An Approach to Studying Soil-Landscape Relationships in Virginia

by

Mark H. Stolt

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in
Agronomy

Approved:

James C. Baker
J.C. Baker Co-Chairman

Thomas W. Simpson
T.W. Simpson Co-Chairman

Lucian W. Zelazny
L.W. Zelazny

James B Campbell
J.B. Campbell

W. Lee Daniels
W.L. Daniels

May, 1990
Blacksburg, Virginia

"Eventually, all things merge into one, and a river runs through it. The river was cut by the world's great flood and runs over rocks from the basement of time. On some of the rocks are timeless raindrops. Under the rocks are words and some of the words are theirs."

N. Maclean

"Dawn comes soon enough for the working class."

X

Acknowledgements

Many well deserved thanks are due to Dr. James C. Baker for his friendship, guidance, and timely advice throughout the length of this study. I would also like to thank Dr Baker for constantly keeping things in perspective and acknowledging that at times fishing can be just as important as soils.

Thanks are also expressed to Dr. Thomas W. Simpson for his help and support through the course of this research and for helping me become a better teacher and soil judging coach.

I would also like to express my appreciation to Drs. Lucian Zelazny, W. Lee Daniels, and James B. Campbell for serving on my committee and for their helpful advice in matters of mineralogy, soil genesis, and variability and statistics.

The assistance of Dr. William Edmonds in solving several statistical and computer software problems is gratefully acknowledged.

Many thanks are due to Drs. Martin C. Rabenhorst and Delvin S. Fanning (who reside at the University of Maryland) for their help and the use of their much needed equipment for the micromorphology and elemental analysis portions of this research.

The help of the Virginia Tech Soil Survey crew, especially Steve Thomas, Bruce Legge, Mike Genthner, and Dean Gall, in site selection and sampling is also gratefully acknowledged.

Thanks are also expressed to Steve Feldman and Paul Gassman for putting in much time and effort in the mineralogy portion of this study. I would also like to thank Louise Price for her assistance in the characterization of the soils examined. The untiring help of Harry Beahl is also gratefully acknowledged.

The completion of this research may not have occurred until another decade had passed without the able assistance of Margaret Baker and the other students that helped in the field and Soil Survey Lab. I would also like to thank Dale Price who ground a ton of samples and made 687 pellets.

Thanks are expressed to Pam Thomas and Vicky Ballard (I am sorry you're not here to read this, Vicky) for making me feel completely welcome from the very start of my stay at Virginia Tech.

Thanks to all the graduate students and staff that made these past three and one-half years a pleasant and rewarding experience. In particular, I would like to say thanks to Barry Stewart, who endured much of the same course-work, and offered much support and friendship in these and other tests. I would also like to thank Barry for keeping me abreast of the latest social happenings on campus.

Many thanks are due to my father Hjalmer, my brother George, and my sisters Teresa and Sandy for their love and support throughout these years of graduate school. I would especially like to thank my father for encouraging me to finish my degrees so I could get a real job. Well Pop, I had a real job once and I didn't like it.

Special thanks are expressed to Katie Haering, who acted as my editor and chief, for her assistance, friendship, and encouragement during this study.

Last but far from least, I would like to thank my cats Bulb and Bramble (B & B) for their companionship, continued support, and their often and timely comic relief.

Table of Contents

INTRODUCTION

Many conceptual soil genesis models have been developed since the advent of soil science. The most well known and frequently taught model is Jenny's (1941), which was derived from the ideas of Dokuchaev, and defines the five factors of soil formation (organisms, climate, topography, parent material, and time). At a local level, climate and organisms can be assumed to be a constant, therefore changes in soils (differentiation) can be said to be related to time, topography, and parent material. Given an infinite amount of time, it can be assumed that on a given parent material the factor that affects soil formation is topography or landscape position.

Jenny (1941) used a broad approach to model soil genesis. On a more specific scale, Simonson (1959) proposed that soils form as a result of a series of transformations, transfers, additions, and removals of the soil constituents within the soil profile. Combining Jenny's (1941) and Simonson's (1959) models, and assuming climate and parent material are equal, the types and rates of gains, losses, transfers, and transformations of the different soil constituents will vary depending on the landscape position.

This research examined the gains, losses, transformations, and transfers of the soil constituents at the summit, backslope and footslope landscape positions of soils located in the Piedmont and Blue Ridge Highlands regions of Virginia. This dissertation is a collection of 5 research projects which examined these soil-landscape relationships from several perspectives. The individual projects focused on a separate set of objectives. The objectives were:

Chapter 1) To describe the zone of transition between soil and saprolite using field, laboratory, and micromorphological techniques, and to develop guidelines to separate BC horizons from Bt and C horizons formed in saprolite.

Chapter 2) To estimate and describe the sources of variability within the soils studied.

Chapter 3) To evaluate the application of reconstruction analysis to studying the relationships between soil genesis and landscape position, and to describe the soil-landscape relationships in the Piedmont and Blue Ridge Highlands.

Chapter 4) To describe a simple and inexpensive system for taking undisturbed samples of deep saprolite.

Chapter 5) To characterize saprolite formed from gneissic rocks and examine the genesis of these materials.

CHAPTER 1

Micromorphological investigation of the soil-saprolite zone of transition.

Abstract

Most residual soils occurring in the southeastern U.S. have formed in saprolite. Between the saprolite and argillic horizon lies a zone that divides material undergoing pedogenesis from that undergoing geochemical process. Although this transition can be several meters thick, few studies have adequately described and defined this zone. Physical, chemical, mineralogical, and micromorphological properties and characteristics were examined of representative soils and saprolite formed from schistose or gneissic rocks of the Piedmont and Blue Ridge Highlands regions of Virginia. Although the morphology of the Piedmont soils was better expressed, micromorphological characteristics were very similar in these two regions. Argillic horizons showed considerable oriented clay (3-16%), strong to moderate subangular blocky microstructure, porphyric c/f RDP, low (<0.5) c/f_{20u} ratios, and many planar voids. Oriented clay and peds were absent from C horizons. Microstructure was termed rock controlled to describe the apedal nature of these horizons. The c/f RDP was chitonic or gefuric with the c/f_{20u} ratio at least double that of the argillic horizon. Subangular blocky peds were observed in all of the transition horizons. Microstructure

ranged from medium subangular blocky to weak subangular blocky/rock controlled. The c/f$_{20\mu}$ ratios and c/f RDP were intermediates between the argillic horizons and saprolite. Although some BC and C horizons in the field appeared structureless massive, evidence of pedogenic process such as oriented clay and subangular blocky micropeds was observed. These transition horizons were designated as either BCt, BC, or CB depending on the amount of oriented clay and the rates of change with depth of clay, DCB extractable Fe, and sand contents. Weathering of mica grains showed slight to almost total pellicular and parallel linear alteration to HIV, kaolinite, or an interstratified component of these minerals. Alteration of quartz grains was slight, and occurred in pellicular and irregular linear forms. Feldspar alteration was generally less than 25 % and occurred in the form of pellicular, or parallel or cross-linear patterns to kaolinite or gibbsite.

Introduction

In defining the limits between soil and nonsoil, the authors of Soil Taxonomy (Soil Survey Staff, 1975) commented that the lower limit of the soil is the most difficult to define. Difficulty arises in determining where the pedologic process stops and the geochemical begins. Pedologic refers to the formation of soil, whereas geochemical refers to, in the case of hard rock, the formation of saprolite. In most residual soils there is a zone of transition between the parent material (saprolite) and soil, designated by a BC or CB horizon. These horizons are dominated by the properties of one master horizon but have subordinate properties of the other (Soil Survey Staff, 1981).

The thickness of the zone of transition most often depends upon the type of rock. Stoops (1983) reported that for granitic rocks the transition is gradual but for basalts, serpentinites, and marbles the changes are much more abrupt. These changes occur as the saprolite (chemically weathered rock) is altered into heterogeneous soil material (Stoops 1983).

Working in the Piedmont of North Carolina, Calvert et al (1980) examined the transformation of a granite gneiss to soil. The regolith was over 5 meters thick with a 30 cm transition zone between a meter of soil and 4 meters of saprolite. In the field, the transition showed variegated colors, weak medium subangular blocky structure, and a few discontinuous clay films along ped faces.

Flach et al (1968) examined BC transition horizons in an Oxisol from Puerto Rico, and a Vertisol from California. The regolith of the Vertisol, formed from a quartz diorite, was less than 1.5 meters thick, with a transition zone of 15 cm. The Oxisol, however, had a zone of transition over 1.5 meters thick and was underlain by 4 meters of saprolite. For the Oxisol, the transition from saprolite to solum showed a disappearance of rock structure, formation of blocky structure, and a textural change from loam to clay. In thin sections of saprolite, rock structure could be observed in the form of alternating bands of colorless and red opaque material. The colorless bands consisted of kaolinite plates or books. Goethite and amorphous Fe forms occurred within the red opaque bands. In the transition zone much of the matrix was altered to translucent or isotropic reddish-brown material. Altered kaolinite books and iron bands continued to be observable. In the lower B horizon, evidence of saprolite structure was restricted to a few brown lattice-like zones of oriented plasma. Mineralogy and surface area of the transition zone and saprolite were very similar.

In the Piedmont region of North Carolina, Cady (1950) examined the transformation of hard rock to soil using micromorphological and mineralogical techniques. He examined an Iredell soil formed in metagabbro, and a Davidson soil formed from diorite. The Iredell soil was shallow to hard rock (110 cm) with changes between hard rock, weathered rock, saprolite, and soil occurring over a short distance. The B horizons showed no evidence of rock or saprolite structure with much of the clay showing orientation or birefringence. The clay in the C horizon showed no birefringence.

In the Davidson soil, geologic weathering occurred to over 6 meters. From the description given by Cady (1950), the regolith between 1.5 and 4.5 meters appears to represent the zone of transition between soil and saprolite. In thin section, an increase in quartz in the silt fraction was observed relative to the saprolite. Although this zone was substantially altered, rock or saprolite microstructure could be observed as Fe coated quartz grains or rock and mineral pseudomorphs. Similar evidence of saprolite structure could be observed into the lower B horizons.

Although the transition between soil and saprolite may occur over several meters, as in the Davidson soil Cady (1950) studied, research focused on understanding the changes that occur in this zone has been limited. In addition, because of the lack of guidelines and criteria for horizonation, the soil-saprolite zone of transition lacks significant definition. Therefore the objectives of this research were to describe the transition zone using field, laboratory, and micromorphological techniques, and to develop guidelines to separate BC horizons from Bt and C horizons in soils formed in saprolite.

Materials and Methods

Soil and saprolite morphology was examined in upland soils formed from schistose or gneissic rocks of the Piedmont and Blue Ridge Highlands regions of Virginia. Over 50 summit and backslope soils were examined in these two regions before eight representative pedons were chosen for detailed study. Four occurred in the Piedmont and four in the Blue Ridge Highlands. Soil pits were excavated and the most representative face was described using the National Soils Handbook (Soil Survey Staff 1981). In the field, C horizons were differentiated by variegated colors, lack of continuous clay films, and massive structure. Field criteria for transition horizons included a substantial decrease in clay relative to the clay maximum in the argillic horizon, weak, medium or coarse subangular blocky structure, and evidence of rock structure (usually mottles related to parent material).

Bulk samples were taken from each horizon for physical, chemical, and mineralogical analysis. Clods were taken for bulk density and water retention measurements. Oriented clods were collected for preparation of thin sections.

Bulk samples were air-dried, ground and passed through a 2mm sieve. Particle size distribution (PSD) was determined by pipette (Gee and Bauder, 1986). Dithionite citrate bicarbonate (DCB) extractable Fe was removed following the procedures of Holmgren (1967), and analyzed by inductively coupled plasma spectrometry (ICP). Percent elemental Zr was determined from pellets using x-ray fluorescence techniques. Pellets were made from ground silt or sand samples that were mixed in a ratio of 1:1 with boric acid. Mineralogy of the silt fraction was determined using x-ray diffraction. Percent kaolinite was determined by differential scanning calorimetry (DSC) with a poorly crystalline Georgia kaolinite as a standard. Percent of the remaining minerals was estimated by relative peak areas.

Bulk density and water retention values were determined following the procedures of Brasher et al. (1966). Thin sections were prepared from air-dried clods after impregnation with an epoxy resin. Thin sections were examined in plane-polarized (PPL) and cross-polarized (XPL) light. Micromorphological descriptions were made using the guidelines and terminology of Bullock et al. (1985). Estimations of percent oriented clay, c/f_{20u} ratios, and voids were made from traverse line counts at 63X magnification. Three transects of at least 100 counts each were made near the top, middle, and bottom of each slide.

Results

Soils in the Piedmont generally showed better expressed argillic horizons, thicker sola, and higher clay contents than those of the Blue Ridge Highlands. In both regions several meters or more of saprolite occurred beneath each solum. Properties and characteristics for the soils studied in detail were similar within each region, therefore examples of two soils from each region are presented.

Soils studied in the Piedmont region formed from saprolite derived from a mica gneiss component of the Lovingston formation (Bloomer and Werner, 1955). Study sites were located in Nelson County, VA, near the town of Lovingston. Soils occurred in woodlands at the summit (Pedon 1) and backslope (Pedon 2) landscape positions and fit the concept of the Hayesville series (clayey-oxidic-mesic Typic Hapludults). Table 1 gives abbreviated profile descriptions from the lower B horizons to the lowest C horizon sampled in the soil pits. These soils had relatively thick (16 and 28 cm) surface horizons (A and E horizons combined) over

Table 1. Abbreviated profile descriptions. Abbreviations include: Wk=weak, Med=medium, Mod=moderate, Co=coarse, Sl Ma=structureless massive; C=clay, CL=clay loam, fSL=fine sandy loam, L=loam, SiL=silt loam, SL=sandy loam; com=common, cont=continuous, dis=discontinuous.

Horizon	depth	Structure	Texture	Color	Clay films
	cm	**Pedon 1 Piedmont**			
Bt3	48-63	Mod Med SBK	C	2.5YR 4/6	many cont.
Bt4	63-126	Wk Med SBK	SCL	2.5YR 4/6	few cont.
BC	126-170	Wk Co SBK	fSL	2.5YR 5/8	few dis.
C1	170-202	Sl Ma	fSL	2.5YR 5/8 5YR 6/8 7.5YR 5/8 10YR 5/6	few clay flows
C2	202-245	Sl Ma	fSL	2.5YR 5/8 5YR 6/6 10YR 7/6	few clay flows
C3	245-420	Sl Ma	fSL	2.5YR 5/8 5YR 6/6 10YR 7/6	
		Pedon 2 Piedmont			
Bt4	98-130	Mod Co SBK	C	2.5YR 4/6	com. cont.
BC	130-150	Wk. Co SBK	L	2.5YR 4/6	few dis.
C1	150-187	Sl Ma	fSL	2.5YR 4/6, 6/6 7.5YR 3/2	few clay flows
C2	187-216	Sl Ma	fSL	2.5YR 4/6 5YR 6/8 7.5YR 3/2	few clay flows
C3	216-275	Sl Ma	fSL	2.5YR 4/6 5YR 6/8 7.5YR 3/2	few clay flows

Table 1. (cont.)

Horizon	depth	Structure	Texture	Color	Clay films
	cm				
Pedon 3 Blue Ridge Highlands					
Bt3	83-120	Wk Med SBK	CL	5YR 5/6	com. cont.
BC	120-150	Wk Co SBK	L	7.5 YR 5/6, 4/6, 6/8, 10YR 6/4, 4/6 N 2/0, 8/0	few cont.
C1	150-205	Sl Ma	SL	7.5 YR 5/6, 4/6, 6/8, 10YR 6/4, 4/6 N 2/0, 8/0	few dis.
C2	205-310	Sl Ma	FSL	7.5 YR 5/6, 4/6,6/8, 10YR 6/4,4/6 N 2/0,8/0	few dis.
Pedon 4 Blue Ridge Highlands					
Bt2	54-72	Wk Med SBK	C	2.5YR 5/6	com. cont.
BC1	72-96	Wk Med SBK	SiL	2.5YR 5/8	com. cont.
BC2	96-114	Wk Med SBK	SiL	2.5YR 5/8	com. cont.
C1	114-176	Sl Ma	L	7.5YR 5/8 5YR 7/8 N 8/0	few cont.

well expressed argillic horizons. Soil textures ranged from clay in the argillic horizon to fine sandy loam in the C horizon. Evidence of illuvial clay was observed as clay films on ped faces or clay flows along relic fissure cracks of the saprolite in all but the C3 horizon of Pedon 1.

Soils examined in the Blue Ridge Highlands were located in Montgomery County, VA, near the town of Pilot. Both soils occurred in woodlands on summit landscape positions and showed relatively thick (18 and 28 cm) surface horizons over moderately expressed argillic horizons. Some evidence of illuviated clay was observed in each horizon. Pedon 3 developed from saprolite derived from an augen gneiss (the Pilot gneiss of Lewis, 1975) and fits the concept of the Chester series (fine loamy, mixed, mesic Typic Hapludults). Textures ranged from clay loam in the argillic horizon to sandy loam in the saprolite (Table 1). Saprolite derived from a gneissic schist component of the Blue Ridge Complex (Dietrick, 1954) was the parent material for Pedon 4. This fits the concept of the Elioak series (clayey, kaolinitic, mesic Typic Hapludults). Textures ranged from clay in the argillic horizon to loam and silt loam in the saprolite.

General trends in physical and chemical properties could be observed with depth in all of the soils studied. Sand contents increased with depth and percent clay, fine clay, DCB extractable Fe, and 1/3 bar water content decreased with depth (Table 2). The PSD data are consistent with expected trends for Udults formed from saprolite. The high clay contents in the argillic horizon relative to the C material are due to weathering of larger particles to clay size and clay

Table 2: Selected Physical Properties and Characteristics, and Percent Clay Free Zr by weight.

Horizon	Depth	Sand	Clay	fine Clay	Clay Free Zr	1/3 bar H2O	DCB Fe	Bulk Density
	--cm--	%						g/cm3
				Pedon 1 Piedmont				
Bt3	48-63	33	52	24	.06	N.D.	2.60	1.28
Bt4	63-126	51	30	14	.06	21	2.32	1.37
BC	126-170	60	19	9	.05	30	2.10	1.47
C1	170-202	67	8	3	.05	16	1.20	1.38
C2	202-245	74	8	3	.05	15	.92	1.34
C3	245-420	76	6	2	.05	N.D.	.84	1.30
				Pedon 2 Piedmont				
Bt4	98-130	37	42	21	.40	39	3.96	1.45
BC	130-150	50	30	14	.10	28	3.04	1.39
C1	150-187	66	13	7	.10	30	1.95	1.46
C2	187-216	67	13	5	.10	30	1.95	1.32
C3	216-275	71	8	4	.08	N.D.	1.95	1.36
				Pedon 3 Blue Ridge Highlands				
Bt3	83-120	40	36	17	.04	23	3.69	1.49
BC	120-150	58	9	4	.03	16	2.02	1.43
C1	150-205	66	5	1	.03	17	1.82	1.40
C2	205-310	59	4	1	.03	16	1.96	1.38
				Pedon 4 Blue Ridge Highlands				
Bt2	54-72	20	42	19	.08	33	4.02	1.49
BC1	92-96	27	24	12	.04	29	2.97	1.48
BC2	96-114	31	11	5	.04	29	2.18	1.36
C1	114-176	51	5	1	.04	29	1.74	1.37

illuviation. The degree of weathering and amount of illuviation decreases with depth, and therefore as clay contents decrease, sand contents increase. DCB extractable Fe and water retention follow the same trend as clay contents. Bulk density in subsoil horizons is dependent upon particle density and size, expression of macro and micro-structure, and void space unrelated to structure. Correlation between bulk density and other soil properties or characteristics with depth however was not readily apparent.

In the soil, Zr is found almost exclusively in the form of the mineral zircon, which is very resistant to weathering and stable in the soil environment (Brewer 1976, and Milnes and Fitzpatrick, 1989). Therefore as the other mineral forms weather and are lost from the coarser fractions, zircon accumulates in the horizon. Brewer (1976) suggested examining the percent by weight of a stable constituent such as zircon with depth to ascertain the soil parent material. The horizon in which the Zr content decreases to a constant level is the parent material. Barshad (1964) suggested that fractions greater than 2u of the stable constituent be examined because the clay fraction is mobile in the soil system. As an estimate of percent zircon (the mineral), percent Zr was determined for the silt and sand fractions and percent Zr by weight was calculated on a clay free basis (Table 2). Zirconium contents decreased with depth indicating that a weathering trend could be observed between the B and C horizons. In 3 out of the 4 pedons however (Pedon 2 was the exception), Zr contents did not decrease below the BC horizon. This may suggest that percent Zr by weight is not a good indicator of the true parent material, or the true parent material was not reached.

Micromorphology

In thin section, soil micropeds ranged from strong subangular blocky in the Bt horizons to apedal in the C horizons (Table 3). Ped size was found to increase with depth. The upper Bt horizons showed the smallest peds (3.5 mm) as well as the most expressed ped structure as strong to moderate subangular blocky (Figure 1). The c/f_{20u} ratio of the Bt horizons was generally less than 0.5 with an open or open/close porphyric c/f related distribution pattern (c/f RDP).

All of the C horizons showed some "rock controlled" microstructure. The term rock controlled was used for saprolite horizons because Bullock et al. (1985) do not appear to have a term to describe the microstructure of saprolite. These horizons were mostly composed of coarse material oriented with the rock foliation or fragments (Figure 2). Voids were common and were chiefly vughs, and complex and packing voids. The C horizons that showed only rock controlled microstructure were apedal, and had the highest c/f ratios. In the Blue Ridge Highlands, C horizons had lower c/f ratios than C horizons in the Piedmont due to the much greater percent fine silt (2-20u) in the former horizons (Table 2). Although some areas of the C horizons tended toward monic c/f RDP, most of the C horizons contained enough fine material between mineral grains to be classed as chitonic, or chitonic-/gefuric.

Subangular blocky peds could be observed in all of the BC horizons. Microstructure in these horizons ranged from medium subangular blocky

Table 3: Selected Micromorphological Properties and Characteristics.

Abbreviations include: Wk-weak, Mod-moderate, Str-strong, SBK-subangular blocky, RC-rock controlled, porph-porphyric

Horizon	Depth	Oriented Clay	Planar Voids	vughs	Packing voids	20um c/f ratio	Micro-Structure	2um c/f Related Distribution
	cm	---------------%---------------						
				Pedon 1 Piedmont				
Bt3	48-63	16.2	7.5	3.4	.0	.3	Str SBK	open porph
Bt4	63-126	11.2	3.2	1.3	.0	.6	Str/Mod SBK	open porph, some close porph
BC	126-170	4.5	1.3	4.2	1.0	.9	Wk SBK/RC	chitonic, some close porph
C1	170-202	.7	.0	3.8	6.0	1.5	RC/Wk SBK	chitonic-gefuric
C2	202-245	1.4	.6	7.4	3.1	1.9	RC/Wk SBK	chitonic-gefuric
C3	245-420	.3	.0	7.3	6.7	2.7	RC	chitonic-gefuric
				Pedon 2 Piedmont				
Bt4	98-130	5.8	4.0	1.5	.0	.3	Str/Mod SBK	open porph, some close porph
BC	130-150	3.1	1.3	3.1	.0	.5	Mod SBK	close porph, some open porph and chitonic
C1	150-187	6.0	.3	6.9	2.2	1.4	Wk SBK/RC	chitonic, some close porph and gefuric
C2	187-216	.3	.6	5.1	1.5	.9	RC/Wk SBK	close porph-chitonic
C3	216-275	.0	.0	4.5	7.3	4.1	RC	chitonic-gefuric

Table 3 (cont.): Selected Micromorphological Properties and Characteristics.

Abbreviations include: Wk-weak, Mod-moderate, Str-strong, SBK-subangular blocky, RC-rock controlled, porph-porphyric

Horizon	Depth	Oriented Clay	Planar Voids	vughs	Packing voids	20um c/f ratio	Micro-Structure	2um c/f Related Distribution
	cm	---------------%			-----------------			
				Pedon 3 Blue Ridge Highlands				
Bt3	83-120	9.1	4.6	.9	.0	.4	Mod SBK	open porph, some porph
BC	120-150	4.9	2.7	5.6	.0	.6	Wk SBK/RC	open & close porph, some chitonic
C1	150-205	.0	2.5	3.8	.6	.8	RC/crack	chitonic
C2	205-310	.0	.3	4.2	.6	1.0	RC/crack	chitonic
				Pedon 4 Blue Ridge Highlands				
Bt2	54-72	12.3	8.9	3.4	.0	.3	Str SBK	open & close porph
BC1	72-96	6.2	9.1	4.2	.0	.3	Mod SBK	open & close porph
BC2	96-114	.0	.0	1.3	3.9	1.3	RC/Wk SBK	chitonic-gefuric
C1	114-176	.0	1.3	4.8	3.2	1.9	RC	gefuric-chitonic

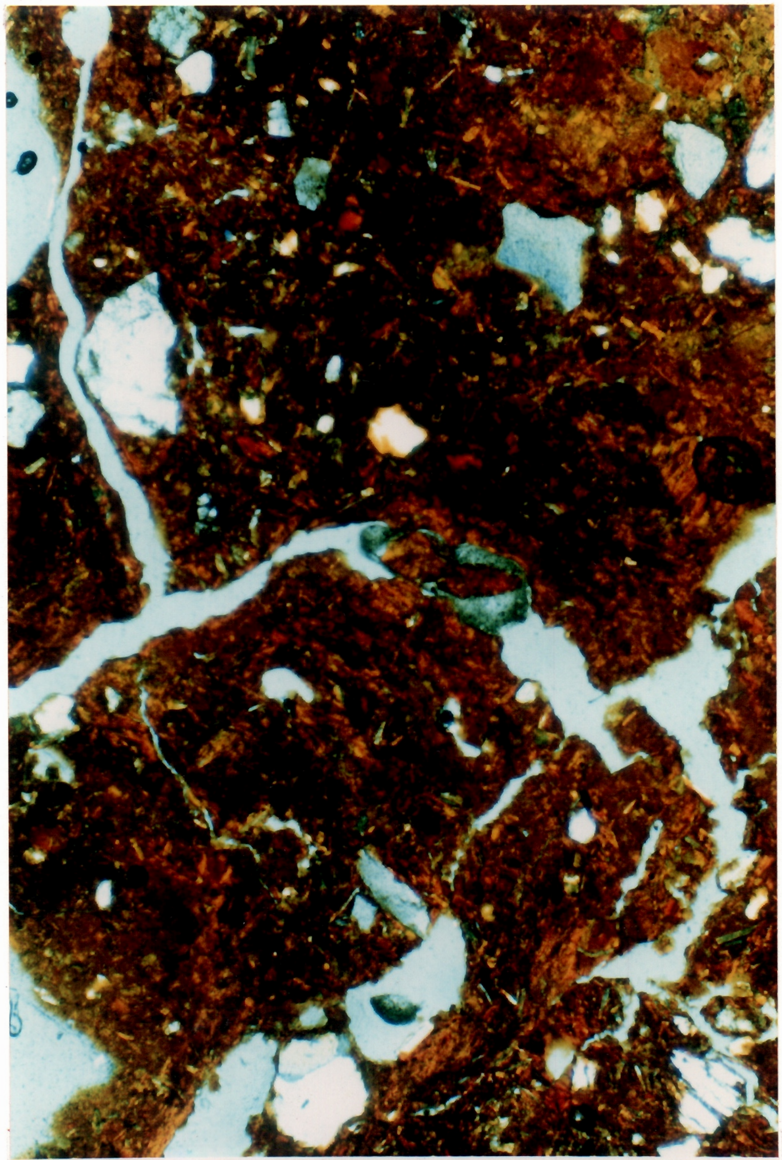

Figure 1. Strong subangular blocky microstructure in the Bt3 horizon of Pedon 1 under PPL at 40x magnification. The c/f related distribution pattern (RDP) is open porphyric. Frame length is 3.6 mm.

Figure 2. Rock controlled microstructure in a C horizon under PPL at 20x magnification. Frame length is 7.6 mm.

to weak subangular blocky/rock controlled. The c/f ratios and c/f RDP were intermediates between the argillic horizons and the saprolite. Parent rock fragments could be found in all horizons. Those found in the Bt horizons however were small, less than 1 mm, and surrounded by speckled birefringence fabric.

Several methods are used to quantify the percent minerals, voids or pedofeatures in a thin section. The most common methods are traverse line counts, point counts, and area counts (Brewer 1976). Percent oriented clay and voids were determined by transverse line counts at 63X magnification. Percent oriented clay decreased with depth and ranged from 16.2% in the Bt3 horizon of Pedon 1 to absent in the lowest C horizons. All of the BC horizons, with the exception of BC2 of Pedon 4, showed considerable oriented clay (3.1-6%) and several of the C horizons in the Piedmont pedons showed greater than 1 % oriented clay. McKeague et al. (1980) raised several questions regarding estimation of oriented clay. The basic problems arise from the difficulties in distinguishing oriented clay due to illuvition from inherited oriented clay or that related to pressure. Birefringence fabric is speckled in these acid soils, and therefore fabrics related to pressure are absent. Clay that formed through alteration of mica and shows strong extinction phenomena was observed. Fortunately distinguishing between these forms of clay only presents itself as a problem in the horizons that have porphyric c/f RDP. Oriented clay related to illuviation in the BC and C horizons is not difficult to determine because of the coarse nature of these horizons as indicated by the chitonic or gefuric c/f RDP. Therefore the estimations of oriented clay in the BC and C horizons are most likely representative of clay moved through the illuvial process.

Voids were divided into planar (including channels), vughs (including complex voids), and packing voids (Table 3). Most of the planar voids occurred as micro-structural breaks for subangular blocky peds so that Bt horizons which had better expressed subangular blocky microstructure (moderate and strong), contained the most planar voids. Many of the planar voids showed parallel basic distribution patterns. The referred distribution pattern of these voids was parallel to the soil surface and did not follow the rock foliation which was apparent in the lower horizons. Planar voids were few in horizons with weak subangular blocky microstructure and in most cases absent in horizons with rock controlled microstructure. Most planar voids showed textural coatings of limpid or dusty clay. Crack microstructure was evident in the C1 and C2 horizons of Pedon 3. Planar voids in these horizons were lacking in textural coatings but in many cases showed Fe hypo-coatings.

Vughs were found throughout the horizons, and most showed textural coatings of limpid or dusty clay when oriented clay occurred in the horizon. Vughs in the C horizons were for the most part complex voids and absent of coatings. Packing voids were absent from the Bt horizons and only common in C horizons with chitonic-gefuric c/f RDP. In horizons with both packing voids and oriented clay, limpid clay could be found coating the voids. These coatings were thin (20-30u), microlaminated, and sharply oriented.

Mineralogy

Quartz, mica, and feldspar were the most common mineral grains observed in thin section. Alteration of quartz occurred in a pellicular and irregular linear pattern. Most of the coarse (> 1 mm) and many of the medium (.5-1 mm) quartz grains showed slight (< 2.5%) pellicular alteration. The degree of alteration and the number of grains that showed pellicular alteration decreased with depth. Irregular linear alteration, although slight (< 2.5%), was apparent in most quartz grains. The degree of alteration, and number of grains altered did not appear to change with depth.

Feldspar grains showed pellicular, and parallel and cross-linear alterations (Fig. 3). Alterations were generally less than 25 % and the degree of alteration remained constant with depth. Mica grains showed slight (< 2.5%) to total parallel linear alteration (Fig. 4). Pellicular alteration was also prevalent in the mica grains. Mica in the C horizons did not show as much alteration as those in the Bt and BC horizons.

In order to examine the alteration products of the mica and feldspar grains, silt mineralogy of Pedons 1, 2, and 3 was examined using x-ray diffraction (XRD) techniques (Table 4). Mineralogical trends with depth were similar to those observed in thin section. Mica contents increased with depth in the Piedmont soils, as kaolinite, hydroxy-interlayered vermiculite (HIV), and interstratified components of these three minerals decreased. Mica has been reported to weather to vermiculite, HIV, or kaolinite by several authors (Norfleet and Smith

Figure 3. Cross-linear alteration of a feldspar grain. Micrograph was taken under XPL at 100x magnification. Frame length is 1.5 mm.

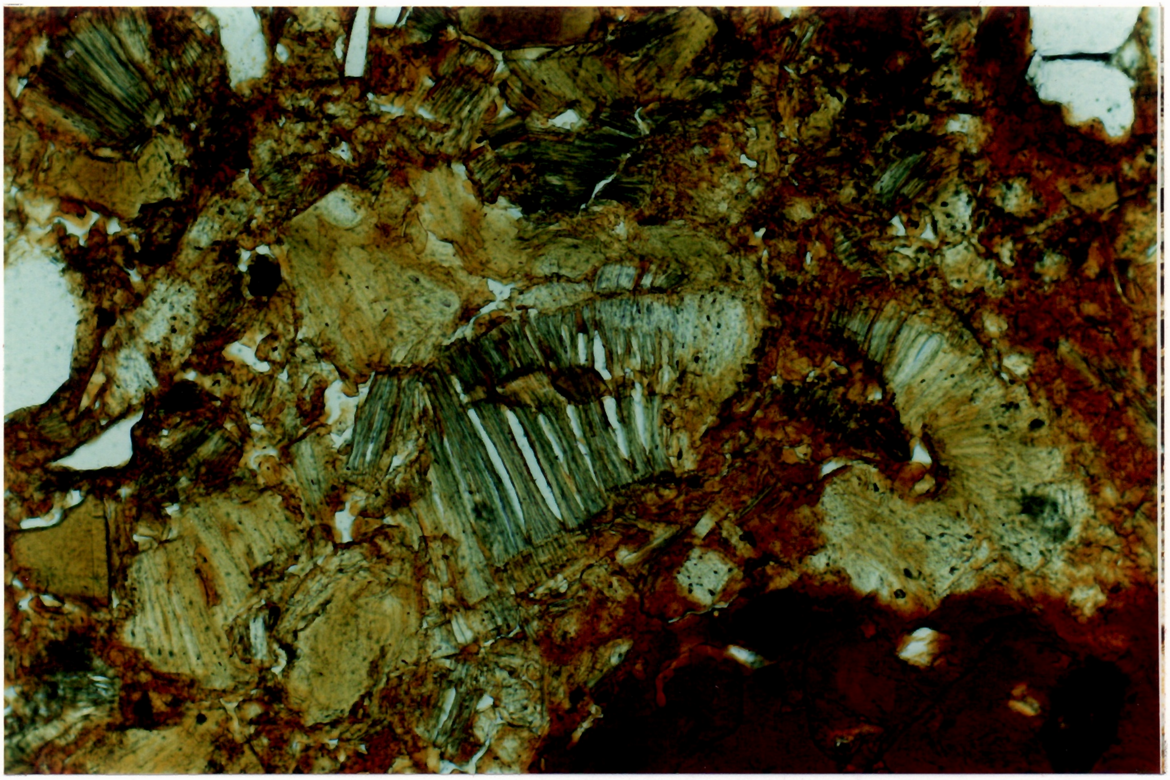

Figure 4. Parallel-linear alteration of a mica grain. The micrograph was taken under PPL at 100x magnifiaction. Frame length is 1.5 mm.

Table 4. Mineralogy of the Silt (2-50u) Fraction of Pedons 1, 2, and 3.

Horizon	Kln	Qtz	Verm	Mica	Gibs	Feld	HIV	INT
				%				
				Pedon 1 Piedmont				
Bt3	36	18		18	1	16	8	3
Bt4	32	17		20	t	17	6	8
BC	29	16		23	-	18	6	8
C1	31	17		27	-	20	5	t
C2	22	17		30	-	18	5	8
C3	18	16		32	-	21	5	8
				Pedon 2 Piedmont				
Bt4	38	17		15	-	15	10	5
BC	35	18		18	t	18	7	4
C1	32	17		23	2	16	5	5
C2	29	18		28	-	15	6	4
C3	19	16		33	-	20	2	10
				Pedon 3 Blue Ridge Highlands				
Bt3	15	20	t	18	-	25	12	5
BC	15	25	t	23	-	20	12	5
C1	10	20	t	30	-	20	12	5
C2	11	20	t	32	-	23	10	3

Kln=Kaolinite, Verm=Vermiculite, Qtz=Quartz, Gibs=Gibbsite, Feld=Feldspar, HIV=Hydroxy interlayered Vermiculite, INT=Randomly interstratified component

1989, Wysocki et al. 1988, Fanning et al. 1989, Barnhisel and Bertsch 1989). Harris et al. (1980) reported direct alteration of biotite to kaolinite in the Piedmont of Virginia. Both muscovite and biotite were observed in the thin sections of the Piedmont soils. Therefore mica is most likely altering to kaolinite, HIV, or an interstratified component.

Although thin sections showed alteration of feldspar, this mineral component showed only a minimal weathering with depth. In acid soils the weathering end products of feldspar are generally kaolinite and gibbsite (Eswaran and Bin, 1978, Calvert et al. 1980, Huang 1989). In the Piedmont soils, trace amounts to 2 % gibbsite were found in the Bt horizons of Pedon 1 and BC and C1 horizons of Pedon 2. The gibbsite is most likely not silt size, but occurring as a coating on the feldspar grains. The amount of kaolinite contributed by the weathering of feldspar is difficult to determine.

Similar weathering trends were observed in Pedon 3 in the Blue Ridge Highlands. Kaolinite contents however were much less than those in the Piedmont, and gibbsite was absent indicating a less weathered soil. Mica is apparently weathering to kaolinite, HIV, or a randomly interstratified component of these minerals.

Discussion

Considerable changes have occurred in the area between the argillic horizon and true saprolite in these soils. Field descriptions indicate that this zone of transition is relatively thin (20-44 cm), but micromorphology and lab data suggest that in the Piedmont the zone is much thicker.

The clay content of the BC horizon of Pedon 1 is 19 % and line counts of thin sections indicate that 4.5 % occurs as oriented clay coatings. Therefore this horizon meets the requirements as part of the argillic horizon. In the field however, this horizon showed evidence of rock structure as parent material mottles as well as a substantial decrease in clay relative to the maximum (52 vs 19%). Based on this data, the horizon was renamed BCt. Although the National Soils Handbook (Soil Survey Staff, 1981) allows subscripts, by convention, transition horizons are not accompanied by subscripts in the southeast region of the U.S.. It is apparent from these observations that BCt best describes these type of transition horizons.

Although the C1 and C2 horizons of Pedon 1 were described as structureless massive in the field, both oriented clay and some weak subangular blocky microstructure were observed in thin section. These features are indicative of pedologic process, therefore these horizons should not be considered C horizons. In order to evaluate how micromorphology correlates with the lab data, the percent sand, total and fine clay, DCB extractable Fe, and sand Zr reported in Table 1 were plotted vs depth. Data were presented on a relative scale so that trends for the various parameters could be viewed on the same plot (Figure 5). The slopes of the sand, clay and DCB Fe lines suggest two separate trends. The first trend shows that the transition between the argillic horizon and saprolite is gradual with depth, but that a substantial amount of change occurs. The clay data suggest that the first zone of transition occurs between the Bt3 and the BC horizon. The percent sand, and to a

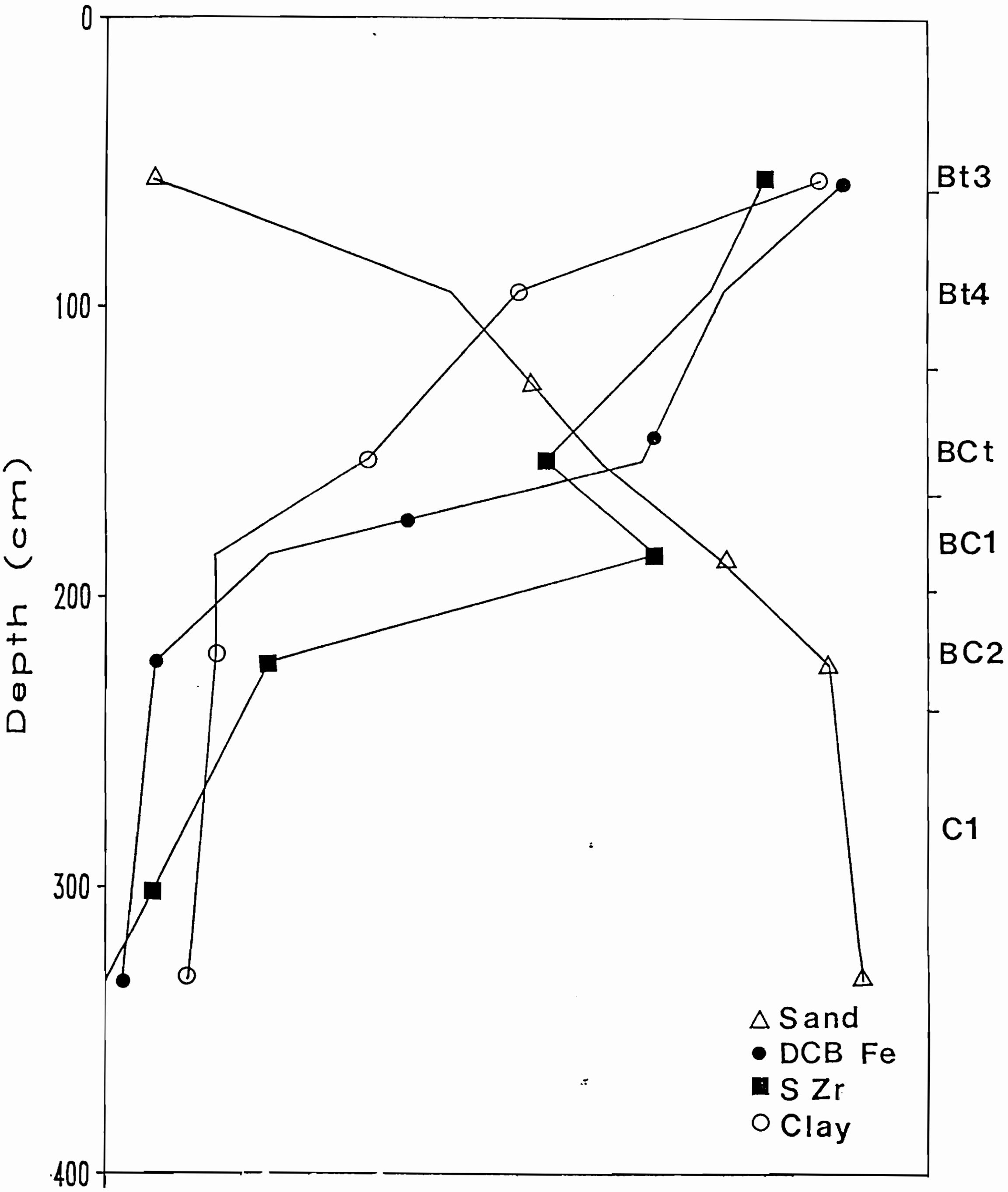

Figure 5. Percent sand, clay, DCB Fe, and sand Zr in Pedon 1. The x axis is on a relative scale of percent in order to compare the various parameters with depth. Soil horizonation was determined after laboratory results. Symbols on the lines do not represent data points.

lesser degree the percent DCB Fe, suggest the first transition ends at the CB horizon. Below this point very little change occurs with depth. The BC horizon appears to fall within the first trend and therefore the rates of change with depth are occurring at approximately the same rate as the other B horizons. The CB horizon occurred within the boundaries of the second trend and therefore changes occurring within this horizon are very similar to the C horizon. Sand Zr does not appear to level off with depth. The thickness of the saprolite in Pedon 1 is over 6 meters indicating that rock weathering or dissolution is occurring well below the solum. Therefore sand Zr may not level off until the parent rock is reached.

The transition horizons occurring in Pedon 2 were very similar to Pedon 1. The BC horizon of Pedon 2 contained 30 % clay, 14 % fine clay, and greater than 3 % oriented clay which meets the requirements for part of the argillic horizon. Because the clay content was still relatively high, and the horizon showed moderate subangular microstructure, the horizon is best described as part of the argillic horizon and therefore was renamed as Bt5. Although the clay content decreased to 13 %, 6 % oriented clay was observed in the C1 thin section. These percentages meet the requirements as part of the argillic horizon. Rock structure observed in the field however precludes using a Bt6 to describe this horizon, so BCt was used. The C2 horizon in Pedon 2 showed evidence of illuvial clay and weak subangular blocky microstructure, but appeared to be more like the C horizon than the B (Figure 6), and was therefore designated as a CB horizon. The C3 horizon was determined to be the parent material and renamed C1.

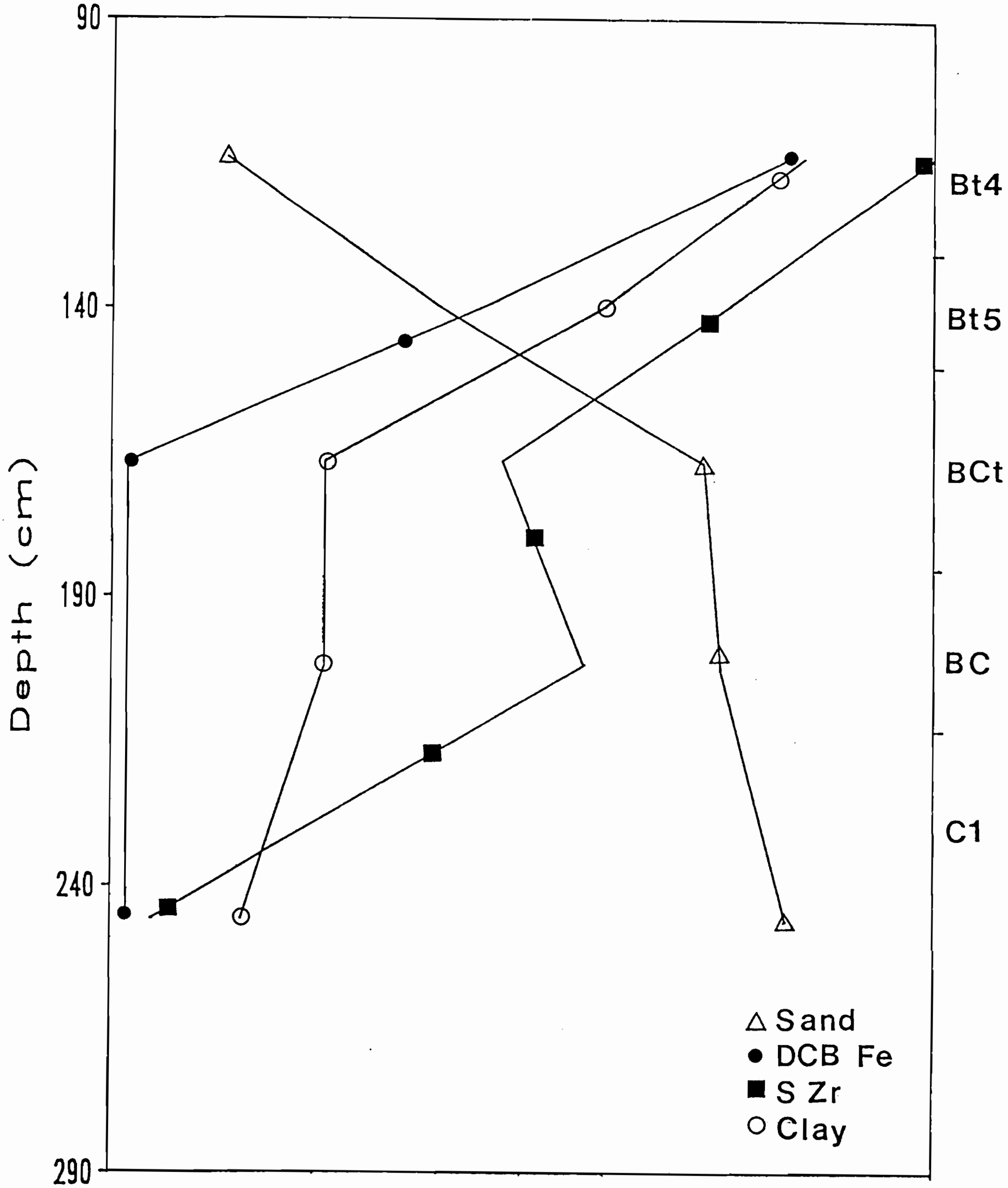

Figure 6. Percent sand, clay, DCB Fe, and sand Zr in Pedon 2. The x axis is on a relative scale of percent in order to compare the various parameters with depth. Soil horizonation was determined after laboratory results. Symbols on the lines do not represent data points.

The pedons studied in the Blue Ridge Highlands showed thinner zones of transition between soil and saprolite than those in the Piedmont (Figure 7 and 8). In Pedon 3 the BC horizon showed 5 % oriented clay, therefore the horizon was designated a BCt. Evidence of pedologic process such as oriented clay and subangular blocky microstructure were absent from the C1 and C2 horizons, so their horizon designations were left as those given in the field.

Thin sections of the BC1 horizon in Pedon 4 showed over 6 % oriented clay, moderate subangular blocky microstructure, porphryric c/f RDP and enough total and fine clay to meet the requirements as an argillic horizon. Therefore the horizon was designated a Bt3. Because both the BC2 and C1 horizons were lacking oriented clay, but the BC2 showed evidence of structure in thin section and in the field, these horizons were labelled BC and C1 respectively.

Summary and Conclusions

Although horizons in the field may appear structureless massive, pedologic process may have still occurred. The most common types of processes are clay illuviation and development of microstructural breaks and subangular blocky micropeds. Clay illuviation was observed along microped faces, or within planar or packing voids or vughs in all horizons between the argillic horizon and saprolite. Alternating wetting and drying cycles are most likely the cause of microstructural breaks and subangular blocky micropeds in these horizons.

Distinguishing transition horizons in the field can be difficult.

