VIRGIN HARDWOOD FOREST SOILS OF WESTERN NORTH CAROLINA

by

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(ABSTRACT)

Little is known about the original properties of soils in the East. Eight virgin soils and associated southern Appalachian hardwood vegetation were studied in western North Carolina. The study sites ranged in elevation from 720 to 1200 m on steep slopes. Overall these soils are quite deep and highly weathered due to high rainfall (>200 cm) and soluble feldspathic parent material. Organic matter contents of the surface horizons were quite high (4.5 - 16 %), and they contained moderate to strong crumb structure. All but one soil contained cambic subsurface horizons and were either Typic Haplumbrepts or Umbric Dystrochrepts. The majority of soils in the watershed are formed in colluvium, but significant amounts of residual soils occur on sideslopes, and appear to be quite stable. The present day landforms appear to be the result of periglacial activity.

North-facing soils were higher in whole soil clay, organic matter, and A horizon exchangeable cations than

south-facing soils. Cation exchange capacity in these soils is almost totally dependent on organic matter content, and the mineral fraction is relatively inert. All soils were in the oxidic mineralogy class. Gibbsite was common throughout all soils and hydroxy-interlayered vermiculite (HIV) is the dominant clay-sized phyllosilicate in surface horizons. Kaolinite was low in all soils, but was more abundant on south-facing slopes. The silt fractions and sand fractions contained significant quantities of weathered 2:1-type minerals

The vegetation varied from mixed-mesophytic cove hardwoods on north-facing slopes to mixed oak-hickory and oak-pine on south-facing slopes. Many trees in coves exceed 1.3 m in diameter and 50 m in height. Total litter production averaged 3494 kg/ha, and the litter layers were typified by thin leaf (L), and well developed fermentation (F) and humus (H) layers. Cations and P are concentrated in the litter layers and immediate surface soil, while N is mixed deep into the profile. Due to their oxidic mineralogy, low CEC, decreasing clay content with depth, and concentration of cations and P in litter and standing biomass these soils highly resemble tropical Oxisols.

ACKNOWLEDGEMENTS

The work that I report in this Dissertation is the combined effort of literally dozens of people, and I apologize to any that I have forgotten. First of all, I want to thank the staff of TVA for designing and building Cheoah Dam in time to flood the major logging grade into the Little Santeetlah watershed, thereby saving this beautiful corner of the southern Appalachian forest from logging.

This study was planned, laid out, and executed with constant advice and help from , and I thank him greatly for his friendship and encouragement over the years. This project involved a great deal of field work and sampling in very remote and rugged terrain. The following people hiked, labored and sweated over many miles of steep slopes, rocky trails, and rhododendron hells: , , , , , , , , , , , , and . I particularly want to thank for identifying and measuring the plants at each site, and for drawing the beautiful diagrams in Chapter 4.

Once we had the samples back in Blacksburg, the following people worked on various aspects of the lab work: , , ,

, , , ,

, , , ,

, and . I also greatly appreciate the help of , , and in typing up various tables and appendices, and simultaneously keeping all of my bills paid and phone messages straight.

The members of my graduate committee have all been tolerant and helpful, and I thank each of them for their assistance. agreed to oversee my work on a study quite unsual for him, and I greatly appreciate his patience with me, and quiet firm leadership. and have helped tremendously with technical and theoretical aspects of this work, and has been particularly helpful in the review of this manuscript. has constantly been supportive of me over the years, and kept faith in me through several trying occasions, a fact that I am continually grateful for. I also want to thank for cultivating my interest in soil and environmental sciences, and for teaching me all that he could in a very short time about soils, the ups and downs of research, and the complexity of University life. These men have collectively set a great professional and personal example for me, one that I am just beginning to really appreciate.

Finally, and most of all, I want to thank my wife and my parents for supporting me through the seemingly endless years or coursework, research, and writing that have culminated in this Dissertation.

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Chapter I

INTRODUCTION AND OBJECTIVES

When the first Europeans settled the coast of southeastern North America they were confronted with a vast forested wilderness that stretched from the Atlantic to the tall grass praries of the midwest. While limited areas of soil were maintained free of trees by Indians and fire, the vast majority had been in dynamic equilibrium with its vegetation since the last ice age, when a colder climate forced the boreal forests south, and then retreated, allowing the temperate deciduous forests to return. Remnants of the boreal spruce/fir forest still remain at higher elevations along the backbone of the Appalachians, but the vast majority of southeastern U. S. soils were at equilibrium with hardwood or mixed pine-hardwood vegetation before they were cleared or logged. Virtually no productive soils remain in their original form, and we know very little about their equilibrium morphology and properties.

The soils that we study today have all been disturbed to some degree, and we really have no way of knowing whether or not they have achieved a new equilibrium with their environment and vegetation, or if they are still changing. For example, the assignment of erosion classes to soils within mapping units is very difficult when only eroded A horizons are available for comparison. It is also very difficult to gauge the effects of intensive agriculture or logging on long term soil productivity when the only comparison is to another disturbed system.

The Joyce Kilmer Forest, just south of the Great Smoky Mountains National Park offers a remarkable opportunity to study large areas (1600 ha) of highly productive soils in dynamic equilibrium with their original vegetation. This dissertation represents the first integrated research on these virgin soils along with their associated vegetation, and is divided into three separate studies with the following objectives:

a. Chapter 2. To describe and analyze the morphology of these virgin soils for use as benchmarks in other studies, and to examine the effects of topographic position and continuous hardwood vegetation on soil properties in an undisturbed system.
b. Chapter 3. To determine the dominant soil weathering sequences and the chemical and mineralogical properties of these undisturbed soils, and to relate these properties to variations in topography, parent material, and vegetation.
c. Chapter 4. To characterize the vegetation, litter layers, and soil/litter nutrient pool associated

with this highly productive, undisturbed forest system, and to compare it with other southern Appalachian forest soil systems.

Chapter II

SOIL MORPHOLOGY, GEOMORPHOLOGY, AND CLASSIFICATION

2.1 ABSTRACT

Little is known about the form and properties of the original soils in the eastern United States, the majority of which have been disturbed in one way or another. Eight sites with virgin forest soils formed under southern Appalachian hardwood vegetation were extensively examined in the Joyce Kilmer Memorial Forest in western North Carolina. The study sites ranged in elevation from 720 to 1200 m and only two sites occurred on < 50% slopes. Overall these soils are quite deep and highly weathered due to the high rainfall (>200 cm) and relatively high solubility of the feldspathic parent material. Average solum depth was 90 cm and depth to metasandstone bedrock was typically > 1.3 m. Soils on northerly aspects had thick umbric epipedons with higher organic matter accumulations than soils on south-facing slopes. Organic matter contents of A1 horizons ranged from 4.5 to 16%, and the surface horizons contained moderate coarse and medium crumb structure. All but one soil contained cambic subsurface horizons and had decreasing clay contents with depth from the surface. Argillic horizons are present only

at low elevations on south-facing slopes in this watershed. While the majority of soils in the watershed are formed in colluvium, significant amounts of deep residual soils occur on sideslopes and appear to be quite stable. The present-day landforms appear to be the result of periglacial activity. Windthrow has probably been a significant factor in mixing surfaces of these soils over time. Due to their decreasing clay content with depth, oxidic mineralogy, and low CEC, these soils highly resemble tropical forest soils.

