Soil Catenas on Glacial Moraines of the Central Oregon Cascades

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THESIS APPROVAL

The abstract and thesis of Jason Erik Haugland for the Master of Science in Geography were presented April 23, 1998, and accepted by the thesis committee and the department.

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ABSTRACT

An abstract of the thesis of Jason Erik Haugland for the Master of Science in Geography presented April 23, 1998.

Title: Soil Catenas on Glacial Moraines of the Central Oregon Cascades.

Soil development of two catenas in the central Oregon Cascades near Sisters, Oregon was examined on the Suttle Lake (Late Wisconsin age) (44° 25' N, 121° 43' W) and the Jack Creek (Illinoian age) moraines (44° 28' N, 121° 41' W) with regard to the factors of time as well as slope position.

Soils on both catenas are classified as Typic Vitricryands, regardless of slope position. The uniformity of soil classification suggests a limited development, perhaps the result of localized volcanic activity (Blue Lake event, 3500 YBP) adding pyroclastic material to the soils and retarding soil development. High NaF pH readings confirm the volcanic ash additions to the soils. Field and laboratory results characterize the texture of the soils as containing low clay percentages and having loamy-sand to sand textures. The 1:1 water pH tests are slightly acidic for both catenas, ranging from 5.8 to

6.9. Soil color hues for the soils are primarily 10YR. Organic matter percentages decrease with depth and are higher on the Jack Creek catena, ranging from 2.9 to 1.2 %, compared to the Suttle Lake catena (1.6 to 0.2 %).

Soil indices such as the Profile Development Index (PDI) and Color Development Equivalent (CDE) have been used in past chronosequence studies. A paired t-test of the PDI values shows that soils are more developed on the Jack Creek catena at a 0.05 confidence level. Correlation coefficients of slope positions and PDI values suggest that soil development on the Jack Creek catena is fairly uniform. On the Suttle Lake catena, soil development increases downslope. CDE values suggest the shoulder position of the Jack Creek catena to have the maximum development while the toe slope position of the Suttle Lake catena has the most developed soil.

This study recommends the use of soils for future chronosequence studies, but in conjunction with other methodologies due to the high levels of volcanic disturbance in the area.

SOIL CATENAS ON GLACIAL MORAINES OF

THE CENTRAL OREGON CASCADES

by

JASON ERIK HAUGLAND

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CHAPTER I

INTRODUCTION

The properties and characteristics of soils contain valuable information which, when properly interpreted, allows earth scientists to reconstruct the landscape development. Therefore, soils have been the focus of many Quaternary studies. Yet, when dealing with relief, or hillslopes, it has not been until recently that the entire hillslope has been the focus in regards to soil development. Past studies have focused primarily on flat surfaces where limited erosional or depositional processes have occurred (Birkeland 1984). If soils are to be used for age-dating of surficial deposits, such as in chronosequence studies, then the knowledge of soil genesis on the entire slope is needed. This knowledge is useful in determining which slope position is the most useful in the age-dating of Quaternary deposits.

The development of soils on hillslopes results from many processes: vertical pedogenic processes such as the translocation of clays and salts into illuvial horizons, lateral geomorphic processes such as colluviation and sediment creep, and soil moisture variations with slope position (Gerrard 1981). These processes can result in different soils at different slope positions. For instance, B horizons may become thicker with more developed structures downslope than the upperslope soils (Birkeland 1984). The associated sequence of soils down a slope is called a catena (Milne 1935). This study examines two different aged catenas. Hence, it is a study involving the factor of time with the evolution of catenas, or a chronosequence catena study, in the Oregon Cascades. It is tied to glacial processes in that soil catena chronosequences are investigated on two different aged glacial moraines on the eastern side of the Cascade Range near the town of Sisters, Oregon.

There are three related purposes to this study. One is to investigate soil development in relation to slope position along the catenas. This is done by noting soil characteristics and properties in the field and laboratory as defined by the U.S. Soil Survey Staff (1975) and Birkeland et al. (1991b).

The second purpose is to ascertain which slope positions along the catenas have the most mature soil profile development. This is done by the use of two established soil indices, Buntley and Westin's (1965) Color Development Equivalent (CDE) index and Harden's (1982) Profile Development Index. The Buntley and Westin index incorporates the hues and chromas of a soil to determine degree of development. Harden's PDI is a methodology that quantitatively incorporates soil properties of chronosequences into an index, of which a product is obtained that tells a soil's degree of development from that of its initial unweathered parent material. Harden's PDI has been used in the Sierra Nevada and Rocky Mountains; yet to date Harden's approach in the Oregon Cascades is absent in the literature (Swanson 1984; Berry 1987, 1990; Birkeland 1992).

The final purpose is to investigate the validity of using the two above mentioned soil indices in the Oregon Cascades. These soil indices may determine which slope position is the most developed for its respective catena. If soil development is found to be more mature on a particular slope position then future studies involving age dating can focus on these positions in the Oregon Cascades. Also, the output from the indices can statistically ascertain if the soils of the two catenas are significantly different from one another. If the soils are found to be significantly different then the soil indices are indeed worthy tools in the dating of landforms in the Oregon Cascades. To do this a paired t-test was performed using PDI values from various slope positions of the two catenas. The null hypothesis (H_0) and alternate hypothesis (H_A) are:

H_0 = There is no difference between the age of Jack Creek and Suttle Lake age soils.

H_A = The Jack Creek soils are more developed than the Suttle Lake soils.

CHAPTER II

STUDY AREA

The study area is comprised of two sites about three kilometers apart on the lee side of the Cascade Range. The lee side receives less precipitation than the windward side of the Cascade Range due to rain shadow effects. The vegetation reflects these drier conditions in that *Pinus ponderosa* is the climax species of the area compared to *Tsuga heterophylla* on the west side. The study sites are glacial end moraines of Illinoian and Wisconsin aged glacial advances and are separated by U.S. Highway 20 within the Deschutes National Forest of Jefferson County, Oregon (Figures 1 and 2). The site on the Wisconsin aged moraine is southeast of Highway 20 located at T13S, R8E, S25 and impounds Suttle Lake. The site on the older Illinoian aged moraine is breached by Jack Creek and is located northwest of Highway 20 at T12S, R9E, S6. The younger Suttle Lake moraine south of the highway contrasts with that of the Jack Creek moraine in that it has steeper slopes and a greater continuity. The older Jack Creek moraine has been dissected through time resulting in hummocky and gentler slopes. Both sites were mapped originally and ages determined by Scott (1977).

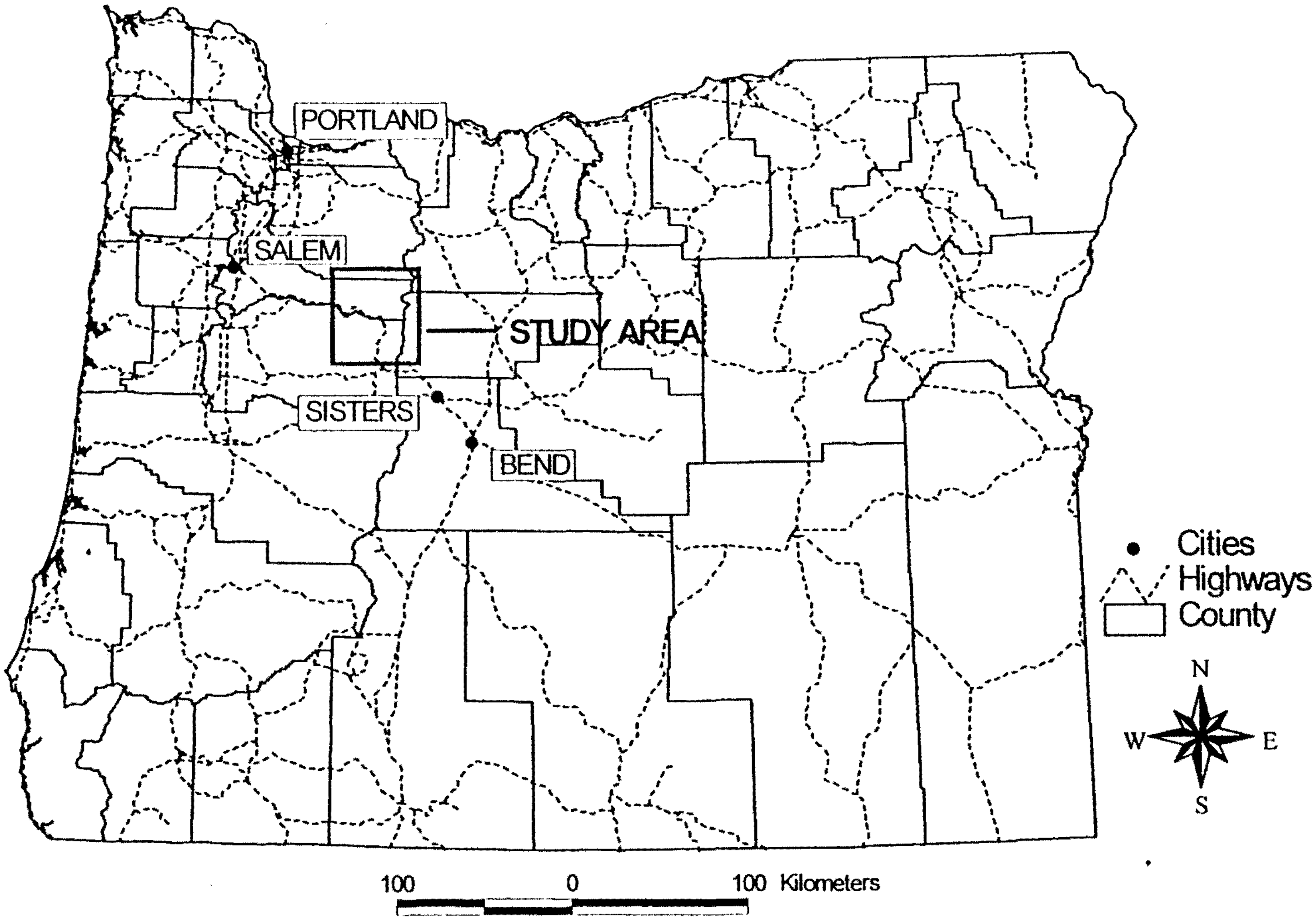


Figure 1. Study area within the State of Oregon.

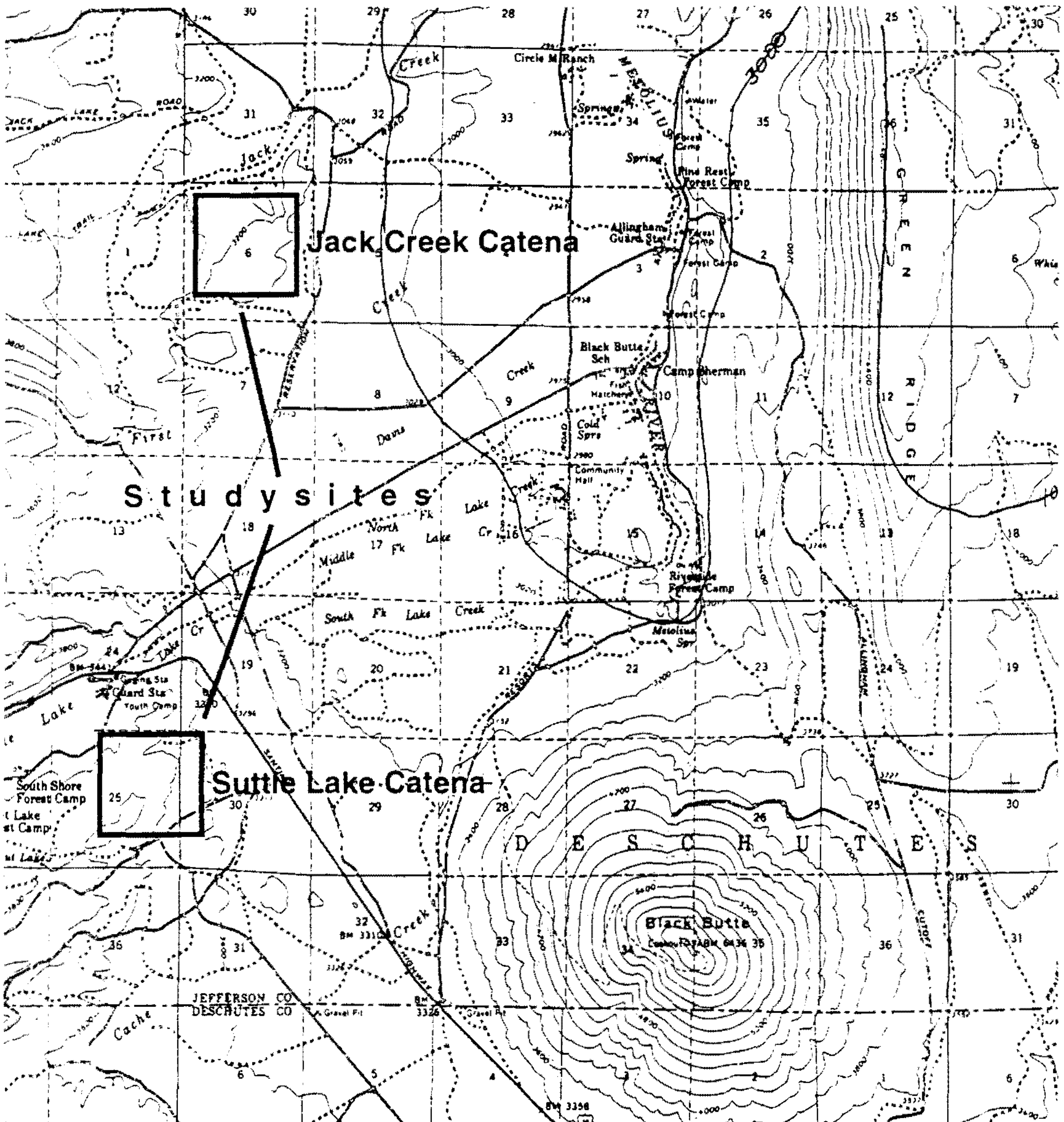


Figure 2. Study area in relation to U.S. Highway 26, Black Butte, and the Metolius River. The figure has been adapted from USGS Sisters Quadrangle (1959) 15 minute series (Topographic). 1:92,160.

Geology of the central Oregon Cascades

The Cascade Range is a linear north/south trendi ng mountain range 1100 km in length (Gannon 1981). It extends from California near the 40th parallel to well beyond the 49th parallel in British Columbia (Porter et al. 1983). Since the end of the Pleistocene, the Cascades have produced at least one major volcanic outburst per century (Harris 1980). Metamorphic, sedimentary, and granitic terranes are also found in the Cascade uplands, most widely in Washington state (Porter et al.1983).

The Oregon Cascade Range is divided into two physiographic divisions commonly known as the Western Cascades and the High Cascades (Price 1978). The Western Cascades are older and range in heights of 518 m on the western margin to 1768 m on the eastern margin. This is only half the elevation of the tallest peaks of the High Cascades which reach elevations of over 3353 m (Orr et al. 1992).

The geologic history of the Cascade Range began approximately 40 million years ago during the mid to late Tertiary (Gannon 1981). Movement of crustal plates triggered intense volcanic activity by a chain of volcanoes east of the Eocene shoreline, which was the current Willamette Valley (Orr et al. 1992). The volcanism was the result of subduction of the Farallon plate beneath the North American plate (Figure 3). Thick accumulations of lava and ash built up the Western Cascade volcanoes. During the Miocene and

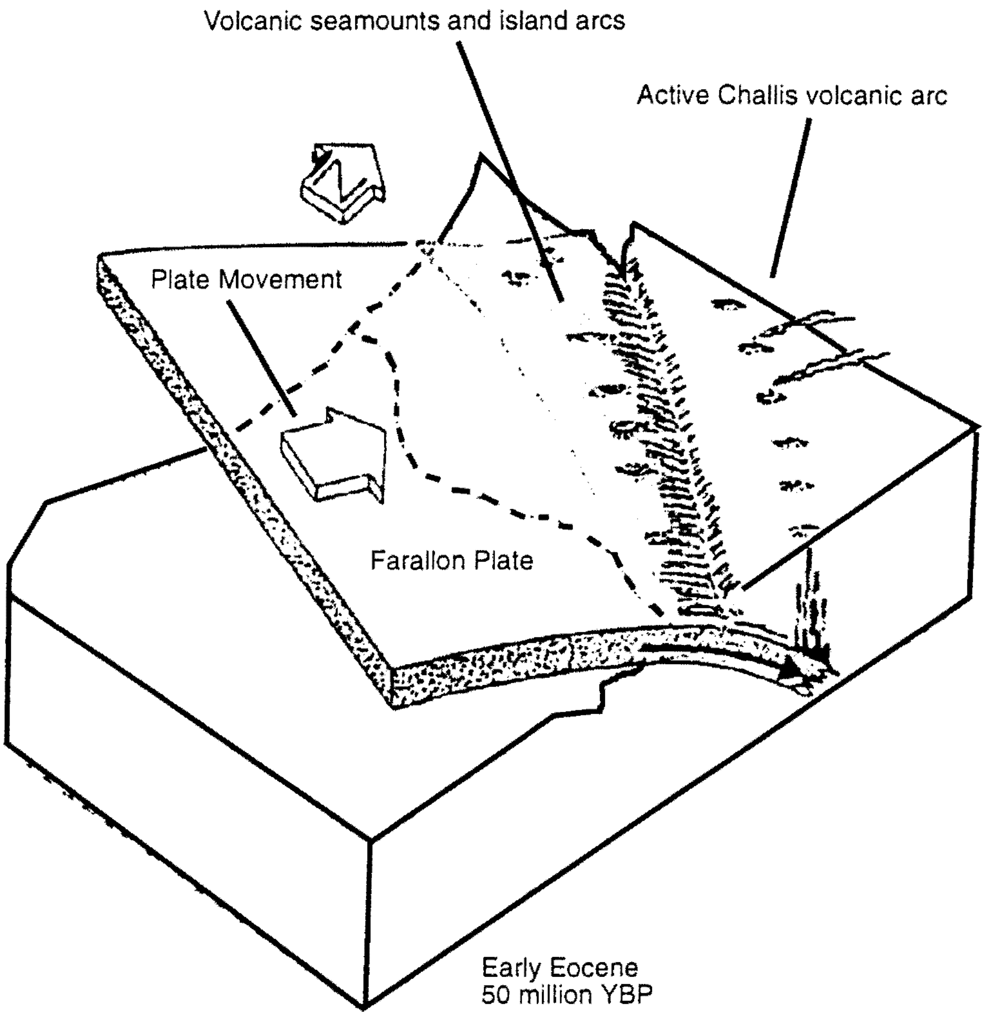


Figure 3. Subduction of the Farallon Plate beneath the North American Plate. Adapted from Orr et al. (1992).

Pliocene, volcanic activity shifted east where folding and tilting were followed by large outpourings of lava. Approximately five million years ago the Western Cascades were once again tilted, resulting in a gentle slope on the western side and a steep escarpment on the east (Orr et al. 1992). The High Cascades consist of several thousand distinct stratovolcanoes overlying portions of the Western Cascades of Oregon (Gannon 1981).

The development of the High Cascades originates with the westward tilting of the Western Cascades and the sinking of the Cascade graben, which initiated a period of volcanism. Yet, the High Cascades were formed primarily through episodic volcanic activity throughout the Quaternary (Scott 1977). Overlappings of shield volcanoes and cinder cones built up the platform of the High Cascades. During the early phase of development, basalts, tuffs, and ash flows formed at the base of the range. In the last four million years, lavas and tuffs dominated by basalts have been ejected from a number of small cones formed on the sides of larger, already existing shield volcanoes. Basalt represents up to 85 percent of the High Cascades by volume (Orr et al. 1992).

The study area is situated within the High Cascades. Three Quaternary stratovolcanoes lie near the site, Mount Jefferson, Mount Washington, and Three Fingered Jack (Scott 1977). Mount Jefferson is the second highest peak in Oregon with an elevation of 3199 m and is located approximately 30 km northwest of the study site. The surrounding rugged terrain ranges from 1676 to 1981 m in elevation. Mount Jefferson originated with a highly explosive vent erecting a cone of tephra and pyroclastic material. The cone once reached 3658 m but glacial erosion has reduced its size making it one of the most deeply eroded high stratovolcanoes in Oregon. Mount Jefferson may be extinct, since it appears not to have erupted since before the last two glaciations (Harris 1988).

Three-Fingered Jack (2390 m) is located 11 km northwest of the study area. It has been extinct for 100,000 to 200,000 years. The summit consists of a saw-toothed ridge composed of loose tephra underlain by a vertical dike three meters thick. As on Mount Jefferson, glaciers have cut deeply into the mountain. Cone building eruptions are thought to have ceased 200,000 years ago. Thus the cone is deeply dissected by the last two glaciations (Harris 1988).

Mt. Washington (2362 m) is 14 km to the southwest of the study site. There is an absence of literature in regards to Mt. Washington and its eruptive history. Yet it is thought to have been inactive for approximately 100,000 to 200,000 years (Harris 1988).

Black Butte, six kilometers to the southeast of the study area, is a large cinder cone that was most likely active before the last ice age (Figure 4) (Alt and Hyndman 1981). It lacks a fresh appearance since it is now covered by a ponderosa pine forest suggesting time for pedogenetic processes to occur

Figure 4. Suttle Lake impounded by a Wisconsin aged moraine. Note Black Butte in the background. Adapted from Orr et al.(1992).

and produce a medium for plant growth. Black Butte lies at the head of the Metolius River and is thought to have formed approximately 500,000 years ago by erupting from vents along a fault escarpment (Orr et al. 1992). The Black Butte cone was superimposed over the Metolius River and the associated river drainages.

Approximately two kilometers northwest of Suttle Lake lies a water-filled crater called Blue Lake, a deep crater that was blasted out of solid rock by violent steam explosions approximately 3500 years ago. Very little molten magma was erupted, yet dark cinders are found up to five kilometers away and are visible in the top layers of soils (Alt and Hyndman 1981). A stream trickles northeastwards from the lake eventually emptying into Suttle Lake. Suttle Lake, on the other hand, is glacial in origin and it is dammed by lateral and terminal moraines (Figure 4).

Quaternary glaciation

The High Cascades were repeatedly subjected to valley and ice cap glaciations during the Quaternary. The many cirques, glacially carved valleys, deeply eroded composite cones, and well developed end moraines bear evidence to this (Scott 1977). An icecap extended from 30 km north of Mount Jefferson to Mount McLoughlin 300 km to the south (Figure 5) (Harris 1980). Farther north on Mount Hood, glacial ice stretched down the Sandy River reaching Brightwood, Oregon (Scott 1996; Scott et al. 1997). The

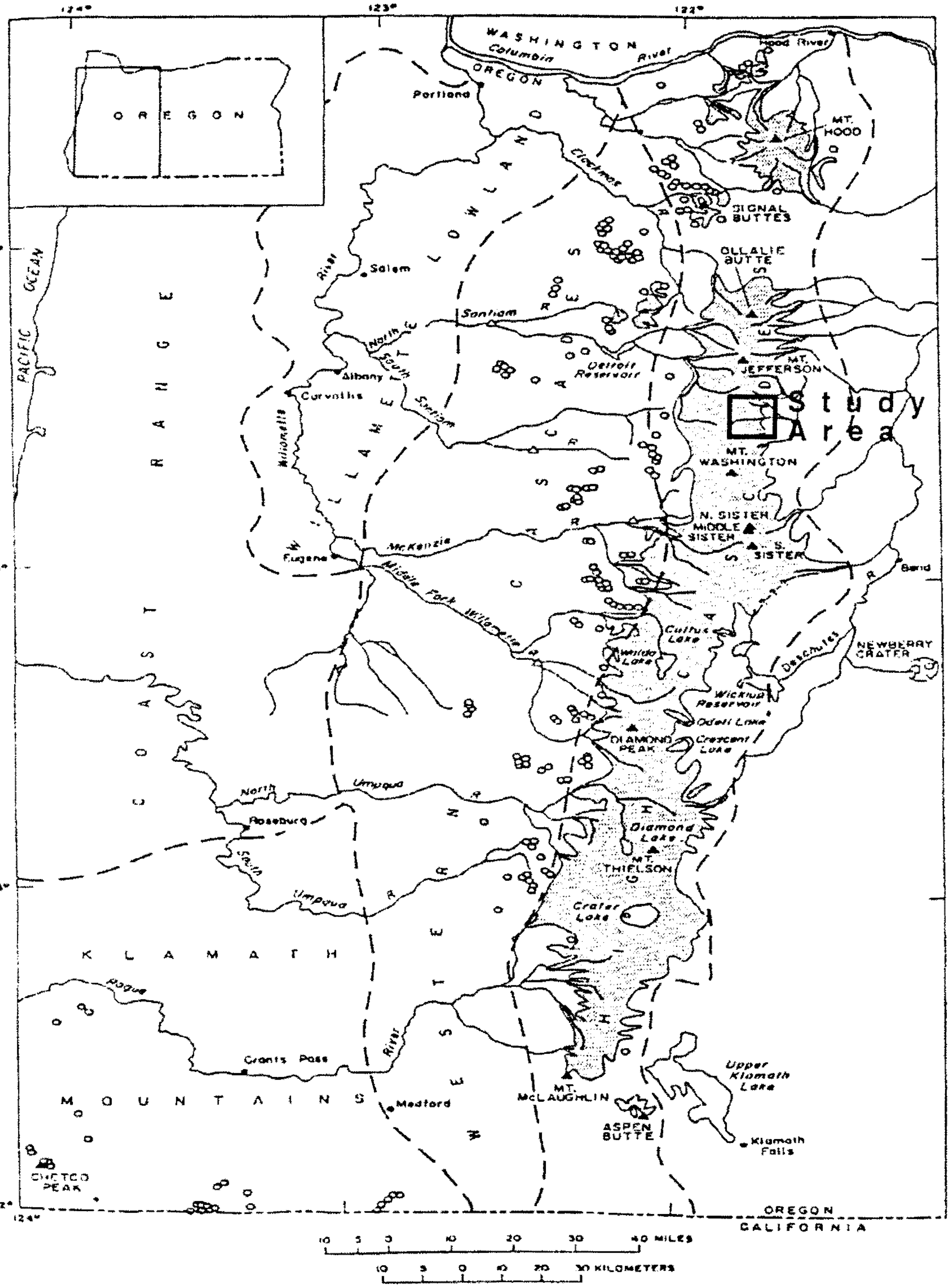


Figure 5. Extent of a late Pleistocene ice cap over the Oregon Cascades. Adapted from Crandell (1965).

Western Cascades also had ice masses, but they were smaller (Orr et al. 1992).

Scott (1977) has identified evidence for two glaciations in the central Oregon Cascades: (1) the Jack Creek glaciation, which is estimated to be late Illinoian or early Wisconsin age, and (2) the Cabbot Creek glaciation with emphasis upon the Suttle Lake subdivision of the Wisconsin age. The Jack Creek drift is the oldest glacial event from which moraines are preserved. Moraines of this age typically have subdued topography, few surface boulders, and a hummocky-dissected appearance. Dates range from either 40,000 to 80,000 years before present (Y.B.P.) to 120,000 to 200,000 Y.B.P. and correlate with the Hayden Creek drift of Mount Rainier, the Bull Lake drift of the Rocky Mountains and the Pre-Tahoe drift of the Sierra Nevada (Table I) (Crandell 1969; Crandell and Miller 1974; Scott 1977).

