Applying GIS to Soil-geomorphic Landscape Mapping in the Lookout Creek Valley, Western Cascades, Oregon

by

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Abstract

Large scale, first order, soil-landscape mapping was conducted on soils supporting old-growth forests in western Oregon at the H.J. Andrews Experimental Forest. Soils representative of geomorphic landscape units within the Lookout Creek Valley bottom including the 1.5-hectare Detritus Input Removal and Transfer (DIRT) study site were sampled, analyzed, mapped, classified and soil development rates estimated. Temporal relations of soil map units were analyzed using the Profile Development Index (PDI), rock and mineral weathering method (RMW), and correlation with relative dating efforts of H.J. Andrews researchers. Chronofunctions were developed based on terrace chronosequence soil-geomorphic map units. The DIRT study investigated how rates and sources of plant litter control the accumulation and turnover of organic matter and nutrients in forest soils. Twenty-one 10 x 15 meter plots (one control and six treatments with three replicates) were sited on five coalesced Pleistocene and Holocene alluvial fans, emanating from the adjacent valley hillslope, covering a remnant Pleistocene alluvial terrace. A first order soil-landscape survey of the study site, mapped at a scale of 1:500, revealed nine geomorphic landscape map units, ten soil map units, two soil orders (Andisol and Inceptisol), three soil taxonomic subgroups (Typic Hapludands, Andic Dystrudepts and Vitrandic Dystrudepts) and four PDI age classes. Geographic Information Systems technology was used to spatially relate treatment plots to soil map units, soil taxonomic classification and PDI. Results show high variability in soil map units and geomorphic landscape units among the DIRT Plots.

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1.0 Introduction

Study of the geology, geomorphology and soils of the H.J. Andrews Experimental Forest, Cascade Range, Oregon, have focused on catchment to basin scales (Stephens, 1964; Dyrness, 1967; Legard and Meyer, 1973; Swanson and James, 1975a and 1975b; Swanson et al., 1982; Grant and Swanson, 1995). Whereas basin-wide landscape surveys provide general information, they are conducted at a scale that is not commensurate to the many ongoing, plot-size Long Term Ecological Research (LTER) studies. One component of the LTER program is the Detritus Input Removal and Transfer (DIRT) study where researchers investigate the role of plant litter, both from above and belowground, in controlling the accumulation and turnover of organic matter and nutrients in forest soils.

Little attention has been given to large-scale investigation in the Cascade Range, Oregon, of mountainous floodplains and the interaction between hillslope erosional and depositional processes and soil systems. Soil-landscape relations and distribution are complex in these environs where a number of geomorphic, hydrologic and soil-forming processes spatially and temporally interact. The principal processes responsible for this heterogeneity are disturbance driven and include earthflows, landslides, debris flows, rotational slumps, alluvial deposition and entrenchment, surface and sub-surface water flow paths, fire and treethrow. For the H.J Andrews, researchers identified, in particular, the widespread nature of alluvial fans covering remnant fluvial terraces as a driving mechanism (Swanson and James, 1975a and 1975b; Grant and Swanson, 1995). This should lead to high spatial and temporal soil-geomorphic landscape variability throughout the development of valley bottoms at the H.J. Andrews, the setting of the individual DIRT plots.

The intent of this study is two fold: 1) Investigation of geomorphology and soils of coalesced alluvial fan deposits covering a remnant terrace of Lookout Creek. This entails first-order, soil-landscape mapping, pedon descriptions, taxonomic classification and relative dating of soils, and 2) Spatial analysis of the DIRT plot study site. This entails relating soil map units with the various DIRT plot treatments and controls with the intent of providing researchers insight to the heterogeneity, distribution and physical properties of these forest soils.

2.0 Materials and Methods

2.1 Study Site

The H.J. Andrews Experimental Forest is located on the western slope of the Cascade Range, an active volcanic arc. It is roughly 80 km (50 mi.) east of Eugene, Oregon and includes the entire watershed of Lookout Creek, about 6400 hectares (15,800 acres) (Figure 1). Elevation ranges from 410 to 1630 m (1350 to 5340 ft) with steep (35 to 90%) valley side slopes and incised stream drainages underlain by bedrock consisting of a suite of volcanic rocks of basalt and andesite composition, including pyroclastic tuffs, breccias, lava flows, ash flows, air fall tuffs, cinder beds and fluvial tuffaceous sediments (Dyrness, 1967; Swanson and James, 1975a).

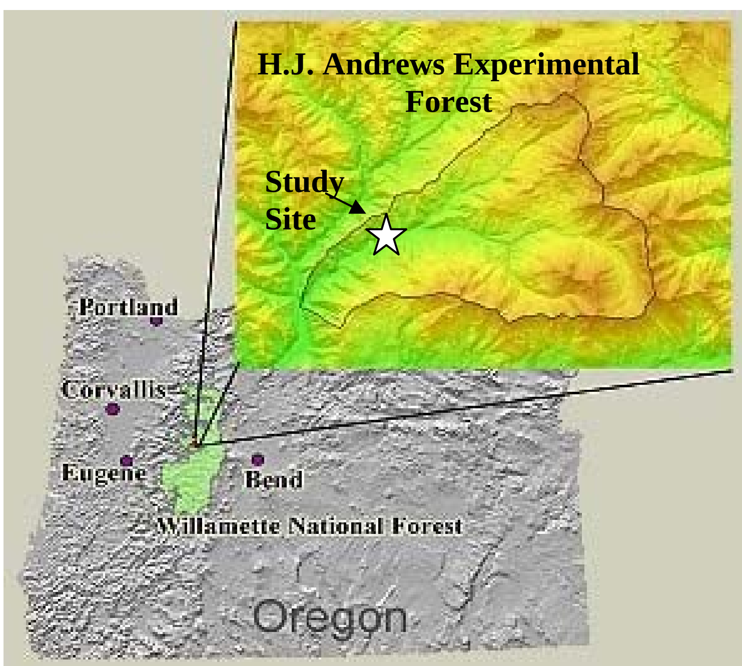

Figure 1. Location of H.J. Experimental Forest in the Western Cascades, Oregon. Star shows location of study site within the Lookout Creek valley bottom.

The study site is located within the Lookout Creek valley (N44^0 13'51.71, W122^0 13'16.21) and ranges in elevation from 531 to 556m. It lies within the maritime climate zone having mild wet winters and cool dry summers. Temperatures range from 1 ^{0}C in January to 18 ^{0}C in July with a mean annual precipitation of 215 cm (H.J. Andrews meteorological records 2003).

2.2 Field Methods

Large-scale soil-geomorphic field mapping was aided by the production of a detailed site map. A topographic base map, with 0.25 meter contour intervals, was generated using a Topcon total station theodolite, data logger survey equipment and AutoCAD 2000i. Survey data points were coded to distinguish DIRT plot and soil pit locations. Printouts of the map at a scale of 1:500 were used during field reconnaissance to delineate geomorphic landscape units and soil mapping units. Fifteen small soil pits representative of geomorphic landscape units within the study area and chronosequence were described and sampled using Soil Survey Methods (Soil Survey Staff, 1993; Schoeneberger et al., 1998). Soil map units are defined as sets of interrelated properties that are characteristic of soil as a natural body (Soil Survey Staff, 1993). Boundaries of soil map units were refined using a bucket auger and small shovel pits. Compass, tape and clinometer were used to survey a transect across the study site including Lookout Creek terraces and active floodplain.

Soil classification was determined according to criteria in the Keys to Soil Taxonomy (Soil Survey Staff, 1998). Where data were not available for various levels of the taxonomic classification system, inferences were made based on field observation and correlation with existing data (Paeth, 1970; Brown, 1975).

2.3 Analytical Methods

Analysis of field mapping efforts and soil data were aided through the use of GIS. ArcView GIS 3.2 was used for map production and spatial analysis through intersection of various map themes (i.e. plot boundaries, plot treatments, soil map units). Soil map units, geomorphic landscape units, taxonomic map units and profile development map units were digitized by hand.

Soil development was quantified using the Profile-Development Index (PDI) (Harden, 1982; Harden and Taylor, 1983; Birkeland et al., 1991; Birkeland, 1999). Selected field properties of pedon horizons were assigned points, dependent on particular aggradations of pedologic properties compared to those of the assumed parent material. Differences in parent material between the two main morphological units, terraces and alluvial fans, are recognized. Terrace sediments are fluvial deposits with no inherent pedologic properties, having 5% clay content. Alluvial fan sediments are reworked hillslope colluvium and remnant terrace soils that preserve some pedologic soil properties: 15% clay content, very friable, moderately hard, slightly sticky and slightly plastic. Soil field properties used in calculations were: total texture (combination of percent clay, plasticity and stickyness), consistence (dry and moist) and structure. Determination of total texture was altered in the following manner: 1 point was given for every 1 percent increase in clay for a maximum of 100 points and a new total texture maximum of 160 points. Determination of consistence was altered to comply with current

Soil Survey Manual methodology (Soil Survey Staff, 1993) as follows: current descriptors for consistence, dry and moist, has increased to eight sub-categories for a new maximum of 80 points each.

Relative dating of two remnant terraces was accomplished using the rock and mineral weathering method (RMW) (Colman and Pierce, 1981; Birkeland and Noller, 2000). Cobble size andesitic rock clasts were collected from soil pit 5 at a depth of 95 cm (sample size of 25) and soil pit 12 at a depth of 60 cm (sample size of 21), which corresponds to terrace three-soil *J* and terrace one-soil *L*, respectively. Clast samples were cracked open using a hammer and cold chisel. Measurement of weathering rind thickness was taken perpendicular to the clast exterior along the flattest and cleanest surface available. Measurements were taken to the nearest 0.01 mm using a digital caliper.

Relative dating based on the fundamental laws of stratigraphy was applied to soil-landscape mapping units (Daniels and Hammer, 1992).

1. The law of superposition states that younger beds, unless overturned or thrust faulted, overlie older beds. Application of this law is fundamental to understanding the age relations and probable areal distribution of sediments or surface materials.

2. A geomorphic surface is younger that the youngest deposit or land surface it cuts, and younger than a higher surface to which it ascends.

3. The ascendancy and descendancy law states a hillslope is the same age as the sediment to which it descends. A hillslope is younger than the higher surface to which it ascends.

2.4 Laboratory Methods

Soil analyses followed USDA-NRCS established procedures (Klute, 1986; Sparks et al.1996). Soil pH was determined in a 1:1 water and a 1:2_M $CaCl_2$ solution, (procedure 8C1b). Selected soil pits (pedons) were analyzed for Andic soil properties (bulk density, phosphate retention, Al and Fe) in upper and lower profile control sections at approximately 15cm and 40cm depths. Bulk density was determined by the core method. Phosphate retention (procedure 6S4b), Fe (procedure 6C9b) and Al (procedure 6G12b) were determined by the Central Analytical Laboratory, Oregon State University.

3.0 Results

3.1 Geomorphic Landscape Mapping Results

Geomorphic landscape mapping of the Lookout Creek valley bottom, along transect A-$A^{/}$, provided a broad perspective of the study sites' geomorphic setting (Figure 2). Five geomorphic features were identified in the study site area: (1) active Lookout Creek channel, (2) active floodplain terrace (T1), (3) remnant floodplain terraces (T2 and T3), (4) alluvial fan, and (5) valley side-wall colluvium. Aggrading Lookout Creek sediments, followed by incision (down-cutting) and lateral migration of the channel, formed the valley terrace features. Lookout Creek no longer accesses remnant terraces two and three. Alluvial fan and colluvial deposits overlie T3. Reference in this paper to geomorphic map units, soil map units and horizons are alphanumeric. To avoid confusion, geomorphic map units are distinguished as follows; fan one - F1, colluvium - C, terrace five - T5. Soil map units are distinguished by italic font style. Reference to soil-geomorphic map units are made by combining geomorphic map units with corresponding soil map units. For example, alluvial fan two and corresponding soil *D* is referred to F2-*D*, terrace two, soil *K* is T2-*K*. Soil horizons are distinguished by bold font style.

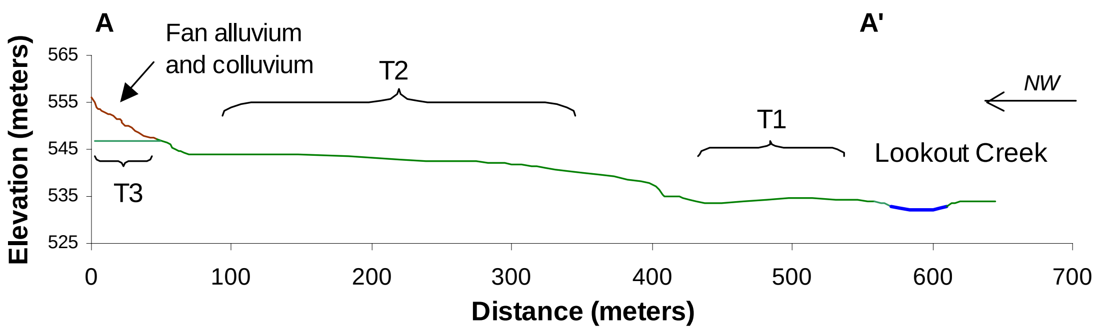

Figure 2. Transect A-A’, cross-sectional view of northern Lookout Creek valley bottom. Alluvial fan and colluvial deposits cover terrace three, site of the DIRT Plot study.

Geomorphic landscape unit T1, the highest active Lookout Creek floodplain terrace surface, is 1.5 m above the low-flow water surface. The terrace surface is vegetated, undulating and dissected by parallel overflow channels. Geomorphic landscape unit T2, the lowest remnant terrace, has a slightly sloping surface with an elevation 2.5 to 6.5 m above T1. Geomorphic landscape unit T3, the highest remnant terrace surface, has an elevation 2.5 m above T2 and 10.5 m above the Lookout Creek low-flow water surface. Alluvial fan and hillslope deposits overlying terrace three range in depth from 70cm to 9 m. Relative age sequence of Lookout valley geomorphic landscape terrace units is T1 < T2 <T3.

The DIRT plot study is sited on colluvial and alluvial fan deposits emanating from the adjacent valley side-wall, overlying remnant Lookout Creek alluvial T3. NIne distinct geomorphic landscape map units were delineated within the DIRT study site (Figure 3).

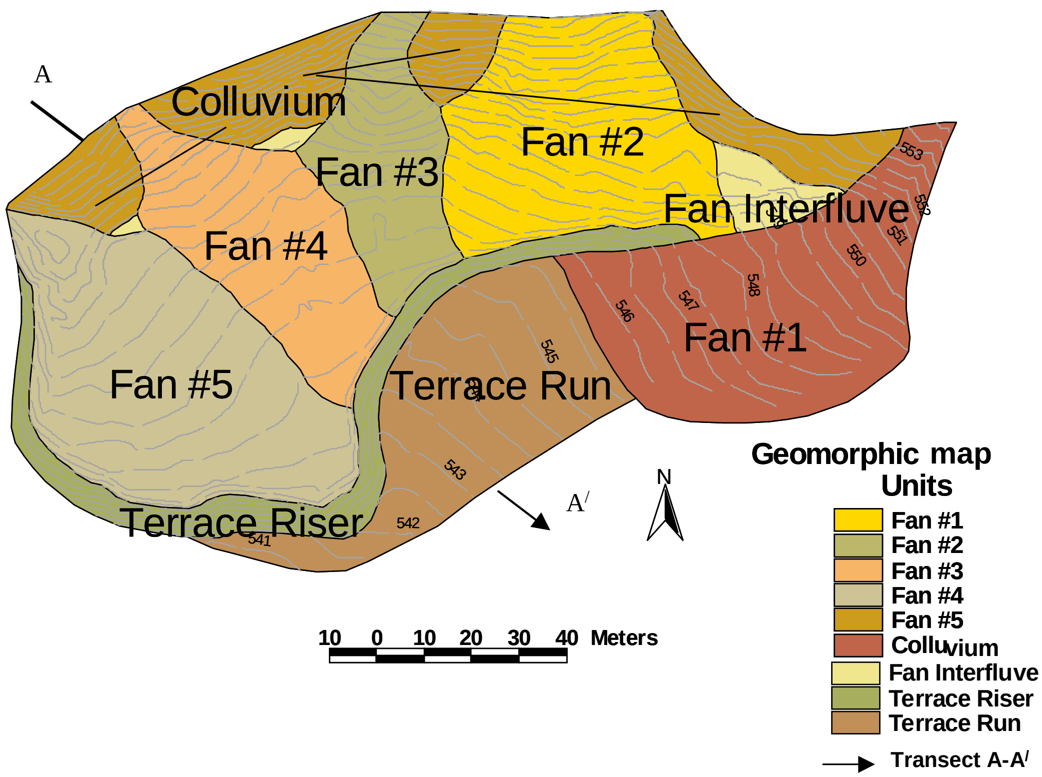

Figure 3. Map of DIRT study site showing the distribution of geomorphic map units. Location of transect A-A' shown.

Alluvial fans represent 68% of the mapped study site area. The fans formed at the intersection of five small ephemeral drainage basins with the larger Lookout Creek drainage basin. Average stream slope gradient decreases from 30% in the steep confines of the upland drainage basin to 18% onto the fan apex. Fan area (Fa) is positively correlated with contributing drainage area (Da), with Fa/Da ratios of 3.4 to 22.7 (Table 1).

Table 1. Area of mapped geomorphic units and ratio of fan area to contributing drainage area.

Geomorphic map unit	Area (m2)	Area (Hectares)	Fan Contributing Drainage Area (Hectares)	Ratio Fa/Da*
Fan #1	2577 (13000)**	0.26 (1.3)**	27.80	21.4
Fan #2	2405	0.24	4.11	17.1
Fan #3	1277	0.13	0.44	3.4
Fan #4	1837	0.18	1.50	8.3
Fan #5	3153 (6000)**	0.32 (0.6)**	13.60	22.7
Colluvium	1881	0.19		
Fan interfluve	273	0.03		
Terrace two riser	1066	0.11		
Terrace two run	2099	0.21		
Total	16569	1.66		

* Fa = Fan area; Da = Drainage area
** ( ) = Estimated total fan area beyond mapped study site.

As fan growth progressed in the past, their lateral margins coalesced, forming a continuous fan apron with dissected (eroded) distal fan leading edges. For this study alluvial fans were delineated on the basis of surface morphology, including considerations of the geometry of topographical contours. Cross-fan profiles are convex. Radial fan profiles varied between planar and concave slope form with distinct fan morphology (Figure 4). Radial fan gradients (averages of the five fans) decreased from fan apex (18 %), to mid-fan (10%), to distal fan (5%) positions.