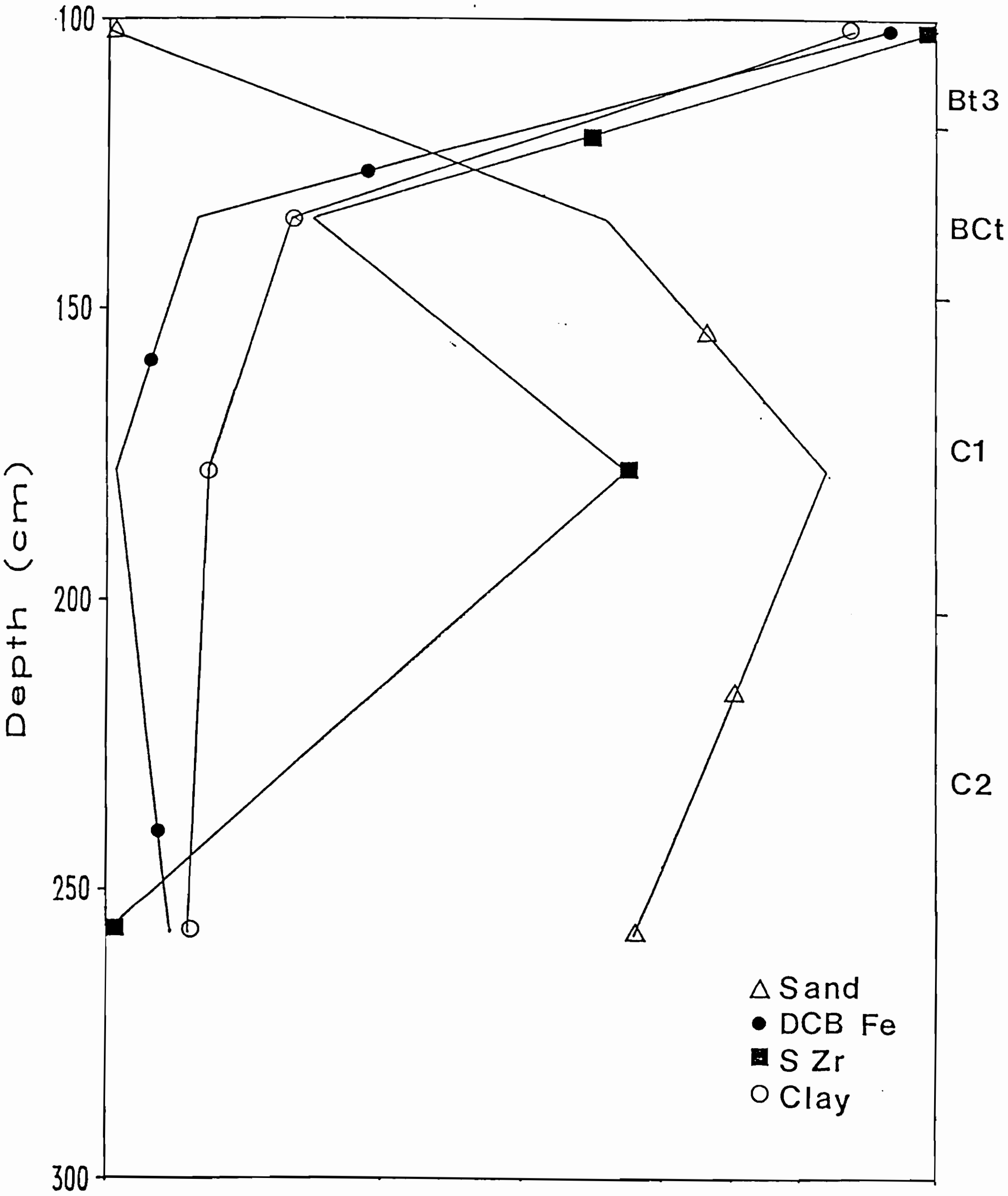

Figure 7. Percent sand, clay, DCB Fe, and sand Zr in Pedon 3. The x axis is on a relative scale of percent in order to compare the various parameters with depth. Soil horizonation was determined after laboratory results. Symbols on the lines do not represent data points.

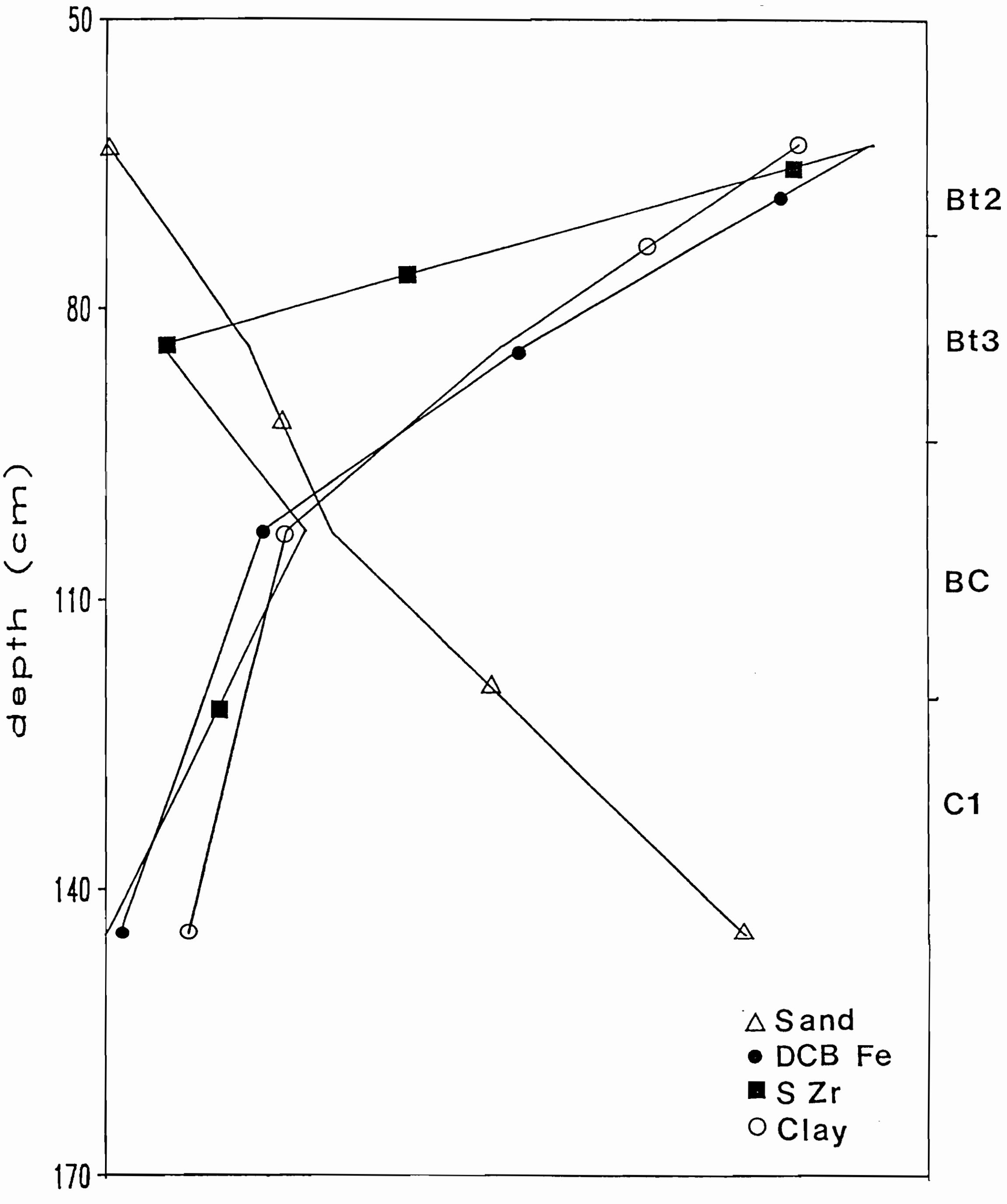

Figure 8. Percent sand, clay, DCB Fe, and sand Zr in Pedon 4. The x axis is on a relative scale of percent in order to compare the various parameters with depth. Soil horizonation was determined after laboratory results. Symbols on the lines do not represent data points.

Horizon designation in the field was done by consensus between the authors as well as soil survey personnel currently working in the counties in which the study sites occurred. Many of the horizons however, which were labelled in the field as C horizons, were actually transition horizons. From this study the following recommendations apply to making field descriptions of soil-saprolite transition horizons, and saprolite C horizons: 1) Percent clay should not decrease following the first C horizon. 2) C horizons should lack subangular blocky microstructure and illuvial clay in small macro-voids as observed in a hand lens. Clay flows are allowed in C horizons if they are restricted to large macropores along relic fissure cracks or similar nonpedologic breaks in the structureless massive saprolite. 3) Horizons with moderate evidence of rock structure should be labelled a transition horizon, even if the horizons meets the clay requirements as part of the argillic horizon.

Field evidence for soil-saprolite transition horizons may differ depending on the parent rock. These laboratory criteria can be used to correlate with the field descriptions. Those horizons designated as BCt should contain subangular blocky microstructure and substantial oriented clay. Horizons labelled BC should have some subangular blocky microstructure and show rates of change with depth of physical and chemical properties such as percent sand, clay, fine clay, and DCB Fe more like the B than C horizon. Those horizons designated as CB should be very similar to the C horizon but show some evidence of pedologic process such as some subangular blocky microstructure.

Percent total and fine clay, DCB extractable Fe, and percent sand were the parameters that were best correlated with micromorphological observations. Percent Zr by weight, percent sand Zr, bulk density, or water retention were not effective in distinguishing between Bt, transition, and C horizons. Percent Zr by weight and sand Zr, although often considered a good indicator of parent material, were not effective parameters in determining parent material in these soils. These parameters may be a better estimator of the depth of geochemical weathering.

The effect of weathering was obvious throughout the zone of transition. Mica showed slight to almost total pellicular and parallel linear alteration to HIV, kaolinite, or an interstratified component of these minerals. Alteration of quartz was slight, and where occurring was in the pellicular and irregular linear form. Feldspar alteration was generally less than 25 % and occurred in the form of pellicular, or parallel or cross-linear patterns. In the Piedmont, gibbsite and kaolinite were the alteration products of feldspar, but in the Blue Ridge Highlands gibbsite was absent from the silt fraction.

Soils in the Piedmont generally showed better expressed argillic horizons, thicker sola, thicker zones of transition, and higher clay contents, silt gibbsite and higher silt kaolinite contents than those of the Blue Ridge Highlands. These trends indicate that these soils are more weathered than those of the Blue Ridge Highlands.

Micromorphology showed argillic horizons to have considerable amounts of oriented clay (3-16%), strong to moderate subangular blocky microstructure, porphyric c/f RDP, low c/f_{20u} ratios (<0.6) and many planar voids. Oriented clay and peds were absent from the C horizons.

Microstructure was termed rock controlled to describe the apedal nature of these horizons although packing voids and vughs were common. Planar voids were in most cases absent. The c/f RDP was chitonic or gefuric with the c/f_{20u} ratio at least double of the argillic horizon. The horizons between the argillic and parent material showed micromorphological properties and characteristics of both of these master horizons.

CHAPTER 2

Evaluation of reconstruction techniques for examining soil-landscape relationships: I. Soil variability and parent material uniformity

Abstract

Relationships between soil development and the factors of soil formation, such as parent material or landscape position, can often be hidden or confounded by random soil variability. To reduce these affects, random variability must be recognized and separated from the systematic variability associated with parent material, pedogenesis, or landscape position. In this study variability in particle size, elemental composition, and DCB extractable Fe and Al was examined in soils at various levels within four representative toposequences in the Piedmont and Blue Ridge Highlands regions of Virginia. Subsamples were taken from near surface, Bt and C horizons within soil pits to examine the total variability of the study using a nested design, to test for differences between horizons and landscape positions, and to assess lateral variability within individual pedons. Total variability was partitioned between study sites, landscape positions, horizons, and random variability. The percent of the total variability contributed by landscape position was found to be minimal (7%) to totally absent, suggesting that for upland soils in which study sites are spread

between different regions and of different parent materials, landscape position has minimal effects on soil development. Lateral variability was found to be highest in the C horizons, with over 86% of the variables examined showing the highest average CV in the these horizons. These results are expected from moderately well to well developed upland soils in which near surface and argillic horizons have undergone substantial ordering due to weathering, and pedogenic processes. Mean CV's ranged from 7.6% for total sand to 33.5% for fine clay. Silt Ti, Fe, and K had the lowest mean CV for the elemental data (9.9, 10, and 8% respectively) and silt Zr (29.7%) and sand Fe (29.9%) had the highest. These data suggest considerable lateral variability, and support the need for multiple sampling within horizons. Significant differences between near surface, Bt and C horizons were found at the .05 level for 77 to 98 % of the particle size and 58 to 83 % of elemental and DCB extractable sample means. Parent material uniformity was evaluated using confidence intervals (CIs) of silt Ti:Zr ratios and clay-free sand fraction, as well as distributions of sand and silt Zr, and clay-free particle size with depth. Confidence intervals about the mean for clay-free sand were found to be too sensitive to be used as an indicator of parent material uniformity. Variations in parent material were most likely related to differential weathering rates, slight aeolian additions, or slight variations in the parent rock. Lithologic discontinuities were found to be difficult to recognize without obvious field evidence, and it is suggested that data should strongly support each other before a discontinuity is identified.

Introduction

Spatial variability is universal to all soils and can have several sources depending upon the type and level of the investigation. These sources are generally divided into systematic and random components. Systematic variability is due to recognizable differences in weathering rates, lithology, topography, or hydrology. Random variability is attributed to unrecognizable differences in these parameters, as well as differences due to sampling and laboratory error (Wilding and Drees 1983).

Statistical methods employed to separate, distinguish, and report the systematic and random components of soil variability depend upon the type and objectives of the study. Edmonds et al. (1985) and Thomas et al. (1989) used a nested design to examine variability within mapping units. Analysis of variance tables were used to report sources of variability within the mapping units and associated sampling sites. Campbell (1978) employed semivariance to examine relationships between variability and distance in two adjacent map units. Variance was reported as semivariograms. Many studies in which sampling designs were examined have used coefficients of variation (CVs) to examine and describe soil variability (Ball and Williams 1968, Harradine 1949, Drees and Wilding 1973, and Mausbach et al. 1980). Coefficients of variation are a means in which variability for a set of parameters can be expressed and compared regardless of units or orders of magnitude.

Uniform parent material is a necessary requirement for studies using reconstruction techniques. Unconformities in the parent material can be attributed to stratification in the parent rock resulting in variability in the particle size or mineralogy (Brewer 1976), or lithologic discontinuities in the profile due to colluvial, alluvial, or aeolian additions. Several methods are used to examine parent material uniformity. Clay-free particle size distributions with depth is the most commonly used method to distinguish discontinuities (Ronstad et al., 1976; Brewer, 1976; Barshad 1964). Clay particles move through the profile during the illuvial process causing systematic variability between horizons. To remove these affects, particle distributions with depth are examined on a clay free basis for evidence of lithologic discontinuities or parent material stratification.

In most instances, other methods such as index mineral or element trends (usually zircon or the elemental equivalent Zr, or Zr:Ti ratios) are used in conjunction with particle size distributions to assess the uniformity of a parent material with depth. As with particle size distributions, Zr and Ti should be examined in fractions greater than 2u because of clay illuviation (Ronstad et al., 1976; Brewer, 1976). Barshad (1964) suggested that at least two greater than 2u fractions be examined. If Zr:Ti ratios are employed it should be recognized that inherent complications with Ti can occur. Chapman and Horn (1968) and Kaup and Carter (1987) found Ti occurring in soils in the form of leucoxene coatings on sand grains such as quartz, or Ti occurring in weatherable minerals such as biotite, hornblende, and sphene (Kaup and Carter, 1987).

Uniform parent material, as defined by Brewer (1976), is material that shows less variability than that induced during the sampling and determination of the soil constituents. Evaluation of variability due to sampling within individual pedons however has been limited. Drees and Wilding (1973) examined elemental variability within sampling units of soils formed in glacial deposits and Smeck and Wilding (1980) reported values for particle size fractions within pedons. Similar studies have not been published on residual soils.

The overall focus of this study was to examine soils at summit, backslope, and footslope landscape positions within toposequences to evaluate the relationships between landscape position and soil genesis. In order to examine these relationships using reconstruction and other techniques, differences related to random variability must be recognized and separated from the systematic variability associated with parent material, pedogenesis, or landscape position. Therefore this study was designed with the following objectives: i) to estimate and describe lateral variability within horizons of the same pedon and determine if differences in mean values for physical, chemical, and elemental parameters between horizons within the same pedon are significant; ii) to evaluate the degree of uniformity of the parent material within each pedon and across the landscape; and iii) to determine the sources of variability for the overall study, and estimate the contribution of each source to the total variability.

Materials and Methods

Field Methods

Over fifty soil-landscape associations were examined in the Piedmont physiographic province and Blue Ridge Highlands region of

Virginia in an attempt to find relatively undisturbed residual soils formed from uniform parent material. Most reconnaissance sites were located in old churchyards, cemeteries or homesteads in soils formed from gneissic or schistose rocks. Soil and saprolite morphology at summit positions were examined with a bucket auger to a depth of 3.5 meters or lithic contact. Samples were taken from soils that showed evidence of residual nature, uniform parent material, and minimal unnatural disturbance, and particle size distribution with depth and sand and silt mineralogy were determined. Soils at the backslope and footslope positions of these sites were also examined to determine if the residual portion of these soils had formed from similar parent rock.

Four representative toposequences were chosen for detailed study. Sites 1 and 2 were located in the Piedmont and sites 3 and 4 in the Blue Ridge Highlands regions of Virginia (Figure 1). Soil pits were excavated at the summit, backslope, and footslope positions. Horizonation of four faces a meter apart on the long face of each pit wall (Fig. 2) were examined. The most representative face was described using the National Soils Handbook (Soil Survey Staff 1981). Bulk samples were taken from each of four faces labelled A, B, C, and D. Samples taken from the horizon just below the A horizon, the best expressed Bt horizon (determined by maximum clay content), and the lowest C horizon accessible within the pit, were bagged separately. Samples taken from the other horizons were combined to form a composite sample for each horizon and bagged.

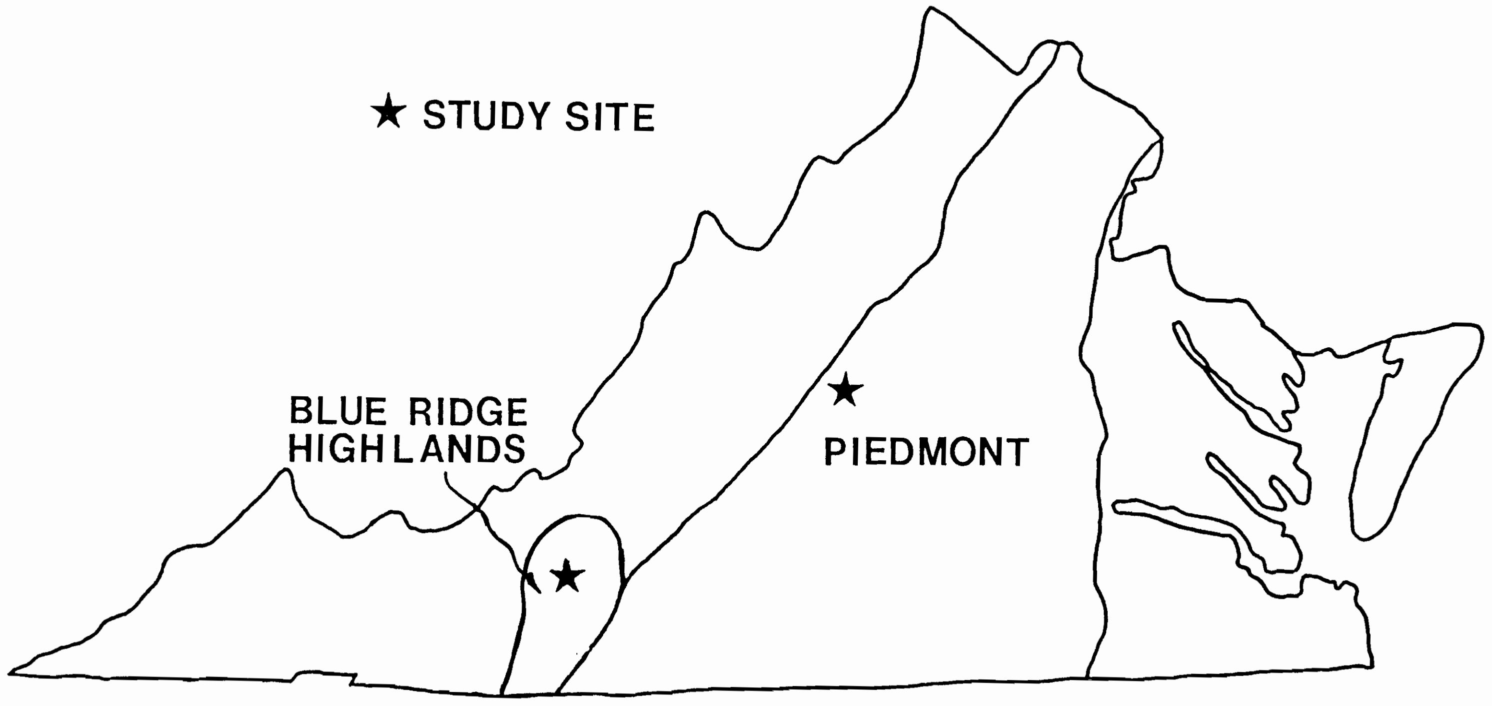

Figure 1. Location of study area and sites.

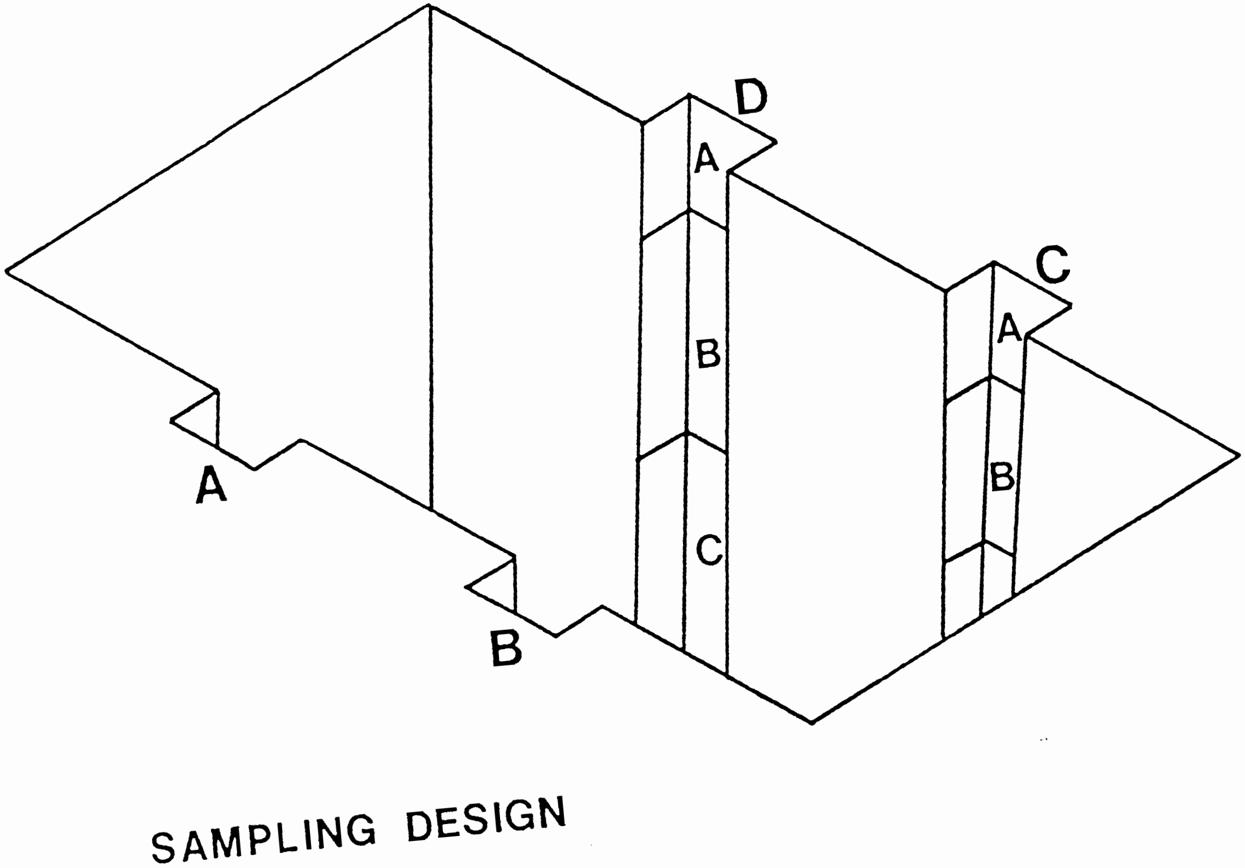

Figure 2. Diagram of sampling scheme within individual pedons (after Drees and Wilding 1973).

Laboratory Methods

Bulk samples were air-dried, ground and passed through a 2mm sieve. Particle size distribution (PSD) was determined by pipette (Gee and Bauder, 1986). Dithionite-citrate-bicarbonate (DCB) extractable Fe and Al were removed following the procedures of Holmgren (1967), and analyzed by inductively coupled plasma spectrometry (ICP). Elemental Zr, Ti, Fe, Ca, and K were determined from pellets using x-ray fluorescence (XRF) techniques. Pellets were made from ground silt or sand samples that were mixed in a ratio of 1:1 with boric acid. Silt and clay fractions were separated by gravimetric and centrifugation methods. Silt fractions were oven dried, lightly ground in an agate mortar with a pestle, rewetted and dropped on a glass slide. Clay fractions were prepared on tiles saturated with K, or Mg with glycerol solvation following the procedure of Rich and Barnhisel (1977). Magnesium tiles were analyzed at 25 C and the those that were K saturated slides were analyzed at 25, and after heating to 300, and 550 degrees C. Percent kaolinite and gibbsite were determined by differential scanning calorimetry (DSC) using poorly crystalline Georgia kaolinite and a Reynold's synthetic for kaolinite and gibbsite standards. Percentages of the remaining minerals were estimated using relative peak intensities.

Statistical Methods

The value obtained for an individual variable (Y_{ijkl}) such as percent sand can be explained by the ideal statistical model:

$$Y_{ijkl} = u + S_i + P_{ij} + H_{ijk} + E_{ijkl}$$

where u is equal to the population mean; S_i is representative of the effects due to site; P_{ij} is representative of the effects due to landscape position; H_{ijk} is related to the effects due to horizon; and E_{ijkl} is that which is due to random error. The percent of the variability explained by each effect can be estimated by a nested design if subsamples are taken of the lowest class (Webster 1977). These methods were employed using a SAS (SAS 1985) computer program. The percent of the total variance attributed to each component of the model was estimated by dividing the variance attributed to the individual component by the total variance (SAS 1985).

Analysis of variance was used to test if sample means were different between horizons, and if sample means of C horizons were significantly different between landscape positions. Significance of the differences were determined using a F test. Percent of the variability explained by horizon or landscape position was determined as above. Significantly different sample means for the landscape positions were separated by least significant difference (LSD). Analysis of variance and LSD calculations were performed on a computer using SAS (SAS 1985) programs. Descriptive statistics such as means, confidence intervals and coefficients of variations were calculated following the procedures of Zar (1984).

Results and Discussion

The total variability within this study can be attributed to differences between study sites, landscape positions, horizons, and variability within horizons due to lateral variability, sampling and lab error. The distribution of the variability can be explained by the statistical model:

$$s^2_{total} = s^2_{site} + s^2_{pos.} + s^2_{hor.} + s^2_{error}$$

Using a nested design and subsampling within horizons, sources of the variability within the study can be separated and the amount contributed by each component can be estimated (Webster 1977). Estimations of the percent of the total variability attributed to the individual components is given in Table 1. The percent of the total variability contributed by landscape position was found to be minimal (7%) to totally absent. These data suggest that for upland soils in which study sites are spread between different regions and parent materials, landscape position contributes little to the total variability. Therefore, for studies on a fairly large scale of upland soils, parent material and regional climate factors are much more important than landscape position on soil development.

Of the variables examined, none showed greater than 66% of the variability related to site, and only sand Zr and Ti, and total silt showed greater than 50% related to site. The various sand and silt fractions show an equal amount of variability explained by site and horizon. Therefore, even though the soils examined occurred in two different regions and the parent materials varied from mica gneiss in the Piedmont to augen gneiss and gneissic schist in the Blue Ridge Highlands, the soils and parent materials appear very similar. Total, fine, and coarse clay, sand, DCB extractable Fe and Al, and silt Zr, Ti, Fe, and K, and sand Fe were the variables in which variability was

Table 1. Percent of the total variability explained by site, position, horizon, and error.

Variable	Site	Position	Horizon	Error
	--------------------	%	--------------------	
VC Sand	43	0	48	9
Co Sand	49	0	44	7
Med Sand	46	0	46	8
Fine Sand	49	0	46	5
VF Sand	44	0	53	3
Co Silt	47	0	42	11
Fine Silt	47	0	46	7
Co Clay	4	0	93	3
Fine Clay	4	0	92	4
Sand	17	0	78	5
Silt	56	0	34	10
Clay	4	0	93	3
DCB Fe	2	0	91	7
DCB Al	5	0	88	7
Sand Zr	58	2	26	13
Silt Zr	26	0	44	29
Sand Ti	66	2	19	14
Silt Ti	13	3	78	6
Sand Fe	8	0	73	19
Silt Fe	0	0	92	8
Sand K	41	7	28	25
Silt K	5	0	69	26

explained primarily by horizon. These results should be expected from moderately well to well developed upland soils in which weathering and illuviation are the major soil forming processes.

Variability of Parent Materials Between Landscape Positions

Morphology of the residual parent materials within sites appeared very similar. In order to better describe the similarities and differences of the parent material, particle size and elemental composition data from the C horizons were analyzed using analysis of variance. Means that were shown to be significantly different at the .05 level were separated by least significant difference (LSD). The C horizons of the summit and backslope positions at Sites 1 and 2 were saprolite formed from a mica gneiss. The residual parent materials of the footslope soils not weathered to saprolite, and were designated as a Cr horizons. Because the Cr horizons showed considerable evidence of illuvial clay, particle size data were examined and analyzed on a clay free basis. For Site 1, sand Zr and silt Ti (Table 2) are the only elemental fractions which were significantly different at the three landscape positions. The other elemental fractions and all of the particle size fractions (Table 3) were statistically equivalent across the landscape, or only one position showed some variation. The C horizons in Site 2 appear very uniform across the landscape with no means significantly different between all three landscape positions, and few differed between any two landscape positions (Tables 2 and 3).

The C horizons at Site 3 were saprolite formed from an augen gneiss. The sand fractions are rich in K and the silt fractions rich in

Table 2. Sample means of elemental sand and silt fractions. Sample means with different letters are signigicantly different at the .05 level.

Position	S Zr	Si Zr	S Ti	Si Ti	S Fe	Si Fe	S K	Si K
	%							
				Site 1				
Summit	.03a	.16a	.30a	.40a	1.88a	2.55a	4.54a	3.03a
Backslope	.10b	.10a	.66b	.70b	4.74b	4.49b	4.15a	3.21a
Footslope	.19c	.12a	.66b	1.00c	2.62a	3.54b	4.19a	2.85a
				Site 2				
Summit	.18a	.01a	1.03a	.60a	5.11a	3.15a	3.74a	3.97a
Backslope	.14b	.02a	1.04a	.69a	4.48a	3.31ab	3.87a	4.12a
Footslope	.15ab	.42b	.69a	.67a	4.36a	3.86b	5.05a	2.58b
				Site 3				
Summit	.08a	.02a	.95a	.47a	.91a	5.32ab	5.15a	2.72a
Backslope	.06a	.02a	1.03a	.33a	1.57b	4.25a	5.08a	2.75a
Footslope	.06a	.02a	1.17a	.30a	2.27c	6.06b	4.90a	2.55a
				Site 4				
Summit	.04ab	.02a	.96a	.48a	1.29a	1.72a	3.59a	1.92a
Backslope	.03a	.02a	1.03ab	.87b	2.89b	5.33b	4.51b	2.83b
Footslope	.05b	.02a	1.23b	.75c	2.85b	4.27c	3.13a	2.31c

Table 3. Sample means for clay-free particle size fractions. Sample means with different letters are significantly different at the .05 level.

Position	cfS	cfVC	cfC	cfM	cfF	cfVF	cfSi	cfCSi	cfFSi
					%				
					Site 1				
Summit	83a	7a	17a	13a	28a	18a	17a	19a	7a
Backslope	76a	3b	8b	10a	32a	23b	24a	14b	10ab
Footslope	77a	11a	15a	11a	25b	15a	23a	9a	14b
					Site 2				
Summit	66a	2a	5a	7a	30a	22a	34a	14a	20a
Backslope	62a	1a	4a	6a	28a	22a	38a	14a	23a
Footslope	71a	4a	8b	8b	28a	22a	29a	15a	14a
					Site 3				
Summit	62a	15a	18a	9a	13ab	7a	38a	8a	30a
Backslope	69b	19a	18a	9a	15b	7a	31b	7a	24b
Footslope	74c	26b	21b	9a	12a	5b	26c	5b	21b
					Site 4				
Summit	56a	19a	13a	5ab	10a	8a	4a	18a	26a
Backslope	58a	17a	13a	6b	11a	11b	4a	22a	20b
Footslope	50a	14a	11a	5a	11a	10b	5a	18a	31c

Fe (Table 2). Sand Fe was the only elemental fraction that differed significantly between the three landscape positions. The other elemental fractions were very similar. Although the various sand and silt fractions appeared fairly uniform across the landscape, total sand and silt were found to be significantly different between the three positions (Table 3). These data suggest that some variation in the particle size fractions occurs between landscape positions, but the elemental composition and therefore mineralogy of the silt and sand fractions are essentially the same.

The residual parent material for the soils at Site 4 is saprolite formed from a gneissic schist. Silt Ti, Fe, and K, as well as fine silt differ significantly between the three landscape positions (Table 2). The other elemental and particle size fractions were similar. These data suggest that the mineralogy of silt fractions may vary slightly depending upon the landscape position.

Variability Within Horizons

Variability within horizons of the same pedon, or lateral variability, was examined for 3 horizons within each pit. These included the horizon just below the A horizon (in most cases an E horizon), the most expressed argillic horizon (Bt2 or Bt3 horizons), and the lowest C horizon that could be sampled within the soil pits. Lateral variability was examined for various particle size fractions, DCB extractable Fe and Al; and elemental Zr, Ti, Fe, and K occurring within the sand and silt fractions. The variability of these parameters are reported as coefficients of variation (CVs).

In every case the highest mean CV for the particle size fractions occurred in the C horizon (Table 4), and in 7 out of the 10 DCB and elemental parameters, the C horizon had the highest CV value (Table 5). These data suggest that for nearly all variables the C horizon is the most variable. Similar findings were reported by Mausbach et al. (1980). These trends would be expected in well developed soils. The surface and Bt horizon have undergone substantial change due to pedogenesis. Therefore the E and Bt horizons, which show ordering from the pedogenic process, show much less variability than the C horizons.

The mean CVs for the particle size and elemental data were similar. For the particle size data, mean CVs ranged from 7.6% for total sand to 33.5% for fine clay. Silt Ti, Fe, and K had the lowest mean CV for the elemental data (9.9, 10, and 8% respectively) and silt Zr (29.7%) and sand Fe (29.9%) had the highest. The average CV values for all of the silt and sand fractions, with the exception of medium sand, were lower in the near surface horizons than the Bt. Coefficients of variation for clay however were lower for the Bt horizons. Sand and silt contents are higher in the near surface horizons than the Bt horizons where the percent clay is higher. These trends suggest that CVs may be biased toward variables with the highest mean. Several of the CV values for elemental Zr in the Bt and C horizons, elemental Fe in the near surface horizons, and fine clay in the C horizons were extreme. Coefficients of variation are applicable to most data except when covariance occurs (Wilding and Drees 1983). These problems arise because the values determined for the parameters are at the detection limits of the instrument or the individual procedure. Zirconium was determined by XRF

Table 4. Range and average coefficient of variation values by horizon for particle size fractions

Horizon	Sand	VC	C	M	F	VF	Silt	CSi	FSi	Clay	CC	FC
	%											
	Range											
E	1-8	6-27	2-12	2-59	1-11	1-11	1-15	6-32	0-10	3-36	3-63	5-63
Bt	4-18	5-55	5-64	2-26	2-22	4-14	2-29	4-43	2-38	1-45	1-66	3-75
C	1-17	15-87	7-47	7-64	3-65	1-19	1-46	8-70	4-35	9-79	:10-78	18-128
	Average											
E	3	16	6	15	4	6	4	15	5	11	15	24
Bt	9	28	18	11	9	10	11	18	12	10	11	15
C	10	43	21	19	17	10	15	22	18	38	36	60
$\bar{X}$	7.6	28.8	15.5	15	10.4	8.8	10.4	18.5	12	22	21	33.5

Table 5. Range and average coefficient of variation by horizon for elemental and DCB extractable variables.

Horizon	DCB Fe	DCB Al	S Zr	Si Zr	S Ti	Si Ti	S Fe	Si Fe	S K	Si K
	%									
	Range									
E	7-37	5-23	5-24	3-18	0-41	3-7	4-116	1-24	2-14	4-18
Bt	2-39	3-43	9-111	8-42	2-45	4-18	9-46	3-19	1-26	2-13
C	8-43	4-39	6-38	5-128	2-82	3-41	4-59	2-26	:3-44	0-14
	Average									
E	13	13	12	11	10	5	43	11	7	8
Bt	11	10	27	23	16	8	24	11	10	6
C	23	22	20	52	21	16	25	9	14	10
$\overline{X}$	15.8	15.1	20.1	29.7	16	9.9	29.9	10	10.5	8

which has a reported detection limit of .01%. In several of the Bt and C horizons the values for sand and silt Zr were at or close to the detection limit. This may also explain the high CV values for fine clay in the C horizons. The CV values for fine clay that were above 75% all occurred in horizons that had less than 3 % fine clay which is an often quoted value for the detection limit for clay in PSD analysis.

The amount of variability that is acceptable within a study is difficult to assess. In this study, although there are a wide range in CV values, the average CVs for 88 % of the properties measured were less than 30 %. Wilding and Drees 1983) grouped soil properties by CV values into three classes; least, where CV values were less than 15%, moderate (15-35%), and most variability, CV values greater than 35%. Most of the properties examined had mean CV values that fall into the moderate to least amount of variability. By subsampling within horizons, the amount of variation about the true mean can be reduced. The coefficient of variation is equal to the standard deviation divided by the mean (C.V = S.D./$\bar{x}$) where:

$$S.D. = \{ (X-\bar{x})^2/N\}^{1/2} \qquad \text{(Zar 1984)}$$

When the number of samples taken (N) is four, as is the case in the sampling scheme used in this study, the standard deviation is essentially one half as large as if only one sample was taken. Therefore by subsampling laterally within the horizon the average variability about the mean, described by the CV values, has been reduced by approximately one half. Taking four subsamples reduces the variability about the mean so that over 88 % of the variables measured would fall within the least variable class.

Analysis from the nested design indicated that a considerable amount of the variability in this study could be explained by differences in the horizons. To better assess the amount of variability explained by horizons, analysis of variance was used to examine differences in means for the horizons subsampled at each landscape position. For the summit and backslope landscape positions, 96 and 98 % of the particle size fraction means were significantly different at the .05 level. Table 6 shows the percent of variability explained by differences in horizons and the probability that the means are equal for selected particle size fractions. Seventy seven percent of the particle size means for the footslope soils were significantly different. For Sites 1 and 2 however only 63 % of the particle fractions were different. These soils were shallow to rock and much less developed than at the associated summits and backslopes. Therefore differentiation of the horizons was somewhat limited which is indicated by the analysis of variance data.

Compared to the particle size data, considerably less of the elemental and DCB extractable means were significantly different at the .05 level (Table 7). Overall, 70 % of the summits, 83 % of the backslopes, and 58 % of the footslope means were found to be significantly different. Footslope soils at Sites 1 and 2 showed only 45 % of the elemental and DCB extractable means significantly different. These data suggest that the degree of soil development has affected elemental data as well as the particle size, but elemental data are more subject to variability. Although the fine clay fraction showed as high coefficients of variation as silt or sand Zr, Ti, and Fe, the magnitude in

Table 6. Percent of variability explained by horizon (S2) for selected particle size fractions and probability (P) of rejecting the null hypothesis that the particle fraction means are equal.

Position	ms		fsi		fc		sand		silt		clay	
	% S2	P	% S2	P	% S2	P	% S2	P	% S2	P	%S2	P
						Site 1						
summit	94	<.01	99	<.01	99	<.01	98	<.01	98	<.01	99	<.01
backslope	98	<.01	99	<.01	99	<.01	94	<.01	98	<.01	99	<.01
footslope	86	.05-.01	95	<.01	77	.1-.05	73	.25-.1	97	<.01	84	.05-.01
						Site 2						
summit	99	<.01	94	<.01	99	<.01	98	<.01	92	<.01	99	<.01
backslope	96	<.01	96	<.01	98	<.01	98	<.01	95	<.01	98	<.01
footslope	91	<.01	92	<.01	98	<.01	69	.25-.1	83	.05-.01	97	<.01
						Site 3						
summit	91	<.01	60	.5-.25	99	<.01	99	<.01	86	.05-.01	99	<.01
backslope	98	<.01	97	<.01	98	<.01	99	<.01	98	<.01	99	<.01
footslope	93	<.01	99	<.01	97	<.01	98	<.01	99	<.01	97	<.01
						Site 4						
summit	98	<.01	99	<.01	83	.05-.01	97	<.01	98	<.01	85	.05-.01
backslope	99	<.01	98	<.01	99	<.01	99	<.01	97	<.01	99	<.01
footslope	99	<.01	98	<.01	85	.05-.01	99	<.01	97	<.01	92	.05-.01

Table 7. Percent of variability explained by horizon (S2) for selected DCB fractions and probability (P) of rejecting the null hypothesis that the elemental and DCB extractable means are equal.

Position	DCB Fe		SiZr		SiTi		SiFe		SiK	
	% S2	P	% S2	P	% S2	P	% S2	P	% S2	P
					Site 1					
summit	95	<.01	90	<.01	98	<.01	65	<.01	44	.1-.05
backslope	92	<.01	56	.05-.01	95	<.01	97	<.01	73	<.01
footslope	77	<.01	62	.05-.01	44	.1-.05	95	<.01	10	.5-.25
					Site 2					
summit	99	<.01	99	<.01	99	<.01	91	<.01	73	<.01
backslope	91	<.01	94	<.01	98	<.01	87	<.01	85	<.01
footslope	80	<.01	41	.1-.05	91	<.01	3	.5-.1	84	<.01
					Site 3					
summit	82	<.01	92	<.01	73	<.01	98	<.01	76	<.01
backslope	97	<.01	85	<.01	90	<.01	87	<.01	0	1.0-.75
foootslope	96	<.01	98	<.01	91	<.01	97	<.01	0	1.0-.75
					Site 4					
summit	94	<.01	38	.25-.1	83	<.01	81	<.01	90	<.01
backslope	95	<.01	0	.5-.25	94	<.01	93	<.01	52	.05-.01
footslope	77	<.01	89	<.01	98	<.01	95	<.01	0	1.0-.75

the differences between a C and Bt horizon, or an E and Bt horizon are much different. Fine clay for the C1 and Bt2 horizons of the backslope soil at site 4 were 0.3 and 18.2 % respectively. The silt Zr contents however were .019 for the C1 horizon and .026 for the Bt2 horizon. The differences in fine clay for these horizons are 40 times the differences for silt Zr.

Uniformity of the Parent Material

The soils examined in this study are moderately well to well developed, and have probably survived a good portion of the Pleistocene Era. It would seem unreasonable to conclude that there have been no additions to these soils during this period of time. To determine if these additions have significantly affected these soils, the uniformity of the parent material was examined in the field and laboratory.

Unconformities in the parent materials were recognized in the field at the footslope position in each of the study sites. The material at the surface appeared to be colluvium or local alluvium that had moved down slope. Similar material and discontinuities were found at the backslopes of Site 2 in the Piedmont and Site 3 in the Blue Ridge Highlands. No indication of lithologic discontinuities could be found in the field for the other six pedons.

The most common methods for distinguishing lithologic discontinuities are examination of clay-free particle size distributions, Ti:Zr ratios, and index mineral (or their elemental equivalent) trends with depth. In this study sand Ti:Zr ratios could not be used because elemental analysis showed a weathering trend with depth for sand Ti. It is often assumed that Ti occurs primarily in the mineral form rutile which is resistant to weathering. Kaup and Carter (1987) and Chapman and Horn (1968) however found soils with leucoxene coatings on quartz grains and minerals such as hornblende, biotite and sphene containing considerable amounts of Ti. In our study biotite and pseudomorphs of hornblende were observed in thin sections of these soils. Loss of these minerals at the surface due to weathering could attribute to the higher sand Ti contents observed with depth. Silt fractions showed an accumulation of Ti and Zr within the surface horizons, therefore Ti:Zr ratios of the silt fraction were examined. Confidence intervals (CIs) were calculated for the silt Ti:Zr ratios as well as the clay-free sand fraction for horizons in which lateral variability (previously presented) was examined (Table 8). These confidence intervals were extrapolated to similar horizons within the same pedon. Sand and silt Zr, and clay-free particle size distributions were also plotted with depth (Figures 3-5).

Confidence intervals for clay-free sand contents were small for the near surface horizons (+ or - 1.5-6% of the mean) and larger for the Bt and C horizons (+ or - 4-18 and 8-26% respectively). Confidence intervals for silt Ti:Zr were 12-37% for the near surface, 19-48% for the B, and 34-51% for the C horizons. Drees and Wilding (1973) reported for 6 subsamples of soils developed in glacial materials C.I.s. for Ti:Zr ratios ranging from 9 to 23%. The C horizon for the summit soil at site 2 showed a C.I. of 171%. This extreme value probably occurred because the Zr content was at or near .01%, which is the detection limit for XRF. Therefore covariance may have contributed to this high C.I..

Table 8. Confidence intervals and means for clay free sand and silt Ti/Zr ratios.

Horizon	depth	C.I. clay free sand	Clay free sand $\bar{x}$	C.I. Silt Ti/Zr	Ti/Zr $\bar{x}$
	cm	%			
			Site 1 Summit		
A	0-7	66.4-69.6	68	2.9-5.3	4.1
E	7-16	64.5-67.5	66	2.8-5.2	4.0
Bt1	16-31	58.8-65.2	62	4.6-6.8	5.7
Bt2	31-48	55.9-62.1	59	3.2-4.8	4.0
Bt3	48-63	64.5-71.5	68	3.5-5.1	4.3
Bt4	63-126	69.2-76.8	73	3.2-4.6	3.9
BCt	126-170	70.2-77.8	74	3.2-4.8	4.0
BC1	170-202	75.4-88.6	82	1.8-3.6	2.7
BC2	202-245	73.7-88.3	81	1.8-3.8	2.8
C1	245-420	73.7-88.3	81	2.0-4.2	3.1
			Site 1 Backslope		
A	0-7	64.0-62.9	65	3.3-6.5	4.9
E	7-28	61.1-62.9	62	3.9-7.7	5.8
Bt1	28-43	50.6-71.4	61	4.4-8.4	6.4
Bt2	43-70	46.5-65.5	56	4.8-9.4	7.1
Bt3	70-98	47.3-66.7	57	4.1-7.9	6.0
Bt4	98-130	52.3-73.7	63	4.7-9.1	6.9
BCt	130-150	58.1-81.9	70	4.4-8.4	6.4
BC1	150-187	69.9-82.1	76	3.3-10.3	6.8
BC2	187-216	69.9-82.1	76	3.5-10.7	7.1
C1	216-275	70.8-83.2	77	4.9-15.3	10.1
			Site 4 Summit		
A	0-7	24.6-35.4	30	8.3-15.0	11.6
E	7-18	24.6-35.4	30	8.4-15.4	11.9
BE	18-28	21.3-30.7	26	10.9-19.7	15.3
Bt1	28-54	23.0-33.0	28	12.5-22.7	17.6
Bt2	54-72	28.7-41.3	35	12.6-22.8	17.7
Bt3	72-96	28.7-41.3	35	16.2-29.4	22.8
BC	96-114	27.9-40.1	34	26.1-47.3	36.7
C1	114-176	47.6-58.4	53	17.4-40.6	29.0

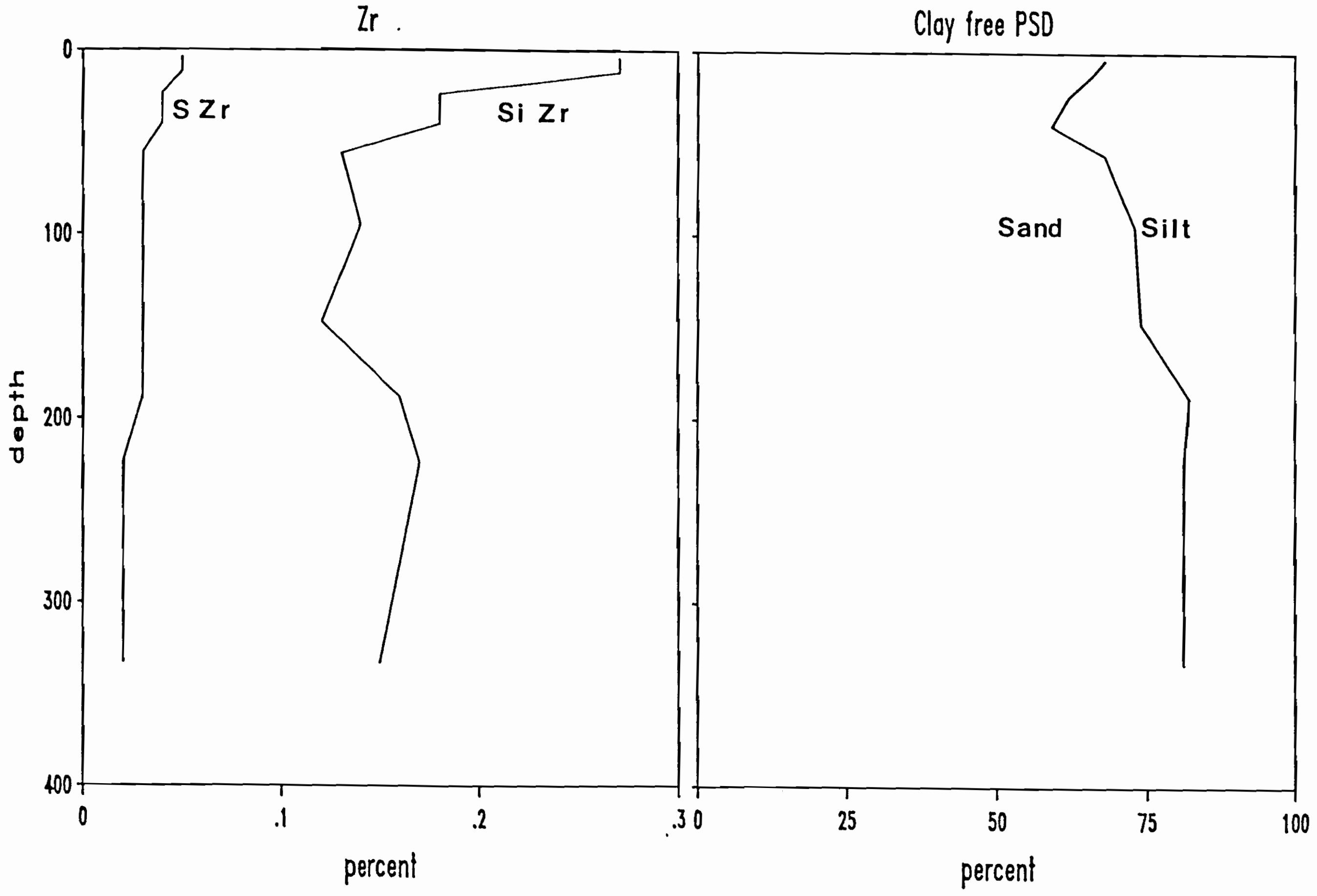

Figure 3. Sand and silt Zr, and clay-free PSD distributions with depth for the summit soil at Site 1.