TABLE I

CORRELATED REGIONAL GLACIATIONS

AGE	Sierra Nevada	Rocky Mountains	Washington Cascades	Oregon Cascades
WISCONSIN	Tioga/Tahoe	Pinedale	Evans Creek	Suttle Lake
ILLINOIAN	Pre-Tahoe	Bull Lake	Hayden Creek	Jack Creek

Adapted from Scott (1977), Berry (1990), and Swanson (1985).

The Suttle Lake subdivision of the Cabot Creek glaciation is named after Suttle Lake, Oregon. The terminal moraines are characterized by sharp bouldery crests and surface boulders (Scott 1977). The Suttle Lake Drift correlates with Evans Creek drift of Mount Rainier, the Pinedale drift of the

Rocky Mountains, and the Tahoe/Tioga drift of the Sierra Nevada with ages approximated in the range 25,000 to 15,000 years (Crandell 1969; Crandell and Miller 1974; Scott 1977; Mahaney et al. 1981).

Climate

The major weather and climatic controls in Oregon are 1) latitude, 2) differing influences between land and water, 3) mountain barriers, and 4) elevation (Dart and Johnson 1981).

Latitude influences the distrib ution of insolation and the seasonal migration of pressure cells. Oregon's mid-latitudinal position results in noticeable variation in insolation and temperature characteristics between winter and summer. The climate of Oregon is also affected by the seasonal migration of the North Pacific subtropical high and the jet stream and its associated cyclonic storms. This results from the seasonal shifting of the Pacific subtropical high (Figure 6). During summers the anticyclonic subtropical high shifts northward displacing the jet stream poleward, resulting in the summer precipitation minimum. The reverse is true for the winter maximum. Here the subtropical high retreats to lower latitude allowing the jet stream and associated cyclonic storm belts to re-establish themselves over the Pacific Northwest (Trewartha 1961).

GENERALIZED PRESSURE AND WINDS

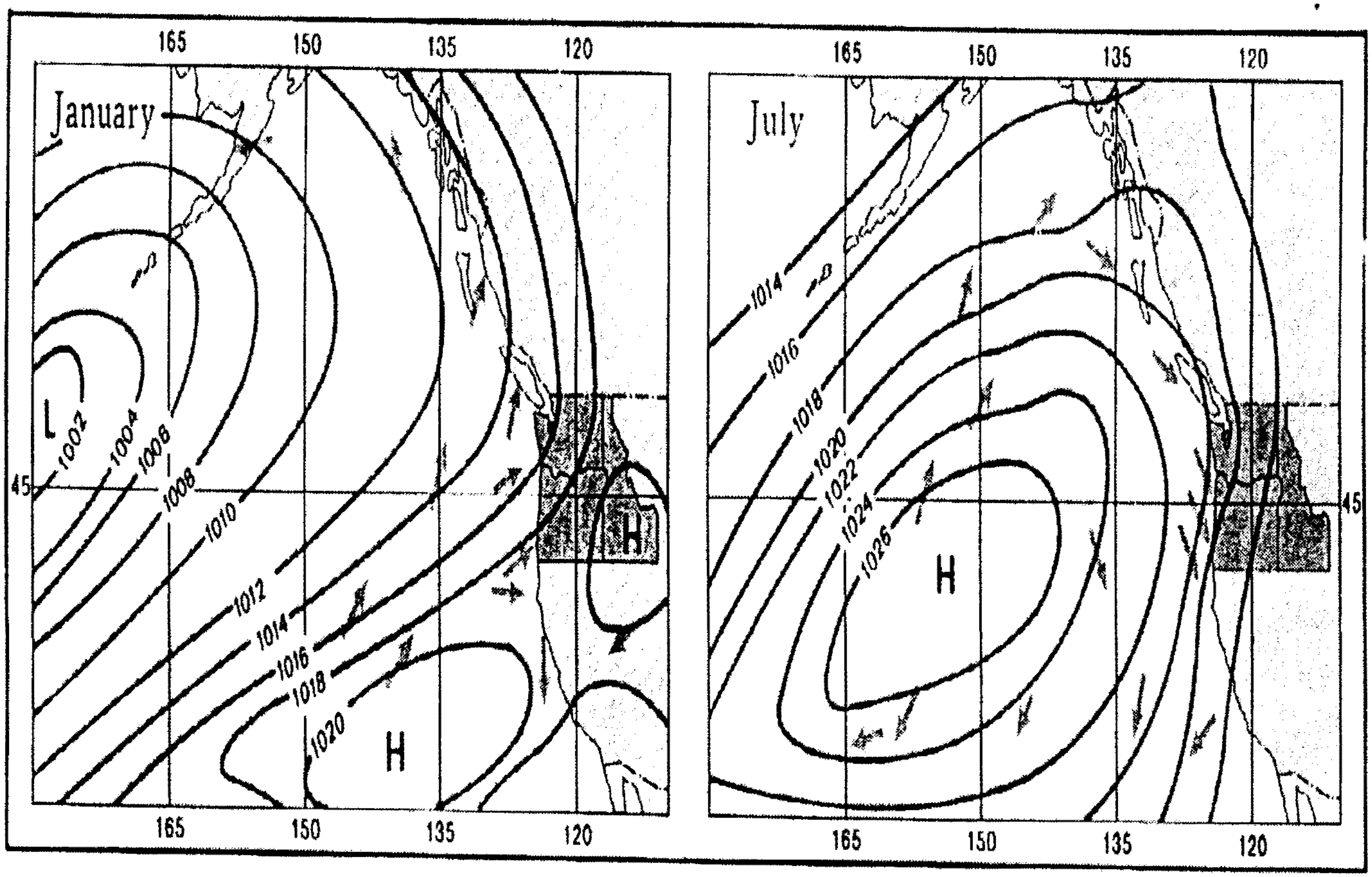


Figure 6. Seasonal shifting of the Pacific Subtropical High pressure cell. Adapted from Jackson (1993).

The western side of the Cascades has a marine environment with heavy precipitation, moderate temperatures, and a high percent of cloud cover. However, the east side of the range has a climate that is more continental (Price 1978). Orographic precipitation is produced when the maritime moisture ascends the windward portion of the range causing air masses to cool and condense. Rain shadows occur on the lee sides where the air descends and warms causing evaporation and reduced precipitation. This is illustrated by the west side receiving up to 254 cm/year while portions east of the divide receive approximately 38 cm/year (Dart and Johnson 1981).

The summit of the Jack Creek and Suttle Lake moraines have elevations of 1016 m and 1190 m respectively; hence elevation plays a role in the climate of the area. This is illustrated in that both sites have cryic soil temperature regimes. A cryic soil temperature regime is,

> "A soil temperature regime that has mean annual soil temperatures of > 0° C but < 8° C, > 5° difference between mean summer and mean winter soil temperatures at 50 cm, and cold summer temperatures." (Soil Science Society of America 1987).

Climatie data for the two sites were obtained from the Western Regional Climate Center (1997) using data from the Sisters Ranger Station District 23 km to the east of the sites (Table II). Average annual precipitation for the Sisters Ranger District is 36 cm with a majority occurring between

TABLE II

MONTHLY MEANS OF SISTERS RANGER STATION DISTRICT, OREGON. LATITUDE: 44° 18', LONGITUDE: 121° 33', ELEVATION: 969.9M, PERIOD: 1961-1990. (WESTERN REGIONAL CLIMATE CENTER 1997)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Temperature (C)													
Maximum	5.2	7.9	10.7	13.8	18.7	23.9	28.7	28.3	23.7	17.4	8.7	5.0	16.2
Minimum	-6.2	-4.6	-3.6	-2.4	0.4	3.8	5.2	5.1	1.4	-1.7	-3.6	-6.5	-0.9
Mean	-0.5	1.7	3.6	5.7	9.5	13.9	16.9	16.7	12.5	7.8	2.6	-0.7	7.7
Precipitation (cm)													
Monthly Mean	6.5	4.2	3.1	1.9	1.4	1.4	1.0	1.1	1.2	2.1	5.6	6.2	36.0
Snowfall (cm)													
Monthly Mean	22.5	13.9	11.4	0.8	0.1	0.0	0.0	0.0	0.0	0.4	12.0	18.5	100.1

the months of November to February. The mean annual temperature is 7.7° C. Both sites are slightly higher than the Sisters Ranger Station. The Jack Creek and Suttle Lake moraines are 46 m and 220 m higher in elevation than the Sisters Ranger Station and are located west of Sisters; hence precipitation values should be higher for the study area. The temperature values for the two sites were extrapolated from the station readings using the adiabatic lapse rate of 6.5° C per 1000m (Table III).

The climate was obviously much cooler during the time of the initial moraine deposition than now. Equilibrium line altitudes (ELAs), which are the divisions between the accumulation zone of a glacier and its ablation zone (Small and Witherick 1989), were approximately 950 m lower during the Suttle Lake advance, implying much cooler times (Scott 1977).

Vegetation

Vegetation zones found on the eastern side of the Cascade Range are compressed into seven climax forest types within a vertical distance of 1300 m and a horizontal distance of 25 km. Ranging from highest to lowest elevation these zones are the *Abies lasiocarpa, Abies amabilis, Tsuga heterophylla, Abies grandis, Pseudotsuga menziessi, Pinus ponderosa*. and the *Juniperus occidentalis* zones. This contrasts with the western slope of the Cascade Range in which only three climax vegetation types occur

TABLE III

EXTRAPOLATED MONTHLY TEMPERATURE MEANS (FROM TABLE II) FOR THE JACK CREEK AND THE SUTTLE LAKE SITES USING AN ADIABATIC LAPSE RATE OF 6.5°/1000M.

Jack Creek Moraine	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Temperature (C)													
Maximum	4.9	7.6	10.4	13.5	18.7	23.6	28.4	28.0	23.4	17.1	8.4	4.7	15.9
Minimum	-6.5	-4.9	-3.9	-2.7	0.1	3.5	4.9	4.8	1.1	-2.0	-3.9	-6.8	-1.2
Mean	-0.8	1.4	3.3	5.4	9.2	13.6	16.6	16.4	12.2	7.5	2.3	-1.0	7.4

Suttle Lake Moraine	.Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Temperature (C)													
Maximum	3.8	6.5	9.3	12.4	17.2	22.5	27.2	26.9	22.3	16.0	7.3	3.6	14.8
Minimum	-7.7	-6.0	-5.0	-3.8	-1.0	2.4	3.7	3.7	-0.0	-3.2	-5.0	-7.9	-2.3
Mean	-1.9	0.2	2.1	4.3	8.1	12.5	15.5	15.2	11.1	6.4	1.2	-2.2	6.2

within a vertical distance of 2000 m and a horizontal distance of 60 km. Ranging from highest to lowest elevation, these zones are the *Tsuga mertensiana, Abies amabilis,* and *Tsuga heterophylla* (Price 1978).

Vegetation associated with the two study sites lies within the xerophytic zonal group with *Pinus ponderosa* being the climax species (Franklin and Dyrness 1988). Tree species consist of Ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), White fir (*Abies concolor*), Western larch (*Larix occidentalis),* and Western white pine (*Pinus monticola*). Herbaceous plants include grasses and shrubs such as Bracken fern (*Pteridium aquilinum),* Common snowberry (*Symphoricarpos albus*), golden snowbrush (*Castanopsis chrysophylla*), Oregon grape (*Berberis aquifolium*), currants, blackberry sedges, and forbs (Larsen 1976). The vegetation of the study sites reflects the climate and geology of the area (Figure 7). The dry summers compounded with the porous, well-drained and unstable volcanic soils pose limitations to many species (Price 1978). Ponderosa pine is capable of existing in drier conditions where the soils are sandy and coarse textured as opposed to growing on fine textured clayey soils. The sandy, coarse-textured soils allow for broader extension of roots and ultimately improve access to moisture from periodic melting of snow (Dart and Johnson 1981).

Figure 7. Typical vegetation of the study sites. Ponderosa pine and Bracken fern are abundant.

Soils

The High Cascades are dominated by immature soils developed in volcanic pyroclastic ejecta or glacially deposited materials. Soils which have developed from glacially developed material often show increased profile development compared to soils developed from ejecta. These soils are typically composed of a thin dark-colored A horizon with sandy loam or loamy sand textures and are underlain by a transitional AC horizon which grades into an unaltered coarse sand to gravely sand parent material. Soils developed on glacial tills are more common in the northern High Cascades. They are characteristically deeper and well drained with gravelly sandy loam surfaces and are underlain by gravelly loam surfaces (Franklin and Dyrness 1988).

Soils for the two study sites are near the break between glacial till and glacial outwash, as would be expected for end moraines. Parent materials consist of volcanic ash and scoria over glacial till. They have been classified as the Haynap series for the Suttle Lake moraine and the Belrick series for the Jack Creek moraine (Myhrum and Ferry, In Press). The Haynap series are classified by the USDA Soil Taxonomy system (Soil Survey Staff 1997) as ashy-skeletal Typic Vitricryands which are typical Andisols, soils heavily influenced by volcanic processes, and they contain a high occurrence of volcanic glass in a cryic temperature regime. The Haynap soils are excessively well drained, being derived from a moderately thick layer of dark colored cinders and ash over glacial till. The surface soils are cindery sands while the subsoils are loamy sands and cobbly to stony loams. The permeability is very rapid for the surface soils and the percolation of water inevitably slows once the glacial till is reached. The Belrick soils are classified as ashy Typic Vitricryands, the same as the Haynap series with the exception of particle size in that the Haynap series has coarser particles (Myhrum and Ferry, In Press).

CHAPTER III

SOIL GEOMORPHOLOGY

The study of soil genesis and classification has been referred to as a system of bridges connecting the disciplinary islands of chemistry, biology, physics, geology, geography, climatology, agricultural sciences, economics, anthropology, and archeology (Buol et al. 1989). R.B. Daniels and R.D. Hammer in Soil Geomorphology (1992) state that geomorphology and soil science should be a joined science.

The marriage of pedology and geomorphology provides a framework for the study both of soil genesis and the evolution and stability of landscape elements. The more that soils are understood, in terms of rates of soil forming processes and variations related to position on a landform, the more insight can be gained about landform processes (McFadden and Knuepfer 1990). Hence soils, along with evidence provided by other processes, can be thought of as a potential source of information about past processes on landform surfaces, (Catt 1986).

SOIL FORMATION

V.V. Dokuchaev, a 19th century Russian earth scientist, was one of the first to study soil on a scientific basis. He believed that the study of genetic pedology was one of the most valuable keys to understanding all the aspects of physical geography (Beckinsale and Chorley 1991). Dokuchaev published a field study concerning Chernozem soils of the Ukraine in 1883 that laid the foundation for soil geography and soil sciences (Buol et al. 1989). He identified five main factors that lead to soil formation. Hans Jenny (1941) incorporated these five factors into the often cited factors of soil formation equation:

$$\mathbf{S=f(cl,o,r,p,t....)}$$

where **S** denotes soil as a function of climate (**cl**), organisms (**o**), topographical relief (**r**), parent material (**p**), and time (**t**). Jenny left the equation open so that other factors could be added as identified through time.

Jenny (1961 and 1980) later allowed the equation to be solved one factor at a time. The new equations allow one factor to vary while the others are held constant, since it would not be possible to ascertain the effect of each factor on soil development if all factors were allowed to vary (Birkeland 1984). The following functions were established:

S=f(**cl**,o,r,p,t,...) climofunction/climosequence (1)

S=f(**o**,cl,r,p,t,...) biofunction/biosequence (2)

$S=f(\mathbf{r},cl,o,p,t,...)$ topofunction/toposequence (3)

$S=f(\mathbf{p},cl,o,p,t,...)$ lithofunction/lithosequence (4)

$S=f(\mathbf{t},cl,o,p,r,...)$ chronofunction/chronosequence (5)

$S=f(\mathbf{...},cl,o,r,p,t)$ dotfunction/dotsequence (6)

The dominant factor is denoted in the above equation by the first letter within the parenthesis. The other factors are of lesser importance and less variable within the formation of soils. The last equation (6) reflects unspecified variable factors that are not listed (Jenny 1961).

Jenny (1980) proposed a modification to the functions in which the importance of an individual factor is phonetically illustrated by placing the soil forming factor of study singly within the parenthesis. The equation for a chronofunction using this approach would be:

$l,v,a,s=f(\mathbf{t}),cl,o,r,p,...$ (7)

This equation (7) states that the total system (l), vegetation (v), animals (a), and soils (s), are dependent upon the main function of time. The other functions are still important, yet to a lesser degree.

Three of the above equations are thought to pertain to this study: the topofunction equation (3), the lithofunction equation (4), and the chronofunction equation (5). The topofunction equation is relevant since this study looks at soil development along a slope; hence the role of topography with soil development. The other variables in the factors of soil formation for the study sites are thought to be the differing parent materials and the time involved. Both study sites are glacial moraines containing till, yet the Suttle Lake moraine has a mantle of scoria covering the original glacial till, meaning that a new sequence of lithology has occurred, a lithosequence. However, the chronology of the two moraines bears the brunt of the study. This is because the moraines are of different ages, and the quantitative soil indices used in this study focus primarily on soil development with age. Like Swanson (1984, 1985), who used a similar approach in the Wind River Range of Wyoming, it is realized that the assumption of similar climates for both catenas through time may be wrong. Evidence is lacking to modify the account for climatic change; hence this study has assumed climatic uniformity for both catenas.

THEORETICAL CONCEPTS

Catena

Soil geomorphology studies are concerned with the spatial analysis of a particular attribute, such as soil development. Synthetic models based on spatial relationships such as hillslope position and degree of soil development are then needed (Allen 1996). A catena provides a model of soil distribution on a slope.

The intersection of geomorphology and pedology was conceptually enhanced by the formalization of the catena concept by Milne (1935), who realized that particular slope forms are associated with particular soil sequences (Gerrard 1992). He stated that an association of slope variation and soil profile development should be defined as a catena, which is also known as a toposequence (McFadden and Kneupfer 1990). A catena was initially defined by Milne as a unit of mapping convenience of soils and their linked position to topography (Figure 8). Catenas are now thought of as an interaction of soils and landforms, and therefore soil processes and geomorphic processes are combined together forming an alliance of the two fields (Gerrard 1992). Soils forming on hillslopes contain information about the history of slope stability over millenia (McFadden and Kneupfer 1990).

Glacial moraines provide ideal environments for studying soil development. The approximate ages of deposition of many moraines are known which allows estimation of the time for pedogenesis. Also, glaciers have repeatedly advanced down the same valleys creating moraines of similar composition but of different ages that lie in close proximity (Gerrard 1992).

Chronosequence

Soil chronosequence studies have contributed greatly to the understanding of landform evolution (McFadden and Knuepfer 1990). The 1987 *Glossary of Soil Science Terms* (Soil Science Society of America 1987) defines a chronosequence as,

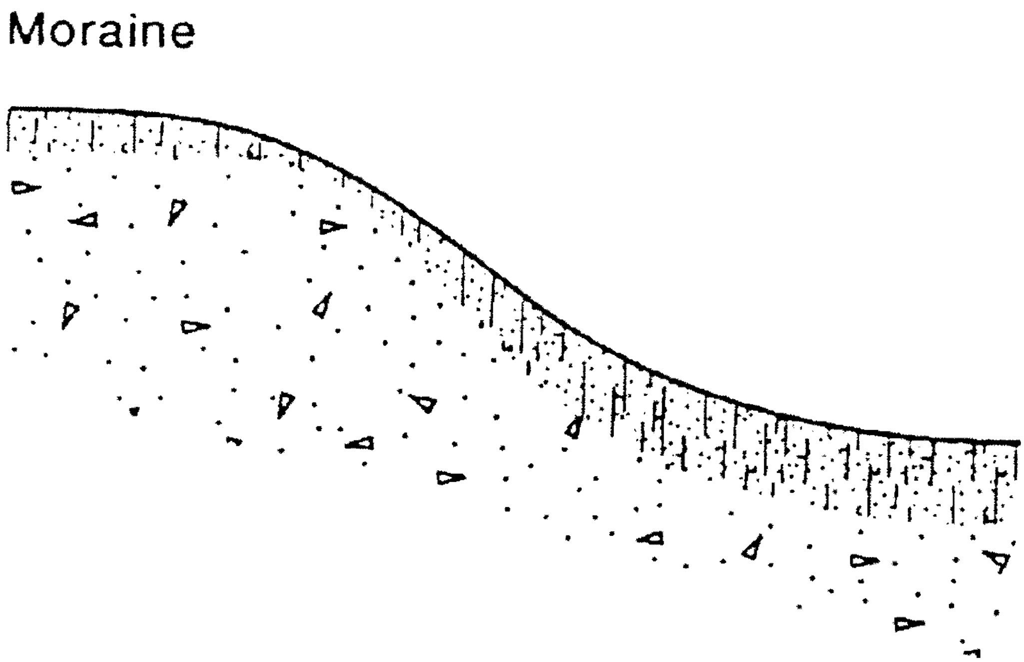


Figure 8. The cartoon above is a representation of a glacial moraine catena. Lines and stippled pattern show degree of soil development in relation to slope position. Adapted from Birkeland et al. (1991b).

> "A sequence of related soils that differ, one from the other in certain properties primarily as a result of time or a soil forming factor."

The rationale for using a chronosequence to study landform process is that the time factor or the temporal construct is the most important variable while other soil forming factors are considered constant (Gerrard 1992). Soil chronosequence studies then are especially useful when attempting to date events in a particular landscape.

Vreeken (1975) described four different principal kinds of chronosequences of soils that differ in age: (1) post-incisive, (2) pre-incisive, (3) fully time-transgressive with historical overlap, and (4) fully time-transgressive without historical overlap. A post-incisive chronosequence is an array of soils that have been forming at different points in the past and that are currently still exposed or were simultaneously buried. A pre-incisive chronosequence is an array of soils that formed simultaneously but were buried during more recent events except for one of the soils still being at the ground surfaces. Fully time-transgressive chronosequences are arrays of soils that began development and were buried at different times. Soils from such sequences may have coexisted at the ground surface, hence subdivisions of with or without historical overlap must be incorporated (Vreeken 1975). Post-incisive sequences are most commonly studied for landscape formation (Birkeland 1990).

Various catena chronosequences have been done in the Wind River Range, the Salmon River Mountains of Idaho and the Sierra Nevada on glacial deposits (Richmond 1976; Mahaney 1978; Swanson 1985; Berry 1987,1990). This study investigates post-incisive chronosequences, where the soils have formed at different points in the past and are still currently forming along a catena.

PREVIOUS WORK

There have been many notable chronosequence studies done throughout North America, yet few of these use a soil catena chronosequence approach. Many studies focus on development of weathering rinds of cobbles, lichenometry, or they use the development of soils. Most do not focus, however, on soil development of the entire slope in contrast to a catena chronosequence approach. The Rocky Mountains and Sierra Nevada have received the most attention concerning soil chronosequence studies as compared to the Cascade Range. There have been some soil chronosequence studies in the state of Washington and Oregon such as Mahaney's (1981) study of Mount Adams and Kiver's (1974) study of Holocene glaciation in the Wallowa Range of Oregon; yet little work has occurred within the Oregon Cascades (Scott 1996).

Rocky Mountain chronosequences

Notable soil chronosequences have been done by Berry (1987) in the Salmon River Mountains of Idaho and in the Wind River Range (Richmond 1976; Mahaney 1978; Swanson 1985). The relative age difference between Pinedale (~20,000 Y.B.P) and Bull Lake (~140,000 Y.B.P.) deposits is reflected in the development and genesis of soils upon the associated tills. Both Pinedale and Bull Lake soils are zonal yet the Pinedale soils tend to be thin with no loess mantle, whereas Bull Lake soils are thicker and more mature (Richmond 1976). Swanson (1985), studying catenas on Bull Lake and Pinedale deposits in the Willow Lake region of the Wind River Range, Wyoming, found Pinedale soils to be weakly developed due to the youth of the deposits and unstable slope (24°). Pinedale aged soils tended to be coarse grained, non-calcareous Typic Cryoborolls with A/Bw/C profiles which tended to thicken considerably downslope. Typic Cryoborolls are typical Mollisols that have a cryic temperature regime and, as designated by the Bw, have weakly developed B horizons. Color hues for the B horizons are generally 10YR. Bull Lake soils were found to be more strongly developed than soils at similar positions on the Pinedale moraines because the deposits were older and had gentler slopes (16°). Bull Lake soils were found to be mostly Argic Cryoborolls with A/Bt/C profiles. They are identical to the Pindale soils except that the B horizon is much more developed and contains argillic clays as designated by a Bt horizon. The Bull Lake soils often contain stage II carbonate development which is characterized by continual clast coatings of carbonate (Birkeland 1984) and have textural B horizons with Munsell colors ranging from 7.5YR to 5YR. Argillic horizons are absent or minimal in the upper slopes but are thick at the bottom of slopes, suggesting gradual deposition that allowed for the upward growth of argillic horizons. The pedogenic clay mineral mica-smectite is more common in Bull Lake soils than Pinedale soils, a result of weathering products of mica or the eolian deposition and deep translocation of clay (Swanson 1985).

Swanson (1984, 1985) and Berry (1987) incorporated a catena approach to their chronosequence studies, investigating soils of various slope positions. Using the Profile Development Index (PDI) they found that downslope positions along the glacial moraines contained more mature soil profiles. Berry's study (1987) found the foot slope position to have the most developed soil profiles while Swanson (1984, 1985) stated soils on the back slope are the most developed. This study also looks for particular slope positions with the most mature soil development.

Sierra Nevada chronosequences

Like the Pinedale and Bull Lake aged deposits, soils developed upon Pre-Tahoe and Tioga/Tahoe deposits reflect relative ages based on degree of development. As in the Rocky Mountains, soils of older deposits have greater development structures, with harder consistencies, more grussified stones and A/Bt/Cox profiles (Berry 1990) with Cox horizons being weathered C horizons (Birkeland 1990). The grussified stones are a result of chemical weathering in which the granite as a whole breaks up into a mass of tiny plate-like fragments known as grus (Small and Witherick 1989). Birkeland (1992) found that soils on tills of 20,000 year old deposits have A/Cox and A/Bw/Cox profiles, with some having argillic Bt horizons in the Sierra Nevada. These younger soils have Munsell colors no redder than 10YR to 7.5YR with clay contents between 3 to 10 percent. The older soils of approximately 140,000 years old are best expressed with colors of red (7.5YR to 5YR hues) and Bt clay percentages ranging from 9 to 20 percent.

Birkeland and Burke's (1988) catena chronosequence studies of alpine moraines in the Sierra Nevada suggest that like Berry's (1987) and Swanson's (1984, 1985) studies in the Rocky Mountains, that downslope positions along the glacial moraine contain the most mature soil profile of the catena.

Cascade chronosequences

Several chronsequence studies have been done in the Cascade Range, yet few have focused on soil catena chronsequence studies. For example, Carver (1987) focused on surface stone weathering, surface stone frequency, and surface stone angularity of various glacial drifts in the

Mountain Lakes Wilderness area of the southern Oregon Cascades, with just brief mention of soils in terms of depth. Farther north in the state of Washington, chonosequence studies of Mount Rainier (Colman and Pierce 1983), Mount Adams (Mahaney et al. 1983), and the Northern Cascades (Wait et al. 1982) tended to focus on degree of weathering rinds and surface area covered by lichens on glacial drift to determine ages.