2.2 INTRODUCTION

The majority of soils in the eastern United States formed in equilibrium with forest vegetation, and almost all have been logged or cultivated. The virgin soils that remain tend to be found on harsh high altitude sites where logging was impractical, or in small isolated stands preserved by classification as historic sites or by private landholders. Since the vast majority of soils in the east were disturbed before the recent advances in soil science, very little is known about their original form and properties. This is particularly true of surface horizons, most of which have been subjected to extensive erosion and physical manipulation. Intensive cultivation and erosion has removed a vast majority of the original O and A horizons from the southeastern U.S. Piedmont

(Trimble, 1975) and logging has had similar or even more drastic effects (Clarkson 1964) on many steeply sloping Appalachian soils. This is particularly true of areas logged before the 1930's without erosion control or reforestation practices. Mass wasting and mud-flows were common in the high rainfall areas of the southern Appalachians during this period (Hursh, 1941). Thus, when we attempt comparative studies of soils to discern the influences of various soil forming factors or effects of land uses over time, we really do not have benchmark soils for reference. The fact that distinct surface horizons can re-form quite rapidly in severely disturbed materials (Daniels, et al. 1980, Smith, et al. 1971) further complicates our interpretations.

The Joyce Kilmer Memorial Forest in Graham Co., North Carolina (Fig. 1) contains 1600 ha of virgin hardwood forests and soils. Although many areas of the watershed are quite steep (>50%), it is a highly productive site (Lorimer,1978) which remained unlogged only because of a fortuitous combination of ownership changes and the fact that TVA flooded the main railroad grade into it around 1930. Since that time the U.S. Forest Service has maintained it in its original state. Because of its size, landscape diversity, varying hardwood timber types and uniform parent material, it affords an excellent opportunity to study the effects of topographic position

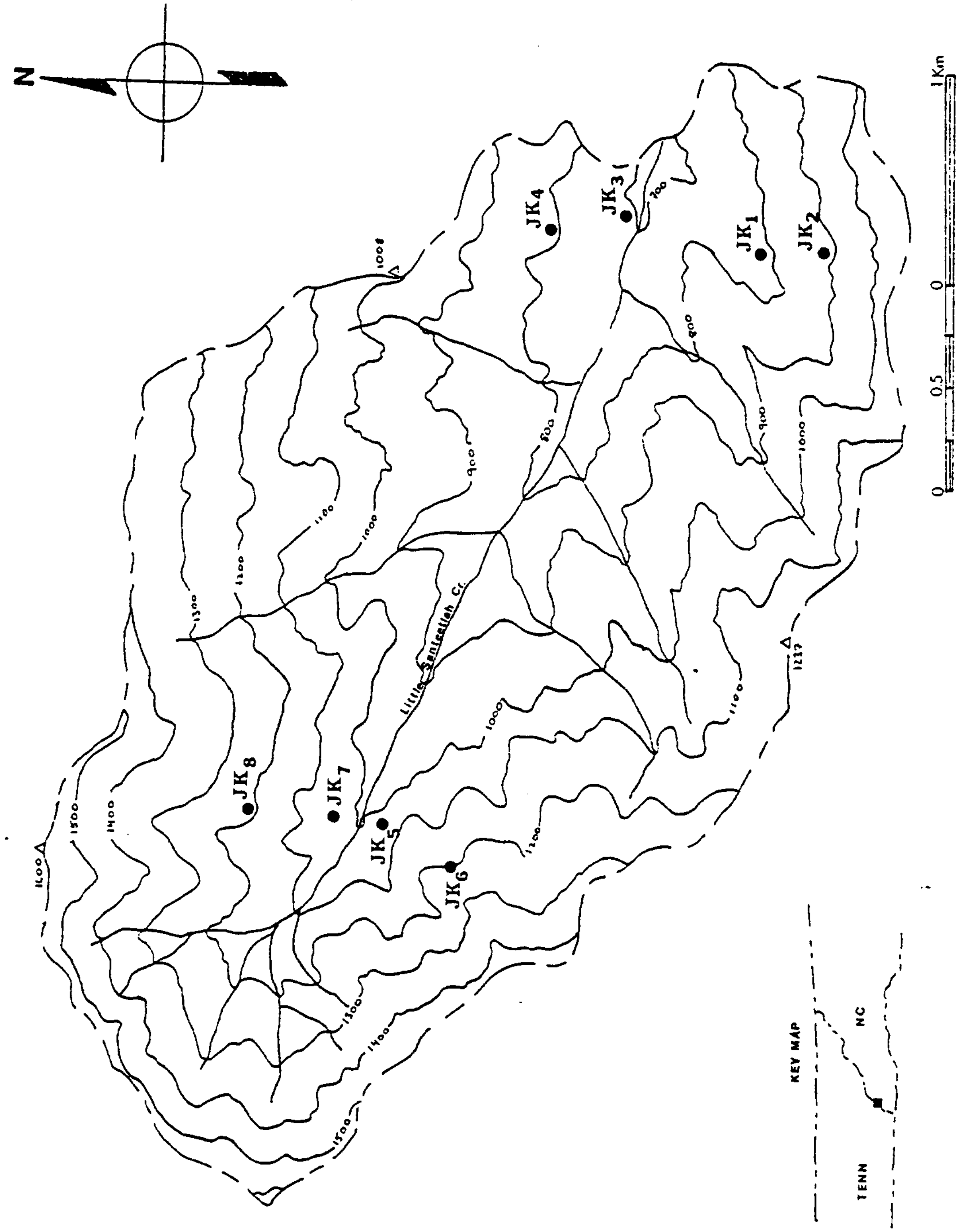


Figure 1. Map of the Little Santeetlah Creek watershed and the location of sampling sites.

and vegetation on soil properties without the complications of human activities.

Few detailed studies of southern Appalachian soils have been undertaken to date, and very little soil mapping has been performed outside of populated low elevation (<600m) valleys. Franzmeier, et al. (1969) studied the effects of aspect and elevation on soils derived from acid sandstones and shales in eastern Kentucky and Tennesee, and reported that soils in mid-slope positions were coarser textured and lower in base saturation than soils on lower slopes. Soils on south-facing slopes contained thinner A horizons with lower organic matter contents, and B horizons with higher clay contents than those on north-facing slopes. Similar relationships were reported by Finney, et al (1962) for sloping soils in southeastern Ohio. In both studies the differences were attributed to higher irradiation, evapotranspiration and soil temperatures on the southern slopes and associated differences in vegetation, weathering, and oxidation rates.

In a study conducted in Transylvania Co. North Carolina, Losche, et al (1970) found that aspect strongly affected profile differentiation and degree of weathering in soils derived from granitic biotite gneiss. Typic Hapludults and Typic Dystrochrepts were described on steep slopes (>50%) and all soils were quite deep (>1m). No reference was made as to whether the soils were residual or colluvial, but the high rainfall of the area (250 cm) and temperate climate had combined to produce extremely deep soil weathering. In a second part of the same study the authors found virtually no significant aspect effects in a lower rainfall (93 cm) environment in southwest Virginia, and the soils were much less weathered than those in North Carolina. The soils in the Joyce Kilmer area were reconnasaince mapped as stony loams by Goldston and Gettys (1953), and the only other soils information reported to date is contained in a soil-vegetation study by Oosting and Bordeau (1954). They studied virgin eastern hemlock (Tsuga canadensis) stands in footslope and rocky alluvial positions and reported deep, organic rich surface horizons, "crumbly structure", and were surprised by the uniformity of soil properties from site to site.

Our major objective in this study was to describe and analyze virgin hardwood forest soils for use as benchmarks, and to examine the effects of topographic position and continuous hardwood vegetation on major soil properties in an undisturbed system. While the data and relationships reported in this paper are certainly specific to the parent material and region studied, we believe that they reveal many important aspects of the original soils of the Appalachians.

