	11.19	1.08
P7R5	very fine	0.47	0.13
P7R5	fine	1.35	0.40
P7R5	total	1.82	0.53
P8R1	micro	173.72	13.80

Sample	Root Size Class	Moist Root Mass (g)	Oven Dry Root Mass (g)
P8R1	very fine	4.71	0.53
P8R1	total	178.43	14.33
P8R2	micro	157.88	19.39
P8R2	very fine	23.39	3.72
P8R2	very coarse	32.18	6.43
P8R2	total	213.45	29.54
P8R3	micro	219.53	24.51
P8R3	very fine	18.05	2.74
P8R3	total	237.58	27.25
P9R1	very fine	97.48	12.37
P9R1	fine	86.97	13.40
P9R1	medium	70.45	18.21
P9R1	coarse	39.13	7.95
P9R1	very coarse	63.59	15.06
P9R1	total	357.62	66.99
P9R2	very fine	64.77	10.30
P9R2	fine	70.79	11.64
P9R2	medium	39.92	12.17
P9R2	coarse	76.24	19.30
P9R2	very coarse	76.70	27.40
P9R2	total	328.42	80.81
P9R3	very fine	86.45	12.78
P9R3	fine	47.45	9.28
P9R3	medium	135.34	39.36
P9R3	total	269.24	61.42

Appendix 25 - Approximate Sand to Ash Content Ratios

Sample	Sand : Ash Ratio	Ash Content (g kg-1)	von Post Humification
1021	1 : 2.3	23	4
712	1 : 1.1	925	8
733	1 : 1.1	928	8
213	1 : 1.0	448	8
1131	1 : 1.5	448	8