Scott (1977) distinguished two prominent soil glacial events for a chronosequence study along the eastern flank of the High Cascades in the vicinity of study areas. Soil profiles were examined on the moraine crests of the Jack Creek Drift and Suttle Lake Drift. Jack Creek Drift was found to be oxidized to depths of 1.5 to 2 m. Fresh till of Jack Creek age contains subrounded to subangular cobbles and boulders, is compact, and very dark-grayish brown with moist colors of 2.5Y 3/2. Soils range from weakly developed Umbrepts to moderately developed Orthods with A/Bw/Cox profiles. Moist Munsell colors of a reddish brown 7.5YR 4/4 were found in B horizons 40 to 70 cm thick. The Jack Creek B horizons are more distinguished than Suttle Lake aged drift. Some textural development was also found in the B horizons in terms of stickiness (Scott 1977).

Suttle Lake soils were found to be thin and weakly developed, less than a meter thick with A/Bw/Cox profiles. The top A horizons are 0 to 20 cm thick and overlie poorly developed B horizon 25 to 40 cm thick with moist color values of 10YR 4/3. The B/Cox boundary is characteristic of a slight change in color. The Cox horizon ranges from 30 to 60 cm in thickness and is composed of a moist yellowish-brown (10YR 4/2) parent material of a slightly weathered nature. Below the Cox horizon is unweathered till or outwash of moist very dark grayish-brown 2.5Y 3/2 Munsell colors. In general, the soils are very granular and stony (Scott 1977).

Scott (1977) did not utilize a catena chronosequence approach. Of the two different aged glacial moraines he focused primarily on the summit slope position, which since that time has been suggested to be perhaps a poor representation of a surficial deposit's maximum degree of soil development (Birkeland et al. 1991a; Swanson 1984, 1985). Also, Harden's Profile Development Index had not been developed at that time. This thesis study incorporates a catena chronosequence approach utilizing soil indices which contribute to Scott's previous work.

<u>Characteristics of soil chonosequence studies</u>

As mentioned before, much of the previous work has focused on chronosequence studies where only one slope location was studied, such as at the summit of a moraine. Few have taken a catena approach looking at the sequences of soils with slope position. Also, many studies only briefly focused on soils as proxy indicators of age, and instead they focused on such phenomena as weathering rinds, Al and Fe translocation, and lichen growth.

Table IV shows select soil properties for varying ages of regional glaciations.

Soil development appears to be greatest in the older glacial deposits. For instance, the Illinoian deposits of the Rocky Mountains and Sierra Nevada the Bull Lake and Pre-Tahoe drifts, have more developed argillic B horizons, textural qualities, and redder hues than their younger Wisconsin aged counterparts. The same holds true for the Cascade Range with the exception of argillic B horizons. The older Hayden Creek / Jack Creek deposits have been noted to have redder hues of B horizons and greater textural qualities than the younger Evans Creek / Suttle Lake drift.

TABLE IV

SOIL PROFILES ASSOCIATED WITH VARYING REGIONAL GLACIATIONS

GLACIAL EPOCH	PINEDALE (W)	BULL LAKE (I)	EVANS CREEK - SUTTLE LAKE (W)	HAYDEN CREEK - JACK CREEK (I)	TIOGA - TAHOE (W)	PRE - TAHOE (I)
PROFILE	A/Bw/C	A/Bt/Cox	A/Bw/Cox	A/Bt/Cox	A/Cox & A/BW/Cox	A/Bt/Cox
TEXTURAL B HORIZON	NO	YES	NO	SOME	NO	YES
MUNSELL B COLOR	10YR	7.5YR TO 5YR	10YR	7.5YR	10YR TO 7.5YR	7.5YR TO 5YR

Adapted from Scott (1977), Swanson (1985), Berry (1990), and Birkeland (1992). Illinoian and Wisconsin glaciations are represented by (I) and (W) respectfully. Scott (1977) originally labelled the Suttle Lake B horizons as having a Bs; this may be a misinterpretation to the new Soil Taxonomy system at that time, hence today it would most likely be considered a Bw.

CHAPTER IV

METHODOLOGY

SITE SELECTION

The initial criterion for site selection was to find two surficial deposits in the Cascade Range of different ages such as Ilinoian and Wisconsin ages. This was not easy, however, because the volcanic history of the Oregon Cascade Range has tended to destroy or cover glacial deposits of early Illinoian or Wisconsin ages (Scott 1996). This is especially true with the thickness of Mazama tephra as one gets closer to Crater Lake. In some areas of the southern Oregon Cascades several meters of Mazama tephra superimpose the pre-existing surficial deposits, making a study of soils from different glacial events difficult. The region of the central Oregon Cascades near Sisters, Oregon, was finally chosen by researching literature of the geology of the area, interviewing individuals with knowledge of the central Oregon Cascades, and by analyzing USGS 7.5 minute quads. Two glacial end moraines with one of Illinoian or early Wisconsin age and another of mid- to late Wisconsin age lie in near proximity to one another and are easily accessible by road. The thickness of Mazama ash is not deep enough to impede on assessing degree of soil development in this region.

FIELD METHODS

Soil pits were chosen on similar aspects and orientations on both Suttle Lake and Jack Creek moraines to provide a control in variability. Soil pits were chosen at various positions of the hillslope, or catena, following the nomenclature provided by Ruhe and Walker (1968). Hence, the summit, shoulder, back slope, foot slope, and toe slopes of each catena were excavated (Figures 9 and 10). Symbols used to differentiate the two catenas are JC (for Jack Creek) and SL (for Suttle Lake). Letters following the nomenclature of the two catenas give the position of the soil profile on the slope as suggested by Ruhe and Walker (1968) with:

SU = Summit

SH = Shoulder

BS = Back slope

FS = Foot slope

TS = Toe slope.

Hence, an excavated soil profile on the summit of the Suttle Lake moraine would be noted as SLSU. Soil field properties and soil classifications were described following the guidelines of the Soil Survey Staff (1975), Birkeland (1984), and Birkeland et al. (1991b). Appendix A shows the field sheet used and describes the soil properties that were examined. Within individual soil pits, soil horizons were identified and described. Moist soil colors were

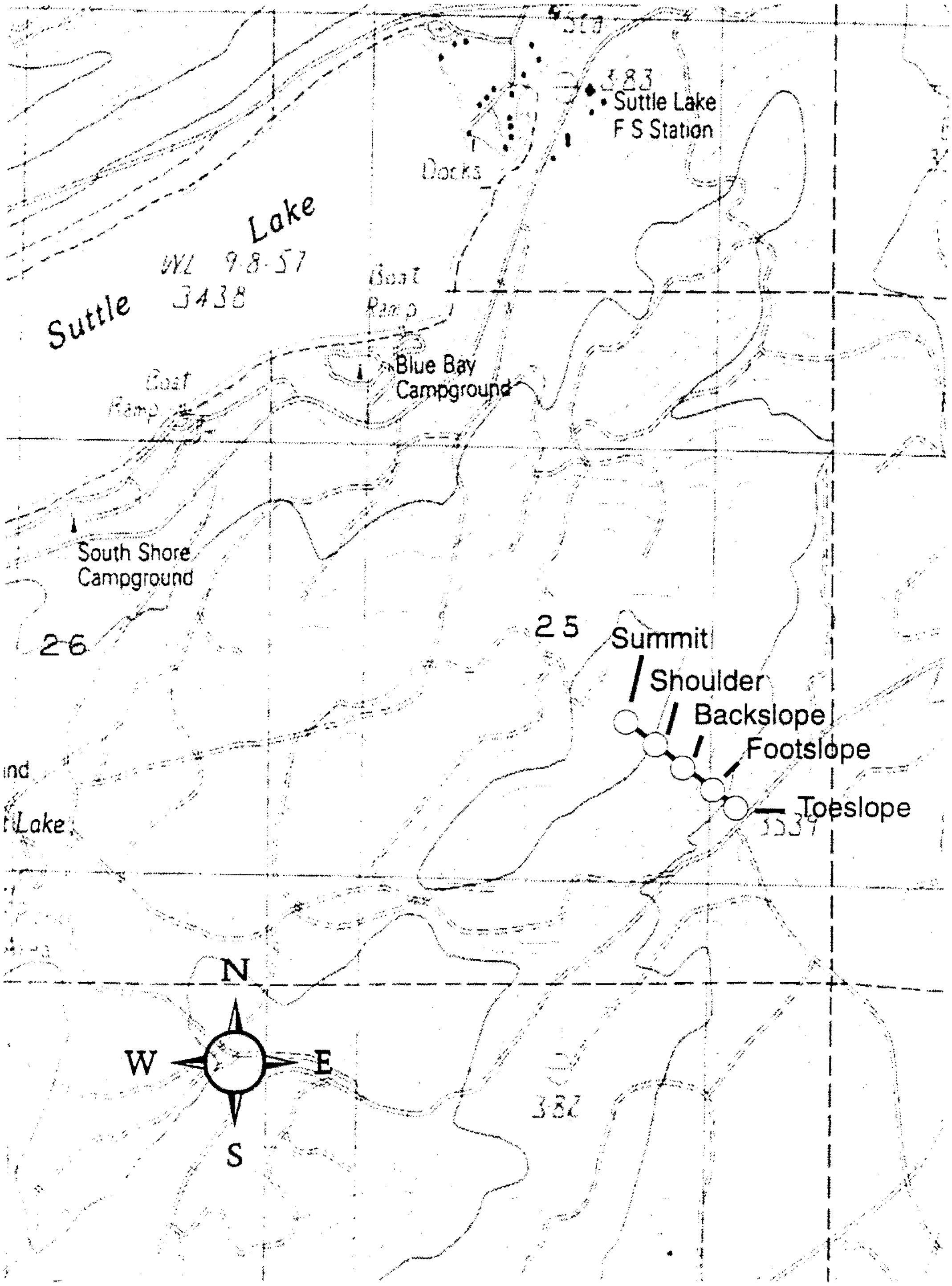


Figure 9. Suttle Lake Catena, 1:19,128. Circles show approximate locations of soil excavations as defined by Ruhe and Walker (1968). Contour interval is 40 feet. (USGS Black Butte, Oregon Quadrangle 7.5 Minute Series 1988.)

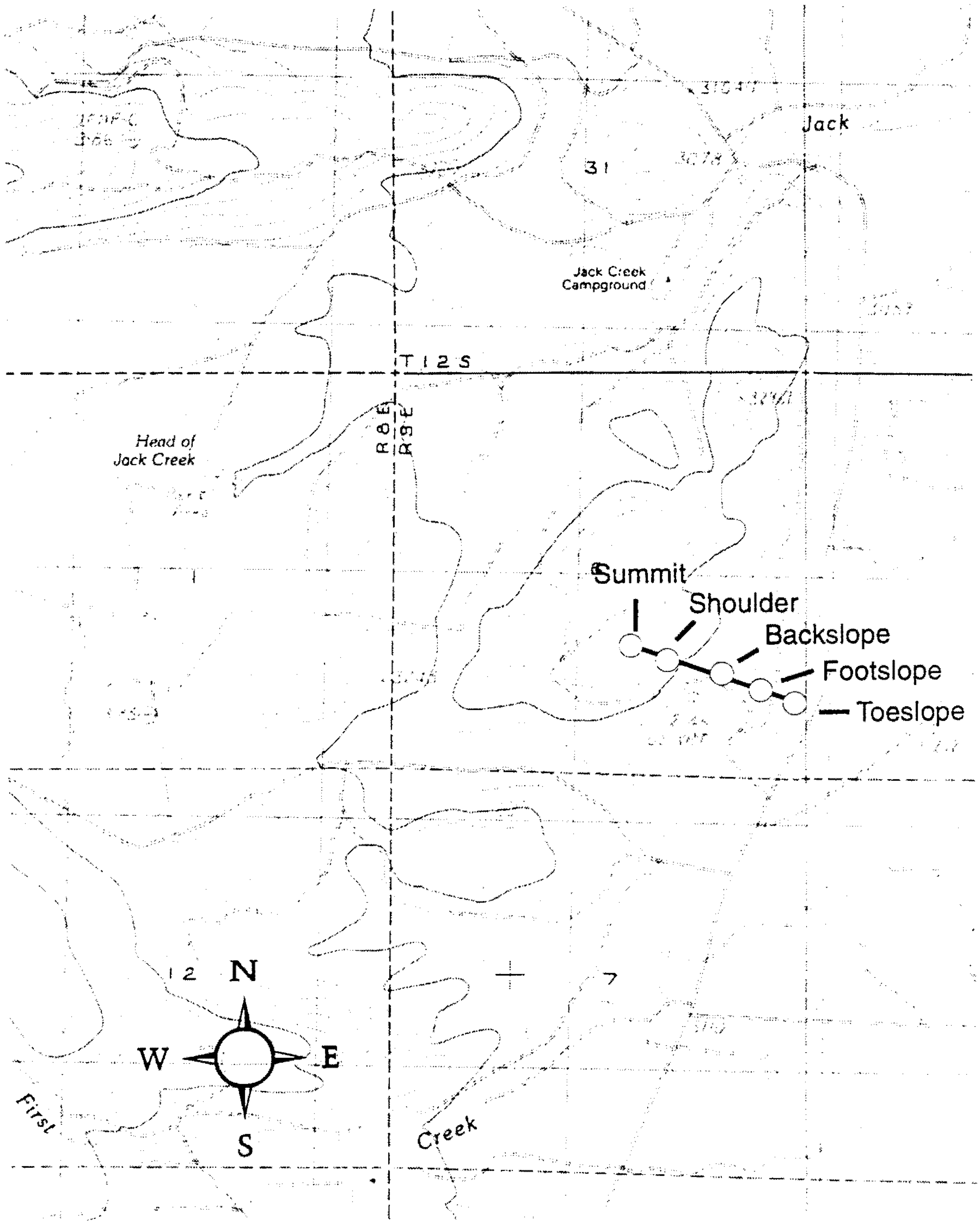


Figure 10. Jack Creek Catena, 1:27,399. Circles show approximate locations of soil excavations as defined by Ruhe and Walker (1968). Contour interval is 40 feet. (USGS Black Butte, Oregon Quadrangle 7.5 Minute Series 1988).

described using the Munsell Color Company Inc. (1954), and soil properties such as texture, structure, consistency, and boundary abruptness were described. Soil samples from each horizon were then collected for lab analysis. Bulk densities were collected using a collection tube with a volume of 230 cm^3 being pounded into the wall of the pits. The samples were then dried, weighed and divided by the volume. The observed dominant vegetation species of the area were also noted.

LABORATORY ANALYSIS

Several laboratory analyses were performed to gain a thorough understanding of soil formation. For each individual horizon within a profile, dry Munsell colors, pH, particle size analysis, and percent organic matter values were obtained.

Particle size analysis

The particle size boundaries distinguished are as follows (Soil Survey Staff 1975):

Sand = 2mm to .063mm

Silt = .063mm to .002mm

Clay = < .002mm

Organics were removed from A horizons using the H_2O_2 method. Particles larger than sand were removed through sieving. The fines were then disaggregated by a deflocculant of sodium hexametaphosphate and wet sieved. The sands were dried and sieved into several increments based on phi sizes. Silt and clay percentages were then determined using the pipette method in which 25 ml draws were taken at various time increments (Galehouse 1971).

pH

Two soil pH tests were performed using a Chemtrix 41100 pH meter with a Whatman Ag/AgCl electrode. The first test was to determine the acidity of the soils. This was done by using the standard USDA 1:1 water test (15 grams of distilled water to 15 grams of dried soil) (Procedure 8C1a, USDA 1972). The second pH test was a sodium fluoride (NaF) test which can be used to determine the presence of carbonates, gibbsite and amorphous aluminum in soils (Fieldes and Perrott 1966). The sodium fluoride test determines if there is a high aluminum content which is often typical of a soil influenced by volcanic ash, thereby emphasizing the impact of volcanic activity on pedogensis and aiding research in terms of classification purposes.

Organic matter %

Total organic matter was determined using a loss on combustion method (Allison 1965). Soil weights were taken before and after combustion, and the difference between the two weights designated the total organic material of the individual soil horizon.

SOIL INDICES

Profile Development Index

The degree of soil development is based upon quantitative and qualitative field descriptions that measure the amount of pedological change which has taken place since deposition of parent material (Birkeland et al. 1991b). For this particular study Harden's (1982) Profile Development Index (PDI) with suggestions by Birkeland et al. (1991b) was used. Differences in soil properties between initial unweathered parent material and individual soil horizons are quantified and values are calculated and normalized into an index which then describes the relative degree of soil development between the two catenas. Fresh parent material was obtained from the summit of the Suttle Lake moraine at a depth of 170 cm. The steps used to calculate the PDI as described by Harden (1982), Harden and Taylor (1983), and Birkeland and Burke (1988) are listed in Figure 11.

Intervals of ten points are used in the quantification process for each stage of development from that of the parent material. For each soil property, the direction of point increase is the direction of development of that property through time. Properties are subsequently normalized with what is called a current maximum, the maximum possible value that can be obtained for an individual soil property. A numerical value is obtained between 0 (no development) and 1 (maximum development) for the soil property. The

STEPS IN CALCULATING THE PDI

1. Describe soil profile.

⇓

2. Assess parent material.
(measure fresh deposits)

⇓

3. Quantify each field property for each horizon.
(assign ten points to increases in step)

⇓

4. Normalized quantified properties.
(divide by current maximum)

⇓

5. Sum normalized properties for each horizon.

⇓

6. Divide by number of quantified properties.
(horizon index is obtained)

⇓

7. Multiply by horizon thickness.

⇓

8. Sum horizon products through profile.

⇓

9. Divide sum by depth of soil description.

Figure 11. A flow diagram showing the steps used in calculating the PDI, from Birkeland et al. (1991b).

normalized values for each soil property of individual horizons are then summed. The summation of the soil properties is divided by the total number of properties for that horizon giving a horizon index value. The horizon index value is multiplied by horizon thickness in centimeters in order to weight the horizon properties. The horizon products are summed and divided by soil profile depth resulting in a weighted Profile Development Index.

Five soil properties were used for the two catenas: 1)rubification, 2)total texture, 3)dry consistence, 4)moist consistence, and 5)structure. The soil properties used in this study concerning Harden's PDI and the equations used to obtain values are shown in Table IV.

Rubification is the general reddening of soils. This is caused by a release of iron from primary minerals and dispersion of iron oxide particles in increasing amounts. The progressive weathering, such as oxidization or hydration, gives the soil a reddish to reddish brown appearance (Buol et al. 1989). Harden's index quantifies rubification by incorporating moist and dry differences between the parent material and individual soil horizons.

Total texture incorporates increases in stickiness and plasticity between unweathered parent material and that of individual horizons as well as changes on the textural triangle between parent material and horizons (Birkeland et al. 1991b).

Consistence of a soil describes the degree of cohesion and adhesion or resistance to deformation or rupture (Soil Science Society of America 1987). Increases in dry consistency, which describes soil hardness, and increases in moist consistency, which describes soil firmness, between parent material and soil horizons are quantified.

TABLE V

EQUATIONS OF SOIL PROPERTIES USED IN HARDEN'S PROFILE DEVELOPMENT INDEX (PDI)

<table>
<tr><th>SOIL PROPERTY</th><th>EQUATION</th></tr>
<tr><td><u>Rubification</u>: 10pts/increase in hue redness
5Y⇒2.5Y⇒10YR⇒7.5YR⇒5YR⇒2.5YR⇒10R⇒5R
PM⇒HP
10pts/increase in chroma
0⇒1⇒2⇒3⇒4⇒5⇒6⇒7⇒8
PM ⇒HP(m)</td><td>$Xr = 10\,[(\text{hue } \Delta Xo) + (\text{chroma } \Delta Xo)]\text{dry} + 10[(\text{hue } \Delta Xo) + (\text{chroma } \Delta Xo)]\text{moist}$

Divide by current maximum (190)
$Xrn = Xr \div 190$</td></tr>
<tr><td><u>Total Texture</u>: 10pts/line crossing toward clay on texture triangle
10 pts/increase in stickiness
so⇒ss⇒s⇒vs
PM⇒HP

10 pts/increase in plasticity
po⇒ps⇒p⇒vp
PM⇒HP</td><td>$Xt = 10[(\text{textural } \Delta Xo) + (\text{stickiness } \Delta Xo) + (\text{plasticity } \Delta Xo)]$

Divide by current maximum (90)
$Xtn = Xt \div 90$</td></tr>
<tr><td><u>Dry Consistence</u>: 10 pts/increase in hardness
lo⇒so⇒sh⇒h⇒vh⇒eh
PM⇒HP</td><td>$Xdc = 10(\text{dry consistence } \Delta Xo)$

Divide by 2 * current maximum (2 * 50 = 100)
$Xdcn = Xdc \div 100$</td></tr>
<tr><td><u>Moist Consistence</u>: 10 pts/increase in firmness
lo⇒vfr⇒fr⇒fi⇒efi
PM⇒HP</td><td>$Xmc = 10(\text{moist consistence } \Delta Xo)$

Divide by 2 * current maximum (2 * 50 = 100)
$Xmcn = Xmc \div 100$</td></tr>
<tr><td><u>Structure</u>:<table><tr><td>points</td><td>5</td><td>10</td><td>20</td><td>30</td></tr><tr><td>grade</td><td></td><td>1</td><td>2</td><td>3</td></tr><tr><td>type</td><td>pl</td><td>gr
sbk
abk</td><td>pr</td><td>col</td></tr></table></td><td>$Xs = [(\text{grade} + \text{type}) \text{ of } 1^{o}]$

Divide by maximum primary possible (60)
$Xsn = Xs \div 60$</td></tr>
</table>

The grouping of peds or soil structural units on the basis of size from the very fine to coarse is termed soil structure (Buol et al. 1989). Changes in structural classes between parent material and individual soil horizons are noted and quantified.

Harden's PDI uses other soil properties as well; yet for the purpose of this study several were excluded for two reasons. One, soil properties such as melanization and pH are not associated with age, hence they were excluded from the index. Two, many of the other soil properties the PDI uses are absent from the soils of this study. For example, color mottling, carbonate morphology, and clay films are absent from the soils of this study. Appendix A explains soil properties and their symbols used in the Profile Development Index.

Buntley & Westin Color Development Equivalent (CDE) index

The Buntley and Westin (1965) Color Equivalent (CDE) index uses color associated with the hue and chroma variables of a soil. The *Glossary of Soil Science* (1987) defines chroma as,

> "The purity, strength, or saturation of a color; directly related to the dominance of the determining wavelength of the light and inversely related grayness."

Hue is defined as, "being caused by light of certain wavelengths and changes with the wavelength." Buntley and Westin (1965) state that the hue and chroma variables tend to be closely allied with alterations in the parent materials of soils concerning stage of development and intensity of weathering. They suggest that since both hue and chroma pertain to wavelength, they are dependent variables of color, and their interaction can be a useful indicator of stage of soil development.

A methodology was designed in which hues of the Munsell Color Charts (1954) are assigned a numerical notation (Table VI). Redder hues often imply degrees of greater soil development, hence are given numerical values. The numerical notations that are obtained from the specified hues are then multiplied by their chroma values to obtain a Color Development Equivalent (CDE) with higher values indicating degrees of greater soil development.

TABLE VI

BUNTLEY WESTIN COLOR DEVELOPMENT EQUIVALENT (CDE)

Redder	------	---------	-------	--------	--------	--------	------	-----	Yellower
Hues	10R	2.5YR	5YR	7.5YR	10YR	1.25Y	2.5Y	5Y	N
Numerical Notation	7.0	6.0	5.0	4.0	3.0	2.5	2.0	1.0	0

Hence using this index a soil with a Munsell hue and chroma of 7.5YR 4/3 would be calculated as follows:

7.5YR 4/3 = a CDE of 4X3, or 12.

CHAPTER V

RESULTS

FIELD SOIL PROPERTIES

Jack Creek catena

Of the two study sites the Jack Creek moraine appears to be the less complex catena. Glacial, volcanic, and hillslope processes have contributed to both catenas, but the Jack Creek moraine has noticeably less volcanic influence than that of the Suttle Lake moraine. Small pyroclastic material is present on the surface of the Jack Creek moraine, yet not to the extent and abundance of the Suttle Lake moraine. The presence of large erratics and cobbles on the surface or immediately below occurs on the Jack Creek moraine illustrating the unsorted nature of moraines (Figure 12). Appearance and morphology of the Jack Creek moraine reflect its early Wisconsin to late Illinoian age (Scott 1977). Moraines of similar ages found in the Sierra Nevada and Rocky Mountains have similar attributes, such as stream dissection and a hummocky, gentle sloping nature (Swanson 1984).

Five soil profiles were examined at different slope positions along the Jack Creek moraine: the summit, shoulder, back slope, foot slope, and toe slope (Figure 13). Once the summit location was excavated and described, a

Figure12. A large erratic found at the summit of the Jack Creek moraine.

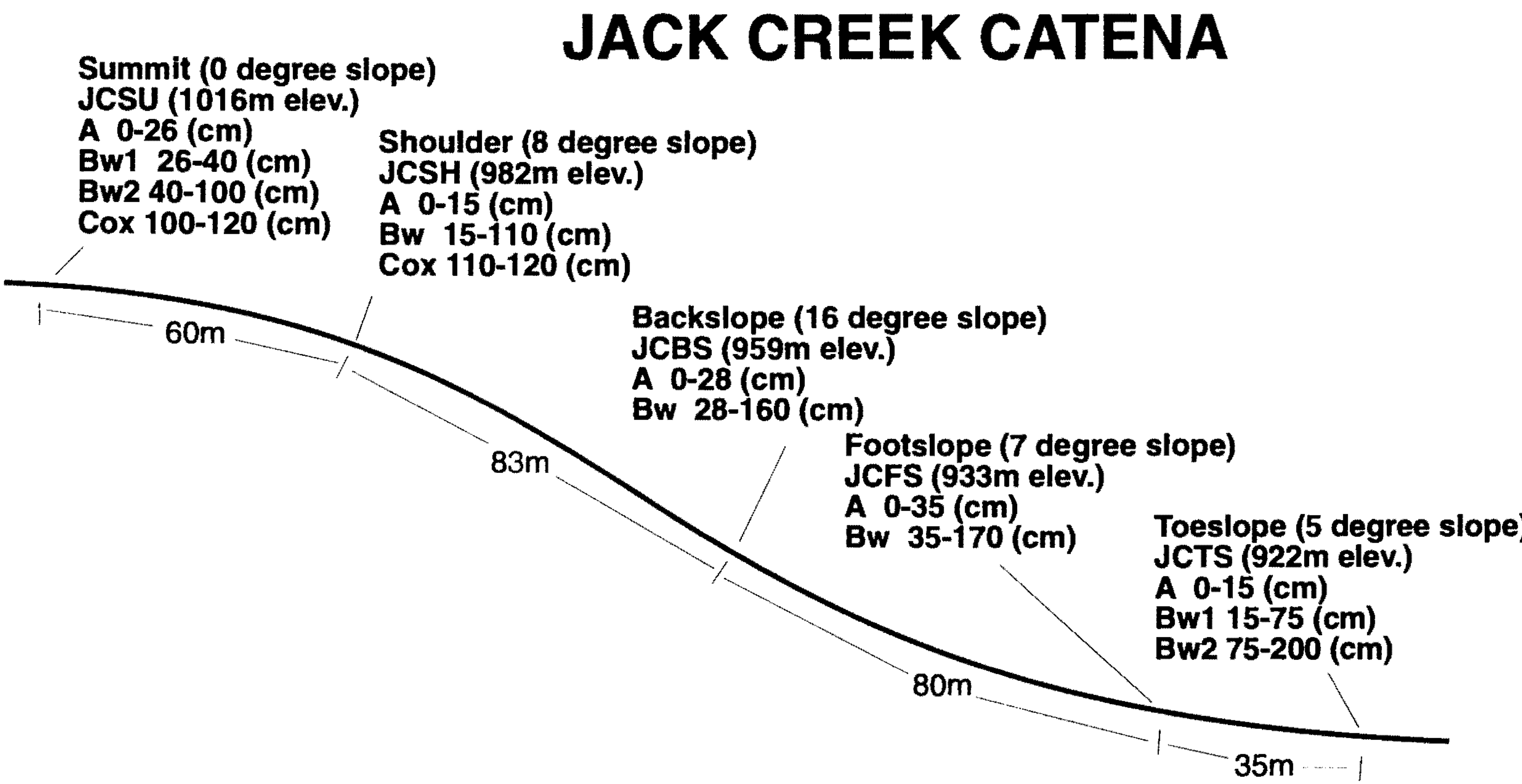


Figure 13. Horizons and depths of Jack Creek profiles. Elevations and distance between slope positions are given. Slope is not to scale.

transect was drawn down the moraine, and soils pits were then examined at the appropriate slope locations. The soils on the Jack Creek moraine were classified as Typic Vitricryands using USDA Soil Taxonomy (Myhrum and Ferry in press). These soils are Andisols, or soils which have volcanic properties such as an abundance of scoria and ash that generally lead to low bulk densities, < 0.90 g/cm^3. Profiles for the Jack Creek catena soils typically have shallow A horizons with weakly developed B horizons that are noted as Bw. Oxidized C horizons (Cox) were found at the JCSU and JCSH locations, yet were not obtainable further down slope at similar depths. Appendix B gives a complete description of the soil profiles and properties for both catenas.