2.3 MATERIALS AND METHODS

2.3.1 Study Area Description

The Joyce Kilmer Memorial Forest lies just southwest of the Great Smokey Mountains National Park in a steeply sloping watershed (Fig. 1) incised into rocks of the precambrian Great Smokey Group (King, et al. 1968). The bedrock is composed primarily of massive metasandstones, with lesser amounts of metasiltstones, graywackes, and phyllites. The metasandstones within the watershed are commonly feldspathic, and some contain appreciable amounts of carbonates. Many of the finer textured metasiltsones and phyllites contain pyrites. The high ridges around the watershed are capped with resistant quartzitic metasandstones and conglomerates. A detailed discussion of the geology and mineralogy of the parent materials is included in Chapter 3. Little Santeetlah Creek drains the watershed, and elevations range from 700 to >1600 m on the watershed divide. The vegetation ranges from mixed-mesophytic cove hardwood associations in the moist lower landscape positions to mixed oak-hickory stands on the steeper side slopes to heath slicks (rhododendron laurel-azaelea) on high exposed ridge tops. Many of the trees in moister sites exceed 50 m in height and 1.3 m in diameter. Mountain silverbells (Halesia carolina) is a major component of the higher altitude forests on the north slopes while extensive areas of mixed oak-pine forest with dense mountain laurel (*Kalmia latifolia*) understory are common on hotter low elevation south facing slopes. American chestnut (*Castanea dentata*) was a major component of the forest before it was eradicated by the chestnut blight in the 1940's. Chapter 4 contains considerable detail on the vegetation present at all study sites.

The watershed forms a symmetric oval with its main axis oriented NNW-SSE. Thus, the soils on one side face primarily S-SW, and on the opposite side N-NE. The majority of the watershed is in the mesic temperature regime, with an average yearly air temperature of 13^{o} C. The average yearly rainfall at the two closest National Weather Service stations is 146 cm (Tapoco) and 158 cm (Andrews), but both of these stations are below 600 m in elevation. The actual precipitation received in the Little Santeetlah Creek watershed is certainly much higher, the local U.S. Forest Service office estimates the rainfall at >200 cm.

2.3.2 SAMPLING AND ANALYTICAL METHODS

Eight intensive sampling sites were located on two transects, one in the lower portion of the watershed, and one in the upper portion (Fig. 1). Elevations of the sampling sites ranged from 732 to 1220 m, and the transects were located across the watershed so that aspects on one side were N to NE, and S to SW on the opposing side. Each site was designated on a map before we entered the watershed. After hiking into each site, we surveyed the soils in the immediate area with a probe, and then chose the pit location in what we considered to be a typical soil for that immediate area. Soils in rocky drainage ways and recent stream deposits were excluded, since they were minor components of the overall soil body. Only two sites occurred on slopes $< 50\%$. Soil pits were dug by hand at each site, and the soils were described during the summers of 1982 and 1983 according to the U.S. Soil Survey Handbook (1983). Large bulk samples were taken from each delineated horizon for laboratory analysis, and small sub-samples for N analyses were chilled immediately. Three bulk density cores were taken with a 5-cm diameter sampler from the center of each major A, B and C horizon. Numerous rock samples were collected from bedrock outcrops, colluvial deposits and drains. The organic horizons were separated into Oi, Oe and Oa layers, and sampled from five 0.1 m^2 quadrats at each site. Detailed notes were taken on slope geometry, landscape position, extent of windthrow mounds, and other perturbations. (i.e. chestnut blight).

In order to characterize overall soil morphology in the area surrounding each of the study sites, four transect studies were conducted at each site. The transects were run directly up and down slope (on and 180° to aspect) and across slope (90° and 270° to aspect), and consisted of 5 sampling points each at 30 m intervals from pit center. At each point, 3 observations were taken with a 1.25 m soil probe, and a composite description of average horizon depths was recorded. Additional data on parent material, gemorphic setting, and any abberant soil properties were recorded for each point. Solid cliff lines, ravines, and dense rhododendron made it impossible to sample all 20 points at all sites, so the distributions and data reported reflect the proportion of actual sites sampled. In addition to this concentrated work at the 8 intensive sampling sites, we investigated the entire watershed for many weeks, making hundreds of individual soil observations with a probe. Many of the basic geomorphic relationships reported in this chapter are the result of these extensive investigations.

Bulk soil and litter samples were immediately air dried upon return to the laboratory. The air-dry soil samples were sieved through a 10-mesh sieve to remove coarse fragments, and the litter samples were oven dried at 70° C and weighed. Bulk density cores were dried at 105° C and weighed. The particle size distribution of the < 2 mm soil fraction was determined by sieving (sand) and pipette analysis (silt and clay). Soil organic carbon was determined by a Walkely-Black method, and soil pH was

Table 1. Topographic characteristics, surface soil (0-7.5 cm) organic matter content and litter layer weights.

Site	Elevation	Aspect	Slope	Surface Organic Matter	Litter Layer Weights			
					Oi	Oe	Oa	Total
	m		%	%	Mg/ha			
North Facing Slopes								
1	732	N-NE	22	18.38	0.40	10.89	6.92	18.21
2	857	NE	53	14.41	0.61	7.81	6.91	15.33
5	1068	E-NE	59	15.48	0.44	9.27	10.07	19.78
6	1220	NE	57	14.83	0.34	5.54	7.47	13.35
South Facing Slopes								
3	738	SE	31	8.05	0.88	7.71	15.67	24.26
4	863	S-SW	55	7.77	0.77	10.08	3.91	14.76
7	1043	S-SW	60	10.66	1.26	6.96	5.60	13.82
8	1220	S	54	10.19	0.97	7.60	6.82	15.39

Table 2. Selected physical and chemical characteristics of mineral horizons.

Site	Horizon	Depth	Coarse Frag.	Sand	Silt	Clay	Bulk Density	Organic Matter	pH	CEC	Base Sat.	Effective CEC
		cm	----------------	%	----------------		Mg/M^3	%		$cmol \cdot kg^{-1}$	%	$cmol \cdot kg^{-1}$
						North Facing Slopes						
1	A1	0- 13	1.4	24	43	33	0.76	16.1	5.77	42.8	33	14.2
	A2	13- 30	1.0	24	44	32		10.7	5.34	36.7	8	4.7
	AB	30- 43	0.7					3.8	5.21	24.5	2	2.4
	Bw1	43- 64	1.5	29	40	31	1.24	1.0	5.21	16.5	4	4.5
	Bw2	64-128	0.9	31	36	33		0.7	5.30	15.6	4	4.9
	R	128+										
2	A1	0- 15	6.0	40	41	19	0.98	8.6	5.21	31.9	14	5.4
	A2	15- 42	4.7	44	42	14		2.6	5.02	16.9	1	1.9
	Bw	42-110	9.3	53	32	15	1.32	1.1	5.16	10.4	1	1.9
	C	110-145	12.7	69	25	6	1.48	0.2	5.45	2.9	3	0.3
	CR	145-386	0.8	73	24	3		0.1	5.60	0.9	2	0.3
	R	386+										
5	A1	0- 6	1.3	30	41	29		17.0	4.12	52.9	10	10.3
	A2	6- 20	6.8	33	43	24	0.74	8.7	4.50	37.4	2	4.9
	A3	20- 31	0.2	36	46	18		5.8	4.96	29.6	2	3.7
	BA	31- 50	0.3	36	48	16		2.9	4.89	21.2	2	3.1
	Bw	50- 94	0.6	42	43	15	1.05	1.3	5.14	14.4	2	2.7
	CB	94-141	0.9	56	34	10		0.7	5.38	10.4	2	1.8
	CR	141-170+	0.1	72	27	1	1.75	0.3	5.51	3.6	3	0.9
6	A1	0- 12	3.7	40	37	23		12.8	4.81	38.1	2	4.7
	A2	12- 27	0.6	38	42	20	0.99	8.6	5.02	27.7	1	3.1
	AB	27- 52	3.1	44	40	16		4.2	4.89	23.2	1	2.9
	Bw1	52- 93	0.8	45	36	19		1.1	5.03	11.3	2	2.8
	Bw2	93-118	2.8	46	36	18	1.33	0.6	5.11	10.4	3	3.6
	CB	118-150	2.2	59	29	12		0.3	5.14	6.8	3	2.3
	C	150-170+	1.7	65	29	6	1.51	0.2	5.44	4.6	3	1.2

Table 2 cont.