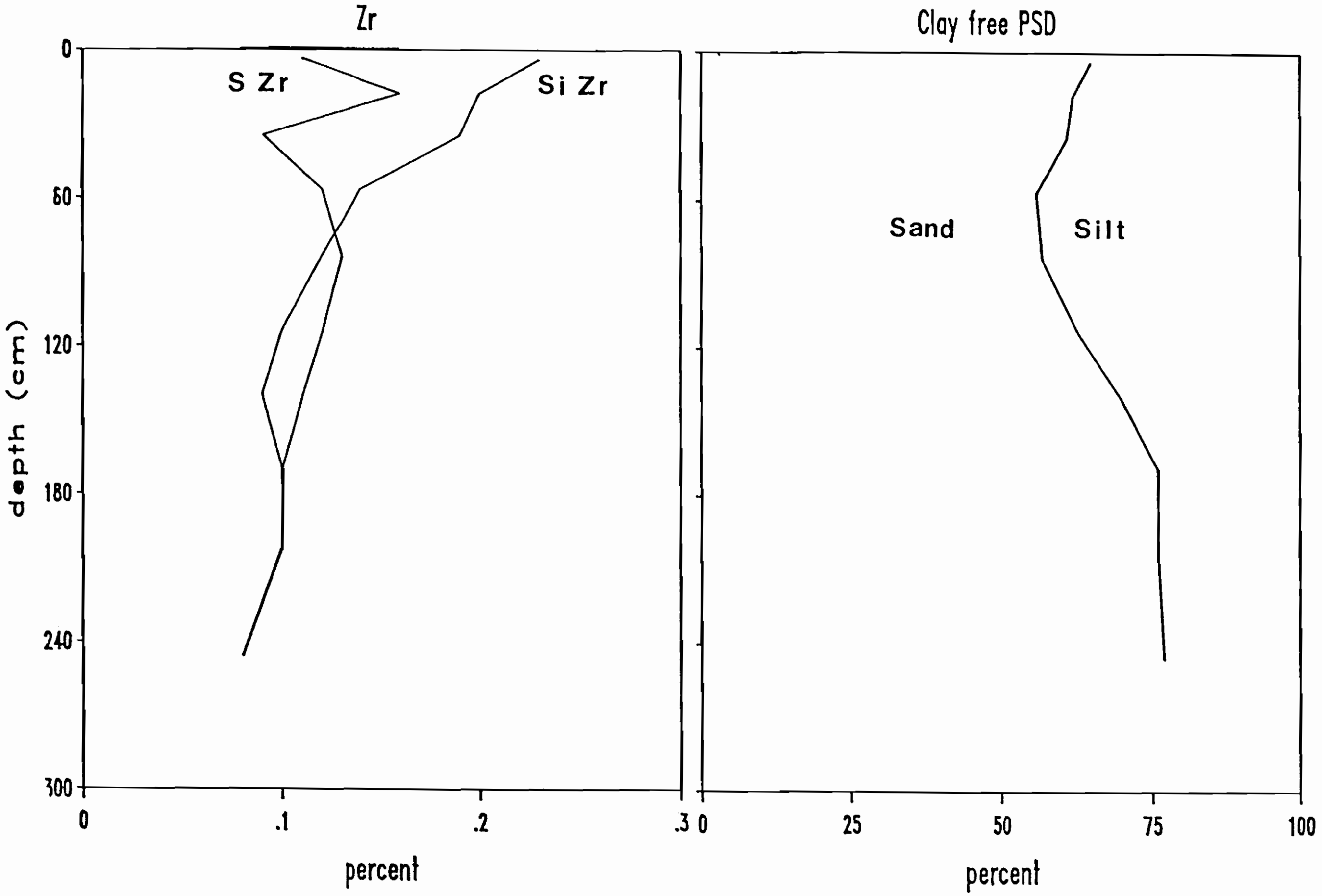

Figure 4. Sand and silt Zr, and clay-free PSD distributions with depth for the backslope soil at Site 1.

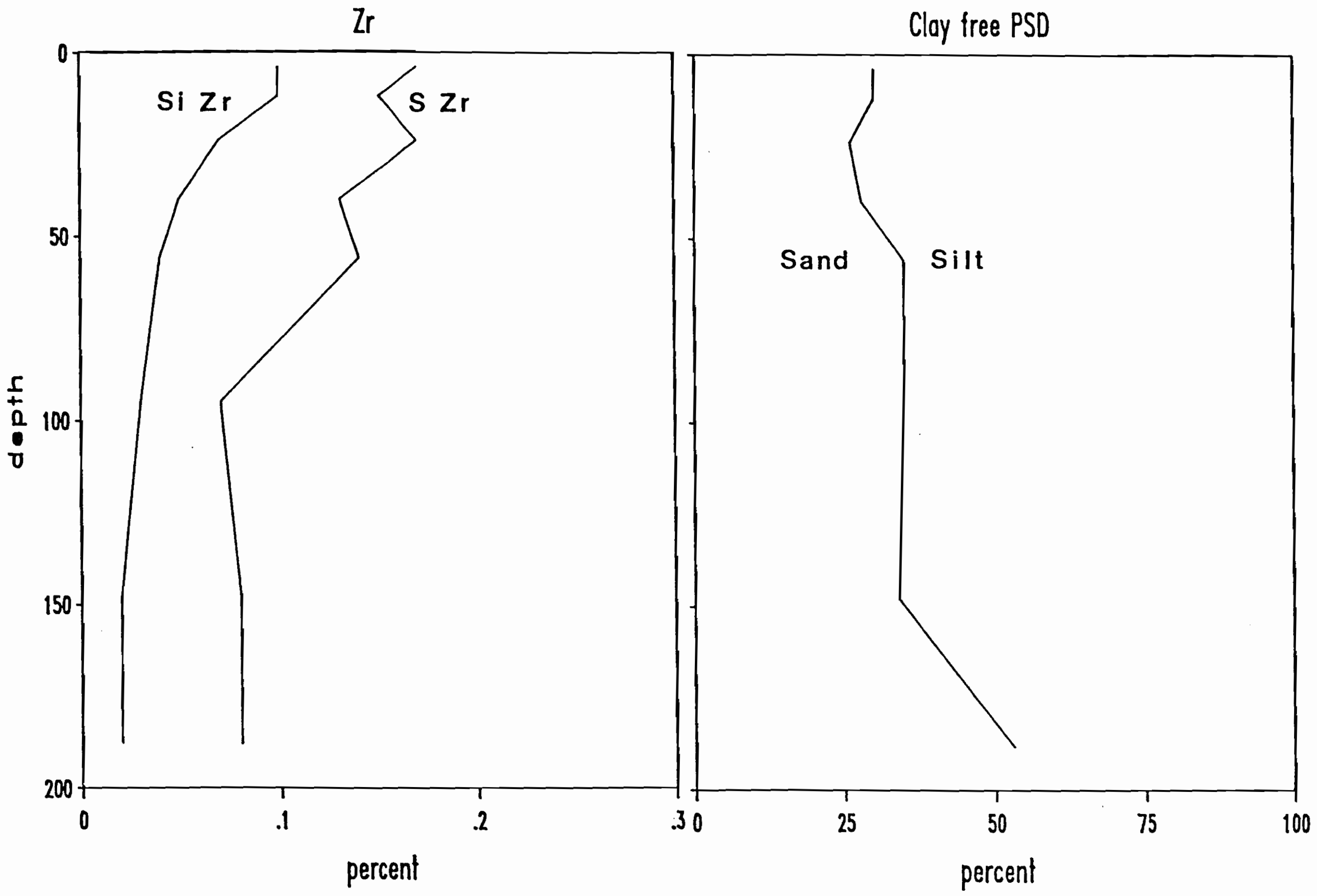

Figure 5. Sand and silt Zr, and clay-free PSD distributions with depth for the summit soil at Site 4.

Confidence intervals, clay-free PSD, and sand and silt Zr distributions with depth indicated variations in parent materials in each of the six pedons. Variations occurred either between the first two horizons, between two of the argillic horizons or between the solum and the parent material. Each pedon showed variation in at least one these areas. Because the interpretations for each of the pedons were the same, three representative examples are presented.

Clay-free PSD of each pedon showed that the sand content decreased from the surface horizon to the argillic horizon, and then increased from the argillic horizon to the C material (Figures 3, 4, and 5). For the summit of Site 1 (Figure 3) this change in clay-free PSD occurs between the Bt1 and Bt2 horizon. Confidence intervals of the clay-free sand and silt Ti:Zr ratios of these horizons overlap indicating that the differences between the sample means were not significant at a level of .05 (Table 8). Distributions of silt Zr (although somewhat variable) and sand Zr support the Ti:Zr and clay-free sand data and suggest that these variations are not significant. Confidence intervals for the clay-free sand and distribution of silt Zr with depth suggest variation in the parent materials between the Bt2 and Bt3 horizons of this profile. Distribution of the sand Zr or clay-free PSD with depth, and the confidence intervals for silt Ti:Zr ratios do not support significant variation in the parent material. Therefore the majority of the data suggest that a lithologic discontinuity does not occur in this soil and weathering rates may contribute to the variability observed.

The primary assumption in examining the clay-free PSD is that the sand and silt fractions weather at approximately the same rates, and the silt fraction does not illuviate. Silt fractions have been shown to move in coarse textured soils but within these soils the process is unlikely. Thin sections of the parent materials showed that quartz, mica, and feldspar were the most common silt and sand size minerals. Mica and feldspar in acid environments show weathering rates much faster than quartz, so that in this soil environment quartz is accumulating in the surface horizons. Silt mineralogy (available in the Table 13 of Chapter 3) shows a dramatic increase in quartz from the B horizons to the surface. The clay-free PSD data suggest that the larger quartz grains weather at a slower rate than silt fractions. Weathering of quartz is primarily a desilication process. The sand fractions have a smaller surface area than the silt, so that rates of weathering and desilication are higher for silt size than sand size quartz (Drees et al. 1989).

Changes in the distribution of Zr with depth do not always indicate a change in parent material, but may indicate a less weathered environment. In the soil Zr is found almost exclusively in the form of the mineral zircon, which is very resistant to weathering and stable in the soil environment (Brewer 1976, and Milnes and Fitzpatrick, 1989). Therefore as other mineral forms weather and are lost from the coarser fractions as clay or to the soil solution, zircon accumulates in the horizon. Although there is some variability, accumulation of Zr can be observed in for silt Zr in Figures 3, 4, and 5 and for sand Zr in Figures 3 and 5. The Zr trends suggest that most active zone of weathering is within the upper 50 to 60 cm of the soil. This corresponds to the zone where the clay-free sand decreases from the soil surface to the argillic horizon which supports the explanation that variation in this zone is primarily due to weathering.

Confidence intervals for clay-free sand of three of the six pedons showed significant variations between the A horizon and the underlying horizon. Confidence intervals for the clay-free sand of the backslope of Site 1 (Table 8) do not overlap which is indicative of variation in the parent material. Distribution of sand Zr (Figure 4) also suggests some variability between these horizons. The distribution of silt Zr, clay-free PSD and confidence intervals for silt Ti:Zr ratios do not support the conclusion of significant variability. One proposal that may explain the slight differences between A and E horizons, especially where the silt content is higher in the A than E horizon, is aeolian additions. Elemental data from the silt fractions of all the soils examined showed that horizons within the upper 50 cm contain measurable Ca, where-as for the lower horizons and saprolite, Ca in the silt fraction is undetectable. The sand fraction is generally void of Ca throughout the profiles. These data may indicate that aeolian additions of silt have occurred within the recent geologic past. These additions may be masked by the residual sand in the surface horizons. Another explanation for higher Ca levels in the silt fraction at the surface may be biocycling. Exchangeable Ca was 5 to 10 times greater in the A horizons than the lower horizons. Mineralogy of the silt fractions indicate considerable amounts of HIV minerals. These minerals have a high charge capacity and may hold Ca on the exchange sites that was biocycled to the surface by trees.

Site 4 is located in the Blue Ridge Highlands. Confidence intervals for clay-free sand (Table 8) indicate a significant variation between the BC1 and C horizon. The clay-free PSD (Figure 5) also indicate variation in parent materials. The Zr distributions and C.I. for silt Ti:Zr ratios however do not support significant variation. These variations may be related to slight variations in the parent rock. The saprolite from these soils has formed from a gneissic schist. Thin zones (10-40 cm thick) of a more schistose, almost phylite like material, are common in these soils. These zones lie parallel to the rock structure and are much less weathered than the primary parent materials and may therefore contribute to variability in these soils.

Although variations were found in the parent materials in each of the pedons examined, data strongly supporting the case for lithologic discontinuities were absent. From the preceding discussion it is apparent that lithologic discontinuities are difficult to recognize without obvious field evidence. Clay-free distributions and Ti:Zr ratios are the most common methods used to examine uniformity of parent material. Confidence intervals about the mean for clay-free sand indicated that each pedon contained significant variation between horizons to warrant a discontinuity. The majority of the other indices did not support the case for a discontinuity. It appears that C.I. about the mean for clay-free sand are too sensitive to be used as an indicator for uniformity of parent material. Therefore, if field evidence of variation in parent material is lacking, several methods should be employed to distinguish discontinuities. These methods should strongly support each other before a discontinuity is identified.

Conclusions and Summary

The data from this study indicated that considerable variability occurred at each level of the investigation. The following general conclusions were made about variability for soils formed from saprolite in the Piedmont and Blue Ridge Highlands of Virginia:

1) Landscape position appears to be a much less important factor in explaining soil development than parent materials or regional climate.
2) Lateral variability is much larger in C, than Bt or near surface horizons.
3) Multiple sampling within horizons should be employed in soils research to reduce the amount of inherent variability about the sample mean.
4) Without field evidence, lithologic discontinuities are difficult to identify.

Summary

A nested statistical design partitioned the overall variability in this study between study sites, landscape positions, horizons, and random variability. The percent of the total variability attributed to landscape position was minimal or totally absent indicating that for upland soils in which study sites are spread between different regions and of different parent materials, landscape position appears to be a much less important factor in explaining soil development than parent materials or regional climate. Even though the soils examined occurred in two different regions, and the parent materials ranged from mica gneiss to gneissic schist, analysis of the total variance indicated that the soils and parent materials examined were very similar. Only sand Zr, Ti, and K, and total silt showed substantially greater variability explained by site than by horizon. Total, fine, and coarse clay, total sand, DCB extractable Fe and Al, and silt Ti, Fe, K, and Zr were the variables in which total variability was explained primarily by horizon. These results were expected for these moderately well to well developed upland soils in which weathering and illuviation are the major soil forming processes.

Lateral variability within horizons was found to highest in the C horizons. Surface and Bt horizon have undergone substantial pedogenesis resulting in an ordering of the soil constituents into the various horizons. Therefore in developed soils genetic horizons show less inherent variability than the associated parent material. The mean coefficient of variation for several variables was greater than 30 % indicating that considerable lateral variability occurs within horizons of these soils. These data suggest that multiple sampling of horizons within a pedon is critical to accurately estimate the population mean. Four subsamples per horizon were shown to reduce the average amount of variability around the true mean to an acceptable amount for most of the parameters examined.

Analysis of variance was used to determine if sample means between horizons were significantly different. Significant differences between near surface, Bt and C horizons were found at the .05 level for 77 to 98 % of the particle size and 58 to 83 % of elemental and DCB extractable sample means. Footslope soils showed the lowest number of significantly different means which supports field observations that horizon differentiation was less evident in the footslope soils than associated backslope and summit soils.

Lithologic discontinuities were recognized in the field in all of the footslope and two of the backslope soils. To evaluate the uniformity of the parent material for the other soils statistical and laboratory methods were employed. These methods included confidence intervals (CIs) for silt Ti:Zr ratios and clay-free sand, and distributions of sand and silt Zr, and clay-free particle size with depth. Confidence intervals of clay-free sand indicated variations in parent materials for each of the summit and backslope soils examined. The majority of the other indices however did not support the case for lithologic discontinuities. Therefore C.I. about the mean for clay-free sand may be too sensitive to be used as an indicator of parent material uniformity. Variations in parent material were most likely related to differential weathering rates, slight aeolian additions, or slight variations in the parent rock. Lithologic discontinuities were found to be difficult to recognize without obvious field evidence, and it is suggested that data should strongly support each other before a discontinuity is identified.

CHAPTER 3

Evaluation of reconstruction techniques for examining soil-landscape relationships: II. Reconstruction Analysis and Soil Genesis

Abstract

Reconstruction analysis is a means of quantitatively determining the gains and losses of the soil constituents that occur during soil genesis. In this study, soil reconstruction techniques were employed to examine the relationships between landscape position and soil genesis in relatively undisturbed wooded soils in the Piedmont and Blue Ridge Highlands regions of Virginia. Although backslope soils occurred on slopes of up to 18%, profile morphology and clay distributions of the summit and the backslope soils were very similar. Footslope soils were found to be bisequel and had less expressed argillic horizons. Transects across the toposequences indicated that there was little difference in soil morphology between landscape positions occurring in the convex portion of the upper landscape. Therefore any differences observed in profile morphology between summit and backslope soils developed in gneissic or schistose materials, can be related to man-induced erosion or differences in parent materials. Soil reconstruction results indicated that summit and backslope soils were undergoing the same soil forming processes, and these processes were occurring at the same rates. Both depositional and pedologic processes were found to

contribute to the formation of the footslope soils. Weathering of sand particles to smaller particles was the major soil forming process occurring in the summit and backslope soils, and this process was equally important in the footslope soils if weatherable minerals occurred in the parent materials. Substantial gains in clay indicated that illuviation/eluviation was the second most important process occurring in these soils. Larger gains were observed in the argillic horizons of the summit and backslope soils than were observed in the associated footslope soils. In the surface horizons of the Piedmont soils, weathering of larger particles to clay size material was found to be in equilibrium with clay eluviation. Losses of elemental Fe, K, and Ti were found to coincide with the weathering of silt and sand particles. Losses and gains of DCB extractable Fe and Al were generally associated with gains or losses of clay-sized material. Mineral suites consisting primarily of kaolinite, quartz, mica, feldspar, hydroxy-interlayered vermiculite (HIV), chlorite, gibbsite, and randomly interstratified minerals were found in both the Piedmont and Blue Ridge Highlands soils. Differences in mineralogy between landscape positions were minimal, although surface horizons of the Piedmont backslope soil contained more gibbsite and less kaolinite than the summit surface soil, suggesting that losses of silica through lateral flow may occur in the surface horizons of backslope soils.

Introduction

Soil genesis modeling has taken many forms since Dokuchaev's first factorial type model. Although several models have been proposed, a solvable quantitative model is still lacking. To develop such a model, especially one that is computer compatible, a means to quantitatively measure the pedologic processes is necessary. One method to quantitatively measure soil genesis is through soil reconstruction techniques.

Soil reconstruction techniques, pioneered by Marshall and Haseman, (1942), and popularized by Brewer (1976), and Smeck and Wilding (1980), are employed to quantitatively measure gains and losses of the various soil constituents relative to those of the parent material. These gains and losses are equated to pedogenesis. These techniques are often thought of as calculations of soil formation (Brewer, 1976). Reconstruction techniques are most often applied to individual soils or employed to examine a specific soil forming process. Sudom and St Arnaud (1971) used reconstruction techniques to examine gains and losses of soil constituents in a Boralf (Orthic Gray Luvisol). Wang and Arnold (1973) used these techniques to examine a Hapludalf and Fragiocrept formed from similar parent materials under similar soil conditions in order to understand the processes involved in fragipan formation. Reconstruction techniques have also been used to explain differences in clay distributions between soils formed from similar parent materials (Smeck et al. 1968) and to examine clay accumulations in poorly drained soils (Smeck et al. 1981).

Relationships between landscape position and soil genesis have been explored by several authors using various techniques. In Texas, West et al. (1988) used reconstruction techniques to examine the effect of landscape position on the development of carbonate-rich horizons. These authors found that gains and losses of carbonates at the summit could be best explained by the relative stability of the summit soils and thus continued and deeper leaching. The backslope soils however were unstable, and carbonate distribution with depth was affected by erosion more than through downslope enrichment of carbonates. Much of the soil-landscape research has concerned young soils developed in loess (Ruhe and Walker 1968, Walker et al. 1968, Kleis 1970, Huddleston and Riecken 1973, Huddleston et al. 1975). Ruhe and Walker (1968) constructed hillslope models by curve-fitting linear, exponential, power, and polynomial equations to soils data. From the hillslope models, these researchers concluded that the quantitative affects of erosion, sedimentation, time, and soil environment on soil properties could reasonably be predicted. Walker et al. (1968) used trend surface analysis to assess soil-landscape relationships and found that the summit was least affected by erosion, the backslope showed the greatest affect of erosion, and footslope soils showed the highest clay and organic matter contents. Kleis (1970) used a "systematic" approach to studying soil-landscape relationships in soils that were less than 2900 years old, and found that quadratic equations could be used to geometrically describe summit positions, while logarithmic equations best described the backslope and footslope positions. Using these equations, differences observed between the landscape positions were primarily related to hillslope sedimentation, with minimal differences related to pedogenesis. Huddleston and Riecken (1973) and Huddleston et al. (1975) used principal component analysis to distinguished between pedologic and geologic processes within a landscape. These studies found the summit positions to be the most stable landscape positions, with most of the variability related to a pedogenesis factor. Substantial erosion and deposition had occurred at the backslope and footslope positions, and thus most of the variability observed within the backslope and footslope soils was found to be related to geologic processes such as hillslope erosion and gully sedimentation.

Other than the work of West et al. (1988), the use of reconstruction techniques to examine soil-landscape relationships has been limited. Therefore this study was initiated with the following objectives: 1) To describe the soil-landscape relationships in the Piedmont and Blue Ridge Highlands of Virginia. 2) To determine the gains and losses of the soil constituents at the summit, backslope, and footslope landscape positions of these soils. 3) To evaluate the application of reconstruction techniques to studying relationships between soil genesis and landscape position.

Materials and Methods

Field and laboratory methods are as previously described in Chapter 2.

Reconstruction Techniques

Reconstruction calculations can be based on the percentage of the stable constituent or a constant volume (Brewer 1976). Although some researchers have argued that horizon formation does not alter the volume of soil material (Wild, 1961), most researchers agree that changes in volume occur during horizonation. Therefore calculations were based on a stable constituent. Calculations for soil reconstruction were taken primarily from Brewer (1976). Zirconium (Zr) was chosen as the stable constituent. Clay is mobile in the soil system, therefore percent Zr by weight was calculated on a clay free basis as follows:

$$\% \text{ Zr} = [(\% \text{ sand Zr} \times \% \text{ sand}) + (\% \text{ silt Zr} \times \% \text{ silt})].01$$

To adjust for changes in volume, the volume factor (after Wilding et al. 1980) was used instead of the reciprocal presented by Brewer (1976). The volume factor was calculated by :

$$\text{volume factor (VF)} = \frac{(\text{BDpm} \times \text{Zrpm})}{\text{BDh} \times \text{Zrh}}$$

where: BDh = bulk density of horizon;

BDpm = bulk density of parent material;

Zrh = Zr content of horizon;

Zrpm = Zr content of parent material.

Gains and losses of the soil constituents are presented on a weight/-volume (g/cm^3) basis. Gains and losses were calculated by:

$$\Delta \text{X} = \text{Xpm} - \text{Xh}$$

where: ΔX = change in constituent;

$\text{Xpm} = (\text{BDpm} \times \text{Pxpm}) \div \text{VF}$

$\text{Xh} = \text{BDh} \times \text{Pxh}$

Xpm = weight in grams of constituent in parent material;

Xh = weight in grams of constituent in horizon;

Pxh = percentage by weight of constituent in horizon;

Pxpm = percentage by weight of constituent in parent material.

Brewer (1976) listed the necessary criteria to properly use the reconstruction techniques. These include a uniform parent material and parent material that was unaltered by pedogenic process. Wang and Arnold (1973) showed that reconstruction techniques can be used on soils with discontinuities or multiple parent materials, if the state and composition of the original parent materials can be determined. To determine the parent material for the residual portion of the soils, thin sections of the C horizons were examined for evidence of pedogenic process such as soil macro or micro structure, and illuvial clay in vughs and packing voids. The first C horizon which lacked evidence of pedogenic process was used as the parent materials. Parent materials that were not residual in nature were assumed to have been transported from upslope of their present position. Thin sections, clay free particle size analysis, regression techniques, and elemental composition were used to estimate the initial state and composition of these materials.

Study Site Descriptions

Study sites 1 and 2 are located in the Piedmont near the town of Lovingston, VA. The residual soils have formed in saprolite and weathered rock derived from a mica gneiss (Lovingston Formation, Virginia Division of Mineral Resources 1963). These sites are situated in woodlands of an old estate which dates back to the 1700's. The large oak trees, which were interspersed with many much larger stumps, suggested that selective cutting had been the only cultural disturbance affecting the summit and backslope soils. The summit soils had slopes less than 2 percent. Slopes at the backslopes were 18 percent for Site 1, and 7 percent for Site 2. The soils at the footslopes occurred on landscapes sloping at 5 and 6 percent. Stone lines composed of angular quartz gravels were observed in the footslope soil of Site 1 and the backslope and footslope soils of Site 2, indicating discontinuities. The likely source of the quartz gravels was the quartz veins or stringers that commonly occur within the parent rock, saprolite, and soil material. At the summit of Site 1 saprolite extended to at least 8.5 meters below the soil surface. The thickness of the regolith at the backslope was less than 5 meters and less than 1.5 meters at the footslope (Figure 1). The thickness of the saprolite was not determined between the summit and the backslope but a general trend is given by the dashed line. Saprolite at the summit of Site 2 extends to 5 meters below the soil surface and the saprolite thickness decreases down the landscape.

Study sites 3 and 4 occur in the Blue Ridge Highlands near the town of Pilot, Virginia. Site 3 was located within the property of High Rock Church and Cemetery. The summit and backslope soils at this site appear to be have undergone minimal cultural disturbance. Large oak trees 1.5 to 2 meters in diameter are the primary vegetation. Over 300 growth rings were counted in one of the primary branches of one of these oaks.

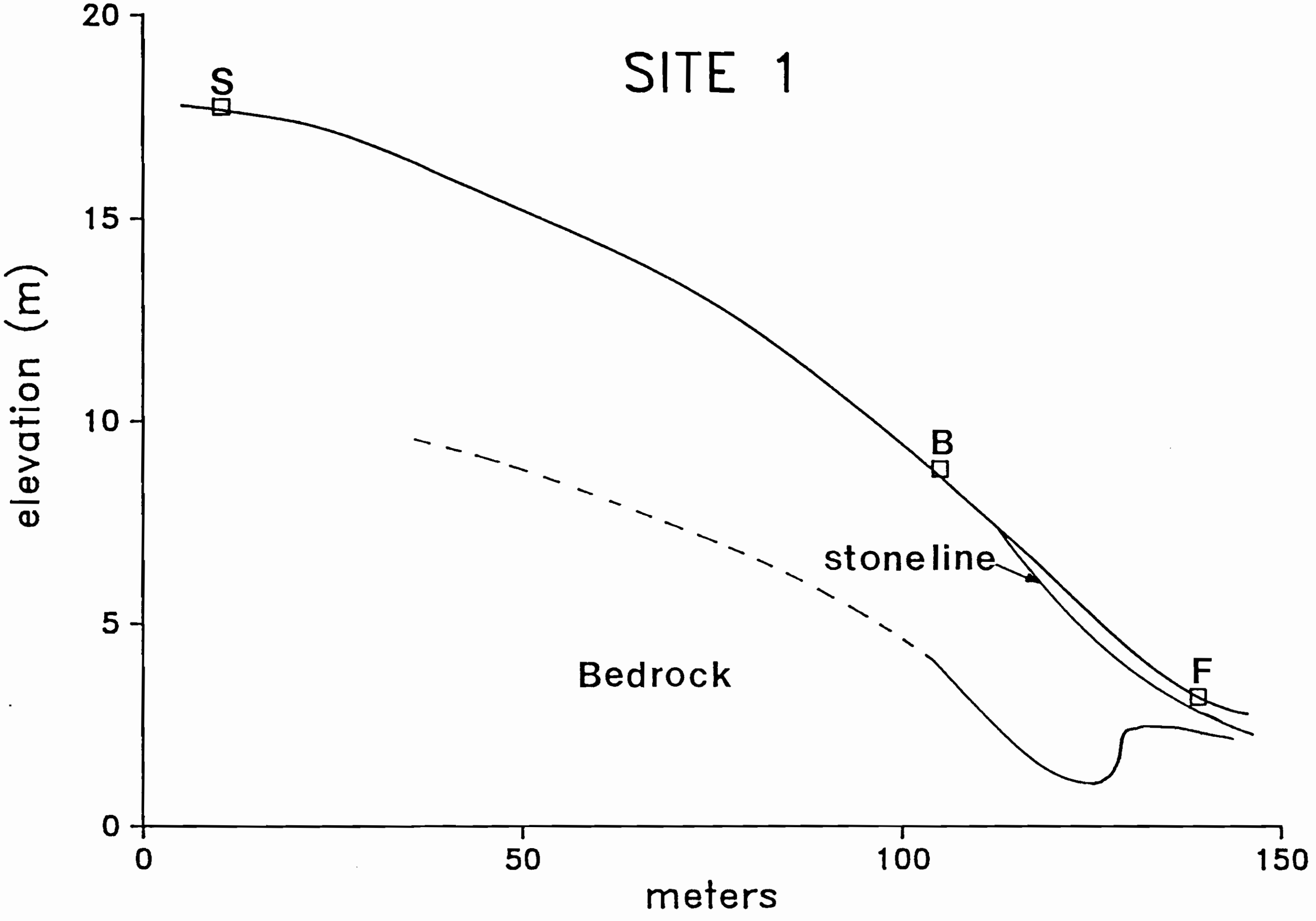

Figure 1. Cross section of Site 1. Vertical exaggeration is 5 times.

The residual portion of the soils at this site have formed in saprolite derived from an augen gneiss (Pilot Gneiss, Lewis 1975). The pedons sampled were located on landscape positions with slopes of 2 (summit), 18 (backslope), and 6 percent (footslope).The thickness of the regolith is over 11.5 meters at the summit and decreases down the landscape. A stoneline was observed within the backslope and footslope soils.

The toposequence at Site 4 occurs within a mature oak woodlands. The saprolite is derived from a gneiss schist component of the Blue Ridge Complex (Dietrick, 1954). The summit is nearly level, and the backslope and the footslope had slopes of 14 and 6 percent, respectively. Saprolite extended to over 10 meters at the summit and showed a slight decrease across the landscape (Figure 2). A discontinuity was recognized at the footslope position.

Results and Discussion

Results of the reconnaissance efforts indicated that for both the Piedmont and Blue Ridge Highland regions, the profile morphology of the summit and backslope soils were similar. Substantial differences in profile morphology however were found between these soils and the footslope soils. The surface horizons (A and E combined) for the summit and backslope soils at Site 1 were relatively thick (Table 1). Profile morphology indicated that both of these positions were stable even though the backslope soil occurred on an 18% slope. In these woodlands, the tree canopy, surface litter, and root mat appear to have stabilized and protected these slopes from surface erosion. The footslope

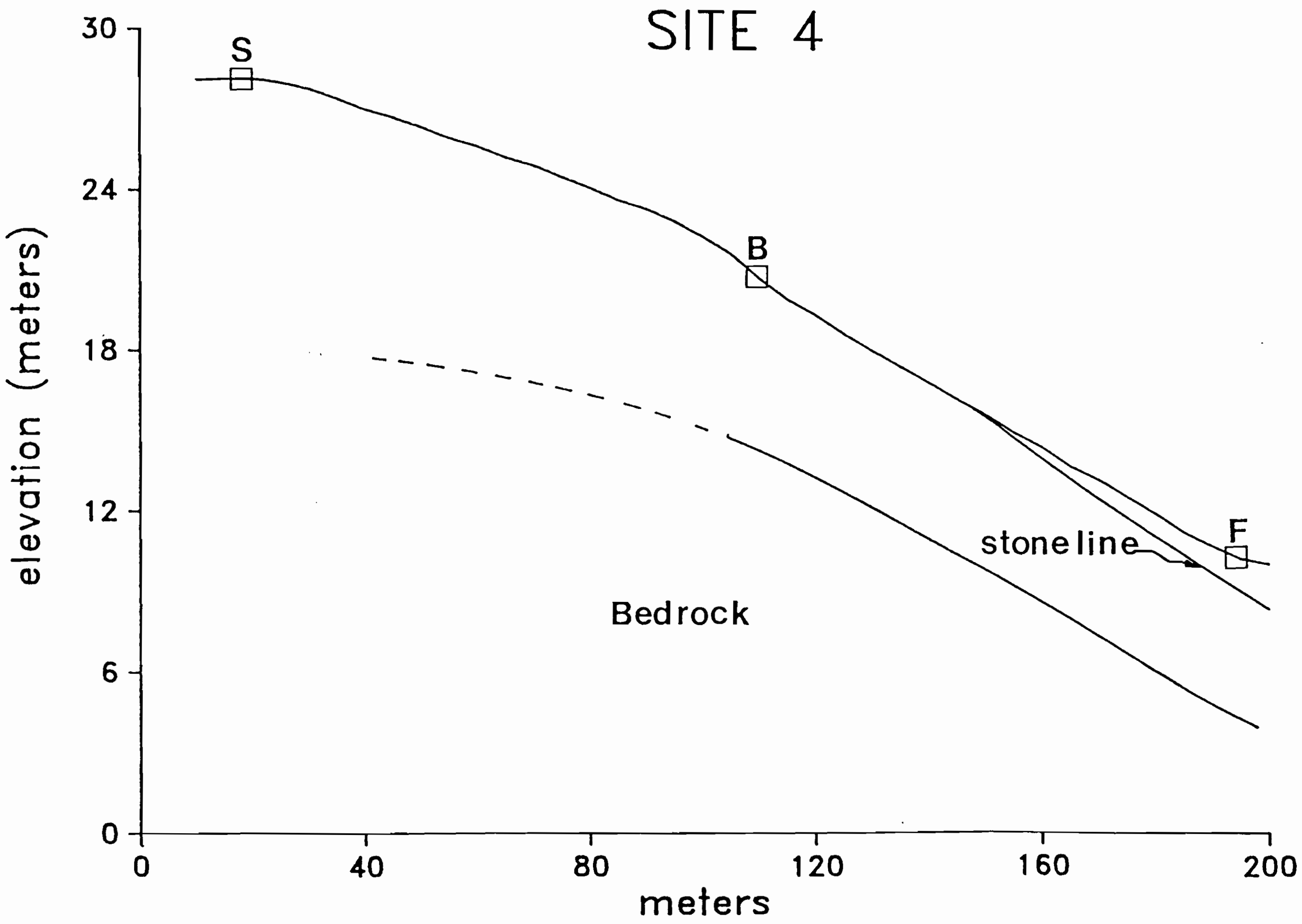

Figure 2. Cross section of Site 4. Vertical exaggeration is 7 times.

Table 1. Abbreviated profile descriptions of summit, backslope, and footslope soils of Site 1.

Abbreviations include: (for structure) Wk=weak, Med=medium, Mod=moderate, Co=coarse, Sl Ma=structureless massive, vf=very fine, f=fine, grn=granular, SBK=subangular blocky; (for texture) C=clay, CL=Clay loam, fSL=fine sandy loam, L=loam, SiL=silt loam, SL=sandy loam, g=gravelly, vg=very gravelly; (for clay films) com=common, cont=continuous, disc=discontinuous.

Horizon	depth	Structure	Texture	Color	Clay Films
			Summit		
A	0-7	Wk vf/f grn	SL	10 YR 3/3	
E	7-16	Wk f grn	fSL	10 YR 5/8	
Bt1	16-31	Mod f SBK	CL	5 YR 5/6	
Bt2	31-48	Mod Med SBK	C	2.5 YR 5/6	many cont
Bt3	48-63	Mod Med SBK	C	2.5 YR 4/6	many cont
Bt4	63-126	Wk Med SBK	SCL	2.5 YR 4/6	few cont
BCt	126-170	Wk Co SBK	fSL	2.5 YR 5/8	few disc
BC1	170-202	Sl Ma	fSL	2.5 YR 5/8 5 YR 6/8 7.5 YR 5/8 10 YR 5/6	few clay flows
BC2	202-245	Sl Ma	fSL	2.5 YR 5/8 5 YR 6/6 10 YR 7/6	few clay flows
C1	245-420	Sl Ma	fSL	2.5 YR 5/8 5 YR 6/6 10 YR 7/6	

Table 1. (cont.)

Horizon	depth	Structure	Texture	Color	Clay Films
				Backslope	
A	0-7	Wk f grn	fSl	10 YR 3/3	
E	7-28	Wk Mod SBK	fSL	7.5 YR 6/8	
Bt1	28-43	Wk Mod SBK	L	2.5 YR 4/8 mottles: 5 YR 5/6	com cont
Bt2	43-70	Mod Med SBK	C	2.5 YR 4/6 mottles: 5 YR 5/6	many cont
Bt3	70-98	Mod Med SBK	C	2.5 YR 4/6	many cont
Bt4	98-130	Mod Co SBK	C	2.5 YR 4/6 mottles: 5 YR 6/8	com cont
BCt	130-150	Wk Co SBK	L	2.5 YR 4/6 mottles: 5 YR 6/6, 10 YR 8/8	few disc
BC1	150-180	Sl Ma	fSL	2.5 YR 4/6, 2.5 YR 6/6, 7.5 YR 3/2	few clay flows
BC2	187-216	Sl Ma	fSL	2.5 YR 4/6, 5 YR 6/8, 7.5 YR 3/2	few clay flows
C1	216-275	Sl Ma	fSL	2.5 YR 4/6, 5 YR 6/8, 7.5 YR 3/2	few clay flows

Table 1. (cont.)

Horizon	depth	Structure	Texture	Color	Clay Films
			Footslope		
A	0-10	Wk f grn	fSL	10 YR 4/3	
AB	10-24	Wk Med SBK	fSL	7.5 YR 4/6	
Bw1	24-45	Wk Mod SBK	fSL	7.5 YR 5/6	
Bw2	45-67	Wk Co SBK	fSL	7.5 YR 5/6	
2Bt	67-100	Mod f SBK	gSCL	10 YR 5/6 mottles: 2.5YR 5/8, 7.5YR 6/3	many disc
2Crt	100-135	Sl Ma	SCL	5 YR 6/8, 2.5 YR 2/1, 2.5 YR 5/8, 7.5 YR 6/8, 7.5 YR 7/2, 10 YR 6/3	com disc

soil lies at the edge of the head of a drainageway. This soil was bisequel. The lower horizons have developed from weathered rock with no saprolite present between soil and rock, and the upper horizons have developed in what appeared to be recent deposition (local alluvium) from upslope. The upper horizons showed weakly expressed soil development in the form of a cambic horizon. A significant erosional event in the recent geologic past may have both removed the upper horizons from the residual soil and deposited the more recent materials. Several hand-dug pits were found near the backslope pedon. Although the age could not be documented, the materials that formed the upper sequence of the footslope soil may have washed down slope from these pits. The material for the A - Bw2 horizons had similar physical and chemical properties to the A horizon of the backslope soil (Table 2). Wang and Arnold (1973) showed that reconstruction techniques could be applied to soils with discontinuities if the initial parent materials of the soil could be recognized. Therefore, for reconstruction of the footslope soil at Site 1, the A horizon material from the backslope soil was used as the parent material for the A - Bw2 horizon, and the parent rock found at the footslope was used as the parent material for the 2Bt and 2Crt horizons. Saprolite was used as the parent material for the summit and backslope soils which are residual in nature.

Table 3 shows selected reconstruction results. The volume factor is a means of estimating the volume of parent material used to form a relative amount of a given horizon (Smeck and Wilding 1980), and is dependent upon bulk density, sand and silt content, and the percent by weight of the stable constituent. The A horizons of these soils have

Table 2. Selected Physical, Chemical, and Elemental Data for the Summit, Backslope, and Footslope of Site 1.

HORIZON	depth	B.D.	Sand	Silt	fSi	Clay	fC	DCB Fe	DCB Al	S Zr	S Ti	S Fe	S K
	--cm--	-g/c	%										
						Summit							
A	0-7	1.05	58.20	27.60	19.90	14.20	5.30	.78	.16	.05	.17	.03	3.19
E	7-16	1.32	59.10	30.50	20.80	10.40	2.50	.79	.18	.05	.20	.11	3.80
Bt1	16-31	1.52	43.90	27.40	18.90	28.70	10.10	1.81	.28	.04	.18	.29	4.10
Bt2	31-48	1.37	30.70	21.10	15.20	48.20	20.70	3.35	.42	.04	.21	.37	3.56
Bt3	48-63	1.28	32.80	15.70	10.50	51.50	24.00	3.60	.42	.03	.22	.86	4.33
Bt4	63-126	1.37	51.30	18.60	9.00	30.10	14.20	2.32	.27	.03	.22	1.00	3.76
BCt	126-170	1.47	59.60	21.40	10.70	19.00	9.20	2.10	.22	.03	.24	.95	4.27
BC1	170-202	1.38	66.70	15.10	6.20	7.90	2.80	1.20	.13	.03	.30	1.88	4.53
BC2	202-245	1.34	74.10	17.90	7.80	8.00	2.60	.92	.09	.02	.26	2.12	4.66
C1	245-420	1.30	76.20	18.30	6.80	5.50	1.50	.84	.08	.02	.24	2.01	4.74
						Backslope							
A	0-7	1.61	56.60	30.50	21.40	12.90	4.30	.64	.21	.11	.30	.40	4.03
E	7-28	1.61	56.40	24.80	22.90	8.80	1.40	.68	.14	.16	.26	.34	4.08
Bt1	28-43	1.62	45.90	29.90	24.00	24.20	8.00	1.33	.20	.09	.20	.14	3.83
Bt2	43-70	1.47	31.50	25.10	18.60	43.40	18.70	3.05	.33	.12	.36	.87	3.81
Bt3	70-98	1.45	24.70	18.90	14.60	56.40	26.70	4.32	.46	.13	.52	1.63	3.53
Bt4	98-130	1.45	36.70	21.60	13.40	41.70	21.00	3.96	.34	.12	.53	2.51	3.71
BCt	130-150	1.39	49.50	20.80	13.90	29.70	13.80	3.04	.26	.11	.64	3.96	4.07
BC1	150-187	1.46	66.00	21.10	7.00	12.90	6.80	1.95	.17	.10	.55	4.01	4.05
BC2	187-216	1.32	66.60	20.90	8.90	12.50	5.30	1.95	.15	.10	.66	4.74	4.15
C1	216-275	1.36	71.00	21.10	8.60	7.90	3.50	1.95	.18	.08	1.11	5.30	3.76
						Footslope							
A	0-10	1.03	53.40	32.00	22.20	14.60	5.00	.76	.22	.09	.25	.30	4.30
AB	10-24	1.43	57.90	32.10	22.40	10.00	2.50	.83	.18	.13	.23	.23	3.94
Bw1	24-45	1.52	54.60	32.50	23.20	12.90	3.30	.93	.18	.14	.27	.43	3.98
Bw2	45-67	1.64	53.70	33.40	23.70	12.90	2.70	1.05	.17	.15	.29	.37	3.98
2Bt	67-100	1.45	52.40	24.10	16.80	23.50	7.20	2.24	.30	.20	.42	.63	3.69
2Crt	100-135	1.65	59.60	17.50	10.70	22.90	8.00	2.90	.34	.19	.66	2.62	4.19
ROCK	135	2.41	.00	.00	.00	.00	.00	.21	.06	.11	.84	6.57	3.83

Table 3. Gains and Losses of Selected Physical, Chemical, and Elemental Constituents for the Summit, Backslope, and Footslope Soils of Site 1.

HORIZON	depth	volume factor	DCB Fe	DCB Al	Ti	Fe	K	Sand	Silt	fSi	Clay	fC
	--cm--		g/100cc									
						Summit						
A	0-7	.51	-1.32	-.04	-.26	-5.00	-7.83	-133	-18	4	1	2
E	7-16	.38	-1.86	-.04	-.35	-6.62	-10.37	-186	-23	4	-5	-2
Bt1	16-31	.55	.75	.24	-.09	-4.02	-6.13	-115	-2	13	31	12
Bt2	31-48	.81	3.23	.45	-.13	-2.54	-4.52	-81	-1	10	57	26
Bt3	48-63	1.43	3.85	.47	-.04	-.94	-1.49	-27	4	7	61	29
Bt4	63-126	.98	2.06	.26	-.06	-1.26	-2.24	-31	1	3	34	17
BCt	126-170	.87	1.83	.20	-.04	-1.26	-1.66	-27	4	6	20	11
BC1	170-202	.91	.46	.07	-.01	-.61	-1.20	-17	-5	-1	3	2
BC2	202-245	.92	.04	.01	-.01	-.06	-.56	-9	-2	1	3	1
C1	245-420	1.00	.00	.00	.00	.00	.00	0	0	0	0	0
						Backslope						
A	0-7	.48	-4.50	-.17	-1.88	-12.90	-4.36	-110	-11	10	-2	-3
E	7-28	.46	-4.67	-.31	-2.14	-13.54	-5.10	-119	-22	11	-9	-8
Bt1	28-43	.64	-2.01	-.06	-1.31	-9.46	-3.12	-77	3	21	22	5
Bt2	43-70	.94	1.65	.22	-.84	-5.63	-2.08	-57	6	15	52	22
Bt3	70-98	1.27	4.18	.47	-.64	-3.66	-1.61	-40	5	12	73	35
Bt4	98-130	1.05	3.22	.26	-.73	-3.72	-1.49	-38	4	8	50	26
BCt	130-150	1.00	1.57	.12	-.69	-2.93	-.97	-28	0	8	31	14
BC1	150-187	.81	-.41	-.05	-.86	-3.11	-.65	-22	-4	-4	6	4
BC2	187-216	.86	-.50	-.09	-.73	-2.33	-.70	-24	-6	-2	4	1
C1	216-275	1.00	.00	.00	.00	.00	.00	0	0	0	0	0
						Footslope						
A	0-10	1.35	.19	.03	.05	.01	.38	3	5	3	3	1
AB	10-24	.82	.21	-.06	-.08	-.18	-.07	-4	-1	-1	-5	-3
Bw1	24-45	.75	.35	-.07	.00	.04	-.40	-11	-1	0	-2	-2
Bw2	45-67	.74	.64	-.08	.09	.15	-.30	-7	3	3	-1	-3
2Bt	67-100	1.19	2.83	.31	-.95	-11.94	-3.94	76	35	24	34	10
2Crt	100-135	1.12	4.34	.43	-.87	-10.56	-3.31	98	29	18	38	13
A-Bw2 pm		1.00	.00	.00	.00	.00	.00	0	0	0	0	0
ROCK	135	1.00	.00	.00	.00	.00	.00	0	0	0	0	0

low bulk density values which can be attributed to high amounts of roots and organic materials in these horizons. These low bulk density values raised the volume factor, and thus increased the calculated gains and reduce the losses. In a similar manner, clay illuviation reduced the amount of silt and sand in the Bt horizons, which raised the volume factor. Therefore, in Bt horizons where maximum illuviation occurs, such as the Bt3 horizons of the summit and backslope soils of Site 1, the gains and losses of the elemental constituents, and sand and silt fractions have been altered slightly from the trends down the profile.

Although the amount of changes that have occurred in the upper four horizons of the footslope soil of Site 1 were minimal, several key points can be inferred from these data. Soil development in the upper portion of the footslope soil was restricted to a cambic horizon. This development can be observed in the slight increase in DCB Fe with depth. More importantly, the other gains and losses can be used as an estimate of the amount of inherent error in the reconstruction procedure. For the elemental parameters 0.4 g/100 cm^3 appears to be the maximum variation from zero which is indicative of the amount of error associated in measuring the gains and losses of the elemental constituents. The DCB extractable Al shows a maximum deviation from zero of .08 g/100 cm^3, which may indicate that the gains in DCB Fe were an actual trend. For the particle size fractions, sand showed the most deviation (± 11 g/100 cm^3), with approximately ± 5 g/100 cm^3 for the silt and clay fractions. Data from the footslope pedon also showed that material from upslope can be used for the parent material in reconstruction analysis for the lower landscape positions which are not entirely residual in nature.

Reconstruction analysis for the 2Bt and 2Crt of the footslope soil showed losses for all of the elemental constituents, and gains for the particle size fractions. The losses of coarse fragments are not shown. The parent material for these two horizons was the rock at the base of the profile. The bulk density of the rock was 2.41 g/cm^3, and apparently slightly weathered. Clay films were recognized in both the 2Bt and 2Crt horizons. Thus the gains in clay were apparently not entirely due to physical weathering of rock to clay size particles. Losses in elemental Fe were greater than the DCB- extractable Fe, which may indicate that Fe is being lost from the system. Because this soil has an argillic horizon over bedrock, these data suggest that for footslope landscape positions, rock weathering and formation of argillic horizons may occur at faster rates than the formation of saprolite.

The gains and losses of the soil constituents for the summit and backslope soils at Site 1 were very similar. The greatest losses occurred in the sand fraction, indicating that weathering of sand particles is probably the major process occurring in these soils. Although these losses were observed in both the summit and backslope soils, noticeably less losses occurred at the surface of the backslope soil. Losses of sand particles decreased with depth indicating that weathering also decreased with depth. Losses of total silt occurred in the A and E horizons, but minimal change in silt content occurred below the E horizons. In the upper horizons, the weathering of sand to silt is probably occurring at a slower rate than that of silt to clay, and losses of silt particles are occurring. Below E horizons however, the weathering of both sand and silt likely occurs at similar rates. The fine silt fraction shows a slightly different trend than the total silt fraction, with gains occurring in the upper Bt horizons, especially in the backslope soil. These gains may be related to differential weathering of this particle size.