The soil profile at JCSU occurs at an elevation of 1016 m and was described as having an A/Bw1/Bw2/Cox horizon (Figure 14). The A horizon is 26 cm in depth, has a granular structure and a moist 10YR 3/6 color. The A horizon boundary is clear and smooth grading into the Bw1 horizon. Both Bw horizons are weakly developed B horizons with subangular blocky structures. Yet, there is a general lightening of color with depth, hence the distinction between the B horizon with a Bw1, occurring at a depth of 26-40 cm, and a Bw2 occurring at a depth of 40-100 cm. The Bw1 horizon has a moist color of 10YR 3/6 while the Bw2 is lighter in appearance having a moist 10YR 5/6 color. There is a clear and distinct boundary between the Bw2 and the Cox

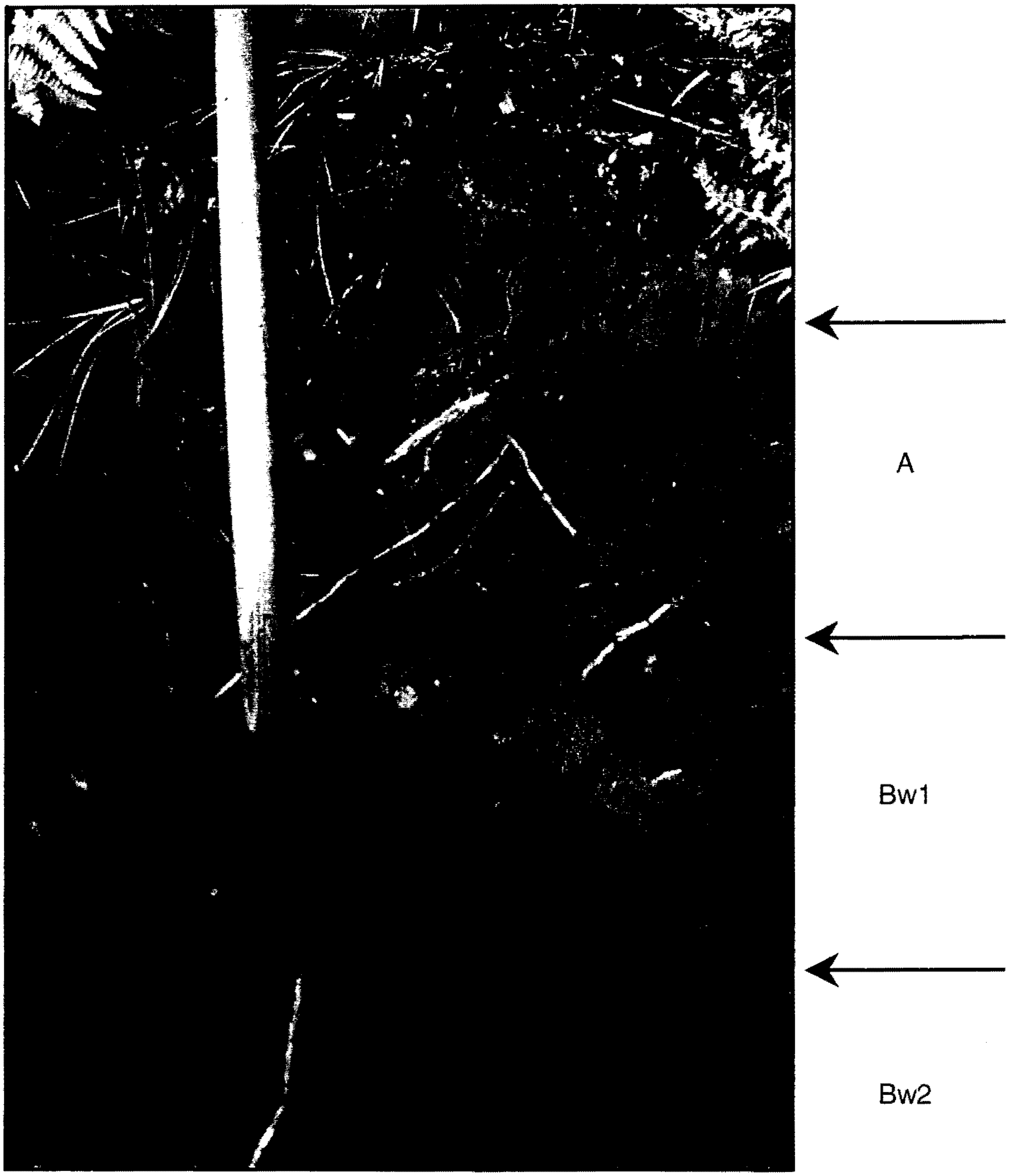


Figure 14. Soil profile of JCSU. The Cox horizon below Bw2 is not visible in this photograph.

horizon. The distinctness is immediately evident at a depth of 100 cm from the color change between the two horizons. The Bw2 horizon has a 10YR 5/6 moist color while the Cox is a light grayish brown color of 2.5Y 6/2. The structure differs from the other horizons as well, in that the Cox horizon is massive, or structureless. All horizons of JCSU have a loamy sand texture, indicating a dominance of sand size particles.

The JCSH soil (Figure 15) occurs 60 meters downslope at an elevation of 982 m and is nearly identical to the JCSU soil. The JCSH soil is described with a A/Bw/Cox profile. The A horizon is 15 cm in depth compared to 26 cm for the JCSU. It consists of a dark yellowish brown moist color of 10YR 4/4 with a granular structure. A clear smooth boundary grades into the Bw horizon with a subangular blocky structure and a moist color of 10YR 4/6. As with the JCSU profile a distinct boundary occurs between the Bw and the Cox horizon, again primarily due to color but also with structure. The Cox horizon has a light grayish color of 2.5Y 6/2 and is massive, or structureless. The Cox horizon occurs at a depth of 110 cm, 10 cm deeper than with the JCSU profile. All horizons within the profile have loamy sand textures.

The JCBS soil is described with an A/Bw profile and occurs 83 m downslope from JCSH at an elevation of 959 m. The A horizon is 28 cm in depth and has a dark yellowish 10YR 3/4 moist color with a granular structure. The Bw horizon begins at a depth of 28 cm and continues to a depth of 160 cm. A subangular structure with a brownish yellow moist color

Figure 15. Soil profile of JCSH. The Cox horizon below the Bw is not shown in this photograph.

of 10YR 6/6 was found throughout the horizon. At the depth of 160 cm large clasts within the profile made further excavation almost impossible. This is also why no Cox horizon was described. Loamy sand textures were described for all horizons.

The JCFS soil has an A/Bw profile very similar to the JCBS profile (Figure 16). Elevation for the JCFS location is 933 m and occurs 92 m downslope from the JCBS. At this location the thickest A horizon of the catena has a depth of 35 cm. The A horizon has a dark yellowish brown 10YR 3/4 moist color and a granular structure. The Bw horizon continues from 35 cm to a depth of 170 cm, where again the abundance of large clasts impeded further investigation. The Bw horizon has a subangular blocky structure and a dark yellowish brown 10YR 4/4 moist color. Loamy sand textures are found for all horizons.

The JCTS soil is similar to the JCSU soil in that it contains two Bw horizons. The elevation is 922 m approximately 35 meters downslope from the JCFS. An A/Bw1/Bw2 profile was described. The A horizon contains a shallow A horizon of only 15 cm in depth. A granular structure and a very dark brown 10YR 2/2 moist color was noted for the A horizon. The A horizon grades into the Bw1 horizon which has a subangular blocky structure and a dark yellowish brown 10YR 3/4 moist color. The Bw2 horizon begins at 75 cm

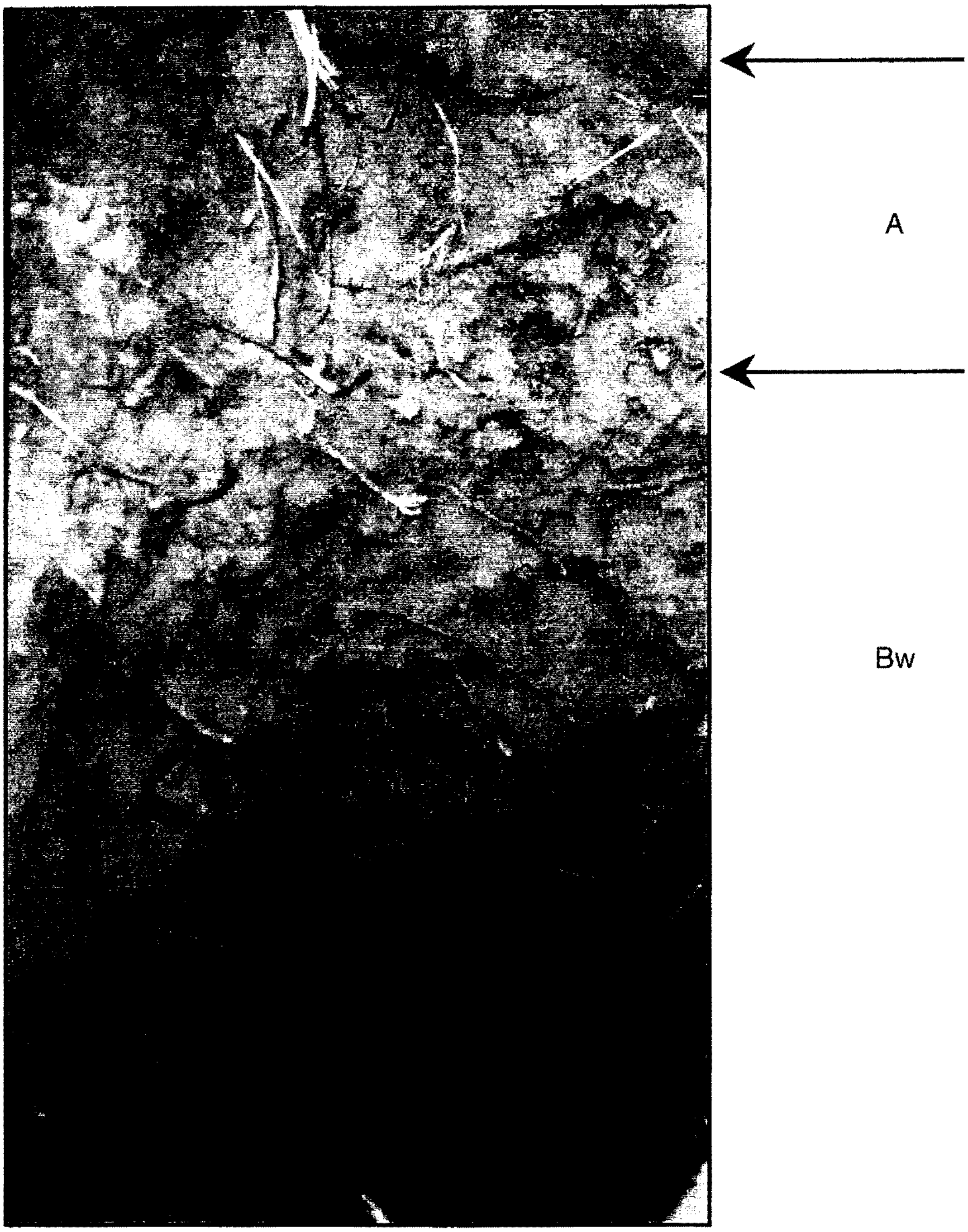


Figure 16. The soil profile of JCFS. A Cox horizon was not found after 170 cm of depth.

and differs from the Bw1 horizon only concerning color. The Bw2 horizon has a strong brown 7.5YR 4/6 moist color, hence the delineation between the two Bw horizons. At a depth of 200 cm large clasts impeded further excavation. All horizons have a loamy sand texture.

The presence of gravels, cobbles, and boulders varies with depth throughout the various positions of the catena. At the summit JCSU location large erratics and cobbles occur at the surface and increase with depth. The JCSU Cox horizon at a depth of 100 cm has roughly 75 % gravel or larger sized particles. The JCSH position contains a few surface boulders, yet not until a depth of 20 cm do cobbles become prevalent, again increasing in percentages with depth. Hence, a trend appears in which cobbles tend to decrease in depth downslope. The remainder of the slope positions have notable cobbles occurring at depths of 40 cm for JCBS, 70 cm for JCFS, and 100 cm for the JCTS locations.

Table VII shows the thickness of the A and B horizons for the five slope positions. Except for the shoulder and toe slope, thickness of the A horizons increases downslope. Both the shoulder and toe slope have A horizons 15 cm in depth, yet the summit has a depth of 26 cm and increases downslope at the back slope and toe slope positions with depths of 28 cm and 35 cm respectively. The B horizons of all profiles increase in depth downslope for the five profiles of the Jack Creek catena. The summit has a combined Bw thickness of 84 cm and increases to 185 cm at the toe slope.

TABLE VII

THICKNESS OF JACK CREEK A AND B HORIZONS IN (CM).

	JCSU	JCSH	JCBS	JCFS	JCTS
A HORIZON	26	15	28	35	15
B HORIZON	74	95	132	135	185

Most likely the thickness' for the JCBS, JCFS, and JCTS Bw horizons are deeper, since further excavation was hampered by a dominance of clasts. Yet, digging terminated under identical conditions for all three horizons thus displaying a degree of uniformity.

<u>Suttle Lake catena</u>

Volcanic activity is immediately evident at the Suttle Lake catena from the abundance of pyroclastic material found both at the surface and throughout the profiles of the soils. The site on the Suttle Lake catena lies approximately 5 km northeast from Blue Lake, a water filled crater that formed from a volcanic eruption approximately 3500 years ago. The scoria deposits on the Suttle Lake moraine probably originated from this event, creating sequences of buried soils (Taylor 1965).

Like the Jack Creek moraine, the Suttle Lake moraine reflects its suggested late-Wisconsin age in terms of morphology (Scott 1977). It has a sharp, continuous, non-dissected ridge with steeper slopes that are more pronounced than the Jack Creek moraine. Moraines of similar ages in the Sierra Nevada and Rocky Mountains have been noted to have the same morphology (Swanson 1984).

As with the Jack Creek moraine, five soil profiles were examined (Figure 17). Soil classification was awkward in that most of the Suttle Lake sites contained buried soils. Therefore, soil classification was taken from a soil survey of the Upper Deschutes, Oregon, area. The soil survey classified the soils as Typic Vitricryands, the same for the Jack Creek soils (Myhrum and Ferry, In Press).

The SLSU site occurs at an elevation of 1190 m and has a soil profile of A/Bw/2Coxb (Figure 18). The A horizon is only 8 cm deep. It has a single grain structure and a very coarse sandy texture. The moist color is a dark brown 10YR 3/3. A clear smooth boundary grades into the Bw horizon where structural as well as color changes occur. The Bw has a subangular blocky structure with a dark yellowish brown 10YR 4/4 color. A sandy texture is described for the 32 cm of Bw horizon as well. A clear boundary is noticed between the Bw and Cox horizon in terms of texture, structure and color. The Cox horizon has a structureless, or massive structure, and a moist light olive

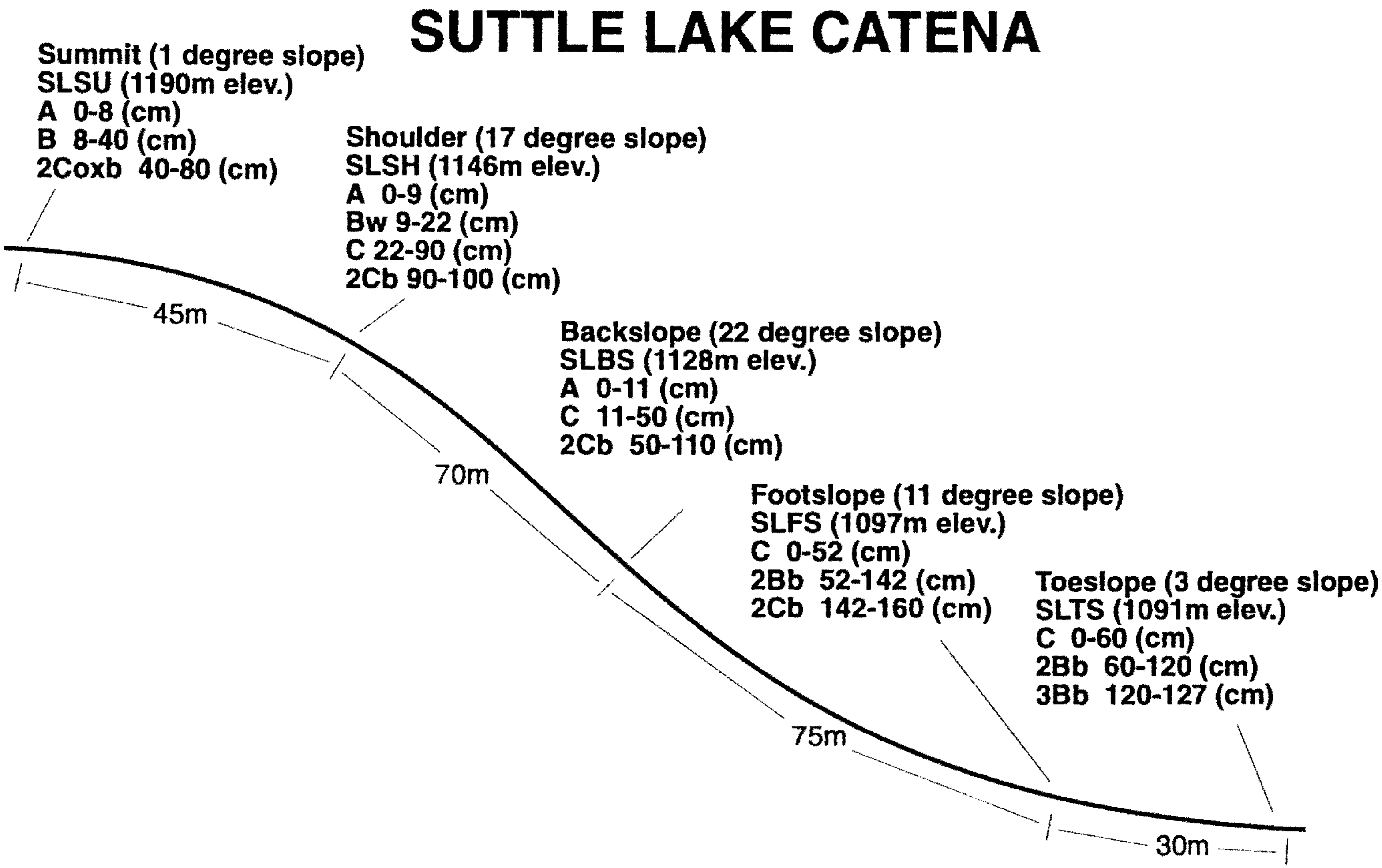


Figure 17. Horizons and depths of Suttle Lake profiles. Elevations and distances between slope positions is given. Slope is not to scale.

Figure 18. Soil profile of SLSU. The 2Coxb horizon is more characteristic of glacial till.

brown color of 2.5Y 4/4. Textural qualities for the Cox horizons are loamy sand, not a sandy texture such as in the above horizons. The A and Bw horizons display greater pyroclastic materials and coarser textures than the Cox horizon. The Cox horizon is believed to be more representative of the original glacial till parent material hence it is classified as a buried soil even though the gradation between the horizons and different parent materials is quite gradual, especially compared with the buried soils downslope.

The complex SLSH soil occurs approximately 45 m downslope of the SLSU at an elevation of 1146 m and is described as having an A/Bw/C/2Cb profile (Figure 19). The A horizon is only 9 cm in depth. It has a very dark brown 10YR 2/2 moist color with a single grain structure that clearly grades into the Bw horizon. The Bw horizon contains structural as well as color differences from that of the A horizon. The Bw has a very dark yellowish brown 10YR 4/4 moist color and a subangular blocky structure. Directly below the Bw horizon at a depth of 22 cm a scoria deposit of gravel sized particles approximately 68 cm in depth occurs. Most likely this is from the Blue Lake volcanic event and reflects a change in parent material from that of the initial glacial till. The scoria has moist colors of 7.5YR 3/4 and 10YR 2/2. Another buried horizon occurs below the C horizon scoria deposit. The 2Cb horizon begins at 90 cm, is structureless, and has a dark yellowish brown 10YR 3/2 color. The number 2 precedes the master horizon indicating a new sequence in parent material. By practice the number 1 is omitted from the

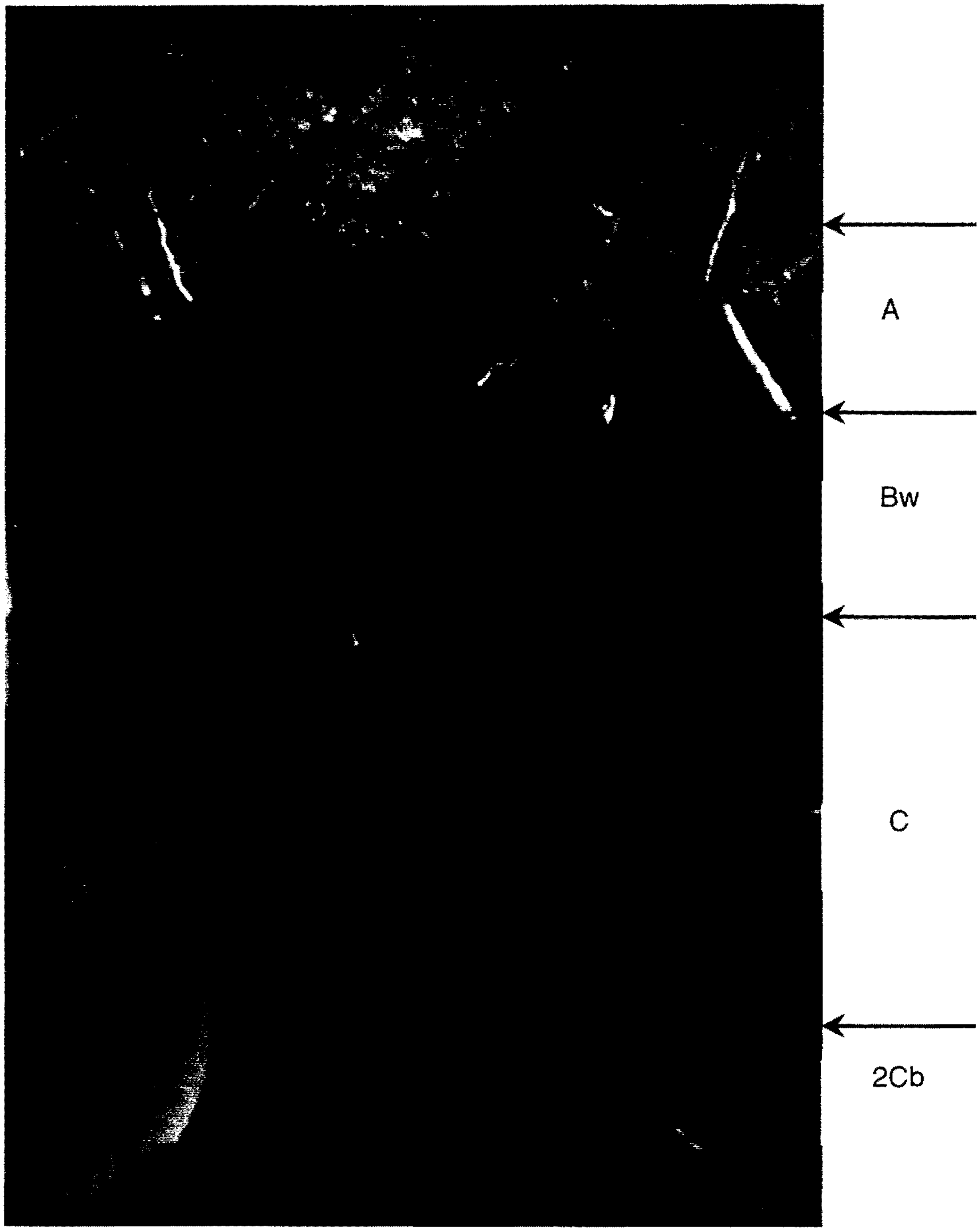


Figure 19. The Soil profile of SLSH. Note the abundance of scoria in the C horizon.

first sequence of parent material, hence the new parent material sequence proceeds from 2 upwards in numeric order for additional parent material sequences that are encountered. The lower case b of the 2Cb horizon indicates that the horizon has been buried. This horizon like all previous horizons contains a sandy texture.

The SLBS soil occurs 70 m downslope of the SLSH at an elevation of 1128 m and is described with a A/C/2Cb profile (Figure 20). The A horizon is 11 cm in depth and has a single grain structure with a very dark brown moist color of 10YR 2/2 and a sandy texture. The A horizon grades abruptly into the C horizon, which is the scoria deposit. The C horizon extends for 39 cm in depth and consists of gravel sized particles with very few fine sized particles in the matrix. The C horizon is noted with a black 10YR 2/1 and a dark reddish brown 2.5YR 3/4 moist color. Gradually at 50 cm in depth the C boundary grades into the 2Cb horizon, which has structural, textural, and color differences. The 2Cb horizon represents a buried sequence in parent material from the scoria deposit above, hence the 2 in front of the master horizon. The 2Cb horizon has a brown 10YR moist color, and a subangular blocky structure. This horizon also has more fine sized particles giving it a loamy sand texture. The 2Cb horizon originates from the original glacial till parent material, while the above horizons originate from the scoria.