Site	Horizon	Depth	Coarse Frag.	Sand	Silt	Clay	Bulk Density	Organic Matter	pH	CEC	Base Sat.	Effective CEC
		cm	----------------%----------------				Mg/M^3	%		$cmol\text{-}kg^{-1}$	%	$cmol\text{-}kg^{-1}$
						South Facing Slopes						
3	A	0- 12	8.9	58	29	13	1.21	4.5	4.71	14.5	2	2.9
	Bw	12- 33	9.7	54	32	14		0.7	5.24	14.6	2	1.4
	Bt	33- 84	1.3	55	26	19	1.40	0.3	5.19	5.3	11	1.4
	C	84-126	0.2	63	26	11	1.54	0.1	5.33	4.3	7	1.0
	R	126+										
4	A	0- 14	34.0	49	38	13	1.24	6.3	4.59	19.6	3	4.3
	Bw	14- 63	10.7	49	40	11	1.65	0.6	5.06	7.0	5	1.6
	R	63+										
7	A1	0- 9	2.4	46	38	16		9.2	4.97	27.4	2	4.1
	A2	9- 19	3.8	49	36	15	0.96	3.9	4.71	18.3	1	2.5
	BA	19- 37	2.4	48	37	15		1.4	4.80	10.7	2	2.5
	Bw	37- 70	3.5	49	34	17	1.35	0.6	4.80	9.7	3	3.1
	CB	70-100	0.9	63	26	10		0.8	4.95	7.7	5	2.4
	CR	100-140+	38.0	81	16	3	1.69	0.1	5.20	2.6	4	0.4
8	A	0- 10	4.8	46	35	19	1.06	10.6	4.68	31.9	2	4.4
	BA	10- 20	10.1	49	35	16		3.3	4.88	14.3	2	2.4
	Bw	20- 31	6.2	53	33	14	1.28	1.3	5.31	10.4	3	2.1
	BC	31- 57	3.7	57	29	14		0.6	5.29	8.6	3	2.1
	CB	57- 75	0.3	60	28	12		0.3	5.38	8.0	2	1.6
	CR	75-125	0.1	72	22	6	1.62	0.1	5.09	4.7	4	1.1
	R	125+										

Table 3. Morphological properties of major mineral horizons and pedon classification.

Site	Horizon	Depth	Color	Texture	Structure	Consistence	Boundary	Classification
					North Facing Slopes			
1	A1	0- 13	10YR3/1	cl	2c&mcr	mfr	cs	Typic Haplumbrept
	A2	13- 30	10YR3/3	cl	1f&msbk	mvfr	gs	fine loamy, oxidic, mesic
	Bw2	64-128	10YR4/6	cl	1f&msbk	mvfr	as	
	R	128+	Rounded Gray Metasandstone Boulder					
2	A1	0- 15	10YR3/2	l	2c&mcr	mfr	cs	Typic Haplumbrept
	A2	15- 42	10YR3/3	l	1mcr/1fsbk	mvfr	gs	coarse loamy, oxidic, mesic
	Bw	42-110	10YR4/4	l/sl	1f&msbk	mvfr	gw	
	CR	145-386	10YR7/1& 10YR2/1	ls	o-m	mfi	as	
	R	386+	Gray Metasandstone Bedrock					
5	A2	6- 20	10YR3/2	l	2mcr/2msbk	mfr	cw	Typic Haplumbrept
	A3	20- 31	10YR3/3	l	1f&msbk	mvfr	cw	coarse loamy, oxidic, mesic
	Bw	50 -94	10YR5/6	l	1f&msbk	mvfr	gw	
	CR	141-170+	10YR5/1	ls/sl	o-m	mfr		
6	A1	0- 12	10YR2/2	l	2c&mcr	mfr	cs	Typic Haplumbrept
	AB	27- 52	10YR3/3	l	1f&msbk	mvfr	gs	coarse loamy, oxidic, mesic
	Bw1	52- 93	10YR4/4	l	1msbk	mvfr	ds	
	C	150-170+	2.5Y6/4	sl	o-m	mfr		

Table 3 cont.

Site	Horizon	Depth	Color	Texture	Structure	Consistence	Boundary	Classification
					North Facing Slopes			
3	A	0- 12	10YR4/3	sl	1mcr/1msbk	mvfr	cs	Typic Hapludult
	Bt	33- 84	7.5YR5/6	sl/scl	1msbk	mvfr	gw	fine loamy, oxidic, mesic
	C	84-126	10YR5/6	sl	o-m	mfr	aw	
	R	126+	Dark Gray Fine Grained Metasandstone Bedrock					
4	A	0- 14	10YR3/4	l	1fcr/1fsbk	mvfr	cs	Umbric Dystrochcrept
	Bw	14- 63	10YR5/6	l	1msbk	mvfr	as	coarse loamy, oxidic, mesic
	R	63+	Dark Gray Fine Grained Metasandstone Bedrock					
7	A1	0- 9	10YR3/2	l	2mcr/1msbk	mfr	cs	Umbric Dystrochrept
	A2	9- 19	10YR4/4	l	1m&fsbk	mvfr	gw	coarse loamy, oxidic, mesic
	Bw	37- 70	10YR5/6	l	1msbk	mvfr	gw	
	CR	100-140+	10YR5/1	ls	o-m	mfi		
8	A	0- 10	10YR3/2	l	2mcr	mfr	cw	Umbric Dystrochrept
	BA	10- 20	10YR4/4	l	1f&msbk	mvfr	cs	coarse loamy, oxidic, mesic
	Bw	20- 31	10YR4/6	l/sl	1f&smbk	mvfr	cs	
	CB	57- 75	10YR5/3	sl	o-m	mfi	cw	
	CR	75-125	10YR5/2	sl	o-m	mfi	aw	
	R	125+	Gray Metasandstone Bedrock					

determined in the supernatant portion of a 1:1 soil:water paste. Cation exchange capacity was calculated as the sum of pH 7 NH_4OAc extractable bases and $BaCl_2$-TEA acidity. Effective CEC was calculated as the sum of extractable bases and KCl exchangeable acidity.