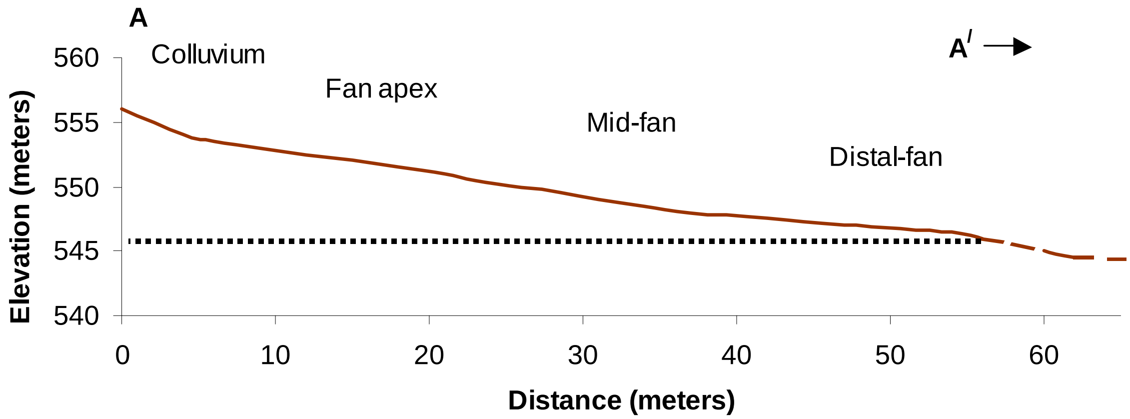

Figure 4. Expanded view of transect A-A' reveals a (radial) profile of colluvium and alluvial fan deposits overlying remnant terrace three (dotted line). Alluvial fan morphological positions are shown.

Colluvial geomorphic map units have planar slope complexity with gradients between 35 and 45 percent. Fan interfluve units represent areas of topographical convergence, where two lateral fan edges coalesce and intermix with colluvium. The terrace riser geomorphic unit associated with T2 varies in height from four meters at the western edge grading to one meter eastward into fan F1 and F2 deposits. Relative age sequence of all geomorphic landscape units is T1 < F1 < T2 < F2, F3, F4, F5, and Fan Interfluves (I) < Colluvium (C) and T3.

3.2 Soil Mapping Results

Soil map unit delineations were based on physical and chemical soil properties distinct and separable from other soil map units. Geomorphic landscape mapping proved to be a good proxy for soil map unit delineation. Soil-geomorphic landscape relations were formulated through differentiation and comparison of described and observed soil profile descriptions representative of geomorphic units (Table 2 and Table 3). Soil mapping of the DIRT study site and adjacent Lookout Creek valley bottom revealed twelve map units. Ten soil map units are delineated within the DIRT study site (Figure 5).

Table 2. Morphological properties of described soils.

Soil & Pit (#)	Horizon	Depth (cm)	Bound-ary	Moist color	Dry color	Field Texture	Structure	Consistence			Roots	Pores	Rock Fragments
								Dry	Moist	Wet			
A (10)	Oi	0 - 4											
	A	4 - 13	CS	10YR3/2	10YR4/2	GRML	2 M GR	S	VFR	MS; MP	2 F, 2M	3 VF DT	10% SR F GR, 5% SR M GR
	Bw1	13 - 33	CS	10YR4/4, 10YR4/6	10YR4/6, 10YR5/3	GRMCL	2 M SBK	SH	FI	SS; SP	2 F, 2M	3 M DT, 2 F IR	10% SR F GR, 6% SR M GR
	2Bw2	33 - 44	CS	10YR4/3	10YR6/3	CL	2 M SBK	HA	FI	MS; MP	1F	2 F DT	3% SA M GR
	2Bw3	44 - 90+		10YR4/3	10YR6/4	CL	2 M-C SBK	HA	FR	MS; MP		3 F DT	10% SA C GR
B (9)	Oi	0 - 4											
	A	4 - 18	CS	10YR2/1	10YR5/4	GRCSL	1 F GR	S	VFR	SO; PO	3 M, 2 C	3 F DT, 3 F IR	15% SR F GR, 5% SR M GR
	B/A	18 - 42	CW	10YR3/3	10YR5/4	GRCSL	2 M SBK	SH	FR	SS; SP	3 M, 1 C	3 F DT, 3 F IR	15% SA C GR, 5% SA M GR
	B1	42 - 68	CS	10YR4/4	10YR6/4	GRCSCL	SGR, 1 M SBK	S	VFR	MS; SP	1F, 1M	2 F DT, 2 F IR	35% SA C GR, 8% SR M GR, 3% SR F GR
	2Bw2	68 - 85	CS	10YR4/4	10YR6/4	GRCL	2 M-C SBK	SH	FR	MS; MP	1 F	3 VF, 2 F DT	30% SA C GR, 20% SR M GR, 4% SR F GR
	2C	85 - 95		10YR4/4	10YR6/3	GRCSL	SGR	L	L	SS; PO			35% SA C GR, 8% SR M GR, 4% SR F GR
C (6)	OI	0 - 3											
	A1	3 - 10	CW	10YR3/3	10YR4/4	L	3 M GR	S	VFR	SO; PO	2 M	2 M , 1 F DT	
	A2	10 - 24	CW	10YR3/3	10YR5/4	L	2 C-M GR	S	VFR	SS; SP	2 F, 2 M	3 M, 1 F DT	
	Bw1	24 - 43	GW	10YR3/4	10YR5/4	L	2 M SBK	SH	FR	MS; MP	2 F, 2 M	2 M, 1 F DT	
	Bw2	43 - 83	GW	10YR4/4	10YR6/4	L	2 C SBK	SH	FR	MS; MP	1 F, 1 M	2 F,1 M DT	1% SA M GR
	Bw3	83 - 95+		10YR4/4	10YR6/4	L	2 C SBK	MH	FI	MS; VP			5% SA C GR
D_2 (15)	Oi	0 - 3											
	A	3 - 5	CS	10YR3/2	10YR4/3	SIL	1 F GR	S	VFR	MS; MP	2 VF, 2 F		
	Bw1	5 - 22	CW	10YR4/3	10YR5/4	SICL	2 M SBK, 2 M GR	SH	FR	MS; VP	2 F, 2M	2 F DT	
	Bw2	22 - 30	CW	10YR4/4	10YR5/4	SICL	2 M SBK	MH	FI	MS; VP	1 F, 1 M	2 F DT	
	2Ab	30 - 46	CS	10YR3/2	10YR4/3	CL	2 M SBK, 2 M GR	SH	FI	MS; MP	2 M, 1 C	2 F DT	
	2Bw3	46 - 95+		10YR4/4	10YR5/4	CL	2 M SBK	HA	FI	MS; VP	1 M	2 F, 1 M DT	

Table 2. (Continued).

Soil & Pit (#)	Horizon	Depth (cm)	Bound-ary	Moist color	Dry color	Field Texture	Structure	Consistence Dry	Consistence Moist	Consistence Wet	Roots	Pores	Rock Fragments
E (8)	Oi	0 - 3											
	A	3 - 10	CS	10YR3/3	10YR5/3	L	3 M, 2 M GR	SH	FR	MS; MP	2 M, 1 F	1 VF DT	
	Bw	10 - 34	CS	10YR4/3	10YR5/4	CL	2 C SBK	SH	FI	MS; MP	2 M	2 VF, 1 F DT	
	C/B	34 - 43	CS	10YR4/4	10YR5/4	SL	1 F-M SBK	S	VFR	SS; SP	2 M	2 F DT	
	2Bw1	43 - 80	GW	10YR4/3	10YR5/4	CL	2 C SBK	SH	FR	MS; MP	2 C, 1 M	2 F, 2 VF DT	
	2Bw2	80 - 95+		10YR4/3, 10YR4/2	10YR5/4, 10YR6/2	CL	2 C SBK	HA	FI	VS; VP	1 M	2 F, 1 VF DT	
F (1)	Oi	0 - 3											
	A1	3 - 14	CW	10YR3/2	10YR4/2	L	2 M GR	S	VFR	SO; PO	3 F, 3 M	3 VF DT	
	A2	14 - 27	CW	10YR3/2	10YR5/3	L	2 F-M GR	SH	FR	SS; SP	3 F, 2 C	3 F DT	
	B/A	27 - 39	AW	10YR3/3	10YR5/4	L	2 M GR	SH	FR	MS; MP	2 F, 2 M	3 F, 3 M DT	
	Bw1	39 - 68	GW	10YR4/3	10YR6/3	CL	2 M SBK	MH	FR	MS; VP	1 M	2 F DT	3% SA M GR
	B2	68 - 90	CW	10YR4/3	10YR5/4	XGRL	2 F-M SBK	HA	FI	MS; MP	1 F, 1 M	2 F DT	40% SA C GR, 10% SA M GR
	Bw3	90 - 120+		10YR4/4	10YR6/4	CL	2 M SBK	HA	FR	VS; VP	1 F, 1 M	1 F DT	10% SA M GR
G (3)	Oi	0 - 3											
	Oa	3 - 5											
	A1	5 - 15	CW	10YR3/2	10YR4/3	L	2 F-M GR	S	VFR	SO; PO	3 M, 2 F	2 M, 2 F DT	
	A/B	15 - 30	CW	10YR4/3	10YR4/4	L	2 M-C GR	S	VFR	SO; PO	2 F, 2M	2 M, 2 F DT	2% SA M GR, 2% SA F GR
	Bw1	30 - 45	CW	10YR4/3	10YR5/4	L	2 F-M GR	SH	FR	SS; MP	1 M	2 F DT	2% SA M GR, 2% SA F GR
	Bw2	45 - 60	CW	10YR4/3	10YR5/4	L	2 M-C SBK	MH	FR	MS; MP	1 M	2 F DT	5% SA M, 5% SA C GR
	Bw3	60 - 95+		10YR4/4	10YR5/4	CBXL	2 M-C SBK	HA	FR	MS; VP	1 M	2 F DT	10% SR C GR, 10% SR CB

Table 2. (Continued).

Soil & Pit (#)	Horizon	Depth (cm)	Bound-ary	Moist color	Dry color	Field Texture	Structure	Consistence			Roots	Pores	Rock Fragments
								Dry	Moist	Wet			
H_1 (4)	Oi	0 - 3											
	A1	3 - 6	CW	10YR2/1	10YR3/2	L	2 F GR	S	VFR	SO; PO	2 VF, 2 F	2 F DT	4% SA M GR, 2% SR F GR
	A2	6 - 25	CW	10YR3/3	10YR5/3	L	2 F-M GR	S	VFR	SO; PO	2 F, 2 M	3 F, 3 M DT	4% SA F GR, 2% SA M GR
	B/A	25 - 40	CW	10YR4/3	10YR5/4	L	2 F-M SBK	S	FR	SS; SP	2 F, 2 M	3 F, 3 M DT	5% SA F GR, 2% SA M GR
	Bw1	40 - 58	CW	10YR4/3	10YR5/4	L	2 M SBK	S	FR	MS; MP	2 F, 2 M	3 F, 3 M DT	3% SA M GR
	Bw2	58 - 96	CW	10YR4/4	10YR6/3	L	2 C-M SBK	SH	FI	MS; VP	2 F, 2 M	3 F, 3 M DT	3% SA M GR
	Bw3	96 - 133	GW	10YR4/4	10YR6/4	CL	2 M-C SBK	MH	FI	MS; VP	1 M	2 F DT	4% SA M GR, 2% SA F GR
I (2)	Oi	0 - 3											
	A	3 - 5	AS	10YR3/2	10YR4/3	L	1 F GR	S	VFR	SS; SP	1 F, 1 M	3 F DT	
	1C	5 - 6	VS	10YR4/3	10YR4/4	L	SGR	S	VFR	SS; SP	1 F	1 F DT	
	2C	6 - 14	CB	10YR4/4	10YR5/4	SL	SGR	S	L	SO; PO	1 M	3 F IR	
	3C	14 - 17	CB	10YR4/3	10YR6/3	SL	SGR	S	L	SO; PO	1 F	3 M IR	
	4C	17 - 21	CB	10YR5/4	10YR6/4	L	SGR	SH	VFR	SS; SP	1 F		
	5Ab	21 - 35	CS	10YR3/2	10YR5/3	L	3 M-C GR	SH	VFR	SS; SP	2 F, 2 C	3 M DT	
	5A/B	35 - 55	GW	10YR3/3	10YR5/3	L	2 M GR, 2 M SBK	MH	FR	MS; MP	2 F, 2 C	3 M DT	
	5Bw1	55 - 73	CW	10YR4/3	10YR3.5/3, 10YR6/3	L	2 M SBK	H	FR	MS; MP	2 F, 2 C	2 F, 2M DT	
	5Bw2	73 - 110+		10YR4/4	10YR5/8, 10YR6/3	CL	2 C SBK	VH	FI	VS; VP	1 F	2 F DT	
J (5)	Oi	0 - 3											
	A	3 - 9	CS	10YR3/2	10YR4/3	L	3 F-M GR	S	VFR	SO; PO	2 F, 1VF	1 VF DT	3% SA F GR
	A/B	9 - 19	CW	10YR4/3	10YR5/4	L	2 M GR, 2 M SBK	S	VFR	SS; SP	2 M, 1 F	2 F DT	1% SA F GR
	Bw1	19 - 29	GW	10YR4/4	10YR6/4	CL	2 F SBK	SH	FR	MS; MP	2 M, 1 F	2 M DT	1% SA F GR
	Bw2	29 - 69	GW	10YR4/4	10YR5/4	CL	2 M SBK	HA	FI	MS; VP	2 M, 1 F	2 M DT	
	Bw3	69 - 95	GW	10YR4/4	10YR5/4	CBVSL	1 M SBK	S	VFR	SS; MP	1 M	1 M DT	40% SR CO, 10% SR C GR, 5% SR M GR
	C	95 - 105+		10YR3/4	10YR4/6	CBXLS	SG	L	L	SO; PO			85% SR CO

Table 2. (Continued).

Soil & Pit (#)	Horizon	Depth (cm)	Bound-ary	Moist color	Dry color	Field Texture	Structure	Consistence			Roots	Pores	Rock Fragments
								Dry	Moist	Wet			
K (11)	Oi	0 - 3											
	A	3 - 11	CS	10YR3/2	10YR4/3	L	2 M GR	S	FR	MS; MP	2 F, 2 VF	2 F DT	
	B	11 - 36	CS	10YR4/3	10YR5/3	L	2 M SBK	SH	FR	MS; MP	1 C	2 F DT	
	1C	36 - 72	CS	10YR4/3	10YR5/4	GRVSL	SG	L	L	SO; PO	1 F	3 M IR	40% SR M GR, 5% R F GR
	2C	72 - 77	CS	10YR4/3	10YR6/3	L	1 M SBK	S	VFR	SS; SP	1 C, 1 M	1F, 1 VF DT	
	3C	77 - 82	CS	10YR4/2	10YR5/3	SIL	1 M SBK	MH	FI	SS; SP	2 F, 2 VF	3 F, 2 VF DT	
	4C	82 - 97	CS	10YR4/3	10YR6/3	SL	1 M SBK	S	VFR	SO; PO	1 C, 1 M	1 F DT	
	5Bw2	97 - 110	CS	10YR4/4	10YR6/4	SICL	1 M SBK	MH	FR	MS; VP	1 M	1 F DT	3 % SR F GR
L (12)	Oi	0 - 3											
	A	11-Mar	CB	10YR3/4	10YR5/4	SL	1 F GR	S	VFR	SO; PO	3 M, 2 F	3 M IR, 2 F-M DT	
	1C	16 - 31	CS	10YR4/3	10YR5/4	LS	SG	L	L	SO; PO	3 M, 2 C	3 M IR, 2 F-M DT	
	2C	31 - 60	CS	10YR4/3	10YR5/4	SL	1 M SBK	S	VFR	SO; PO	2 M, 2 C	2 M IR, 2 F DT	
	3C	60 - 100	CS	10YR4/4	10YR5/4	CBVSL	SG	L	L	SO; PO	1 M	1 F DT	35% R CO, 20% R C GR, 3% R F GR

Table 3. Morphological properties of observed soils.

Soil & Pit (#)	Horizon	Depth (cm)	Bound-ary	Moist color	Dry color	Field Texture	Structure	Consistence			Roots	Pores	Rock Fragments
								Dry	Moist	Wet			
D_1 (14)	Oi	0 - 3											
	A	3 - 8	CS	10YR3/1	10YR4/2	SIL	1 F GR	S	FR	MS; MP	2 VF, 2 F	2 F DT	
	Bw	8 - 24	CS	10YR4/3	10YR5/4	SICL	2 M SBK	HA	FI	MS; VP	2 F, 1 M	2 F, 2M DT	
	2Ab	24 - 41	GS	10YR3/2	10YR5/3	CL	2 M SBK	SH	FR	MS; VP	1 F, 1 M	3 VF, 2 F DT	
	2Bw	41 - 58	CS	10YR4/3	10YR5/4	CL	2 M SBK	MH	FI	MS; VP	1 F	3 VF, 2 F DT	
	3Ab	58 - 73	CS	10YR3/2	10YR4/3	CL	2 M SBK	SH	FR	MS; MP	1 F	2 F DT	
	3Bw	73 - 110+		10YR4/3	10YR5/4	CL	2 C SBK	MH	FI	MS; VP		2 F DT	
H_2 (4)	Oi	0 - 3											
	A1	3 - 17	GW	10YR3/2	10YR4/ 3	L	1 M GR	S	VFR	SO; PO	2 F, 2 M	1 F, 1M DT	2% SR F GR
	A2	17 - 50	CS	10YR3/2	10YR4/3	L	2 M-C GR	S	VFR	SS; SP	2 F, 2 M	1 F, 1M DT	10% SR F GR, 2% SR M GR
	Bw1	50 - 100	GW	10YR4/3	10YR5/4	L	2 M, 1 M SBK	S	VFR	MS; SP	2M	1 F DT	3% SA M GR
	Bw2	100 - 120+		10YR4/4	10YR6/4	L	2 M-C SBK	MH	FR	MS; VP		1 F DT	2% SA M GR
C&H (7)	Oi	0 - 3											
	Oa	3 - 4											
	Bp	4 - 7	AS	10YR4/3	10YR6/3	L	1 M SBK	MH	FI	MS; MP	1 F	1 F DT	5% SR M GR
	B1	7 - 29	GW	10YR4/3	10YR6/3	L	2 M SBK	SH	FI	MS; MP	1 F,1M	3 M , 2 F DT	2% SA F GR
	B2	29 - 48	GW	10YR4/3	10YR6/3	L	1 M SBK	SH	FI	MS; MP	2 M, 1 F	2 F DT	2% SA M GR
	2B3	48 - 75	GS	10YR4/3	10YR6/3	L	2 C SBK	SH	FI	MS; MP	1 F	2 F, 2 VF DT	
	2B4	75 - 95+		10YR4/3	10YR6/3	L	2 M SBK	SH	VFI	MS; MP	1 F	2 F DT	10% SA M GR
H (13)	Oi	0 - 4											
	A1	4 -10	AS	10YR2/1	10YR4/2	L	1 M GR	L	L	SO; PO	3 M	3 M DT	
	A2	10 - 24	CS	10YR2/2	10YR4/3	L	1 M GR	S	VFR	SS; SP	3 F, 3 M	3 M DT	9% SR F GR
	Bw1	24 -47	CS	10YR4/4	10YR6/4	L	2 M SBK, 2 F GR	S	FR	SS; SP	3 F, 3 M	1 F DT	5% SR F GR, 5% SR C GR
	Bw2	47 -76	CS	10YR4/4	10YR6/4	L	2 M SBK	S	FR	MS; MP	2 F, 2 M	1 F DT	8% SR M GR, 5% C SR FGR
	C	76 - 100+		10YR5/4	10YR6/4	GRVSL	SG	L	L	SO; PO	1 M	1 F DT	85% SR C GR, 3% SR M GR