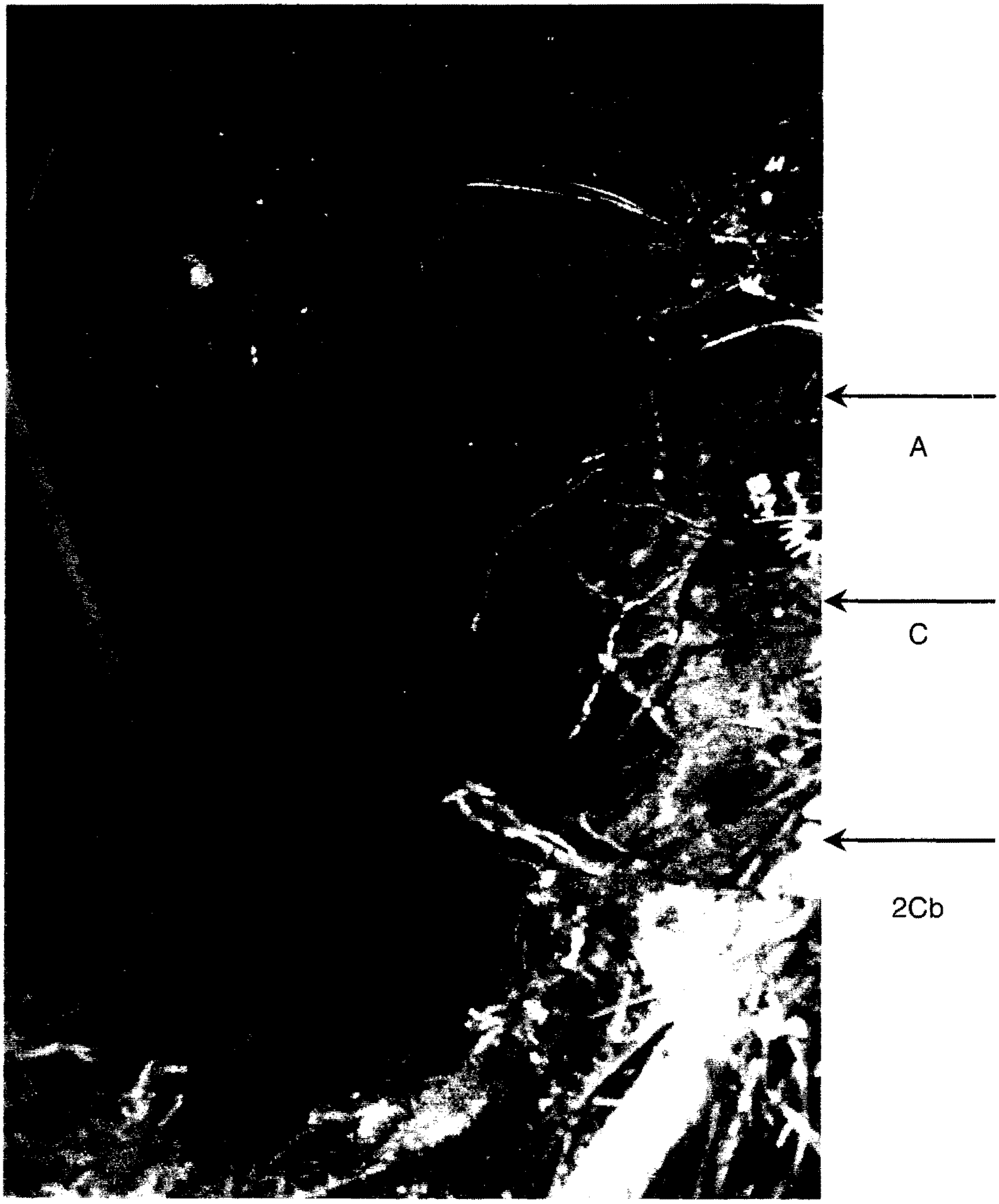


Figure 20. Soil profile of SLBS. Note the transition between the scoria layer of the C horizon and the glacial till of the 2Cb horizon below.

The SLFS soil occurs 75 m downslope of the SLBS at an elevation of 1097 m and has a C/2Bb/2Cb profile. At this slope location the scoria deposit is found to lie at the top of the profile, with a depth of 52 cm. The scoria has a black 10YR 2/1 moist color and consists of gravel sized particles with very few fines. Since the new parent material is found at the top of the horizon, a C is noted for the top horizon of the profile. The C horizon exists over a 90 cm buried B horizon. The buried B horizon is described as 2Bb and has structural, textural and color differences than the above C horizon. The 2Bb horizon consists of a subangular blocky structure, a dark yellowish brown 10YR 3/4 moist color, and a loamy sand texture. The 2Bb gradually grades into the buried C horizon. The 2Cb horizon begins at 142 cm and has an olive brown 10YR 4/3 moist color with a loamy sand and is structureless. The 2Bb and 2Cb horizons are the original glacial till soils.

The SLTS, found 30 m downslope of the JCFS at an elevation of 1091 m, is described with a C/2Bb/3Bb profile. The top C horizon consists of 60 cm of scoria of gravel sized particles overlying soils of glacial till origins. It consists of a single grain structure and a black 10YR 2/1 moist color. The top C horizon grades into a buried B horizon, which has 60 cm of depth. The 2Bb horizon has a very dark brown 10YR 2/2 moist color, a subangular blocky structure, and a loamy sand structure. At approximately 120 cm the 2Bb horizon grades distinctly into yet another buried horizon, the 3Bb horizon.

The most striking feature of the 3Bb horizon is its color. The 3Bb horizon has a yellowish red 5YR 5/8 moist color. This contrasts greatly with the above dark reddish brown 2Bb horizon. Also, the texture of the 3Bb horizon is sandy loam, not loamy sand as in the 2Bb horizon, indicating more silt and clay sized particles.

The complexities of the processes acting on the Suttle Lake moraine have affected the whole catena. This is evident in the differing parent materials, horizons, and thickness of the parent materials as one moves downslope. For instance, the SLSU, SLSH, and SLBS are the only profiles with A horizons. These increase down slope, with the SLSU A horizon having a depth of 8 cm, 9 cm for SLSH, and 11 cm for SLBS. Another example is with the contact between the scoria and glacial till parent materials. This contact occurs at various depths in regards to slope position. The contact between the two parent materials occurs at a profile depth of 90 cm for the SLSH, 50 cm of depth for the SLBS, 52 cm of depth for the SLFS and 60 cm of depth for the SLTS. Scoria deposits also are noted to occur closer to the surface down slope. At the SLSH a scoria layer is found at 22 cm within the profile, 11 cm in depth at the SLBS, and at the surface for the SLFS and SLTS positions.

LABORATORY SOIL PROPERTIES

Four tests were conducted on the soil samples: particle size analysis, 1:1 water pH, sodium fluoride (NaF) pH, and organic matter content. Each soil horizon of the profiles was tested except for the scoria layers of the Suttle Lake Catena. The scoria deposits were tested for organic matter, yet due to the gravelly nature of the scoria and an absence of fines, particle size analysis and pH testing were not performed.

Particle size analysis

Particle sizes are fairly uniform throughout the profiles of both catenas. Little variations occur in terms of percentages of fines with depth, except for the scoria layers of the Suttle Lake catena which contain few fine sized particles.

The Jack Creek catena shows little variation in particle size with depth within the five slope positions (Table VIII). All profiles are dominated by sand size particles, and the entire catena has a loamy sand texture. Percentages range from 71.6 % for the JCSU Cox horizon to 81.8 % for the JCSU A horizon. Sand sized particles slightly decrease with depth for the JCSU, JCSH, and JCBS positions by margins of only a few percentage points at most. Yet down slope, the JCFS and JCTS locations slightly increase in sand sized particles with depth, again by only a few percentage points at most.

TABLE VIII

PARTICLE SIZES OF JACK CREEK SOILS

LOCATION	HORIZON	DEPTH (CM)	TEXTURE	SAND %	SILT %	CLAY %
JCSU	A	0-26	LOAMY SAND	81.8	16.7	1.5
	Bw1	26-40	LOAMY SAND	79.4	19.3	1.3
	Bw2	40-100	LOAMY SAND	78.8	19.7	1.5
	Cox	100-120	LOAMY SAND	71.6	27.6	0.8
JCSH	A	0-15	LOAMY SAND	79.8	18.7	1.4
	Bw	15-110	LOAMY SAND	78.4	20.3	1.4
	Cox	110-140	LOAMY SAND	78.4	20.7	0.9
JCBS	A	0-28	LOAMY SAND	79.8	18.9	1.3
	Bw	28-160	LOAMY SAND	79.2	19.6	1.2
JCFS	A	0-35	LOAMY SAND	74.5	24.2	1.3
	Bw	35-170	LOAMY SAND	77.0	21.8	1.2
JCTS	A	0-15	LOAMY SAND	76.1	22.7	1.2
	Bw1	15-75	LOAMY SAND	77.8	21.2	1.0
	Bw2	75-200	LOAMY SAND	80.2	18.5	1.3

Trends concerning silt sized particles are exactly opposit e of the trends for the sand sized particles for the entire catena. Silt percentages tend to increase with depth for the JCSU, JCSH, and JCBS positions yet decrease with depth for the lower JCFS and JCTS positions. This is exactly the inverse of the trend of the sand sized particles in relation to depth and slope position. Silt percentages for the entire catena range from a low of 16.7 % at the JCSU A horizon to a high of 27.6 % for the JCSU Cox horizon.

Clay size particle percentages are extremely low for the entire catena. The highest clay percentage of the entire catena is found at the JCSU A horizon with 1.5 %, and the lowest occurs at the JCSU Cox position with only

0.8 %. Few noticeable trends are observed for the clay size particles concerning depth and slope position. For instance, the JCSU clay percentages decrease with depth from 1.5 % for the A horizon to 1.3 % for the Bw1 horizon whereupon they increase to 1.5 % in the Bw2 horizon and then again decreased to 0.8 % in the Cox horizon.

More variation occurs throughout the Suttle Lake catena in regards to particle size, slope position, and depth (Table IX). Sand percentages range from a high of 93.5 % for the SLBS A horizon to a low of 65.8 % for the second buried B horizon of SLTS, horizon 3Bb. Sand size particles are dominant throughout the profiles of the Suttle Lake catena, yet there is a greater distribution in percentages between the horizons which is not the case for the Jack Creek catena. For instance, the first buried B horizon of SLTS, 2Bb, contains 80.0 % sand while the second buried B horizon, 3Bb, contains only 65.8 % sand. This represents a range of 14.2 %, a much higher range than any of the Jack Creek profiles which range in only a few percentage points at most between horizons. Percentages of sand are generally found to be lower at greater depths, after the boundary between the volcanic and glacial parent materials. Yet, prior to this boundary it was difficult to note any trends of sand size particles with depth or slope position. The changing parent materials of the catena and the occurrence of buried soils leads to the noted different textural components of the soils. The Suttle Lake catena contains sand, loamy sand, and sandy loam textures.

Silt percentages are low for all the upper horizons within the pyroclastic parent material. Percentages range from a high of 9.2 % for the SLSU A horizon to 4.9 % for the SLBS A horizon. Yet, at deeper depths where the buried soils of glacial parent material occur, silt percentages are higher. This is illustrated best in the SLTS, where the two buried B horizons of glacial parent materials, 2Bb and 3Bb, contain 19.1 % and 32.2 % silt respectively.

Clay percentages for the Suttle Lake catena are low and sporadic, like the Jack Creek catena. Essentially, the clay percentages are statistically the same for the catena ranging approximately from 1.0 to 2.0 %.

Organic matter %

Soil organic matter content was determined using the loss on ignition method (Allison 1965) for each horizon of the excavated soil profiles (Table X). For the Jack Creek catena organic matter levels decrease with depth, with the higher organic percentages occurring in the upper plant root zones. Percentages are fairly consistent throughout the catena. The top A horizons generally have percentages ranging from 2.9 % to 1.7 % and decrease to 1.3 % to 1.5 % for the bottom most horizon of each Jack Creek profile.

TABLE IX

PARTICLE SIZES OF SUTTLE LAKE SOILS

LOCATION	HORIZON	DEPTH (CM)	TEXTURE	SAND %	SILT %	CLAY %
SLSU	A	0-8	SAND	93.0	5.9	1.1
	Bw	8-40	SAND	93.4	5.5	1.0
	2Coxb	40-80	LOAMY SAND	80.3	18.4	1.3
SLSH	A	0-9	SAND	88.7	9.2	2.1
	Bw	9-22	SAND	92.6	5.5	1.9
	C	22-90	ND	ND	ND	ND
	2Cb	90-100	SAND	92.6	5.9	1.7
SLBS	A	0-11	SAND	93.5	4.9	1.7
	C	11-50	ND	ND	ND	ND
	2Cb	50-110	LOAMY SAND	81.0	17.8	1.2
SLFS	C	0-52	ND	ND	ND	ND
	2Bb	52--142	LOAMY SAND	84.6	14.4	1.0
	2Cb	142-160	LOAMY SAND	71.4	28.0	1.6
SLTS	C	0-60	ND	ND	ND	ND
	2Bb	60-120	LOAMY SAND	80.0	19.1	0.9
	3Bb	120-127	LOAMY SAND	65.8	32.2	2.1

No data (ND) was obtained for scoria layers.

The Suttle Lake catena also shows decreases in organic matter percentages with depth with exceptions occurring in horizons containing scoria deposits. The scoria deposits contain the lowest organic matter levels regardless of slope position and depth within the profile. Coarse grained scoria deposits of gravely sized particles have higher organic percentages occurring in the horizons immediately above and below. The SLTS is different in that organic matter levels increase with depth, as opposed to

TABLE X

ORGANIC MATTER PERCENTAGES OF JACK CREEK AND SUTTLE LAKE SOIL HORIZONS

MAPPING UNIT	HORIZON	DEPTH (cm)	%ORGANIC MATTER
JCSU	A	0-26	2.9
JCSU	Bw1	26-40	2.0
JCSU	Bw2	40-100	1.5
JCSU	Cox	100-120	1.3
JCSH	A	0-15	2.2
JCSH	Bw	15-110	1.6
JCSH	Cox	110-140	1.4
JCBS	A	0-28	2.4
JCBS	Bw	28-160	2.2
JCFS	A	0-35	1.7
JCFS	Bw	35-170	1.5
JCTS	A	0-15	2.0
JCTS	Bw1	15-75	1.6
JCTS	Bw2	75-200	1.4
SLSU	A	0-8	1.2
SLSU	Bw	8-40	1.1
SLSU	2Coxb	40-80	1.1
SLSH	A	0-9	1.4
SLSH	Bw	9-22	0.7
SLSH	C	22-90	0.2
SLSH	2Cb	90-100	0.4
SLBS	A	0-11	1.3
SLBS	C	11-50	0.4
SLBS	2Cb	50-110	1.2
SLFS	C	0-52	0.5
SLFS	2Bb	52-142	1.6
SLFS	2Cb	142-160	1.3
SLTS	C	0-60	0.5
SLTS	2Bb	60-120	0.9
SLTS	3Bb	120-127	1.5

the other profiles of both catenas where organic levels generally decrease with depth. For example, the surface scoria layer, the C horizon contains 0.5 % organic matter, while the 2Bb and the 3Bb have 0.9 % and 1.5 % organic matter levels respectively.

The Jack Creek catena soils generally have higher organic matter levels than those of the Suttle Lake catena. Organic matter levels for the Jack Creek catena range from a high of 2.9 % to a low of 1.3 % while the Suttle Lake catena have a high of 1.5 % and a low of 0.2 %.

pH

A 1:1 water pH test and a sodium fluoride (NaF) test were performed on all horizons of the two catenas' profiles except for the scoria layers of the Suttle Lake catena (Table XI). The 1:1 pH test determines a soil's acidity while the NaF pH test identifies which soils might contain volcanic ash.

All soils are slightly acidic with pHs ranging from a high of 6.9 to a low of 5.8. The two catenas do not vary from one another in terms of acidity. The pH 1:1 water test shows that there is little variation in pH levels in regards to depth and slope position for the two catenas. For the Jack Creek catena the pHs rise slightly for the JCSU, and JCBS with depth, yet the other slope positions showed no trends with depth. The Suttle Lake catena has slight

TABLE XI

PHS OF JACK CREEK AND SUTTLE LAKE SOIL HORIZONS

MAPPING UNIT	HORIZON	DEPTH (cm)	1:1 pH	NaF pH	
				2 Min.	60 Min.
JCSU	A	0-26	6.1	10.3	10.9
JCSU	Bw1	26-40	6.2	10.3	10.9
JCSU	Bw2	40-100	6.6	10.0	10.5
JCSU	Cox	100-120	6.7	9.8	10.3
JCSH	A	0-15	6.6	10.2	10.8
JCSH	Bw	15-110	6.9	9.9	10.5
JCSH	Cox	110-140	6.7	9.7	10.1
JCBS	A	0-28	6.3	10.3	10.9
JCBS	Bw	28-160	6.6	10.1	10.7
JCFS	A	0-35	6.7	10.3	10.8
JCFS	Bw	35-170	6.1	10.1	10.7
JCTS	A	0-15	6.0	10.4	10.9
JCTS	Bw1	15-75	6.2	10.1	10.7
JCTS	Bw2	75-200	6.1	10.2	10.8
SLSU	A	0-8	6.0	9.7	10.4
SLSU	Bw	8-40	6.1	10.0	10.6
SLSU	2Coxb	40-80	6.5	10.0	10.6
SLSH	A	0-9	5.8	9.9	10.6
SLSH	Bw	9-22	6.2	10.1	10.4
SLSH	2Cb	90-100	6.3	9.9	10.5
SLBS	A	0-11	5.8	10.5	10.9
SLBS	2CB	50-110	6.3	10.1	10.4
SLFS	2Bb	52-142	6.2	10.1	10.6
SLFS	2Cb	142-160	6.0	9.9	10.6
SLTS	2Bb	60-120	6.1	9.4	10.2
SLTS	3Bb	120-127	6.9	10.0	10.6

Note: pHs for scoria deposits were not obtained and are absent from the above table.

increases of only a few tenths of a percentage point with depth for all slope locations except for the SLFS. The SLFS pHs decrease by a margin of 0.2 , from 6.2 at the 2Bb horizon to 6.0 at the 2Cb horizon. Overall, no outstanding pH findings were obtained between the two catenas concerning slope position and depth.

The NaF pH tests amorphous aluminum content in soils, which provides a reflection of ash content by measuring Al-OH groups in the soils (Theng 1980). The USDA Soil Taxonomy (Soil Survey Staff 1975) states that if the pH reads greater than 9.4 after two minutes in a one gram soil / 50 ml 1M NaF solution, there is a dominance of amorphous material. Readings were taken at intervals of 2 and 60 minutes. These readings are useful in determining the extent of which volcanic processes have had on the development of soils concerning parent material input. The readings are important for classification purposes as well. All soil samples tested exceeded the criteria for highly amorphous soils, showing the prescence of volcanic ash in all of the soils.

CHAPTER VI

DISCUSSION

FIELD AND LABORATORY RESULTS

Field and laboratory results provide evidence regarding the degree of soil development. Both sites have poorly developed soils which vary little in field and laboratory results. Organic matter content, pH and particle size distributions are similar for both sites with differences occurring mainly in horizon thickness and Munsell color.

pH

The two pH tests showed little variation between the sites. The 1:1 pH test showed that soils for both sites are slightly acidic with no noticeable changes occurring with slope position or age of the surficial deposit. The Jack Creek catena has pH levels ranging from a high of 6.9 to 6.0 while the Suttle Lake catena has pH levels ranging from 6.9 to 5.8 (Table XI). Some minor increases of pH levels with depth for the Suttle Lake catena are noted, yet this generality does not exist for the Jack Creek catena. Statistical trends could be ascertained pertaining to depth and pH levels, yet Birkeland (1984) states that pH levels of soils can reach a steady state fairly rapidly. Hence trends with depth due not necessarily hold any relevance in a chronosequence study. Therefore, for this study, pH is deemed to be not a good indicator of soil development and age dating.

Sodium fluoride pH readings prove that the soils exceed the criteria for highly amorphous soils containing high ash contents. The high readings stress the influence of volcanic processes in pedogenic processes for the area, hence the classification of Typic Vitricryand for the soils, soils derived from volcanic parent materials.

Organic matter

Organic matter percentages were obtained for both sites to note any trends with depth and slope position for the two sites. For the Jack Creek catena organic matter levels tend to decrease with depth, with the higher organic percentages occurring in the upper plant root zones. Organic matter percentages range from 2.9 % to 1.3 % for the Jack Creek catena. The decrease in organic matter with depth also occurs in the Suttle Lake catena, with exceptions occurring in horizons containing scoria deposits. Suttle Lake organic matter percentages range from a high of 1.6 % to a low of 0.2 % (Table X). The scoria horizons of the Suttle Lake catena are poor medians for plant growth since they are extremely well drained and contain few fine sized particles. Soil texture influences the amount of organics in soils. Soils which are high in clay and silt are generally higher in organic matter than are the coarse textured soils (Brady 1990). Consequently, these scoria horizons have very low organic matter percentages, and horizons above and below these deposits generally have higher organic matter percentages.

The toe slope of the Suttle Lake catena is interesting in that orga nic matter levels increase with depth, as compared to the other profiles of both catenas. This can be explained by the fact that the top surface horizon is composed of scoria and has limited organic matter accumulations. Organic levels increase with depth from this point and are highest in the bottom 3Bb horizon which is thought to be a buried B horizon. The 3Bb horizon contains more silt and clay size particles than the above horizon, hence the horizon is capable of retaining more organics (Brady 1990).

The Jack Creek catena has higher organic matter percentages than the Suttle Lake Catena. This is perhaps due to the textural components of the catenas. The Suttle Lake catena has higher sand percentages and less silts and clays, hence organic percentages are lower. Like pH, soil organic matter levels reach a steady state in several hundred to thousands of years (Birkeland 1984), hence the relevance of using organic matter percentages for a chronosequence study is questionable. The difference between the organic matter percentages of the two catenas in this study is thought to be primarily a function of the textural components of the soils.

<u>Particle size</u>

Particle size analysis shows little difference between the two catenas. Low clay percentages with high sand percentages are prevalent for both catenas, yet the Suttle Lake catena does have slightly sandier textures. Sand percentages range from 71.6 % to 81.8 % for the Jack Creek catena and from 65.8 % to 93.5 % for the Suttle Lake catena. The low 65.8 % of the Suttle Lake catena is from an older sequence of parent material found in the second buried B horizon, 3Bb, of the SLTS. Clay percentages are extremely low for both catenas, ranging from 0.8 % to 1.5 % on the Jack Creek catena and 0.9 % to 2.1 % on the Suttle Lake catena.

The overall low clay percentage findings is odd. For the Suttle Lake catena the low clay findings can perhaps be explained by its close proximity to Blue Lake. The Blue Lake eruption occurred 3500 years ago and mantled the Suttle Lake moraine with coarse grained pyroclastic material. The Jack Creek moraine is three kilometers to the north of the Suttle Lake moraine and escaped the mantling scoria deposits. Volcanic ejecta is found on the surface and throughout the soils of the Jack Creek catena, but the Jack Creek catena has more characteristics of glacial parent material than the younger Suttle Lake catena. For instance, a large erratic occurs at the summit and cobbles are found at varying depths throughout the catena.

If the Jack Creek catena is of its suggested age, then higher clay percentages should be found. Hence there are two possible reasons for the low clay percentages in the Jack Creek catena. One, the suggested age of the moraine is wrong, even though the moraine's morphology correlates with the suggested age. The second reason is the more probable. An earlier local volcanic event deposited material on the moraine, as in the Blue Lake eruption. Since the Jack Creek moraine is farther from the source, smaller sand size particles were deposited on the moraine, not larger scoria deposits as with the Suttle Lake moraine. This deposit combined with the glacial till, yet the moraine still maintained characteristics common of glacial till, such as the existence of an erratic and cobbles found throughout the Jack Creek profiles. The increased sandy texture could have then allowed the translocation of clays deep within the soil, perhaps far deeper than depths excavated for this study.

Hillslope processes

Evidence of hillslope processes is noted through the profile horizons of both catenas. Previous work on hillslope processes (Carson and Kirkby 1972; Kirkby 1978; Young 1972) and catenas (Gerrard 1981; Conacher and Dalrymple 1977; Birkeland 1984; Swanson 1984) states that soils of upper positions can be expected to be influenced by erosion while soils of lower slope positions can be expected to be influenced by deposition. This applies to both catenas.

Horizons of soil profiles tell of past hillslope processes which have acted on the catenas producing the described profiles. For instance, the Jack Creek catena has progressively thicker B horizons downslope, from 74 cm at the JCSU to 185 cm at the JCTS. This suggests erosion and lateral transport from upslope to deposition downslope. The Suttle Lake catena displays evidence of hillslope processes with regards to the scoria deposits. Scoria deposits are found within the profiles at the upperslope positions yet occur at the surface for the two lower slope positions, the SLFS and SLTS.

Horizons of the SLTS soil profile suggest a sequence of three depositional events. At the surface is a scoria deposit, 60 cm in thickness. Directly below is a buried 2Bb horizon, most likely of the initial parent material of the Suttle Lake moraine. Yet below this is a second buried B horizon, 3Bb, which contrasts sharply with the above 2Bb horizon in that it has a redder hue and more silt and clay percentages. This horizon is most likely pre-Suttle Lake in age, possibly of Jack Creek age or even older.

SOIL INDICES

Two soil indices were used to ascertain degree of soil development along the slope positions of the two catenas. The Profile Development Index (PDI) of Harden (1982) incorporates five soil properties while the Color Development Equivalent (Buntley and Westin 1965) uses one. In both indices numeric values are obtained with higher values suggesting a greater degree of soil development.

Profile Development Index

Five soil properties were used in the Profile Develop ment Index (PDI): rubification, texture, dry consistency, moist consistency and structure. These soil properties generally evolve and change with time from that of the original parent material. Hence, if samples of the original parent material can be obtained and if the parent material's soil properties are gathered, then the evolution of the soil properties can be quantified throughout the profile. Higher PDI values represent greater soil development, while lower PDI values represent little development from that of the parent material. PDI values range from a high of 1.0, maximum development, to a low of 0.0, no development. Appendix C contains tables that show the process of how the values are obtained.

Total profile PDI values vary little along the Jack Creek catena (Table XII and Figure 21). The JCFS position obtained a minimal value of 0.19 while the JCSH obtained the highest value of 0.23. The PDI values suggest that the least developed soil profile occurs at the foot slope position, while the most developed profile occurs at the shoulder slope position, but Peason's correlation coefficients values show that the slope positions are statistically the same.

Table XII

SUMMARIZED WEIGHTED MEAN PROFILE DEVELOPMENT INDICES FOR JACK CREEK AND SUTTLE LAKE CATENAS

JACK CREEK	**CATENA**	**SUTTLE LAKE**	**CATENA**
SLOPE POSITION	WMPDI	SLOPE POSITION	WMPDI
SUMMIT	0.22	SUMMIT	0.09
SHOULDER	0.23	SHOULDER	0.08
BACK SLOPE	0.21	BACK SLOPE	0.12
FOOT SLOPE	0.19	FOOT SLOPE	0.19
TOE SLOPE	0.21	TOE SLOPE	0.17
AVERAGE	0.21	AVERAGE	0.13

Total profile PDI values for the Suttle Lake catena show a minimum at the shoulder slope position (0.08), with the maximum value (0.19) occurring at the foot slope, not the shoulder as in the Jack Creek catena. These values suggest that the shoulder is the least developed horizon while the foot slope is the most developed of the Suttle Lake catena in terms of the soil properties of the catena's profiles. This correlates with Swanson's (1984) findings in Wyoming's Wind River Range. He stated that dryer conditions, more erosion upslope, greater stability and more abundant soil water downslope influence soil properties along the catena such that greater PDI values occur downslope. Yet downslope of the SLFS the SLTS position contains a lower value than that of the SLFS position, perhaps due to increased colluviation downslope retarding soil development.