2.4 RESULTS AND DISCUSSION

2.4.1 Soil Morphology and Classification

Considering the fact that all but two of the sampling sites occurred on slopes > 50% (Table 1) these soils are surprisingly deep and free of coarse fragments (Table 2). Complete soil descriptions of all pedons are in Appendix I. Average solum depth of the 8 soils was 90 cm and average depth of the A horizons was 25 cm. Depth to hard rock was frequently > 1.3 m. The colors and overall solum depths of all soils were quite similar (Table 3). Seven of the 8 soils contained cambic subsurface horizons with clay contents that decreased with depth. All four soils on the north-facing slopes were Typic Haplumbrepts, while 3 of the 4 soils on the south facing slopes were Umbric Dystrochrepts. The sole argillic horizon was found at site 3 in the lowest south facing soil, a Typic Hapludult. Soil pH ranged from 4.1 to 5.8, and the percent base saturation of all soils was extremely low. The high CEC values reported in Table 2 are artifacts of the $BaCl_2$-TEA acidity technique for determining acidic components in acid high organic matter soils, and the effective CEC of these soils is generally less than 5 cmol/kg. All profiles were in the oxidic mineralogy class. Greater detail on the chemical and mineralogical characteristics of these soils is included in Chapter 3.

The A horizon organic matter accumulations and overall depths were greater on north facing slopes, and generally increased with elevation as expected (Table 2). The influence of aspect and elevation was readily apparent when whole soil organic matter contents are compared (Fig. 2). Surface A horizon organic matter contents varied from 17.0 to 8.6 % on the northerly aspects and from 10.6 to 4.5 % on opposing south facing slopes. Total A horizon depth ranged from 52 cm in the highest north-facing soil (Fig. 3) to < 19 cm on the southerly aspects. Significant amounts of organic matter are mixed deeply into the subsoil in these profiles, particularly on north aspects. Much of this subsoil organic matter is derived from old root voids and channels filled with A horizon material (Fig. 3). The organic matter contents of the mineral soil surface layers (0 - 7.5 cm) also vary by aspect, but did not show a regular increase with altitude (Table 1). Total litter layer weights were quite similar for all soils except at site 3 which was the only site dominated by laurel, pine and other dry site species. The A horizon depths on both aspects were much deeper than those

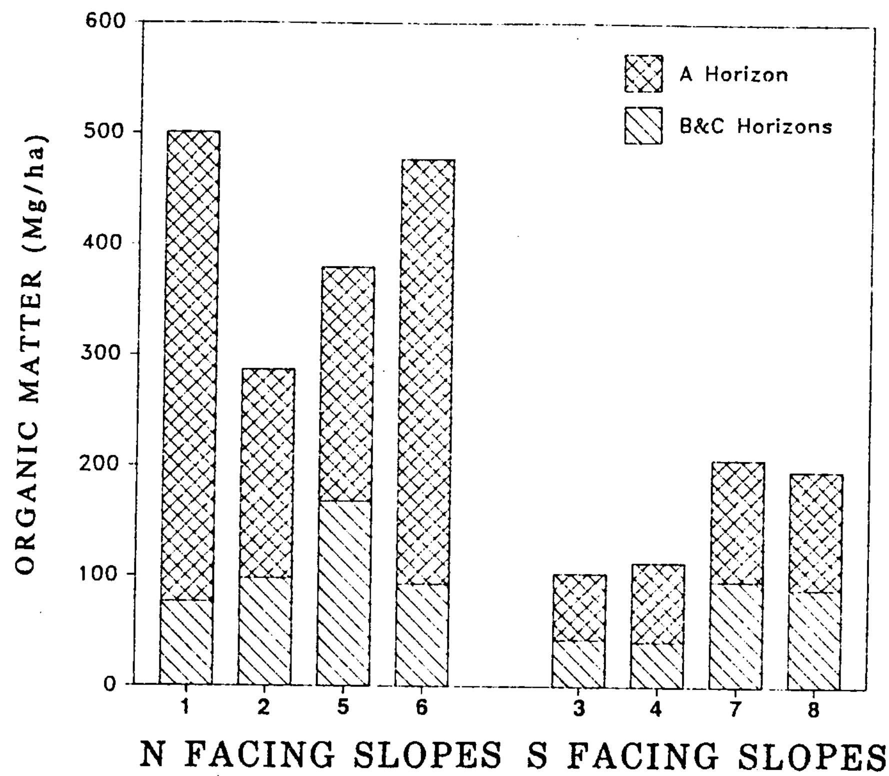


Figure 2. Whole soil organic matter contents. Values are corrected for bulk density and coarse fragments.

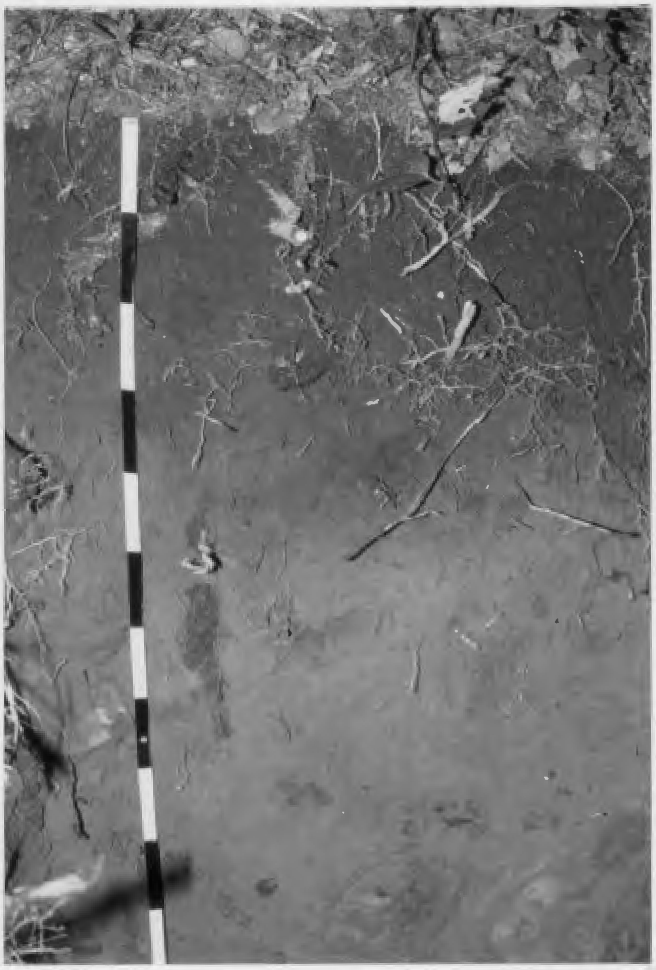


Figure 3. Deep (52 cm) A horizon in soil 6. Note the Krotovina on the right edge, and the deep inclusions of darkened material into the B horizon.

reported by Losche, et al (1970).

The surface horizons of these soils, particularly those on north aspects contained striking moderate to strong, medium and coarse crumb structure (Table 3 and Fig. 4). Individual crumbs were friable, separated readily from adjacent peds, and were penetrated by numerous fine and medium roots. Surface horizons with lower organic matter contents contained mixtures of moderate, medium crumbs and moderate fine and medium subangular blocks. Many of the individual crumbs were >10 mm in diameter, and were riddled with channnels and pores. Crumb structure is seldom described by modern soil scientists, perhaps it is a relic of the past, found only in relatively undisturbed high organic matter horizons. The structural development in these surfaces is the strongest that we have observed in the Appalachians where many present day soils are actively forming new A horizons in eroded subsoil materials.

The subsurface horizons in these soils contain porous, very friable, weak subangular blocks. Clay skins were conspicuously absent, with only occasional clay bridges evident between sand grains. Tubular and vesicular pores were common through and in the peds. Wet-dry cycles in these subsoils are rare due to the extremely wet climate, thus the weak structural development. Highly weathered and massive metasandstone saprolites formed deep

Figure 4. Coarse crumb structure in the A horizon of a soil near site 1.