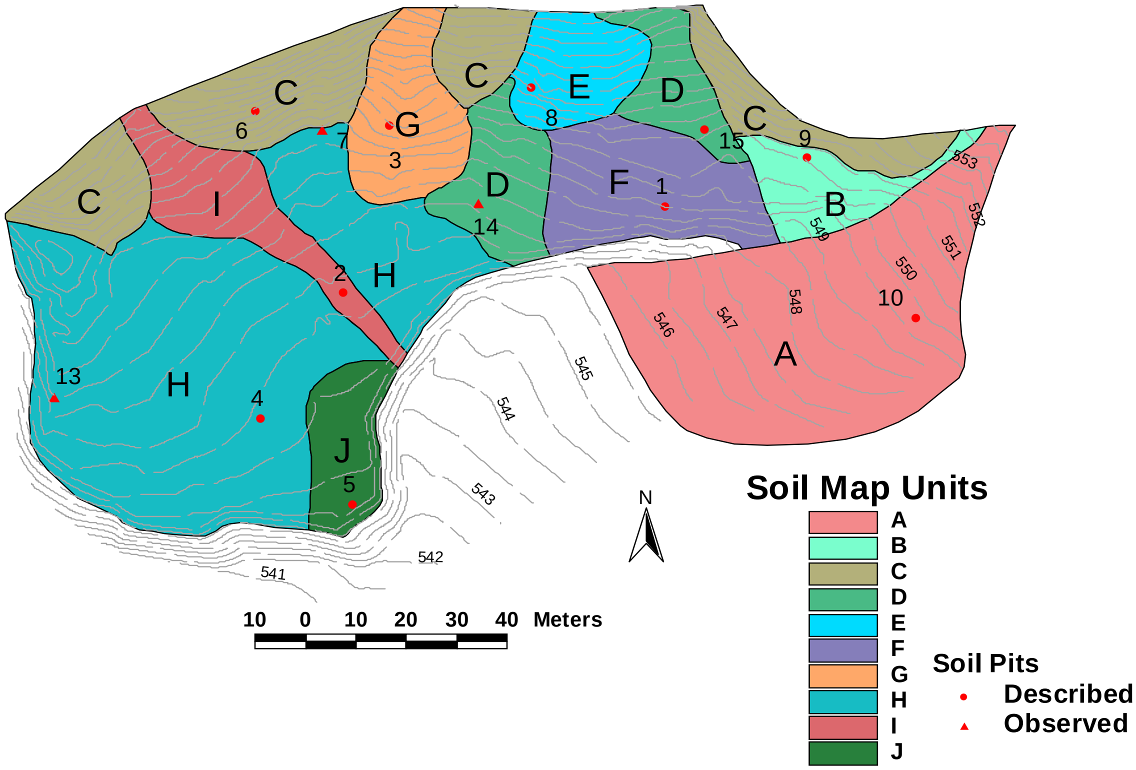

Figure 5. Map of DIRT study site showing the distribution of soil map units and location of soil pits. Soil pits 11 and 12 are located outside the mapped area to the south, on T2 – soil map unit *K* and T1 – soil map unit *L*, respectively.

Soil map units are broadly defined and categorized on the basis of composition and depositional process of the parent material (Table 4). Stream-terrace soils *J*, *K* and *L* formed from coarse-textured alluvial sediments deposited by Lookout Creek. Alluvial fan soils *A, D, E, F, G, H,* and *I* formed from fine-to medium-textured residual colluvium, deposited by episodic mud and debris flows and rotational slump processes, followed by fluvial reworking of surface sediments. Colluvial soils *C*, and *B* formed from medium-to coarse-textured colluvium deposited by slope creep processes.

Table 4. Soil map unit area and corresponding parent material and geomorphic units.

Soil	**Area (m^2)**	**Area (%)**	**Parent material**	**Geomorphic map unit**
A	2959.1	20.8	Fan alluvium	F1
B	483.1	3.4	Fan alluvium/colluvium	Fan interfluve
C	1920.5	13.5	Colluvium	Colluvium
D	975.9	6.9	Fan alluvium	F2, F3
E	536.6	3.8	Fan alluvium	F2
F	986.6	6.9	Fan alluvium	F2
G	723.5	5.1	Colluvium\fan alluvium	F3
H	4399.7	31.0	Fan alluvium	F3, F4, F5
I	731.4	5.1	Fan alluvium	F4
J	488.1	3.4	Floodplain alluvium	F5, T3
K	na	na	Floodplain alluvium	T2
L	na	na	Floodplain alluvium	T1

Horizon designations common to all soils were surface organic **Oi** horizons overlying organic rich **A** horizons. Depth of **A** horizons varied between 5 cm and 27 cm. Granular structure and loam texture were common for all **A**-horizons. **B**-horizon designation varied greatly with depth and included vertical subdivisions, discontinuities and combination horizons. Soils all have 10YR Hues. Color value and chroma of **B** horizons varied little, with values of 5 or 6 dry, 4 moist, and chromas of 3 or 4 moist or dry. All soils are considered well-drained.

Soils diverged into two categories based on parent materials and age of alluvial deposition, evidenced by horizon morphological and chemical property differences. Andrews assemblage soils *A*, D_1, D_2 and *E* developed on young active alluvial fan deposits. Lookout assemblage soils *C*, *F*, *G*, *H,* and *J* developed on colluvium, alluvial terrace, and old inactive fan deposits. Soils *I* and *B* did not fit into either soil assemblages (figure 6). Vertical distribution of clay, field texture and pH, P, Al and Fe differed between the two categories (Figure 7 and Figure 8). These soil properties (except pH) can be inherited from parent material weathered prior to deposition or accumulated through eluvial - illuvial translocation.

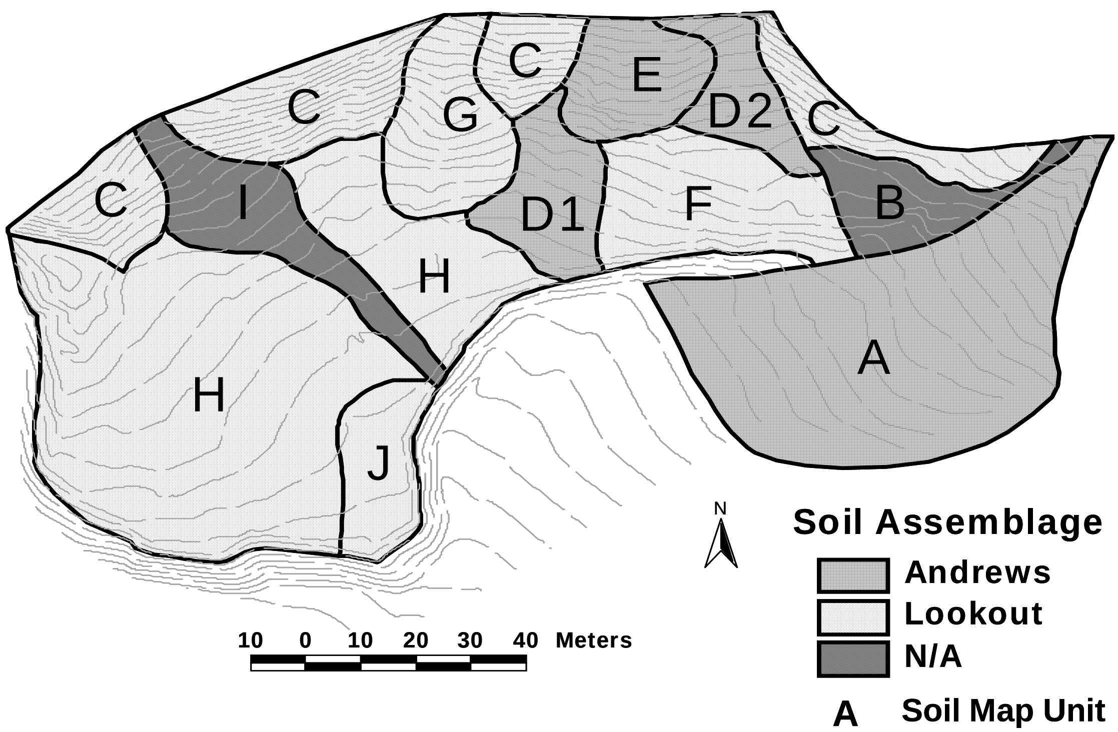

Figure 6. Map of soil assemblages, Lookout and Andrews, based on common morphological and chemical soil properties.

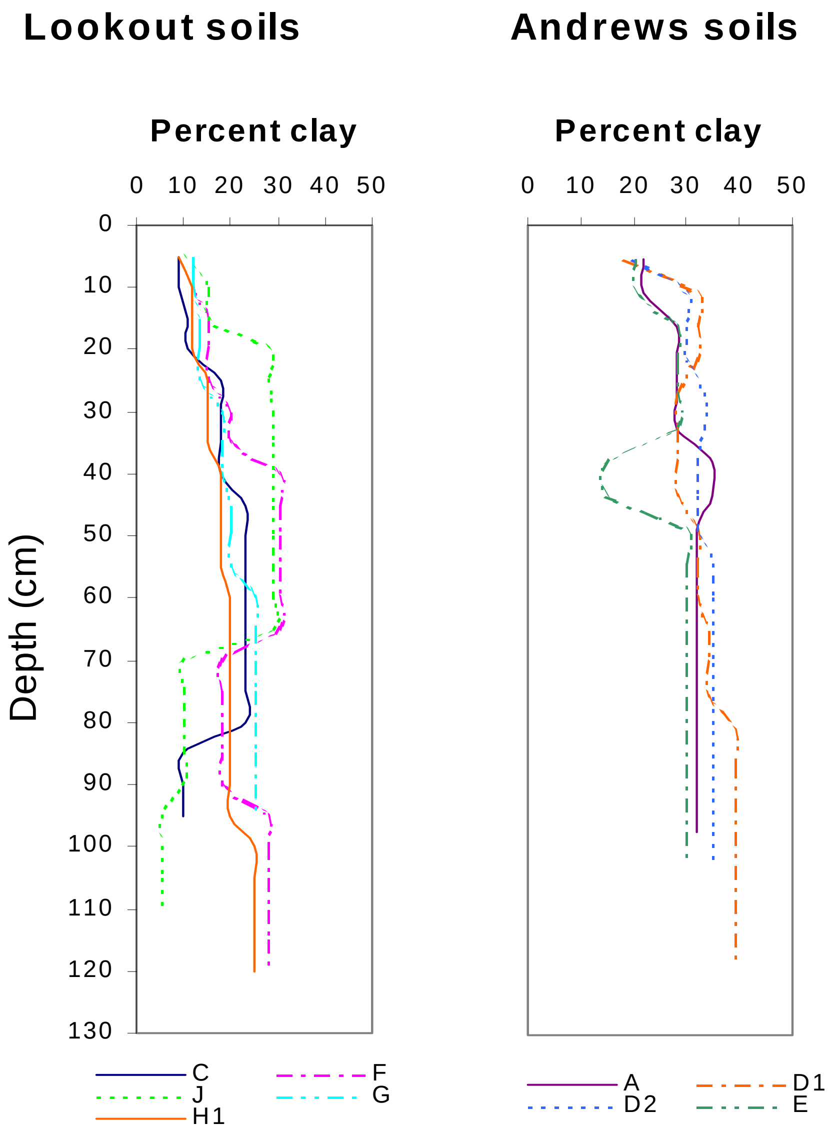

Figure 7. Comparison of Lookout and Andrews soil assemblage profiles showing variation of clay with depth.

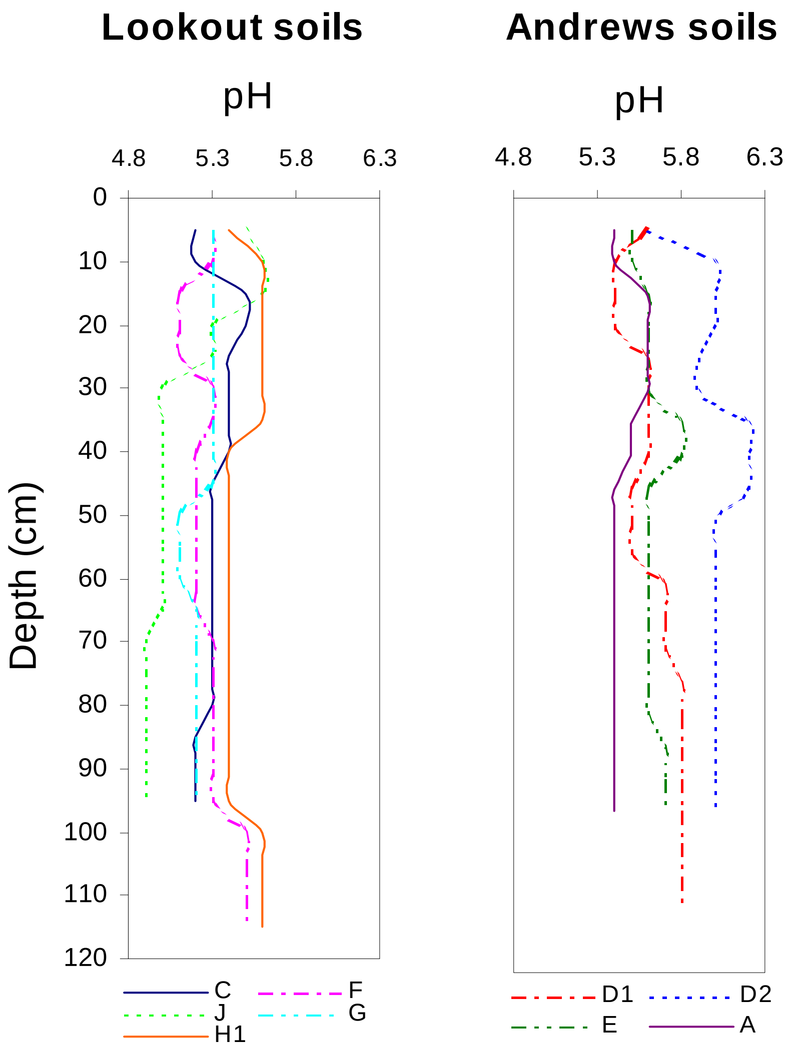

Figure 8. Comparison of Lookout and Andrews soil assemblage profiles showing variation of clay with depth.

Lookout assemblage soils exhibit clay contents between 9 and 12 percent in surface **A** horizons. Clay concentrations of between 20 and 30 percent are present at depths between 15 and 80 cm, typically decreasing significantly below. These profiles show translocation of clay, a result of profile stability and time. Field texture varied by horizon and included sandy loam, loamy sand, loam and clay loam. Soil pH was more acidic and varied between 4.9 and 5.4, except in surface **A** horizons and the **B/A** horizon of soil H_1. Soil P, Al and Fe percentages were higher. Soil phosphorus levels were higher, averaging 87 percent, in the upper and lower profile control sections. Soil Al + 1/2Fe levels were higher, averaging 1.73 percent, in the upper profile control section.

Andrews assemblage soils exhibit clay contents between 18 and 22 percent in surface **A** horizons. Clay concentrations of between 28 and 32 percent persist to depth with minimal variation except at horizon discontinuities. Lithologic discontinuities are recognized as abrupt textural changes (% clay), rock fragment distribution (particularly a decrease with depth), and buried **A** horizons, with the exception of soil *E***.** These profiles indicate inherited clay from alluvial parent materials, showing minimal clay eluviation. Subsoil horizon field texture was clay loam or silty clay loam. Soil pH was less acidic and varied between 5.4 and 6.0. Soil phosphorus levels were lower, averaging 62 percent, in the upper and lower profile control sections. Soil Al + 1/2Fe levels were lower, averaging 0.68 percent, in the upper profile control section.

3.3 Soil Classification Results

Taxonomic classification places these soils within the Andisol and Inceptisol soil orders (Soil Survey, 1998). Classification of soil map units of the DIRT study site and adjacent Lookout Creek valley bottom revealed three taxonomic subgroups, three of which underlie the DIRT study plots (Figure 9). Typic Hapludands and Andic Dystrudepts are the dominant taxa, representing 37.9 percent and 42.9 percent of the study site area, respectively (Table 5). Andic properties characterize the upper and lower profile control sections of all soils sampled (Table 6). Estimation of andic properties, due to incomplete profile data, was needed for placement of soils *H* and *F* in the Andisol order.

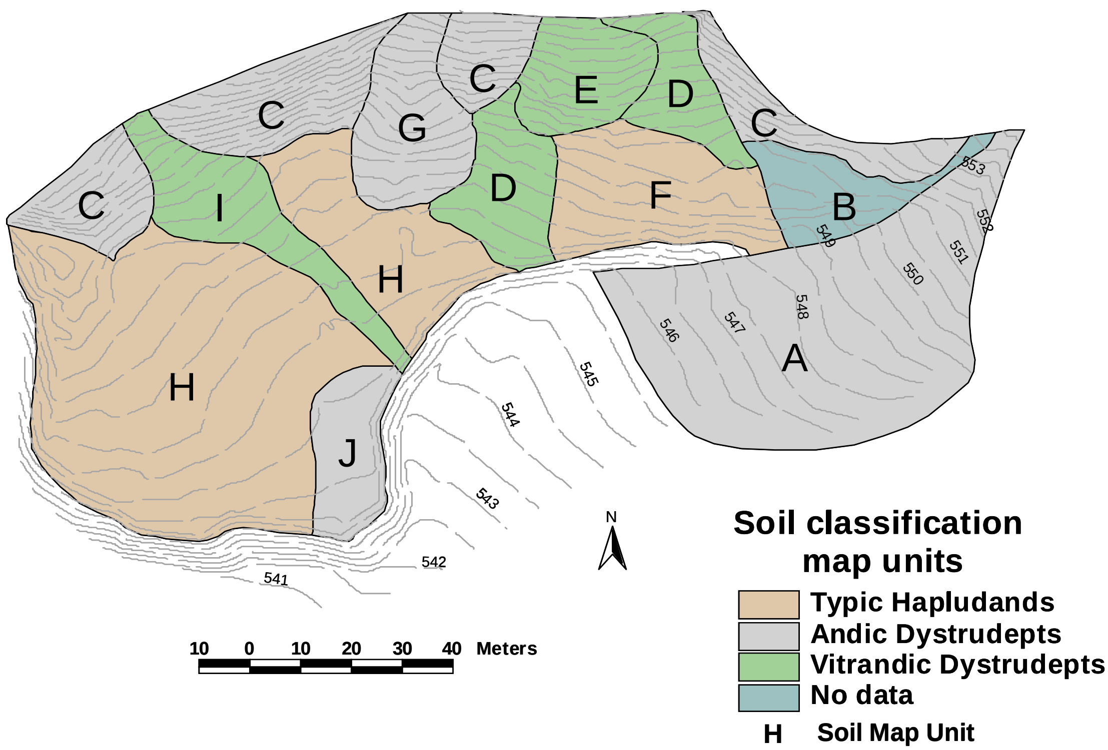

Figure 9. Map of DIRT study site showing the taxonomic classification of soil map units.