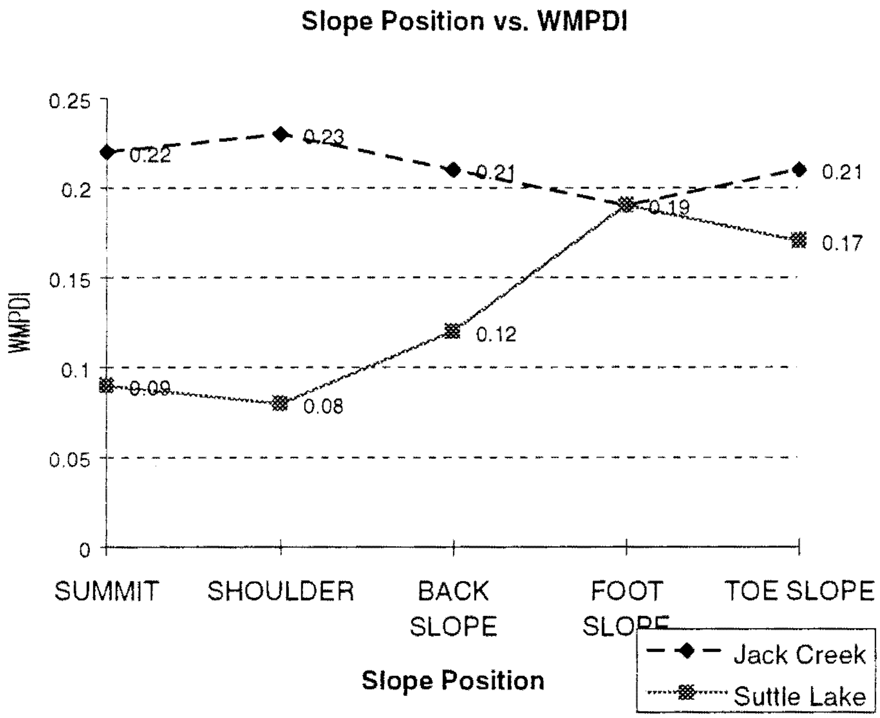


Figure 21. Slope position and WMPDI values for the two catenas.

The B horizons of both catenas are looked at in regards to soil development as well. These horizons are often the most valuable horizons in terms of Quaternary research (Birkeland 1984). The B horizons are the illuvial horizons, or the accumulation zones of a soil profile. They often contain the most advanced degree of development in terms of such soil properties as structure, redness of color, consistency, and clay accumulation.

Table XIII shows the PDI values for the illuvial B horizons of the Jack Creek and Suttle Lake catenas. The SLBS has been excluded since it contains no B horizon. The JCSU and JCTS contain two Bw horizons within their profiles. The PDI values for the Bw1 and Bw2 have been averaged in these instances. The two buried B horizons have not been averaged for the SLTS profile since these horizons are derived from different sequences of parent material.

For the Jack Creek catena the JCSH and the JCTS contain the highest B horizon PDI value (0.25), suggesting that the most developed B horizon of the entire catena occurs at the shoulder and toe slope position. The JCFS Bw horizon obtained the lowest PDI B horizon value (0.19) of the catena, suggesting that this horizon contains the weakest developed B horizon of the catena. The second buried B horizon, 3Bb, of the SLTS has the highest B horizon PDI value for the Suttle Lake catena with a value of 0.33. This is the reddest of all the soils found for both catenas and may be of Jack Creek age or even older as indicated by its hue. The Suttle Lake minimum B horizon value (0.13) is the SLSU and the SLBS positions, suggesting the least developed B horizon occurs at these slope positions.

TABLE XIII

PDI VALUES FOR JACK CREEK AND SUTTLE LAKE CATENA
B HORIZONS

MAPPING UNIT	HORIZON	PDI HORIZON VALUE
JCSU	Bw1 & Bw2	0.24
JCSH	Bw	0.25
JCBS	Bw	0.23
JCFS	Bw	0.20
JCTS	Bw1 & Bw2	0.25
SLSU	Bw	0.13
SLSH	Bw	0.17
SLFS	2Bb	0.20
SLTS	2Bb	0.15
SLTS	3Bb	0.33

In terms of soil development, the PDI suggests different slope positions as having the minimum or maximum soil development. For the Jack Creek catena the JCSH has the maximum development while the JCFS has the minimal development. The exact opposite occurs with the Suttle Lake catena in that the maximum development is found at the SLFS whereas the minimum is at the SLSH.

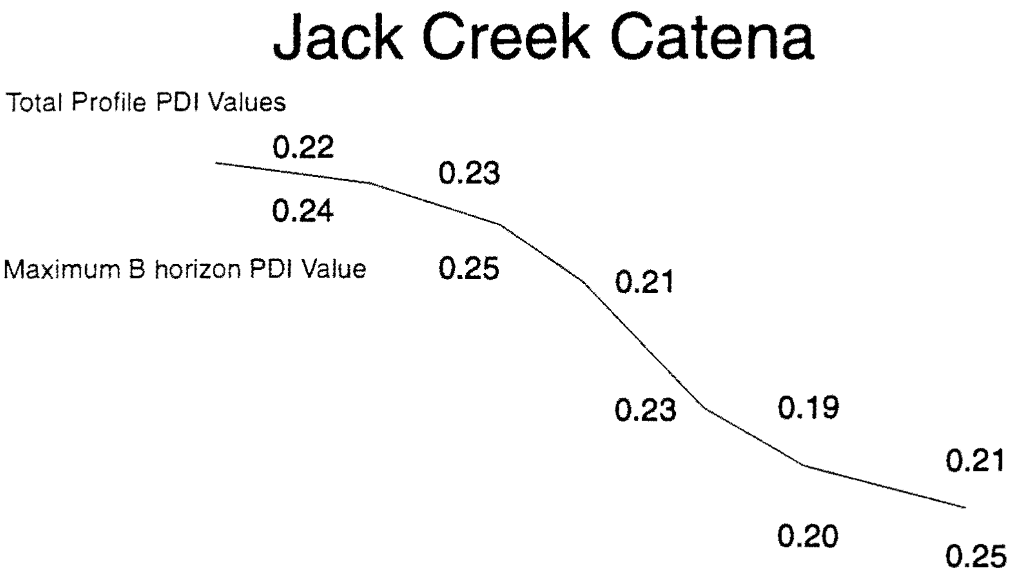
The PDI values of the two catenas differ as well. Every slope position of the Jack Creek catena, with the exception of the JCFS, has a higher value than any of the Suttle Lake slope positions, indicating advanced development. The foot slope position is 0.19 for both catenas. The range in values differs for both catenas also. A small range in values occurs for the Jack Creek catena with values from 0.19 to 0.23; yet the Suttle Lake catena has a larger range, from 0.08 to 0.19. From these differing PDI values two questions can be statistically determined. Are the catenas of different ages? Do the differing PDI values suggest that the Jack Creek moraine is older than the Suttle Lake moraine, hence having more time for soil development to occur? The second question examines if trends in the amount of soil development exist within each catena. For example, does soil development increase or decrease with a certain slope direction.

To determine the first answer, if the soil indices indicate different ages in regards to the two moraines, a paired t-test is performed. The null hypothesis (H_0) and alternate hypothesis (H_A) are:

H_0 = There is no difference between the age of Jack Creek and Suttle Lake age soils.

H_A = The Jack Creek soils are more developed than the Suttle Lake soils.

Two t-tests were performed, one using only the maximum B horizon PDI values and one using the total profile PDI values (Figure 22). Since the SLBS



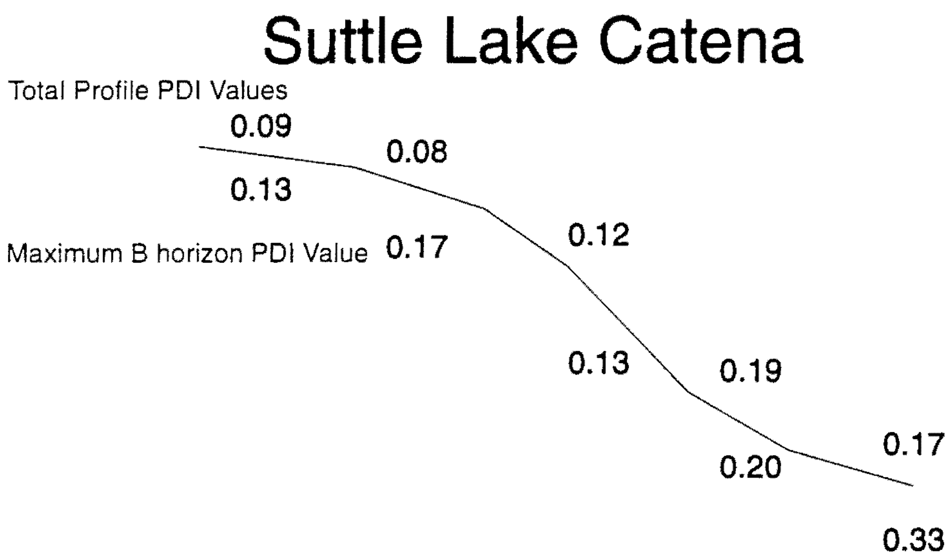


Figure 22. Total profile and maximum B horizon PDI values associated with slope position which are used for statistical testing. The SLBS does not have a B horizon, hence the 2Cb horizon value was used in its place.

lacks a B horizon, the 2Cb horizon was substituted in its place. The values of the Jack Creek summit are paired with the values of the Suttle Lake summit, and so forth. The t-test, using the maximum B horizon PDI values, shows that there is a difference between the two catenas in terms of soil development. The null hypothesis is rejected and the alternative hypothesis is accepted within a 95 % confidence value. When the total profile PDI values are used the null hypothesis is rejected with a confidence interval of 95 % as well, indicating that there is indeed a difference between the two catenas in regards to soil development. Hence the higher PDI values of the Jack Creek catena along with the supporting acceptance of the alternate hypothesis strongly suggests that the two moraines are of different age. The Jack Creek moraine, being older, has allowed more time for soil development to occur, hence the greater PDI values.

To determine the second answer, if trends in soil development exist within each catena, Pearson's correlation coefficient is used. The independent variable is the five slope positions arbitrarily ranked from one to five, with the summit slope position being one and the other down slope positions ascending in rank with the toe slope being five. The dependent variable consists of the PDI values for the associated slope positions. The values used are the same ones used for the t-test, the maximum B horizon PDI values and the total profile PDI values for each slope position (Figure

22). This test determines if soil development, as indicated by PDI values, shows any tendencies as one moves downslope. Table XIV shows the results.

TABLE XIV

CORRELATION COEFFICIENTS OF SOIL DEVELOPMENT DOWNSLOPE

	Jack Creek PDI Values	Jack Creek Maximum B Horizon Values	Suttle Lake PDI Values	Suttle Lake Maximum B Horizon Values
Correlation coefficient	-0.64	-0.23	0.88	0.82

The Jack Creek B horizon PDI values, with a correlation coefficient of -0.23, shows no real significant trend in regards to B horizon development and slope position. Jack Creek total profile PDI values produce a correlation coefficient of -0.64, implying an inverse relation of soil development and downward slope position. Yet these values are statistically insignificant within a 0.05 confidence level, hence the degree of soil development is fairly uniform as one moves downslope.

The correlation coefficients suggest that Suttle Lake soils become increasingly more developed downslope, both in the B horizons and overall profiles. Correlation coefficients for the B horizon PDI values and the total profile PDI values were 0.82 and 0.88 respectively, both significant correlation values at the 0.05 confidence level.

The statistical trends above are thought to be representative of soils found distributed throughout each of the two moraines. The statistical tests were performed on soil index values from Quantitfied field soil properties. These soil properties were similar to additional field excavations done to a lesser degree of intensity on other catenas. With similar field soil properties, similar trends would most likely result throughout the moraine.

Color Development Equivalent

The Color Development Equivalent (CDE) incorporates the hue and chroma variables of a soil (Buntley and Westin 1965). These variables are thought to be closely allied with alteration in the parent material, such as weathering. The moist field Munsell hues and chromas (Munsell Color Company Inc. 1954) were obtained for each horizon of the Jack Creek and Suttle Lake profiles. Hues were then assigned numeric values which were then multiplied by their chroma value to obtain a product. For example, the Bw horizon of the SLSH has a moist color of 10YR 3/6. The hue of 10YR is assigned a numerical equation of 3 which is then multiplied by the soil's chroma (6), giving it a CDE value of 18. The CDE methodology is designed so that soils with higher numeric products are thought to reflect their degree of development and maturity (Buntley and Westin 1965). Table XV shows the CDEs for the soil horizons of the Jack Creek and Suttle Lake catenas. The highest horizon value of each profile is listed on the very right hand column.

Assuming that this methodology represents the aspect of genetic or developmental color associated with the hue and chromas of the soils, then horizons and profiles that show higher values should then represent greater soil development. Except for the SLTS, the CDE values were generally higher for the Jack Creek catena soils. The second buried B horizon, 3Bb, of the SLTS contained the highest value (40) of the two catenas. This high value suggests the greatest maturity of all the soils sampled. The SLBS shows the lowest development having a high score of only 9 in the 2Cb horizon.

For the Jack Creek catena, the JCSH Bw horizon obtained the highest value (24). The CDE suggests that the foot slope was the least developed, with a minimum value of 12 for the catena.

Comparison of soil indices

The indices differ in suggesting which slope position along the catenas is the most and least developed. Table XVI shows most and least developed slope positions for the two catenas according to the indices. The table splits the PDI values between total profile PDI and B horizon values. As stated before, the illuvial B horizons are often considered the most important in terms of Quaternary research (Birkeland 1984), hence they are singled out

TABLE XV

CDE VALUES FOR THE JACK CREEK AND SUTTLE LAKE CATENAS

MAPPING UNIT	HORIZON	CDE VALUE	HIGHEST HORIZON VALUE
JCSU	A	18	
JCSU	Bw1	18	18
JCSU	Bw2	18	
JCSU	Cox	4	
JCSH	A	12	
JCSH	Bw	24	24
JCSH	Cox	4	
JCBS	A	12	18
JCBS	Bw	18	
JCFS	A	12	12
JCFS	Bw	12	
JCTS	A	6	
JCTS	Bw1	12	18
JCTS	Bw2	18	
SLSU	A	9	
SLSU	Bw	12	12
SLSU	2Coxb	8	
SLSH	A	6	
SLSH	Bw	18	18
SLSH	2Cb	6	
SLBS	A	6	9
SLBS	2Cb	9	
SLFS	2Bb	12	12
SLFS	2Cb	12	
SLTS	2Bb	6	40
SLTS	3Bb	40	

in the table. The highest CDE horizon value for each slope position of the two catenas is used in Table XVI to determine the most and least developed slope positions along the catenas.

TABLE XVI

A COMPARISON OF SOIL INDICES, SLOPE POSITION, AND DEGREE OF SOIL DEVELOPMENT FOR THE JACK CREEK AND SUTTLE LAKE CATENAS USING THE TOTAL PDI VALUES, THE B HORIZON PDI VALUES AND THE HIGHEST HORIZON CDE VALUES FOR EACH SLOPE POSITION

INDEX: DEGREE OF DEVELOPMENT	**JACK CREEK**		**SUTTLE LAKE**	
PDI: Most Developed Slope Position.	Total PDI Shoulder	B Horizon Toe Slope / Shoulder	Total PDI Foot Slope	B Horizon Toe Slope
PDI: Least Developed Slope Position.	Total PDI Foot Slope	B Horizon Foot Slope	Total PDI Shoulder	B Horizon Summit
CDE: Most developed Slope Position.	Back Slope		Toe Slope	
CDE: Least Developed Slope Position.	Foot Slope		Back Slope	

Only one outcome is shared between the PDI and CDE indices for the Jack Creek catena, they both indicate that the least developed slope position is the JCFS. Total PDI values state that the JCSH is the most developed while B horizon PDI values tie JCSH and JCTS as being the most developed. The CDE claims the JCBS to be the most developed.

There is only one shared outcome between the two indices for the Suttle Lake catena as well. The B horizon PDI value and the CDE value suggest that the SLTS is the most developed slope position. The total profile PDI value suggests the SLFS as the most developed slope position. PDI total profile values and B horizon values suggest that the SLSH and SLSU positions are the least developed respectively, while the CDE values suggests it to be the SLBS.

One commonality exists from the findings of Table XVI between the two catenas. PDI B horizon values state that the B horizon toe slope position is the most developed B horizon of both catenas. This horizon and slope position therefore may be of value in future studies.

Relation with past chronosequence studies

Table XVI illustrates that the two methodologies used on the two different aged moraines produce different results in regards to development of soils. Yet, using only the B horizon PDI values it can be stated that the toe slope soils for both catenas have more development and mature. This correlates with studies in the Rocky Mountains (Swanson 1984; Berry 1987) as well as studies of the Sierra Nevada (Birkeland and Burke 1988). For each of these studies the downslope position with the most mature profile was identified. This is important for it has been suggested that if time is a limiting factor then not all slope positions need to be examined. Instead, the summit position and a downslope position will suffice (Birkeland et al. 1991a). Swanson (1985) suggests that the downslope positions be the back slope, while Berry (1987) and Birkeland and Burke (1988) suggest the foot slope position. Using the B horizon PDI values this study supports using the toe slope as the down slope position. This is also the slope position which the CDE identified as having the most developed soil on the Suttle Lake catena.

Soil properties of this study tend to show less development than that of other studies done on deposits of similar ages. Chronosequences done in the Sierra Nevada on moraines similar to Jack Creek age were found to have redder hues, 7.5YR to 5YR, and argillic B horizons (Birkeland 1992). The Rocky Mountains also contained similar findings on moraines equivalent to Jack Creek age, with B horizon hues 7.5YR to 5YR and some argillic B horizons. (Birkeland 1984). This contrasts with the Jack Creek moraine with hues primarily 10YR and with B horizons of very little clay content.

Use of soil indices in the High Cascades

As mentioned earlier in Chapter III, few chronosequence studies in the Cascades have focused strictly on soils, especially using a catena approach. Methods such as measuring weathering rinds, lichenometry, surface stone frequencies, etc., have been used instead. Hence, comparison in determining slope position with the most mature profile as well as the applicability of using soil indices with past studies is nearly impossible. Yet, Scott's (1977) study of the Metolius River area of Oregon gave considerable attention to the soils of the area. He did not incorporate a catena approach or use soil indices in his study; instead, he described the soils from the moraine summits. His soil descriptions differ slightly from this study of summit sites yet the depths of the master horizons and colors are fairly consistent. Most interestingly is that he described the B horizons of the Jack Creek catena as having hues of 7.5YR while this study found the B horizons to be mainly 10YR. For the Suttle Lake soil he failed to mention the scoria deposits, yet this is consistent since this study found the scoria deposits to occur primarily downslope from the summit. The subtle difference between Scott's summit findings and mine may simply result from site location on the moraine as well as differences in soil sampling techniques.

For this particular study sole use of Harden's (1982) PDI may not be a reliable method of age dating the two surficial deposits. Five soil properties were used: 1)rubification, 2)total texture, 3)dry consistence, 4)moist consistence, and 5)structure. These soil properties varied from not at all to little between the unweathered parent material and the soils of the two catenas. A paired t-test shows that the two catenas' total profile PDI values are significantly different from one another, yet higher PDI values often resulted from basically one soil property. Rubification, or the general reddening of the soils, tends to weigh heavily upon the calculation of the PDIs for the various slope positions, especially since many times the other soil properties showed no change from the initial parent material. Yet it was difficult to ascertain if the rubification of the soils was from the general weathering and oxidization of the soils or from an influx of new redder pyroclastic material into the system, such as from the Blue Lake eruption. Hence the use of one soil property for age dating quickly becomes questionable. The significance the t-test shows would be more assuring with additional proxy dating techniques.

The PDI does seem to have merit with the second buried B horizon of the SLTS (Table XII). The 3Bb horizon contains the highest B horizon PDI value of both catenas. This is logical for several reasons. One, it is an older soil which has been buried previously by two events, suggesting a greater age and more time for development. Two, it has the reddest colors and highest rubification value of any horizon. Finally, it has the highest textural value of any horizon in this study.

The second soil index used was the Buntley-Westin (1965) Color Development Equivalent (CDE). This index uses only one soil property, soil color, or more specifically the hue and chroma characteristics of a soil's color. As with the PDI, the use of the CDE is thought to be a questionable method of age dating for this study. Redness of a soil is often associated with age, yet when other soil properties associated with age such as, high clay percentages, structure, etc., are missing it leads one to question if the redness of the soils is a result of weathering or color properties associated with parent material. As with the PDI, the CDE does have merit with the second buried B horizon of the SLTS, the 3Bb horizon (Table XV). This horizon obtained the highest value of any of the horizons. When correlated with the advanced texture and sequences in which it has been buried, the high SLTS value is logical.

CHAPTER VII

CONCLUSIONS

Two soil catenas of differing ages were investigated along the eastern flank of the Cascade Range in central Oregon. Both catenas exhibit poorly developed soils, yet several conclusions can be drawn from this study. From these conclusions recommendations are made for future work.

SOIL CHARACTERISTICS

Soils for all slope positions of both catenas have the same classification, Typic Vitricryands. Classification was determined using USDA Soil Taxonomy (Soil Survey Staff 1997) from low bulk density readings (< 0.90 g/cm^3) and high sodium fluoride readings, which indicate amorphous soils. Also, the classification matched that of the soil survey for the region (Myhrum and Ferry In Press). The uniformity in classification along both catenas suggests a limited development. It would be thought that as time progressed upslope erosion along with downslope deposition would result in different soils along the catenas. The uniformity in the classification of the soils can perhaps be explained by disturbance from local volcanic activity. The Blue Lake eruption (3500 years BP) mantled the Suttle Lake moraine with scoria and to a lesser degree is thought to have deposited sand size particles on the

Jack Creek moraine. This recent event and burial by pyroclastic material then has not allowed sufficient time for pedogensis to produce different soils.

The Jack Creek catena is typified with having a profile of A/Bw/Cox horizons with the Bw horizons becoming thicker downslope. Only the JCSU and JCSH have Cox horizons, yet it is believed that the remainder of the slope positions contain Cox horizons as well. For these positions cobbles and boulders made deeper excavation difficult, hence it can only be presumed that the Cox horizons are there.

Lab results for the Jack Creek catena are fairly consistent throughout the entire catena. A 1:1 water pH test shows that pH levels are slightly acidic with ranges from 6.0 to 6.9. A sodium fluoride test shows that all horizons throughout the catena exceed the standard for amorphous soils. Organic matter percentages, ranging from a 2.9 % to 1.3 %, decrease with depth for all slope positions. Particle size distribution of the entire catena is dominated by sand, with very little clay content. The sandy nature of the soils is punctuated by all horizons of the Jack Creek profiles having loamy sand textures.

Lab results for the Suttle Lake catena are not as consistent as the Jack Creek catena. This most likely is due from the mantling of scoria and is noticeable with the contrast in soil properties at the contact between the two parent materials. An exception to this is the pH readings. A 1:1 pH water test shows that all profile horizons are slightly acidic ranging from 5.8 to 6.9. A sodium fluoride test shows that all horizons throughout the catena exceed the standard for amorphous soils. The organic matter percentages are lower than the Jack Creek catena ranging from 1.6 to 0.2, with the minimums occurring in the horizons of scoria. Like the Jack Creek catena, particle size distribution is dominated by sand size particles with very little clay contents. Differences occur though in the amount of sand percentages between the volcanic and glacial parent materials. The horizon profiles dominated by the volcanic pyroclastic parent materials often exceed 90 % sand, while the glacial parent material contains sand percentages in the 80s. This difference in particle size percentages between the two parent materials is also noted in differences on the textural triangle. Horizons dominated by pyroclastic material have sand textures while horizons of the glacial till have loamy sand textures.

Lab results were instrumental in determining that a second buried B horizon exists at the SLTS. This horizon contains the highest organic matter, pH and clay and silt size particle percentages for the entire catena. These results, compounded with the dry, red 7.5YR hue, illuminated this horizon ending with the conclusion that it is a buried B, probably of Jack Creek age.

SOIL INDICES

PDI values

Correlations of the PDI values show that soil development is fairly uniform throughout the Jack Creek catena, with perhaps a small decrease in development downslope. The Jack Creek total profile PDI values contain a small range from a low of 0.19 to a high of 0.23. Total profile PDI values show that the JCSH is the most developed profile of the catena while the JCFS is the least developed. When the B horizon PDI values are isolated the JCSH and JCTS have the highest value (0.25) while the JCFS has the lowest value (0.20). Hence both PDI B horizon values and total PDI values claim the JCSH to be the most developed and the JCFS to be the least developed slope position, but these are not statistically significant.

Correlations of the PDI values show that soil development is not uniform throughout the catena. Soils tend to increase in development downslope. The Suttle Lake total profile PDI values contain a larger range than that of Jack Creek with a low of 0.08 and a high of 0.19. Total profile PDI values show that the SLFS position is the most developed slope position while the SLSH is the least developed profile. Isolated B horizon PDI values show that the SLTS position is the most developed (0.33) while the SLSU position (0.13) is the least developed.

Statistically, the PDI values show that there is significance, in terms of soil development, between the slope positions of the two catenas. A paired t-test shows that within a 95 percentile the soil profiles of the Jack Creek catena are more developed than the profiles of the Suttle Lake catena. This then corroborates Scott's (1977) claim that the Jack Creek moraine is of older age than the Suttle Lake moraine since the soils have had more time to develop.

CDE values

The highest CDE horizon values from each profile of the two catenas was used to determine soil development. For the Jack Creek catena the JCSH position obtained the highest value, indicating maximum development which also correlates with the PDI findings. The least developed position is the JCFS, which also correlates with the PDI findings.

Maximum soil development on the Suttle Lake catena occurs at the SLTS position. This position obtained the highest value from the older buried 3Bb horizon. Minimal soil development occurs at the SLBS position.

FUTURE WORK

Future chronosequence studies in the Oregon Cascades should acknowledge the impacts of which episodic volcanism has influenced the land

and soils. Pyroclastic material from these events ranging from gravel size scoria to clay size ash has been added to soils throughout the range. In some instances these depositional events have completely mantled the soils, establishing a new sequence of parent material. In other cases a gradual eolian influx of smaller size particles subtly changes the characteristics of the soil from that of its initial parent material. Hence, the range is geologically more dynamic than other areas where soil catena chronosequences have been done, such as the Sierra Nevada and Rocky Mountains. In these two ranges soils form virtually undisturbed from time of initial deposition. With a major volcanic eruption every 200-300 years, disturbance is a common factor in the Cascades (Harris 1988). Therefore, future chronosequence studies of the Oregon Cascades should incorporate several methodologies, not relying solely on soil development or choose areas where volcanic eruptions have been rare for the past 200,000 years like the Mt. Jefferson or Mt. McLoughlin areas.

Soils are a valid source of information which are capable of telling the history of erosional and depositional events and should be used. Yet in the Oregon High Cascades they should be used in conjunction with other methodologies such as surface stone frequencies, lichenometry, weathering rinds, and perhaps most of all tephrachronology. Findings from correlations of several methodologies would be more sound than relying solely on the relative differences of poorly developed soils.

REFERENCES

Allen, C.E. 1996. *Alpine Soil Geomorphology: The Development and Characterization of Soil in the Alpine-Subalpine Zone of the Wallowa Mountains, Oregon.* Master of Science in Geography, Portland State University.

Allison, L.E. 1965. Organic Carbon. In *Methods of Soil Analysis pt. II.* ed. .A. Black, pp. 1367-1378. Madison, Wisconsin: American Society of Agronomy.