The particle size fractions which show the largest gains were clay and fine clay. Maximum gains occurred in the argillic horizon, indicating that illuviation is the second most important soil forming process occurring in these soils. Gains and losses of clay in the A and E horizons were within the acceptable range in error of 0, indicating that a state of equilibrium between clay eluviation and weathering of larger particles to clay and fine clay has been reached in these two horizons.

Although the gains are much smaller, the DCB extractable Fe and Al show similar trends to the clay fractions. The maximum gains in DCB Fe and DCB Al occurred in the same horizon as the maximum gains in clay. These results were expected as DCB Fe is generally found in close association with the clay fractions. Some losses of DCB Fe have occurred in A and E horizons which were not accompanied by losses of clay. These losses may be associated with Fe and Al chelation by organic acids.

The elemental constituents for the summit and backslope soils of Site 1 show decreasing losses with depth which supports the particle size weathering trends. Losses of Fe and Ti were larger and losses of K smaller, in the backslope soil than in the summit soil. These data suggest that the mineral composition of the silt and sand fractions may be slightly different between landscape positions. Thin sections of the parent materials of these soils showed that quartz, feldspar, muscovite and biotite were the primary sand and silt-sized minerals. Biotite is generally Fe rich and has been shown to have some Ti substitutions. Since the backslope had greater Ti and Fe losses the backslope soil may contain slightly more biotite than the summit soil. Although some Fe may be lost from the silt and sand fractions to clay size particles, most is probably released during the oxidation and weathering of biotite. The losses of elemental Fe in the summit and backslope soils were slightly higher than the gains in DCB Fe which may indicate that some of the Fe released from primary minerals is being lost from the soil system.

The gains and losses of the soil constituents at the summit of Site 2 were very similar to those at the summit and backslope of Site 1 and will not be discussed in detail. Stone lines were recognized at the backslope and footslope soils at Site 2 indicating lithologic discontinuities. The backslope soil showed two discontinuities (Table 4). The lower portion of the soil was formed from saprolite, The stone line at the backslope was relatively thick encompassing both the 2Bt5 and 2Bt6 horizons. The argillic horizons above the stoneline were as well developed as those at the summit, indicating that the depositional material these horizons had formed in was relatively old. Thin sections of the Bt4 horizon revealed considerable amounts of mica gneiss fragments, indicating that the parent materials for the A through Bt4 horizons were saprolite or weathered rock. Comparisons between residual

Table 4. Abbreviated profile descriptions of backslope and footslope soils of Site 2.

Abbreviations include: Wk=weak, Med=medium, Mod=moderate, Co=coarse, Sl Ma=structureless massive, f=fine, vf=very fine, grn=granular, SBK=subangular blocky, C=clay, CL=clay loam, fSL=fine sandy loam, L=loam, SiL=silt loam, SL=sandy loam, g=gravelly, vg=very gravelly, com=common, cont=continuous, disc=discontinuous.

Horizon	depth	Structure	Texture	Color	Clay films
			Backslope		
A	0-8	Wk f grn	L	7.5 YR 4/4	
Bt1	8-35	Wk Med SBK	L	5 YR 5/8	com cont
Bt2	35-64	Mod Med SBK	C	2.5 YR 4/6	com cont
Bt3	64-92	Mod Med SBK	C	2.5 YR 4/8	con cont
Bt4	92-120	Mod Med SBK	C	2.5 YR 4/8 mottles: 7.5 YR 5/8	com cont
2Bt5	120-148	Mod Med SBK	vgC	2.5 YR 4/6	com cont;
2Bt6	148-165	Wk Co SBK	CL	2.5 YR 4/6	few cont
3BC1	165-187	Wk Co SBK	SCL	2.5 YR 4/6 mottles: 5 YR 5/8	few cont
3BC2	187-245	Sl Ma	fSL	2.5 YR 4/6, 5 YR 6/8, 7/5 YR 6/8	
3C1	245-320	Sl Ma	fSL	2.5 YR 4/6, 4/8, 7.5 YR 8/4, 10 YR 6/8, 10 YR 5/4	

Table 4. (cont.)

Horizon	depth	Structure	Texture	Color	Clay Films
			Footslope		
A	0-11	Wk f SBK/grn	L	10 YR 3/3	
E	11-25	Wk Med SBK	fSL	10 YR 5/8	
Bt1	25-37	Wk Med SBK	L	7/5 YR 4/6	com cont
Bt2	37-61	Wk Med SBK	L	5 YR 5/8	com cont
2BC	61-79	Wk Med SBK	fSL	5 YR 4/6 mottles: 7/5 YR 4/6	com cont
2C	79-90	Sl Ma	SCL	5 YR 6/6, 7/8, 7.5 YR 5/8, 7.5 YR 4/4, 10 YR 6/6	
2Cr	90-100	Sl Ma	fSL	7.5 YR 5/8, 10 YR 5/8, 10 YR 8/4, 10 YR 2/1	

parent materials of the summit and backslope soils (Tables 2 and 3 of Chapter 2) showed that (with the exception of Zr content) these materials were not significantly different at the .05 level. Therefore the saprolite material for the summit soil was used for the parent material for the A through Bt4 horizons. The 2Bt5 and 2Bt6 horizons were quite different than the the other horizons on this landscape. The 2Bt5 horizon has over 35 percent coarse fragments, mainly angular quartz, and the sand Zr content is nearly 3 times larger than any of the other horizons on the landscape (Table 5). Therefore a good match of parent material, especially for the 2Bt5, horizon was not found. These horizons appear to be an old erosional surface, so the E horizon for the summit was used as the parent material. The saprolite was used as the parent material for the 3BCt and 3BC horizons.

Soil reconstruction results (Table 6) show similar weathering trends and gains and losses of similar magnitude to those observed at the summit and backslope of Site 1. These trends indicate that sand weathering and clay illuviation/eluviation were the most important processes in the formation of these soils. Eluvial horizons were not present in the backslope soil. This pedon was located in an area void of large trees, and was sampled because it was the only area on the backslope that the backhoe could access. This small cleared area may have been a woods road or turn-around where some cultural disturbance had occurred. The present A horizon was possibly part of the upper argillic horizon prior to disturbance. Thus the gains in clay may have been relic additions from illuvition, and the smaller losses of sand relative to the summit soil (data not presented) may be related to

Table 5. Selected Physical, Chemical, and Elemental Data for the Backslope and Footslope of Site 2.

HORIZON	depth	B.D.	Sand	Silt	fSi	Clay	fC	DCB Fe	DCB Al	S Zr	S Ti	S Fe	S K
	--cm--	-g/c	%										
								Backslope					
A	0-8	1.01	42.80	34.90	26.60	22.30	6.70	.48	.11	.46	.89	.43	1.87
Bt1	8-35	1.54	39.40	37.10	29.80	23.50	7.00	1.57	.22	.40	.92	.55	1.98
Bt2	35-64	1.53	28.10	28.40	23.40	42.90	14.70	3.73	.42	.34	.87	.50	1.90
Bt3	64-92	1.37	21.20	20.60	16.80	51.20	25.60	5.03	.51	.29	.96	1.19	2.08
Bt4	92-120	1.44	29.60	20.20	15.90	50.20	20.80	5.40	.43	.27	1.02	1.68	2.13
2Bt5	120-148	1.56	38.30	15.10	10.60	46.60	20.00	4.08	.29	1.21	1.31	1.64	1.69
2Bt6	148-165	1.45	35.70	26.60	17.10	37.70	16.20	3.91	.27	.54	1.22	2.72	2.26
3BCt	165-187	1.46	46.00	29.50	21.40	24.50	9.90	1.98	.12	.15	.92	3.49	3.50
3BC	187-245	1.45	52.80	31.60	19.50	15.60	5.90	1.71	.12	.15	1.04	4.48	2.75
3C1	245-320	1.32	56.10	27.20	15.60	16.70	4.80	1.31	.12	.11	.60	2.49	1.93
A-Bt4 PM		1.25	62.60	32.50	18.60	4.90	3.00	1.79	.15	.18	1.03	5.11	3.74
2Bt PM		1.25	46.70	39.10	31.30	31.30	14.20	1.20	.19	.43	.96	.36	1.33
								Footslope					
A	0-11	1.17	48.10	35.60	24.90	16.30	4.00	1.03	.32	.36	.64	.75	2.91
E	11-25	1.43	53.00	36.00	25.40	11.00	2.10	1.00	.23	.29	.78	1.07	3.06
Bt1	25-37	1.53	46.00	34.40	25.50	19.60	5.70	1.57	.28	.22	.85	1.52	3.44
Bt2	37-61	1.55	47.90	26.20	17.30	25.90	8.40	2.22	.33	.26	.90	3.27	3.48
2BC	61-79	1.46	48.40	27.40	12.90	16.80	5.40	3.17	.41	.25	.84	3.32	5.13
2C	79-90	1.47	56.80	21.00	10.30	22.20	8.40	2.51	.31	.15	.69	5.53	5.05
2Cr	90-100	1.62	68.20	16.20	6.00	15.70	8.40	2.22	.25	.13	.54	5.29	5.24
Rock	100	2.46	.00	.00	.00	.00	.00	.22	.11	.10	.78	4.52	3.16
A-Bt2 PM		1.25	58.20	31.80	22.20	10.00	3.00	.87	.22	.20	1.10	4.88	3.99

Table 6. Gains and Losses of Selected Physical, Chemical, and Elemental Constituents for the Backslope and Footslope Soils of Site 2.

Horizon	depth	volume factor	DCB Fe	DCB Al	Ti	Fe	K	Sand	Silt	fSi	Clay	fC
	--cm--		g/100cc									
						Backslope						
A	0-8	.50	-3.99	-.26	-1.15	-10.04	-7.27	-113	-46	-20	10	-1
Bt1	8-35	.38	-3.54	-.16	-1.37	-13.04	-9.31	-148	-51	-16	20	1
Bt2	35-64	.57	1.75	.31	-.82	-8.45	-6.04	-95	-28	-5	55	16
Bt3	64-92	1.07	4.80	.52	-.29	-3.85	-2.92	-44	-10	1	64	32
Bt4	92-120	.71	4.64	.36	-.68	-5.73	-4.69	-67	-28	-10	64	25
2Bt5	120-148	.43	2.89	-.10	-1.72	-.14	-3.06	-76	-90	-74	32	22
2Bt6	148-165	1.11	4.31	.18	-.15	1.97	.91	-1	-6	-11	39	20
3BCt	165-187	.81	.76	-.02	.15	.27	.52	-24	-1	6	9	7
3BC	187-245	.76	.21	-.03	.28	1.20	-.42	-21	-1	1	-6	0
3C1	245-330	1.00	.00	.00	.00	.00	.00	0	0	0	0	0
						Footslope						
A	0-7	.71	-.32	-.01	.16	-6.37	-3.05	-46	-14	-10	2	-1
E	7-11	.64	-.28	-.10	.41	-5.82	-3.05	-39	-11	-7	-4	-3
Bt1	11-25	.78	1.00	.07	.59	-3.93	-1.63	-23	1	3	14	4
Bt2	25-37	.76	2.02	.15	.46	-2.95	-1.77	-21	-11	-10	24	8
2BC	37-61	.70	3.87	.21	-1.73	-11.74	-6.22	71	40	19	25	8
2C	61-79	.91	3.10	.16	-1.33	-6.36	-3.56	84	31	15	33	12
2Cr	90-100	.84	2.97	.08	-1.49	-5.88	-2.69	110	26	10	25	14
Rock	100	1.00	.00	.00	.00	.00	.00	0	0	0	0	0
A-Bt2 PM		1.00	.00	.00	.00	.00	.00	0	0	0	0	0

surface erosion.

A bisequel soil occurred at the footslope of Site 2. This soil was similar to the footslope pedon at Site 1, except that substantial development in the form of an argillic horizon occurred above the discontinuity. Although the materials for the upper soil had moved from upslope, and were local alluvial or colluvial parent materials, a good match for these materials in the backslope or summit soils was difficult to find. Therefore the parent materials for these horizons were estimated using several assumptions and regression techniques. Parent materials generally contain less clay than the horizons which developed in the materials. The clay content of the E horizon was 11 %, and the clay content of the saprolite at the summit was 5 %, therefore the clay contents of the parent materials were assumed to range between 5 and 10 %. Silt and sand contents were based on the sand:silt ratios of the upper horizons, and adjusted depending on clay content. To estimate the percent DCB Fe and Al, and elemental constituents, regression techniques were employed. DCB extractable Fe and Al vs clay content were found to have a correlation coefficient of .99. These regression lines were used to estimate the DCB extractable Fe and Al contents for the two clay contents. Correlation coefficients were examined for the elemental constituents vs depth. Elemental Fe, K, and Ti in both the silt and sand fractions showed correlation coefficients greater than .89. Using these regression lines the percent Fe, K, and Ti were estimated. The estimates were made at a depth value equal to the middle of the present 2C horizon. The distribution of Zr was shown in the companion paper (Figures 3-5 in Chapter 2) to have a curvalinear, rather than linear, distribution in the surface and near surface horizons. Therefore estimates of Zr content were based on the assumption that Zr accumulates at the surface and decreases with depth, and the Zr contents of the parent materials were set at .02 % less than the lowest Zr content in the upper four horizons (Table 5).

The reconstruction results using 5 % clay indicated that measurable gains of clay occurred in the A and E horizons. In the field these horizons showed obvious eluvial morphology, thus 10 % clay and 3 % fine clay were most likely the best estimate of the clay content of the parent material. These results are presented in Table 6. The reconstruction results for the footslope soil, although not absolutely quantitative, can be used to examine the relative magnitude and direction of the changes in the soil constituents following pedogenesis. Losses of sand were greatest at the surface and decreased with depth. These losses are less than half of those observed for the backslope soil. Clay gains occurred in the argillic horizon, indicating clay illuviation is an important process in these soils. These gains were smaller than those observed at the backslope soil, and suggested, with the support of the sand losses, that the footslope soils are substantially less weathered or developed than the backslope and summit soils. Weathering trends were observed for Fe and K which supports the conclusions that sand and possibly silt particles are weathering. Gains in DCB extractable Fe also occurred in the argillic horizons.

For the residual horizons (2Bt2 to 2Cr), the parent rock was chosen as the parent material. Larger gains in sand content occurred with increasing depth, indicating that continued weathering of sand particles occurred after initial weathering of rock to soil particles. The losses in sand were accompanied by increases in silt-sized material. These gains decreased with depth. Losses of elemental constituents show decreasing losses with depth which supports the previous conclusions that sand particles have weathered after the initial weathering of the rock.

Site 4 occurs in a mature oak woodlands in the Blue Ridge Highlands. The profile morphology of the summit and backslope soils were very similar (Table 7). Although the primary parent materials for these soils were saprolite derived from a gneissic schist, thin zones of a more schistose material occurred within the saprolite. Examination of the uniformity of the parent material with depth showed indications of this variation in parent material (Figure 5 and Table 8 in Chapter 2). To reduce any effects this variation may have on the soil reconstruction results, data for the C horizons sampled in the soil pit were averaged (Table 8). Although sand, silt, and elemental Fe and K show weathering trends with depth, slight variations in silt gains and losses occurred in the lower horizons in both the summit and backslope soils (Table 9). These variations were attributed to stratification in the parent rock. Therefore in these horizons, the gains and losses of soil constituents which show substantial variation from the weathering trend, were assumed to be an inaccurate estimation of soil processes. The weathering trends observed for elemental Ti and fine silt in the summit soil were not evident in the backslope soil. Losses of sand and silt were also less in the backslope soil.

Gains in clay were observed in the surface horizons of the summit

Table 7. Abbreviated profile descriptions of summit, backslope, and footslope soils of Site 4.

Abbreviations include: Wk=weak, Med=medium, Mod=moderate, Co=coarse, Sl Ma=structureless massive, SBK=subangular blocky, grn=granular, vf=very fine, f=fine, C=clay, CL=clay loam, fSL=fine sandy loam, L=loam, SiL=silt loam, SL=sandy loam, SiCL=silty clay loam, g=gravelly, vg=very gravelly, com=common, cont=continuous, disc=discontinuous.

Horizon	depth	Structure	Texture	Color	Clay Films
			Summit		
A	0-7	Wk f grn	SL	10 YR 3/3	
E	7-18	Wk Med SBK/ wk thin platy	SL	10 YR 7/4	
BE	18-28	Wk Med SBK	SiCL	7.5 YR 5/8	few cont
Bt1	28-54	Mod Med SBK	SiCL	5 YR 5/8	many cont
Bt2	54-72	Wk Med SBK	C	2.5 YR 5/6 mottles: 5 YR 7/1, 7.5 YR 7/8	com cont
Bt3	72-96	Wk Med SBK	SL	2.5 YR 5/8 mottles: 5 YR 7/1, 7.5 YR 7/8	com cont
BC	96-114	Wk Med SBK	SiL	2.5 YR 5/8 mottles: N 8/0, & 7/5 YR 7/8	com cont
C1	114-176	Sl Ma	L	2.5 YR 5/8, 5 YR 7/8, N 8/0	few cont
C2	176-265	Sl Ma	L	2.5 YR 5/8, 5 YR 7/8, N 8/0	few cont
C3	265-330	Sl Ma	SiL	2.5 YR 6/6, 5 YR 7/8, N 8/0	few cont

Table 7. (cont.)

Horizon	depth	Structure	Texture	Color	Clay Films
			Backslope		
A	0-9	Wk f grn	SiL	10 YR 3/3	
A2	9-16	Wk f grn	SiL	10 YR 4/6	
Bt1	16-27	Wk Med SBK	SiL	5 YR 5/4	com cont
Bt2	27-48	Mod Med SBK	CL/C	5 YR 5/8	many cont
Bt3	48-63	Mod Med SBK	CL	2.5 YR 5/6 mottles: 10 YR 6/4	many cont
BCt	63-81	Wk Med SBK	L	2.5 YR 5/8, 10 YR 6/4 mottles: 10 YR 2/1, 5 Y 8/1	com cont
BC	81-96	Sl Ma	SL	10 YR 6/4 mottles: N 8/0, 7.5 YR 7/8	few disc
C1	96-144	Sl Ma	L	2.5 YR 5/8, 5 YR 7/8, 10 YR 6/3, 10 YR 2/1, N 8/0	
C2	144-170	Sl Ma	L	2.5 YR 5/8, 5/YR 7/8, 10 YR 6/3, 10 YR 2/1, N 8/0	
C3	170-241	Sl Ma	SL	2.5 YR 5/8, 5 YR 7/8, 10 YR 6/4, 10 YR 2/1, N 8/0	

Table 7. (cont.)

Horizon	depth	Structure	Texture	Color	Clay Films
			Footslope		
A	0-18	Wk Med grn	gSiL	10 YR 4/3	
BA	18-32	Wk Med SBK	gSiL	10 YR 4/3, 7.5 YR 5/6	
Bt1	32-47	Mod Med SBK	gSiL	7.5 YR 5/6	com cont
Bt2	47-73	Mod Med SBK	gL	7.5 YR 5/6 mottles: 10 YR 7/8	many cont
2Bt3	73-105	Wk Med SBK	L	7.5 YR 5/6 mottles: 10 YR 7/8	com cont
2BCt	105-163	Wk Co SBK	L	10 YR 8/3, 10 YR 7/6, 2.5YR 4/6 10 YR 7/1	com cont
2BC	163-192	Sl Ma	L	10 YR 8/3, 10 YR 7/6, 10 YR 7/1, 10 YR 2/1	
2C1	192-285	Sl Ma	SL	10 YR 6/4 mottles: 10 YR 7/1, 10 YR 2/1, 10 YR 8/3	

Table 8. Selected Physical, Chemical, and Elemental Data for Summit, Backslope, and Footslope Soils of Site 4.

HORIZON	depth	B.D.	Sand	Silt	fSi	Clay	fC	DCB Fe	DCB Al	S Zr	S Ti	S Fe	S K
	--cm--	-g/c	%										
Summit													
A	0-7	1.09	23.60	56.10	40.20	20.30	5.80	1.25	.25	.17	1.69	.52	2.21
E	7-18	1.34	24.80	58.40	43.40	16.80	3.60	1.73	.28	.15	1.47	.46	1.96
BE	18-28	1.50	18.50	53.90	42.30	27.60	7.70	2.07	.34	.17	1.69	.93	2.49
Bt1	28-54	1.45	17.00	43.10	33.80	39.90	14.90	3.49	.48	.13	1.30	.89	2.88
Bt2	54-72	1.49	20.00	37.80	28.50	42.20	18.70	4.02	.55	.14	1.16	1.28	3.73
Bt3	72-96	1.48	26.50	50.00	30.80	23.50	11.50	2.97	.35	.07	.94	1.18	3.58
BC	96-114	1.36	30.60	58.30	33.70	11.10	5.00	2.18	.21	.08	1.23	2.01	4.97
C1-C3	114-330	1.37	48.90	48.20	26.90	2.90	.60	2.07	.15	.05	1.01	1.37	3.50
Backslope													
A	0-9	.95	22.30	54.00	40.00	23.70	7.20	1.61	.30	.09	1.55	1.00	3.30
A2	9-16	1.14	19.20	57.20	42.30	23.60	6.30	1.63	.33	.10	1.69	1.17	3.29
Bt1	16-27	1.50	17.80	58.80	45.80	23.40	7.50	2.09	.35	.10	1.68	1.19	3.68
Bt2	27-48	1.47	21.40	40.30	28.90	38.30	17.70	3.36	.49	.08	1.20	1.86	4.26
Bt3	48-63	1.42	33.10	37.70	23.10	29.20	16.80	2.30	.19	.07	1.05	2.68	4.69
BCt	63-81	1.50	46.30	39.60	21.90	14.10	8.30	2.16	.26	.06	1.11	2.80	4.58
BC	81-96	1.45	50.60	43.80	24.20	5.60	2.40	1.76	.19	.05	.81	2.10	4.14
C1-C3	96-241	1.48	51.40	47.20	23.40	1.40	.30	1.26	.13	.04	1.06	3.01	4.33
Footslope													
A	0-18	1.34	23.10	50.60	39.40	26.40	5.80	2.29	.25	.10	2.73	2.53	1.78
AB	18-32	1.49	24.20	53.60	41.10	22.30	5.20	2.34	.28	.15	3.05	2.66	1.77
Bt1	32-47	1.53	21.80	54.20	43.80	24.00	6.70	2.75	.27	.15	2.64	2.77	1.96
Bt2	47-73	1.59	25.20	48.90	38.60	25.90	6.70	3.09	.19	.09	2.11	2.08	2.54
2Bt3	73-105	1.59	30.90	44.70	33.50	24.40	6.90	3.04	.12	.06	1.46	1.19	2.82
2BCt	105-163	1.50	42.50	36.10	24.40	21.40	10.50	3.27	.08	.06	.79	1.65	3.25
2BC	163-192	1.30	34.30	50.90	35.60	14.80	5.50	2.46	.15	.09	1.28	2.31	2.98
2C1	192-285	1.53	48.70	47.90	30.10	3.40	.60	2.14	.17	.05	1.23	2.85	3.13
A-Bt2 PM		1.25	24.30	55.70	43.40	20.00	5.00	2.29	.25	.12	2.64	2.88	2.09

Table 9. Gains and Losses of Selected Physical, Chemical, and Elemental Constituents for the Summit, Backslope, and Footslope of Site 4.

HORIZON	depth	volume factor	DCB Fe	DCB Al	Ti	Fe	K	Sand	Silt	fSi	Clay	fC
	--cm--						g/100cc					
						Summit						
A	0-7	.49	-4.45	-.15	-1.00	-4.38	-6.06	-112	-74	-32	14	5
E	7-18	.41	-4.63	-.13	-1.19	-5.12	-7.15	-131	-84	-32	13	3
BE	18-28	.49	-2.72	.09	-.81	-3.99	-5.39	-110	-55	-12	33	10
Bt1	28-54	.80	1.52	.44	-.44	-1.78	-2.46	-59	-20	3	53	21
Bt2	54-72	.78	2.36	.56	-.61	-1.48	-2.17	-56	-28	-5	58	27
Bt3	72-96	1.14	1.91	.34	-.13	.31	-.10	-19	16	13	31	16
BC	96-114	1.05	.26	.09	.04	.85	.57	-22	16	11	11	6
C1-C3	114-330	1.00	.00	.00	.00	.00	.00	0	0	0	0	0
						Backslope						
A	0-9	1.01	-.32	.09	-.33	-4.85	-3.20	-54	-18	4	20	6
A2	9-16	.85	-.33	.15	-.30	-5.61	-3.69	-67	-17	8	24	7
Bt1	16-27	.69	.43	.25	-.51	-6.58	-4.17	-84	-13	18	32	11
Bt2	27-48	1.14	3.31	.55	-.21	-2.42	-1.50	-35	-2	12	55	26
Bt3	48-63	1.23	1.74	.11	-.23	-1.31	-.36	-15	-3	5	40	23
BCt	63-81	.78	.85	.14	-.47	-2.83	-1.69	-28	-30	-12	19	12
BC	81-96	.92	.52	.07	-.33	-1.65	-.85	-10	-13	-3	6	3
C1-C3	96-241	1.00	.00	.00	.00	.00	.00	0	0	0	0	0
						Footslope						
A	0-18	.88	-.20	-.02	-.26	-.88	-.70	-4	-12	-9	7	1
AB	18-32	.66	-.85	-.06	-.53	-1.12	-1.07	-10	-26	-21	-4	-2
Bt1	32-47	.72	.22	-.02	-.46	-.78	-.63	-9	-14	-9	2	2
Bt2	47-83	1.12	2.36	.02	.25	.72	.94	13	16	13	19	5
2Bt3	73-105	1.30	2.31	-.01	.48	-1.08	.04	-8	14	18	35	10
2BCt	105-163	1.21	2.20	-.10	-.28	-.81	.16	2	-6	-1	28	15
2BC	163-192	.98	-.15	-.07	-.40	-1.82	-1.00	-32	-9	-1	14	6
2C1	192-285	1.00	.00	.00	.00	.00	.00	0	0	0	0	0
A-Bt2 PM		1.00	.00	.00	.00	.00	.00	0	0	0	0	0

and backslope soils. The saprolite of these soils contained more than 45 % silt and over half occurred as fine silt. These data suggest that the fine silt is weathering to clay at a faster rate than clay eluviation. Thus the equilibrium between these two processes may be dependent upon particle size distributions. The backslope soil did not have an eluvial horizon and the clay content of the A1 and A2 horizons were greater than the A horizon at the summit. Therefore it was assumed that the surface horizons of this soil had been removed by erosion. The absence of the most weathered horizons in this profile may explain the differences in losses between the summit and backslope soils, or they may be attributed to less weathering at the backslope landscape position.

The footslope soil at Site 4 is a bisequel soil with a solum thickness nearly twice that of the summit and the backslope soils (Table 7). The upper 73 cm was colluvium that overlies residual soil material and saprolite. Although the colluvial materials have been transported from upslope, a good match for the parent materials of the upper horizons was difficult to find. Therefore the procedures previously discussed for the estimation of the parent material of the footslope soil at Site 2 were used to estimate the original parent materials of these horizons (Table 8). The reconstruction results for the colluvial and residual portions of these soils suggest minimal changes with depth except for the clay fractions (Table 9). The parent materials for the upper horizons were most likely material derived from the surface and upper argillic horizons of a soil that occurred upslope. These materials were substantially weathered prior to deposition, therefore particle weathering should be minimal and clay illuviation the major soil forming process. The gains of clay and DCB Fe in the argillic horizon indicate that eluviation and illuviation were active processes in this soil. These gains are about half as much as the gains of clay that occurred in the argillic horizons of the summit and backslope soils at Site 4.

Mineralogy

The parent rock for the soils at Site 1 was a mica gneiss. The transformation of this rock into saprolite and soil has resulted in a mineral suite consisting of kaolinite, quartz, mica, feldspar, hydroxy-interlayered vermiculite (HIV), chlorite, gibbsite, goethite, hematite and randomly interstratified minerals. Although small amounts of vermiculite may occur in these soils, especially at the surface where bases were cycled or in the C horizons where weathering was less intense, most of the 10-14 A minerals were recognized as HIV. Therefore vermiculite and HIV were reported as HIV, with the understanding that most, and in many cases all of the mineral is in the hydroxy-interlayered form.

Summit and backslope soils of Site 1 had similar silt mineralogy (Table 10). In both soils, silt-sized quartz has accumulated in the surface and upper Bt horizons. As previously discussed in the companion paper, quartz is resistant to weathering and becomes concentrated in the upper horizons where the maximum amount of weathering and eluviation occurs (Drees et al. 1989). Below the Bt3 horizons, the amount of quartz stays relatively constant. Although the differences in feldspar

Table 10: Silt (2-50u) Mineralogy for Site 1.

Horizon	KLN	QTZ	MICA	GIBB	FLD	HIV	INT
				%			
			Summit				
A	17	40	4	-	27	11	1
E	17	34	4	1	24	19	1
Bt1	24	22	10	1	22	20	t
Bt2	26	22	15	1	19	15	t
Bt3	26	18	18	1	16	10	t
Bt4	32	17	20	t	17	13	t
BCt	29	16	23	-	18	10	3
BC1	31	16	27	-	18	8	t
BC2	22	17	30	-	18	12	t
C1	18	16	32	-	21	12	t
			Backslope				
A	7	47	5	t	30	10	t
E	9	47	4	1	28	10	1
Bt1	17	35	8	1	25	13	1
Bt2	25	28	11	t	22	12	1
Bt3	30	21	13	t	19	16	1
Bt4	38	17	15	-	15	15	t
BCt	35	18	18	t	18	10	t
BC1	32	17	23	2	16	10	t
BC2	29	18	28	-	15	10	t
C1	19	16	33	-	20	11	t
			Footslope				
A	8	36	9	t	26	20	t
AB	9	35	9	t	26	20	t
Bw1	13	24	11	t	24	25	2
Bw2	11	25	18	t	19	25	t
2Bt	16	21	25	t	15	20	2
2Crt	31	10	30	t	12	15	1

Abbreviations: KLN=kaolinite, QTZ=quartz, GIBB=gibbsite, FLD=feldspar, HIV=hydroxy interlayer vermiculite, INT=randomly interstratified content between the A and Bt3 horizon are not as extreme as those of quartz, feldspar shows a similar accumulation in the upper horizons. These results indicate that feldspar, although often thought of as a weatherable mineral, may be relatively stable in these soil environments. The secondary minerals that have formed from the weathering of feldspar were most likely kaolinite and gibbsite, since these are generally the end products of feldspar weathering in acid soils (Eswaran and Bin, 1978, Calvert et al. 1980, Huang 1989). Kaolinite was one of the most abundant silt minerals in these soils and traces of gibbsite were found in the surface and argillic horizons. Gibbsite probably occurs as coatings on the silt grains rather than in silt-sized particles.

Mica alteration and weathering occurred with depth. Mica has been reported to weather to vermiculite, HIV, or kaolinite by several authors (Norfleet and Smith 1989, Wysocki et al. 1988, Fanning et al. 1989, Barnhisel and Bertsch 1989). Harris et al. (1980) reported direct alteration of biotite to kaolinite in the Piedmont of Virginia. Both muscovite and biotite were observed in the thin sections of the saprolite of these soils. These micas are apparently weathering to form kaolinite, HIV, or interstratified minerals. Most of the losses of Fe and K observed in the reconstruction analysis of these soils were probably related to mica weathering, especially biotite, which was observed in thin sections of the C horizons.

Except for silt-sized HIV content, the silt mineralogy of the upper four horizons of the footslope soil was very similar to the surface and upper argillic horizons of the backslope soil. These horizons have formed in recently deposited material which likely underwent substantial weathering prior to deposition. As a result, trends in mineral content with depth in the footslope soil were absent. The 2Bt and 2Crt horizons of this soil formed directly from bedrock. The mineralogy of the 2Crt was very similar to the BC horizons in the summit and backslope soils, which may indicate that substantial mineral alteration has occurred during the early stages of bedrock weathering and soil formation.

Similar amounts of clay-sized kaolinite were found in the argillic horizons of the summit and backslope soils (Table 11). The clay-sized kaolinite content of the surface horizons of the backslope soil however was noticeably different than the kaolinite content of the surface horizons of the summit soil. Similar trends were observed for silt-sized kaolinite. Although these differences may not be significant, one explanation for the differences might be that leaching and eluviation are more active in the surface horizons of the backslope soil, which occurs on an 18 percent slope. At this landscape position, water not only moves downward through the profile, but also laterally through the surface horizons, which limits kaolinite formation by removing silica. The highest amounts of gibbsite in all the profiles at Site 1 were found in the surface horizons of the backslope soil, which supports the conclusion that silica has been removed from these horizons. Less kaolinite was also found in the lower solum of the backslope soil than in the same horizons of the summit soil. These differences were slight and may indicate that the lower solum of the backslope is less weathered, or slight differences occur in the content

Table 11. Clay (<2.0u) Mineralogy for Site 1.

Horizon	KLN	QTZ	GOET	GIBB	MICA	FLD	HIV	INT	CHL	HEM	DCB Fe2O3
	%										
				Summit							
A	43	4	-	2	7	3	40	t	t	-	5.5
E	39	6	-	2	6	3	43	t	t	t	4.6
Bt1	48	3	-	4	4	-	42	t	t	1	7.0
Bt2	58	-	t	4	5	-	29	t	t	2	8.4
Bt3	60	-	t	3	4	t	26	-	t	4	8.5
Bt4	60	-	t	4	7	t	25	-	t	2	8.7
BCt	61	-	1	2	6	4	22	-	t	3	10.6
BC1	62	-	2	1	10	1	17	-	t	4	6.7
BC2	59	-	2	1	12	2	19	t	t	4	9.5
C1	58	1	2	t	18	2	15	t	t	4	9.7
				Backslope							
A	28	11	-	4	5	3	45	t	3	-	4.5
E	31	13	-	4	5	5	36	5	3	-	4.9
Bt1	33	8	t	4	5	4	40	3	t	1	5.1
Bt2	47	2	t	3	4	2	34	3	t	2	8.2
Bt3	54	t	2	2	4	-	28	3	t	3	9.6
Bt4	59	t	1	1	5	2	34	t	-	4	11.0
BCt	60	t	1	1	2	-	30	t	-	5	11.3
BC1	58	-	1	1	5	1	28	1	-	4	14.6
BC2	54	-	1	t	15	1	24	t	-	4	13.5
C1	49	-	-	0	20	t	26	t	-	4	22.9
				Footslope							
A	29	9	-	3	4	3	49	t	2	-	5.4
AB	29	10	-	3	5	4	45	2	2	-	7.0
Bw1	38	11	-	1	6	6	34	1	3	-	6.5
Bw2	44	9	-	2	4	5	28	t	6	-	4.8
2Bt	56	5	2	t	7	4	18	t	4	t	8.5
2Crt	57	1	2	t	7	t	30	t	-	t	7.5

Abbreviations: KLN=kaolinite, QTZ=quartz, GOET=goethite, GIBB=gibbsite, FLD=feldspar, HIV=hydroxy interlayer vermiculite, INT=randomly interstratified, CHL=chlorite.

of primary minerals which weather to kaolinite.

Mica contents were relatively low at the surface and did not increase substantially until the BC and C horizons. In acid environments, mica is generally altered or transformed to HIV, secondary chlorite, some interstratified component or kaolinite. After kaolinite, HIV was the most abundant clay-sized mineral in these soils. The highest amounts of HIV occurred in the surface horizons, indicating that HIV and kaolinite were the most important weathering products of mica, and that HIV may be as stable in the surface horizons as kaolinite under the present soil conditions. Hydroxy-interlayered vermiculite is commonly found in the surface horizons of Ultisols which have formed in parent materials containing mica (Barnhisel and Bertsch 1989, Norfleet and Smith 1989). Measurable amounts of secondary chlorite were also found in the surface horizons of the backslope soil. In cases where both secondary chlorite and HIV are found, HIV is generally considered to be an intermediate between mica and secondary chlorite (Barnhisel and Bertsch 1989).

Most of the quartz and feldspar found in the clay fraction of the summit and backslope soil occurred in the surface and upper argillic horizons. As weatherable minerals decrease in the sand and silt fractions, quartz and feldspar grains become more evident. These trends were observed in the silt mineralogy of these two soils. Apparently, after most of the weatherable minerals are removed, only quartz and feldspar are left to undergo physical breakdown to clay-sized material.

The Bt, BC, and C horizons in the summit and backslope soils were primarily red in color (2.5 YR 4/8). Soils which are 5 YR or redder generally receive the red color from hematite (Schwertmann and Taylor 1989). Hematite and geothite were recognized in both the summit and backslope soils. In Table 12 the amount of DCB extractable Fe in the clay fraction is reported as Fe_2O_3. These results indicate that about half of the extractable Fe in these soils is in a crystalline form of hematite or geothite. Although the Fe_2O_3 content of the A and E horizons were between 4.5 and 5.5 %, hematite or geothite were absent from the clay mineralogy. These data suggest that under these conditions more than 5.5 % Fe_2O_3 is necessary in order for hematite or geothite to precipitate in a crystalline form.

Clay mineralogy of the A through Bw2 horizons of the footslope soil was very similar to that of the upper horizons of the backslope soil. Kaolinite and HIV contents were noticeably different between the A and AB horizons and the two Bw horizons. A similar trend was observed for silt-sized quartz, which may indicate parent material stratification. The material in which the Bw horizons have formed may have been deposited in a different event than the material for the A and AB horizons. These horizons are relatively young. If there were two depositional events, the amount of time between them must have been minimal. Clay mineralogy of the 2Bt and 2Crt horizons of the footslope soil was very similar to the summit and backslope Bt and BC horizons. Much of the clay in these horizons occurred as clay films or clay coatings. The high kaolinite content found in these horizons may indicate that the soil that occurred above these horizons prior to truncation was moderately well developed. Although 4 of the 6 horizons at the footslope had greater than 6 % Fe_2O_3, only trace amounts of hematite were found in this soil, and these occurred in the 2Bt and 2Crt horizons. Hematite formation generally occurs in well developed and well drained soils (Schwertmann and Taylor 1989). The footslope soil is much less developed than the summit and backslope soils, and occurs in the wettest area of the landscape which was not a soil environment conducive to the formation of hematite.

The soils found at Site 3 have formed in saprolite derived from an augen gneiss. The profile morphology of these 3 soils are very similar (Table 12) with the surface horizons of the summit and backslope soils were between 30 and 41 cm thick. The silt and clay mineralogy of the soils at Site 3 were similar to the mineralogy of the soils at Site 1, and many of the same weathering mechanisms and transformations were believed to have occurred (Tables 13 and 14). The mineralogy and trends in mineral content for the silt and clay fractions of Site 3 were similar at all three landscape positions. In both the silt and clay fractions, quartz and feldspar has accumulated in the surface horizons and showed decreasing amounts with depth. As previously discussed, quartz is resistant to weathering and becomes concentrated in the upper horizons and feldspar, although often thought of as a weatherable mineral, may be relatively stable in these soil environments. Mica content increased with depth. Kaolinite, HIV, and a randomly interstratified component appeared to have resulted from the weathering and transformation of mica. These secondary soil minerals are generally considered the weathering products of mica in well drained, acid soil environments. In the silt fraction, HIV content varied between horizons, showing no obvious trends with depth. In the clay fraction

Table 12: Abbreviated profile descriptions of summit, backslope, and footslope of Site 3.

Abbreviations include: Wk=weak, Med=medium, Mod=moderate, Co=coarse, Sl Ma=structureless massive, SBK=subangular blocky, vf=very fine, f=fine, grn=granular, C=clay, CL=clay loam, fSL=fine sandy loam, L=loam, SiL=silt loam, SL=sandy loam, g=gravelly, vg=very gravelly, com=common, cont=continuous, disc=discontinuous.

Horizon	depth	Structure	Texture	Color	Clay Films
			Summit		
A	0-18	Mod f grn	SL	10 YR 3/2	
E	18-28	Wk Med SBK	SL	7.5 YR 4/2	
BE	28-45	Wk Med SBK	L	7.5 YR 5/6	
Bt1	45-58	Wk Med SBK	CL	7.5 YR 5/6 mottles: 7.5 YR 5/6, 5 YR 5/6, 2/5 YR 5/6	com cont
Bt2	58-83	Mod Med SBK	CL	5 YR 5/6 mottles: 5 YR 4/6, 5 YR 6/6, 2.5 YR 4/6	many cont
Bt3	83-120	Wk Med SBK	CL	5 YR 5/6 mottles: 10 YR 5/6, 5 YR 6/6, 5 YR 4/6	com cont
BCt	120-150	Wk Co SBK	L	7.5 YR 5/6, 7.5 YR 4/6, 7.5 YR 6/8, 10 YR 6/4, 10 YR 4/6, N 2/0 & N 8/0	few cont
C1	150-205	Sl Ma	SL	7.5 YR 5/6, 7.5 YR 4/6, 7.5 YR 6/8, 10 YR 6/4, 10 YR 4/6, N 2/0 & N 8/0	few disc

Table 12. (cont.)

Horizon	depth	Structure	Texture	Color	Clay Films
			Backslope		
A	0-18	Mod f grn	SL	10 YR 3/4	
E	18-41	Wk Med SBK	SL	10 YR 5/4, 10 YR 4/4	
EB	41-58	Wk Med SBK	SCL	7.5 YR 4/4, 10 YR 3/4, 7.5 YR 5/4 mottles: 2.5 YR 5/8	
Bt1	58-75	Mod Med SBK	CL	5 YR 5/8 mottles: 2.5 YR 6/8, 2.5 YR 4/8, 7.5 YR 5/8	com cont
Bt2	75-106	Mod Med SBK	CL	5 YR 5/8 mottles: 2.5 YR 6/8, 2.5 YR 4/8, 7.5 YR 5/4	many cont
Bt3	106-128	Wk Med SBK	SCL	5 YR 5/8 mottles: 2.5 YR 5/8, 2.5 YR 6/8 & 6/6, 7/5 YR 5/8	com cont
BC	128-150	Wk Co SBK	SL/SCL	5 YR 5/8 mottles: 2.5 YR 5/8, 5 YR 6/2	com cont
C1	150-200	Sl Ma	SL	5 YR 5/4, 2.5 YR 6/4, 2.5 YR 5/4, 10 YR 6/2, 10 YR 8/2, 10 YR 6/8	few cont

Table 12. (cont.)

Horizon	depth	Structure	Texture	Color	Clay Films
			Footslope		
A	0-18	Wk f SBK/grn	SL	10 YR 3/4	
E	18-30	Wk Med SBK	SL	10 YR 5/6	
BE	30-44	Wk Med SBK	L	10 YR 5/8	
2Bt1	44-75	Mod Med SBK	CL	5 YR 5/8 mottles: 7.5YR 5/8 2.5 YR 5/8, 10 YR 3/1	many cont
2Bt2	75-114	Wk Co SBK	SCL	5 YR 5/8 mottles: 2.5YR 4/8 7.5 YR 6/8, 2.5 YR 4/8	com cont
2BC	114-145	Wk Co SBK	SL	10 YR 6/8 mottles: 7.5YR 4/6 2.5 YR 5/6	com cont
2C1	145-190	Sl Ma	SL	10 YR 6/4, 10 YR 7/8, 10 YR 2/1, 5 YR 5/8, 5 YR 8/1	

Table 13: Silt (2-50u) Mineralogy for Site 3.

Horizon	KLN	QTZ	MICA	FLD	HIV	INT
			%			
			Summit			
A	5	45	8	29	10	3
E	5	38	5	32	17	3
BE	4	40	5	32	17	2
Bt1	8	33	12	25	16	3
Bt2	11	25	12	25	24	3
Bt3	12	23	14	25	20	6
BCt	13	22	25	20	18	2
C1	10	20	30	20	18	2
			Backslope			
A	4	45	8	32	10	t
E	4	42	5	25	22	2
BE	8	40	6	24	19	3
Bt1	10	40	7	24	18	1
Bt2	11	35	10	23	21	t
Bt3	17	28	9	24	21	1
BC	19	20	15	21	24	1
C1	20	14	20	23	20	3
			Footslope			
A	4	41	5	35	14	t
E	3	40	6	32	17	2
BE	7	34	10	29	19	1
2Bt1	15	27	6	27	23	2
2Bt2	10	21	9	28	30	2
2BC	7	16	17	25	28	2
2C1	8	15	25	21	30	1

Abbreviations: KLN=kaolinite, QTZ=quartz, FLD=feldspar,
HIV=hydroxy interlayer vermiculite,
INT=randomly interstratified.

Table 14. Clay (<2.0) Mineralogy for Site 3.

Horizon	KLN	QTZ	GIBB	MICA	FLD	HIV	CHL	INT	DCB FeOOH
	%								
				Summit					
A	20	5	-	5	5	55	10	-	.8
E	19	5	-	6	5	55	10	-	.8
BE	29	5	t	5	5	45	10	-	1.7
Bt1	43	2	t	8	5	40	t	-	3.4
Bt2	48	1	t	10	4	36	t	-	4.8
Bt3	52	t	-	10	3	34	t	-	1.4
BCt	39	t	-	35	t	26	-	-	.7
C1	30	t	-	45	t	26	-	-	1.0
				Backslope					
A	21	6	t	4	7	51	10	-	.8
E	15	6	t	4	7	57	10	-	2.2
BE	44	5	-	7	5	34	5	-	1.6
Bt1	42	5	-	7	5	40	t	-	3.0
Bt2	43	3	-	7	3	43	t	-	2.5
Bt3	54	2	-	7	2	34	t	-	2.4
BC	45	1	-	7	t	46	-	-	.9
C1	50	2	-	16	5	26	-	12	.7
				Footslope					
A	24	7	-	5	5	50	9	t	.6
E	23	7	-	5	6	49	10	t	.8
BE	35	9	-	7	6	32	11	t	1.4
2Bt1	45	5	-	9	4	35	2	t	2.2
2Bt2	47	5	-	10	2	35	t	t	2.4
2BC	35	3	-	20	t	41	t	-	1.9
2C1	25	3	-	35	1	35	t	-	.3
2C2	21	3	-	50	1	25	t	-	.6

Abbreviations: KLN=kaolinite, QTZ=quartz, GIBB=gibbsite, FLD=feldspar, HIV=hydroxy interlayer vermiculite, CHL=chlorite, INT=randomly interstratified.

however, HIV content was highest in the surface and decreased with depth. These trends are often found in acid soils where mica occurs as a primary mineral (Norfleet and Smith 1989, Barnhisel and Bertsch 1989). Significant amounts of secondary chlorite were also found in the clay fractions of the surface horizons. Gibbsite however was only found in trace amounts even though considerable amounts of Al were present in the soil system, as indicated by high amounts of Al-interlayered minerals.

Soil-Landscape Relationships

Field descriptions from the reconnaissance efforts and profile descriptions of the representative study pedons indicated that summit and backslope soils had very similar profile morphology. Although backslopes are most often thought of as an erosional landscape position, the backslope soils that occurred in mature woodlands, with slopes of up to 18%, were found to be as stable as those soils occurring on the summit. Some evidence of erosion was observed in two of the backslope soils, but these effects were probably related to cultural practices. Two of the four backslope soils studied had lithologic discontinuities with substantial material present above stone lines. These data suggest that backslopes can also occur as depositional landscape positions.

Footslope soils generally had different morphology than soils occurring on the backslope and summit. All of the footslope soils examined were bisequel, and the upper soil material was composed of colluvial sediments that were transported downslope. The footslope soils also showed less profile development than the associated summit and backslope soils. These differences in profile development were substantial in the Piedmont. The clay distributions of the summit and the backslope soils at Site 1 were very similar (Figure 3). The maximum clay content was between 55 and 60 % and the slope of the lines toward and away from the clay maximum were nearly identical. The clay distribution of the footslope soil however, showed evidence of a bisequel soil, with a lower clay content than the summit and backslope soils. Differences in morphology and profile development were also observed between the footslope soils of the Blue Ridge Highlands and the associated summit and backslope soils. These differences were not as evident as those in the Piedmont (Figure 4). The maximum clay content of the footslope soil was only slightly less than that of the summit and backslope soils.

Transects were made across each of the toposequences, and auger descriptions were made at intervals between the study pedons. These auger descriptions indicated that differences in morphology were not apparent between landscape positions until the concave portion of the lower landscape was reached (Figures 1 and 2). These results suggest that differences in morphology between summit and backslope soils developed in gneissic or schistose materials, can be related to man-induced erosion or differences in parent materials, rather than landscape position.

Reconstruction analysis indicated that the sand fraction showed the largest losses of the soil constituents, and therefore sand weathering was the major soil forming process occurring in these soils. The

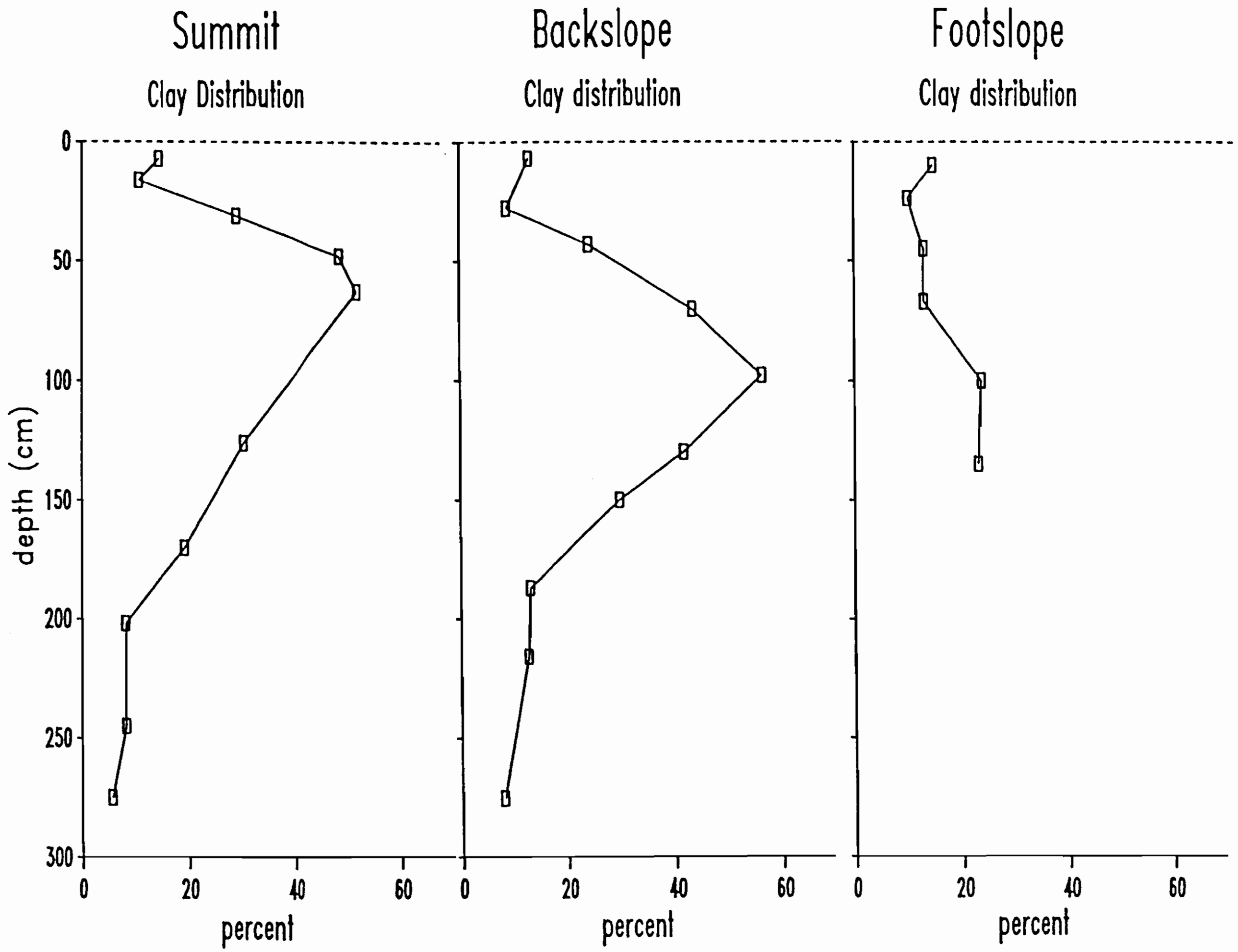

Figure 3. Clay Distribution of the Summit, Backslope, and Footslope Soils at Site 1.