Table 5. Subgroup classification of mapped soils and areal coverage.

Classification	**Soil**	**Area (m^2)**	**Area (%)**
Typic Hapludands	F	986.6	6.9
	H	4399.7	31.0
		Total	37.9
Andic Dystrudepts	A	2959.1	20.8
	C	1920.5	13.5
	G	723.5	5.1
	J	488.1	3.4
	K*	na	na
		Total	42.9
Vitrandic Dystrudepts	D	975.9	6.9
	E	536.6	3.8
	I	731.4	5.1
		Total	15.8
No data	B	483.1	3.4
	L*	na	na

* Soils K and L are not within the mapped study site.

Table 6. Upper and lower profile control sections of selected soils, andic characteristics and classification.

Soil	Horizon (control)	Horizon depth (cm)	Bulk density (g/cm^3)	Phosphate retention (%)	Al+1/2Fe (%) (acid oxalate)	Classification
A	Bw1	13 - 33	na	69	0.97	Andic Dystrudepts
	2Bw2	33 - 44	na	79	1.17	
C	A2	10 - 24	0.89	96	1.69	Andic Dystrudepts
	Bw2	43 - 83	0.98	76	0.59	
D_1	Bw	8 - 24	na	59	0.69	Vitrandic Dystrudepts
	2Ab	24 - 41	na	56	0.58	
D_2*	Bw1	5 - 22	na	59	0.43	Vitrandic Dystrudepts
	2Ab	30 - 46	na	72	1.01	
E	Bw	10 - 34	na	51	0.64	Vitrandic Dystrudepts
	C/B	34 - 43	na	48	0.55	
F	A2	14 - 27	0.77	92	1.97	Typic Hapludands
	Bw1	39 - 68	1.08	76	0.77	
G	A/B	15 - 30	0.86	92	1.64	Andic Dystrudepts
	Bw1	30 - 45	1.05	78	0.50	
H_1	A2	6 - 25	0.68	94	2.18	Typic Hapludands
	Bw1	40 - 58	1.02	59	0.52	
H_2	A1	3 - 17	na	96	2.40	Typic Hapludands
	A2	17 - 50	na	97	3.41	
I	5Ab	21 - 35	1.03	48	0.46	Vitrandic Dystrudepts
	5A/B	35 - 55	1.03	65	0.86	
J	A/B	9 - 19	0.92	93	1.63	Andic Dystrudepts
	Bw2	29 - 69	0.83	92	0.83	
K	A	3 - 11	na	82	1.09	Andic Dystrudepts
	B	11 - 36	na	82	1.00	
	1C	36 - 72	na	47	0.64	

* Soil D_2 was used for taxonomic classification of soil D_1
** Soils B and L were not analyzed for andic properties.

All soils have diagnostic umbric epipedons. All soils have a medial over loamy particle size class and a mixed mineralogy class. The Keys to Soil Taxonomy lacked a particle-size class for soils D_2 and *I*, which had alluvium overlying an andic control section. Soil moisture regime is Udic. Soil temperature regime is Mesic (Brown, 1975).

3.4 Relative Soil Dating Results

Use of the profile development index (Harden, 1982, 1990) quantitatively assesses selected soil field properties, producing profile and horizon indices for the interpretation of a chronological succession in soil-profile evolution. PDI values ranged from 6.4 to 30.8, representing the lowest and highest level of soil development. Distribution of PDI values, plotted one-to-one, facilitates grouping of soils into four age classes (Figure 10). Mapping of the DIRT study site and adjacent Lookout Creek valley bottom using the four PDI-based classes shows that only three lie within the DIRT study site (Figure 11), of these, PDI class three underlies 50 percent of the mapped study site area (Table 7).

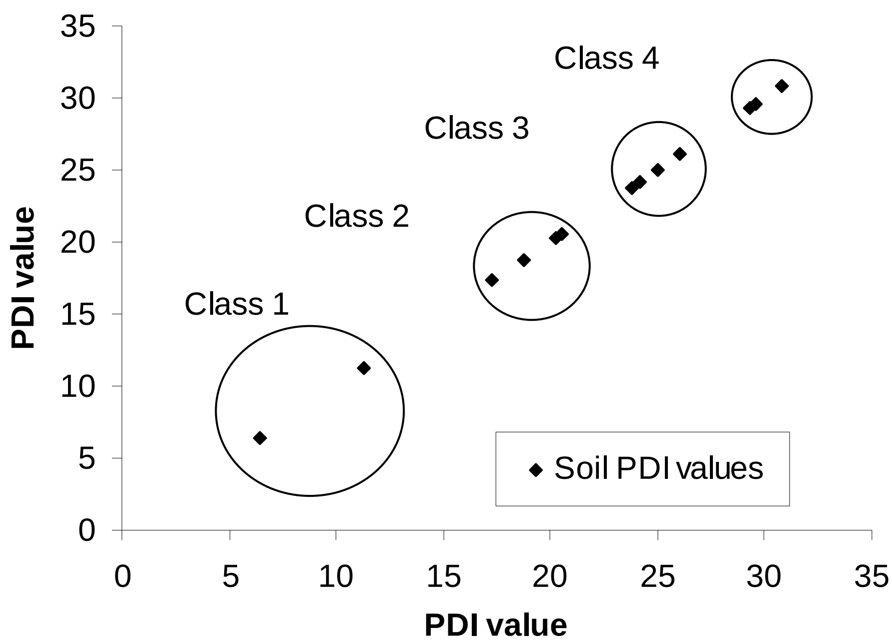

Figure 10. Groupings of PDI values representing four classes of soil development. PDI class one, having the lowest PDI values, indicates the least soil development, whereas PDI class four, having the greatest PDI values, indicates the greatest soil development.

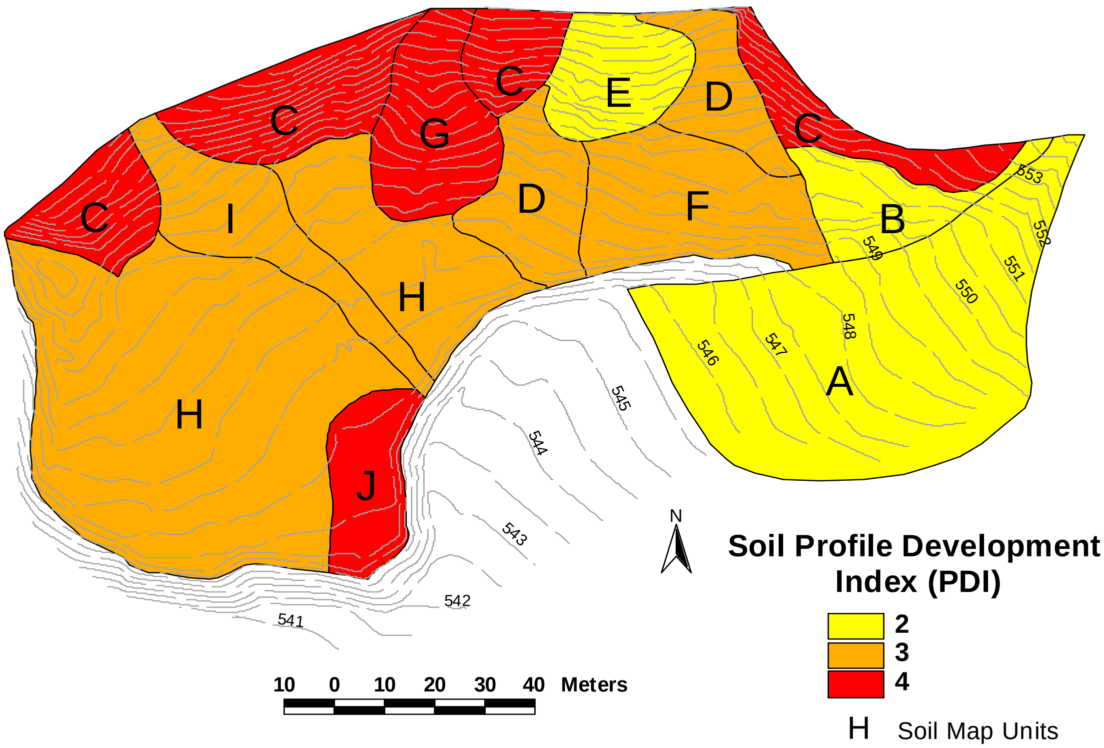

Figure 11. Map of DIRT study site showing the distribution of PDI age classes. PDI class one include treethrown influenced soil H2, not shown and terrace one soil *L* located outside the mapped area to the south. Terrace two soil *K* within PDI age class two is located outside the mapped area to the south.

Table 7. PDI age class of mapped soils and areal coverage.

PDI class	Soil	PDI value	Area (m^2)	Area (%)
1	L*	6.4	na	na
	H_2**	11.3	na	na
2	A	20.6	2959.1	20.8
	B	18.8	483.1	3.4
	E	17.3	536.6	3.8
	K*	20.3	na	na
			Total	28.0
3	D	25.0	975.9	6.9
	F	26.1	986.6	6.9
	H_1	24.2	4399.7	31.0
	I	23.8	731.4	5.1
			Total	49.9
4	C	29.6	1920.5	13.5
	G	29.3	723.5	5.1
	J	30.8	488.1	3.4
			Total	22.1

* Soils K and L are not within mapped study site and represent terrace soils.
** Soil H_2 is a profile influenced by treethrow and is within soil map unit H.

The rock and mineral weathering method (RMW) evaluates weathering rind thickness for use as an indicator of relative and numerical age (Coleman and Pierce, 1981). Mean weathering rind thickness differed significantly between the two sample sites. Terrace one had a mean rind thickness of 0.38 mm (p value <0.05). Terrace three had a mean rind thickness of 1.27 mm (p value <0.05).

3.5 DIRT Plot Soils

The DIRT study plots, typically 15 x 30m, include a control and six treatments, replicated three times for a total of 21 plots (Table 8). Figure 12, shows the spatial distribution of control and treatment plots across the study site. GIS proved to be a valuable tool for spatial and temporal analysis through theme intersection of DIRT plots with soil, classification and PDI layers.

Table 8. DIRT Plot treatments, identification number and area.

Plot treatment	Plot number	Area (m^2)
Control	8	147.7
	12	143.4
	14	140.7
Double Litter	2	149.5
	13	104.2
	17	205.5
Double Wood	5	145.2
	10	149.0
	16	97.3
No Inputs	19	36.4
	49	71.0
	69	43.4
No Litter	3	150.1
	7	149.5
	11	150.3
No O/A Horizon	9	141.2
	15	150.6
	18	145.8
No Soil Inputs	1	38.9
	4	80.7
	6	42.1

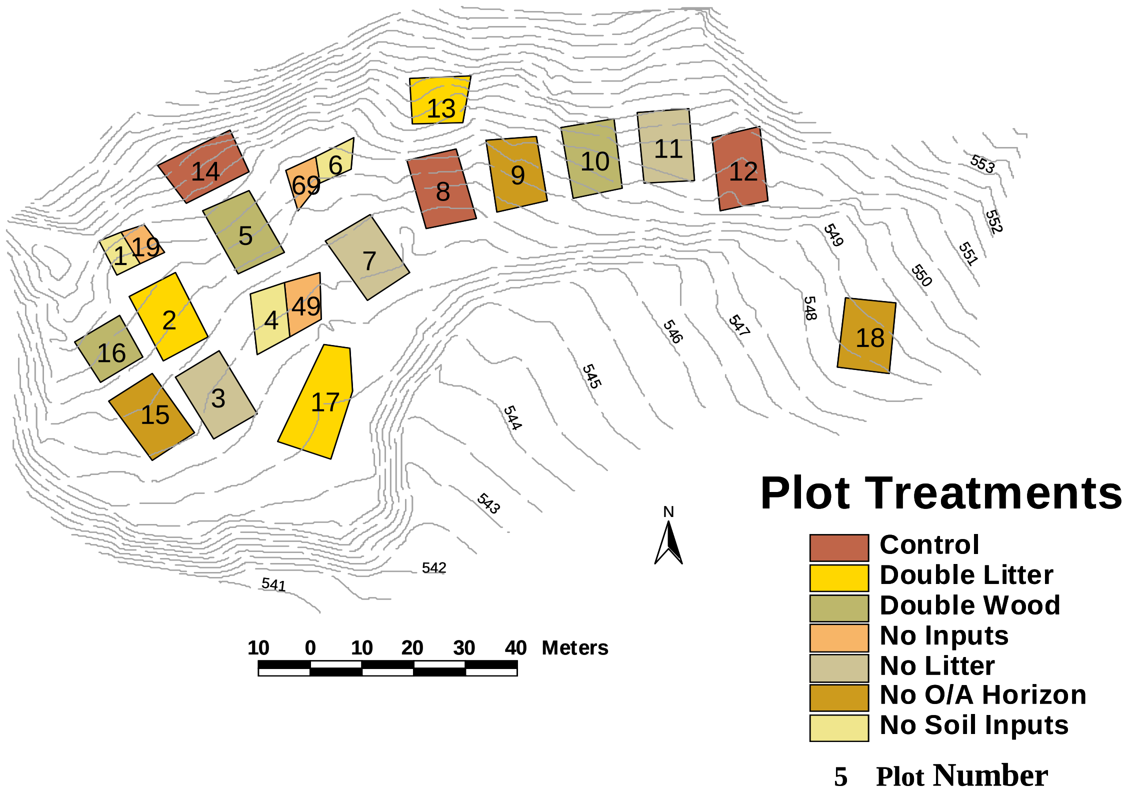

Figure 12. Map of DIRT study site showing the location of individual DIRT Plots and respective treatment.

Intersection of DIRT plots with soil map units resulted in high spatial variability between replicate and control plots as well as within individual plots (Fig.13). Ten soil map units were found to underlie the plots, each with differing coverage, which varied from a low of 0.3% for soil *B*, to a high of 45.7% for soil *H*. Soil *H* is well represented by all treatments, though only 3.2 percent underlies control plot 8 (Table 9).

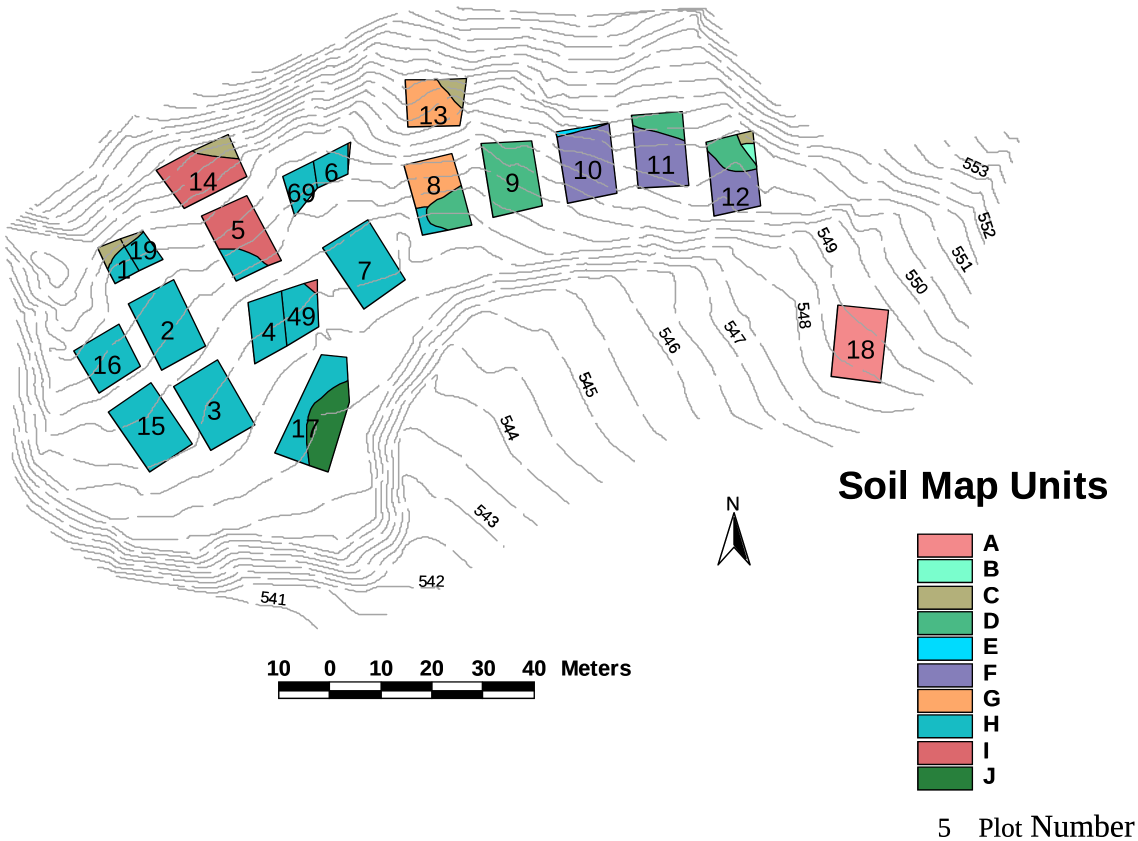

Figure 13. Map of DIRT study site showing the distribution of soil map units underlying individual plots.

Table 9. Soil map unit area underlying all DIRT Plots and control plots.

Soil map unit	Plot area (m^2)	Plot area (%)	Control plot area (m^2)	Control plot area (%)	Control plot number
A	146.1	5.9	0	0.0	
B	6.5	0.3	6.5	1.5	12
C	75.8	3.0	30.2	7.0	12 and 14
D	278.9	11.2	97.5	22.6	8 and 12
E	7.7	0.3	0	0.0	
F	334.6	13.4	83.2	19.3	12
G	171.6	6.9	83.2	19.3	8
H	1136.6	45.7	13.6	3.2	8
I	231.9	9.3	117.3	27.2	14
J	98.8	4.0	0	0.0	

Intersection of DIRT plots with soil classification map units shows prevalence for classification within the Andisol soil order (Figure 14). Typic Hapludands were found to underlie 59.3 percent of all DIRT plots. Vitrandic Dystrudepts and Andic Dystrudepts were represented to a lesser extent, 20.9 and 19.6 percent, respectively (Table 10). Control and replicate plot treatments, which have no inputs and no **O/A** horizon, are underlain by all taxonomic subgroups.