Alt, D.D. and Hyndman, D.W. 1981. *Roadside Geology of Oregon.* Missoula: Mountain Press Publishing Co.

Beckinsale, R.B. and Chorely, R.J. 1991. The History of the Study of Landforms or the Development of Geomorphology. N.Y., Routledge.

Berry, M.E. 1987. Morphological and chemical characteristics of soil catenas on Pinedale and Bull Lake moraines slopes in the Salmon River Mountains, Idaho. *Quaternary Research* 28: 210-225.

Berry, M. E. 1990. Soil catena development on fault scarps of different ages, eastern escarpment of the Sierra Nevads, California. *Geomorphology* 3: 333-350.

Birkeland, P.W. 1984. *Soils and Geomorphology.* New York: Oxford University Press.

Birkeland, P.W. 1990. Soil-geomorphic research - a selective overview. *Geomorphology* 3: 207-224.

Birkeland, P.W. 1992. Quaternary soil chronosequences in various environments - extremely arid to humid tropical. In Martini, I.P. and Chesworth, W. (eds.), *Developments in earth surface processes 2: weathering, soils, and paleosols.* Elsevier, New York.

Birkeland, P.W., Berry, M.E., and Swanson, D.K. 1991a. Use of soil catena field data for estimating relative ages of moraines. *Geology* 19: 281-283.

Birkeland, P.W., and Burke, R.M. 1988. Soil catena chronosequences on eastern Sierra Nevada moraines, California, U.S.A. *Arctic and Alpine Research.* 20: 473-484.

Birkeland, P.W., Machette, M.N., and Haller, K.M. 1991b. *Soils as a Tool for Applied Quaternary Geology.* Miscellaneous Publication 91-3 Utah Geological and Mineral Survey.

Brady, N.C., 1990. *The Nature and Properties of Soils.* New York: MacMillan Publishing Company.

Buntley, G.J., and Westin, F.C. 1965. A Comparative Study of Development Color in a Chestnut-Chernozem-Brunziem Soil Climosequence. *Soil Science Proceedings* 29: 579-582.

Buol, S.W., Hole, F.D., & McCracken R.J. 1989. *Soil Genesis and Classification.* Ames: Iowa State University Press.

Carson, M.A., and Kirkby, M.J. 1972. *Hillslope Form and Process.* Cambridge, Cambridge University.

Carver, G.A. 1987. Glacial Geology of the Mountain Lakes Wilderness and Adjacent Parts of the Cascade Range, Oregon. University Microfilms International, Ann Arbor. Ph.D. Dissertation University of Washington.

Catt, J.A. 1986. *Soils and Quaternary Geology: A Handbook for Field Scientists.* Oxford: Clarendon Press.

Colman, S.M., and Pierce, K.L. 1983. Correlation of Quaternary Glacial Sequences in the Western United States Based on Weathering Rinds and Related Studies. In *Correlation of Quaternary Chronologies,* ed. W.C. Mahaney, pp.437-454. Toronto: York University.

Conacher, A.J., and Dalrymple, J.B. 1977. The nine unit landsurface model: an approach to pedogeomorphic research. *Geoderma* 18:1-154.

Crandell, D.R. 1965. The glacial history of western Washington and Oregon. In *The Quaternary of the United States,* ed. H.E. Jr., Wright and D.G. Frey, pp. 341-353. Princeton: Princeton University Press, Princeton, N.J.

Crandell, D.R. 1969. Surficial geology of Mt. Rainier National Park, Washington: U.S. *Geeological Surevey Bulletin* 1288, 41 p.

Crandell. D.R. and Miller R.D. 1974. *Quaternary stratigraphy and extent of glaciation in the Mt. Rainier region, Washington*: U.S. Geological Survey Professional Paper 847, 59 p.

Daniels, R.B. and Hammer, R.D. 1992. *Soil Geomorphology.* New York: Wiley and Sons Inc.

Dart, J.O. and Johnson, D.M. 1981. *Oregon Wet High and Dry.* Portland: The Hapi Press.

Fieldes, M. and Perrott, K.W. 1966. The Nalture of Allophane in Soils: Part Three-Rapid Field and Laboratory Test for Allophane. *New Zealand Journal of Science* 9:623-629

Franklin, J.F., and Dyrness. 1988. *Natural Vegetation of Oregon and Washington.* Oregon State University Press.

Galehouse, J.S., 1971. Sedimentation Analysis. In *Procedures in Sedimentary Petrology*, ed. R.E. Carver, pp.69-87. New York: Wiley-Interscience.

Gannon, B.L. 1981. *Geology of a volcanic complex on the south flank of Mount Jefferson, Oregon.* Master of Arts in Geology, Portland State University.

Gerrard, A.J., 1981. *Soils and Landforms.* London: George Allen and Unwin.

Gerrard, J. 1992. *Soil Geomorphology.* London: Chapman and Hall.

Harden, J.W. 1982. A Quantitative Index of Soil Development from Field Descriptions: Examples from a Chronosequence in Central California. *Geoderma* 28:1-28.

Harden, J.W. and Taylor, E.M. 1983. A quantitative comparison of soil development in four climatic regimes: *Quaternary Research* 10:342-359.

Harris, S.L. 1980. *Fire and Ice.* The Mountaineers Publishing, Company.

Harris, S.L. 1988. *Fire Mountains of the West: the Cascades and Mono Lake volcanoes.* Mountain Press Publishing Company.

Jackson, P. and Kimerling, J. 1993. *Atlas of the Pacific Northwest.* Corvallis: Oregon State University.

Jenny, H. 1941. *Factors of Soil Formation.* New York: McGraw-Hill.

Jenny, H. 1961. Deviation of State Factor Equations of Soils and Ecosystems. *Soil Science Society Proceedings*: 385-388.

Jenny, H. 1980. *The Soil Resource.* New York: Springer -Verlag Inc.

Kirkby, M.J. 1978. Implications for sediment transport. In *Hillslope Hydrology,* ed. M.J. Kirkby, pp. 325-360. Chichester: John Wiley and Sons.

Kiver, E.P. 1974. Holocene glaciation in the Wallowa Mountains Oregon. In *Quaternary Environments: Proceedings of a Symposium, York University Geographical Monographs 5,* ed. W.C. Mahaney, pp. 169-195. Toronto: Department of Geography, York University.

Larsen, D.M. 1976. *Soil Resource Inventory Deschutes National Forest Pacific Northwest Region.* U.S. Department of Agriculture, Forest Service, Deschutes National Forest. pp. 381.

Mahaney, W.C. 1978. Late-Quaternary stratigraphy and soils in the Wind River Mountains, western Wyoming. In *Quaternary soils*, ed. W.C. Mahaney, pp. 223-264. Norwich: Geo Abstracts Ltd.

Maheney, W.C., Fahey, B.D., and Lloyd, D.T. 1981. Late Quaternary glacial deposits, soils, and chronology, Helll Roaring Valley, Mount Adams, Cascade Range, Washington. *Arctic and Alpine Research* 13 (3):339-356.

McFadden, L.D. and Knuepfer, P.K.. 1990. Soil geomorphology: the linkage of pedology and surficial processes. *Geomorphology* 3:197-205.

Milne, G. 1935. Some suggested units of classification and mapping particular for East African soils. *Soil Research* 4 (3):183-198.

Munsell Color Company, Inc. 1954. Munsell Soil Color Chart. Baltimore: Munsell Color Company, Inc.

Myhrum, R. and Ferry, B. In Press. Soil Survey of U*pper Deschutes River Area, Oregon including part of Deschutes, Jefferson and Klamath Counties.* United States Department of Agriculture, Natural Resources Conservation Service.

Orr, E.L., Orr, W.N. and Baldwin, E.M. 1992. *Geology of Oregon*. Dubuque: Kendall/Hunt Publishing Co., 3rd edition.

Porter, S.C., Pierce K.W., and Hamilton, T.D. 1983. Late Wisconsin mountain glaciation in the western United States. In *Late-Quaternary environments of the United States Volume I*, ed. H.E. Jr. , Wright and S.C. Porter, pp. 71-114. Minneapolis: University of Minnesota Press.

Price, L.W. 1978. Mountains of the Pacific Northwest, USA: A study in contrasts. *Arctic and Alpine Research* 10(2):465-478.

Richmond, G.M. 1976. Pleistocene stratigraphy and chronology in the mountains of western Wyoming. In *Quaternary Stratigraphy of North America*, ed. W.C. Mahaney, pp. 353-380. New York: Dowden, Hutchinson, and Ross Incorporation.

Ruhe, R.V. and Walker, P.H. 1968. Hillslope models and soil formation. *I. Open System. Trans. of the 9th International Congress of Soil Science* 4:551-560.

Scott, W.E. 1977. Quaternary glaciation and volcanism, Metolius River area, Oregon. *Geological Society of America Bulletin* 88:113-124.

Scott, W.E. 1996. Personnal Communication. Cascade Volcano Observatory. Vancouver, Washington.

Scott, W.E., Pierson, S.P., Costa, J.E., Gardner, C.A., Vallance, J.W., and Major, J.J. 1997. *Volcano Hazards in the Munt Hood Region, Oregon: USGS Open-File Report 97-89.*

Small, J., and Witherick, M. 1989. *A Modern Dictionary of Geography.* New York: Edward Arnold.

Soil Science Society of America. 1987. *Glossary of Soil Science Terms.* Madison: Soil Science Society of America.

Soil Survey Staff. 1975. *Soil Taxonomy*: U.S. Department of Agriculture Handbook No. 436.

Soil Survey Staff. 1997. *Keys to Soil Taxonomy, 7th ed., Pocahontas Press,* Blacksburg, VA.

Swanson, D.K. 1984. Soil Catenas on Pinedale and Bull Lake Moraines, Willow Lake, Wind River Mountains, Wyoming. Master of Science. Thesis, University of Colorado, Boulder.

Swanson, D.K. 1985. Soil catenas on Pinedale and Bull Lake moraines, Willow Lake, Wind River Mountains, Wyoming. *Catena* 12:329-342.

Taylor, E.M. 1965. Part I: History of volcanic activity, in Recent volcanism between Three-Fingered Jack and North Sister, Oregon Cascade Range. *Ore Bin* 27:121-147.

Theng, B.G. ed. 1980. *Soils With Variable Charge.* New Zealand Society of Soil Science. Palmerston North, New Zealand: Offset Publications.

Trewartha, G.T. 1961. *The Earth's Problem Climates.* Madison: University of Wisconsin Press.

USDA. 1972. *Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples.* USDA Soil Conservation Service, Soil Survey Illustrations Report No. 1. Procedure 8c1a. pp. 59.

U.S. Geological Survey. 1959. *Sisters Quadrangle, Oregon 15 Minute Series (Topographic).* U.S. Geological Survey, Denver, CO.

U.S. Geological Survey. 1988. *Black Butte Quadrangle, Oregon 7.5 Minute Series (Topographic).* U.S. Geological Survey, Denver, CO.

Vreeken, W.J. 1975. Prinicipal kinds of chronosequences and their significance on soil history. *Journal of Soil Science* 26: 378-394.

Waitt, R.B.Jr., Yount, J.C., and Davis, P.T. 1982. Regional Significance of an Early Holocene Moraine in Enchantment Lakes Basin, North Cascade Range, Washington. *Quaternary Research* 17: 191-210.

Western Regional Climate Center "U.S. Climate Historical Summaries" 1997. http://www.wrcc.dri.edu/ (18, Nov. 1997).

Young, A. 1972. *Slopes.* London: Longman Group Limited.

APPENDIX A

Field Work Sheet and Soil Property Abbreviations

Soil Description: Location ____

Site No. _____ Date _________ Time ___________ Vegetation ____

Elevation _________ Slope ___________ Aspect ________ Geomorphic Surface ________________________________

Parent Material(s) ____________________________________ Described by ______________________________

Depth (cm)	Horizon	Color	Structure	Gravel	Consistence			Texture	pH	Clay films	Bound-aries	notes
		moist / dry		%	Wet	Moist	Dry					
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
		....	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo vfr fr fi vfi efi	lo so sh h vh eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	

Field data sheet suggested by Birkeland et al. (1991b).

Soil Property Descriptions

The key properties and their symbols which were used in this study are described below. The depth, horizon, gravel %, and pH sections of the previous work sheet will not be described as their explanations are fairly self evident. The clay films section of the work sheet will also not be described since this study did not find any clay films. The color, structure, consistence, texture, and boundaries section of the work sheet will be briefly explained giving descriptions and explanations of abbreviations used. Field work sheet and descriptions are from Birkeland et al. (1991b).

Color: Munsell Soil Color Charts (1954) were used to describe moist colors, taken in the field in direct sunlight. Dry colors were taken in the laboratory from dried sieved samples.

Structure: Size and morphology of soil peds are described by their grade, type, and size of individual peds.

Grade:

m = massive.	A vertical face is maintained through an abundance of aggregation, yet no formation of structure type.
sg = single grain.	No aggregation is present.
1= weak.	Individual peds are barely observable in place, and few are observable when disturbed.
2 = moderate.	Peds are easily observable but not distinct.

3 = strong.	Peds are distinct and visible in place, and when disturbed the entire mass consists of peds in their entirety.

Type:

g = granular.	Spheroid crumb like appearance.
abk = angular blocky.	Peds with equidimentional blocks with planar faces.
sbk = subangular blocky.	Peds with blocky appearances yet with rounded faces.
pr = prismatic.	A flat-topped bed with particles arranged about a vertical line.
cpr = columnar.	Ped is identical to prismatic yet has rounded tops.
pl = platy.	Soil particles are arranged on a horizontal plane.

Size: Size classification varies according to type of structure. Abbreviations are presented below.

vf = very fine
f = fine
m = medium
c = coarse
vc = very coarse

Consistence: Consistence is cohesion of soil particles with one another, resistance of soil to deformation, and the adherence of soil to fingers. This property varies with water content, thus dry, moist, and wet consistency readings are taken. Moist and wet readings are taken in the field. Moist values are derived from the samples as they are taken in the field. Wet samples are acquired by the addition of water to the sample in the field. Dry samples are taken in the laboratory after all moisture has been removed.

Dry consistence:

lo = loose.	Noncoherent
so = weakly coherent.	Crushes easily to powder or a single grain.
sh = slightly hard.	Ped breaks easily between the thumb and forefinger.
h = hard.	Can be broken in the hands, yet is difficult to break between thumb and forefinger.
vh = very hard.	Ped breaks in hands, yet with difficulty.
eh = extremely hard.	Ped cannot be broken in hands.

Moist consistence:

lo = loose.	Noncoherent
vfr = very friable.	Ped crushes with gentle pressure.
fr = friable.	Ped crushes easily between thumb and forefinger with gentle to moderate pressure.
fi = firm.	Ped crushes between thumb and forefinger with moderated pressure, yet resistance is distinctly noticeable.
vfi = very firm.	Ped barely crushes between thumb and forefinger, under strong pressure.
efi = extremely firm.	Ped crushes under very strong pressure, yet cannot be crushed between thumb and forefinger.

Wet consistence:

Wet consistence measures both the stickiness and plasticity of a soil. Stickiness is measured by noting the adherence of wet soil to the fingers when it is pressed between the thumb and forefinger. Plasticity is measured by observing a wet soil's ability to form a thin ribbon or rod when it is rolled between the thumb and forefinger.

<u>Stickiness</u>

so = nonsticky.	Almost no adherence when pressure is released.

ss = slightly sticky.	Soil adheres to thumb and forefinger, yet comes off quite cleanly after pressure is released.
vs = very sticky.	Soil sticks to both thumb and forefinger and is markedly stretched when digits are separated.

Plasticity

po = nonplastic.	A thread cannot be formed.
ps = slightly plastic.	A thread can be formed, yet mass is deformed with very slight force.
p = plastic.	A thread can be formed with mass being deformed by slight force.
vp = very plastic.	A thread can be formed with mass being deformed by moderate to strong force.

Texture: Texture describes the amount of sand, clay, and silt found within the fine earth fraction as used on the textural triangle. Abbreviations are as follows.

C = Clay	SCL = Sandy Clay Loam
CL = Clay Loam	SL = Sandy Loam
L = Loam	Si = Silt
LS = Loamy Sand	SiC = Silty Clay
S = Sand	SiCL = Silty Clay Loam
SC = Sandy Clay	SiL = Silt Loam

Boundaries: Boundaries describe the lower boundary of each soil horizon in terms of distinctness and topography.

Distinctness:

a = abrupt.	Transition between horizons is less than 2 cm.
c = clear.	Transition between horizons is 2-5 cm thick.

g = gradual.	Transition between horizons is 5-15 cm thick.
d = diffuse.	Transition between horizons is more than 15 cm thick.

Topography:

s = smooth.	The boundary between horizons is parallel to the surface of the soil.
w = wavy.	Pockets between boundaries are wider than their depth.
i = irregular.	Pockets between boundaries are deeper than their width.
b = broken.	Horizon boundaries are unconnected with other parts.

APPENDIX B

Soil Properties and Profile Descriptions of Jack Creek and Suttle Lake Catenas

Soil Properties of Jack Creek Catena

SLOPE POSITION	HORIZON	DEPTH CM	STRUCTURE	DRY COLOR	MOIST COLOR	CONSISTENCE WET	CONSISTENCE DRY	CONSISTENCE MOIST	TEXTURE	BOUNDARIES	pH	%SAND	%SILT	%CLAY	%> 2mm	% O.M.
SU	A	0-26	1FGR	10YR4/6	10YR3/6	SOPO	SO	LO	LS	CS	6.1	81.8	16.7	1.5	20.6	2.9
	Bw1	26-40	2MSBK	10YR4/4	10YR3/6	SOPO	SO	LO	LS	GS	6.2	79.4	19.3	1.3	25.6	2
	Bw2	40-100	2MSBK	10YR5/8	10YR5/6	SOPO	SO	LO	LS	CS	6.6	78.8	19.7	1.5	42.6	1.5
	Cox	100-120	M	10YR6/2	2.5Y6/2	SOPO	SO	LO	LS		6.7	71.6	27.6	0.8	64.6	1.3
SH	A	0-15	1FGR	10YR5/4	10YR4/4	SOPO	SO	LO	LS	CS	6.6	79.8	18.7	1.4	17.9	2.2
	Bw	15-110	2MSBK	10YR5/8	10YR4/6	SOPO	SO	LO	LS	CS	6.9	78.4	20.3	1.4	43.2	1.6
	Cox	110-140	M	10YR6/2	2.5Y6/2	SOPO	SO	LO	LS		6.7	78.4	20.7	0.9	65.2	1.4
BS	A	0-28	1MGR	10YR4/4	10YR3/4	SSPS	SH	VFR	LS	CS	6.3	79.8	18.9	1.3	19.8	2.4
	Bw	28-160	2MSBK	10YR6/8	10YR6/6	SOPO	SO	LO	LS		6.6	79.2	19.6	1.2	42.1	2.2
FS	A	0-35	2MGR	10YR4/4	10YR3/4	SOPO	SO	LO	LS	CS	6.7	74.5	24.2	1.3	25.2	1.7
	Bw	35-170	2MSBK	10YR4/6	10YR4/4	SOPO	SO	LO	LS		6.1	77	21.8	1.2	20	1.5
TS	A	0-15	1FGR	10YR3/3	10YR2/2	SOPO	SO	LO	LS	CS	6	76.1	22.7	1.2	40.1	2
	Bw1	15-75	2MSBK	10YR4/4	10YR3/4	SOPO	SO	LO	LS	GS	6.2	77.8	21.2	1	35	1.6
	Bw2	75-200	2MSBK	10YR5/6	7.5YR4/6	SOPO	SO	LO	LS		6.1	80.2	18.5	1.3	30	1.4

JACK CREEK SOIL DESCRIPTION

MAPPING UNIT: JCSU DATE DESCRIBED: 10/12/96 ELEVATION: 1016m LOCATION: Summit

CLASSIFICATION: Typic Vitricryand QUADRANGLE: Black Butte

GEOMORPHIC SURFACE: Moraine SLOPE/ASPECT: 0°, SE

VEGETATION: *Pinus ponderosa*, sedges, forbs

COMMENTS: Dark yellowish brown to yellowish brown horizons with gradual to clear subtle boundaries. Sandy loam texture with very little clay content.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
A	0-26	10YR4/6d 10YR3/6m	81.8	16.7	1.5	20.6	LS	2.9	1fgr	6.1
Bw1	26-40	10YR4/4d 10YR3/6m	79.4	19.3	1.3	25.6	LS	2.0	2msbk	6.2
Bw2	40-100	10YR5/8d 10YR5/6m	78.8	19.7	1.5	42.6	LS	1.5	2msbk	6.6
Cox	100-120	10YR6/2d 2.5Y6/2m	71.6	27.6	0.8	64.6	LS	1.3	m	6.7

JACK CREEK SOIL DESCRIPTION

MAPPING UNIT: JCSH DATE DESCRIBED: 10/12/96 ELEVATION: 982m LOCATION: Shoulder

CLASSIFICATION: Typic Vitricryand QUADRANGLE: Black Butte

GEOMORPHIC SURFACE: Moraine SLOPE/ASPECT: 8°, SE

VEGETATION: *Pinus ponderosa*, sedges, forbs

COMMENTS: Dark yellowish brown to yellowish brown horizons with gradual to clear subtle boudaries. Loamy sand textures with very little clay content.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
A	0-15	10YR5/4d 10YR4/4m	79.8	18.7	1.4	17.9	LS	2.2	1fgr	6.6
Bw	15-110	10YR5/8d 10YR4/6m	78.4	20.3	1.4	43.2	LS	1.6	2msbk	6.9
Cox	110-140	10YR6/2d 2.5Y6/2m	78.4	20.2	0.9	65.2	LS	1.4	m	6.7

JACK CREEK SOIL DESCRIPTION

MAPPING UNIT: JCBS DATE DESCRIBED: 10/12/96 ELEVATION: 959m LOCATION: Back slope

CLASSIFICATION: Typic Vitricryand QUADRANGLE: Black Butte

GEOMORPHIC SURFACE: Moraine SLOPE/ASPECT: 16°, SE

VEGETATION: *Pinus ponderosa*, sedges, forbs.

COMMENTS: Dark yellowish brown, yellowish brown, and brownish yellow horizons with gradual to clear boudaries. Loamy sand texture with little clay content.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
A	0-28	10YR4/4d 10YR3/4m	79.8	18.9	1.3	19.8	LS	2.4	1mgr	6.3
Bw	28-160	10YR6/8d 10YR6/6m	79.2	19.6	1.2	42.1	LS	2.2	2msbk	6.6

JACK CREEK SOIL DESCRIPTION

MAPPING UNIT: JCFS   DATE DESCRIBED: 10/12/96   ELEVATION: 933m   LOCATION: Foot slope

CLASSIFICATION: Typic Vitricryand   QUADRANGLE: Black slope

GEOMORPHIC SURFACE: Moraine   SLOPE/ASPECT: 7°, SE

VEGETATION: *Pinus ponderosa,* sedges, forbs

COMMENTS: Dark yellowish brown to yellowish brown horizons with gradual to clear boundaries. Loamy sand textures with little clay content.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
A	0-35	10YR4/4d 10YR3/4m	74.5	24.2	1.3	25.2	LS	1.7	2mgr	6.7
Bw	35-170	10YR4/6d 10YR4/4m	77.0	21.8	1.2	20.0	LS	1.5	2msbk	6.1

JACK CREEK SOIL DESCRIPTION

MAPPING UNIT: JCTS DATE DESCRIBED: 10/12/96 ELEVATION: 922m LOCATION: Toe slope

CLASSIFICATION: Typic Vitricryand QUADRANGLE: Black Butte

GEOMORPHIC SURFACE: Moraine SLOPE/ASPECT: 5°, SE

VEGETATION: *Pinus ponderosa,* sedges, forbs

COMMENTS: Very dark brown, dark yellowish brown, and strong brown horizons with gradual to clear boundaries. Loamy sand texture with very little clay content.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
A	0-15	10YR3/3d 10YR2/2m	76.1	22.7	1.2	40.1	LS	2.0	1fgr	6.0
Bw1	15-75	10YR4/4d 10YR3/4m	77.8	21.2	1.0	35.0	LS	1.6	2msbk	6.2
Bw2	75-200	10YR5/6d 7.5YR4/6m	80.2	18.5	1.3	30.0	LS	1.4	2msbk	6.1

Soil Properties of Suttle Lake Catena

SLOPE POSITION	HORIZON	DEPTH CM	STRUCTURE	DRY COLOR	MOIST COLOR	CONSISTENCE WET	CONSISTENCE DRY	CONSISTENCE MOIST	TEXTURE	BOUNDARIES	pH	%SAND	%SILT	%CLAY	%> 2mm	%O.M.
SU	A	0-8	SG	10YR4/4	10YR3/3	SOPO	LO	LO	S	CS	6	93	5.9	1.1	49.8	1.2
	Bw	8-40	1MSBK	10YR5/6	10YR4/4	SOPO	SO	LO	S	CS	6.1	93.4	5.5	1	35	1.1
	2Coxb	40-80	M	2.5Y5/4	2.5Y4/4	SOPO	SO	LO	LS		6.5	80.3	18.4	1.3	56	1.1
SH	A	0-9	SG	10YR4/2	10YR2/2	SOPO	SO	LO	S	CS	5.8	88.7	9.2	2.1	43.8	1.4
	Bw	9-22	1FSBK	10YR4/6	10YR3/6	SOPO	SO	LO	S	CW	6.2	92.6	5.5	1.9	39	0.7
	C	22-90	SG	ND	7.5YR3/4 & 10YR2/2	SOPO	ND	LO	ND	CW	ND	ND	ND	ND	ND	0.2
	2Cb	90-100	M	10YR5/2	10YR3/2	SOPO	SO	LO	S		6.3	92.6	5.9	1.7	17.6	0.4
BS	A	0-11	SG	10YR4/2	10YR2/2	SOPO	SO	LO	S	AS	5.8	93.5	4.9	1.7	41.2	1.3
	C	11-50	SG	ND	2.5YR3/4 & 10YR2/1	SOPO	ND	LO	ND	GS	ND	ND	ND	ND	ND	0.4
	2Cb	50-110	1FSBK	2.5Y4/4	10YR4/3	SOPO	SO	LO	LS		6.3	81	17.8	1.2	18	1.2
FS	C	0-52	SG	ND	10YR2/2	SOPO	ND	LO	N D	CS	ND	ND	ND	ND	ND	0.5
	2Bb	52--142	2MSBK	10YR3/6	10YR3/4	SOPO	SO	LO	LS	CS	6.2	84.6	14.4	1	8.5	1.6
	2Cb	142-160	M	2.5Y6/6	2.5Y5/6	SOPO	SO	LO	LS		6	71.4	28	1.6	53	1.3
TS	C	0-60	SG	ND	10YR2/1	SOPO	ND	LO	ND	CS	ND	ND	ND	ND	ND	0.5
	2Bb	60-120	2MSBK	10YR3/3	10YR2/2	SOPO	SO	LO	LS	CS	6.1	80	19.1	0.9	4.9	0.9
	3Bb	120-127	M	7.5YR5/8	5YR5/8	SSPS	SH	VFR	SL		6.9	65.8	32.2	2.1	16.5	1.5

No Data (ND) was obtained for many of the horizons with a large percentage of scoria deposits.