C and CR horizons at sites 2, 3, 5, 7 and 8, and the remnants of the original rock structure could frequently be traced well up into the profile (Fig. 5). However, several soils did contain sub-rounded coarse fragments in their upper horizons. Soils 1, 4 and 6 were weathered entirely into colluvium and contained abrupt rock contacts or tongued down between large rounded boulders and cobbles. Soil 7 contained 70 cm of highly weathered colluvium over intact saprolite (Fig. 5).

One of the most impressive features of these soils is the dense network of roots throughout their sola, and common roots even at great depths. The surface horizons were riddled with all sizes of tree, shrub and herb roots, while the B horizons were typified by common fine, medium and coarse roots. Fine and medium roots were also found throughout the C and CR horizons. At site 2, several fine roots were recovered from auger borings below 3 m. Due to this dense reinforcing root network and the extensive nature of much of the vegetation, mass movement or wasting of these soils would be quite difficult without the complete removal or movement of the vegetation as well. Very little evidence of recent short range slope-creep (i.e., bowed tree trunks) was evident at any sites. Due to the maturity of the forest cover, dead standing trees and wind throws were numerous, and wind throw mounds (Fig. 6) were common at all sites, generating an undulating

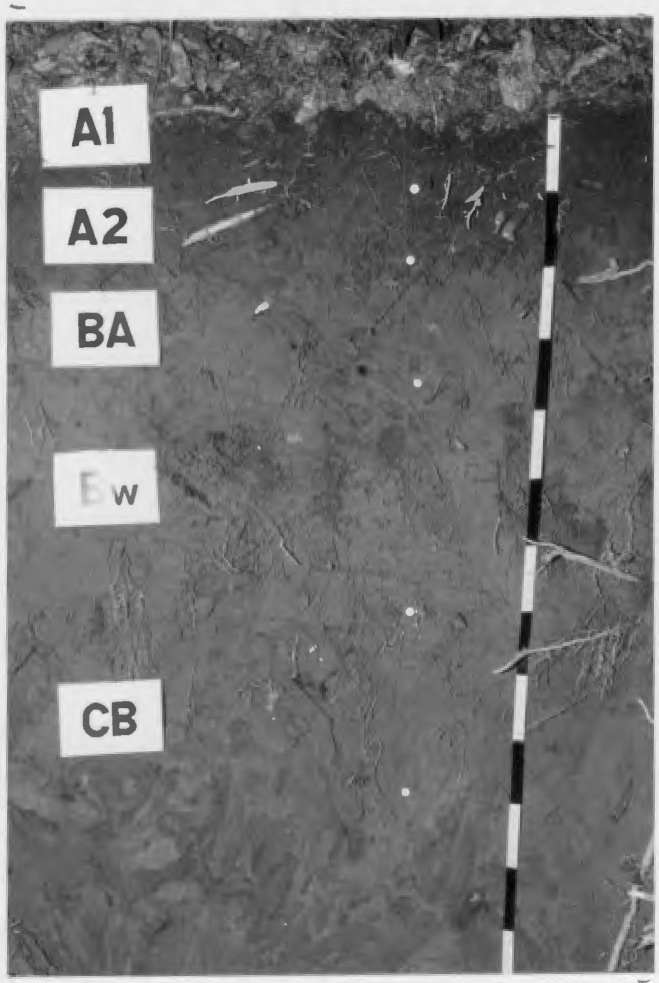


Figure 5. Profile of soil 7. The C and CR horizons below 70 cm are highly weathered metasandstone saprolite, while the solum above 70 cm is colluvium.

Figure 6. Windthrow mound near site 2 showing the uprooting and mixing of B horizon material into the surface. Winthrow mounds were common at all sites, particularly on north-facing slopes.

micro-topography. Wind throw mounds were much more extensive on north facing slopes, particularly at higher elevations.

2.4.2 Physical Characteristics

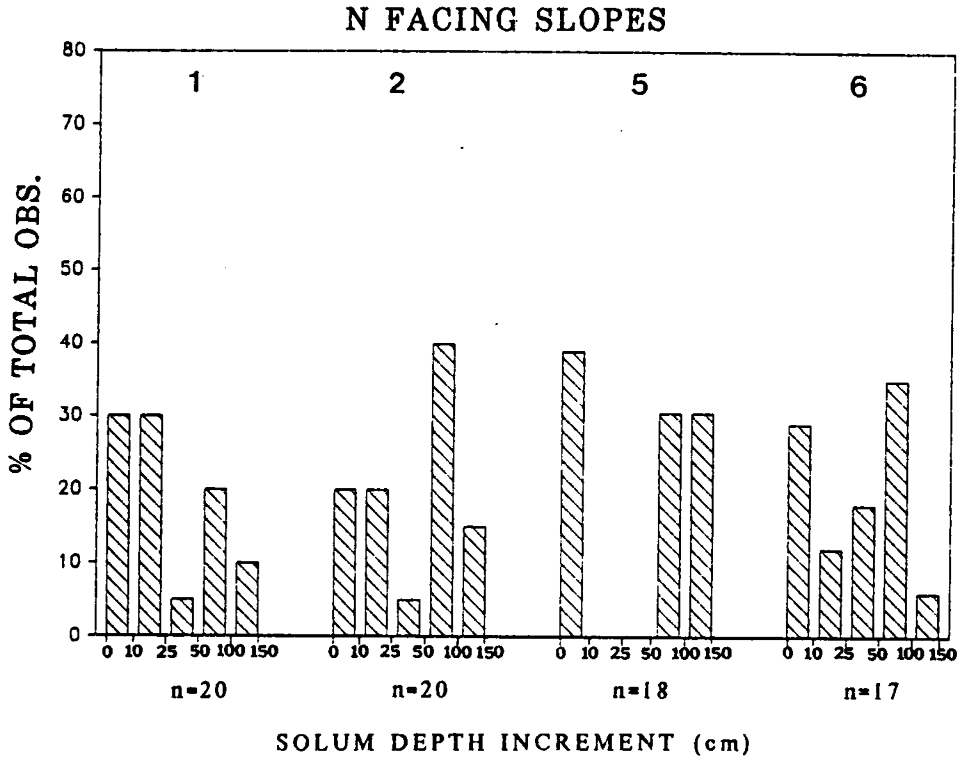
The metasandstone parent material imparted dominantly coarse loamy textures to all soils, particularly in their subsurface horizons. Soil 1 is appreciably finer in texture than all others (Table 2), possibly because its colluvial parent material was considerably weathered before deposition, or it was enriched with fines washing out of the large watershed above it. This soil formed in a large (>10 ha) gently sloping colluvial deposit that fills the bottom of a large cove and may have been transported a considerable distance. Large boulder trains radiate from this massive deposit up into the intermittant drainage ways that feed into it. The other two dominantly colluvial soils (4 and 6) occur on steep slopes well above the valley floor, appear to be the result of more local slope movement over time, and have coarser textures. The clay and silt contents of all soils decrease with depth as sand increases, except for soil 3 which contains a weak argillic horizon. The C and CR horizons are quite coarse, usually >60% sand.