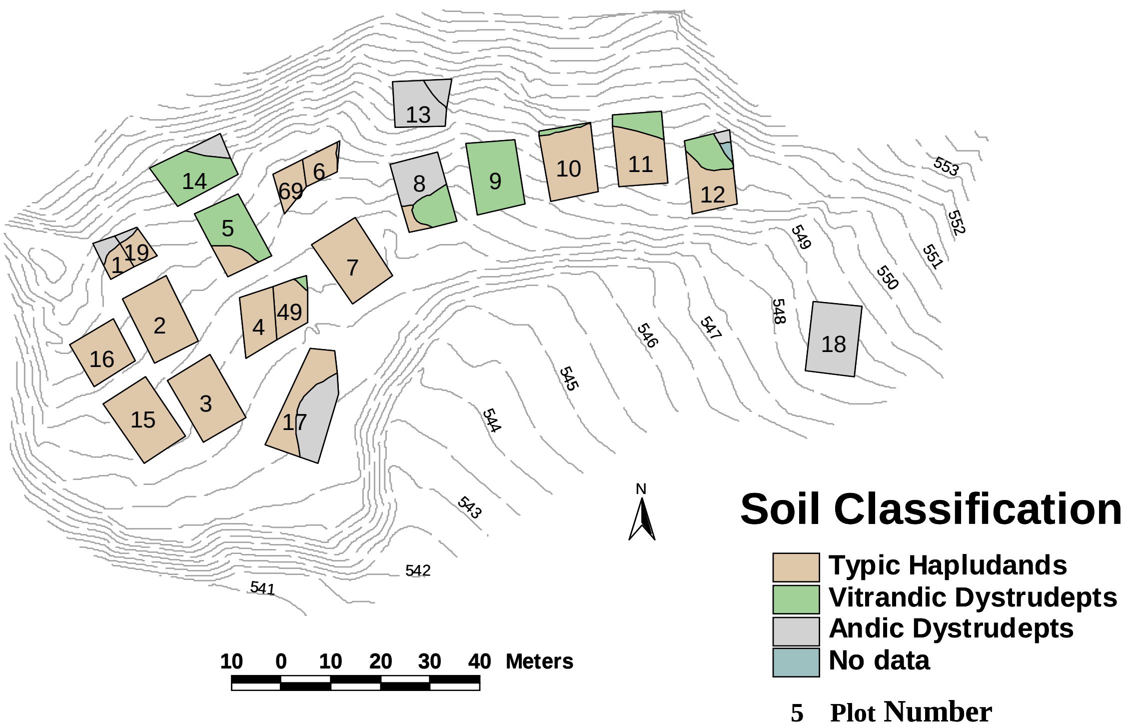

Figure 14. Map of DIRT study site showing the distribution of soil classification sub-groups underlying individual plots.

Table 10. Soil classification map unit area underlying all DIRT Plots and control plots.

Subgroup classification	Plot area (m^2)	Plot area (%)	Control plot area (m^2)	Control plot area (%)	Control plot number(s)
Typic Hapludands	1471.2	59.3	96.7	22.4	8,12
Andic Dystrudepts	485.6	19.6	113.4	26.3	8, 12, 14
Vitrandic Dystrudepts	518.5	20.9	214.8	49.8	8, 12, 14
No data	6.5	0.3	6.5	1.5	12

Intersection of DIRT plots with PDI age class map units shows prevalence for grouping within class 3 (Figure 15). PDI class three underlies 79.9 percent of the total plot area and is represented by all control plots. PDI age classes two and four are represented to a lesser extent, 6.5 and 13.7 percent (Table 11).

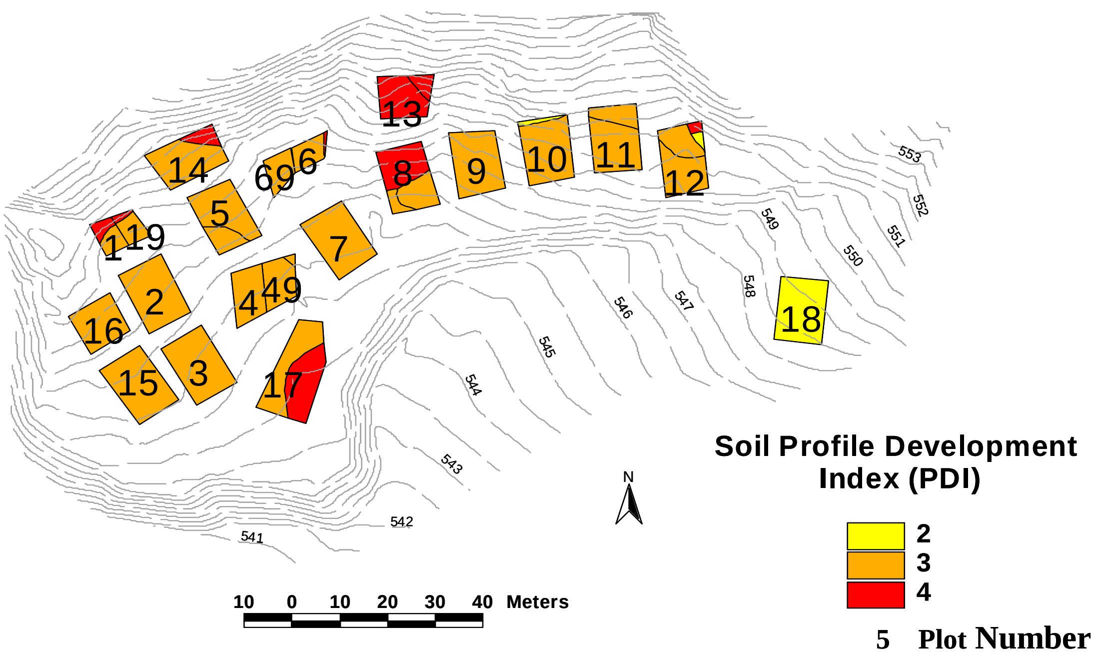

Figure 15. Map of DIRT study site showing the distribution of PDI age class map units underlying individual plots.

Table 11. Soil PDI age class map unit area underlying all DIRT Plots and control plots.

PDI age class	Plot area (m^2)	Plot area (%)	Control plot area (m^2)	Control plot area (%)	Control plot numbers
2	392.0	6.5	6.5	1.5	12
3	1750.2	79.9	311.5	72.2	8, 12, 14
4	339.5	13.7	113.4	26.3	8, 12, 14

4.0 Discussion

4.1 Soil-Geomorphic Mapping Relations

Mapping results show that geomorphology and associated forest soil systems are highly heterogeneous, varying both spatially and temporally where hillslope mass-wasting processes and fluvial (valley-bottom) processes interplay. Soil-geomorphic mapping efforts identified ten geomorphic map units and twelve soil map units within the valley-bottom study site and seven geomorphic map units and ten soil map units within the DIRT study site. Alluvial fans, fluvial terraces and upland footslope (colluvium) are the major landscape partitions, each having distinct and separable geomorphic characteristics and soil properties between and within these divisions. Discussion will primarily focus on alluvial fan soil-geomorphology, the dominant landscape feature underlying individual DIRT Plots.

The study site within the Lookout Creek valley bottom is unique, occupying the widest valley bottom stream reach, which is upstream from the narrowest reach (Grant et al., 1995). A massive earthflow originating from the northern face of Lookout Ridge constricted the channel, raised stream base level, and impeded material transfer through the reach, resulting in a broad aggraded valley bottom (Swanson and James, 1975a). As channel incision ensued and stream base levels were lowered, terraces T2 and T3 were abandoned above the current floodplain (T1). Valley-side alluvial fans and colluvium systematically advanced over T3 and T2 once the surface was abandoned as a floodplain.

Comparison between geomorphic and soil map units generally shows a high spatial correlation. The inherent dynamic nature of alluvial fans results in spatial differences. Discrepancies between soil and geomorphic map unit delineations are the result of each fan having differing disturbance regimes, sediment-source area dynamics, and surface-and-subsurface water flow paths, all of which influence soil formation through time.

Episodic mass-wasting events followed by seasonal deposition and fluvial reworking of surface sediments gave form to the alluvial fan features, referred to as ‘wet’ fans in humid environments (Graf, 1988). The more homogeneous fan deposits of sand, silt and clay with no apparent variation in particle size downslope support this. Soil properties to a depth of 1 m lacks large, angular rock fragments more typical of a debris slide or torrent. The presence of rounded and subrounded rock fragments and rounded gravel-size clay aggregates within the soil matrix suggest mud debris flows are the principal mass-wasting mechanism. Additions of bedload and suspended sediments occur seasonally, mixing with surface sediments, enhancing alluvial fan morphology. The intermittent stream feeding F2, soils *D* and *E*, dissects a much older alluvial fan whose soils have high clay contents and lack rock fragments. Fan sediments originating from small watersheds (< 40 hectares) are finer grained and better sorted than fans of larger watersheds, suggesting annual deposition of bedload and suspended sediments are primary agents of fan construction (Swanson and James, 1975a).

Return intervals for soil mass-movement events (debris flows) occurring in small watersheds (< 40 hectares) at the H.J. Andrews are estimated at one in 580 years (Swanson et al., 1982). Extreme rainfall events with an approximate 100-year recurrence interval are thought to initiate these events (Fredricksen, 1965). Alluvial fan profiles contained charcoal in nearly every horizon, indicating that the combined effects of large forest fires, resulting in hydrophobic soils, coupled with extreme rainfall events may be a prerequisite for triggering mud debris flows.

Coarse fragments of andesite, greenish tuff and breccia representative of catchment parent materials are present at depth within soils *A*, *C*, *G* and *F*. Dyrness (1967) established a correlation between tuff and breccia deposits and hillslope instability occurring in an elevation band between 620m and 810m, just above the study site. Soils formed on these parent materials are particularly prone to soil mass movements (Dyrness and Paeth et al., 1971).

More subtle erosional processes modifying the soil-geomorphic landscape include soil creep, rotational slump and treethrow. Soil creep is a continuous downslope movement of surface soil occurring on higher gradient colluvial soils, as well as more moderate slopes, with movement rates of mm/yr (Swanson et al., 1982). Soil-geomorphic map unit F2-*G* formed as a result of a deep-seated rotational slump of the entire soil mass possibly in response to toe-slope erosion of Lookout Creek when T3 was the active floodplain. Soil map unit *G* has retained former soil profile characteristics of colluvial soil *C*, developing fan morphology characteristics by means of soil creep and surface modifying erosion processes. Treethrow disturbances are prevalent throughout the study site resulting in upthrown root masses, displacement of soil up to 1 m, and pit-mound microtopography. Soil H_2 is representative of treethrown soil H_1, and exhibits mixing of soil materials, thicker **A** horizon, and a broken 45^0 horizon boundary grading into the **Bw2** horizon of soil H_1 at 50 cm. Small et al. (1990) and Birkeland (1999) suggest that the uprooting of trees may arrest progressive soil development through reversed horizon sequences, loss of horizons and disrupted lateral continuity. Comparison of PDI values between soils H_1 (24.2) and H_2 (11.2) indicates that soil horizon properties of treethrown soils are reduced dramatically. Although the extent of treethrown soils at the study site is unknown, forested areas have been documented as having between 10 to 65 percent of soils in a disturbed state (Armson and Fessenden, 1973; Pawluk and Dudas, 1982; Beatty, 1984; Meyers and McSweeney, 1995). Meyers and McSweeney (1995) recommend that treethrow influenced landscapes (> 25% of the area) should be mapped as complexes that explicitly identify the occurrence of pit/mound soils in the delineation**.** Over long periods of time the entire forest floor eventually undergoes disturbance through the tree uprooting process and may be the greatest single factor influencing soil pedogenesis in forests (Small et al., 1990).

Stratigraphic relationships between valley terraces and alluvial fans provide a general chronological sequence of soil-geomorphic evolution within the study site. Terrace age increases with height and distance from the Lookout Creek channel resulting in T1<T2<T3 age sequence. Alluvial Fans F1, F2 and F5, with the greatest fan area - drainage area (Fa/Da) ratios 21.4, 17.1 and 22.7 respectively, have had the greatest spatial and temporal influence on fan morphology and soil properties. These fans began forming

as Lookout Creek abandoned T3 as the active floodplain. Lateral erosion (`toe-cutting') of alluvial fans by axial rivers (Lookout Creek) is a common response for incising channels that are subject to local base-level changes (Leeder and Mack, 2001). Lookout Creek eroded coalesced distal fan edges and T3 when T2 was the active floodplain during the transition between the Late Pleistocene and Holocene, approximately 7 ka to 10 ka years ago, leading to divergences in subsequent fan development and soil formation.

Fan morphology and sediment characteristics provide clues to the depositional processes, temporal variability and geomorphic dynamics of contributing drainage areas (Gomez-Villar and Garcia-Ruiz, 2000). Alluvial fans F1, F2 and F5 each responded to distal fan erosion differently due to contrasting contributing drainage area dynamics, sediment supply volume and stream surface water discharge feeding the fans. Whether a fan aggrades or becomes dissected is controlled by the critical power of the stream feeding the fan and its ability to transport available sediment, which depends on stream discharge and volume of sediment supplied (Harvey et al., 1999). Differentiation between younger alluvial fan soils of the Andrews assemblage and older fan and terrace three soils (T3) of the lookout assemblage occurred at this time.

High sediment volume and high surface-water discharge of the contributing catchment area feeding F1 resulted in fan aggradation and progradation over T2 surface. F1-*A* is currently an inactive young fan within the Andrews assemblage. Soil property differences between other assemblage one soils include, presence of subrounded and subangular gravels, incised fan morphology, better drained soil, higher P and Al+1/2 Fe percentages, and Andic Dystrudepts classification.

Fan morphology of F2 is subdivided into two sectors, inactive (F2-*F*) and active (F2-*D* and F2-*E*). Moderately high-sediment volume and low surface-water discharge of the contributing catchment area feeding F2 resulted in development of F2-*D*, then F2-*E*, both of which overlie the apex and mid-fan position of the stable F2-*F*. Low surface-water discharge inhibited channel incision of the fan toe or fan surface abandonment. Comparison of alluvial fan PDI values with those of F2 shows these soils are the most developed, *F* (26.8) and *D* (25.0) and the least developed, *E* (17.3) fan soils. PDI values for soil *E* and *D* may be elevated due to the particularly high clay content of catchment parent materials.

Distinction between F2-*F* and other assemblage one soils is a **B2** horizon at 68 cm comprised of coarse gravel stream deposits aligned parallel with the fan axis, representing a period of higher stream discharge prior to distal fan dissection. The divergent (convex-convex) slope shape along the axial center of the fan has shed additional surface sediment inputs resulting in an older more stable profile, typical of Lookout assemblage soils.

Active alluvial fan soils *D* and *E* represent a continuum of development and disturbance through time where differentiation between fan forming events becomes difficult. Episodic (long term) mud debris flows concentrate in the proximal position, being replaced down fan by transitional processes linked to seasonal suspended sediment fluvial events, resulting in regressive soil pedogenesis limiting **A** horizon development between 2 to 7 cm. Convergent topographic flow paths have resulted in buried **A** horizons and higher soil-water content within soil *D*.

Low sediment volume and high surface-water discharge of the contributing catchment feeding F5 resulted in stream incision and fan surface abandonment (Leeder and Mack, 2001). Inactive, older F5-H_1 is a member of Lookout assemblage soils, although pH values in the upper **A** and **A/B** horizons are the highest for this assemblage. Soil H_1 is similar to soil F in many respects; both classify as Typic Hapludands and are within PDI class three. Upper horizon profiles are similar, although at depth soil *F* exhibits greater clay content and a **B2** horizon with 40% subangular coarse gravel stream sediments.

The greatest disparity between geomorphic mapping area and soil mapping area delineations was between F5-*H* and both F3-*G* and F4-*I*. Soil *H*, the largest soil map unit, has had a greater influence on soil development due to the larger contributing drainage prior to its abandonment than younger overlying F4-*I* and F3-*G*. Soil-geomorphic units F3-*G* and F4-*I* have the lowest Fa/Da ratios, 3.4 and 8.3 respectively, and have had minimal influence on soil characteristics at mid and distal fan positions. Soil map unit F3-*G* is a member of Lookout assemblage soils and correlates strongly with colluvial soil C-*C*, which, having fan surface morphology is more characteristic of an old rotational slump. Designation of soil *G* as a phase of soil *C* may be more appropriate. Soil map unit *I*, associated with F4, consists of recent (~50 years), well-sorted, stratified fluvial deposits 17 cm thick overlying a buried **A** horizon. Soils *I* and *B* did not fit into either soil assemblage due to erratic horizon properties to depth.

4.2 Soil Classification

Soil taxonomic classification designations are based on soil profile and lab data of the author and correlation with prior soil investigations and mapping efforts within the H.J. Andrews (U.S. Forest Service, 1964; Paeth, 1970; Paeth et al., 1971; Brown, 1975). Soil field data, soil bulk density (B_d), phosphate retention (Pr), and Al + ½ Fe percentage results show the prevalence of andic properties for these soils, although certain classification criteria are incomplete for definitive classification. Andic characteristics of the mapped soils are expressed to varying degrees. Two soil order separations are recognized -- Andisol and Inceptisol -- and three soil subgroup separations -- Typic Hapludands, Andic Dystrudepts and Vitrandic Dystrudepts.

Andisols are typically derived from volcanic ash, though they also may form through the weathering of pyroclastic materials, tuffs, lahars, volcanic flows, sedimentary rocks and intrusive igneous rocks (Wada, 1989; Soil Survey Staff, 1998). Many H.J. Andrews researchers document Mazama pumice and ash fall deposits near the surface of older terraces and alluvial fans and at depth within younger alluvial fans. (Paeth, 1970; Swanson and James, 1975a,b; Brown 1975). In the H.J. Andrews, soils with 10YR hues contain amorphous material in the clay fraction ranging from 42 to 60 percent (Paeth et al., 1971). Typical clay mineralogy of weathered pyroclastic parent materials is dominated by allophane, an amorphous clay (Shoji et al., 1993).

Soil lab data are extrapolated beyond the two profile control sections to meet taxonomic criteria (Soil Survey Staff, 1998), particularly the 60-60 rule. The 60-60 rule states that andic properties must be found in 60 percent of the upper 60 cm (Soil Survey Staff, 1998). For example, it was assumed that for soils H_1 and *F*, the **A1** horizons overlying the upper profile control section and the **B/A** horizons underlying the lower profile control section met B_d, P_r and Al + ½ Fe criteria. Paeth (1970) found glass within the coarse silt fraction of H.J. Andrews (local) soils. Assuming similar glass contents for studied soils, the Al + ½ Fe requirement is reduced accordingly, resulting in an Al + ½ Fe minimum requirement of 1.7 percent (Soil Survey Staff, 1998). Upper profile control sections, typically sampled within the **A** horizon, expressed the strongest andic characteristics, indicating the presence of Al-humus complexes. A more conservative characterization of these soils would place them in the Andic Dystrudepts subgroup.

Soils H_1, H_2 and *F* classify as medial over loamy, mixed, mesic Typic Hapludands. These soils, which developed in the oldest fan alluvium, lack lithologic discontinuities suggesting limited alluvial sediment additions or fluvial disturbances during the Holocene. Placement in the Andisols order may be due to the relatively stable position these Lookout assemblage soils had. Soil H_2 is representative of treethrown soil H_1, and exhibits the most pronounced andic characteristics. Topographical influences of treethrow mounds can result in thicker **A** horizons and elevated Al and Fe concentrations in **B** horizons (Schaetzl, 1990). The ability for fan contributing drainage area to concentrate air fall tephra and exhume weathered soils derived from volcanic parent materials also may have enhanced andic properties of these fan soils.