SUTTLE LAKE SOIL DESCRIPTION

MAPPING UNIT: SLSU DATE DESCRIBED: 11/09/96 ELEVATION: 1190m LOCATION: Summit

CLASSIFICATION: Typic Vitricryand QUADRANGLE: Black Butte

GEOMORPHIC SURFACE: Moraine SLOPE/ASPECT: 1°, SE

VEGETATION: *Pinus ponderosa, Pseudotsuga menziesii, Symphoricarpus albus,* sedges, forbs

COMMENTS: Weakly developed soil with sandy textured horizons and low clay contents. The A and Bw horizons are gradational horizons between volcanic material and glacial till parent material of the Cox horizon.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
A	0-8	10YR4/4d 10YR3/3m	93.0	6.0	1.0	49.8	S	1.2	sg	6.0
Bw	8-40	10YR5/6d 10YR4/4m	93.4	5.5	1.0	35	S	1.1	1msbk	6.1
2Coxb	40-80	2.5Y5/4d 2.5Y4/4m	80.3	18.4	1.3	56	LS	1.1	m	6.5

SUTTLE LAKE SOIL DESCRIPTION

MAPPING UNIT: SLSH DATE DESCRIBED: 11/09/96 ELEVATION: 1146m LOCATION: Shoulder

CLASSIFICATION: Typic Vitricryand QUADRANGLE: Black Butte

GEOMORPHIC SURFACE: Moraine SLOPE/ASPECT: 17°, SE

VEGETATION: *Pinus ponderosa, Pseudotsuga menziesii, Symphocarpus albus,* sedges, forbs

COMMENTS: Weakly developed soil with 68 cm of scoria in the C layer. A buried C horizon, 2Cb, of predominantly glacial till parent material occurred at 90 cm of depth. Sandy textures prevail with little clay content.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
A	0-9	10YR4/2d 10YR2/2m	88.7	9.2	2.1	43.8	S	1.4	sg	5.8
Bw	9-22	10YR4/6d 10YR3/6m	92.6	5.5	1.9	39.0	S	0.7	1fabk	6.2
C	22-90	7.5YR3/4 & 10YR2/2m	ND	ND	ND	ND	ND	0.2	sg	ND
2Cb	90-100	10YR5/2d 10YR3/2m	92.6	5.9	1.7	17.6	S	0.4	m	6.3

No Data (ND) was collected for many of the soil properties of horizons with a large percentage of scoria deposits.

SUTTLE LAKE SOIL DESCRIPTION

MAPPING UNIT: SLBS DATE DESCRIBED: 11/09/96 ELEVATION: 1128m LOCATION: Back slope

CLASSIFICATION: Typic Vitricryand QUADRANGLE: Black Butte

GEOMORPHIC SURFACE: Moraine SLOPE/ASPECT: 22°, SE

VEGETATION: *Pinus ponderosa, Pseudotsuga menziesii, Symphocaripus albus,* sedges, forbs

COMMENTS: Weakly developed soil with 39 cm of scoria in the C horizon. Underneath the scoria lies the initial parent material lin the 2Cb horizon.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
A	0-11	10YR4/2d 10YR2/2m	93.5	4.9	1.7	41.2	S	1.3	sg	5.8
C	11-50	2.5Y3/4 & 10YR2/1 m	ND	ND	ND	ND	ND	0.4	sg	ND
2Cb	50-110	2.5Y4/4d 10YR4/3m	81.0	17.8	1.2	18	LS	1.2	1fsbk	6.3

No Data (ND) was collected for many of the soil properties of horizons with a large percentage of scoria deposits.

SUTTLE LAKE SOIL DESCRIPTION

MAPPING UNIT: SLFS DATE DESCRIBED: 11/09/96 ELEVATION: 1097m LOCATION: Foot slope

CLASSIFICATION: Typic Vitricryand QUADRANGLE: Black Butte

GEOMORPHIC SURFACE: Moraine SLOPE/ASPECT: 11°, SE

VEGETATION: *Pinus ponderosa, Pseudotsuga menziesii, Symphocaripus albus,* sedges, forbs

COMMENTS: Weakly developed soil with 52 cm of scoria occurring at the surface C horizon with glacial parent material lying below.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
C	0-52	10YR2/2m	ND	ND	ND	ND	ND	0.5	sg	ND
2Bb	52-142	10YR3/6d 10YR3/4m	84.6	14.4	1.0	8.5	LS	1.6	2msbk	6.2
2Cb	142-160	2.5Y6/6d 2.5Y5/6m	71.4	28..0	1.6	53	LS	1.3	m	6.0

No Data (ND) was collected for many of the soil properties of horizons with a large percentage of scoria deposits.

SUTTLE LAKE SOIL DESCRIPTION

MAPPING UNIT: SLTS DATE DESCRIBED: 11/09/96 ELEVATION: 1091m LOCATION: Toe slope

CLASSIFICATION: Typic Vitricryand QUADRANGLE: Black Butte

GEOMORPHIC SURFACE: Moraine SLOPE/ASPECT: 3°, SE

VEGETATION: *Pinus ponderosa, Pseudotsuga menziesii, Symphocaripus albus,* sedges, forbs

COMMENTS: Weakly developed soil with 60 cm of scoria occuring at the top C horizon of the profile. Bottom horizons are two buried B horizons with redder hues, higher silt and clay concentrations as well as higher organic carbon levels.

HORIZON	DEPTH (cm)	COLOR (DRY) (MOIST)	SAND %	SILT %	CLAY %	% > 2mm	TEXTURE	ORGANIC MATTER %	STRUCTURE	pH 1:1 WATER
C	0-60	10YR2/1m	ND	ND	ND	ND	ND	0.5	SG	ND
2Bb	60-120	10YR3/3d 10YR2/2m	80.0	19.1	0.9	4.9	LS	0.9	2msbk	6.1
3Bb	120-127	7.5YR5/8d 5YR5/8m	65.8	32.2	2.1	16.5	SL	1.5	m	6.9

No Data (ND) was collected for many of the soil properties of horizons with a large percentage of scoria deposits.

APPENDIX C

Profile Development Index Values for Horizons and Profiles
of Jack Creek and Suttle Lake Catenas

JACK CREEK PDI VALUES

MAPPING UNIT: JCSU　　LOCATION: SUMMIT　　HORIZON: A

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR4/6d 10YR3/6m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 4)d + 10(1+4)m Xr = 100	Xrn = 100 ÷ 190 Xrn = 0.53
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 1FGR	PARENT MATERIAL STRUCTURELESS	Xs = 10(1) + 10(1) Xs = 20	Xtn = 20 ÷ 60 Xtn = 0.33
				SUM = 0.96

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.96 ÷ 5
= 0.19

JACK CREEK PDI VALUES

MAPPING UNIT: JCSU LOCATION: SUMMIT HORIZON: Bw1

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR4/4d 10YR3/6m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1+2)d + 10(1+4)m Xr = 70	Xrn = 70 ÷ 190 Xrn = 0.37
TOTAL TEXTURE	HORIZON PROPERTY LS SO PS	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 2MSBK	PARENT MATERIAL STRUCTURELESS	Xs = 10(2) + 10(1) Xs = 30	Xsn = 30 ÷ 60 Xtn = 0.50
				SUM = 0.97

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.97 ÷ 5
= 0.19

JACK CREEK PDI VALUES

MAPPING UNIT: JCSU   LOCATION: SUMMIT   HORIZON: Bw2

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	<u>HORIZON PROPERTY</u> 10YR5/8m 10YR5/6d	<u>PARENT MATERIAL</u> 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 6)d +10(1 + 4)m Xr = 110	Xrn = 110 ÷ 190 Xrn = 0.58
TOTAL TEXTURE	<u>HORIZON PROPERTY</u> LS SO PO	<u>PARENT MATERIAL</u> LS SO PO	Xt = 10(0 + 1 + 1) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	<u>HORIZON PROPERTY</u> SO	<u>PARENT MATERIAL</u> LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	<u>HORIZON PROPERTY</u> LO	<u>PARENT MATERIAL</u> LO	Xmc = 10(0) Xmc = 0	Xmcn = 0÷ 100 Xmcn = NA
STRUCTURE	<u>HORIZON PROPERTY</u> 2MSBK	<u>PARENT MATERIAL</u> STRUCTURELESS	Xt = 10(2) + 10(1) Xt = 30	Xtn = 30 ÷ 60 Xtn = 0.50
				SUM = 1.18

Horizon Index = Sum of normalized values ÷ number of quantifies properties
= 1.18 ÷ 5
= 0.24

JACK CREEK PDI VALUES

MAPPING UNIT: JCSU LOCATION: SUMMIT HORIZON: Cox

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	<u>HORIZON PROPERTY</u> 10YR6/2d 2.5Y6/2m	<u>PARENT MATERIAL</u> 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 0)d + 10(0+0)m Xr = 10	Xrn = 10 ÷ 190 Xrn = 0.05
TOTAL TEXTURE	<u>HORIZON PROPERTY</u> LS SO PO	<u>PARENT MATERIAL</u> LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	<u>HORIZON PROPERTY</u> SO	<u>PARENT MATERIAL</u> LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.1
MOIST CONSISTENCY	<u>HORIZON PROPERTY</u> LO	<u>PARENT MATERIAL</u> LO	Xmc = 10(1) Xmc = 10	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	<u>HORIZON PROPERTY</u> M	<u>PARENT MATERIAL</u> STRUCTURELESS	Xs = 10(0) +10(0) Xs = 0	Xsn = 0 ÷ 60 Xsn = NA
				SUM = 0.15

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.15 ÷ 5
= 0.03

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: JCSU LOCATION: SUMMIT

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
A	0.19	26	4.94
Bw1	0.19	14	2.66
Bw2	0.24	60	14.40
			SUM = PDI SUM = 22.00

* To establish a degree of uniformity, only the A and B horizons are calculated.

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 22.00 ÷ 100
WMPDI = 0.22

JACK CREEK PDI VALUES

MAPPING UNIT: JCSH LOCATION: SHOULDER HORIZON: A

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR5/4d 10YR4/4m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 2)d + 10(1+2)m Xr = 40	Xrn = 40 ÷ 190 Xrn = 0.21
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 1FGR	PARENT MATERIAL STRUCTURELESS	Xs = 10(1) + 10(1) Xs = 20	Xsn = 20 ÷ 60 Xsn = 0.33
				SUM = 0.64

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.64 ÷ 5
= 0.13

JACK CREEK PDI VALUES

MAPPING UNIT: JCSH LOCATION: SHOULDER HORIZON: Bw

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR5/8d 10YR4/6m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 6)d +10(1 + 4)m Xr = 120	Xrn = 120 ÷ 190 Xrn = 0.63
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.1
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 2MSBK	PARENT MATERIAL STRUCTURELESS	Xs = 10(2) + 10(1) Xs = 30	Xsn = 30 ÷ 60 Xsn = 0.50
				SUM = 1.23

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 1.23 ÷ 5
= 0.25

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: JCSH LOCATION: SHOULDER

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
A	0.15	15	1.95
Bw	0.25	95	23.75
			SUM = PDI SUM = 25.70

* To establish a degree of uniformity, only the A and B horizons are calculated.

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 25.7 ÷ 110
WMPDI = 0.23

JACK CREEK PDI VALUES

MAPPING UNIT: JCBS LOCATION: BACK SLOPE HORIZON: A

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR4/4d 10YR3/4m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 2)d + 10(1+2)m Xr = 40	Xrn = 40 ÷ 190 Xrn = 0.21
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.1
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 1MGR	PARENT MATERIAL STRUCTURELESS	Xs = 10(1) +10(1) Xs = 20	Xsn = 20 ÷ 60 Xsn = 0.33
				SUM = 0.64

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.64 ÷ 5
= 0.13

JACK CREEK PDI VALUES

MAPPING UNIT: JCBS LOCATION: BACK SLOPE HORIZON: Bw

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR6/8d 10YR6/6m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 6)d +10(1 + 4)m Xr = 100	Xrn = 100 ÷ 190 Xrn = 0.53
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc =10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 2MSBK	PARENT MATERIAL STRUCTURELESS	Xs = 10(2) + 10(1) Xs = 30	Xsn = 30 ÷ 60 Xsn = 0.50
				SUM = 1.13

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 1.13 ÷ 5
= 0.23

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: JCBS LOCATION: BACK SLOPE

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
A	0.13	28	3.64
Bw	0.23	132	30.36
			SUM = PDI SUM = 34.00

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 34.00 ÷ 160
WMPDI = 0.21

JACK CREEK PDI VALUES

MAPPING UNIT: JCFS LOCATION: FOOT SLOPE HORIZON: A

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR4/4d 10YR3/4m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 2)d +10(1 + 2)m Xr = 60	Xrn = 60 ÷ 190 Xrn = 0.32
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 1MGR	PARENT MATERIAL STRUCTURELESS	Xs = 10(1) + 10(1) Xs = 20	Xsn = 20 ÷ 60 Xsn = 0.30
				SUM = 0.72

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.72 ÷ 5
= 0.14

JACK CREEK PDI VALUES

MAPPING UNIT: JCFS LOCATION: FOOT SLOPE HORIZON: Bw

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	<u>HORIZON PROPERTY</u> 10YR4/6d 10YR4/4m	<u>PARENT MATERIAL</u> 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 4)d +10(1 + 2)m Xr = 80	Xrn = 80 ÷ 190 Xrn = 0.42
TOTAL TEXTURE	<u>HORIZON PROPERTY</u> LS SO PO	<u>PARENT MATERIAL</u> LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	<u>HORIZON PROPERTY</u> SO	<u>PARENT MATERIAL</u> LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	<u>HORIZON PROPERTY</u> LO	<u>PARENT MATERIAL</u> LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	<u>HORIZON PROPERTY</u> 2MSBK	<u>PARENT MATERIAL</u> STRUCTURELESS	Xs = 10(2) + 10(1) Xs = 30	Xsn = 30 ÷ 60 Xsn = 0.50
				SUM = 1.02

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 1.02 ÷ 5
= 0.20

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: JCFS LOCATION: FOOT SLOPE

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
A	0.14	35	4.9
B	0.20	135	27.0
			SUM = PDI SUM = 31.90

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 31.90 ÷ 170
WMPDI = 0.19

JACK CREEK PDI VALUES

MAPPING UNIT: JCTS LOCATION: TOE SLOPE HORIZON: A

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR3/3d 10YR2/2m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 +1)d + 10(1 + 0)m Xr = 30	Xrn = 30 ÷ 190 Xrn = 0.16
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn =10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 1FGR	PARENT MATERIAL STRUCTURELESS	Xs = 10(1) + 10(1) Xs = 20	Xsn = 20 ÷ 60 Xsn = 0.33
				SUM = 0.59

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.59 ÷ 5
= 0.12

JACK CREEK PDI VALUES

MAPPING UNIT: JCTS LOCATION: TOE SLOPE HORIZON: Bw1

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR4/4d 10YR3/4m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 2)d +10(1 + 2)m Xr = 60	Xrn = 60 ÷ 190 Xrn = 0.32
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 2MSBK	PARENT MATERIAL STRUCTURELESS	Xs = 10(2) + 10(1) Xs = 50	Xsn = 50 ÷ 60 Xsn = 0.83
				SUM = 1.25

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 1.25 ÷ 5
= 0.25

JACK CREEK PDI VALUES

MAPPING UNIT: JCTS | LOCATION: TOE SLOPE | HORIZON: Bw2

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR5/6d 7.5YR4/6m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 +4)d + 10(2 + 4)m Xr = 110	Xrn = 110 ÷ 190 Xrn = 0.58
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 2MSBK	PARENT MATERIAL STRUCTURELESS	Xs = 10(2) + 10(1) Xs = 30	Xsn = 30 ÷ 100 Xsn = 0.30
				SUM = 0.98

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.98 ÷ 5
= 0.20

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: JCTS LOCATION: TOE SLOPE

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
A	0.12	15	1.8
Bw1	0.25	60	15
Bw2	0.20	125	25
			SUM = PDI SUM = 41.8

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 41.8 ÷ 200
WMPDI = 0.21

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLSU   LOCATION: SUMMIT   HORIZON: A

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR4/4d 10YR3/3m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 2)d +10(1 + 1)m Xr = 50	Xrn = 50 ÷ 190 Xrn = 0.26
TOTAL TEXTURE	HORIZON PROPERTY S SO PO	PARENT MATERIAL LS SO PO	Xt = 10(-1 + + 0) Xt = -10	Xtn = -10÷ 90 Xtn = -0.11
DRY CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xdc = 10(0) Xdc = 0	Xdcn = 0 ÷ 100 Xdcn = NA
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY SG	PARENT MATERIAL STRUCTURELESS	Xs = 10(0) + 10(0) Xs = 0	Xsn = 0÷ 60 Xsn = NA
				SUM = 0.15

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.15 ÷ 5
= 0.03

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLSU　　　LOCATION: SUMMIT　　　HORIZON: Bw

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR5/6d 10YR4/4m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 4)d +10(1 + 2)m Xr = 80	Xrn = 80 ÷ 190 Xrn = 0.42
TOTAL TEXTURE	HORIZON PROPERTY S SO PO	PARENT MATERIAL LS SO PO	Xt = 10(-1 + 0 + 0) Xt = -10	Xtn = -10÷ 90 Xtn = -0.11
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 1MSBK	PARENT MATERIAL STRUCTURELESS	Xs = 10(1) + 10(1) Xs = 20	Xsn = 20÷ 60 Xsn = 0.33
				SUM = 0.64

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.64 ÷ 5
= 0.13

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLSU LOCATION: SUMMIT HORIZON: 2Coxb

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 2.5Y5/4d 2.5Y4/4m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(0+2)d + 10(0 + 2)m Xr = 40	Xrn = 40 ÷ 190 Xrn = 0.21
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY M	PARENT MATERIAL STRUCTURELESS	Xs = 10(0) + 10(0) Xs = 0	Xsn = 0÷ 60 Xsn = NA
				SUM = 0.31

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.31 ÷ 5
= 0.06

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: SLSU LOCATION: SUMMIT

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
A	0.03	8	0.24
Bw	0.13	32	4.16
2Coxb	0.13	40	2.40
			SUM = PDI SUM = 6.80

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 6.80 ÷ 80
WMPDI = 0.09

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLSH LOCATION: SHOULDER HORIZON: A

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR4/2d 10YR2/2m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 0)d +10(1 + 0)m Xr = 20	Xrn = 20 ÷ 190 Xrn = 0.22
TOTAL TEXTURE	HORIZON PROPERTY S SO PO	PARENT MATERIAL LS SO PO	Xt = 10(-1 + 0 + 0) Xt = -10	Xtn = -10 ÷ 90 Xtn = -0.11
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY SG	PARENT MATERIAL STRUCTURELESS	Xs = 10(0) + 10(0) Xs = 0	Xsn = 0 ÷ 60 Xsn = NA
				SUM = 0.11

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.11 ÷ 5
= 0.02

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLSH LOCATION: SHOULDER HORIZON: Bw

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR4/6d 10YR3/6m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 4)d +10(1 + 4)m Xr = 100	Xrn = 100 ÷ 190 Xrn = 0.53
TOTAL TEXTURE	HORIZON PROPERTY S SO PO	PARENT MATERIAL LS SO PO	Xt = 10(-1 + 0 + 0) Xt = -10	Xtn = -10 ÷ 90 Xtn = -0.11
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 1FSBK	PARENT MATERIAL STRUCTURELESS	Xs = 10(1) + 10(1) Xs = 20	Xsn = 20÷ 60 Xsn = 0.33
				SUM = 0.85

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.85 ÷ 5
= 0.17

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLSH LOCATION: SHOULDER HORIZON: 2Cb

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR5/2d 10YR3/2m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 0)d +10(1 + 0)d Xr = 20	Xrn = 20 ÷ 190 Xrn = 0.11
TOTAL TEXTURE	HORIZON PROPERTY S SO PO	PARENT MATERIAL LS SO PO	Xt = 10(-1 + 0 + 0) Xt = -10	Xtn = -10 ÷ 90 Xtn = -0.11
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY M	PARENT MATERIAL STRUCTURELESS	Xs = 10(0) + 10(0) Xs = 0	Xsn = 0 ÷ 60 Xsn = NA
				SUM = 0.10

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.10 ÷ 5
= 0.02

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: SLSH LOCATION: SHOULDER

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
A	0.02	9	0.18
Bw	0.17	13	2.21
C	ND	68	ND *
2Cb	0.02	10	0.20
			SUM = PDI SUM = 2.59

* Scoria deposits with no data are left out of the equation.

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 2.59 ÷ 32
WMPDI = 0.08

SUTTLE LAKE VALUES

MAPPING UNIT: SLBS LOCATION: BACK SLOPE HORIZON: A

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR4/2d 10YR2/2m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 0)d + 10(1 +0)m Xr = 20	Xrn = 20 ÷ 190 Xrn = 0.11
TOTAL TEXTURE	HORIZON PROPERTY S SO PO	PARENT MATERIAL LS SO PO	Xt = 10(-1 + 0 + 0) Xt = -10	Xtn = -10 ÷ 90 Xtn = -0.11
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY SG	PARENT MATERIAL STRUCTURELESS	Xs = 10(1) + 10(1) Xs = 20	Xsn = 20 ÷ 60 Xsn = 0.33
				SUM = 0.43

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.43 ÷ 5
= 0.09

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLBS LOCATION: BACK SLOPE HORIZON: 2Cb

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 2.5Y4/4d 10YR4/3m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(0 + 2)d + 10(1 +1)m Xr = 40	Xrn = 40 ÷ 190 Xrn = 0.21
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 +0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	HORIZON PROPERTY 1FSBK	PARENT MATERIAL STRUCTURELESS	Xs = 10(1) + 10(1) Xs = 20	Xsn = 20 ÷ 60 Xsn = 0.33
				SUM = 0.65

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.65 ÷ 5
= 0.13

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: SLBS LOCATION: BACK SLOPE

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
A	0.09	11	0.99
2C	ND	39	ND
2Cb	0.13	60	7.8
			SUM = PDI SUM = 8.79

* Scoria deposits with no data are left out of the equation.

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 8.79 ÷ 71
WMPDI = 0.12

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLFS　　LOCATION: FOOT SLOPE　　HORIZON: 2Bb

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 10YR3/6d 10YR3/4m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	$Xr = 10(1 + 4)d + 10(1 + 2)m$ $Xr = 80$	$Xrn = 80 \div 190$ $Xrn = 0.42$
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	$Xt = 10(0 + 0 + 0)$ $Xt = 0$	$Xtn = 0 \div 90$ Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	$Xdc = 10(1)$ $Xdc = 10$	$Xdcn = 10 \div 100$ $Xdcn = 0.10$
MOIST CONSISTENCY	HORIZON PROPERTY LO	PARENT MATERIAL LO	$Xmc = 10(0)$ $Xmc = 0$	$Xmcn = 0 \div 100$ Xmcn = NA
STRUCTURE	HORIZON PROPERTY 2MSBK	PARENT MATERIAL STRUCTURELESS	$Xs = 10(2) + 10(1)$ $Xs = 30$	$Xsn = 30 \div 60$ $Xsn = 0.50$
				SUM = 1.02

Horizon Index = Sum of normalized values ÷ number of quantified properties

$= 1.02 \div 5$

$= 0.20$

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLFS LOCATION: FOOT SLOPE HORIZON: 2Cb

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 2.5Y6/6d 2.5Y5/6m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(+4)d +10(0 +4)m Xr = 80	Xrn = 80 ÷ 190 Xrn = 0.42
TOTAL TEXTURE	HORIZON PROPERTY LS SO PO	PARENT MATERIAL LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	HORIZON PROPERTY SO	PARENT MATERIAL LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	HORIZON PROPERTY VFR	PARENT MATERIAL LO	Xmc = 10(1) Xmc = 10	Xmcn = 10 ÷ 100 Xmcn = 0.10
STRUCTURE	HORIZON PROPERTY M	PARENT MATERIAL STRUCTURELESS	Xs = 10(0) + 10(0) Xs = 0	Xsn = 0 ÷ 60 Xsn = NA
				SUM = 0.62

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.62 ÷ 5
= 0.12

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: SLFS LOCATION: FOOT SLOPE

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
C	ND	52	ND
2Bb	0.20	90	18.0
2Cb	0.12	18	2.16
			SUM = PDI SUM = 20.16

* Scoria deposits with no data are left out of the equation.

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 20.16 ÷ 108
WMPDI = 0.19

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLTS LOCATION: TOE SLOPE HORIZON: 2Bb

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
	HORIZON PROPERTY	PARENT MATERIAL		
RUBIFICATION	10YR3/3d 10YR2/2m	2.5Y5/2d 2.5Y3/2m	Xr = 10(1 + 1)d + 10(1 +0)m Xr = 30	Xrn = 30 ÷ 190 Xrn = 0.16
TOTAL TEXTURE	LS SO PO	LS SO PO	Xt = 10(0 + 0 + 0) Xt = 0	Xtn = 0 ÷ 90 Xtn = NA
DRY CONSISTENCY	SO	LO	Xdc = 10(1) Xdc = 10	Xdcn = 10 ÷ 100 Xdcn = 0.10
MOIST CONSISTENCY	LO	LO	Xmc = 10(0) Xmc = 0	Xmcn = 0 ÷ 100 Xmcn = NA
STRUCTURE	2MSBK	STRUCTURELESS	Xs = 10(2) + 10(1) Xs = 30	Xsn = 30 ÷ 60 Xsn = 0.50
				SUM = 0.76

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 0.76 ÷ 5
= 0.15

SUTTLE LAKE PDI VALUES

MAPPING UNIT: SLTS   LOCATION: TOE SLOPE   HORIZON: 3Bb

SOIL PROPERTY	OBSERVED VALUES		SOIL PROPERTY VALUE	NORMALIZATION VALUE
RUBIFICATION	HORIZON PROPERTY 7.5YR5/8d 5YR5/8 m	PARENT MATERIAL 2.5Y5/2d 2.5Y3/2m	Xr = 10(2 + 6)d + 10(3 +6)m Xr = 170	Xrn = 170 ÷ 190 Xrn = 0.90
TOTAL TEXTURE	HORIZON PROPERTY SL SS PS	PARENT MATERIAL LS SO PO	Xt = 10(2 +1 + 1) Xt = 0	Xtn = 40 ÷ 90 Xtn = 0.44
DRY CONSISTENCY	HORIZON PROPERTY SH	PARENT MATERIAL LO	Xdc = 10(2) Xdc = 20	Xdcn = 20 ÷ 100 Xdcn = 0.20
MOIST CONSISTENCY	HORIZON PROPERTY VFR	PARENT MATERIAL LO	Xmc = 10(1) Xmc = 10	Xmcn = 10 ÷ 100 Xmcn = 0.10
STRUCTURE	HORIZON PROPERTY M	PARENT MATERIAL STRCUTURELESS	Xs = 10(0) + 10(0) Xs = 0	Xsn = 0 ÷ 60 Xsn = NA
				SUM = 1.64

Horizon Index = Sum of normalized values ÷ number of quantified properties
= 1.64 ÷ 5
= 0.33

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX

MAPPING UNIT: SLTS LOCATION: TOE SLOPE

HORIZON	HORIZON INDEX VALUE (HI)	HORIZON THICKNESS (cm)	HI X THICKNESS
C	ND	60	ND
2Bb	0.15	60	9.0
3Bb	0.33	7	2.31
			SUM = PDI SUM = 11.31

* Scoria deposits with no data are left out of the equation.

WEIGHTED MEAN PROFILE DEVELOPMENT INDEX (WMPDI) = PDI ÷ DEPTH OF SOIL (cm)

WMPDI = 11.31 ÷ 67
WMPDI = 0.17