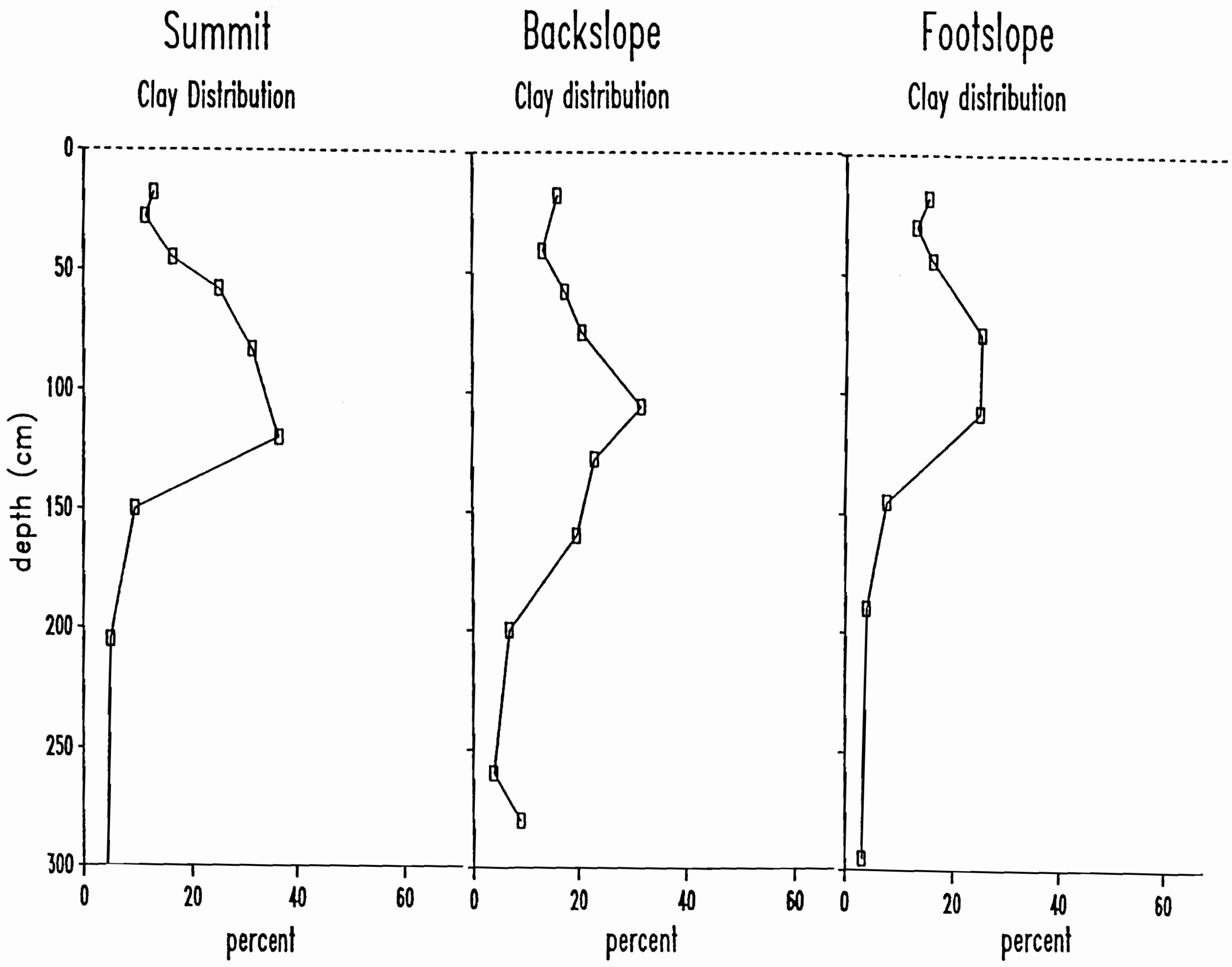

Figure 4. Clay Distribution of the Summit, Backslope, and Footslope Soils at Site 3.

largest losses of sand occurred in the surface horizons, with losses decreasing with depth. The summit soils showed slightly more losses of sand than the associated backslope soils. The significance of these differences is questionable. These data may suggest that the backslope soils are slightly less weathered than the summit soils. Two of the backslope soils studied however, showed evidence of man induced erosion due to cultural practices which would reduce the amount of losses at the soil surface. Losses of sand within the footslope soils were less than those in the summit and backslope soils. Sand weathering appeared to be the major soil forming process of footslope soils formed from weathered rock or saprolite. Parent materials that were deposited as local alluvium or colluvium, and derived from the surface or upper argillic horizons, were substantially weathered prior to deposition. The horizons of the footslope soils which have formed in these materials, showed minimal losses of sand.

Clay and fine clay were the soil constituents that showed the largest gains. These gains occurred in the argillic horizons as a result of clay illuviation. After sand weathering, clay illuviation was the most important soil forming process at each landscape position. Gains in clay were essentially the same at both the summit and backslope soils. Gains in clay in the Bt horizons of the footslope soils however, were about one half as much as those occurring within the argillic horizons of the summit and backslope soils. These reconstruction results support the conclusions that the summit and backslope soils are very similar. Soil forming processes in these soils, and the present rates at which these processes occur, are essentially the same.

Footslope soils are less developed and the rates of soil forming processes are dependent upon the type of parent material. Both depositional and pedogenic processes control the development of the soils that occur at the footslope landscape position.

Differences in silt and clay mineralogy between the summit and the backslope soils were minimal. The surface horizons of the backslope soil at Site 1 in the Piedmont contained noticeably less silt and clay-sized kaolinite, than the surface horizons of the summit soil. More clay-sized gibbsite was also present in the surface horizons of the backslope soil, indicating that losses of silica may be occurring in these horizons through lateral flow. Significant amounts of hematite occurred in the argillic horizons and lower solum of the summit and backslope soils at Site 1 in the Piedmont, but was only found in trace amounts in the associated footslope soil, indicating that the soil at the footslope was less developed. In the upper horizons of this footslope soil, evidence of stratification was observed in the mineralogy. Therefore depositional processes have apparently influenced the mineralogy of this soil, more than weathering or pedogenic process. In the Blue Ridge Highlands the only difference in mineralogy between the landscape positions was that slightly less kaolinite occurred in the footslope soil than in the associated summit and backslope soils.

Conclusions

In this study soil morphology, reconstruction techniques, and silt and clay mineralogy were employed to examine the relationships between landscape position and soil genesis. Profile morphology indicated that the summit and the backslope soils in both the Piedmont and Blue Ridge Highlands regions of Virginia were very similar. Most studies have indicated that the backslope soils are unstable and therefore are less developed than associated summit soils. This study however showed that, although slopes at the backslope were as steep as 18%, backslope soils in woodlands were found to be as stable as those found at the summits.

All of the footslope soils examined were bisequel and had less expressed argillic horizons than the summit or backslope soils. These differences in profile development were substantial in the Piedmont and considerably less in the Blue Ridge Highlands. Transects were made across each of the toposequences. The profile descriptions from these transects indicated that differences in morphology were not apparent between landscape positions until the concave portion of the lower landscape was reached. Therefore it was concluded that when differences in morphology are observed between summit and backslope soils developed in gneissic or schistose materials, these differences can be related to man-induced erosion or differences in parent materials.

Reconstruction techniques were found to effectively quantify the gains and losses of the soil constituents at each landscape position. These techniques are often thought to be restricted in use to only soils with a single uniform parent material. This study however, showed that reconstruction analysis can be applied to bisequel soils, and soil material from upslope can often be used as the parent material for backslope and footslope soils where discontinuities occur. Thin sections, elemental analysis, and regression techniques were found to aid in the determination of the state of the parent materials in bisequel soils.

Reconstruction results indicated that summit and backslope soils have undergone the same soil forming processes, and these processes were occurring at the same rates. Both depositional and pedologic processes were found to contribute to the soil formation at the footslope position. Weathering of sand particles to smaller particles was the major soil forming process occurring in the summit and backslope soils. This process was also found to be important in the footslope soils if weatherable minerals occurred in the parent materials. Substantial gains in clay indicated that illuviation/eluviation was the second most important soil forming process, although clay movement was more pronounced in the summit and backslope soils than in the footslope soils. In the surface horizons of the Piedmont soils formed from mica gneiss, weathering of larger particles to clay size material was found to be in equilibrium with clay eluviation. Similar results were not observed in the more schistose materials examined in the Blue Ridge Highlands. It was concluded that in the silty schistose material, the weathering of silt to clay occurs at a faster rate than clay eluviation. In all of the soils, losses of elemental Fe, K, and Ti were found to coincide with the weathering of silt and sand particles. Losses and gains of DCB extractable Fe and Al were generally associated with gains and losses of clay-sized material.

Similar mineral suites of kaolinite, quartz, mica, feldspar, hydroxy-interlayered vermiculite (HIV), chlorite, gibbsite, and randomly interstratified minerals were found in the soils of the Piedmont and Blue Ridge Highlands. Differences in mineralogy were found to be minimal between landscape positions. In the Piedmont at Site 1 significant amounts of hematite were found in the summit and backslope soils, but only traces could be found in the footslope soil. Trends in mineralogy supported the conclusion that the summit and backslope soils were better developed than the footslope soils. The kaolinite content of the surface horizons of the backslope soils of the Piedmont was noticeably lower than the kaolinite content of the surface horizons of the summit soil, which may indicate that leaching and eluviation are more active in the surface horizons of the backslope soils. At the backslope water not only moves downward through the profile, but also laterally through the surface horizons. This may limit kaolinite formation by removing silica. The highest amounts of gibbsite in all the profiles examined occurred in the surface horizons of the backslope soils, which supports the conclusion that Si has been removed from these horizons. The weathering products of mica in these soils were HIV, kaolinite, and secondary chlorite. In the Piedmont, feldspar had apparently weathered to gibbsite and kaolinite, but in the Blue Ridge Highlands only trace amounts of gibbsite were observed.

CHAPTER 4

Bucket Auger Modification for Obtaining Undisturbed Samples of Deep Saprolite

Abstract

A simple modification of a standard bucket auger and an associated sampling system provide an efficient and inexpensive means of obtaining undisturbed samples of deep saprolite. Samples can be used for determination of bulk density, water holding capacity, and coefficient of linear extensibility (COLE), or examination of macro or micro-morphology. Bulk density values determined for B and C horizons with a modified bucket auger (values ranging from 1.32 to 1.68 g/cm^3) were comparable to those obtained by either clod or double cylinder methods.

Introduction

Saprolite has been defined as thoroughly decomposed rock in which the texture and structure of the original rock is preserved (Becker 1895), or a soft, friable, isovolumetrically weathered bedrock that retains fabric and structure of the parent rock (Pavich 1986). Saprolite is formed through the dissolution and chemical alteration of crystalline rocks. This soil parent material has a widespread occurrence throughout the U.S. and in other regions of the world where crystalline rocks occur near the earth's surface. The largest area of soils formed from saprolite in the U.S. occurs in the eastern Piedmont. Overstreet et al. (1968) estimated that 95 percent of the Piedmont is overlain by saprolite. Although the occurrence of saprolite is widespread, and an understanding of saprolite genesis, weathering, and morphology are of considerable importance, very little research has focused on saprolite characterization.

To thoroughly study saprolite, undisturbed samples must be obtained for the determination of bulk density, water holding capacity, and coefficient of linear extensibility (COLE), and examination of macro and micro-morphology. In some instances undisturbed samples can be taken from the walls of soil pits. These pits rarely exceed 2 meters in depth, and saprolite is generally overlain by a meter or two of soil, and commonly more than 10 meters thick. Therefore, obtaining undisturbed samples of saprolite has been restricted to areas such as road cuts and high walls in land fills, or involved expensive and cumbersome equipment such as truck or trailer mounted drill rigs. Drill rigs can not be safely operated on slopes greater than 15%, and many areas such as woodlands or sampling sites of significant distance from roadways are inaccessible to trucks. In addition, most tools capable of taking undisturbed samples of deep saprolite, even those which are manually operated, are sufficiently expensive to preclude widespread availability for field use. The objective of this paper is to describe a simple and inexpensive system for taking undisturbed samples of deep saprolite using a modified bucket auger and associated sampling system.

Auger Modification

A used 7 cm (outside diameter) bucket auger is modified with a hacksaw and file. The hacksaw is used to cut the teeth from the auger bucket (about 2 cm back from the weld). Following the cutting, a file is used to sharpen and taper the bucket portion of the auger from outside to inside to facilitate cutting during saprolite sampling (Fig. 1). The inside of the bucket should be filed or sanded so that it is smooth and free of burrs.

Sampling System and Auger Usage

Samples are best obtained from two adjacent auger holes. One of the auger holes is used for bulk sampling and profile description and the other for sampling with the modified bucket auger. The following is a stepwise procedure for obtaining undisturbed samples with a modified bucket auger.

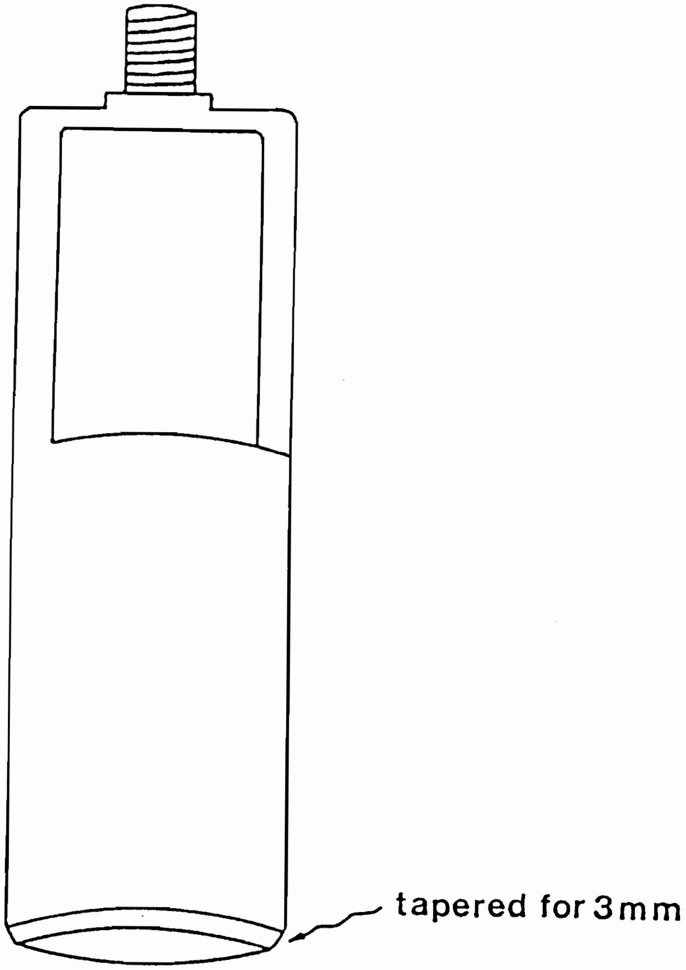

Figure 1. Diagram of a modified bucket auger for obtaining undisturbed samples from deep saprolite.

Begin by sampling and describing the soil from one of the auger holes bored with a standard bucket auger. When a horizon is reached in which undisturbed samples are needed, the second auger hole should be bored and soil removed to the top of the horizon. Remove the standard cutting bucket from the auger extension and attach the modified bucket. Coat the inside of the bucket with a thin film of vegetable oil from an aerosol can, and the outside with a thin film of petroleum jelly. Push the modified bucket auger into the hole until firmly against the top of the horizon to be sampled. Replace the auger handle with an old handle, and drive the modified bucket into the saprolite with a sledge hammer. A 2 x 3 x 5 cm piece of steel can be welded onto the old auger handle to receive the sledge hammer blows. The modified bucket should penetrate enough to obtain a sample at least 3 cm in length. Three blows are usually sufficient to obtain a 3-9 cm sample. More than 5 blows tends to disturb some samples causing parting along rock structure. Remove the modified bucket auger from the hole and detach the bucket from the auger extension. Insert a wooden spacer (2 cm thick, 6.5 cm in diameter) in the bottom of the modified bucket, and place it over the handle of the upright sledge hammer. Push the modified bucket slowly over the sledge hammer handle until approximately 0.5 cm of sample is exposed. With a sharp knife trim the sample flush with the cutting edge of the modified bucket. In a slow smooth motion push the modified bucket over the sledge hammer handle until the entire core is exposed and can be removed. How the sample is treated following removal depends on the required analyses.

Bulk density at field moisture content can be easily determined by trimming the opposite end of the sample flat to form a cylinder. Measure and record the length of the cylindrical sample and wrap it in aluminum foil for transport to the lab. Determine the oven dry weight of the sample and divide the value by the sample volume to determine bulk density (g/cm^3) where:

$$\text{volume} = \pi r^2 h,$$

and $\pi = 3.14$, r = 1/2 inside diameter of the modified bucket, and h = the length of the sample.

Bulk density values at differing moisture contents, water holding capacity at different water retention pressures, and COLE values can be determined by wrapping the sample in a hair net, dipping the sample in saran resin, and following the procedures of Brasher et al. (1966) or Grossman et al. (1968), respectively.

If the macro or micro-morphology of the sample is to be examined, the orientation of the sample should be noted and the sample wrapped in foil for transport to the lab.

Discussion

The modified bucket auger system has several advantages over other methods for obtaining undisturbed samples at depths below 2 meters. Undisturbed samples taken below 2 meters are most often taken with a truck mounted drill rig. These drill rigs and the vehicle used to transport them are expensive and very restricted in their usage. Because of their size, drill rigs are inaccessible to areas with rough terrain, areas away from an access road, wet areas, woodlands, and sites with slopes greater than 15 percent. Drill rigs offer an excellent method for quickly obtaining a sample from a given depth, but for continuous sampling they are slow and labor-intensive. All of the auger flights must be disassembled with each sample, thus making the task very time consuming. Two people (the same number needed to operate a drill rig) using the modified auger system were able to take undisturbed samples of saprolite to depths of over 11 meters in half of the time required for sampling the same area with a truck-mounted drill rig.

The double cylinder sampler is the only other manually operated system that we are aware of that can be used for taking undisturbed samples. The double cylinder method is most often used for bulk density sampling and offers no means of taking bulk samples for routine analysis. The extensions for a bucket auger do not fit a double cylinder sampler. Therefore extensions would be needed for both a bucket auger and the bulk density sampler. Samples taken with a double cylinder are small (4.6 cm in diameter and 2.6 cm in length) in comparison to those taken with a modified bucket auger (6.7 cm in diameter and 3 to 9 cm in length). The larger modified bucket samples can be used for morphological examination. Examination of modified bucket auger samples with a binocular microscope showed no detrimental effects to structure, orientation, or primary fabric of the saprolite material. Therefore, it appears that samples taken by this method can also be used for micromorphological purposes.

Several methods are currently used for bulk density measurements. The most common are the clod (Brasher et al. 1966) and the double cylinder (Blake 1965) methods. These two methods were compared with bulk density values determined at field moisture content for samples obtained using the modified bucket auger. To compare these methods over a range of bulk density values, samples were obtained from the A, Bt2, Bt3, and BC horizons of a soil formed in coarse fragment-free alluvial sediments, and three C horizons developed from an augen gneiss. Three samples were taken from each horizon to determine the mean bulk density (Table 1). With the exception of the A horizon, all of the modified bucket auger bulk density measurements were within .03 g/cm^3 of either the clod or double cylinder values, and in most cases were between the values determined by the other methods. The clod method showed the least amount of variability, and except for the A and C2 horizons, the modified bucket auger showed less variability than the double cylinder method. These data suggest that the modified bucket auger method may be more precise for determining bulk density than the double cylinder method. In addition, because the samples from the modified bucket auger are larger, the determined bulk density values may be more representative than those determined by the double cylinder.

The modified bucket auger system has been used to efficiently obtain undisturbed saprolite samples suitable for bulk density, moisture retention, and COLE measurements, and macro and micro-morphological examination to a depth of over 11 meters. This system offers several advantages over conventional methods and provides a simple, efficient, and inexpensive means of sampling saprolite and other low coarse fragment materials such as aeloian, fluvial, or marine sediments.

Table 1. Mean bulk density ($\overline{x}$ B.D.) and standard deviation (S.D.) values at field moisture content determined by the clod, double cylinder, and modified bucket auger methods. The A, Bt2, Bt3, and BC horizons were sampled from a soil developed in coarse fragment-free alluvium, the C horizons were from saprolite developed from an augen gneiss.

	clod		double cylinder		modified bucket	
horizon	$\overline{x}$ B.D.* g/cm^3	S.D.	$\overline{x}$ B.D. g/cm^3	S.D.	$\overline{x}$ B.D. g/cm^3	S.D.
A	.96	.026	.94	.066	.82	.127
Bt2	1.60	.006	1.53	.042	1.59	.015
Bt3	1.60	.023	1.61	.081	1.61	.020
BC	1.67	.046	1.58	.025	1.60	.025
C1	1.40	.029	1.33	.047	1.37	.035
C2	1.52	.020	1.40	.031	1.37	.101
C3	1.48	.055	1.32	.090	1.50	.060

* n = 3

Chapter 5

Characterization and Genesis of Saprolite Derived from Gneissic Rocks in the Piedmont and Blue Ridge Highlands of Virginia

Abstract

Saprolite is the most prevalent parent material of soils occurring in the Piedmont and Blue Ridge Highlands regions of Virginia. Soil-saprolite-landscape associations were examined in these regions in order to describe and characterize saprolite formed from gneissic rocks, and to determine the relationships between soils, landscape position, and saprolite genesis. Three representative landscape associations were chosen as study sites, and the soil and saprolite were examined at the summit, backslope, and footslope positions of each. Thickness of saprolite was found to decrease from the summit to the footslope. Greater amounts of saprolite at the summit were apparently related to the relative stability of the summit position compared to the backslope and footslopes. Reconstruction results indicated that between 20 and 36 % of the mass of the partially weathered rock, which is the precursor of saprolite, is lost during the formation of saprolite. From 73 to 82 % of these losses occurred as Al

or Si. Initial soil formation was shown to occur at a faster rate than saprolite formation, but after substantial profile development, the rate of soil formation is reduced to a rate below that of saprolite formation, and saprolite begins to accumulate below the solum.

Introduction

In the Piedmont, crystalline rocks of all types have been altered to saprolite by chemical weathering (Overstreet et al. 1968). It has been estimated that 95 percent of the Inner Piedmont belt is overlain by saprolite (Overstreet et al. 1968); the exception being the major stream valleys of the region (Fisher 1970; Overstreet et al. 1968). Thus saprolite is arguably the most prevalent soil parent material in the Piedmont.

By definition, saprolite is thoroughly decomposed rock in which the texture and structure of the original rock is preserved (Becker, 1895), or a soft, friable, isovolumetrically weathered bedrock that retains fabric and structure of the parent rock (Pavich, 1986). Cleaves (1974) divided saprolite into two types: massive and structured. Massive saprolite shows no rock structure in the field, and is the transition between soil and structured saprolite. Pavich (1986) divided the regolith into soil, massive and structured saprolite, and weathered rock.

Chemical weathering of rock to saprolite is an isovolumetric process that results in a porous medium that has the lowest bulk density within the regolith (Pavich, 1985, 1986; Overstreet et al. 1968; Costa and Cleaves, 1984; Calvert et al. 1980). Reports of the amount of mass lost during saprolite formation include 75 % for a granite in the Piedmont of Virginia (Pavich 1986), 40-60 % for mafic rocks in the Maryland Piedmont (Cleaves 1974), and 20-50 % for schistose material in the Piedmont of Maryland (Costa and Cleaves 1984).

Cleaves et al. (1970), studied the physical and chemical processes in a closed basin system and reported that chemical solution of material by ground water (saprolite formation) resulted in as much as 5 times as much mass lost as through mechanical erosion. Primary compounds lost during the formation of saprolite are CaO, Na_2O, SiO_2, MgO, FeO, or Al_2O_3 (Pavich 1985, 1986, Cleaves 1974, Costa and Cleaves 1984, Calvert et al. 1980).

Two steps occur during the formation of saprolite. The initial step is the transformation of easily altered minerals in the rock into secondary forms, resulting in weathered rock. This is followed by oxidation of Fe, subsequent lowering of the pH, and continued leaching of bases and desilication (Pavich 1985, 1986, Cleaves 1974, Costa and Cleaves 1984, Calvert et al. 1980). Pavich (1985, 1986) and Calvert et al. (1980) report the greatest rates of weathering occur in the lower portion of saprolite and weathered rock.

Saprolite on the Piedmont can be totally absent in eroding landscapes or can be over 63 meters thick as reported in North Carolina (Overstreet et al. 1968). Saprolite thickness is dependent upon several factors. Costa and Cleaves (1984) found that rocks of differing mineralogy and particle size distributions, on similar landscapes, were overlain by different thicknesses of saprolite. In general, rocks of greater metamorphism showed greater overburdens of saprolite. Backslopes were found to contain little or no saprolite due to mass wasting. Costa and Cleaves (1984) found that ephemeral and first order streams flowed over saprolite, while second order or greater streams flowed on bedrock. These researchers concluded that landscapes associated with second order or greater streams were eroding at a faster rate than saprolite formation.

Pavich (1985 and 1986) proposed that the rate of saprolite formation, and therefore thickness, was related to the type and thickness of soil over the saprolite. He estimated that the rate of saprolite formation in the Piedmont of Virginia was at least 4 meters per million years, indicating that most of the saprolite in Virginia has formed in the last one to two million years.

In this research, saprolite was studied along toposequences in two regions of Virginia. The objectives of the study were: 1) To describe and characterize saprolite formed from gneissic materials in the Piedmont and Blue Ridge Highlands regions of Virginia; and 2) to examine the relationships between soils, landscape position, and saprolite genesis.

Materials and Methods

Over fifty soil-saprolite-landscape associations developed in gneissic materials were examined in the Piedmont physiographic province and Blue Ridge Highlands region of Virginia in order to locate representative study sites. Soil and saprolite morphology were examined at summit and backslope positions to a depth of 3.5 meters or lithic contact with a bucket auger. Three representative toposequences were chosen for detailed study. Sites 1 and 2 were located in the Piedmont, and Site 3 in the Blue Ridge Highlands regions of Virginia. Soil pits were excavated at the summit, backslope, and footslope landscape positions. The most representative face was described and sampled using the National Soils Handbook (Soil Survey Staff 1981). Samples below the bottom of the soil pit were obtained with a bucket auger for sampling and description purposes. Bulk density clods for C horizons were obtained using a modified bucket auger. Rock samples were obtained from the bottom of the auger holes by chiseling the rock with a cold chisel welded to an auger extension, and collecting the samples with a bucket auger. Rock samples were also collected from nearby rock outcrops and at the bottom of the footslope soils at Sites 1 and 2.

Laboratory Methods

Bulk samples were air-dried, ground and passed through a 2mm sieve. Particle size distribution (PSD) was determined by pipette (Gee and Bauder, 1986). Dithionite-citrate-bicarbonate (DCB) extractable Fe was removed following the procedures of Holmgren (1967), and analyzed by inductively coupled plasma spectrometry (ICP). Elemental composition of the rock and saprolite was determined by ICP after HF digestion (Bernas 1968). To distinguish C horizons from soil-saprolite transition horizons, thin sections were examined for evidence of pedogenic process such as micro structure or illuvial clay in vughs and packing voids. The first horizon which lacked evidence of pedogenic process was named the C1 horizon. Reconstruction calculations were based on a constant volume basis (Brewer 1976).

Results and Discussion

Study Site Descriptions

Study sites 1 and 2 are located in the Piedmont near the town of Lovingston, VA. The saprolite and soils were derived from a mica gneiss (Lovingston Formation, Virginia Bureau of Mines 1967). Soils at the summit and backslope positions fit the concept of the Hayesville series (clayey; oxidic; mesic; Typic Hapludults) At the summit of Site 1, soil and saprolite extended to at least 8.5 meters below the soil surface. The thickness of the regolith at the backslope was less than 5 meters, and less than 1.5 meters at the footslope (Figure 1). The depth to bedrock was not determined between the summit and the backslope, and a general trend is given by the dashed line. Between the backslope and footslope, the bedrock does not conform to the shape of the landscape. Saprolite was absent at the footslope and an argillic horizon had formed in the weathered rock just above the bedrock.

Saprolite at the summit of Site 2 extended to 5 meters below the soil surface and the saprolite thickness decreased down the landscape (Figure 2). At this study site, the bedrock for the most part conformed to the shape of the landscape. A definite stone line was recognized across much of this landscape indicating a period of landscape instability. Over a meter of material occurred above the stone line at the backslope. This soil was well developed and the stone line occurred within the argillic horizon. Therefore the current landscape between summit and backslope has been relatively stable for an extended period. Saprolite was absent at the footslope although a weakly

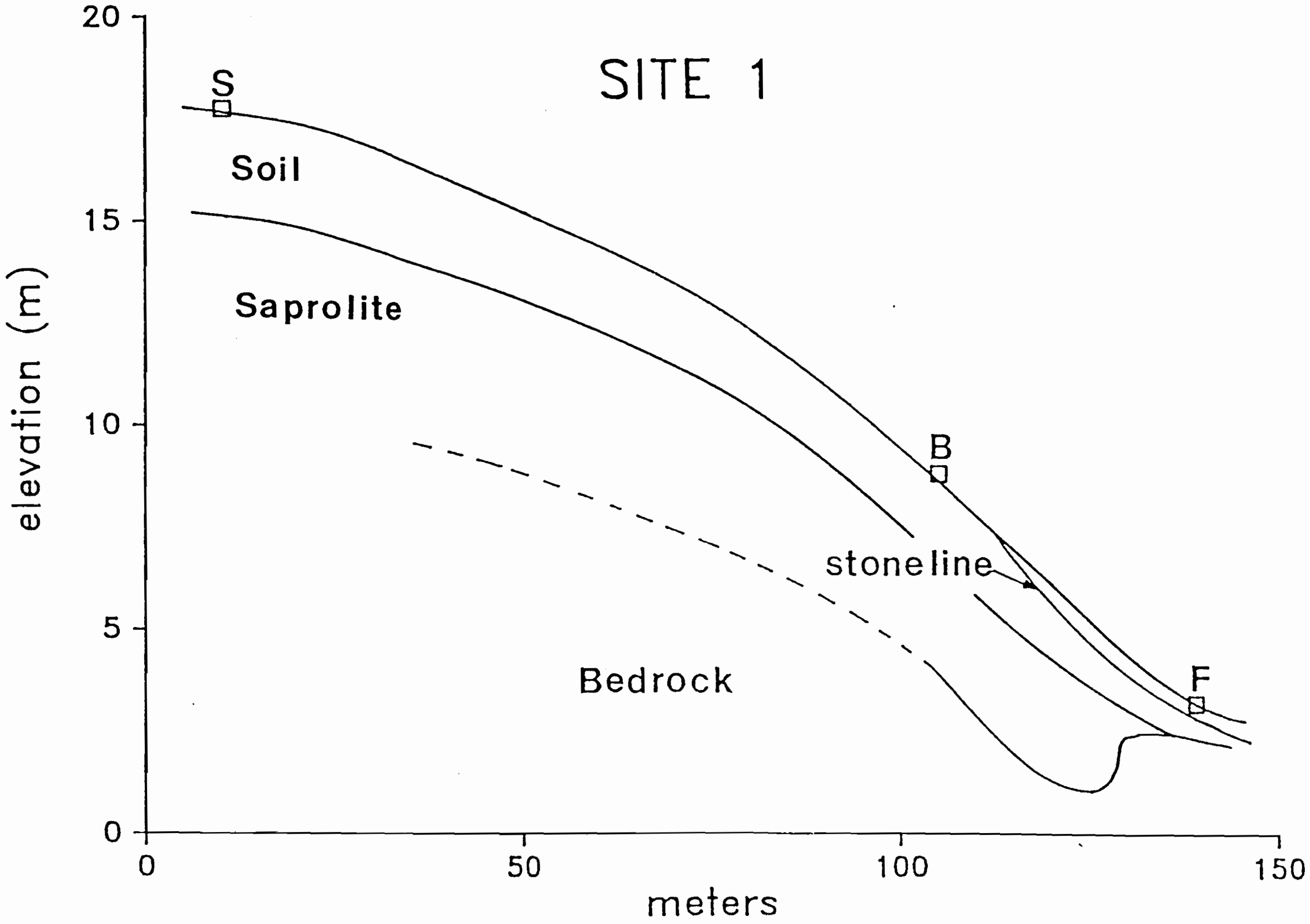

Figure 1. Cross section of Site 1. Vertical exaggeration is 5 times.

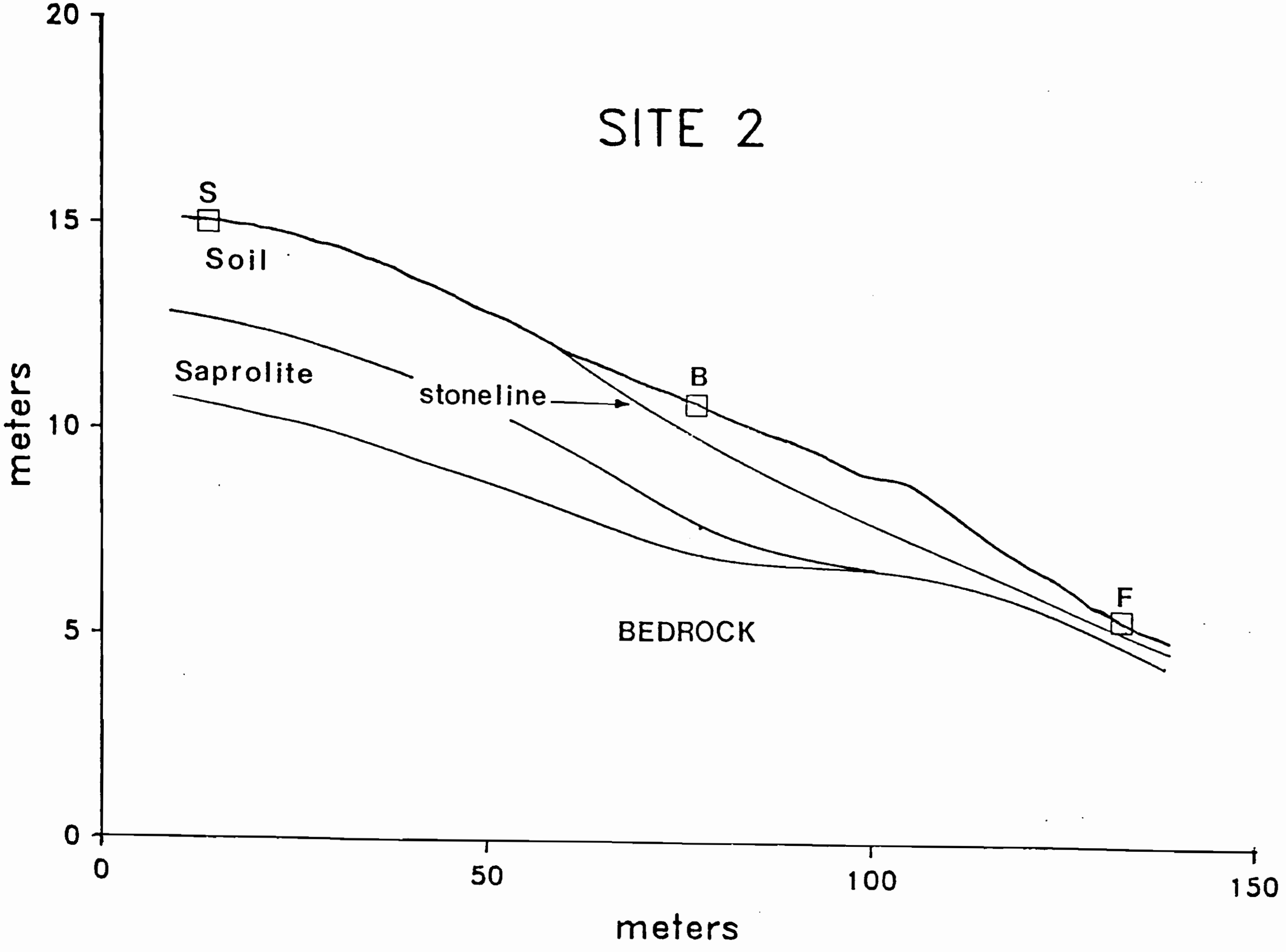

Figure 2. Cross section of Site 2. Vertical exaggeration is 5 times.

expressed argillic horizon occurred within the bisequel soil.

Study site 3 is located in the Blue Ridge Highlands near the town of Pilot, Virginia. Soils and saprolite at this site have formed from an augen gneiss (Pilot Gneiss; Lewis 1975). Although the footslope soil showed slightly less development, the soils at the three landscape positions fit the concept of the Chester series (fine loamy; mixed; mesic; Typic Hapludults). The thickness of the regolith was over 11.5 meters at the summit and decreased down the landscape (Figure 3). A stone line occurs across much of this landscape suggesting that a period of landscape instability had occurred. The bedrock however does not conform to the present landscape.

Saprolite characterization and genesis

In a typical upland residual soil, the regolith consists of a solum and C and Cr horizons (saprolite) which overly bedrock. Table 1 describes the C and Cr horizons of the summit and backslope soils examined at the 3 study sites. Most of the saprolite showed variegated colors related to parent material. The primary colors of the upper saprolite were the same as the matrix color of the argillic or transition horizon above the saprolite, and apparently resulted from oxidized Fe. Most of the saprolite observed was oxidized except for the saprolite above the bow-shaped form of the bedrock between the backslope and footslope positions at Site 1. The matrix color of the lower saprolite in this area of the landscape was gray (5Y 6/2) indicating reducing conditions.

All of the saprolite examined was structureless massive and friable

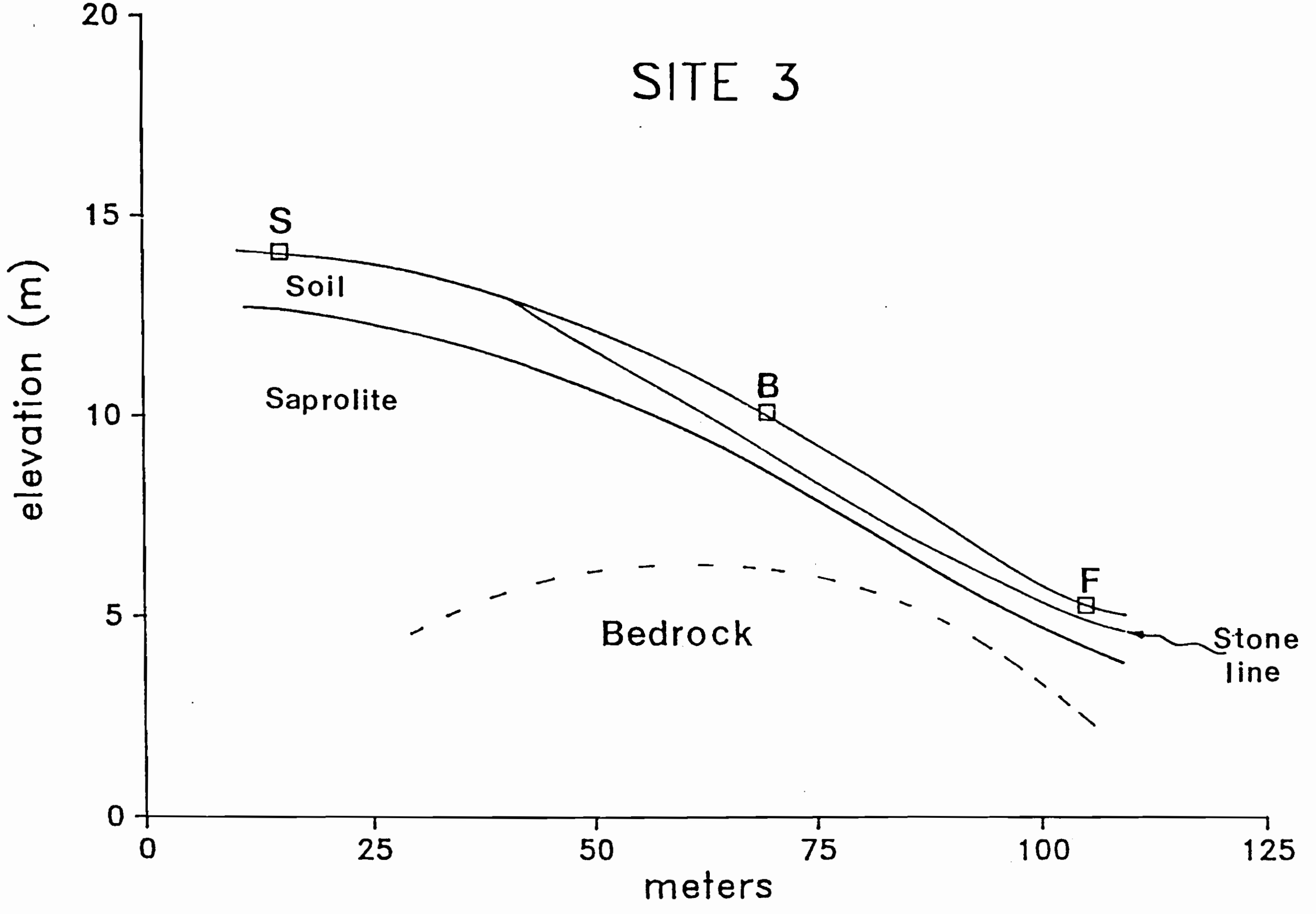

Figure 3. Cross section of Site 3. Vertical exaggeration is 4.5 times.

Table 1. Profile description of the saprolite for the summit and backslopes of Sites 1, 2, and 3.

Site 1 Summit

Horizon	depth cm	Description
C1	245-420	Variegated red (2.5 YR 5/8),reddish yellow (5 YR 6/6), yellow (10 YR 7/6) fine sandy loam; structureless massive, friable; moderately acid.
C2	420-445	Variegated white (10 YR 8/2), very pale brown (10 YR 7/4), very dark grayish brown (10 YR 3/2) loamy fine sand; structureless massive; friable; moderately acid.
C3	445-485	Variegated very pale brown (10 YR 7/4) and very dark grayish brown (10 YR 3/2) loamy fine sand; structureless massive; friable; moderately acid.
C4	485-535	Variegated very pale brown (10 YR 7/4) and brownish yellow (10 YR 6/8) loamy fine sand; structureless massive; friable; moderately acid.
C5	535-620	Variegated light yellowish brown (10 YR 6/4) and brownish yellow (10 YR 6/8) loamy fine sand; structureless massive; friable; moderately acid.
C6	620-725	Variegated light yellowish brown (10 YR 6/4) and brownish yellow (10 YR 6/8) loamy fine sand; structureless massive; friable; moderately acid.
C7	725-750+	Variegated light yellowish brown (10 YR 6/4) and brownish yellow (10 YR 6/8) loamy fine sand; structureless massive; friable; moderately acid.

Table 1 (cont.). Profile description of the saprolite for the summit and backslopes of Sites 1, 2, and 3.

Site 1 Backslope

Horizon	depth cm	Description
C1	216-275	Variegated red (2.5 YR 4/6), reddish yellow (5 YR 6/8), and dark brown (7.5 YR 3/2) fine sandy loam; structureless massive; friable; few clay flows; diffuse wavy boundary; moderately acid.
C2	275-340	Variegated strong brown (7.5 YR 4/6) and yellowish brown (10 YR 5/8) loamy fine sand; structureless massive; friable; few discontinuous clay flows; moderately acid.
C3	340-430	Variegated reddish yellow (7.5 YR 6/6) and yellowish red (5 YR 5/8) loamy fine sand; structureless massive; friable; few discontinuous clay flows; moderately acid.
C4	430-450	Very pale brown (10 YR 7/4) loamy fine sand; few distinct reddish yellow (5 YR 6/8) and few prominent red (2.5 YR 5/8) mottles; structureless massive friable; moderately acid.
Cr	450-460	Pale brown (10 YR 6/3) which crushes to loamy fine sand.
Rock	460+	Mica Gneiss.
		Site 2 Summit
C1	247-280	Variegated red (2.5 YR 5/8), reddish yellow (7.5 YR 7/6), very pale brown (10 YR 8/4), brownish yellow (10 YR 6/8), and very dark greyish brown (10 YR 3/2) loamy fine sand, structureless massive; friable; abrupt wavy boundary; moderately acid.
C2	280-320	Variegated reddish yellow (5 YR 6/8), brownish yellow (10 YR 6/8), very pale brown (10 YR 7/3), and black (10 YR 2/1) loamy fine sand; good rock structure; moderately acid.

Table 1 (cont.). Profile description of the saprolite for the summit and backslopes of Sites 1, 2, and 3.

Horizon	depth cm	Description
C3	320-405	Variegated reddish yellow (7.5 YR 6/8), very pale brown (10 YR 8/4), brownish yellow (10 YR 6/6), and black (10 YR 2/1) loamy fine sand; moderately acid.
C4	405-450	Variegated strong brown (7.5 YR 5/8), yellowish brown (10 YR 5/8), very pale brown (10 YR 2/1) loamy fine sand; moderately acid.
Rock	450+	Mica Gneiss
		Site 2 Backslope
3C1	320-350	Variegated reddish yellow (7.5 YR 7/8) and very pale brown (10 YR 8/3) fine sandy loam; strongly acid.
3C2	350-370	Reddish yellow (5 YR 6/8) fine sandy loam; moderately acid.
3Cr	370-390	Variegated red (2.5 YR 5/8), black (n 2/0), and very pale brown (10 YR 8/3) fine sandy loam; firm; moderately acid.
Rock	390+	Mica gneiss.
		Site 3 Summit
C1	150-205	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; few discontinuous clay films; many Mn coatings; common augens; gradual wavy boundary; strongly acid.

Table 1 (cont.). Profile description of the saprolite for the summit and backslopes of Sites 1, 2, and 3.

Horizon	depth cm	Description
C2	205-310	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; few discontinuous clay films; many Mn coatings; common augens; strongly acid.
C3	310-490	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; few discontinuous clay films; many Mn coatings; common augens; strongly acid.
C4	490-610	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; many Mn coatings; common augens; strongly acid.
C5	610-780	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; many Mn coatings; common augens; strongly acid.

Table 1 (cont.). Profile description of the saprolite for the summit and backslopes of Sites 1, 2, and 3.

Horizon	depth cm	Description
C6	780-1145+	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; many Mn coatings; common augens; strongly acid.
		Site 3 Backslope
C1	150-200	Variegated reddish brown (5 YR 5/4), light reddish brown (2.5 YR 6/4), reddish brown (2.5 YR 5/4), light brownish grey (10 YR 6/2), white (10 YR 8/2), and brownish yellow (10 YR 6/8) sandy loam; structureless massive; friable; few continuous clay films; few fine roots, many Mn coatings; diffuse wavy boundary; moderately acid.
C2	200-260	Variegated reddish brown (5 YR 5/4), light reddish brown (2.5 YR 6/4), reddish brown (2.5 YR 5/4), light brownish grey (10 YR 6/2), white (10 YR 8/2), and brownish yellow (10 YR 6/8) sandy loam; structureless massive; friable; few continuous clay films; few fine roots, many Mn coatings; diffuse wavy boundary; moderately acid.
C3	260-300	Variegated reddish brown (5 YR 5/4), light reddish brown (2.5 YR 6/4), reddish brown (2.5 YR 5/4), light brownish grey (10 YR 6/2), white (10 YR 8/2), and brownish yellow (10 YR 6/8) sandy loam; structureless massive; friable; few continuous clay films; few fine roots, many Mn coatings; moderately acid.
Cr	300-390	Variegated reddish brown (5 YR 5/4), light reddish brown (2.5 YR 6/4), reddish brown (2.5 YR 5/4), light brownish grey (10 YR 6/2), white (10 YR 8/2), and brownish yellow (10 YR 6/8) sandy loam; structureless massive; firm; few fine roots, many Mn coatings; moderately acid.
Rock	390+	Augen gneiss

in consistence. The Cr horizons were generally thin (0-20 cm thick, except for the backslope of Site 3 which was 90 cm thick), and firm in consistence. Bulk density values varied between C horizons and ranged from 1.19 to 1.74. The 26 C horizons sampled had an average bulk density of 1.39 (Table 2). Unweathered rock taken from outcrops nearby had bulk density values of approximately 2.6. Therefore the loss in mass during the formation of saprolite C horizons ranged from 33 to 54 %, with an average loss of 47 % of the original mass. This loss in mass is similar to that reported by Cleaves (1974). Average bulk density values for the Cr horizons, the partially weathered rock chiselled from the bottom of the auger holes, and the slightly weathered rock at the base of the footslope soils at Sites 1 and 2 were 1.8, 2.09, and 2.4 g/cm^3 respectively. These data suggest that bulk densities of the saprolite do not necessarily increase with depth, however there is a gradation between C horizons and completely unweathered bedrock.