Soils *A, C, G, J* and *K* are classified as medial over loamy, mixed, mesic Andic Dystrudepts. These soils developed in a wide range of parent materials including colluvium, terrace alluvium and relatively young fan alluvium. Soils *C, G* and *J* are members of PDI age class four and Lookout assemblage soils. These soils exhibit andic properties within the upper profile control section meeting Andisol criteria, although lack the 60-60 depth requirement (Soil Survey Staff, 1998). Soils *A* and *K* are members of PDI age class two and Andrews assemblage soils. These soils narrowly meet minimum requirements for this classification and are distinguished from other Andrews assemblage soils by their stable positions lacking surficial disturbances.

Soils D_1, D_2, *E*, and *I* classify as medial over loamy, mixed, mesic Vitrandic Dystrudepts. These soils developed on the youngest alluvial fan deposits, which include the most recent mud debris alluvial sediment inputs and are Andrews assemblage soils. Shallow lithologic discontinuities and buried **A** horizons, characterizes these active alluvial fan soils. Andic properties of these soils represent minimum values for this site and are similar to the **C** horizon of terrace soil *K*.

It appears that time, alluvial fan parent material and a period of stability is needed for development of Andisols at this study site, although localized treethrow disturbances can enhance andic characteristics. Seasonal fluvial reworking and surface erosion from surface **A** horizons that are deposited down slope to mid and distal fan positions likely increased andic properties of soils *H* and *F* from what they would have had otherwise.

4.3 Relative Soil Dating

Relative dating based on stratigraphy, PDI and RMW results gives credence to the spatial and temporal variability of soil-geomorphic landscape map units within the Lookout Valley bottom and study site. The soil chronosequence concept is a useful tool for deciphering temporal relations of soil-landscapes by comparing groups of soils that have formed under similar conditions (parent material, climate, biological, relief) with time as the only variable; the mathematical relationship is a chronofunction (Jenny, 1941;

Birkeland, 1999). Terrace soil-geomorphic map units (Figure 2) represent a post-incisive chronosequence (Vreeken, 1975), where initiation of soil formation occurs once surface alluvial deposition ends. Relative dating methods employed in this study are correlated with established chronofunctions, RMW (Coleman and Pierce 1981), PDI (Harden and Taylor 1983; Busacca 1987; Vidic and Lobnic 1997) and relative dating efforts of H.J. Andrews researchers (Swanson and James, 1975b; Gottesfeld et. al.1981, Grant and Swanson, 1995) resulting in a range of ages for each terrace (Table12).

Table 12. Soil-geomorphic map unit, relative date methods and age ranking. Relative age correlation reference, dating methods and estimated soil age(s).

Soil	Geomorphic unit	Soil-geomorphic unit	PDI	PDI class	Weathering rind (mm)	Reference	Correlation dating method	Age(s)
L (1)	T1 (1)	T1-L	6.4 (1)	1	0.37	Coleman and Pierce (1981)	MWR	15 ka*
						Harden and Taylor (1983)	PDI	2 ka*
						Busacca (1987)	PDI	0.8 ka
						Vidic (1998)	PDI	0.9 - 2 ka
						Swanson and James, Grant et al. (1975b: 1995)	Stratigraphy	< 8 ka
						Blaster and Parsons (1968)	Stratigraphy	0.5 - 3.3 ka
						estimated by author	Tree age	0.5 ka
H_2 (1)	F5, F2, F3 (4)	F5- H_2	11.3 (2)	1				
E (2)	F3 (4)	F3-E	17.3 (3)	2				
A (2)	F1 (2)	F1-A	18.8 (4)	2				
K (3)	T2 (3)	T2-K	20.3 (5)	2		Harden and Taylor (1983)	PDI	24 ka*
						Busacca (1987)	PDI	8 ka
						Vidic (1998)	PDI	10.5 ka
						Swanson and James, Grant et al. (1975b: 1995)	Stratigraphy	7 ka
						Blaster and Parsons (1968)	Stratigraphy	> 5.2 ka
B (4)	I (4)	I-B	20.5 (6)	2				
I (2)	F4 (4)	F4-I	23.8 (7)	3				
H_1 (5)	F5 (4)	F5-H_1	24.2 (8)	3				
D_2 (4)	F2, F3 (4)	F2-D_2	25.0 (9)	3				
F (5)	F2 (4)	F2-F	26.0 (10)	3				
G (2)	F3 (4)	F3-G	29.3 (11)	4				
C (5)	C (5)	C-C	29.6 (12)	4				
J (5)	T3 (5)	T3-J	30.8 (13)	4	1.27	Coleman and Pierce (1981)	MWR	50 ka*
						Harden and Taylor (1983)	PDI	100 ka*
						Busacca (1987)	PDI	30 ka
						Vidic (1998)	PDI	21 ka
						Swanson and James, Grant et al. (1975b: 1995)	Stratigraphy	> 8 ka
						Gottesfeld et al. (1981)	Stratigraphy	35 ka

( ) = ranking

* Correlation age not used as data point in chronofunction.

The terrace chronosequence is subdivided into three soil-geomorphic units: (1) youngest terrace (T1-*L*) (active vegetated floodplain) has only an **A** horizon; (2) intermediate terrace (T2-*K*) has an **A-B-C** profile; and (3) oldest terrace (T3-*J*) has an **A-A/B-Bw1-Bw2-Bw3** profile.

Soil-geomorphic unit T1-*L* has the lowest stratigraphic position, least PDI value of 6.4 and thinnest weathering rind of 0.38 mm. Minimum age of this surface is 400 to 500 years based on maximum tree (*Pseudotsuga menziesii*) age. PDI correlation with those of Harden and Taylor (1983), Busacca (1987) and Vidic and Lobnic (1998) date this soil at approximately 0.8 ka, 2 ka and 1 ka, respectively. Weathering rind correlations with Coleman and Pierce (1981) age the clasts at approximately 15 ka years. Floodplain surfaces less than or equal to 3 m above low flow stream height are considered Holocene (<8 ka B.P.) age deposits (Swanson and James, 1975b; Grant and Swanson, 1995). Swanson and James (1975b) suggested a possible correlation between this surface and the Ingram geomorphic unit of the Willamette Valley, which Blaster and Parsons (1968) dated between 0.5 and 3.2 ka years B.P.

Relative dating of the T1-*L* surface is complicated by the dynamic nature of the Lookout Creek floodplain. Periods of relative stability with minimal soil development are followed by instability and erosion as Lookout Creek migrates laterally, re-entraining sediments and eliminating evidence of prior soil development. As a result, the age of T1-*L* represents a minimum, though it could be much older.

Soil-geomorphic unit T2-*K* has a middle terrace stratigraphic position and a PDI value of 20.3. PDI correlation with those of Harden and Taylor (1983), Busacca (1987) and Vidic and Lobnic (1997) date this soil at approximately 24 ka, 8 ka and 10.5 ka, respectively. Swanson and James (1975b) and Grant and Swanson (1995) identified terraces 6 to 10 m above low flow stream height with deposits of Mazama ash near the surface, indicating floodplain abandonment more than 6.6 ka years ago, suggesting a minimum age of 7 ka years. Swanson and James (1975b) suggested a possible correlation between this surface and the Winkle geomorphic unit of the Willamette Valley, which Blaster and Parsons (1968a) assigned a minimum age of 5.3 ka years B.P.

Soil-geomorphic unit T3-*J* has the highest terrace stratigraphic position, greatest PDI value of 30.8 and thickest weathering rind of 1.27 mm. PDI correlation with those of Harden and Taylor (1983), Busacca (1987) and Vidic and Lobnic (1997) date this soil at approximately 30 ka, 100 ka and 21 ka, respectively. Weathering rind correlation with Coleman and Pierce (1981) age the clasts at approximately 50 ka years. High remnant terrace surfaces greater than 10 m above low-flow stream height within the Lookout Creek valley bottom are rare and considered valley wall features (Grant and Swanson, 1995). These are presumably late Pleistocene (> 8 ka yrs) in age. Gottesfeld et al. (1981) dated plant fossils at 35 ka radiocarbon years with a flora representative of a drier and cooler climate buried in alluvial fan sediments emanating from Lookout Creek watershed two, representing a local maximum age for valley bottom features of Lookout Creek.

Alluvial fan morphology and presence of recent Mazama ash deposits have also been used as relative age indicators (Swanson and James, 1975b; Brown, 1975; Grant and Swanson, 1995), although no ash was identified in the study area. Fans F1-*A* and F2-*E* have an active floodplain (i.e. drainage that is not incised) without surface ash deposits and are considered pre-Mazama, and therefore younger than 7 ka. Inactive alluvial fans

F2-*F*, F5-*H* and F2-*D*, have large contributing drainage areas (>24 ha) and dissected distal fan morphology and are considered post-Mazama in age >7 ka.

Age estimates obtained through correlation for each terrace were used to compute the soil chronofunction. Elimination of gross outliers, due to inherent problems of dating methods narrowed the range of possible ages, increasing the plausibility of soil development rates derived from the chronofunction.

Ages for T1 and T3 using the RMW chronofunction of Coleman and Pierce (1981) and PDI chronofunction of Harden and Taylor (1983) seem unreasonable compared to the expected age assignments and are not further used. This problem amplifies the caution expressed by Birkeland and Noller (2000) and Vidic and Lobniz (1997), respectively, for these two methods.

Rind development may be accelerated in floodplain environments, such as unit T1, where the soil matrix may be saturated for longer periods of time compared to the well-drained moraine glacial till studied by Coleman and Pierce (1981). Subsurface weathering rates are related to precipitation and water movement through the soil (Birkeland and Noller, 2000). Precipitation at the study site is nearly two times greater than Coleman and Pierce's (1981) Mount Ranier site.

Vidic (1998) compared temporal trends in profile development (PDI) between areas having differing moisture soil regimes and found that rates (slope of chronofunction) increased with increasing precipitation, contrary to Harden and Taylor (1983) findings. Ogg and Baker (1999) found that time and climate are the two most influential soil-forming factors controlling soil development on alluvial fans. The Merced chronosequence of Harden and Taylor (1983) formed under xeric / thermic soil moisture /

temperature regime, much drier than those of the H.J. Andrews (udic/mesic) was not included in the chronofunction data set. However the Sacramento soil (Busacca, 1987), which formed under similar climatic conditions to that of the Merced soil, was included in the chronofunction data set.

Soil properties used for calculating PDI indices were able to discriminate between all soil map units and correlate strongly with stratigraphic dating. Using PDI values of each terrace as the dependent variable and the various ages obtained through correlation as independent variables, a chronofunction was generated. Semi-logarithmic and power functions yielded the highest correlation, slightly higher than the linear model. Figure 16 shows that soil development increases with the logarithm or power of time, indicating that rates of soil development decrease with time.

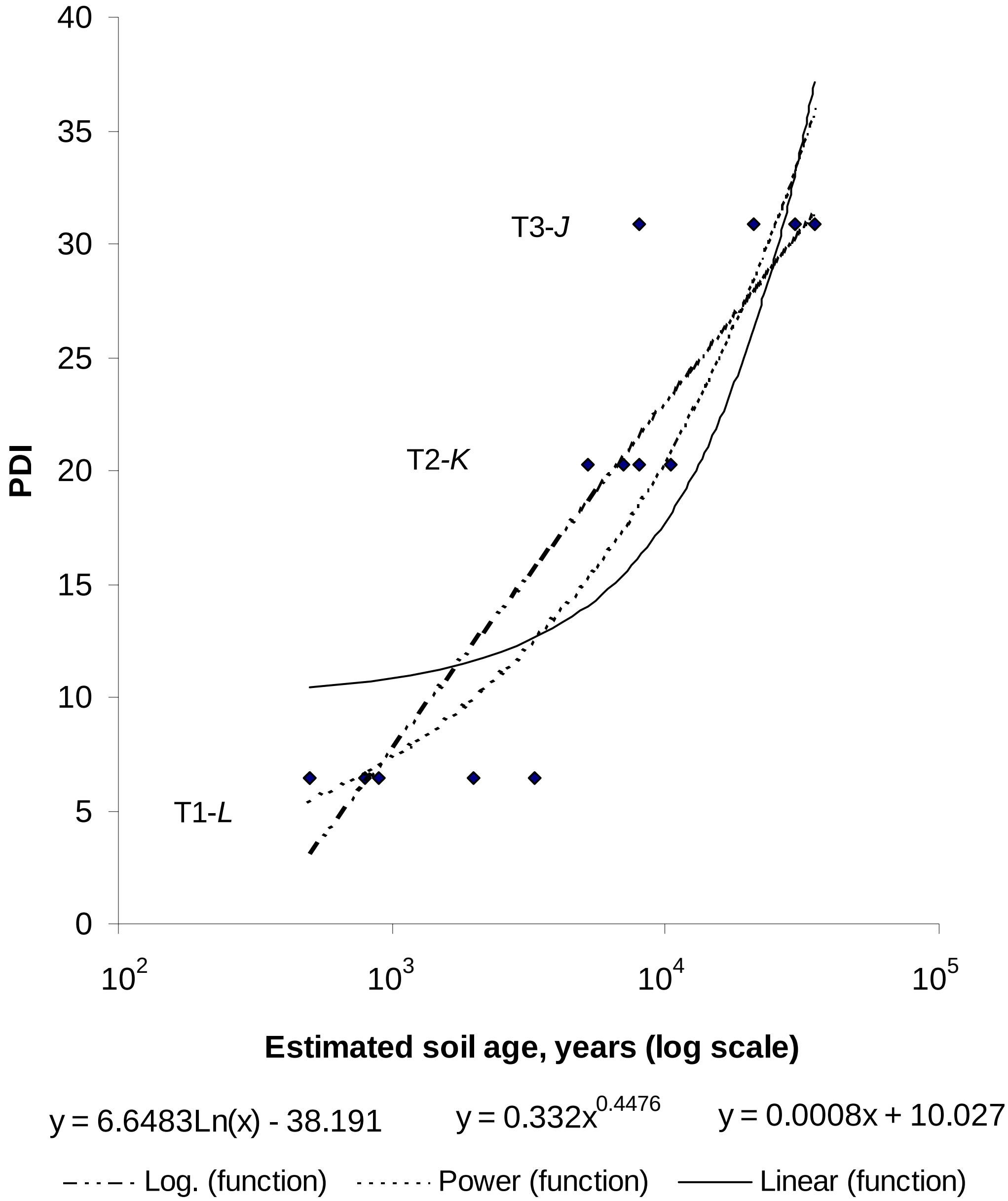

Figure 16. Chronofunctions of profile development indices (PDIs) based on relative dating correlations with the terrace chronosequence. Because age (x) axis is logarithmic, the linear and power chronofunctions appear concave upwards, whereas semi-logarithmic appear linear.

Soil map unit PDI values and each of the three chronofunction formulas, were use to calculate possible maximum and minimum ages for all study site soils (Table 13).

Table 13. Estimated age of soil map units using three chronofunctions using respective soil PDI values.

Soil map unit	**PDI**	**Estimate age (yrs)**		
		Chronofunction		
		Log	**Power**	**Linear**
L*	6.4	900	700	-4,500
H_2	11.3	1,900	2,600	15,000
E	17.3	4,700	6,900	9,100
A	18.8	5,900	8,300	11,000
K **	20.3	7,300	9,800	12,800
B	20.5	7,600	10,000	13,100
I	23.8	12,500	14,000	17,200
H_1	24.2	13,200	14,500	17,700
D_2	25.0	14,800	15,600	18,700
F	26.1	17,500	17,100	20,100
G	29.3	28,600	22,300	24,000
C	29.6	29,700	22,700	24,400
J***	30.8	36,000	25,000	26,000

* = T1, ** = T2, *** = T3

4.4 DIRT Plot Soil Relations

The Detritus Input Removal and Transfer (DIRT) study is investigating the role of plant litter (both from above and belowground) in controlling the accumulation and turnover of organic matter and nutrients in forest soils (Nadelhoffer et al., 2003). This is done by various manipulations of organic inputs to the forest floor, including removal of **O-A** soil horizons and trenching plot perimeters. There are six different field treatment plots and one control, each replicated three times, for a total of 21 plots. GIS was used to intersect the various mapping themes: soils, taxonomy and PDI with individual DIRT plots that allow spatial as well as temporal analysis.

Implications of variability within and among DIRT plot treatments for the ongoing research and results are not known. In order to compare the various DIRT plot treatments with one another and particularly controls, the distribution, physical and chemical properties, taxonomic classification and to a lesser extent age, of the underlying soils should be understood and possible effects on study results recognized. Similarities between all soil map units exist, noticeably color and structure, although other various soil properties tend to diverge with increasing soil depth resulting in distinct soil map units. General soil groupings, Lookout and Andrews soil assemblages, are recognized and based on commonalities rather than differences. Differentiations of the two soil assemblages are broadly based on soil physical and chemical properties (soil profile descriptions), andic properties (classification) and temporal characteristics (PDI age class). Soils *I* and *B* do not fit within an assemblage and underlie 9.6 percent of all plots and 28.7 percent of control plots.

Intersection results of DIRT plot treatments with soil map units show a relatively heterogeneous distribution of soils underlying individual plots. The ten soils identified within the study site all underlie plots, although to varying areal extents. Soil map units *B* and *E* each underlie 0.3 percent of total plot area; in addition, soils *C* and *J* underlie only 3.0 and 4.0 percent respectively. Soils derived from alluvial fan parent materials dominate, underlying 85.8 percent of all plots. Soil *H*, the dominant alluvial fan soil type, underlies 45.7 percent of all plots and is strongly represented by all six treatments, with controls being the only exception, overlying just 13.6 m^2 of soil *H*. Soils *A*, *D*, *F*, *G* and *I* underlie the remaining plots and are all well represented by a control with the exception of soil *A*. Focusing on assemblage soil groupings, Lookout soils underlie 82.6 percent of all plots and 77.4 percent of control plots.

Intersection results of DIRT plot treatments with soil classification map units show Typic Hapludands (soils *H* and *F*) are the dominant taxonomic suborder underlying 59.3 percent of all plots and 22.4 percent of control plots. Andic properties within the upper profile control sections of Typic Hapludands and Andic Dystrudepts subgroups are similar, with the exception of soil *A*, and together form Lookout assemblage soils. Focusing on assemblage taxonomic groupings, Lookout soils underlie 78.9 percent of all plots, 73.0 percent excluding soil *A*, and 48.7 percent of control plots.

Intersection results of DIRT plot treatments with PDI age class map units show class three as the dominant age group underlying 79.9 percent of all plots and 72.2 percent of control plots. Soils *A*, *B* and *E*, which are young alluvial fan soils, represent the only PDI class two soils within the study site and are members of the Andrews soil assemblage. Focusing on assemblage PDI groupings, Lookout soils underlie 93.6 percent of all plots and 98.5 percent of control plots.