The extremely high rainfall and moderate temperatures in this region coupled with a parent material prone to solution weathering have led to deeply weathered profiles. We believe that these soils were deeply weathered initially by dissolution of feldspars and carbonates, and that the silts and clays are generated by accelerated physical and chemical weathering processes in surface horizons. Soils on north-facing slopes are higher in whole soil clay contents than those on south-facing slopes, probably due to the greater amount of leaching on cooler slopes. Clays that are generated in surface horizons then either dissolve or are eluviated completely through the profile. The latter hypothesis is supported by the fact that at sites 1, 2 and 4 we found significant clay accumulations in a thin rind (10 to 15 mm) just above the R horizon contact. The climate of this region is so wet that the B horizons are continuously moist, seldom undergo wet/dry cycles, and may not dry sufficiently to allow flocculation of dispersed clays moving with wetting fronts.

Other than soil 4 which is shallow and strongly colluvial, the coarse fragment contents of most of these soils are low when compared with most steeply sloping Appalachian soils (Franzmeir et al., 1969, Losche, et al., 1970), typically < 10% by weight. Coarse fragments present were quartz and rounded metasandstone gravels and cobbles in surfaces and colluvial horizons or hard saprolite fragments in lower residual horizons. The overall coarse fragment content of the colluvial soils is much higher than that reported here, however, due to the fact that soils 1 and 6 were described and sampled from areas of finer materials within rockier deposits. The bulk density of the A horizons was typically quite low (< 1.0 Mg/m^3) due to high organic matter contents and porous structure. The bulk densities generally remain below 1.4 Mg/m^3 through the porous B horizons, before increasing in the C or CR horizon saprolites.

2.4.3 SOIL TRANSECT STUDIES

The 8 soils just described were selected as being typical of their randomly selected sampling sites, but may not accurately represent the overall morphology of all soils in the watershed. The transect analyses (16 to 20 points each) were conducted at each site to objectively define the distribution of major soil types and overall soil depths in the vicinity of each sampling site. Transects were extensive enough that we believe that we can make accurate inferences about the overall form and depths of these undisturbed soils. Each of the 4 transects at each site extended far enough away (150 m) from plot center that a wide variety of landforms were sampled. The frequency distributions of solum depths for each sampling site are presented in Fig. 7. Solum depth increments used (Fig. 7) were chosen to separate contrasting soil types. Observations in the 0 to 10 cm range represent bare rock outcrops, stony drains and streams, and a few extremely shallow A-R soils in rocky colluvium. The majority of soils in the 10 to 25 cm solum range are thin soils in rocky colluvium, while soils in the 25 to 50 cm solum range are either residual or deeper colluvial soils which tongue down between boulders. Approximately 1/3 of the soils with sola > 50 cm thick were colluvial with cobbles and stones on their surfaces, but the majority of the deeper soils contained deep C or CR saprolite horizons,



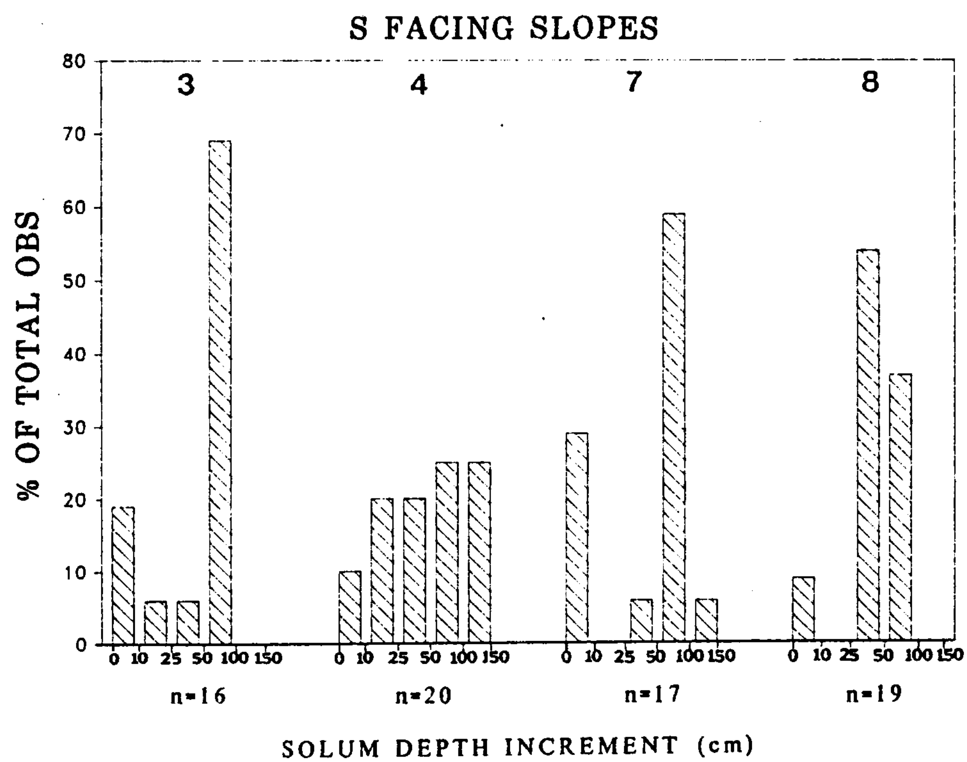


Figure 7. Distribution of solum depths encountered in transect studies at each site.

appeared to be residual, and were present on stone free surfaces with no evidence of slope movement or colluvial activity. The data presented in Fig. 7 refer to solum depths only, and depth to bedrock in most soils is much deeper. Based on the summed observations from all sites, 7% of the land surface is bare rock outcrop, 18% is covered by extremely shallow soils in stoney drains or braided stream deposits, 36% is covered by colluvial soils of varying depths, and 39% of the soils appear to be primarily residual with some surface mixing. Summaries of the field notes from the transect studies are presented in Appendix 2.

During the transect studies it became apparent that a number of soil types different from those examined in the soil pits occur, particularly in shallow colluvium and residuum, and in rocky drains. Assuming low base status in all soils, significant amounts of Typic and Lithic Dystrochrepts, Lithic and Entic Haplumbrepts, and Typic and Lithic Udorthents occur in the soil landscape. Numerous yellowish-red Typic Hapludults were also observed during the transect studies around sites 3 and 4, primarily over iron-rich phyllites and were a major component of the south-facing soils below 800 m. Argillic horizons were seldom encountered anywhere else in the watershed.

The distribution of solum depths from the transect study (Fig. 8) reveals that except for the fact that we excluded extremely shallow soils in stony drains and over rock outcrops, the 8 soils chosen for intensive study do represent the dominant soils in the landscape. The average solum depth and A horizon thickness of deep soils (sola >50 cm) observed on transects at each site (Fig. 8) reveals the same overall trends observed in the pit studies. The A horizons were much thicker on the north-facing slopes, and increased in depth with altitude. Sola thicknesses are all quite similar, but are shallower overall than those described in the pits. This is probably due to the difficulty in accurately delineating a diffuse B-C horizon contact with a soil probe, and the fact that the probe tended to compress the soft A and B horizons to some extent. We believe that the uniformity in solum depth within and between sites is due to the deep in-situ weathering by solution of uniform parent materials, and the uninterrupted influence of the hardwood vegetation.