Particle size distribution was fairly constant within the saprolite of a given pedon, and did not vary more than 6 % for any one fraction. Sand was the dominant particle size fraction, with clay content in most cases being less than 5 %.

For Sites 1 and 2 in the Piedmont, DCB extractable Fe (with the exception of the C1 horizon of the backslope soil at Site 1) was less than 1 % (Table 3). The DCB-Fe values varied with depth showing no clear trends. The DCB Fe contents in the Blue Ridge Highlands soils (Site 3) were generally greater than 1 % indicating that the easily weatherable minerals in the parent rock were probably Fe-rich. The

Table 2. Particle Size Distributions for the Summit and Backslope Soils.

Horizon	depth	B.D.	Sand	VC	C	M	F	VF	Silt	CSi	FSi	Clay	CC
	--cm--	%											
							Site 1 Summit						
C1	245-420	1.30	76.20	3.00	13.50	10.20	28.90	20.60	18.30	11.50	6.80	5.50	4.00
C2	420-445	1.29	75.00	5.50	9.00	12.60	29.60	18.30	23.00	16.30	6.70	2.00	1.10
C3	445-485	1.28	80.40	4.40	16.70	13.10	27.70	18.50	17.50	10.90	6.60	2.10	1.50
C4	485-535	1.30	82.10	3.60	20.40	14.20	26.70	17.20	17.70	12.10	5.60	.20	.20
C5	535-620	1.26	77.70	10.10	17.10	8.90	23.90	17.70	21.20	11.20	10.00	1.10	.60
C6	620-725	1.40	85.70	9.30	21.20	12.50	27.70	15.00	13.30	8.30	5.00	1.00	.40
C7	725-750	1.40	81.80	2.70	15.80	13.30	33.10	16.90	16.80	9.70	7.10	1.40	1.40
							Site 1 Backslope						
C1	216-275	1.36	71.00	4.10	8.50	8.60	28.90	20.90	21.10	12.50	8.60	7.90	4.40
C2	275-340	1.19	82.50	8.90	18.60	10.70	24.40	19.90	14.80	7.50	7.30	2.70	1.90
C3	340-430	1.40	76.40	9.40	13.70	8.70	25.80	18.80	19.80	12.40	7.40	3.80	2.90
C4	430-450	1.41	80.60	16.80	18.80	9.60	21.70	13.70	17.70	10.50	7.20	1.70	1.30
Cr	450-500	1.82	74.10	6.90	11.70	10.20	27.40	17.90	23.60	14.20	9.40	2.30	2.30
Rock		2.06											
							Site 2 Backslope						
C1	247-280	1.62	80.80	3.10	10.10	10.80	35.70	21.10	17.10	12.80	4.30	2.10	1.30
C2	280-320	1.74	80.20	3.10	9.30	9.00	35.70	23.10	18.20	13.30	4.90	1.60	1.10
C3	320-405	1.31	85.10	5.50	12.30	10.30	37.70	19.30	13.10	6.90	6.20	1.80	1.40
C4	405-500	1.37	83.20	5.40	10.90	9.10	37.10	20.70	15.10	8.30	6.80	1.70	1.20
Rock	500+	2.00											

Table 2 (cont.). Particle Size Distributions for the Summit and Backslope Soils.

Horizon	depth	B.D.	Sand	VC	C	M	F	VF	Silt	CSi	FSi	Clay	CC
	--cm--						%						
						Site 2 Backslope							
3C1	320-350	1.30	68.30	13.10	13.30	7.40	20.30	14.20	24.60	11.80	12.80	7.10	5.20
3C2	350-370	1.30	70.40	12.30	13.00	7.80	23.30	14.00	20.00	10.40	9.60	9.60	6.50
3Cr	370-390	1.81	74.40	5.00	11.00	9.70	29.60	19.10	21.40	12.50	8.90	4.20	2.10
Rock	390+	2.21											
						Site 3 Summit							
C1	150-205	1.40	65.50	17.90	19.50	8.90	12.90	6.30	29.60	6.20	23.40	4.90	3.80
C2	205-310	1.38	58.80	15.00	17.00	8.30	12.40	6.10	36.90	7.50	29.40	4.30	3.10
C3	310-490	1.37	61.30	14.50	16.70	10.90	12.80	6.40	34.10	6.00	28.10	4.60	3.80
C4	490-610	1.42	60.70	14.30	16.30	8.90	14.50	6.70	35.10	6.30	28.80	4.20	3.70
C5	610-780	1.47	65.00	16.10	18.10	9.50	14.80	6.50	32.40	8.70	23.70	2.60	2.50
C6	780-1145+	1.47	62.80	18.70	14.00	8.60	14.80	6.70	33.10	7.00	26.10	3.90	3.90
						Site 3 Backslope							
C1	160-200	1.43	65.80	17.70	16.50	8.50	15.00	8.10	27.40	6.90	20.50	6.80	4.50
C2	200-260	1.46	70.50	19.60	18.00	9.30	15.30	8.30	25.60	7.50	18.10	3.90	2.40
C3	260-300	1.42	64.80	17.80	17.10	8.60	14.30	7.00	29.20	6.80	22.40	6.00	4.00
Cr	300-390	1.83	75.60	21.30	22.00	10.80	15.20	6.30	22.20	7.30	14.90	2.20	2.20
Rock	390+	2.08											

Table 3. Elemental and DCB extractable values.

Horizon	depth	Ca	Al	Fe	Mg	Si	Zr	Ti	Na	DCB Fe
	cm	%								
					Site 1 Summit					
C1	245-420	.14	8.41	1.23	.11	30.51	.01	.16	.22	.84
C2	420-445	.16	8.67	.82	.12	30.74	.01	.06	.21	.29
C3	445-485	.17	10.06	.96	.09	21.65	.01	.17	.66	.51
C4	485-535	.07	9.72	2.46	.31	28.58	.01	.73	.21	.60
C5	535-620	.07	9.12	1.80	.15	30.66	.01	.21	.35	.89
C6	620-725	.04	9.85	2.13	.15	29.63	.01	.20	.78	.39
C7	725-750+	.00	2.99	3.11	.13	27.78	.00	.30	.67	.48
					Site 1 Backslope					
C1	216-275	.00	11.70	3.19	.19	26.44	.02	.52	.18	1.95
C2	275-340	.03	9.38	1.75	.11	29.25	.01	.16	.16	.53
C3	340-430	.06	9.63	1.88	.11	30.84	.02	.16	.31	.32
C4	430-450	.11	9.87	2.04	.16	29.85	.02	.14	1.23	.13
Cr	450-460+	.18	9.76	2.39	.24	29.04	.02	.30	1.83	.46
Rock		.45	9.66	3.89	.42	26.69	.01	.46	2.27	.29
					Site 2 Summit					
C1	247-280	.01	9.57	3.18	.22	26.23	.01	.45	.19	.30
C2	280-320	.17	10.72	3.51	.89	26.93	.00	.38	1.59	.24
C3	320-405	.40	7.99	3.38	.38	27.51	.01	.45	.47	.67
C4	405-450	.01	8.90	3.65	.54	24.83	.00	.54	.21	.63
Rock		.28	9.84	4.19	1.32	23.39	.00	.65	1.41	.45

Table 3. Elemental and DCB extractable values.

Horizon	depth	Ca	Al	Fe	Mg	Si	Zr	Ti	Na	DCB Fe
	cm	%								
					Site 2 Backslope					
3C3	320-350	.15	10.02	.89	.12	29.65	.01	.14	.21	.70
3C4	350-370	.12	10.66	1.57	.11	27.65	.01	.18	1.65	.82
3Cr	370-390	.05	9.59	4.34	.58	25.45	.01	.60	1.03	.43
Rock	390+	1.51	10.75	2.88	1.12	28.56	.01	.39	2.91	.10
					Site 3 Summit					
C2	205-310	.13	9.73	1.11	.07	29.66	.01	.15	.31	1.96
C3	310-490	.01	9.77	2.88	.14	27.72	.01	.74	.32	1.98
C4	490-610	.01	9.72	3.19	.13	25.58	.01	.72	.19	2.50
C5	610-780	.00	10.54	2.77	.15	25.52	.01	.63	.15	1.77
C6	780-1145+	.00	9.05	3.55	.14	26.50	.01	1.03	.17	3.02
					Site 3 Backslope					
C2	200-260	.00	9.97	2.31	.08	26.11	.01	.71	.32	1.69
C3	260-300	.08	9.73	1.46	.10	26.73	.00	.52	.78	1.36
Cr	300-390	.60	9.37	1.33	.22	28.49	.00	.33	.74	.65
Rock	390+	.95	9.75	2.58	.29	27.85	.00	.28	1.00	.92

elemental composition of the C and Cr horizons, and the rock samples taken from just below the Cr horizons, are also presented in Table 3. Silica and Al were by far the major elemental components. The primary minerals in the parent rocks were predominantly tecto- and phyllo-silicates. Elemental Fe increased with depth in most cases, and was the only component that showed a trend indicative of weathering with depth. These data along with the oxidized colors observed in the field, suggest that oxidation of Fe may be an important process occurring during and after initial formation of saprolite. With the exception of Si and Al, the highest levels of most other elements were found in the rock samples. Consistent trends with depth for these elements, however, were not apparent. After saprolite formation, chemical weathering and dissolution apparently occur at similar rates regardless of the depth of the saprolitic horizon. These results were also supported by the particle size data which show no changes with depth.

To better assess the effect of chemical weathering on the rock and saprolite, gains and losses of the elemental and DCB extractable constituents were examined on a volume basis relative to the rock samples (Table 4). The rocks used for the gains and losses calculations were those chiseled from the bottom of the auger holes. These rock fragments had undergone substantial weathering as indicated by the low bulk density values (Table 2). For the most part, trends indicating a decrease in weathering can be observed with depth. These trends can be observed for Si in the backslope soils of all three sites, for Al, Fe, and Na in backslopes of Site 1 and 2, and for Ca in the backslopes of Sites 1 and 3.

Table 4. Gains and Losses of elemental and DCB extractable constituents.

Horizon	depth	Ca	Al	Fe	Mg	Si	Zr	Ti	Na	DCB Fe
	cm					g/100 cc				
						Site 1 Backslope				
C1	216-275	-.93	-3.99	-3.68	-.61	-19.02	-.01	-.24	-4.43	2.05
C2	275-340	-.90	-8.74	-5.93	-.73	-20.17	-.01	-.76	-4.49	.03
C3	340-430	-.86	-6.42	-5.38	-.71	-11.81	-.00	-.72	-4.24	-.15
C4	430-450	-.79	-5.98	-5.14	-.64	-12.89	.00	-.75	-2.94	-.41
Cr	450-460+	-.61	-2.14	-3.66	-.43	-2.13	.01	-.40	-1.35	.24
Rock		.00	.00	.00	.00	.00	.00	.00	.00	.00
						Site 2 Summit				
C1	247-280	-.55	-4.18	-3.23	-2.29	-4.29	.01	-.57	-2.51	-.41
C2	280-320	-.27	-1.03	-2.27	-1.09	.08	.00	-.64	-.05	-.48
C3	320-405	-.03	-9.21	-3.95	-2.15	-10.74	.00	-.71	-2.20	-.02
C4	405-450	-.55	-7.49	-3.38	-1.89	-12.76	.00	-.56	-2.53	-.04
Rock		.00	.00	.00	.00	.00	.00	.00	.00	.00
						Site 2 Backslope				
3C1	320-350	-3.15	-10.73	-5.21	-2.32	-24.57	-.00	-.68	-6.16	.69
3C2	350-370	-3.18	-9.90	-4.32	-2.33	-27.17	.00	-.63	-4.29	.85
3Cr	370-390	-3.25	-6.40	1.49	-1.42	-17.05	-.00	.22	-4.57	.56
Rock	390+	.00	.00	.00	.00	.00	.00	.00	.00	.00
						Site 3 Backslope				
C2	200-260	-1.97	-5.72	-1.99	-.48	-19.81	.00	.45	-1.61	.55
C3	260-300	-1.86	-6.46	-3.29	-.46	-19.97	.00	.16	-.97	.02
Cr	300-390	-.87	-3.13	-2.93	-.19	-5.79	.00	.02	-.73	-.72
Rock	390+	.00	.00	.00	.00	.00	.00	.00	.00	.00

In order to examine the total amount of losses occurring in the weathering of the rock to saprolite, the gains and losses were examined on an area basis and the losses totalled for each pedon (Table 5). All of the elements were assumed to occur in an oxide form. The total amount of losses ranged from 20 to 36 %. The average bulk density values for the 15 C and Cr horizons, and 4 rock samples examined in Table 5 were 1.49 and 2.09 g.cm^3 respectively. Therefore the average loss of constituents for the saprolite of these 4 soils was 29 %. This value was essentially the same as the losses measured using the reconstruction calculations (Table 5). The average bulk density value of the unweathered rock sampled from outcrops near these soils was 2.6 g/cm^3, indicating that approximately 20 percent of the mass is lost during the weathering of fresh rock to the partially weathered rock, which is the precursor of saprolite. Therefore, although the elemental forms lost during the weathering of fresh rock to partially weathered rock may differ from those lost during saprolite formation, greater total losses occur during the formation of saprolite. These data show that between 73 and 82 % of the losses that occurred during the chemical weathering and dissolution of partially weathered rock to saprolite, were the result of losses of Al and Si.

The Cr horizon in most of the summit and backslope soils examined was thin (< 20 cm) or nearly absent. This thin transition zone between partially weathered rock and saprolite indicates that the formation of saprolite from partially weathered rock is a relatively fast process, compared to the rates of change following the initial formation of saprolite. Similar findings were presented by Calvert et al. (1980) and

Table 5. Gains and losses of elemental and DCB extractable constituents on an area basis.

Horizon	depth	CaO	Al_2O_3	FeO	MgO	SiO_2	ZrO_2	TiO_2	Na_2O_3	DCB Fe_2O_3	Total Losses	Percent Losses
	cm	/100 cm2										%
						Site 1 Backslope						
C1	216-275	-77	-445	-278	-60	-2110	-1	-24	-353	173		
C2	275-340	-82	-1073	-495	-79	-2465	-1	-82	-394	3		
C3	340-430	-108	-1092	-622	-106	-1997	0	-109	-515	-19		
C4	430-450	-22	-226	-132	-21	-485	0	-25	-79	-12		
Cr	450-460+	-9	-40	-47	-7	-40	0	-7	-18	3		
Rock		0	0	0	0	0	0	0	0	0		
Total		-297	-2876	-1574	-273	-7098	-2	-246	-1360	149	-13577	27
						Site 2 Summit						
C1	247-280	-25	-260	-136	-125	-266	1	-31	-112	-20		
C2	280-320	-15	-78	-130	-72	6	0	-43	-3	-28		
C3	320-405	-4	-1480	-480	-303	-1717	0	-101	-253	-3		
C4	405-450	-74	-1344	-459	-299	-2279	0	-89	-325	-5		
Rock		0	0	0	0	0	0	0	0	0		
Total		-118	-3163	-1097	-799	-4256	0	-264	-693	-55	-10445	26
						Site 2 Backslope						
3C1	320-350	-132	-608	-200	-115	-1386	0	-34	-249	30		
3C2	350-370	-89	-374	-111	-77	-1022	0	-21	-116	24		
3Cr	370-390	-91	-242	39	-47	-641	0	7	-123	16		
Rock	390+	0	0	-304	0	0	0	0	0	0		
Total		-312	-1224	-273	-239	-3049	0	-48	-488	70	-5563	36
						Site 3 Backslope						
C2	200-260	-165	-649	-154	-47	-2234	0	46	-131	48		
C3	260-300	-104	-489	-169	-30	-1502	0	10	-53	1		
Cr	300-390	-109	-533	-339	-28	-980	0	3	-88	-93		
Rock	390+	0	0	0	0	0	0	0	0	0		
Total		-379	-1671	-662	-106	-4716	0	59	-271	-45	-7791	20

Pavich (1986). At the footslope positions Cr horizons were also recognized above bedrock, but saprolite did not occur above these horizons. At the footslope of Site 1, clay films were observed into the fissure cracks of the Cr horizon. Similar horizons were reported by Whittecar (1985) in soils derived from phylitic material. Thus there appears to be two types of Cr horizons. One type is overlain by saprolite and has formed through chemical weathering. The other type is not a precursor to saprolite, and has evolved through physical and chemical weathering, and in some cases shows some pedogenic alteration.

The occurrence of Cr horizons without saprolite, indicates that initially soil formation is occurring at a faster rate than saprolite formation, and at a similar rate to physical and chemical rock weathering. After initial soil formation and mineral weathering, the rate of saprolite formation occurs at a faster rate than soil formation, and saprolite begins to accumulate below the solum. After an extended period of time the amount of energy necessary to further the degree of profile development is greater than the amount in the soil system, and the soil reaches a state of equilibrium. Saprolite formation however, although most likely occurring at a slower rate than when the partially weathered rock was at a shallower depth, continues to form.

Soil-saprolite-landscape relationships

In the three toposequences studied, the form of the bedrock and present landscape were very similar between the backslope and footslope positions. Between the summit and the backslope however, the present landscape did not always conform to the shape of the bedrock (Figures

1, 2, and 3). Pavich (1986) proposed that saprolite thickness could be related to the type and thickness of the overlying soils. Saprolite was much thicker at the summit of Site 1 than the summit of Site 2. These sites were less than a kilometer apart and both the summit and the backslope soils had essentially the same profile morphology and thickness. Therefore the differences in saprolite thickness between the summit and backslope soils at Sites 1, and between the summits at Sites 1 and 2, were not related to soil type or thickness, and may have been related to variations in the mineralogy of the parent rock or landscape stability. Minor differences in the mineralogy or degree of metamorphism of the parent rock at the summit of Site 1 could have caused this material to weather at a faster rate than the rock at the summit of Site 2. Significant material, however was moved from the upper landscape onto the lower landscape in Site 2, as indicated by the thickness of the material above the stoneline (Figure 2). The upper landscape at Site 2 was apparently unstable at some period, during which a significant amount of soil and saprolite may have been removed. As a result, the summit and backslope soils at Site 2 have about equal amounts of saprolite. Evidence for substantial displacement of soil material from the upper landscape of Site 1 was lacking. The thickness of the saprolite was much thicker at the summit than at the backslope, indicating that the summit position was relatively stable in comparison to the backslope at Site 1 and the summit and backslope at Site 2.

At Site 3 the soils at each landscape position were very similar. Significant differences in saprolite thickness were observed between the summit and backslope landscape positions. The stone line across most of the landscape (Figure 3) indicates a period of landscape instability. The erosional period represented by the stone line and depositional material at the backslope and footslope, did not appear to have significantly affected the thickness of the summit regolith.

Footslope soils at Sites 1 and 2 were void of saprolite, and the thickness of the saprolite at the footslope of Site 3 was about 1.5 meters. Costa and Cleaves (1984) found that soils without saprolite were eroding at a faster rate than the rate of saprolite formation. The footslope soils at Sites 1 and 2, which occurred at the head of a drainageway, are probably eroding at least as fast as the saprolite is forming. In addition, the footslope positions tend to be the wetter areas of a toposequence, so that saprolite formation may have been retarded in these soils as compared to the associated summit and backslope soils.

The cross sections of the three study sites indicate that apparently the summit is most stable position on the landscape, and that the footslope and backslope positions are eroding at or near the rates of saprolite formation. Cleaves (1970) reported that unconsolidated sediments, such as saprolite or soil must be present for mass wasting to occur. During the next significant erosional event at Site 3 in which mass wasting occurs, the material at the backslope and footslope may erode to the bedrock. These areas would become much more stable than the summit position, which would then erode at a faster rate than the backslope and footslope. Following significant erosion and mass wasting, the summit position at Site 3 would occur lower on the landscape than the present backslope position, and would become an erosional landscape position. The thickness of the regolith at the backslopes of the soils examined in this study was less than 5 meters. Therefore, if the rate of saprolite formation is at least 4 meters per million years for the Piedmont of Virginia as reported by Pavich (1985), this type of landscape evolution should have occurred in the last one to two million years in the Piedmont and Blue Ridge Highlands regions of Virginia. The amount depositional material observed on the Piedmont and Blue Ridge Highlands landscapes however, do not indicate this degree of denudation. These observations suggest that the rates of saprolite formation may be much less than those proposed by Pavich (1985).

Conclusions

The results of this study indicated that differences in saprolite thickness could be primarily related to landscape stability. Summit positions have thicker overburdens of saprolite than the associated backslope and footslopes, and therefore have been relatively stable over a significant period.

Saprolite forms as a result of chemical alteration and weathering of partially weathered rock. This weathering process is accompanied by a significant loss of mass, primarily Si and Al. Changes from partially weathered rock to saprolite were found to occur at much faster rates than subsequent changes within the saprolite. The changes that occur after saprolite formation are primarily Fe oxidation, removal of bases and Al, and desilication.

In the initial stages of soil development, the rates of soil formation are faster than those of saprolite formation. Therefore saprolite is absent from soils, such as footslope soils, which are in this stage of development. After significant profile development, the rate of soil formation is reduced below the rate of saprolite formation, and saprolite accumulates below the solom. Soil formation finally reaches a stage of equilibrium with the energy in the soil system, and further profile development is minimal. Saprolite however continues to accumulate.

CHAPTER 6

Summary and Conclusions

In this research, various methods and techniques were used to examine soil-landscape relationships from several perspectives. One of the principal methods employed was soil reconstruction analysis. In order to properly use soil reconstruction techniques, the state and composition of the parent material prior to pedogenic alteration should be known, and the parent material(s) should be uniform. To insure that these criteria were met, soil variability within each profile was examined and soil micromorphology was used to examine horizons occurring between the argillic horizon and saprolite to identify the soil parent material. Soil micromorphology indicated that although horizons appeared structureless-massive in the field, many of these horizons had undergone considerable alteration due to pedogenesis, and were in fact transition horizons. As a result, the solum thickness of many of the soils, especially those in the Piedmont, were much thicker than what was commonly thought.

Distinguishing the soil-saprolite transition horizons from C horizons in the field was found to be a difficult task. To better describe the transition and associated saprolite C horizons in the field, these guidelines should be followed: 1) Percent clay should not decrease below the C1 horizon. 2) C horizons should lack subangular blocky microstructure or illuvial clay in small macrovoids. 3) Horizons which show moderate evidence of rock structure should be labelled a transition horizon, even if the horizon meets the criteria as part of the argillic horizon. Micromorphology and laboratory data suggested that there were 3 types of transition horizons. Horizons labelled BCt were those with subangular blocky structure, evidence of rock structure, and substantial oriented clay. Those horizons labelled BC contained some subangular blocky microstructure and increases or decreases in sand, clay, or DCB-Fe contents with depth, were more like those observed in the B than those seen in the C horizons. The transition horizons labelled CB were very similar to the C horizons except that these horizons showed some evidence of pedogenesis.

Soil variability was examined using several techniques at several levels within the study. Most of the overall variability was attributed to differences between study sites or between horizons. Total variability explained by landscape position was minimal, indicating that in soil studies that occur over several regions, landscape position was not as important a soil forming factor as parent material or (possibly) regional climate. Substantial variability was found to occur within horizons of the same pedon, with the most variability occurring within the C horizons. These data indicate the strong need for subsampling within horizons of the same pedon to reduce the variability about the population mean.

Uniformity of the parent material in pedons that did not show field evidence of discontinuities was examined using Zr contents, clay-free particle size distributions, and silt Ti:Zr ratios. Confidence intervals about the sample mean for clay-free sand were too sensitive to be used as an indicator of parent material uniformity. Discontinuities were found to be difficult to determine without the corroborating field evidence.

Reconstruction analysis is a means of quantifying the gains and losses of the various soil constituents during soil formation and development. These techniques were used at the summit, backslope, and footslope landscape positions in order to test the usefulness of these techniques for examining soil-landscape relationships, and to quantitatively measure soil genesis at these positions. Reconstruction analysis was a valuable tool in studying soil-landscape relationships in this study. For toposequences, it was shown that material from upslope could be used for the upper parent materials of bisequel soils. Regression techniques, clay-free particle size distributions, and soil micromorphology can aid in estimating the state and composition of the upper parent material for bisequel soils.

Many studies have indicated that backslope soils are erosional soils and therefore are less developed than the associated summit soils. This study, however, found that soils occurring at the summit and backslope which have formed from gneissic parent material were essentially the same in both morphology and degree of profile development, even though the backslope soils occurred on slopes as great as 18 percent. These observations suggested that differences in profile morphology between summit and backslope soils are most likely related to differences in parent materials or man-induced erosion. Reconstruction analysis indicated that both the summit and backslope soils had undergone the same soil forming processes and degree of profile development. The most important soil forming processes occurring within these soils were sand weathering and clay eluviation/illuviation. Footslope soils were found to be less developed than associated summit and backslope soils, and both depositional and pedologic processes were found to contribute to the formation and development of these soils.

In the Piedmont and Blue Ridge Highlands saprolite is the predominant soil parent material. Few studies, however, have focused on saprolite genesis because of the difficulty in obtaining undisturbed samples for routine analyses such as bulk density, water retention measurements, and morphologic investigation and description. A simple modification of a standard bucket auger was made and an associated sampling system was devised in order to obtain undisturbed samples of saprolite at various wooded locations on level to sloping landscapes. This system was found to work as quickly and efficiently as a truck mounted drill rig. Bulk density measurements made from samples obtained from the modified bucket auger were comparable to those of standard clod or double-cylinder methods.

Many soils on the Virginia Piedmont are less than two meters thick, but the saprolite that occurs under these soils may be over 10 meters thick. These observations appear to indicate that saprolite formation is much more rapid than soil formation. Soils and saprolite were examined along three toposequences to determine the relationships between soils, landscape position and saprolite genesis. Greater amounts of saprolite were found at the summit positions than the associated backslope and footslopes. These differences in saprolite thickness were apparently related to the relative stability of the summit compared to the backslope and footslope positions. Significant losses of primarily Al and Si occur during the chemical weathering of partially weathered rock to saprolite. The rate of saprolite formation appears to be a faster process than the rate of changes in the saprolite following formation. Initial soil development was found to occur at a faster rate than saprolite formation, but after substantial profile development, soil formation occurs at a slower rate than saprolite formation, and saprolite begins to accumulate below a soil. Soil formation may finally reach a rate where the energy needed to further profile development is greater than the amount in the soil system, and soil development is minimal. Saprolite however, continues to form and accumulate under the soil.

These studies have shown that some of the soil-landscape relationships that were commonly thought to occur, may not be entirely true. Those of significant consequence include the findings that for a study occurring over several regions, landscape position is not a very important factor in soil development. In addition, it was revealed that backslope soils are not erosional landscapes in a natural setting, and that the soils that occur at these landscape positions are very similar to the associated summit soils. Therefore, in the type of landscapes examined in this study, only at the lower portion of the landscape do soil-landscape relationships exist. Reconstruction analysis was shown to be an important tool in examining soil forming processes, and several key points were made from the results. Those of primary importance are that: 1) weathering is the most important soil forming process occurring at the summit and backslope positions; 2) weathering occurs at about the same rate at the summit and backslope position; 3) the amount of development occurring at the footslope position can be related to deposition and parent material; and 4) reconstruction analysis can be applied to more than just soils with a single parent material. To conclude, these type of studies should be applied to other types of parent material to determine if the same conclusions can be reached.

REFERENCES

Ball, D.F. and W.M. Williams. 1968. Variability of soil chemical properties in two uncultivated brown earths. Journal of Soil Science 19:379-391.

Barnhisel, R.I. and P.M. Bersch. 1989. Chlorites and hydroxy-interlayered vermiculite and smectite In Minerals in the Soil Environments, Dixon & Weed (eds.) Soil Sci. Soc. Am., Madison WI. Agronomy, 1:729-788.

Barshad, I. 1964. Chemistry of soil development. In F.E. Bear (ed.) Chemistry of the soil. Reinhold Pub. Co., N.Y.

Becker, G.F. 1895. A reconnaissance of the goldfields of the Southern Appalachians. U.S. Geol. Survey 16th Annual Report, pp. 289-290.

Bernas, B. 1968. A new method for decomposition and comprehensive analysis of silicates by atomic absorption spectrometry. Anal. Chem. 40:1682-1686.

Blake, G.R. 1965. Bulk density. In C.A. Black (ed.) Methods of Soil Analysis, Part 1. Agronomy 9:374-390. Madison WI.

Bloomer, R.O., and H.J. Werner. 1955. Geology of the Blue Ridge region in central Virginia. Geol. Soc. Am. Bull. 66:579-606.

Brasher, B.R., D.P. Franzmeier, V. Valais, and S.E. Davidson. 1966. Use of saran resin to coat natural soil clods for bulk density and water retention measurements. Soil Sci. 101: 108.

Brewer, R. 1976. Fabric and mineral analysis: Chapter 4. Calculations of soil formation. Krieger Publ., NY.

Bullock, P., N. Federoff, A. Jongerius, G. Stoops, T. Tursina, and U.Babel. 1985. Handbook for thin section description. Waine Research Publications, Wolverhampton, England

Cady, J.G. 1950. Rock weathering and soil formation in the North Carolina Piedmont region. Soil Sci. Soc. Amer. Proc. 15: 337-342.

Calvert, C.S., S.W. Buol, and S.D. Weed. 1980. Mineralogical characteristics and transformation of a vertical rock-saprolite-soil sequence in the North Carolina Piedmont: I. Profile morphology, chemical composition, and mineralogy. Soil Sci. Soc. Amer. J. 44: 1096-1103.

Campbell, J.B. 1978. Spatial variation of sand content and pH within single contiguous delineations of two soil mapping units. Soil Sci. Soc. Am. J. 42:460-464.

Chapman, S.L., and M.E. Horn. 1968. Parent material uniformity and origin of silty soils in northwest Arkansas based on zirconium-titanium contents. Soil Sci. Soc. Amer. Proc. 32: 265-271.

Cleaves, E.T. 1974. Petrologic and chemical investigation of chemical weathering in mafic rocks, Eastern Piedmont of Maryland. Md. Geol. Survey Report of Invest. No. 25. 28 pp.

Cleaves, E.T., A.E. Godfrey, and O.P. Bricker. 1970. Geochemical balance of a small watershed and its geomorphic implications. Geol. Soc. Amer. Bull. 81: 3015-2032.

Costa, J.E. and E.T. Cleaves. 1984. The Piedmont landscape of Maryland: a new look at an old problem. Earth Surface Processes and Landforms 9: 59-74.

Dietrich, R.V. 1954. Geology of the Pilot Mountain area of Virginia. VPI Bull. Engr. Exp. Sta. #91. 32 p.

Drees, L.R. and L.P. Wilding. 1973 Elemental variability within a sampling unit. Soil Sci. Soc. Amer. Proc. 37: 82-87.

Drees, L.R., L.P. Wilding, N.E. Smeck and A.L. Senkayi. 1989. Silica in soils: quartz and disordered silica polymorphs In Minerals in the Soil Environments, Dixon & Weed (eds.) Soil Sci. Soc. Am., Madison WI. Agronomy 1, 913-974.

Edmonds, W.J., J.C. Baker, and T.W. Simpson. 1985. Variance and scale influences on classifying and interpreting soil map units. Soil Sci. Soc. Am. J. 49:957-961.

Eswaran, H. and W.C. Bin. 1978. A study of a deep weathering profile on granite in peninsular Malaysia: I. Physico-chemical and micromorphological properties. Soil Sci. Am. J. 42: 144-149.

Fanning, D.S., V.Z. Keramidas and M.A. El-Desoky. 1989. Micas In Minerals in the Soil Environments, Dixon and Weed (eds.) Soil Sci. Soc. Am., Madison WI. Agronomy 1, 551-634.

Fisher, F.W. 1970. The Piedmont. In G.W. Fisher, F.J. Pettijohn, J.C. Reed, and K.N. Weaver (eds) Studies of Appalachian geology: Central and Southern. Interscience Publisher.

Flach, K.W., J.G. Cady, and W.D. Nettleton. 1968. Pedogenic alteration of highly weathered parent materials. Trans. 9th Intl. Congr. Soil Sci. 4: 343-351.

Gee, G.W., and J.W. Bauder. 1986. Particle size analysis In A. Klute (ed.) Methods of Soil Analysis, Part 1. Agronomy 9:383-409.

Grossman, R.B., B.R. Brasher, D.P. Franzmeier and J.L Walker. 1968. Linear Extensibility as Calculated from Natural-Clod Bulk Density Measurements. Soil Science Soc. Am. Proc., 32:570-573.

Harradine, F.F. 1949. The variability of soil properties in relation to stage of profile development. Soil Science Society Proceedings, 302-311.

Harris, W.G., L.W. Zelazny, J.C. Baker, and D.C. Martens. 1985. Biotite kaolinization in Virginia Piedmont soils: I. Extent, profile trends, and grain morphological effects. Soil Sci. Soc. Am. J. 49:1290-1297.

Holmgren, G.G.S. 1967. A rapid citrate-dithionite extractable iron procedure. Soil Sci. Soc. Amer. Proc. 31: 210-211.

Huang, P.M. 1989. Feldspars, olivines, pyroxenes, and amphiboles In Minerals in the Soil Environments, Dixon & Weed (eds.) Soil Sci. Soc. Am., Madison WI. Agronomy 1:975-1050.

Huddleston, J.H., J.A. Walsh, D. Jowett, and F.F. Riecken. 1975. Local soil-landscape relationships in western Iowa: II. Quantification of pedologic and geologic effects. Soil Sci. Soc. Amer. Proc. 39: 908-913

Huddleston, J.H. and F.F. Riecken. 1973. Local soil-landscape relationships in western Iowa: I. Distribution of selected physical and chemical properties. Soil Sci. Soc. Amer. Proc. 37: 264-270.

Jenny, H. 1941. Factors of soil formation - a system of quantitative pedology. McGraw Hill, New Tork. 281 pp.

Kaup, B.S. and B.J. Carter. 1987. Determining Ti source and distribution within a Paleustalf by micromorphology, submicroscopy and elemental analysis. Geoderma 40: 141-156.

Kleis, H.J. 1970. Hillslope sedimentation and soil formation in northeastern Iowa. Soil Sci. Soc. Amer. Proc. 24: 289-290.

Lewis, S.E. 1975. Geology of the southern part of Riner quadrangle, Montgomery and Floyd Counties, VA. M.S. Thesis N.C. State, Raleigh, Raleigh, NC. 106pp.

Marshall, C.E., and J.F. Haseman. 1942. The quantitative evaluation of soil formation and development by heavy mineral studies: a Grundy silt loam study. Soil Sci. Soc. Amer. Proc. 7: 448-453.

Mausbach, M.J., B.R. Brasher, R.D. Yeck and W.D. Nettleton. 1980. Variability of measured properties in morphologically matched pedons. Soil Sci. Soc. Am. J. 44:358-363.

McKeague, J.A., R.K. Guertin, K.W.G. Valentine, J. Belisle, G.A. Bourbeau, A. Howell, W. Michalyna, L. Hopkins, F. Page, and L.M. Bresson. 1980. Estimating illuvial clay in soils by micromorphology. Soil Science 129: 386-388.

Milnes, A.R. and R.W. Fitzpatrick. 1989. Titanium and zirconium minerals In Minerals in the Soil Environments, Dixon and Weed (eds.) Soil Sci. Soc. Am., Madison WI. Agronomy 1:1131-1208.

Norfleet, M.L. and B.R. Smith. 1989. Weathering and mineralogical classification of selected soils in the Blue Ridge Mountains of South Carolina. Soil Sci. Soc. Am. J. 53: 1771-1778.

Overstreet, W.C., A.M. White, J.W. Whitlow, P.K. Theobald, P.W. Caldwell, and N.P. Cuppels. 1968. Fluvial monazite deposits in the Southeastern United States. U.S. Geol. Survey Prof. Paper. No. 568. 85 pp.

Pavich, M.J. 1986. Processes and rates of saprolite production and erosion on a foliated granitic rock of the Virginia Piedmont. In S.M. Coleman and D.P. Diether (eds.) Rates of chemical weathering of rocks and minerals. Academic Press, Orlando, FL.

Pavich, M.J. 1985. Appalachian Piedmont morphogenesis: weathering, erosion and Cenozoic uplift. In Tectonic geomorphology. SUNY Binghampton Publications in Geomorphology. Allen and Unwin, London.

Rich, C.I. and R.I. Barnhisel. 1977. Preparation of clay samples for X-Ray diffraction analysis. In J.B. Dixon and S.B. Weed (eds.) Minerals in the Soil Environments. Soil Sci. Soc. Am., Inc. Madison WI. pp. 797-808.

Rostad, H.P.N., N.E. Smeck, and L.P. Wilding. 1976. Genesis of argillic horizons in soils derived from coarse-textured calcareous gravels. Soil Sci. Soc. Amer. J. 40: 739-744.

Ruhe, R.V., and P.H. Walker. 1968. Hillslope models and soil formation: I. Open systems. Trans. 9th Intl. Congr. Soil Sci. 4: 551-560.

SAS Institute. 1985. SAS user's guide: Statistics. 5th ed. SAS Inst., Cary NC.

Schwertmann, U. and R.M. Taylor. 1989. Iron oxides In Minerals in the Soil Environments, Dixon & Weed (eds.) Soil Sci. Soc. Am., Madison WI. Agronomy, 1:379-438.

Simonson, R.W. 1959. Outline of a generalized theory of soil genesis. Soil Sci. Soc. Amer. Proc. 23: 152-156.

Smeck, N.E., L.P. Wilding, and N. Holowaychuk. 1968. Genesis of argillic horizons in Celina and Morley soils of western Ohio. Soil Sci. Soc. Amer. Proc. 32: 550-556.

Smeck, N.E., A. Ritchie, L.P. Wilding, and L.R. Drees. 1981. Clay accumulation in sola of poorly drained soils of western Ohio. Soil Sci. Soc. Am. J. 45: 95-102.

Smeck, N.E. and L.P. Wilding. 1980. Quantitative evaluation of pedon formation in calcareous glacial deposits in Ohio. Geoderma 24: 1-16.

Soil Survey Staff. 1981. Soil survey manual. USDA-SCS Agric. Handb. 430-V-SSM. U.S. Govt. Printing. Ofc., Washington, DC.

Soil Survey Staff. 1975. Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. USDA-SCS Agric. Handb. 436. U.S. Govt. Printing Ofc., Washington, DC.

Stoops, G. 1983. The oxic horizon. In Bullock and Murphy (eds.) Soil Micromorphology, AB Academic Press, Berkhamsted, pp 419-440.

Sudom, M.D. and R.J. St. Arnaud. 1971. Use of quartz, zirconium and titanium as indices in pedologic studies. Can J. Soil Sci. 51: 385-396.

Thomas, P.J., J.C. Baker, and T.W. Simpson. 1989. Variability of the Cecil map unit in Appomattox County, Virginia. Soil Sci. Soc. Am. J. 53:1470-1474.

Virginia Division of Mineral Resources. 1963. Geologic map of Virginia. Virginia Division of Mineral Resources.

Walker, P.H., G.F. Hall, and R. Protz. 1968. Soil trends and variability across selected landscapes in Iowa. Soil Sci. Soc. Amer. Proc. 32: 97-101.

Wang, C. and R.W. Arnold. 1973. Quantifying pedogenesis for soils with discontinuities. Soil Soc. Amer. Proc. 37: 271-278.

Webster, R. 1977. Quantitative and numerical methods in soil classification and survey. Clarendon Press, Oxford, UK.

West, L.T., L.P. Wilding, C.R. Stahnke, and C.T. Hallmark. 1988. Calciustolls in Central Texas: I. Parent material uniformity and hillslope effects on carbonate enriched horizons. Soil Sci. Soc. Amer. J. 52: 1722-1731.

Whittecar, C.R. 1985. Stratigraphy and soil development in upland alluvium and colluvium north-central Virginia Piedmont. Southeastern Geology 26:117-129.

Wild, A. 1961. Loss of zirconium from twelve soils derived from granite. Aust. J. Agric. Res. 12: 300-305.

Wilding, L.P., and L.R. Drees. 1983. Spatial Variability and pedology. In Pedogenesis and soil taxonomy. I. Concepts and interactions. Wilding, Smeck, and Hall (eds.) Elsevier Science Publishers, Amsterdam.

Wysocki, D.A., D.A. Lietzke, and L.W. Zelazny. 1988. Effects of parent material weathering on chemical and mineralogical properties of selected Hapludults in the Virginia Piedmont. Soil Sci. Soc. Amer. J. 52: 196-203.

Zar, J.H. 1984. Biostatistical Analysis. Prentice Hall, Englewood Cliffs, NJ. pp 913-974.

APPENDICES

Appendix A. Profile description of the summit soil at Site 1.

NELSON COUNTY CHURCH SUMMIT (NCCS)
PROFILE DESCRIPTION

HORIZON	DEPTH(cm)	DESCRIPTION
A	0-7	Dark Brown (10 YR 3/3) weak, very fine to fine granular structure; very friable; many fine, medium, and coarse roots; abrupt wavy boundary; extremely acid.
E	7-16	Yellowish brown (10 YR 5/8) fine sandy loam; weak, fine granular structure; friable; common fine and medium roots; clear wavy boundary; very strongly acid.
Bt1	16-31	Yellowish red (5 YR 5/6) clay loam; moderate fine subangular blocky structure; friable; few fine and medium roots; common continuous clay films; gradual wavy boundary; very strongly acid.
Bt2	31-48	Red (2.5 YR 5/6) clay; moderate medium subangular blocky structure; friable; few medium roots; many continuous clay films; gradual wavy boundary; very strongly acid.
Bt3	48-63	Red (2.5 YR 4/6) clay; moderate medium subangular blocky; friable; few medium roots; many continuous clay films; clear wavy boundary; strongly acid.
Bt4	63-126	Red (2.5 YR 4/6) sandy clay loam; few distinct yellowish red (5 YR 5/8) and common prominent very pale brown (10 YR 8/4) mottles; weak, fine subangular blocky structure; friable; few continuous clay films; diffuse wavy boundary; strongly acid.
BC	126-170	Red (2.5 YR 5/8) fine sandy loam; weak coarse subangular blocky structure; friable; few discontinuous clay films; gradual wavy boundary; moderately acid.

Appendix A (cont.)

HORIZON	DEPTH(cm)	DESCRIPTION
C1	170-202	Variegated red (2.5 YR 5/8), reddish yellow (5 YR 6/8), strong brown (7.5 YR 5/8), yellowish brown (10 YR 5/6) fine sandy loam; structureless massive; friable; few clay flows; gradual boundary; moderately acid.
C2	202-245	Variegated red (2.5 YR 5/8), reddish yellow (5 YR 6/6), yellow (10 YR 7/6) fine sandy loam; structureless massive; friable; few clay flows; gradual wavy boundary; moderately acid.
C3	245-420	Variegated red (2.5 YR 5/8), reddish yellow (5 YR 6/6), yellow (10 YR 7/6) fine sandy loam; structureless massive, friable; moderately acid.
C4	420-445	Variegated white (10 YR 8/2), very pale brown (10 YR 7/4), very dark grayish brown (10 YR 3/2) loamy fine sand; structureless massive; friable; moderately acid.
C5	445-485	Variegated very pale brown (10 YR 7/4) and very dark grayish brown (10 YR 3/2) loamy fine sand; structureless massive; friable; moderately acid.
C6	485-535	Variegated very pale brown (10 YR 7/4) and brownish yellow (10 YR 6/8) loamy fine sand; structureless massive; friable; moderately acid.
C7	535-620	Variegated light yellowish brown (10 YR 6/4) and brownish yellow (10 YR 6/8) loamy fine sand; structureless massive; friable; moderately acid.
C8	620-725	Variegated light yellowish brown (10 YR 6/4) and brownish yellow (10 YR 6/8) loamy fine sand; structureless massive; friable; moderately acid.
C9	725-750	Variegated light yellowish brown (10 YR 6/4) and brownish yellow (10 YR 6/8) loamy fine sand; structureless massive; friable; moderately acid.

Described from auger samples below 280 cm.

LOCATION: Nelson County, Virginia, on Oak Ridge Estate, 200 meters south of the Oak Ridge Catholic Church, in the woods.

VEGETATION: Oaks

PARENT MATERIAL: Lovingston gneiss.

LANDSCAPE POSITION: Summit

PHYSIOGRAPHY: Upland

SLOPE: 0-1%

ELEVATION: 300 meters

DRAINAGE: Well

EROSION: None

DESCRIBED BY: M.H. Stolt, J.C. Baker, S. Thomas, B. Legge, A.T. Stevens, and H. Beahl.

DATE: 8/20/88

Appendix B. Profile description of the backslope soil at Site 1.

NELSON COUNTY CHURCH BACKSLOPE (NCCB)
PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	DESCRIPTION
A	0-7	Dark brown (10 YR 3/3) fine sandy loam; weak fine granular structure; very friable; many fine, medium, and coarse roots; abrupt wavy boundary; strongly acid.
E	7-28	Reddish yellow (7.5 YR 6/8) fine sandy loam; weak moderate subangular blocky structure; very friable; common fine, medium, and coarse roots; 10-15% gravel size quartz; abrupt wavy boundary; moderately acid.
Bt1	28-43	Red (2.5 YR 4/8) gravelly loam; few distinct yellowish red (5 YR 5/6) mottles; weak moderate subangular blocky structure; friable, few fine and medium roots; common continuous clay films; 10-20% gravel size angular quartz; gradual wavy boundary; strongly acid.
Bt2	43-70	Red (2.5 YR 4/6) clay; few distinct yellowish red (5 YR 5/6) mottles; moderate medium subangular blocky structure; friable; few fine and medium roots; many continuous clay films; gradual wavy boundary; strongly acid.
Bt3	70-98	Red (2.5 YR 4/6) clay; moderate medium subangular blocky structure; friable; few fine and medium roots; many continuous clay films; diffuse wavy boundary; moderately acid.
Bt4	98-130	Red (2.5 YR 4/6) clay; few distinct reddish yellow (5 YR 6/8) mottles; moderate coarse subangular blocky structure; friable; few fine and medium roots; common continuous clay films; diffuse wavy boundary; moderately acid.
BC	130-150	Red (2.5 YR 4/6) loam; few distinct reddish yellow (5 YR 6/6) and few prominent yellow (10 YR 8/8) mottles; weak coarse subangular blocky structure; friable; few fine and medium roots; few discontinuous clay films; diffuse wavy boundary; moderately acid.

Appendix B (cont.)

HORIZON	DEPTH (cm)	DESCRIPTION
C1	150-187	Variegated red (2.5 YR 4/6), light red (2.5 YR 6/6), and dark brown (7.5 YR 3/2) fine sandy loam; structureless massive; friable; few clay flows; diffuse wavy boundary; moderately acid.
C2	187-216	Variegated red (2.5 YR 4/6), reddish yellow (5 YR 6/8), and dark brown (7.5 YR 3/2) fine sandy loam; structureless massive; friable; good rock structure; few clay flows; diffuse wavy boundary; moderately acid.
C3	216-275	Variegated red (2.5 YR 4/6), reddish yellow (5 YR 6/8), and dark brown (7.5 YR 3/2) fine sandy loam; structureless massive; friable; good rock structure; few clay flows; diffuse wavy boundary; moderately acid.
C4	275-340	Variegated strong brown (7.5 YR 4/6) and yellowish brown (10 YR 5/8) loamy fine sand; structureless massive; friable; few discontinuous clay flows; moderately acid.
C5	340-430	Variegated reddish yellow (7.5 YR 6/6) and yellowish red (5 YR 5/8) loamy fine sand; structureless massive; friable; few discontinuous clay flows; moderately acid.
C6	430-450	Very pale brown (10 YR 7/4) loamy fine sand; few distinct reddish yellow (5 YR 6/8) and few prominent red (2.5 YR 5/8) mottles; structureless massive friable; moderately acid.
Cr	450-460	Pale brown (10 YR 6/3) which crushes to loamy fine sand.
Rock	460+	Mica Gneiss.

Described by auger below 275 cm.

LOCATION: Nelson County, VA, on Oak Ridge Estate, 250 meters south of the Oak Ridge Catholic Church in the woods.

VEGETATION: Oaks

PARENT MATERIAL: Lovingston gneiss

LANDSCAPE POSITION: Backslope

PHYSIOGRAPHY: Upland

SLOPE: 12-15%

ELEVATION: 291 meters

DRAINAGE: Well

EROSION: None

DESCRIBED BY: M.H. Stolt, S. Thomas, B. Legge, A.T. Stevens, and H. Beahl

DATE: 8/20/88

Appendix C. Profile description of the footslope soil at Site 1.

NELSON COUNTY CHURCH FOOTSLOPE (NCCF) PROFILE DESCRIPTION

HORIZON	DEPTH (cm)	DESCRIPTION
A	0-10	Brown (10 YR 4/3) fine sandy loam; weak fine granular structure; friable; many fine, medium, and coarse roots; clear wavy boundary; strong by acid.
AB	10-24	Strong brown (7.5 YR 4/6) fine sandy loam; weak medium subangular blocky structure; friable; common fine, medium, and coarse roots; gradual wavy boundary; strongly acid.
Bw1	24-45	Strong brown (7.5 YR 5/6) fine sandy loam; weak moderate subangular blocky structure; friable; common fine and medium roots; gradual wavy boundary; moderately acid.
Bw2	45-67	Strong brown (7.5 YR 5/6) fine sandy loam; weak coarse subangular blocky structure; friable; few fine and medium roots; abrupt wavy boundary; moderately acid.
2Bt	67-100	Strong brown (10 YR 5/6) gravelly sandy clay loam; few distinct red (2.5 YR 5/8) and few faint reddish yellow (7.5 YR 6/3) mottles; moderate fine subangular blocky structure; friable, few fine and medium roots; many discontinuous clay films; angular quartz stone line marks discontinuity; coarse fragments range from 1 to 36 percent; abrupt wavy boundary; moderately acid.
2Crt	100-135	Variegated reddish yellow (5 YR 6/8), black (2.5 YR 2/1), red (2.5 YR 5/8), reddish yellow (7.5 YR 6/8), pinkish grey (7.5 YR 7/2), and pale brown (10 YR 6/3) sandy clay loam; structureless massive; firm; thin 5-10 cm 2BC horizon above; abrupt wavy boundary; moderately acid.

LOCATION: Nelson County, Virginia, on Oak Ridge Estate, 300 meters south of Oak Ridge Catholic Church in the woods.

VEGETATION: Oaks

PARENT MATERIAL: Local alluvium over residuum.