It should be noted that this analysis did not look at underlying soil differences between the various plot treatments. Spatial analysis results based on soil map units underscore the differences between these soils and the need for detailed soil-geomorphic mapping prior to field plot design. Spatial analysis results based on the more inclusive soil assemblages underscore the general similarities between these soils, offering a starting point for individual plot comparisons by researchers.

5.0 Conclusions

Soil-geomorphic landscape relations within the Lookout Creek valley bottom study site are complex, varying both spatially and temporally where hillslope mass-wasting processes and fluvial processes interplay. The principal processes responsible for this heterogeneity are disturbance driven and include earthflows, rotational slumps, alluvial deposition and entrenchment, fluvial fan dissection, surface and subsurface water flow paths, fire and tree throw. Alluvial fans, fluvial terraces and upland footslopes (colluvium) are the major landscape partitions, each having distinct and separable geomorphic characteristics and soil properties between and within these divisions.

Soil-geomorphic mapping efforts identified nine geomorphic map units and twelve soil map units within the valley bottom study site and eight geomorphic map units and ten soil map units within the DIRT study site. Comparison between geomorphic and soil map units generally shows a high spatial correlation. The inherent dynamic nature of alluvial fans, the dominant landscape feature underlying individual DIRT Plots, results in spatial differences. Discrepancies between soil and geomorphic map unit delineations are the result of each alluvial fan having differing disturbance regimes, sediment-source area dynamics, and surface-and subsurface water flow paths, all of which influence soil formation through time. Episodic mass-wasting mud debris flow events followed by seasonal deposition and fluvial reworking of surface sediments gave form to the alluvial fan features.

Andic characteristics of the mapped soils are expressed to varying degrees. Two soil order separations are recognized – Andisol and Inceptisol – and three soil subgroup separations – Typic Hapludands, Andic Dystrudepts and Vitrandic dystrudepts.

Stratigraphic relationships between valley terraces and alluvial fans provide a general chronological sequence of soil-geomorphic evolution within the study site and correlate strongly with calculated profile development index values. Relative dating based on stratigraphy, PDI and RMW results gives credence to the spatial and temporal variability of this site.

Geographic Information Systems technology was used to spatially relate treatment plots to soil map units, soil taxonomic classification and PDI. Results show high variability in soil map units and geomorphic landscape units among the DIRT Plots.

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Appendices

<u>**Appendix – A** Observed Soil Profile Descriptions</u>

Pedon Description

Soil Map Unit: A
Geomorphic Landscape Unit: Fan 1
Classification: Andic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 10
Parent Material: Fan alluvium
Described and sampled by: John Dixon

Oi - 0 to 4cm.

A - 4 to 13cm; very dark grayish brown (10YR 3/2) gravelly loam, dark grayish brown (10YR 4/2) dry; moderate medium granular structure; soft, very friable, moderately sticky and moderately plastic; common fine and medium roots; many very fine dendritic tubular pores; 10 percent subrounded fine gravels and 5 percent subrounded medium gravels; strongly acid (pH 5.4); clear smooth boundary. Clay 22%.

Bw1 - 13 to 33cm; dark yellowish brown (10YR 4/4) 20% yellowish brown (10YR 4/6) gravelly clay loam, (10YR 5/3) dry; moderate medium subangular blocky structure; slightly hard, firm, slightly sticky and slightly plastic; common fine and medium roots; many medium dendritic tubular pores and common fine interstitial pores; 10 percent subrounded fine gravels and 6 percent subrounded medium gravels; moderately acid (pH 5.6); clear smooth boundary. Clay 28%.

2Bw2 - 33 to 44cm; brown (10YR 4/3) clay loam, (10YR 6/3) dry; moderate medium subangular blocky structure; hard, firm, moderately sticky and moderately plastic; few fine roots; common fine dendritic tubular pores; 3 percent subangular medium gravels; strongly acid (pH 5.5); clear smooth boundary. Clay 35%.

2Bw3 - 44 to 90cm+; brown (10YR 4/3) clay loam, light yellowish brown (10YR 6/4) dry; moderate medium and coarse subangular blocky structure; hard, friable, moderately sticky and moderately plastic; many fine dendritic tubular pores; 10 percent subangular coarse gravels; strongly acid (pH 5.4); Clay 32%.

Pedon Description

Soil Map Unit: B
Geomorphic Landscape Unit: Fan interfluve
Classification: n/a
Soil Pit: 9
Parent Material: Hillslope colluvium/fan alluvium
Described and sampled by: John Dixon

Oi - 0 to 4cm.

A - 4 to 18cm; black (10YR 2/1) fine gravelly sandy loam, yellowish brown (10YR 5/4) dry; weak fine granular structure; soft, very friable, non-sticky and non-plastic; many medium and common coarse roots; many fine dendritic tubular pores and many fine interstitial pores; 15 percent subrounded fine gravels and 5 percent subrounded medium gravels; strongly acid (pH 5.2); clear smooth boundary. Clay 8%.

B/A - 18 to 42cm; dark brown (10YR 3/3) coarse gravelly sandy loam, yellowish brown (10YR 5/4) dry; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many medium and few coarse roots; many fine dendritic tubular pores and many fine interstitial pores; 15 percent subangular coarse gravels and 5 percent subangular medium gravels; moderately acid (pH 5.7); clear wavy boundary. Clay 12%.

B1 - 42 to 68cm; dark yellowish brown (10YR 4/4) very gravelly sandy clay loam, light yellowish brown (10YR 6/4) dry; structureless single grain and faint medium subangular blocky structure; soft, very friable, moderately sticky and slightly plastic; few fine and few medium roots; common fine dendritic tubular pores and common fine interstitial pores; 35 percent subangular coarse gravels, 8 percent subrounded medium gravels and 3 percent subrounded fine gravels; moderately acid (pH 5.8); clear smooth boundary. Clay 20%.

2Bw2 - 68 to 85cm; dark yellowish brown (10YR 4/4) very gravelly loam, light yellowish brown (10YR 6/4) dry; moderate medium and coarse subangular blocky structure; slightly hard, friable, moderately sticky and moderately plastic; few fine dendritic tubular pores; many very fine and common fine dendritic tubular pores; 30 percent subangular coarse gravels, 20 percent subrounded medium gravels and 4 percent subrounded fine gravels; moderately acid (pH 5.7); clear smooth boundary. Clay 13%.

2C - 85 to 95cm; dark yellowish brown (10YR 4/4) very gravelly sandy loam, pale brown (10YR 6/3) dry; structureless single grain; loose, loose, slightly sticky and non-plastic; 35 percent subangular coarse gravels, 8 percent subrounded medium gravels and 4 percent subrounded fine gravels; moderately acid (pH 5.9). Clay 10%.

Pedon Description

Soil Map Unit: C
Geomorphic Landscape Unit: Valley toe slope
Classification: Andic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 6
Parent Material: Hillslope collvium
Described and sampled by: John Dixon

Oi - 0 to 3cm.

A1 - 3 to 10cm; dark brown (10YR 3/3) loam, dark yellowish brown (10YR 4/4) dry; strong medium granular structure; soft, very friable, non-sticky and non-plastic; common medium roots; few fine and common medium dendritic tubular pores; strongly acid (pH 5.2); clear wavy boundary. Clay 9%.

A2 - 10 to 24cm; dark brown (10YR 3/3) loam, yellowish brown (10YR 5/4) dry; moderate coarse and medium granular structure; soft, very friable, slightly sticky and slightly plastic; common fine and common medium roots; many medium and few fine dendritic tubular pores; strongly acid (pH 5.5); clear wavy boundary. Clay 11%.

Bw1 - 24 to 43cm; dark yellowish brown (10YR 3/4) loam, yellowish brown (10YR 5/4) dry; moderate medium subangular structure; slightly hard, friable, moderately sticky and moderately plastic; common fine and common medium roots; common medium and few fine dendritic tubular pores; strongly acid (pH 5.4); gradual wavy boundary. Clay 18%.

Bw2 - 43 to 83cm; dark yellowish brown (10YR 4/4); loam, light yellowish brown (10YR 6/4) dry; moderate coarse subangular blocky structure; slightly hard, friable, moderately sticky and moderately plastic; few fine and few medium roots; common fine and few medium dendritic tubular pores; 1 percent subangular medium gravels; strongly acid (pH 5.3); gradual wavy boundary. Clay 23%.

Bw3 - 83 to 95cm+; dark yellowish brown (10YR 4/4); loam, light yellowish brown (10YR 6/4) dry; moderate coarse subangular blocky structure; moderately hard, firm, moderately sticky and very plastic; 5 percent subangular coarse gravels; strongly acid (pH 5.2). Clay 10%.

Pedon Description

Soil Map Unit: D_2
Geomorphic Landscape Unit: Fan 2
Classification: Vitrandic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 15
Parent Material: Fan alluvium
Described and sampled by: John Dixon

Oi - 0 to 3cm.

A - 3 to 5cm; very dark grayish brown (10Y 3/2) silt loam, brown (10YR 4/3) dry; faint fine granular structure; soft, very friable, moderately sticky and moderately plastic; common very fine and common fine roots; moderately acid (pH 5.6); clear smooth boundary. Clay 20%.

Bw1 - 5 to 22cm; brown (10YR 4/3) silty clay loam, yellowish brown (10YR 5/4) dry; moderate medium subangular blocky and moderate medium granular structure; slightly hard, friable, moderately sticky and very plastic; common fine and medium roots; common fine dendritic tubular pores; moderately acid (pH 6.0); clear wavy boundary. Clay 30%.

Bw2 - 22 to 30cm; dark yellowish brown (10YR 4/4) silty clay loam, yellowish brown (10YR 5/4) dry; moderate medium subangular blocky structure; moderately hard, firm, moderately sticky and very plastic; few fine and medium roots; common fine dendritic tubular pores; moderately acid (pH 5.9); clear wavy boundary. Clay 33%.

2Ab - 30 to 46cm; very dark grayish brown (10YR 3/2) clay loam, brown (10YR 4/3) dry; moderate medium subangular blocky and moderate medium granular structure; slightly hard, firm, moderately sticky and moderately plastic; common medium and few coarse roots; common fine dendritic tubular pores; slightly acid (pH 6.2); clear smooth boundary. Clay 32%.

2Bw3 - 46 to 95cm+; dark yellowish brown (10YR 4/4) clay loam, yellowish brown (10YR 5/4) dry; moderate medium subangular blocky structure; hard, firm, moderately sticky and very plastic; few medium roots; common fine and few medium dendritic tubular pores; moderately acid (pH 6.0); Clay 35%.

Pedon Description

Soil Map Unit: E
Geomorphic Landscape Unit: Fan 2
Classification: Vitrandic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 8
Parent Material: Fan alluvium
Described and sampled by: John Dixon

Oi - 0 to 3cm.

A - 3 to 10cm; dark brown (10YR 3/3) loam, brown (10YR 5/3) dry; moderate medium granular structure; slightly hard, friable, moderately sticky and moderately plastic; common medium and few fine roots; few very fine dendritic tubular pores; strongly acid (pH 5.5); clear smooth boundary. Clay 20%.

Bw - 10 to 34cm; brown (10YR 4/3) clay loam, yellowish brown (10YR 5/ 4) dry; moderate coarse subangular blocky structure; slightly hard, firm, moderately sticky and moderately plastic; common medium roots; common very fine and few fine dendritic tubular pores; moderately acid (pH 5.6); clear smooth boundary. Clay 28%.

C/B - 34 to 43cm; dark yellowish brown (10YR 4/4) sandy loam, yellowish brown (10YR 5/ 4) dry; faint medium and faint fine subangular blocky structure; soft, very friable, slightly sticky and slightly plastic; common medium roots; common fine dendritic tubular pores; moderately acid (pH 5.8); clear smooth boundary. Clay 15%.

2Bw1 - 43 to 80cm; brown (10YR 4/3) clay loam, yellowish brown (10YR 5/4) dry; moderate coarse subangular blocky structure; slightly hard, friable, moderately sticky and moderately plastic; common coarse and few medium roots; common fine and very fine dendritic tubular pores; moderately acid (pH 5.6); gradual wavy boundary. Clay 30%.

2Bw2 - 80 to 95cm+; brown (10YR 4/3) clay loam, 30% dark grayish brown (10YR 4/2), yellowish brown (10YR 5/ 4) 30% light brownish gray (10YR 6/2) dry; moderate coarse subangular blocky structure; hard, firm, very sticky and very plastic; few medium roots; common fine and few very fine dendritic tubular pores; moderately acid (pH 5.7). Clay 30%.

Pedon Description

Soil Map Unit: F
Geomorphic Landscape Unit: Fan 2
Classification: Typic Hapludands, medial over loamy, mixed, mesic
Soil Pit: 1
Parent Material: Fan alluvium and stream sediments.
Described and sampled by: John Dixon

Oi - 0 to 3 cm.

A1 - 3 to 14 cm; very dark grayish brown (10YR 3/2) loam, dark grayish brown (10YR 4/2) dry; moderate medium granular structure; soft, very friable, non-sticky and non-plastic; many fine and medium roots; many very fine dendritic tubular pores; moderately acid (pH 5.6); clear wavy boundary. Clay 12%.

A2 -14 to 27cm; very dark grayish brown (10YR 3/2) loam; brown (10YR 5/3) dry; moderate medium and fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many fine and common coarse roots; many very fine dendritic pores; strongly acid (pH 5.1); clear wavy boundary. Clay 15%.

B/A - 27 to 39cm; dark brown (10YR 3/3) loam, yellowish brown (10YR 5/4) dry; moderate medium granular structure; slightly hard, friable, moderately sticky and moderately plastic; common fine and medium roots; many fine and medium dendritic tubular pores; strongly acid (pH 5.3); abrupt wavy boundary. Clay 20%.

Bw1 - 39 to 68cm; brown (10YR 4/3) clay loam, pale brown (10YR 6/3) dry; moderate medium subangular blocky structure; moderately hard, friable, moderately sticky and very plastic; few medium roots; common fine dendritic tubular pores; 3 percent subangular medium gravels; strongly acid (pH 5.2); gradual wavy boundary. Clay 30%.

B2 - 68 to 90cm; brown (10YR 4/3) loam, yellowish brown (10YR 5/4) dry; moderate fine to medium subangular blocky structure; hard, firm, moderately sticky and moderately plastic; few fine and medium roots; common fine dendritic tubular pores; 40 percent subangular coarse gravels, 10 percent subangular medium gravels; strongly acid (pH 5.3); clear wavy boundary. Clay 18%.

Bw3 - 90 to 120cm+; dark yellowish brown (10YR 4/4) clay loam, light yellowish brown (10YR6/4) dry; moderate medium subangular blocky structure; hard, friable, very sticky and very plastic; few fine and medium roots; few fine dendritic tubular pores; 10 percent subangular medium gravels; strongly acid (pH 5.5). Clay 28%.

Pedon Description

Soil Map Unit: G
Geomorphic Landscape Unit: Fan 3
Classification: Andic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 3
Parent Material: Colluvium/fan alluvium.
Described and sampled by: John Dixon

Oi - 0 to 3cm.

Oa - 3 to 5cm.

A1 - 5 to 15cm; very dark grayish brown (10YR 3/2) loam, brown (10YR 4/3) dry; moderate fine and medium granular structure; soft, very friable, non-sticky and non-plastic; many medium and common fine roots; common medium and common fine dendritic tubular pores; strongly acid (pH 5.3); clear wavy boundary. Clay 12%.

A/B - 15 to 30cm; brown (10YR 4/3) loam, dark yellowish brown (10YR 4/4) dry; moderate medium and coarse granular structure; soft, very friable, non-sticky and non-plastic; common fine and medium roots; common fine and medium dendritic tubular pores; 2 percent medium and 2 percent subangular fine gravels; srongly acid (pH 5.3); clear wavy boundary. Clay 13%.

Bw1 - 30 to 45cm; brown (10YR 4/3) loam, yellowish brown (10YR 5/4) dry; moderate fine and medium granular structure; slightly hard, friable, slightly sticky and moderately plastic; few medium roots; common fine dendritic tubular pores; 2 percent medium and 2 percent fine gravels subangular; strongly acid (pH 5.3); clear wavy boundary. Clay 18%.

Bw2 - 45 to 60cm; brown (10YR 4/3) loam, yellowish brown (10YR 5/4) dry; moderate medium and coarse subangular blocky structure; moderately hard, friable, moderately sticky and moderately plastic; few medium roots; common fine dendritic tubular pores; few faint clay films; 5 percent medium and 5 percent subangular coarse gravel; strongly acid (pH 5.1); clear wavy boundary. Clay 20%.

Bw3 – 60 to 95cm+; dark yellowish brown (10YR 4/4) coarse gravelly clay loam, dark yellowish brown (10YR 4 4) dry; moderate medium and coarse subangular blocky structure; hard, friable, moderately sticky and very plastic; few medium roots; common fine dendritic tubular pores; common faint clay films; 10 percent subrounded coarse gravel and 10 percent subrounded cobbles. Clay 25%.

Pedon Description

Soil Map Unit: H_1
Geomorphic: Landscape Unit: Fan 5
Classification: Typic Hapludands, medial over loamy, mixed, mesic
Soil Pit: 4 (north pit face)
Parent Material: Fan alluvium.
Described and sampled by: John Dixon

Oi - 0 to 3cm

A1 - 3 to 6cm; black (10YR 2/1) loam, very dark grayish brown (10YR 3/2) dry; moderate fine granular structure; soft, very friable, non-sticky and non-plastic; common very fine and fine roots; common fine dendritic tubular pores; 4 percent subangular medium gravel and 2 percent subrounded fine gravel; strongly acid (pH 5.4); clear wavy boundary. Clay 9%.

A2 - 6 to 25cm; dark brown (10YR 3/3) loam, brown (10YR 5/3) dry; moderate fine and medium granular structure; soft, very friable, non-sticky and non-plastic; common fine and medium roots, many fine and medium dendritic tubular pores; 4 percent subangular fine gravel and 2 percent subangular medium gravel; moderately acid (pH 5.6); gradual wavy boundary. Clay 12%.

B/A - 25 to 40cm; brown (10YR 4/3) loam, yellowish brown (10YR 5/4) dry; moderate fine medium subangular blocky structure; soft, friable, slightly sticky and slightly plastic; common fine and medium roots; many fine and medium dendritic tubular pores; 5 percent subangular fine gravel and 2 percent subangular medium gravel; moderately acidic (pH 5.6); clear wavy boundary. Clay 15%.

Bw1 - 40 to 58cm; brown (10YR 4/3) loam, yellowish brown (10YR 5/4) dry; moderate medium subangular blocky structure; soft, friable, moderately sticky and moderately plastic; common fine and medium roots; many fine and medium dendritic tubular pores; 3 percent subangular medium gravel; strongly acidic (pH 5.4); clear wavy boundary. Clay 18%.