LANDSCAPE POSITION: Footslope

PHYSIOGRAPHY: Upland

SLOPE: 2-6%

ELEVATION: 285 meters

DRAINAGE: Moderately well

EROSION: None

DESCRIBED BY: M.H. Stolt, S. Thomas, Bruce Legge, A.T. Stevens, and H. Beahl

DATE: 8/21/88

Appendix D. Profile description of the summit soil at Site 2.

NELSON COUNTY THEATRE SUMMIT (NCTS)
PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-10	Dark yellowish brown (10 YR 4/4) loam; moderate fine granular structure; very friable; common fine, medium, and coarse roots; abrupt wavy boundary; strongly acid.
E	10-17	Reddish yellow (7.5 YR 6/6) loam; weak medium subangular blocky structure; friable; common fine, medium, and coarse roots; clear wavy boundary; strongly acid.
Bt1	17-37	Red (2.5 YR 4/8) clay loam; few distinct yellowish red (5 YR 5/6) mottles; moderate medium subangular blocky structure; friable; common coarse, and few fine and medium roots; common continuous clay films; gradual wavy boundary; strongly acid.
Bt2	37-57	Red (2.5 YR 4/6) clay; moderate medium subangular blocky structure; friable; few fine, medium, and coarse roots; many continuous clay films; diffuse wavy boundary; strongly acid.
Bt3	57-97	Red (2.5 YR 4/8) clay; moderate medium subangular blocky structure; friable; few fine and medium roots; many continuous clay films; diffuse wavy boundary; strongly acid.
BC1	97-123	Red (2.5 YR 5/8) clay loam; few distinct pink (5 YR 7/4) mottles; weak coarse subangular blocky structure; friable; few fine and medium roots; common discontinuous and few continuous clay films; diffuse wavy boundary; moderately acid.

Appendix D (cont)

Horizon	Depth (cm)	Description
BC2	123-160	Red (2.5 YR 5/8) loam; few distinct pink (5 YR 7/4) mottles; weak coarse subangular blocky structure to structureless massive; friable, few fine and medium roots; few discontinuous clay films; gradual wavy boundary; moderately acid.
C1	160-186	Variegated red (2.5 YR 4/6), reddish yellow (5 YR 6/8) and reddish yellow (7.5 YR 6/8) loam; structureless massive; friable; few fine and medium roots; many clay flows; diffuse wavy boundary; moderately acid.
C2	186-247	Variegated red (2.5 YR 4/6), reddish yellow (5 YR 6/8), reddish yellow (7.5 YR 6/8), and very dark greyish brown (10 YR 3/2) fine sandy loam; structureless massive; friable; many clay flows; clear wavy boundary; moderately acid.
C3	247-280	Variegated red (2.5 YR 5/8), reddish yellow (7.5 YR 7/6), very pale brown (10 YR 8/4), brownish yellow (10 YR 6/8), and very dark greyish brown (10 YR 3/2) loamy fine sand, structureless massive; friable; abrupt wavy boundary; moderately acid.
C4	280-320	Variegated reddish yellow (5 YR 6/8), brownish yellow (10 YR 6/8), very pale brown (10 YR 7/3), and black (10 YR 2/1) loamy fine sand; good rock structure; moderately acid.
C5	320-405	Variegated reddish yellow (7.5 YR 6/8), very pale brown (10 YR 8/4), brownish yellow (10 YR 6/6), and black (10 YR 2/1) loamy fine sand; moderately acid.
C6	405-450	Variegated strong brown (7.5 YR 5/8), yellowish brown (10 YR 5/8), very pale brown (10 YR 2/1) loamy fine sand; moderately acid.
Rock	450+	Mica Gneiss

Appendix D (cont.)

LOCATION: Nelson County, Virginia on Oak Ridge Estate, 25 meters east of old theatre site in the woods.

VEGETATION: Oaks

PARENT MATERIAL: Lovingston gneiss

PHYSIOGRAPHY: Upland

LANDSCAPE POSITION: Summit

SLOPE: 0-1%

ELEVATION: 300 meters

DRAINAGE: Well drained

EROSION: None

DESCRIBED BY: M. Stolt, S. Thomas, B. Legge, S. Cromer, A.T. Stevens, and H. Beahl

DATE: 8/25/88

Appendix E. Profile description of the backslope soil at Site 2.

NELSON COUNTY THEATRE BACKSLOPE (NCTB) PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-8	Dark brown (7.5 YR 4/4) loam; weak fine granular structure; very friable; many fine, medium, and coarse roots; clear wavy boundary; very strongly acid.
Bt1	8-35	Yellowish red (5 YR 5/8) loam; weak medium subangular blocky structure; friable; common fine, medium, and coarse roots; common continuous clay films; gradual wavy boundary; very strongly acid.
Bt2	35-64	Red (2.5 YR 4/6) clay; moderate medium subangular blocky structue; friable, few fine and medium roots; common continuous clay films; diffuse wavy boundary; strongly acid.
Bt3	64-92	Red (2.5 YR 4/8) clay; moderate medium subangular blocky structure; friable; few fine and medium roots; common continuous clay films; clear wavy boundary; strongly acid.
Bt4	92-120	Red (2.5 YR 4/8) clay; few distinct strong brown (7.5 YR 5/8) mottles; moderate medium subangular blocky structure; few fine and medium roots; common continuous clay films; gradual wavy boundary; moderately acid.
2Bt5	120-148	Red (2.5 YR 4/6) very gravelly clay; moderate medium subangular blocky structure; friable; common continuous clay films; angular quartz stone line (35% c.f.); abrupt wavy boundary; moderately acid.
2BC1	148-165	Red (2.5 YR 4/6) clay loam; weak coarse subangular blocky structure; friable; few continuous clay films; gradual wavy boundary; moderately acid.

Appendix E (cont.)

Horizon	Depth (cm)	Description
3BC2	65-187	Red (2.5 YR 4/6) sandy clay loam; few distinct yellowish red (5 YR 5/8) mottles; weak coarse subangular blocky structure; friable; few continuous clay films; gradual wavy boundary; strongly acid.
3C1	320-350	Variegated reddish yellow (7.5 YR 7/8) and very pale brown (10 YR 8/3) fine sandy loam; strongly acid.
3C2	350-370	Reddish yellow (5 YR 6/8) fine sandy loam; moderately acid.
3Cr	370-390	Variegated red (2.5 YR 5/8), black (n 2/0), and very pale brown (10 YR 8/3) fine sandy loam; moderately acid.
Rock	390+	Mica gneiss.

Below 275 cm described and sampled with a bucket auger.

LOCATION: Nelson County, Virginia, Oak Ridge Estate, 100 meters west of old theatre site in woods.

VEGETATION: Oaks

PARENT MATERIAL: Colluvium over Lovingston geiss.

PHYSIOGRAPHY: Upland

LANDSCAPE POSITION: Backslope

SLOPE: 12-15%

ELEVATION: 296 meters

DRAINAGE: Well drained

EROSION: Slight

DESCRIBED BY: M.H. Stolt, M. Genthner, S. Thomas, B. Legge, S. Cromer, A.T. Stevens, and H. Beahl

DATE: 8/25/88

Appendix F. Profile description of the footslope soil at Site 2.

NELSON COUNTY THEATRE FOOTSLOPE (NCTF)
PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-11	Dark brown (10 YR 3/3) loam; weak fine subangular blocky breaking to weak fine granular; very friable; many fine and medium roots; abrupt wavy boundary; strongly acid.
E	11-25	Yellowish brown (10 YR 5/8) fine sandy loam; weak medium subangular blocky structure; friable; common fine and medium roots; clear wavy boundary; very strongly acid.
Bt1	25-37	Strong brown (7.5 YR 4/6) loam; weak medium subangular blocky structure; friable; few and fine medium roots; common continuous clay films; clear wavy boundary; very strongly acid.
Bt2	37-61	Yellowish red (5 YR 5/8) loam; weak medium subangular blocky structure; friable; few fine and medium roots; common continuous clay films; clear wavy boundary; strongly acid.
2BC	61-79	Yellowish red (5 YR 4/6) fine sandy loam; few distinct strong brown (7.5 YR 4/6) mottles; weak moderate subangular blocky structure; friable; few fine and medium roots; common continuous clay films; clear wavy boundary; strongly acid.
2C	79-90	Variegated reddish yellow (5 YR 6/6 and 7/8), strong brown (7.5 YR 5/8), dark brown (7.5 YR 4/4), and brownish yellow (10 YR 6/6) sandy clay loam; structureless massive; friable; clear wavy boundary; strongly acid.
2Cr	90-100	Variegated strong brown (7.5 YR 5/8), yellowish brown (10 YR 5/8), very pale brown (10 YR 8/4), and black (10 YR 2/1) that crushes to fine sandy loam; structureless massive; friable, good rock structure; abrupt wavy boundary.

Appendix F (cont.)

LOCATION: Nelson County, Virginia, on Oak Ridge Estate, 200 meters east of old theatre site in woods.

VEGETATION: Oaks

PARENT MATERIAL: Local Alluvium over lovingston augen gneiss.

PHYSIOGRAPHY: Upland

LANDSCAPE POSITION: Footslope

SLOPE: 3-6%

ELEVATION: 290 meters

DRAINAGE: Moderately well

EROSION: None

DESCRIBED BY: M.H. Stolt, M. Genthner, S. Thomas, B. Legge, S. Cromer, A.T. Stevens, and H. Beahl

DATE: 8/24/88

Appendix G. Profile description of the summit soil at Site 3.

HIGH ROCK CHURCH SUMMIT (HRCS)
PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-18	Very dark greyish brown (10 YR 3/2) sandy loam; fine moderate granular structure; very friable; common fine and medium roots; clear smooth boundary; moderately acid.
E	18-28	Brown (7.5 YR 4/2), with very dark greyish (10 YR 3/2) earthworm crotovinas, sandy loam; weak medium subangular blocky structure; very friable; common fine, medium, and coarse roots; gradual wavy boundary; moderately acid.
BE	28-45	Strong brown (7.5 YR 5/6) loam; common zones of dark brown (7.5 YR 3/2); weak medium subangular blocky structure; friable; few fine, medium, and coarse roots; gradual wavy boundary; moderately acid.
Bt1	45-58	Strong brown (7.5 YR 5/6) clay loam; few faint reddish yellow (7.5 YR 6/6), yellowish red (5 YR 5/6), and few distinct red (2.5 YR 5/6) mottles; weak medium subangular blocky structure; friable; common continuous clay films; few fine and medium roots; gradual wavy boundary; moderately acid.
Bt2	58-83	Yellowish red (5 YR 5/6) clay loam; common faint yellowish red (5 YR 4/6), reddish yellow (5 YR 6/6), and red (2.5 YR 4/6) mottles; moderate medium subangular blocky structure; friable; many continuous clay films; few fine and medium roots; gradual wavy boundary; moderately acid.
Bt3	83-120	Yellowish red (5 YR 5/6) clay loam; many distinct yellowish brown (10 YR 5/6), many faint reddish yellow (5 YR 6/6) and reddish brown (5 YR 4/6) mottles; weak medium subangular blocky structure; friable; common continuous clay films; clear wavy boundary; moderately acid.

Appendix G (cont.)

Horizon	Depth (cm)	Description
BC	120-150	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) loam; weak coarse subangular blocky structure; friable; few continuous clay films; common Mn coatings; few augens; gradual wavy boundary; strongly acid.
C1	150-205	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; few discontinuous clay films; many Mn coatings; common augens; gradual wavy boundary; strongly acid.
C2	205-310	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; few discontinuous clay films; many Mn coatings; common augens; strongly acid.
C3	310-490	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; few discontinuous clay films; many Mn coat-ings; common augens; strongly acid.
C4	490-610	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; many Mn coatings; common augens; strongly acid.

Appendix G (cont.)

C5	610-780	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; many Mn coatings; common augens; strongly acid.
C6	780 1145+	Variegated strong brown (7.5 YR 5/6 & 4/6), reddish yellow (7.5 YR 6/8), light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), black (N 2/0), and white (N 8/0) sandy loam; structureless massive; friable; many Mn coatings; common augens; strongly acid.

Described from auger samples below 240 cm. BC horizon showed structure breaks parallel to soil surface and normal to rock structure. Clay coatings occurred along these breaks.

LOCATION: Montgomery county, Virginia, 10 meters east of the entrance to High Rock Church.

VEGETATION: Oaks

PARENT MATERIAL: Augen gneiss (Blue Ridge Complex)

LANDSCAPE POSITION: Summit

PHYSIOGRAPHY: Upland

SLOPE: 1-2%

ELEVATION: 725 meters

DRAINAGE: Well

EROSION: None

DESCRIBED BY: M.H. Stolt, B.R. Stewart, and H. Beahl

DATE: 3/14/89

Appendix H. Profile description of the backslope soil at Site 3.

HIGH ROCK CHURCH BACKSLOPE (HRCB)
PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-18	Dark yellowish brown (10 YR 3/4) sandy loam; moderately fine granular structure; very friable; many medium and coarse roots; clear wavy boundary; moderately acid.
E	18-41	Yellowish Brown (10 YR 5/4) and dark yellowish brown (10 YR 4/4) sandy loam; weak medium subangular block structure parting to weak thin platy; very friable; common fine and medium roots; gradual wavy boundary; strongly acid.
EB	41-58	Dark brown (7.5 YR 4/4) sandy clay loam; few faint dark yellowish brown (10 YR 3/4) and brown (7.5 YR 5/4) \ones due to mixing; few distinct red (2.5 YR 5/8) mottles; weak medium subangular block structure; friable; common fine roots; gradual wavy boundary; moderately acid.
Bt1	58-75	Yellowish red (5 YR 5/8) clay loam; common faint light red (2.5 YR 6/8), red (2.5 YR 4/8), and strong brown (7.5 YR 5/8) mottles; moderate medium subangular blocky structure; friable; common continuous clay films; common fine roots; gradual wavy boundary; strongly acid.
2Bt2	75-106	Yellowish red (5 YR 5/8) clay loam; common faint light red (2.5 YR 6/8), red (2.5 YR 4/8), brown (7.5 YR 5/4) mottles; moderate medium subangular blocky structure; friable; many continuous clay films; common fine roots; thin discontinuous stone line of quartz from 85-90 cm; diffuse wavy boundary; strongly acid.

Appendix H (cont.)

Horizon	Depth (cm)	Description
2Bt3	106-128	Yellowish red (5 YR 5/8) sandy clay loam; many faint red (2.5 YR 5/8), light red (2.5 YR 6/8 & 6/6), and strong brown (7.5 YR 5/8) mottles; weak medium subangular blocky structure; friable; common continuous clay films; few fine roots; observable rock structure; common Mn coatings; clear wavy boundary; strongly acid.
2BC	128-150	Yellowish red (5 YR 5/8) sandy loam/sandy clay loam; many faint red (2.5 YR 5/8) and many distinct pinkish grey (5 YR 6/2) mottles; weak coarse subangular blocky structure; friable; common continuous clay films; few fine roots; common Mn coatings; clear wavy boundary; strongly acid.
2C1	150-200	Variegated reddish brown (5 YR 5/4), light reddish brown (2.5 YR 6/4), reddish brown (2.5 YR 5/4), light brownish grey (10 YR 6/2), white (10 YR 8/2), and brownish yellow (10 YR 6/8) sandy loam; structureless massive; friable; few continuous clay films; few fine roots, many Mn coatings; diffuse wavy boundary; moderately acid.
2C2	200-260	Variegated reddish brown (5 YR 5/4), light reddish brown (2.5 YR 6/4), reddish brown (2.5 YR 5/4), light brownish grey (10 YR 6/2), white (10 YR 8/2), and brownish yellow (10 YR 6/8) sandy loam; structureless massive; friable; few continuous clay films; few fine roots, many Mn coatings; diffuse wavy boundary; moderately acid.
2C3	260-300	Variegated reddish brown (5 YR 5/4), light reddish brown (2.5 YR 6/4), reddish brown (2.5 YR 5/4), light brownish grey (10 YR 6/2), white (10 YR 8/2), and brownish yellow (10 YR 6/8) sandy loam; structureless massive; friable; few continuous clay films; few fine roots, many Mn coatings; moderately acid.

Appendix H (cont.)

Horizon	Depth (cm)	Description
2Cr	300-390	Variegated reddish brown (5 YR 5/4), light reddish brown (2.5 YR 6/4), reddish brown (2.5 YR 5/4), light brownish grey (10 YR 6/2), white (10 YR 8/2), and brownish yellow (10 YR 6/8) sandy loam; structureless massive; friable; few continuous clay films; few fine roots, many Mn coatings; moderately acid.
Rock	390+	Augen Gneiss

Described from auger samples below 260 cm. Evidence of tree thrown in the pit (D-face). The Bt1, Bt2, and Bt3 horizons were very thin along this face.

LOCATION:	Montgomery county, Virginia, 20 meters south of the High Rock Church.
VEGETATION:	Oaks and pines
PARENT MATERIAL:	Augen gneiss (Blue Ridge Complex)
LANDSCAPE POSITION:	Backslope

PHYSIOGRAPHY: Upland

SLOPE: 12-15%

ELEVATION: 715 meters

DRAINAGE: Well

EROSION: None

DESCRIBED BY: M.H. Stolt, B.R. Stewart, and H. Beahl

DATE: 3/16/89

Appendix I. Profile description of the footslope soil at Site 3.

HIGH ROCK CHURCH FOOTSLOPE (HRCF)
PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-11	Dark yellowish brown (10 YR 3/4) sandy loam; weak fine subangular blocky to weak fine granular structure; friable; many fine and medium, and common coarse roots; abrupt smooth boundary; strongly acid.
E	18-30	Yellowish brown (10 YR 5/6) sandy loam; common zones of a horizon material; weak medium subangular blocky structure; friable; few medium and fine roots; gradual wavy boundary; strongly acid.
BE	30-44	Yellowish brown (10 YR 5/8) loam; weak medium subangular blocky structure; friable; few fine roots; abrupt smooth boundary; strongly acid.
2Bt1	44-75	Yellowish red (5 YR 5/8) clay loam; red (2.5 YR 5/8) and very dark grey (10 YR 3/1) mottles; moderate medium subangular blocky structure; friable; many continuous red (7.5 YR 5/8) clay films; few fine roots; stone line of olive brown (2.5 YR 4/4) schist at upper boundary; gradual wavy boundary; strongly acid.
2Bt2	75-108	Yellowish red (5 YR 5/8) sandy clay loam; few faint reddish yellow (7.5 YR 6/8) and few distinct red (2.5 YR 4/8) mottles; weak coarse subangular blocky structure; friable; common continuous red (2.5 YR 4/8) clay films; many of the clay films were parallel to the surface and normal to the rock structure; few fine roots; abrupt wavy boundary; strongly acid.
2Bt3	108-120	Yellowish red (5 YR 5/6) clay; weak medium subangular blocky structure; parting along rock faces; friable; many continuous red (2.5 YR 4/8) clay films; common fine and medium roots; abrupt wavy boundary; strongly acid.

Appendix I (cont.)

Horizon	Depth (cm)	Description
2BC	120-145	Brownish yellow (10 YR 6/8) sandy loam; common faint light yellowish brown and common prominent red (2.5 YR 5/6) mottles; weak coarse subangular blocky structure parting along rock faces, friable; common continuous strong brown (7.5 YR 4/6) clay films; few fine roots; few black (10 YR 2/1) Mn coatings; common white (5 YR 8/1) augers; gradual wavy boundary; strongly acid.
2C1	145-190	Variegated light yellowish brown (10 YR 6/4), yellow (10 YR 7/8), black (10 YR 2/1), yellowish red (5 YR 5/8), and white (5 YR 8/1) sandy loam; structureless massive; friable; few fine roots; common Mn coatings; many augers; gradual wavy boundary; strongly acid.
2C2	190-295	Variegated yellowish brown (10 YR 5/6), very dark brown (10 YR 2/2), reddish yellow (7.5 YR 7/8), yellowish red (5 YR 4/6), and white (5 YR 8/1) sandy loam; structureless massive; friable; few fine roots; common Mn coatings; many augers; strongly acid.
2Cr	295-310	Variegated yellowish brown (10 YR 5/6), very dark brown (10 YR 2/2), reddish yellow (7.5 YR 7/8), yellowish red (5 YR 4/6), and white (5 YR 8/1) sandy loam; structureless massive; friable; few fine roots; common Mn coatings; many augers; strongly acid.
Rock	310+	Augen gneiss.

Described from auger sample below 220 cm. The thickness of the 2Bt3 varies from 8-20 cm. The 2Bt3 horizon was totally absent along the C and D faces. Thin zones of weathered schist (2-3 cm thick) were present in the 2C1 and 2C2 horizons. A blue quartz stone line was observed in the C and D faces within the 2Bt horizon, but could not be located in the A and B faces.

LOCATION: Montgomery County, Virginia, 50 meters south of High Rock Church.

VEGETATION: Black locust

PARENT MATERIAL: Colluvium over augen gneiss

LANDSCAPE POSITION: Foot slope

PHYSIOGRAPHY: Upland

SLOPE: 3-4%

ELEVATION: 700 meters

DRAINAGE: Well

EROSION: None

DESCRIBED BY: M.H. Stolt, M. Matt, M. Baker, and H. Beahl

DATE: 6/2/89

Appendix J. Profile description of the summit soil of Site 4.

Harrison Farm Summit (HFS)
PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-7	Dark brown (10 YR 3/3) silt loam; weak fine granular structure; friable; many fine and medium roots; clear wavy boundary; extremely acid.
E	7-18	Very pale brown (10 YR 7/4) silt loam; weak medium subangular block structure parting to weak thin platy; friable; common fine and medium roots; gradual wavy boundary; extremely acid.
BE	18-28	Strong brown (7.5 YR 5/8) silty clay loam; weak medium subangular block structure; friable; common fine and medium roots; few continuous clay films; gradual wavy boundary; very strongly acid.
Bt1	28-54	Yellowish red (5 YR 5/8) silty clay loam; moderate medium subangular blocky structure; friable; many continuous clay films; few fine and medium roots; gradual wavy boundary; very strongly acid.
Bt2	54-72	Red (2.5 YR 5/6) clay; common distinct light grey (5 YR 7/1)and reddish yellow (7.5 YR 7/8) mottles; weak medium subangular blocky structure; friable; common continuous clay films; few fine and medium roots; some evidence of rock structure; gradual wavy boundary; strongly acid.
BC1	72-96	Red (2.5 YR 5/8) silt loam; many distinct light grey (5 YR 7/1) and reddish yellow (7.5 YR 7/8) mottles; weak medium subangular blocky structure; friable; common continuous clay films; evidence of rock structure; gradual wavy boundary; strongly acid.

Appendix J (cont.)

Horizon	Depth (cm)	Description
BC2	96-114	Red (2.5 YR 5/8) silt loam; many distinct white (N 8/0) and reddish yellow (7.5 YR 7/8) mottles; weak medium subangular blocky structure; friable; common continuous clay films; evidence of rock structure; gradual wavy boundary; strongly acid.
C1	114-176	Variegated red (2.5 YR 5/8), reddish yellow (5 YR 7/8) and white (N 8/0) loam; rock controlled structure; friable; few continuous clay films; common Mn coatings; contained a 10-20 cm zone of hard but weathered schist; clear wavy boundary; strongly acid.
C2	176-265	Variegated red (2.5 YR 5/8), reddish yellow (5 YR 7/8) and white (N 8/0) loam; rock controlled structure; friable; few continuous clay films; common Mn coatings; thin zone of hard but weathered schist at the base of the horizon; clear wavy boundary; moderately acid.
C3	265-330	Variegated light red (2.5 YR 6/6), reddish yellow (5 YR 7/8) and white (N 8/0) silt loam; rock controlled structure; friable; few continuous clay films; common Mn coatings; strongly acid.
C4	330-445	Reddish yellow (7.5 YR 6/8) sandy loam; many distint yellowish red (5YR 5/8) and white (N 8/0) mottles; rock controlled structure; friable; moderately acid.
C5	445-525	Brownish yellow (10 YR 6/8) sandy loam; many distint yellowish red (5YR 5/8) and white (N 8/0) mottles; rock controlled structure; friable; moderately acid.
C6	525-580	Brownish yellow (10 YR 6/8) sandy loam; many distint yellowish red (5YR 5/8) and white (N 8/0) mottles; rock controlled structure; friable; moderately acid.

Appendix J (cont.)

Horizon	Depth (cm)	Description
C7	580-655	Brownish yellow (10 YR 6/8) sandy loam; many distint yellowish red (5YR 5/8) and white (N 8/0) mottles; rock controlled structure; friable; moderately acid.
C8	655-790	Brownish yellow (10 YR 6/8) sandy loam; many distint yellowish red (5YR 5/8) and white (N 8/0) mottles; rock controlled structure; friable; strongly acid.
C9	655-850	Brownish yellow (10 YR 6/8) sandy loam; many distint yellowish red (5YR 5/8) and white (N 8/0) mottles; rock controlled structure; friable; moderately acid.

Notes: Described from auger samples below 285 cm. Quartz vein at 850 cm.

LOCATION: Montgomery county, Virginia, Harrison Farm, off rt 612, first block of woods south of the farmhouse.

VEGETATION: Oaks.

PARENT MATERIAL: Gneissic schist (Blue Ridge Complex).

LANDSCAPE POSITION: Summit.

PHYSIOGRAPHY: Upland

SLOPE: 0-2%.

ELEVATION: 715 meters

DRAINAGE: Well

EROSION: None

DESCRIBED BY: M.H. Stolt, C. Ogg, and H. Beahl.

DATE: 10/25/88

Appendix K. Profile description of the backslope soil at Site 4.

Harrison Farm Backslope (HFB)
PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-9	Dark brown (10 YR 3/3) silt loam; weak fine granular structure; friable; many fine and medium roots; clear wavy boundary; extremely acid.
A2	9-16	Dark yellowish brown (10 YR 4/6) silt loam; weak fine granual structure; friable; common fine and medium roots; clear wavy boundary; very strongly acid.
Bt1	16-27	Reddish brown (5 YR 5/4) silty loam; weak medium subangular block structure; friable; few fine roots; common continuous clay films; gradual wavy boundary; very strongly acid.
Bt2	27-48	Yellowish red (5 YR 5/8) clay loam/clay; moderate medium subangular blocky structure; friable; many continuous clay films; few fine and medium roots; gradual wavy boundary; strongly acid.
Bt3	48-63	Red (2.5 YR 5/6) clay loam; common distinct light yellowish (10 YR 6/4) mottles; moderate medium subangular blocky structure; friable; many continuous clay films; few fine and medium roots; clear wavy boundary; strongly acid.
BC1	63-81	Red (2.5 YR 5/8) and light yellowish brown (10 YR 6/4) loam; many prominent black (10YR 2/1) and white 5Y 8/1) mottles; weak medium subangular blocky structure; friable; common continuous clay films; evidence of rock structure; gradual wavy boundary; strongly acid.
BC2	81-96	Light yellowish brown (10 YR 6/4) sandy loam many prominent white (N 8/0) and many distinct reddish yellow (7.5 YR 7/8) mottles; wrock controlled structure; friable; few fine roots; few discontinuous red (2.5 YR 4/8) clay films; gradual wavy boundary; moderately acid.

Appendix K (cont.)

Horizon	Depth (cm)	Description
C1	96-144	Variegated red (2.5 YR 5/8), reddish yellow (5 YR 7/8), pale brown (10YR 6/3), black (10YR 2/1) and white (N 8/0) loam; rock controlled structure; friable; few fine roots; gradual wavy boundary; moderately acid.
C2	144-170	Variegated red (2.5 YR 5/8), reddish yellow (5 YR 7/8), pale brown (10YR 6/3), black (10YR 2/1) and white (N 8/0) loam; rock controlled structure; friable; few fine roots; clear wavy boundary; moderately acid.
C3	170-241	Variegated red (2.5 YR 5/8), reddish yellow (5 YR 7/8), light yellowish brown (10YR 6/4), black (10YR 2/1) and white (N 8/0) sandy loam; rock controlled structure; friable; few fine roots; clear wavy boundary; moderately acid.
C4	241-360	Light yellowish brown (10 YR 6/4) sandy loam; many prominent white (5Y 8/1), and black (10YR 2/1), and many distinct strong brown (7.5YR 5/8) and reddish yellow (7.5 YR 5/8) mottles; rock controlled structure; friable; moderately acid.
C5	360-410	Light yellowish brown (10 YR 6/4) silt loam; many prominent white (5Y 8/1), and black (10YR 2/1), and many distinct strong brown (7.5YR 5/8) and reddish yellow (7.5 YR 5/8) mottles; rock controlled structure; friable; moderately acid.
C6	410-580	Light yellowish brown (10 YR 6/4) silt loam; many prominent white (5Y 8/1), and black (10YR 2/1), and many distinct strong brown (7.5YR 5/8) and reddish yellow (7.5 YR 5/8) mottles; rock controlled structure; friable; moderately acid.

Appendix K (cont.)

Horizon	Depth (cm)	Description
C7	410-610	Yellowish brown (10 YR 5/4) silt loam; many prominent white (5Y 8/1), and black (10YR 2/1), and many distinct strong brown (7.5YR 5/8) and reddish yellow (7.5 YR 5/8) mottles; rock controlled structure; friable; moderately acid.

Notes: Described from auger samples below 280 cm. Quartz vein at 610 cm.

LOCATION: Montgomery county, Virginia, Harrison Farm, off rt 612, first block of woods south of the farmhouse.

VEGETATION: Oaks and pines.

PARENT MATERIAL: Gneissic schist (Blue Ridge Complex).

LANDSCAPE POSITION: Backslope.

PHYSIOGRAPHY: Upland

SLOPE: 14%.

ELEVATION: 707 meters

DRAINAGE: Well

EROSION: None

DESCRIBED BY: M.H. Stolt and H. Beahl.

DATE: 10/28/88

Appendix L. Profile description of the backslope soil at Site 4.

Harrison Farm Footslope (HFF)
PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-18	Brown (10 YR 4/3) gravelly silt loam; weak medium granular structure; friable; 29% quartz angular gravels; common fine and medium roots; clear wavy boundary; very strongly acid.
BA	18-32	Brown (10 YR 4/3) and strong brown (7.5 YR 5/6) gravelly silt loam; weak medium subangular blocky structure; friable; 29% angular quartz gravels; common fine and medium roots; gradual wavy boundary; very strongly acid.
Bt1	32-47	Strong brown (7.5 YR 5/6) gravelly silt loam; moderate medium subangular blocky structure; friable; common fine and medium roots; 22% angular quartz gravels; common continous clay films; gradual wavy boundary; strongly acid.
Bt2	47-73	Strong brown (7.5 YR 5/6) gravelly loam; common distinct yellow (10YR 7/8) mottles; moderate medium subangular blocky structure; friable; 16% angular quartz gravels; few fine and medium roots; many continuous clay films; gradual wavy boundary; strongly acid.
2Bt3	73-105	Strong brown (7.5 YR 5/6) loam; connon distinct yellow (10 YR 7/8) mottles; weak medium subangular blocky structure; friable; few fine and medium roots; common continous clay films; clear wavy boundary; strongly acid.
2BC1	105-163	Variegated very pale brown (10 YR 8/3) yellow (10 YR 7/6), and light gray (10 YR 7/1) loam; weak coarse subangular blocky structure; friable; few fine and medium roots; common continuous red (2.5 YR 4/6) clay films; gradual wavy boundary; strongly acid.

Appendix L (cont.)

Horizon	Depth (cm)	Description
2BC2	163-192	Variegated very pale brown (10 YR 8/3) yellow (10 YR 7/6), and light gray (10 YR 7/1), and black 10 YR 2/1) loam; rock controlled structure; friable; fine roots; gradual wavy boundary; strongly acid.
2C1	192-285	Light yellowish brown (10 YR 6/4) sandy loam; many prominent light gray (10 YR 7/1), black (10 YR 2/1), and very pale brown (10 YR 8/3) mottles; rock con trolled structure; firm; moderately acid.
2C2	285-335	Strong brown (7.5 YR 5/6) sandy loam; many prominent light gray (10 YR 7/1), black (10 YR 2/1), and very pale brown (10 YR 8/3) mottles; rock controlled structure; friable; moderately acid.
2C3	235-455	Strong brown (7.5 YR 5/6) sandy loam; many prominent light gray (10 YR 7/1), black (10 YR 2/1), and very pale brown (10 YR 8/3) mottles; rock controlled structure; friable; moderately acid.
2C4	455-515	Brownish yellow (10 YR 6/6) sandy loam; many prominent light gray (10 YR 7/1), black (10 YR 2/1), and very pale brown (10 YR 8/3) mottles; rock controlled structure; friable; moderately acid.
2C5	515-555	Yellowish brown (10 YR 5/4) sandy loam; many prominent light gray (10 YR 7/1), black (10 YR 2/1), and very pale brown (10 YR 8/3) mottles; rock controlled; moderately acid.
2Cr	555-600	Yellowish brown (10 YR 5/4) sandy loam; many prominent light gray (10 YR 7/1), black (10 YR 2/1), and very pale brown (10 YR 8/3) mottles; rock controlled moderately acid.
Rock	600+	Gneissic Schist

Notes: Described from auger samples below 285 cm.

LOCATION: Montgomery county, Virginia, Harrison Farm, off rt 612, first block of woods south of the farmhouse.

VEGETATION: White pines.

PARENT MATERIAL: Colluvium over Gneissic schist residium (Blue Ridge Complex).

LANDSCAPE POSITION: Footslope.

PHYSIOGRAPHY: Upland

SLOPE: 2-6%

ELEVATION: 697 meters

DRAINAGE: Well

EROSION: None

DESCRIBED BY: M.H. Stolt and H. Beahl.

DATE: 10/29/88.

Appendix M. Thin section descriptions of the summit soil at Site 1.

Pedon: NCCS Horizon: Bt3 (48-63cm) Size: 5.8x2.2cm
Described by: MHS 1/30/1990

Microstructure:

Subangular blocky soil material, peds are primarily subangular blocky (3.5-15m) with strong to moderate expression, and accommodating to partially accommodating. Few peds have crumb morphology (240-600u), strong expression and are unaccommodating. Void space is distributed between planar voids (7.5% and 30-600u) and vughs (3.4% and 450-2400u). Planar voids show parallel, inclined, and normal basic distribution patterns. Parallel voids show a parallel referred distribution pattern to that of the soil surface.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.26

Mineral components are poorly sorted with an open porphyric c/f related distribution pattern. The birefringence fabric is speckled and 16% of the fine material occurs as oriented clay. The coarse fraction is primarily composed of quartz, feldspar and mica. Quartz grains are 5-600u with less than 2 (0) irregular, cross, linear alteration. Mica grains range in size from 5-300u and show from 25% to total alteration (1-4). Feldspar grains (5-300u) showed less than 25% parallel and cross linear alteration, and mica grains show less than 25% pellicular alteration. Few mica gneiss rock fragments are observed from 0.5-1.0m.

Textural Pedofeatures:

Typic planar void and vugh textural coatings and infillings are common. All coatings and infillings show parallel micro lamination and orange color under PPL. Planar coatings (25-125u) are composed of limpid to dusty clay with sharp to diffuse orientation. Vugh coatings are 12-60u in thickness, composed of limpid clay, and show sharp to diffuse orientation. Dense complete infillings (60-180u) occur within vughs and planar voids and are composed of limpid clay with sharp orientation.

Other Pedofeatures:

A few mottle type nodules (600-800u) occur. These are rich in Fe, dark red under PPL, and moderate to strongly impregnated. A few internal grain hypocoatings (100-150u), rich in Fe, dark red and moderately to strongly inpregnated also occur.

Appendix M (cont.)

Pedon: NCCS Horizon: Bt4 (63-126cm) Size: 5.5x2.1cm
Described by: MHS 1/30/1990

Microstructure:

Subangular blocky soil material, many subangular blocky peds (11-16m) occur with moderate to strong expression, and are accommodating to partially accommodating. Peds with subangular blocky (3-8u) morphology, with strong expression and accommodating, are common. Void space is distributed between planar voids (3.2%), and vughs (13% and 30-300u). The larger planar voids (30-300u) show a parallel distribution pattern while the smaller planar voids (30-200u) show inclined and normal basic distribution patterns. Planar voids showing parallel distribution pattern showed a parallel distribution pattern to that of the soil surface.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.24

Mineral components are poorly sorted with a mostly open porphyric c/f related distribution with some close porphyric distribution. The birefringence fabric is speckled and 10.5% of the fine material occurs as oriented clay. The coarse fraction is primarily composed of quartz, feldspar and mica. Quartz grains are 5-600u with less than 25% (0) pellicular alteration, mica grains range in size between 5-300u with 25% to total parallel (1-4) linear alteration and less than 25% pellicular alteration (0-1). Feldspar grains are 5-300um with less than 75% (0-3) cross linear and less than 25% (0-1) pellicular alteration. Few biotite gneiss rock fragments occur.

Textural Pedofeatures:

Typic planar void and vugh textural coatings are common. Few complete and incomplete infillings occur within vughs and planar voids. All coatings and infillings show parallel micro lamination and orange color under PPL. Many planar coatings (40-125u) are composed of limpid to dusty clay with sharp to diffuse orientation. Vugh coatings (60-120u) are common, and composed of limpid clay with sharp to diffuse orientation. Incomplete infillings (100-300u) are composed of limpid clay with diffuse orientation. Complete infillings range in size between 100-240u, and are composed of limpid clay with sharp orientation.

Other Pedofeatures:

Feldspar internal grain hypocoatings (30um), rich in Fe, dark red under PPL, moderate to strongly impregnated, are common. A few mottle type nodules (60-100um) that are rich in Fe, and moderate to strongly impregnated also occur.

Appendix M (cont).

Pedon: NCCS Horizon: BC (BCt) (126-170cm) Size: 6x1.5cm
Described by: MHS 1/31/1990

Microstructure:

Very weak subangular blocky to rock controlled soil material, peds are very weak subangular blocky (20-30m) with very weak expression, and are non-accommodating. Void space is distributed between packing (1.0% and 30-100u), vughs (4.2% and 30-300u), and planar voids (1.3% and 30-100u). Planar voids show parallel referred distributions to rock structure.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.87

Mineral components are poorly sorted with mostly chitonic c/f related distribution. There is also some enaulic and close porphyric distribution. Birefringence fabric is speckled or absent, and 16.2% of the fine material occurs as oriented clay. Mineral grains are primarily quartz, feldspar, and mica. Quartz grains (5u-1m) have less than 25% (0) irregular linear and less than 25% (0) pellicular alteration, while the mica grains (5-300u) have 25% to total parallel (1-4) linear alteration and less than 25% pellicular (0-1) alteration. The feldspar grains (5u-3m) show less than 25% (0-1) cross linear alteration and less than 25% pellicular (0-1) alteration. There are many biotite gneiss rock fragments present.

Textural Pedofeatures:

There are a few typic vugh coatings (15-100u) and typic planar coatings (15-125u) which have parallel micro lamination, and orange color under PPL. The vugh coatings are composed of limpid clay with sharp to diffuse orientation while the planar coatings are made up of limpid to dusty clay with diffuse orientation. Infillings and typic coatings (15-150u) found around grains and packing voids are common and have parallel micro lamination, orange color, and are composed of limpid clay with diffuse to absent orientation. Planar void infillings composed of limpid clay (15-150u) also have parallel micro lamination, show orange color under PPL, and show sharp orientation.

Other Pedofeatures:

A few irregular amiboidal nodules (70-1200u) which are moderately to strongly impregnated with Fe or Mn are present. A few typic (50-100u) and pseudomorphic (100-300u) nodules rich in Fe also occur.

Appendix M (cont.)

Pedon: NCCS Horizon: C1 (BC1) (170-202cm) Size: 6.7x1.8cm
Described by: MHS 1/31/1990

Microstructure:

Rock controlled to very weak subangular blocky soil material; peds are mostly absent, except for a few coarse subangular blocky (>10m), with weak expression and partially to non-accommodating. Void space is distributed between packing voids (6.0% and 30-100u) and vughs (3.8% and 30-1000u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.48

Mineral components are poorly sorted with chitonic and gefuric related distribution. Birefringence fabric is speckled to absent, and 0.7% of the fine material is illuvial clay. Mineral grains are quartz (5u-1.2m), feldspar (5u-1m), and mica (5-300u). The mica has 25% to total parallel (1-4) linear alteration, while the feldspar has less than 25% cross linear (0-1) alteration, with some pellicular alteration. Many biotite gneiss rock fragments occur.

Textural Pedofeatures:

A few typic planar coatings (30-100u), typic packing void coatings (30-100u), and packing void infillings (60-100u) are present. These show parallel micro lamination, orange color under PPL, and are composed of limpid clay. The infillings are diffuse in orientation, while the coatings are sharp in orientation.

Other Pedofeatures:

A few typic (240u), nucleic (12-50u), and amiboidal (50-150u) nodules occur. All are strongly to moderately impregnated with Fe.

Appendix M (cont.)

Pedon: NCCS Horizon: C2 (BC2) (202-245cm) Size: 6.6x2.2cm
Described by: MHS 1/31/1990

Microstructure:

Rock controlled to very weak subangular blocky soil material, peds are mostly absent, except for a few subangular blocky (710mm), which are very weakly expressed, and non-accommodating. Voids consist of planar (0.6% and 30-100u) and packing voids (3.1% and 30-100u), and vughs (7.4% and 30-1000u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.90

Mineral components are poorly sorted, with chitonic to gefuric related distribution. Birefringence fabric is absent to speckled, and 1.4% of the fine material occurs as oriented clay. Mineral grains are quartz, feldspar, and mica. The quartz grains (5u-1m) show less than 25% (0) irregular linear and pellicular alteration. Mica (5-300u) shows 25% to total (1-4) linear parallel and pellicular alteration. Feldspar grains (5u-3m) show less than 25% (0-1) cross linear and pellicular alteration. The rock fragments are biotite gneiss.

Textural Pedofeatures:

Typic vugh and planar coatings (30-100u) are common, whereas typic packing void coatings (30-100u) and packing void infillings (120-300u) are few. All coatings and infillings show parallel micro lamination and orange color under PPL, and are composed of limpid clay with sharp to diffuse orientation.

Other Pedofeatures:

A few amiboidal (180u) and hollow quasi (100-150u) nodules occur. The amiboidal nodules are moderately impregnated while the hollow quasi nodules are moderately to strongly impregnated with Fe.

Appendix M (cont.)

Pedon: NCCS Horizon: C3 (C1) (245-420) Size: 6.4x2.5cm
Described by: MHS

Microstructure:

Rock controlled soil material, peds are absent. Void space is made up of vughs (7.3% and 30-300u), and packing (6.7% and 30-300u) and complex voids (300-1300u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=2.66

Mineral components have a c/f chitonic-gefuric related distribution pattern. Birefringence fabric is absent, and 0.3% of the fine material occurs as oriented clay. Mineral grains consist of: quartz, which had less than 25% pellicular and less than 25% irregular linear alteration; mica (5-300u), which shows 25% to total parallel linear and less than 25% pellicular alteration; and feldspar (1.8u), which shows less than 25% cross linear and less than 25% pellicular alteration. Mica-gneiss rock fragments are common.

Textural Pedofeatures:

Typic vughs and packing void textural coatings (12-50u) occur. These show parallel micro lamination and orange color under PPL. They are composed of limpid clay with a sharp orientation.

Other Pedofeatures:

A few irregular and typic nodules occur. The irregular nodules range in size between 100-300u, and are moderately impregnated, while the typic nodules are between 100-500u, and are strongly impregnated. Both types are rich in Fe.

Appendix N. Thin section descriptions of the backslope soil at Site 1.

Pedon: NCCB Horizon: Bt4 (98-130cm) Size: 6.5x2.2cm
Described by: MHS 2/11/1990

Microstructure:

Subangular blocky soil material. Peds are subangular blocky (2-10mm) with strong to moderate expression, and accommodating to partially accommodating. Void space is composed of planar voids (4%), with parallel (25-450u), normal, and inclined basic distribution (25-200u). A few vughs (25-500u) also occur.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.28

Mineral components are poorly sorted, with a mostly open porphyric and close porphyric c/f related distribution. Birefringence fabric is speckled and 5.8% of the fine material is found as oriented clay. Mineral grains of quartz, feldspar, and mica are common. The quartz grains (5u-1.2m) show less than 25% (0) pellicular alteration; feldspar grains (5-300u) show less than 25% (0-1) pellicular and less than 75% (0-3) cross linear alteration; and mica (5-300u) shows less than 25% pellicular (0-1) alteration and 25% to total (1-4) parallel linear alteration. A few mica gneiss rock fragments occur.

Textural Pedofeatures:

Typic planar and vugh coatings, and planar infillings occur, and these show parallel micro lamination and orange color when under PPL. Planar coatings (25-250u) have limpid to dusty clay texture with diffuse to sharp orientation, and vugh coatings, 25-150u in thickness, have limpid clay texture with sharp to diffuse orientation. Planar infillings (50-120u) have limpid clay texture with sharp orientation.

Other Pedofeatures:

A few rock pseudomorph nodules (500-1000u) occur which are moderately impregnated with Fe.

Appendix N (cont.)

Pedon: NCCB Horizon: BC (Bt5) (130-150cm) Size: 6.7 x 1.9cm
Described by: MHS 2/11/1990

Microstructure:

Subangular blocky soil material with subangular blocky peds ranging in size between 7-20mm. Peds show moderate expression and are accommodating to partially accommodating. The void space is made up planar voids (1.3% and 25-300u) with parallel and inclined basic distribution, and of vughs (3.1%).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.53

The mineral components are poorly sorted with a mostly close porphyric c/f related distribution. There are also open porphyric and chitonic related distributions present. Birefringence fabric is speckled and 3.1% of the fine material occurs as oriented clay. Mineral grains of quartz, feldspar, mica and hornblend are present. Quartz grains have less than 25% (0) pellicular alteration, mica shows less than 25% (0-1) pellicular alteration and 25% to total (1-4) parallel linear alteration. Feldspar grains show less than 25% (0-1) pellicular alteration as well as less than 75% (0-3) cross linear alteration. There are a few mica-augen gneiss rock fragments.

Textural Pedofeatures:

Typic planar and vugh coatings are common. A few typic planar infillings also occur. All infillings and coatings show parallel micro lamination and orange color under PPL. The typic planar coatings (25-900u) are limpid to dusty clay in texture with diffuse to strong orientation. Typic vugh coatings (25-150u) have limpid clay texture with diffuse to strong orientation. The infillings (50-300u) have limpid clay texture with strong orientation.

Other Pedofeatures:

A few feldspar pseudomorph nodules (200-400u) moderately impregnated with Fe occur.

Appendix N (cont.)

Pedon: NCCB Horizon: C1 (BCt) (150-187cm) Size: 6.7 x 1.9cm
Described by: MHS 2/12/1990

Microstructure:

The microstructure is rock controlled to weak subangular blocky. Peds are weakly expressed, non accommocadating, coarse (710mm) subangular blocky. Void space is composed of vughs (6.9% and 30-1000u), packing (2.2% and 30-100u), planar (0.3% and 50-200u), and complex voids (100-100u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.38

The mineral components are poorly sorted, and exhibit mostly chitonic with some close porphryic and gefuric related distribution. Birefringence fabric is absent to speckled, and 6.0% of the fine material is found as oriented clay. Mineral grains are quartz, feldspar, and mica. Quartz grains (5-400u), mica (5-300u), and feldspar (5-1200u) all show less than 25% pellicular (0-1) alteration. Mica also shows 25% to total parallel linear (1-4) alteration, while the feldspar grains show less than 25% cross linear (0-1) alteration. A few mica gneiss rock fragments occur.

Textural Pedofeatures:

Typic packing and vugh textural coatings range in size between 10-100u. These show parallel micro lamination and limpid clay texture with sharp to diffuse orientation, as well as orange color under PPL.

Other Pedofeatures:

A few mottle type nodules ranging in size 90-150u wide to 1-1.5mm long that are strongly to moderately impregnated with Fe are found along with a few amiboidal nodules (50-300u), also rich in Fe.

Appendix N (cont.)

Pedon: NCCB Horizon: C2 (BC) (187-216cm) Size: 6.1 x 2.3cm
Described by: MHS 2/12/1990

Microstructure:

The microstructure is rock controlled to very weak subangular blocky; peds are subangular blocky, and less than 10mm in size. They are weakly expressed, and accommodating to partially accommodating. Void space is composed of planar (0.6% and 30-120u) voids, vughs (5.1% and 30-200u), and packing voids (30-60u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.85

The mineral components are poorly sorted and exhibit a close porphyric and chitonic related distribution. Birefringence fabric is speckled, and 0.96% of the fine material is oriented clay. Quartz, feldspar, and mica are the primary mineral grains. Quartz grains (5-850u), mica (5-300u), and feldspar (5-1200u) all show less than 25% pellicular (0-1) alteration. Mica grains also show 25% to total (1-4) parallel linear alteration and feldspar grains show less than 75% (0-3) cross linear alteration. Mica gneiss rock fragments occur.

Textural Pedofeatures:

Typic planar, packing, and vugh coatings are present, as well as planar and vugh infillings. All infillings and coatings show parallel micro lamination, and orange color under PPL. The planar coatings (30-300u) are dusty and limpid clay in texture with diffuse to sharp orientation, and the vugh coatings (30-300u) have limpid clay texture with diffuse to sharp orientation. The infillings, both planar and vugh (30-300u), have limpid clay texture with sharp orientation. Packing (30-90u) coatings are composed of limpid clay showing sharp orientation patterns.

Other Pedofeatures:

Vugh and external grain quasi-coatings, 100u thick and strongly to moderately impregnated with Mn are common. A few pseudomorphic gneiss nodules (100u thick), strong to moderately impregnated with Mn and Fe occur. The gneiss fragments pseudomorphs are 1mm in size. Typic nodules (100-300u), rich in Mn, are also present. These are few to common in abundance and are strongly impregnated.

Appendix N (cont.)

Pedon: NCCB Horizon: C3 (C1) (216-275cm) Size: 5.2 x 1.8cm
Described by: MHS 2/12/1990

Microstructure:

Microstructure is rock controlled and peds are absent. Void space is composed of vughs (4.5% and 30-900u) and packing voids (7.3% and 30-300u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=4.1

Mineral components are poorly sorted with chitonic to gefuric related distribution. Birefringence fabric is absent. Mineral grains are quartz (5-800u), mica (5-300u), and feldspar (5u-1.8mm), and all have less than 25% pellicular (0-1) alteration. The mica also has less than 75% parallel linear (0-3) alteration, and the feldspar has less than 25% cross linear (0-1) alteration. Mica gneiss rock fragments also occur.

Textural Pedofeatures:

Very few typic vugh (10-100u) and typic packing (10-30u) coatings occur with parallel micro lamination, limpid clay texture, which show orange color under PPL. These have diffuse to sharp orientation.

Other Pedofeatures:

Vugh quasi-coatings (50-200u), which are moderately to strongly impregnated with Fe and Mn, show dark brown to black color under PPL and are common. A few typic nodules (100-700u), rich in Mn, or Mn and Fe, black to dark brown under PPL and strongly impregnated also occur.

Appendix O. Thin section descriptions of the summit soil at Site 2.

Pedon: NCTS Horizon: Bt3 (57-97cm) Size: 6 x 1.6cm
Described by: MHS 2/13/1990

Microstructure:

Subangular blocky soil material; peds are subangular blocky (3-15mm) with strong to moderate expression and are partially and fully accommodating. Void space is distributed between planar voids (6.9% and 30-250u) and vughs (4.0% and 30-100u). The planar voids have inclined, parallel, and normal basic distribution patterns.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.28

The mineral components are poorly sorted with an open porphyric related distribution pattern. Birefringence fabric fabric is speckled, and 15.3% of the fine material occurs as oriented clay. Quartz (5-350u), feldspar, (5-350u), and mica grains (5-200u) make up the coarse material. All show less than 25% pellicular alternation (0-1).

Textural Pedofeatures:

Typic planar (30-100u) and typic vugh (30-100u) coatings are present. These show parallel micro lamination, orange color under PPL, limpid to dusty clay in texture, and diffuse to sharp orientation.

Notes: Very poor slide, although poorly sorted, much of the skeleton grains are very similar in size (moderate poorly sorted).

Appendix O (cont.)

Pedons: NCTS Horizon: BC1 (Bt4) (97-123cm) Size: 6 x 0.6cm
Described by: MHS 2/13/1990

Microstructure:

Subangular blocky soil material, with moderately expressed subangular blocky peds. Peds are accommodating to partially accommodating. Void space is composed of planar voids (30-350u) and vughs (30-150u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.59

The mineral components are poorly sorted with an open and close porphyric related distribution, and speckled birefringence fabric. 9.6% of the fine material is distributed as oriented clay. Quartz (5-350u), feldspar (5-300u), and mica (5-75u) grains make up coarse material. All mineral grains show less than 25% pellicular alternation (1).

Textural Pedofeatures:

Typic planar (20-100u) and typic vugh (30-100u) coatings with parallel micro lamination are present. The planar coatings show limpid to dusty clay texture and the vugh coatings show limpid clay texture. Both coatings show orange color under PPL and diffuse to sharp orientation.

Other Pedofeatures:

A few typic nodules, strongly to moderately impregnated with Fe, and 100-150u in size, occur.

Notes: Very poor slide; too small and thin to be representative.

Appendix O (cont.)

Pedon: NCTS Horizon: BC2 (BCt) (123-160cm) Size: 5.9 x 1.7cm
Described by: MHS 2/15/1990

Microstructure:

Subangular blocky soil structure, subangular blocky peds, ranging in sizes of 4->14mm, with weak to moderate expression, that are accommodating to partially accommodating. Void space is distributed between planar voids (1.5% and 30-350u) and vughs (2.2% and 30-300u). Planar voids have inclined, parallel, and normal basic distribution patterns.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.67

The mineral components are poorly sorted with mostly close porphyric with some open porphyric and chitonic related distribution. Birefringence fabric is speckled and 3.9% of the fine material occurs as oriented clay. Mineral grains are primarily quartz (5-500u), and mica (5-120u). Hornblend (100-600u) is less common. The quartz and mica grains show less than 25% pellicular alternation (1), and the mica also shows 25% to total parallel linear alternation (1-4). The hornblend grains show total alternation. Mica gneiss rock fragments also occur.

Textural Pedofeatures:

Typic planar and vugh coatings are present, as are incomplete vugh infillings. Planar coatings (30-300u) have limpid to dusty clay texture, and vugh coatings (20-200u) have limpid clay texture. Both types of coatings show parallel micro lamination, orange color under PPL, and diffuse to sharp orientation. One vugh infilling (300u) has silty texture.

Other Pedofeatures:

Internal grain hypo-coatings (30-50u) are common, and rich in Fe and Mn. These are strongly to moderatedly impregnated. A few typic (100-200u) and pseudomorph (30-50u) nodules also occur. The typic nodules are rich in Fe and strongly to moderately impregnated, while the pseudomorph nodules are rich in Fe and Mn and are strongly impregnated.

Appendix O (cont.)

Pedon: NCTS Horizon: C1 (BC) (160-186cm) Size: 5.8 x 1.9cm
Described by: MHS 2/15/1990

Microstructure:

Rock controlled to weak subangular blocky soil structure with subangular blocky peds ranging in sizes 9-718mm. The peds are weakly expressed and are partially to fully accommodating. Void space consists of planar (1.9% and 30-300u), vughs (5.5% and 30-1000u), and packing (1.6% and 5-30u) voids. The planar voids have inclined basic distribution.

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.42

Mineral components are poorly sorted with a chitonic-grfuric related distribution. There is also some close porphyric related distribution. Birefringence fabric is absent to speckled, and 4.3% of the fine material occurs as oriented clay. Quartz (5-500u) and mica (5-200u) primarily make up the coarse material, but a few hornblend grains are found which exhibited total alternation. Quartz and mica grains show less than 25% pellicular alternation (1) and the mica grains show 25% to total parallel linear alternation (1-4) as well.

Textural Pedofeatures:

Typic vugh (30-150u) and typic planar (30-650u) coatings are found, as well as typic packing coatings (10-20u) and complete planar infillings (100-150u). All coatings and infillings show parallel micro lamination and orange color under PPL. Vugh and planar coatings show limpid to dusty clay texture and diffuse to sharp orientation. Planar infillings and packing coatings have limpid texture with sharp orientation.

Other Pedofeatures:

Internal grain hypo-coatings (30-50u) are common. These are strongly to moderately impregnated with Fe. Pseudomorphic nodules (30-50u), strongly impregnated with Fe also occur.

Pedon: NCTS Horizon: C2 (BC) (186-247cm) Size: 6.2 x 1.8cm
Described by: MHS 2/15/1990

Microstructure:

The microstructure is subangular blocky material and rock controlled. The peds are a moderately expressed subangular blocky within clay flows (1-2mm in size), which are accommodating to partially accommodating; and weakly expressed subangular blocky (5->15mm) which is partially accommodating otherwise. Void space is distributed between planar voids (2.2% and 30-700u), packing voids (4.4% and 5-30u), and vughs (3.2% and 30-600u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=2.65

Mineral components have a chitonic-gefuric with some close porphyric related distribution. Birefringence fabric is absent to speckled, and .5% of the fine material occurs as oriented clay. Quartz (5-1000u), mica (5-300u), and hornblend (100-1000u) mineral grains are present. Mica shows less than 25% pellicular alternation (1) and the hornblend shows 25% to total alternation (1-4). Large mica gneiss rock fragments occur, ranging from 500u to 1cm in size.

Textural Pedofeatures:

Typic vugh (30-100u), typic planar (30-300u), and typic packing (20-50u) coatings occur. Complete planar infillings (30-250u) are also present. All coatings and infillings show parallel micro lamination and orange color under PPL. Vugh and planar coatings have limpid to dusty clay texture and diffuse to sharp orientation. The planar infillings and packing coatings both show limpid clay texture with sharp orientation.

Other Pedofeatures:

Internal grain hypo coatings (30-50u) are common, and are strongly to moderately impregnated with Fe. A few pseudomorph nodules (30-50u), strongly to moderately impregnated with Fe are also present.

Appendix O (cont.)

Pedon: NCTS Horizon: C3 (C1) (247-280cm) Size: 6 x 2.0cm
Described by: MHS

Microstructure:

The microstructure is rock controlled. Void space is distributed between planar voids (0.3%) and packing voids (1.6% and 5-30u), as well as vughs (1.3%). Planar voids show normal basic distributions to each other and normal and parallel basic distribution patterns to the rock structure.

Basic Mineral Components:

c/f limit at 20u c/f ratio=9.0

The mineral components are poorly sorted with a gefuric-monic related distribution. Birefringence fabric is absent, as is illuvial clay. Quartz (5-750u), mica (5-300u), feldspar (5-1500u), and hornblend (100-1000u) are the mineral grains present. Mica grains show less than 25% pellicular alternation (1), feldspar shows less than 25% cross linear alternation (1), and hornblend shows total alternation. Mica gneiss rock fragments occur.

Other Pedofeatures:

Vugh and packing void hypo-coatings (30-50u), strongly to moderately impregnated with Mn occur.

Appendix P. Thin section descriptions of the backslope soil at Site 2.

Pedon: NCTB Horizon: Bt4 (92-120cm) Size: 6.5 x 1.9cm
Described by: MHS 2/15/1990

Microstructure:

Subangular blocky soil material; peds with subangular blocky and crumb morphology. The subangular blocky peds are moderately to strongly expressed, ranged in size 0.3-4mm, and are partially to fully accommodating. Peds with crumb morphology are 100-300u in size, have strong expression, and are non-accommodating. Void space is distributed between planar voids (7.8% and 30-500u) and vughs (1.0% and 30-1200u). The planar voids show parallel, inclined, and normal basic distribution.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.22

The mineral components are poorly sorted with an open porphyric related distribution, speckled birefringence fabric, and 19.9% of the fine material distributed as oriented clay. Quartz grains (5-500u) and mica grains (5-200u) are prevalent, and a few hornblend grains (100-300u) also occur. Quartz grains show less than 25% pellicular alternation (1); mica grains show 25% to total parallel linear (1-4) as well as 25-75% pellicular (2) alternation. Hornblend mineral grains show total alternation.

Textural Pedofeatures:

Typic planar and vugh coatings are present, as are typic planar and vugh infillings. All coatings and infillings show parallel micro lamination. Planar (30-400u) and vugh coatings (30-100u) show limpid to dusty texture and are orange under PPL, with diffuse to sharp orientation. A few planar coatings (30-300u in size) show limpid clay texture with diffuse orientation, and are yellow under PPL. Infillings are complete, and they have limpid clay texture with sharp orientation. Infillings showing yellow color under PPL range in sizes 30-100u, while those showing orange color under PPL range in sizes 30-90u. Generally, few infillings occur.

Other Pedofeatures:

Pseudomorph nodules are common and strongly to moderately impregnated with Fe. A few typic nodules, also strongly to moderately impregnated with Fe, and ranging in sizes 100-450u are also found.

Notes: Many pieces of weathered rock indicating P.M. had a considerable amount of saprolite character; Some stress plasmic features (Relic); and yellow argillans and infillings over red argillans occur.

Appendix P (cont.)

Pedon: NCTB Horizon: 2Bt5 (120-148cm) Size: 5.2 x 1.5cm
Described by: MHS 2/19/1990

Microstructure:

Subangular blocky soil material; subangular blocky peds (1-7mm in size) with moderate expression, and are partially to fully accommodating. Void space is distributed between planar voids (2.5% and 30-60u in size), and vughs (1.2% and 30-120u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.91

The mineral components are poorly sorted with an open porphyric related distribution, speckled birefringence fabric, and 9.6% of the fine material is distributed as oriented clay. Quartz grains (5u to 10mm in size), mica grains (5-300u), feldspar (5-300u), and hornblend (100-250u) are the primary mineral components. Quartz shows less than 25% pellicular alternation (1). Mica grains show less than 25% pellicular (1) and 25% to total (1-4) parallel linear alternation. Feldspar shows 25% to total (1-4) cross linear alternation and 25% (2) pellicular alternation. Hornblend grains show total alternation.

Textural Pedofeatures:

Typic vugh infillings (50-250u in size) are very common, show limpid clay texture and sharp orientation. Typic planar (30-100u) and typic vugh coatings (30-100u) are also present (few), and show limpid to dusty clay texture. Planar coatings have diffuse orientation while vugh coatings have diffuse to sharp orientation. All infillings and coatings show parallel micro lamination and orange color under PPL.

Other Pedofeatures:

A few pseudomorph nodules (30-50u in size) are moderately impregnated with Fe about mica grains.

Notes: One half of the slide is large quartz grains (4-10mm), black (common) mineral grains and pellicular weathering are common, Substantial amounts of clay occurs around grains. The clay may have been oriented at some time. Most illuvial clay appears relic. This clay filled voids between grains or occurs as infillings.

Appendix P (cont.)

Pedon: NCTB Horizon: 3BC1 (2Bt6) (148-165cm) Size: 5.2 x 2.0cm
Described by: MHS 2/19/1990

Microstructure:

Weak subangular blocky soil material; peds distributed between subangular blocky within clay films (0.5-2mm) and subangular blocky within the matrix (1-7mm). Peds within the clay films have moderate expression and are partially to fully accommodating. Peds within the matrix are weakly expressed and are partially accommodating. Void space is primarily planar voids (2.0% and 30-150u), and vughs (3.9% and 30-300u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.08

The mineral components are poorly sorted with an open porphyric with some close porphyric related distribution. Birefringence fabric is speckled, and 10.1% of the fine material occurs as oriented clay. Quartz (5u-1cm), mica (5-500u), feldspar (5-100u), and hornblend grains (100-150u), make up the coarse mineral components. The quartz and feldspar show less than 25% pellicular (1) alternation; the feldspar also shows less than 75% cross linear (1-2) alternation; and mica and hornblend both show total alternation.

Textural Pedofeatures:

Typic vugh (30-300u), typic planar (30-150u), and grain coatings (50-150u), plus typic vugh and planar infillings (30-300u) are all present and show parallel micro lamination as well as orange color under PPL. The vugh coatings have limpid and dusty clay texture with diffuse to sharp orientation; the planar coatings have limpid clay texture with diffuse to sharp orientation; the grain coatings, occurring on large grains and coarse fragments, have limpid to dusty texture and diffuse orientation; and the planar and vugh infillings have limpid clay texture and sharp orientation.

Other Pedofeatures:

Typic nodules, 100-300u, are found moderately impregnated in Fe or Mn.

Notes: One half of the slide is large quartz grains (0.5-1cm).

Appendix P (cont.)

Pedon: NCTB Horizon: 3BC2 (3BC1) (165-187cm) Size: 6.6 x 1.4cm
Described by: MHS 2/19/1990

Microstructure:

Rock controlled to weak subangular blocky microstructure; subangular blocky peds >15mm in size with weak expression and partial accommodation. Void space is distributed between planar voids (0.3% and 30-180u in size) and vughs (3.1% and 30-150u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.00

Mineral components are poorly sorted and have close porphyric with some chitonic related distribution. Birefringence fabric is speckled and 4.2% of the fine material occurs as oriented clay. Quartz, hornblend, feldspar, and mica make up the mineral grains. Quartz (5-750u), mica (5-300u), and feldspar grains (30-750u) all show less than 25% pellicular alternation (1), and in addition, mica shows 25% to total parallel linear alternation (1-4), feldspar shows less than 75% parallel and cross linear alternation (1-2), and hornblend (100-250u) shows total alternation.

Textural Pedofeatures:

Typic planar (30-300u) and typic vugh (30-100u) coatings are present along with a few typic vugh infillings. All infillings and coatings show parallel micro lamination and orange color under PPL. The coatings show limpid to dusty texture with sharp to diffuse orientation, and the infillings, which are complete, show limpid texture with sharp orientation.

Other Pedofeatures:

Internal grain hypo-coatings (30-50u) are common, strongly to moderately impregnated with Fe. A few typic (100-210u) and pseudomorph (30-50u) nodules are also observed. The typic nodules are strongly impregnated with Fe; and the pseudomorph nodules are strongly to moderately impregnated with Fe.

Appendix P (cont.)

Pedon: NCTB Horizon: 3C1 (3BC2) (187-245cm) Size: 6.2 x 1.8cm
Described by: MHS 2/19/1990

Microstructure:

Rock controlled to weak subangular blocky soil material with subangular blocky peds occurring within clay flows (0.3 to 3mm in size), and occurring within the matrix (>10mm in size). Those peds in the clay flows are strongly to moderately expressed and are partially accommodating; the matrix peds are weakly expressed and are partially accommodating as well. Void space is distributed between planar voids (0.9% and 30-100u), vughs (3.1% and 30-150u), and packing voids (1.8% and 30-60u in size). The voids have normal, inclined, and parallel basic distribution patterns.

Basic Mineral Components:

c/f limit at 20u c/f ratio=2.44

Mineral components are poorly sorted with a mostly chitonic (some gefuric and close porphyric) related distribution. Birefringence fabric is speckled to absent and 0.9% of the fine material occurs as oriented clay. Quartz (5-750u), mica (5-350u), feldspar (5-750u), and hornblend (50-150u) grains are the primary coarse mineral components. Mica and feldspar grains both show less than 25% pellicular alternation (1); the hornblend shows total alternation. The rock fragments observed are mostly mica gneiss.

Textural Pedofeatures:

Typic vugh (10-50u), packing (10-30u), and planar (10-50u) coatings are found, along with a planar clay flow (1.5x10mm), all exhibiting parallel micro lamination and orange color under PPL. The vugh coatings show limpid to dusty texture, and sharp to diffuse orientation; the packing coatings show limpid clay texture and sharp to diffuse orientation; the planar coatings show limpid clay texture and diffuse orientation; and the clay flow shows limpid clay texture with diffuse orientation.

Other Pedofeatures:

Vugh (50-100u) and internal grain (50-70u) hypo-coatings are found. Vugh hypo-coatings are moderately impregnated while internal grain hypo-coatings are moderately to strongly impregnated with Fe.

Appendix Q. Thin section descriptions of the summit soil at Site 3.

Pedon: HRCS Horizon: Bt2 (58-83cm) Size: 6 x 2.5cm
Described by: MHS 2/21/1990

Microstructure:

Moderate to weak subangular blocky soil material; moderate and weak subangular blocky peds. Void space distributed between planar voids (2.7% and 30-300u) and vughs (1.5% and 30-300u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.33

Mineral components are poorly sorted; open porphyric related distribution. Birefringence fabric is speckled and 4.8% of the fine material occurs as oriented clay. Quartz (10u-1.5mm), feldspar (10-1000u), and mica (10-500u) make up the coarse mineral components. Feldspar, which is common, exhibits less than 25% parallel linear (1) alternation, and 25-75% pellicular (1-2) alternation. Mica grains show 25% to total parallel linear (1-4) alternation. Black opaque grains (75-200u) occur.

Textural Pedofeatures:

Typic vugh coatings (10-100u) and typic planar coatings (10-100u) are present. A few complete dense planar infillings are also present. The vugh coatings and planar infillings are parallel micro laminated, and show limpid texture. The planar coatings shows parallel to absent micro lamination and limpid to impure texture. All infillings and coatings show orange color under PPL. The vugh coatings have diffuse orientation, the planar coatings have diffuse to absent orientation, and the infillings have sharp orientation.

Other Pedofeatures:

A few gneiss pseudomorph nodules (100u-1.5mm), moderately to strongly impregnated with Fe are present, as are a few external grain hypocoatings (50-200u), moderately impregnated with Fe. Both show rust color under PPL. Typic nodules (100-1000u) occur, moderate to strong in Fe and rust under PPL. Typic nodules (75-200u), purely impregnated with Mn, occur and are black under PPL.

Appendix Q (cont.)

Pedon: HRCS Horizon: Bt3 (83-120cm) Size: 5.5 x 2.5cm
Described by: MHS 2/21/1990

Microstructure:

Moderate subangular blocky soil material; mostly moderate with some strong and weak subangular blocky peds. Void space is distributed between planar voids (4.6% and 30-300u) and vughs (0.9% and 30-900u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.35

Mineral components are poorly sorted with an open porphyric (some close porphyric) related distribution. Bifringence fabric is speckled; and 9.1% of the fine material is deposited as oriented clay. Quartz (10-1500u), feldspar (10-1000u), and mica (10-300u) make up the coarse mineral components. Mica grains show 25% to total parallel linear (1-4) alternation, and feldspar grains show less than 75% parallel and cross linear (1-3) alternation.

Textural Pedofeatures:

Typic planar coatings (30-500u) and typic vugh coatings (30-100u) are present. Complete dense vugh and planar infillings (30-1500u) are also present. The infillings and vugh coatings show parallel micro lamination. Planar coatings show limpid to impure texture, and the vugh coatings and infillings show limpid texture. All coatings and infillings show orange color under PPL. The coatings show diffuse orientation and the infillings show sharp orientation.

Other Pedofeatures:

Typic nodules are common, sized 75-200u, and purely impregnated with Fe or Mn and black to rust in color under PPL. Also present are a few mica pseudomorph nodules (moderately and strongly impregnated with Fe), sized 200-300u with rust color under PPL.

Appendix Q (cont.)

Pedon: HRCS Horizon: BC (BCt) (120-150cm) Size: 6.0 x 2.5cm
Described by: MHS 2/21/1990

Microstructure:

Mostly rock controlled with some weak subangular blocky soil material; weak subangular blocky peds. Void space is distributed between vughs (5.6% and 30-500u) and some planar voids (30-250u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.60

Mineral components are poorly sorted; with an open-close porphyric/chitonic related distribution. Birefringence fabric is speckled and 4.9% of the fine material is distributed as oriented clay. Quartz (10-2100u), feldspar (10-2000u), and mica (10-750u) grains occur. Feldspar and mica both show 25% to total alternation. Feldspar shows cross linear alternation (1-4) and mica shows parallel linear alternation (1-4). Augen gneiss rock fragments occur.

Textural Pedofeatures:

Typic vugh (10-100u) and planar (10-100u) coatings are present, both showing diffuse orientation. Dense incomplete planar infillings (clay flow), 100-600u in size, is also present, showing diffuse to sharp orientation. All infillings and coatings show orange color under PPL and limpid texture with parallel micro lamination, with the exception of the planar coatings which show limpid to impure texture, and lamination is sometimes absent.

Other Pedofeatures:

Many irregular typic mottles (50-200u) are present, moderate to strongly impregnated with Fe, showing rust to dark brown color under PPL. Purely impregnated angular to typic nodules (100-300u), rich in Mn, and black in color are common. Also common are moderately to strongly impregnated with Fe external vugh hypocoatings (50-100u) and mottles parallel to the rock structure (30-60u). Both show rust to dark brown color under PPL.

Appendix Q (cont.)

Pedon: HRCS Horizon: C1 (150-205cm) Size: 5.3 x 2.5cm
Described by: MHS 2/25/1990

Microstructure:

Rock controlled to crack soil material; peds absent. Void space is distributed between vughs (3.8% and 30-500u), planar voids (2.5% and 30-75u), and packing voids (5.6% and 30-50u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.81

Mineral components are poorly sorted with a chitonic related distribution. Birefringence fabric is absent. Quartz (10u-1mm), feldspar (10u-10mm), and mica (10-500u) grains make up the mineral grains. Quartz grains show less than 25% pellicular alternation (1), as do mica grains. The feldspar shows 25-75% pellicular (2) alternation. Mica grains also show 25% to total parallel linear (1-4) alternation and the feldspar grains also show 25% to total cross linear (1-4) alternation. Augen gneiss rock fragments are observed.

Other Pedofeatures:

Purely impregnated angular typic nodules (100-300u in size) are rich in Mn, black in color, and common. Typic vugh, planar, and packing coatings (30-75u) are common, as are feldspar pseudo-morphic nodules (200-750u) and typic amboidal nodules (100-300u in size). All nodules are moderately to strongly impregnated with Fe, and rust to dark brown in color under PPL. Many nodules occur as mottles with some parallel to rock structure (30-500u) are present; these are moderately to strongly impregnated with Fe, and rust to dark brown under PPL.

Notes: Vughs include complex voids.

Appendix Q (cont.)

Pedon: HRCS Horizon: C2 (205-310cm) Size: 6.5 x 2.5cm
Described by: MHS 2/25/1990 Notes: a little thick

Microstructure:

Rock controlled, some crack soil material; peds absent. Void space is distributed between vughs (4.2% and 30u-1mm), packing voids (0.6% and 30-50u), and planar voids (0.3% and 30-60u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.02

Mineral components are poorly sorted with chitonic related distribution. Birefringence fabric is absent. Quartz (10u-1.5mm), feldspar (10u-15mm), and mica (10u-1.5mm) grains occur. Quartz and mica show less than 25% pellicular (1) alternation, and feldspar shows less than 75% pellicular (1-2) alternation. Mica also shows less than 75% parallel linear (1-2) alternation, and feldspar shows less than 75% cross linear (1-2) alternation. Augen gneiss rock fragments are observed.

Other Pedofeatures:

Mn rich, purely impregnated angular typic nodules are common, sized 75-500u and black in color under PPL. Many nodules (30-2000u) as mottles are present, strongly to moderately impregnated with Fe and rust to dark brown in color. Also common are vugh and planar hypocoatings (30-100u), moderately to strongly impregnated with Fe and rust to dark brown in color under PPL. Also present are gneiss pseudomorphic nodules (300-1500u) and grain hypocoatings (30-75u), which are both moderately to strongly impregnated with Fe, and rust to dark brown under PPL.

Notes: Some vughs may be complex voids.

Appendix R. Thin section descriptions of the backslope soil at Site 3.

Pedon: HRCB Horizon: 2Bt2 (75-106cm) Size: 6.0 x 2.3cm
Described by: MHS 2/25/1990

Microstructure:

Weak to moderate subangular blocky soil material; with weak and moderate subangular blocky peds. Void space is distributed between vughs (2.2% and 25-250u) and planar voids (4.1% and 30-200u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.36

Mineral components are poorly sorted with open porphyric and some close porphyric related distribution. Birefringence fabric is speckled; and 4.9% of the fine material occurs as oriented clay. Quartz (10u-2mm), feldspar (common, 10u-2mm in size), and mica (10u-1.5mm) made up the mineral grains. Quartz and mica grains show less than 25% pellicular alternation (1); feldspar shows less than 75% pellicular alternation (1-2). Mica grains show 25% to total parallel linear alteration (1-4), and feldspar shows less than 75% (1-3) cross linear alternation. Augen gneiss rock fragments are present.

Textural Pedofeatures:

Typic vugh coatings (30-70u) and typic planar coatings (30-75u) are present. The vugh coatings show limpid to dusty texture, diffuse to sharp orientation, and parallel micro lamination. The planar coatings show limpid clay to silt texture, diffuse orientation, and lamination is either parallel micro or absent. Also present are a few complete dense vugh infillings (30-75u) and complete dense planar infillings (75-200u). The vugh infillings show limpid texture with sharp orientation, and have parallel micro lamination. The planar infillings are limpid to silt in texture, diffuse to absent in orientation, and lamination is either parallel micro or absent. All infillings and coatings show orange color under PPL.

Other Pedofeatures:

Many nodules moderately to strongly impregnated with Fe occur as mottles, some show parallel orientaion to the rock structure, range in size from 30u to 3mm, and are dark brown to rust under PPL. Purely impregnated with Mn angular nodules (75u-500u), black in color, and moderately to strongly impregnated with Fe gneiss pseudomorphic nodules (200-800u), dark brown to rust in color, are both common. Also present are a few typic nodules (100-600u), which are purely impregnated with Fe and Mn, and show a rust to black color under PPL.

Notes: Some stratification evident.

Appendix R (cont.)

Pedon: HRCB Horizon: 2Bt3 (106-128cm) Size: 6.0 x 2.0cm
Described by: MHS 2/25/1990

Microstructure:

Weak subangular blocky soil structure and peds; void space is distributed between planar voids (6.3% and 30-450u), vughs (6.3% and 30u-2mm) and packing voids (0% and 20-38u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.50

Mineral components are poorly sorted; close porphyric with some open porphyric and chitonic related distribution; speckled birefringence fabric. Of the fine material, 14.4% occurs as oriented clay. Quartz (10u-2mm), feldspar (10u-2mm in size), and mica (10-200u) make up the mineral grains. Mica grains show less than 75% parallel linear alternation (1-2) and less than 25% pellicular alternation (1). Feldspar grains show less than 25% cross linear alternation (1) and less than 75% pellicular alternation (1-2). Augen gneiss rock fragments are observed.

Textural Pedofeatures:

Typic vugh coatings (20-200u), typic packing coatings (20-40u), and typic planar coatings (30-500u) are all present; and show orange with some yellow color under PPL. Although most have parallel micro lamination; some planar coatings lack lamination. Packing coatings have limpid clay texture and sharp orientation; the planar coatings have limpid to impure texture and diffuse to absent orientation. The vugh coatings show diffuse to sharp orientation. Also present are complete and incomplete dense vugh infillings (30-200u) and typic vugh clay flows (1-2mm). Both show parallel micro lamination, limpid texture, and orange color with sharp orientation.

Other Pedofeatures:

Many moderate to strongly impregnated with Fe nodules which occur as mottles parallel to the rock structure (75u-10mm) are present. These show dark brown to rust color under PPL. Moderately to strongly impregnated with Fe gneiss pseudomorphic nodules (200u-10mm) are common, showing dark brown to rust color. A few grain hypocoatings (moderately to strongly impregnated with Fe), 20-100u in size are also present, with dark brown color. Irregular nodules (150-250u) purely impregnated with Mn and black in color under PPL also occur.

Pedon: HRCB Horizon: 2BC (128-160cm) Size: 6.0 x 2.5cm
Described by: MHS 2/25/1990

Microstructure:

Mostly moderate with some weak subangular blocky soil material with moderate and weak subangular blocky peds. Void space is composed of planar voids (4.0% and 30-450u) and vughs (3.4% and 25u-1.5mm).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.88

Mineral components are poorly sorted, with close porphyric/chitonic related distribution pattern, and a speckled birefringence fabric with 13.1% as illuvial clay. Quartz (10-2000u), feldspar (10-2000u), and mica grains (10-400u) are the coarse size minerals present. All show less than 25% pellicular alternation (1); quartz also shows less than 25% irregular cross linear alternation (1); mica 25% to total parallel linear alternation (1-4); and feldspar less than 75% cross linear alternation (1-2). Augen gneiss rock fragments are observed.

Textural Pedofeatures:

Typic clay flows, 25mm in size, with parallel micro lamination and layered with limpid and silty fine material, with sharp diffusion and orange color under PPL are present. Typic vugh (20-300u) and planar (20-1000u) coatings are also present, with parallel micro to absent lamination and sharp to diffuse orientation. The vugh coatings have limpid clay texture and the planar coatings have limpid to impure texture with orange color. Vugh (40-150u) and planar (100-1000u) infillings are also found, with parallel micro lamination and orange color. The vugh infillings are dense and complete and limpid in texture, with sharp orientation. The planar infillings are dense and complete to incomplete, with limpid to dusty texture and sharp to diffuse orientation.

Other Pedofeatures:

Strongly to moderately impregnated iron rich grain hypocoatings (30-75u), and nodules that occur as mottles parallel to the rock structure (30-400u), both dark brown to rust color, are common. A few angular nodules (100-250u), purely impregnated with Mn, which are black under PPL are also present. Strongly to purely manganese impregnated planar coatings (50-150u) are also present, and are black under PPL. Also observed are a few strongly to moderately impregnated with Fe, gneiss pseudomorphic nodules (200-1000u), which are dark brown to rust under PPL.

Notes: Much of the slide is illuvial clay (about 25%); large clay flow is 2-5mm thick.

Appendix R (cont.)

Pedon: HRCB Horizon: 2C1 (160-200cm) Size: 5.5 x 2.1cm
Described by: MHS 2/25/1990

Microstructure:

Crack, rock controlled, and weak subangular blocky soil material with weak subangular blocky peds. Vughs (2.3% and 20-400u), planar voids (4.3% and 30-100u), and packing voids (2.0% and 30-60u) make up the void space.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.93

Mineral components are poorly sorted; with close porphyric/chitonic related distribution. Birefringence fabric is speckled and 1.9% of the fine material is deposited as oriented clay. Quartz (10-1000u), feldspar (10-1000u, and common), and mica (10-450u) make up the mineral grains. All mineral grains show less than 25% pellicular alternation (1); quartz shows less than 25% irregular cross linear alternation (1); the mica shows 25% to total parallel linear alternation (1-4); and the feldspar shows less than 75% cross linear alternation (1-3). Augen gneiss rock fragments are observed.

Textural Pedofeatures:

Typic planar and vugh coatings (20-30u) are rare; they show parallel micro lamination and limpid clay texture, orange color and sharp orientation.

Other Pedofeatures:

Many nodules (30-150u) parallel to the rock structure on mottles are present. They are moderately to purely impregnated with iron and manganese, and show rust, dark brown and black color under PPL. Many internal grain (30-60u) and vugh and planar (30-100u) hypocoatings are present; these are moderately to purely impregnated with Fe and Mn and are rust, dark brown and black under PPL. Typic to angular nodules (100-300u), pure, rich in Mn, with black color, are common, as are gneiss pseudomorph nodules (200-1500u), which are moderate to strongly impregnated with Fe and are dark brown to rust in color.

Appendix R (cont.)

Pedon: HRCB Horizon: 2C2 (200-260cm) Size: 6.5 x 2.3cm
Described by: MHS 2/25/1990

Microstructure:

Rock controlled/crack soil material with peds absent. Voids are: planar (0.9% and 30-60u), vughs (0.3% and 30-250u), and packing voids (4.7% and 30-3000u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.59

Horizon show a chitonic/gefuric related distribution, Birefringence fabric is absent. Mineral grains present are quartz , feldspar, and mica. Quartz grains (10u-5mm) show less than 25% irregular cross linear alternation (1); mica grains (10-1000u) show 25% to total parallel linear alternation (1-4); and feldspar grains (10u-3mm), which are common, show less than 75% cross linear alternation (1-2). All mineral grains show less than 25% pellicular alternation (1). Augen gneiss rock fragments are observed.

Textural Pedofeatures:

None

Other Pedofeatures:

Many nodules around mottles parallel to the rock structure (30-150u) are present, are moderately to strongly impregnated with Fe, and are dark brown to rust in color under PPL. All other pedofeatures are common: typic to angular nodules (100-400u), purely impregnated with Mn, and black in color; internal and external grain hypocoatings (30-60u) moderately to strongly impregnated with Fe and dark brown to rust; typic, nodules (75u-2mm), moderately to strongly impreganted with Fe and dark brown to rust; moderate to strong in Fe gneiss pseudomorphic nodules (100-500u), which are dark brown to rust; and planar hypocoatings (30-75u), moderately to purely impregnated with Fe and Mn, and dark brown to rust to black in color.

Notes: Some vughs occur as complex voids

Appendix S. Thin section descriptions of the summit soil at Site 4.

Pedon: HFS Horizon: Bt2 (54-72cm) Size: 6.3 x 2.0cm
Described by: MHS 2/19/1990

Microstructure:

Strong subangular blocky soil material; subangular blocky peds (0.4-5mm in size), strongly to moderately expressed, accommodating to partially accommodating. Void space is composed of planar voids parallel to the surface (8.9% and 25-200u in size), and vughs (3.4% and 30-300u). The planar voids have parallel, inclined, and normal basic distribution patterns.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.29

The mineral components are poorly sorted with an open-close porphyric related distribution pattern. Birefringence fabric is speckled; 12.3% of the fine material occurs as oriented clay. Quartz, feldspar, and mica are the most common minerals observed. Quartz grains are 5-1000u, mica grains are 5-600u and show less than 75% parallel linear alternation (1-2), and feldspar grains (there are few of these) are 5-500u and show less than 75% pellicular (1-2) alternation and less than 75% parallel linear (1-3) alternation. Schist rock fragments are observed.

Textural Pedofeatures:

Typic planar coatings (30-300u in size), typic vugh coatings (30-150u), and vugh and planar infillings (50u-1mm) are all observed, and all show parallel micro lamination as well as orange color under PPL. The planar and vugh coatings have limpid to dusty clay texture and show diffuse to sharp orientation. The infillings, which are complete and the most common, have limpid clay texture with sharp orientation.

Other Pedofeatures:

Typic nodules and mottles are observed; both are rich and strongly impregnated with Fe. The nodules as mottles are 100-150u in size, and the typic nodules are 100-200u in size.

Appendix S (cont.)

Pedon: HFS Horizon: BC1 (Bt3) (72-96cm) Size: 4.5 x 1.8cm
Described by: MHS 2/20/1990

Microstructure:

Moderate subangular blocky soil material; subangular blocky peds (0.5-6mm), moderately to strongly expressed, and partially to fully accommodating. Void space is composed of planar voids (9.1% and 30-500u in size) and vughs (4.2% and 30-250u in size). The planar voids exhibit parallel, inclined, and normal distribution patterns.

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.31

Mineral component sorting is poor with an open and close porphyric related distribution. Birefringence fabric is speckled; 5.4% of the fine material is oriented clay. Quartz, feldspar, and mica are the primary mineral grains. Quartz grains are 5-1000u; mica grains are 5-600u and show 75% to total parallel linear (1-4) alternation; and feldspar grains are 5-200u and show less than 75% cross linear (1-2) alternation as well as less than 25% (1) pellicular alternation. Large schist or mica rock fragments occur.

Textural Pedofeatures:

Typic planar coatings are observed with two morphologies: one (25-600u) show orange-yellow color under PPL with diffuse orientation, while the other (25-60u) show orange color under PPL and sharp to diffuse orientation. There are fewer of the second type. Typic vugh coatings are also present, 25-60u in size, and with limpid to dusty clay texture, orange-yellow color under PPL, and sharp to diffuse orientation. All coatings show parallel micro lamination. Typic vugh or planar infillings are present, range in sizes 100u to 2.5mm, and have limpid clay texture. The infillings are laminated, show orange-yellow color under PPL, and have sharp to diffuse orientation.

Other Pedofeatures:

A few typic (50-150u in size) and mottle type (35-50u in size) nodules are found; the typic nodules are moderately to strongly impregnated with Fe, and the mottled nodules are strongly impregnated with Fe.

Appendix S (cont.)

Pedon: HFS Horizon: BC2 (C1) (96-114cm) Size: 5 x 2.3cm
Described by: MHS 2/20/1990

Microstructure:

Rock controlled soil material; peds absent. Void space is distributed between vughs (1.3% and 30-450u) and packing voids (3.9% and 10-30u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.31

Distribution of minerals is chitonic-gefuric related; birefringence fabric is absent to speckled; and there is 0% illuvial clay. Quartz, feldspar, and mica are the minerals present. Quartz grains are 5-200u in size; mica grains are 5u-3mm, and show less than 25% parallel linear (1) alternation; and feldspar grains are 5u-3mm and show less than 25% cross linear (1) alternation. Both mica and feldspar grains show less than 25% pellicular (1) alternation. Rock fragments are mostly large schist (mica).

Textural Pedofeatures:

Trace typic vugh coatings (10-20u) are observed; they have parallel micro lamination and limpid texture, as well as showing orange color under PPL and diffuse orientation.

Other Pedofeatures:

Many typic nodules are observed; they are 5-200u in size and are strongly to moderatedly impregnated with Fe or Mn, and show rust to dark brown to black color under PPL. Most common are nodules parallel to the rock structure (5-50u) which are rich in Fe and Mn, and are black to rust to dark brown under PPL. Mottle nodules strongly to moderately impregnated with Fe with a rust color under PPL are also present. Internal grain hypo-coatings (10-30u in size), moderately impregnated with Fe, and rust colored under PPL are also common.

Notes: Mostly rock structure with many nodules of various forms.

Appendix S (cont.)

Pedon: HFS Horizon: C1 (C2) (114-176cm) Size: 6.0 x 2.0cm

Microstructure:

Rock controlled soil structure; peds absent. Void space composed of vughs (4.8% and 30-200u) and packing voids (4.5% and 30-60u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.86

Mineral components are poorly sorted with a gefuric-chitonic related distribution. Birefringence fabric is absent and 0% of the fine material is oriented clay. Quartz grains (5u-1.5mm), feldspar grains (5u-1.2mm), and mica grains (5u-1.5mm) make up the mineral components. Mica shows less than 25% parallel linear (1) alternation; the feldspar (common) shows less than 25% cross linear (1) alternation. Both feldspar and mica show less than 25% pellicular (1) alternation. Schist rock fragments are observed.

Other Pedofeatures:

Many nodules parallel to the rock structure and thin (25-40u) are present, strongly to moderately impregnated with in Fe and Mn, and rust to dark brown under PPL. Typic nodules (100-250u) are common, and are strongly impregnated with Mn, and black under PPL. Vugh hypo-coatings are also common, ranging in size 25-30u, and rich in Fe.

Notes: Many vughs may be complex or compound voids. Mostly rock with nodules along rock structure.

Appendix T. Thin section descriptions of the backslope soil at Site 4.

Pedon: HFB Horizon: Bt3 (48-63cm) Size: 5.6 x 1.8cm
Described by: MHS 2/20/1990

Microstructure:

Strong to moderate subangular blocky soil material; strongly to moderately expressed subangular blocky peds present. Void space is distributed between planar voids (9.7% and 30-750u) and vughs (2.8% and 30-1200u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.25

Mineral components are poorly sorted with an open-close porphyric related distribution. Birefringence fabric is speckled and 7.6% of the fine material occurs as oriented clay. Minerals present are quartz , feldspar, and mica. Quartz grains are 5u to 2.1mm in size. Mica grains, 5u to 1.8mm in size, show 25% to total parallel linear (1-4) alternation. Feldspar grains, 5-850u, are common and show less than 25% cross linear (1) alternation. Schist rock fragments, 1.8mm in size are observed.

Textural Pedofeatures:

Typic planar coatings (10-300u) and typic vugh coatings (30-600u) are present, and complete vugh infillings (30-300u) are common. All infillings and coatings show parallel micro lamination and orange color under PPL. The planar coatings show limpid to dusty texture with strong to diffuse orientation, vugh coatings show limpid clay texture with strong to diffuse orientation, and the infillings show limpid clay texture with strong orientation.

Other Pedofeatures:

Trace amounts of typic nodules and mottle type nodules parallel to the rock structure are present. The typic nodules (75-150u) are strongly impregnated with Fe and Mn, and show rust to dark brown color under PPL. The mottle type of nodules (10-30u), are strongly to moderately impregnated with Fe and show rust to dark brown color under PPL.

Appendix T (cont.)

Pedon: HFB Horizon: BC1 (BCt) (63-81cm) Size: 5.7 x 1.7cm
Described by: MHS 2/20/1990

Microstructure:

Moderate subangular blocky structure with moderately expressed (some strongly expressed) subangular blocky peds. Void space is distributed between planar voids (4.8% and 30-500u), vughs (3.2% and 30-400u), and packing voids (1.9% and 10-30u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=0.59

Mineral components are poorly sorted; show close porphyric-chitonic with some open porphyric related distribution. Birefringence fabric is speckled and 5.1% of the fine material occurs as oriented clay. Quartz, feldspar, and mica (23.5%) make up the mineral grains. Quartz grains are 5-750u in size; mica is 5-500u in size and shows 25% to total parallel linear alternation (1-4); and feldspar is 5-500u in size, is common, and shows less than 75% cross linear (1-2) alternation. Both mica and feldspar grains show less than 25% pellicular (1) alternation. Schist rock fragments are observed.

Textural Pedofeatures:

Typic planar (30-240u) and typic vugh (30-100u) coatings are present, as are complete planar and vugh infillings (30-60u). Vugh coatings and infillings show parallel micro lamination; planar coatings show parallel micro lamination or lamination is absent. All infillings and coatings show orange color under PPL; the coatings have limpid to dusty texture while the infillings have limpid texture. The planar coatings have diffuse orientation, the vugh coatings have diffuse to sharp orientation, and the infillings have sharp orientation.

Other Pedofeatures:

Typic nodules (50-120u) and mottle type nodules parallel with the rock structure (10-30u) are common, and show rust to dark brown color under PPL. A few vugh hypo-coatings (30-75u) are also observed; these show rust color under PPL. All hypocoatings and nodules are strongly to moderately impregnated with Fe.

Notes: Some vughs may be complex voids.

Appendix T (cont.)

Pedon: HFB Horizon: BC2 (BC1) (81-96cm) Size: 4.5 x 2.0cm
Described by: MHS 2/21/1990

Microstructure:

Soil material is rock controlled, with some subangular blocky and crack. Peds are absent to very weak subangular blocky, less than 10mm in size with weak expression and partially to non-accommodating. Void space is distributed between planar voids (2.3% and 30-150u), vughs (1.3% and 30-1000u), and packing voids (6.9% and 10-60u).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.73

Mineral components are moderately to poorly sorted with chitonic-gefuric-monic related distribution. Birefringence fabric is absent, and 0% of the fine material occurs as oriented clay. Quartz (10u-2mm) and a few feldspar (10-750u) grains as well as mica (10-300u) make up the mineral grains. The mica shows less than 25% parallel linear (1) alternation, while the feldspar grains show less than 25% of either cross linear (1) or pellicular (1) alternation. Schist rock fragments are observed.

Textural Pedofeatures:

Trace amounts of typic vugh coatings (10-20u in size) are observed with limpid clay texture, parallel micro lamination, sharp orientation, and orange color under PPL.

Other Pedofeatures:

Typic nodules (20-300u in size), moderately to strongly impregnated with Fe, and dark brown under PPL are common, as are coatings parallel to the rock structure (40-60u in size), moderately to strongly impregnated with Fe, and dark brown in color. Also common are incomplete intercalations, 10-30u in size and moderate to strongly impregnated in Mn with a black color under PPL. A few external grain hypo-coatings (75-100u) are observed; they are moderately to strongly impregnated with Fe, and are dark brown in color under PPL. Typic nodules (50-150u) purely impregnated with Mn, black in color, also occur and are few in number. Other features observed are vugh hypocoatings (40-60u) and these are moderately to strongly impregnated with Fe and are dark brown under PPL.

Notes: Monic related distribution may relate to rock fragments; some vughs are complex voids, mostly rock and mottled.

Appendix T (cont.)

Pedon: HFB Horizon: C1 (96-144cm) Size: 6.6 x 1.6cm
Described by: MHS 2/21/1990

Microstructure:

Rock controlled soil material; peds are absent. Void space distributed between vughs (0.9% and 30-100u), packing voids (3.7% and 30-60u), and planar voids (0.6%).

Basic Mineral Components:

c/f limit at 20u c/f ratio=1.73

Mineral components are moderately sorted, with a gefuric-chitonic-monic related distribution pattern. Birefringence fabric is absent and 0% of the fine material is oriented clay. Quartz (10-300u), a few feldspar (10-1000u), and mica (10-50u) make up the mineral grains. The mica and feldspar grains both exhibit less than 25% pellicular (1) alternation; and the feldspar shows less than 25% cross linear (1) alternation. Schist rock fragments are observed.

Other Pedofeatures:

Many irregular mottles (100-750u in size) and mottles parallel to the rock structure (100-300u in size) are present. The irregular mottles are moderately to purely impregnated with Fe, and the parallel mottles are moderately to strongly impregnated with Fe. Both show rust to dark brown color under PPL. Vugh hypocoatings (100-300u in size) and irregular typic nodules in clusters (100-300u in size) are also common. Hypocoatings are moderate to strongly impregnated with Fe, and are dark brown to rust in color; the nodules are moderately to purely impregnated with Mn and are black under PPL.

Notes: Monic related distribution may be related to coarse fragments; some vughs are complex voids. Mostly mottle stained rock; mica grains are small (fine silt size) within rock structure.

VITA

Mark Hjalmer Stolt was born to Agnes and Hjalmer Stolt on July 16, 1956 in Cheverly, Maryland. In his early years he lived with his parents, brother George, and sisters Teresa and Sandy, in Landover Hills, Maryland. During this time he played in the sandlots and asphalt or walked this upper coastal plain landscape searching for pieces of nature, mostly frogs and snakes or his favorite, the box turtle. These years passed swiftly however, and in 1974 he graduated from Bladensburg Senior High School. After high school joined the real world and went to work for Leet-Melbrook, eventually becoming the manager of the white-print shop. Mark didn't enjoy this work very much, and in 1978 he began working as a letter carrier for the U.S. Postal Service. During this time he began attending night classes at Prince George's Community College, where he received an Associate of Arts degree in 1980. From this time forward, he was hooked on education and even gave up his post office job to become a full time student at the University of Maryland, where he earned a Bachelor of Science degree in Agronomy in 1982. He received his Master of Science degree in Agronomy from the University of Maryland in 1986, under the supervision of Dr. Martin Rabenhorst. After meeting several people from Virginia Tech, and finding them to his liking, as well as hearing that there was some good trout fishing in a small stream nearby, Mark moved to Blacksburg to begin working towards a Doctor of Philosophy degree in Agronomy. At Virginia Tech, he was a graduate research assistant to Dr. James C. Baker and Dr. Thomas W. Simpson, and assisted in coaching the 1986, 1987, and 1988 Southeast

Regional Soil Judging championship teams, as well as the 1987 National Soil Judging championship team.

AN APPROACH TO STUDYING SOIL-LANDSCAPE RELATIONSHIPS IN VIRGINIA

by

Mark H.Stolt

Dr. J.C. Baker Department of Crop, Soil,
and Environmental Sciences

(ABSTRACT)

Various methods and techniques were used to examine soil-landscape relationships for residual and colluvial soils of Virginia. Soil micromorphology indicated that although some BC and C horizons in the field appeared structureless, evidence of pedogenic process was observed. These were designated as either BCt, BC, or CB horizons depending on the amount of oriented clay and the rates of change with depth of clay, DCB extractable Fe, and sand contents. Soil variability was examined for the overall study, as well as within toposequences, pedons, and individual horizons. Most of the overall variability was attributed to differences between study sites or between horizons, with minimal amounts due to landscape position. Substantial lateral variability occurred within horizons indicating a strong need for subsampling within horizons of the same pedon. Lithologic discontinuities were found to be difficult to recognize without obvious field evidence. Reconstruction analysis was used to examine soil and saprolite formation. Summit and backslope soils were found to be essentially the same in both morphology and degree of profile development. Sand weathering and clay eluviation/illuviation were the major soil forming processes occurring within these soils. Footslope soils were less developed than associated summit and backslope soils, with both depositional and pedologic processes contributing to soil formation and development. Thickness of saprolite was found to decrease from the summit to the footslope. Thicker saprolite at the summit was apparently related to the greater stability of the summit position compared to the backslope and footslopes. A bucket auger was modified to obtain undisturbed samples of deep saprolite for reconstruction analysis. Saprolite reconstruction indicated that between 20 and 36 % of the mass of the partially weathered rock, which is the precursor to saprolite, is lost during saprolite formation. Most of these losses were either Al or Si. Initial soil formation was shown to occur at a faster rate than saprolite formation, but after substantial profile development, soil formation is reduced to a rate below that of saprolite formation, and saprolite accumulates below the solum. Reconstruction analysis was found to be a valuable tool in studying soil-landscape relationships.