Bw2 - 58 to 96cm; dark yellowish brown (10YR 4/4) loam, pale brown (10YR 6/3) dry; moderate coarse and medium subangular blocky structure; slightly hard, firm, moderately sticky and very plastic, common fine and medium roots; many fine and medium dendritic tubular pores; 3 percent subangular medium gravel; strongly acidic (pH 5.4); clear wavy boundary. Clay 20%.

Bw3 - 96 to 133cm; dark yellowish brown (10YR 4/4) clay loam, light yellowish brown (10YR 6/4); moderate medium and coarse subangular blocky structure; moderately hard, firm, moderately sticky and very plastic; few medium roots; common fine dendritic tubular pores; 4 percent medium subangular gravel and 2 percent subangular fine gravel; strongly acidic (pH 5.3); gradual wavy boundary. Clay 25%.

Pedon Description

Soil Map Unit: I
Geomorphic Landscape Unit: Fan 4
Classification: Vitrandic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 2
Parent Material: Fan alluvium.
Described and sampled by: John Dixon

Oi - 0 to 3 cm.

A - 3 to 5cm; very dark grayish brown (10YR 3/2) loam, brown (10YR 4/3) dry; weak fine granular structure; soft, very friable, slightly sticky and slightly plastic; few fine and medium roots; many fine dendritic tubular pores; strongly acid (pH 5.3); abrupt smooth boundary. Clay 15%.

1C - 5 to 6cm; brown (10YR 4/3) loam, dark yellowish brown (10YR 4/4) dry; structureless single grain; soft, very friable slightly sticky and slightly plastic; few fine roots; few fine dendritic tubular pores; strongly acid (pH 5.5); very abrupt smooth boundary. Clay 12%.

2C - 6 to 14cm; dark yellowish brown (10YR 4/4) sandy loam, yellowish brown (10YR 5/4), dry; structureless single grain; soft, loose, non-sticky and non-plastic; few medium roots; many fine interstitial pores; very strongly acid (pH 5.0); clear broken boundary. Clay 8%.

3C - 14 to 17cm; brown (10YR 4/3) sandy loam, pale brown (10YR6/3) dry; structureless single grain structure; soft, loose, non-sticky and non-plastic; few fine roots; many medium interstitial pores; very strongly acid (pH 4.9); clear broken boundary. Clay 11%.

4C - 17 to 21cm; yellowish brown (10YR 5/4) loam, light yellowish brown (10YR 6/4) dry; structureless single grain; slightly hard, very friable, slightly sticky and slightly plastic; few fine roots; very strongly acid (pH 5.0); clear broken boundary. Clay 20%.

5Ab - 21 to 35cm; very dark grayish brown (10YR 3/2) loam, brown (10YR 5/3) dry; strong medium and coarse granular structure; slightly hard, very friable, slightly sticky and slightly plastic; common fine and coarse roots; many medium dendritic tubular pores; strongly acid (pH 5.2); clear smooth boundary. Clay 21%.

5A/B - 35 to 55cm; dark brown (10YR 3/3) loam, brown (10YR 5/3) dry; moderate medium granular and moderate medium subangular blocky structure; moderately hard, friable, moderately sticky and moderately plastic; common fine and coarse roots; many medium dendritic tubular pores; strongly acid (pH 5.4); gradual wavy boundary. Clay 23%.

5Bw1 - 55 to 73cm; brown (10YR 4/3) with 30% brown (10YR 3.5/3) loam, pale brown (10YR6/3) dry; moderate medium subangular blocky structure; hard, friable, moderately sticky and moderately plastic; common fine and coarse roots; common fine and medium dendritic tubular pores; moderately acid (pH 5.6). Clay 25%.

5Bw2 - 73 to 110cm+; dark yellowish brown (10YR 4/4) with 10% yellowish brown (10YR 5/8), clay loam, pale brown (10YR6/3) dry; moderate coarse subangular blocky structure; very hard, firm, very sticky and very plastic; few fine roots; common fine dendritic tubular pores; strongly acid (pH 5.3). Clay 27%.

Pedon Description

Soil Map Unit: J
Geomorphic Landscape Unit: Fan 5
Classification: Andic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 5
Parent Material: Lookout Creek alluvium/surface alluvial fan deposits.
Described and sampled by: John Dixon

Oi - 0 to 3cm.

A - 3 to 9cm; very dark grayish brown; (10YR 3/2) loam; brown (10YR4/3) dry; strong medium and fine granular structure; soft; very friable; non-sticky and slightly plastic; common fine and few very fine roots; few very fine dendritic tubular pores; 3 percent subangular fine gravel; strongly acid (pH 5.5); clear smooth boundary. Clay 10%.

A/B - 9 to 19cm; brown (10YR 4/3) loam; yellowish brown (10YR 5/4) dry; moderate medium granular structure parting to moderate medium subangular blocky structure; soft; very friable; slightly sticky and slightly plastic; common medium and few fine roots; common fine dendritic tubular pores; 1 percent subangular fine gravel; moderately acid (pH 5.6); clear wavy boundary. Clay 15%.

Bw1 - 19 to 29cm; dark yellowish brown (10YR 4/4) clay loam; light yellowish brown (10YR 6/4) dry; moderate medium subangular blocky structure; slightly hard; friable; moderately sticky and moderately plastic; common medium and few fine roots; common medium dendritic tubular pores; 1 percent subangular fine gravel; strongly acid (pH 5.3); gradual wavy boundary. Clay 28%.

Bw2 - 29 to 69cm; dark yellowish brown (10YR 4/4) clay loam; light yellowish brown (10YR 5/4) dry; moderate medium subangular blocky structure; hard, firm, moderately sticky and very plastic; common medium and few fine roots; common medium dendritic tubular pores; very strongly acid (pH 5.0); gradual wavy boundary. Clay 29%.

Bw3 - 69 to 95cm; dark yellowish brown (10YR 4/4) extremely cobbly sandy loam; light yellowish brown (10YR 5/4) dry; weak medium subangular blocky structure; soft, very friable, slightly sticky and moderately plastic; few medium roots; few medium medium dendritic tubular pores; 40 percent subrounded cobbles, 10 percent subrounded coarse gravels and 5 percent subrounded medium gravels; very strongly acid (pH 4.9); gradual wavy boundary. Clay 10%.

C - 95 to 105cm+; dark yellowish brown (10YR 3/4) extremely cobbly loamy sand; dark yellowish brown (10YR 4/6) dry; single grain structure; loose, loose, non-sticky and non-plastic. 85 percent subrounded cobbles. Clay 5%.

Pedon Description

Soil Map Unit: K
Geomorphic Landscape Unit: Terrace 2
Classification: Vitrandic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 11
Parent Material: Lookout Creek alluvium
Described and sampled by: John Dixon

Oi - 0 to 3cm.

A - 3 to 11cm; very dark grayish brown (10YR 3/2) loam, brown (10YR 4/3) dry; moderate medium ganular structure; soft, friable, moderately sticky and moderately plastic; common very fine and fine roots; common fine dendritic tubular pores; strongly acid (pH 5.1); clear smooth boundary. Clay 16%,

B - 11 to 36cm; brown (10YR 4/3) loam, brown (10YR 5/3) dry; moderate medium subangular blocky structure; slightly hard, friable, moderately sticky and moderately plastic; few coarse roots; common fine dendritic tubular pores; strongly acid (pH 5.3); clear smooth boundary. Clay 14%.

1C - 36 to 72cm; brown (10YR 4/3) extremely gravelly sandy loam, yellowish brown (10YR 5/4) dry; structureless single grain; loose, loose, non-sticky and non-plastic; few fine roots; many medium interstitial pores; 40 percent subrounded medium gravels and 5 percent rounded fine gravels; strongly acid (pH 5.1); clear smooth boundary. Clay 8%.

2C - 72 to 77cm; brown (10YR 4/3) loam, pale brown (10YR 6/3) dry; weak medium subangular blocky structure; soft, very friable, slightly sticky and slightly plastic; few coarse and medium roots; few very fine and fine dendritic tubular pores; strongly acid (pH 5.4); clear smooth boundary. clay 18%.

3C - 77 to 82cm; dark grayish brown (10 YR 4/2) silt loam, brown (10YR 5/3) dry; weak medium subangular blocky structure; moderately hard, firm, slightly sticky and slightly plastic; common very fine and fine roots; many fine and common very fine dendritic tubular pores; strongly acid (pH 5.2); clear smooth boundary. Clay 25%.

4C - 82 to 97cm; brown (10YR 4/3) sandy loam, pale brown (10YR 6/3) dry; weak medium subangular blocky structure; soft, very friable, non-sticky and non-plastic, few coarse and medium roots; few fine dendritic tubular pores; moderately acid (pH 5.8); clear smooth boundary. Clay 8%.

5Bw2 - 97 to 110cm+; dark yellowish brown (10YR 4/4) silty clay loam, light yellowish brown (10YR 6/4) dry; weak medium subangular blocky structure; moderately hard, friable, moderately sticky and very plastic; few medium roots; 3 percent subrounded fine gravels; few fine dendritic tubular pores; strongly acid (pH 5.2); clear smooth boundary. Clay 30%.

Pedon Description

Soil Map Unit: L
Geomorphic Landscape Unit: Terrace 1
Classification: Vitrandic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 12
Parent Material: Lookout Creek alluvium
Described and sampled by: John Dixon

Oi - 0 to 3cm.

A - 3 to 16cm; dark yellowish brown (10Y 3/4) loam, yellowish brown (10YR 5/4) dry; weak fine granular structure; soft, very friable, non-sticky and non-plastic; many medium and common fine roots; many medium interstitial pores and common fine and medium dendritic tubular pores; moderately acid (pH 5.7); clear broken boundary. Clay 7%.

1C - 16 to 31cm; brown (10YR 4/3) loamy sand, yellowish brown (10YR 5/4) dry; structureless, single grain; loose, loose, non-sticky and non-plastic; many medium and common fine roots; many medium interstitial pores and common fine and medium dendritic tubular pores; slightly acid (pH 6.2); clear smooth boundary. Clay 3%.

2C - 31 to 60cm; brown (10YR 4/3) loam, yellowish brown (10YR 5/4) dry; weak medium subangular blocky structure; soft, very friable, non-sticky and non-plastic; many medium and common coarse roots; common medium interstitial pores and common fine dendritic tubular pores; moderately acid (pH 6.0); clear smooth boundary. Clay 7%.

3C - 60 to 100cm+; dark yellowish brown (10YR 4/4) very cobbly loam, yellowish brown (10YR 5/4) dry; structureless, single grain; loose, loose, non-sticky and non-plastic; few medium roots; few fine dendritic tubular pores; 35 percent rounded cobbles, 20 percent rounded coarse gravels, 3 percent rounded coarse gravels and 3 percent rounded fine gravels**;** neutral (pH 6.6); clear smooth boundary. Clay 8%.

Appendix – B Comparison Soil Profile Descriptions

Pedon Description

Soil Map Unit: D_1 (comparison)
Geomorphic Landscape Unit: Fan 2
Classification: Vitrandic Dystrudepts, medial over loamy, mixed, mesic
Soil Pit: 14
Parent Material: Fan alluvium
Described and sampled by: John Dixon

Oi - 0 to 3cm.

A - 3 to 8cm; very dark gray (10YR 3/1) silt loam, dark grayish brown (10YR 4/2) dry; faint fine granular structure; soft, friable, moderately sticky and moderately plastic; common very fine and common fine roots; common fine dendritic tubular pores; moderately acid (pH 5.6); clear smooth boundary. Clay 18%.

Bw - 8 to 24cm; brown (10YR 4/3) silty clay loam, yellowish brown (10YR 5/4) dry; moderate medium subangular blocky structure; hard, firm, moderately sticky and very plastic; common fine and few medium roots; common fine and medium dendritic tubular pores; strongly acid (pH 5.4); clear smooth boundary. Clay 32%.

2Ab - 24 to 41cm; very dark grayish brown (10YR 3/2) clay loam, brown (10YR 5/3) dry; moderate medium subangular blocky structure; slightly hard, friable, moderately sticky and very plastic; few fine and few medium roots; many very fine and common fine dendritic tubular pores; moderately acid (pH 5.6); gradual smooth boundary. Clay 28%.

2Bw - 41 to 58cm; brown (10YR 4/3) clay loam, yellowish brown (10YR 5/4) dry; moderate medium subangular blocky structure; moderately hard, firm, moderately sticky and very plastic; few fine roots; many very fine and common fine dendritic tubular pores; strongly acid (pH 5.5); clear smooth boundary. Clay 32%.

3Ab - 58 to 73cm; very dark grayish brown (10YR 3/2) clay loam, brown (10YR 4/3) dry; moderate medium subangular blocky structure; slightly hard, friable, moderately sticky and moderately plastic; few fine roots; common fine dendritic tubular pores; moderately acid (pH 5.7); clear smooth boundary. Clay 34%.

3Bw - 73 to 110+cm; brown (10YR 4/3) clay loam, yellowish brown (10YR 5/4) dry; moderate coarse subangular blocky structure; moderately hard, firm, moderately sticky and very plastic; common fine dendritic tubular pores; strongly acid (pH 5.8). Clay 39%.

Pedon Description

Soil Map Unit: H_2 (comparison)
Geomorphic Landscape Unit: Fan 5
Classification: Typic Hapludands, medial over loamy, mixed, mesic
Soil Pit: 4 (east pit face)
Parent Material: Fan alluvium.
Described and sampled by: John Dixon

Oi - 0 to 3cm.

A1 - 3 to 17cm; very dark grayish brown (10YR 3/2) loam; brown (10YR 4/3) dry; weak medium granular structure; soft, very friable, non-sticky and non-plastic; common fine and common medium roots; few fine and few medium dendritic tubular pores; 2 percent subrounded fine gravel; acid (pH 5.2); gradual wavy boundary. Clay 9%.

A2 - 17 to 50cm; very dark grayish brown (10YR 3/2) loam; brown (10YR 4/3) dry; moderate medium and coarse granular structure; soft, very friable, slightly sticky and slightly plastic; common fine and common medium roots; few fine and few medium dendritic tubular pores; 10 percent fine subrounded gravel and 2 percent subrounded medium gravel; moderately acid (pH 5.7); clear smooth boundary. Clay 10%.

Bw1 - 50 to 100cm; brown (10YR 4/3) loam, yellowish brown (10YR 5/4) dry; moderate medium and weak medium subangular blocky structure; soft, very friable, moderately sticky and slightly plastic, common medium roots; few fine dendritic tubular pores; 3 percent subangular medium gravel; moderately acid (pH 5.9); gradual wavy boundary. Clay 20%.

Bw2 - 100 to 120cm+; dark yellowish brown (10YR 4/4), clay loam, light yellowish brown (10YR 6/4) dry; moderate medium and coarse subangular blocky structure; moderately hard, friable, moderately sticky and very plastic; few fine dendritic tubular pores; 2 percent subangular medium gravel; moderately acid (pH 5.6); Clay 25%.

Pedon Description

Soil Map Unit: C and H (comparison)
Geomorphic Landscape Unit: On boundary of colluvium and fan 4
Classification: n/a
Soil Pit: 7
Parent Material: Hillslope collvium/fan alluvium
Described and sampled by: John Dixon

Oi - 0 to 3cm.

Oa- 3 to 4cm.

Bp - 4 to 7cm; dark yellowish brown (10YR 4/3) loam, pale brown (10YR 6/3) dry; weak medium subangular blocky structure; moderately hard, firm, moderately sticky and moderately plastic; few fine roots; few fine dendritic tubular pores; 5 percent subrounded medium gravel; strongly acid (pH 5.3); abrupt smooth boundary. Clay 20%.

B1 - 7 to 29cm; dark grayish brown (10YR 4/3) loam, pale brown (10YR 6/3) dry; moderate medium subangular blocky structure; slightly hard, firm, moderately sticky and moderately plastic; few fine and medium roots; many medium and common fine dendritic tubular pores; 2 percent subangular fine gravel; strongly acid (pH 5.4); gradual wavy boundary. Clay 20%.

B2 - 29 to 48cm; dark grayish brown (10YR 4/3) loam, pale brown (10YR 6/3) dry; weak medium subangular blocky structure; slightly hard, firm, moderately sticky and moderately plastic; common medium and few fine roots; common fine dendritic tubular pores; 2 percent subangular medium gravel; strongly acid (pH 5.4); gradual wavy boundary. Clay 24%.

2B3 - 48 to 75cm; dark grayish brown (10YR 4/3) loam, pale brown (10YR 6/3) dry; moderate coarse subangular blocky structure; slightly hard, firm, moderately sticky and moderately plastic; few fine roots; common fine and very fine dendritic tubular pores; moderately acid (pH 5.6); gradual smooth boundary. Clay 15%.

2B4 - 75 to 95cm+; dark grayish brown (10YR 4/3) loam, pale brown (10YR 6/3) dry; moderate medium subangular blocky structure; slightly hard, very firm, moderately sticky and moderately plastic; few fine roots; common fine dendritic tubular pores; 10 percent subangular medium gravel; moderately acid (pH 5.9). Clay 11%.

Pedon Description

Soil Map Unit: H (comparison)
Geomorphic: Landscape Unit: Fan 5 (levee)
Classification: n/a
Soil Pit: 13
Parent Material: Fan and stream alluvium
Described and sampled by: John Dixon

Oi - 0 to 4cm.

A1 - 4 to 10cm; black (10YR 2/1) loam, dark grayish brown (10YR 4/2) dry; faint medium granular structure; loose, loose, non-sticky and non-plastic; many medium roots; many medium dendritic tubular pores; strongly acid (pH 5.2); abrupt smooth boundary. Clay 8%.

A2 - 10 to 24cm; black (10YR 2/1) loam, dark grayish brown (10YR 4/2) dry; faint medium subangular blocky structure; soft, very friable, slightly sticky and slightly plastic; many medium and fine roots; many medium interstitial pores; 9 percent subrounded fine gravels**;** strongly acid (pH 5.2); clear smooth boundary. Clay 9%.

Bw1 - 24 to 47cm; dark yellowish brown (10YR 4/4) loam, dark yellowish brown (10YR 6/4) dry; moderate and fine subangular blocky structure; soft, friable, slightly sticky and slightly plastic; many medium and fine roots; few fine dendritic tubular pores; 5 percent subrounded coarse gravels and 5 percent subrounded fine gravels**;** moderately acid (pH 5.7); clear smooth boundary. Clay 12%.

Bw2 - 47 to 76cm; dark yellowish brown (10YR 4/4) loam, dark yellowish brown (10YR 6/4) dry; moderate medium subangular blocky structure; soft, friable, moderately sticky and moderately plastic; common medium and common fine roots; few fine dendritic tubular pores; 8 percent subrounded medium gravels and 5 percent subrounded coarse gravels**;** strongly acid (pH 5.5); clear smooth boundary. Clay 15%.

C - 76 to 100cm+; light yellowish brown (10YR 6/4) extremely gravelly sandy loam, yellowish brown (10YR 5/4) dry; structureless single grain; loose, loose, non-sticky and non-plastic; few medium roots; few fine dendritic tubular pores; 85 percent subrounded coarse gravels and 3 percent subrounded medium gravels**.**

Appendix – C Compact disk contaning GIS files