2.4.4 SOIL GENESIS AND GEOMORPHOLOGY

Geomorphological research in the central and southern Appalachians (Clark, 1968), southern Ohio (Denny, 1951), and the South Carolina Piedmont (Eargle, 1940) indicate that mass wasting of these landscapes, particularly at higher elevations occurred by periglacial mechanisms 10 to 40,000 years ago. The region south of the ice-sheet, while

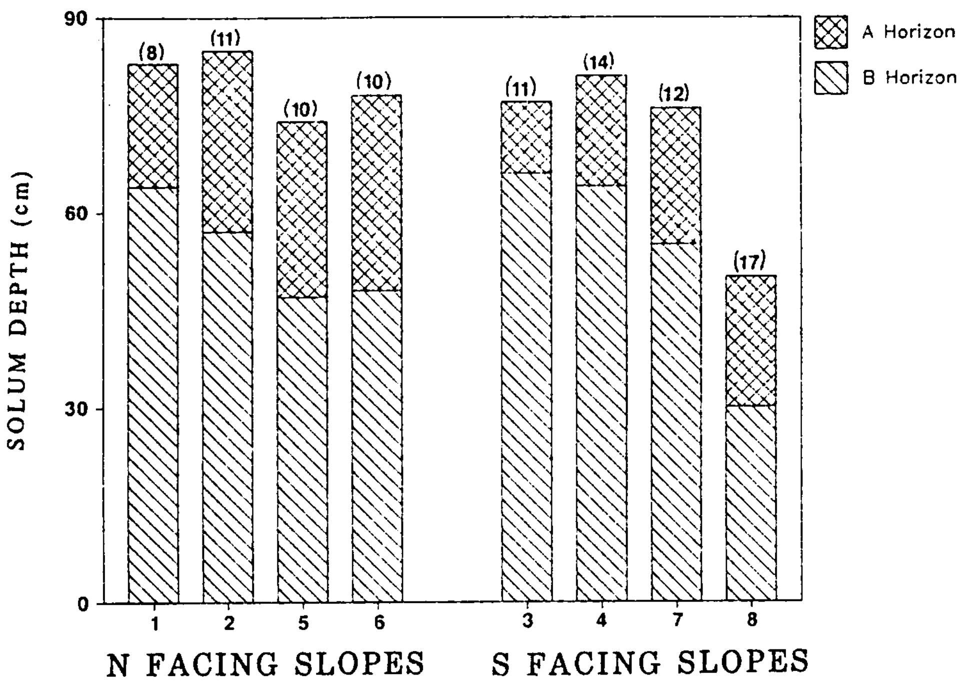


Figure 8. Average solum depths of deeper soils (those containing A and B horizons) encountered in transect studies around each site. Note the close correspondance with overall morphology described in the pit studies. Number of obs. each are ( ).

not glaciated, was under a much colder climate, and the vegeation in many areas was tundra-like, particularly at higher elevations. Boulders, rocks and existing soils were stripped from higher landscapes by solifluction above permafrost layers (Smith, 1949) and deposited in large cove and stream terrace fills, often leaving either hard rock or partially weathered saprolite at the stripped surface to serve as parent material for new soils once the climate warmed. This activity has resulted in the large fan of colluvial debris that blankets the broad cove floor at site 1, the head of the NE facing cove at site 6, and the extremely coarse boulder trains in the bottoms of many drainageways that were commonly encountered during transect studies. We found a mixture of deep and shallow soils in this colluvium, with deep tongues of soil forming in the finer matrix (that may have been pre-weathered before stripping and deposition) surrounded by large (>1 m) rounded boulders and cobbles that were derived from resistant quartzitic metasandstones higher in the landscape. These soils are extensively reinforced with tree roots and show no evidence of recent movement in themselves or the massive trees around them. The shallow colluvial soil at site 4 contains high amounts of angular coarse fragments and appears to be the result of short range colluvial movement, or perhaps a series of wind-throws.

The presence of many very deep residual soils on extremely steep slopes (> 50%) is surprising, however. Five of the 8 soils examined from pits contained highly weathered saprolites in their C and CR horizons, and the transect studies indicated that slightly more than 1/3 of the entire landscape contains residual soils. Most of these soils do contain some evidence of colluvial activity or mixing in their upper horizons, however. Small amounts of angular and rounded gravels and cobbles were usually found in the A horizons and occasionally in the upper B horizons. These may be the product of short range creep of surface materials over long periods of time, or may be due to soil mixing and local redistribution after wind throw of large trees (Fig. 6). Over the thousands of years that these soils have been under hardwood forest cover, it is likely that a major portion of the surface soil has been affected by these processes. Other than the fact that the colluvial soils are rockier and contain rounded cobbles and boulders, there are no significant differences in physical and chemical properties between the profiles that we believe are primarily residual and those that are obviously colluvial. The only exception is the colluvial soil at site 1 which is considerably finer in texture as discussed earlier. The colluvial materials do differ somewhat mineralogically, however, in that they contain smectites in their B horizons (Ch.3). This lack of distinctly different morphological characteristics between the two makes the delineation of discontinuities and cappings quite difficult, and we relied on the presence of of saprolite and relic rock structure in subhorizons to differentiate between colluvium and residuum.

Assuming that the scenario of periglacial stripping (via solifluction above permafrost layers) of the landscape is correct, residual soils at higher elevations have either weathered completely from hard rock, or from partially weathered saprolite exposed at the surface after stripping. The presence of rounded coarse fragments in surfaces of many residual soils at lower elevations is probably indicative of their being capped by materials that moved via solifluction from higher positions in the landscape, and then weathered in place over intact saprolite or rock (Fig. 5). Apparently, extreme weathering conditions, a soluble and massive parent material, and constant vegetative cover have combined to produce deeply weathered residual soils in a relatively short period of time. The stability of these materials on steep slopes over time is enhanced by the very massive nature of the metasandstones and the fact these porous soils pass water rapidly, preventing saturation and loss of shear strength. The importance of vegetation in reinforcing the slopes against wasting is pointed out by the numerous reports of slope failure and flash flooding in the southern

Appalachians after logging around the turn of the century (Hursh, 1941).

The overall soil landscape, then, consists of a mixture of deep residual and colluvial soils of varying depths on side slopes, and very rocky colluvial soils in foot slopes, intermittant drains, boulder trains and recent stream deposits. Rock outcrops commonly occur along the backbones of secondary spur ridges, and occasionally as cliff lines in the upper reaches of the watershed. At extremely high elevations (> 1400 m) the parent material is resistant quartzitic metasandstone and conglomerate and the soils under hardwood vegetation are generally shallow to rock with thick black surface horizons. Numerous heath balds are found on high exposed ridges in this region, and histic epipedons over spodic or placic subhorizons are common. These soils are similar to those reported by McCracken, et al. (1962) at higher elevations in the Smoky Mountains.

2.5 CONCLUSIONS

The outstanding characteristics of these undisturbed soils are their overall depth, thick dark surface horizons, distinctive coarse crumb structure, and uniformity in thickness, texture, and color. Significant amounts of deep stone-free residual soils commonly occur on extremely steep slopes, with little evidence of recent movement other than local surface mixing due to wind throws. The majority of soils in the watershed, however, are formed in colluvial debris on sideslopes and along footslopes, and in the broad boulder trains and valley fills left by periglacial activity. The extremely high rainfall and moderate year-round temperatures in this area have led to an almost tropical soil weathering environment and extremely deep weathering. Due to their decreasing clay content with depth, oxidic mineralogy, low CEC's, and very low base saturations these soils highly resemble Oxisols, and may need to be managed as such. These properties in combination with the fact that these soils occur on extremely steep slopes make these soils very fragile and susceptible to damage by erosion.

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Chapter III

SOIL WEATHERING, MINERALOGY AND CHEMICAL PROPERTIES

3.1 ABSTRACT

Eight undisturbed soils derived from feldspathic meta-sandstones in the Joyce Kilmer Memorial Forest were studied. Gibbsite was common throughout all soils as a product of feldspar weathering, and increased in abundance in the clay fraction with depth. The clay contents in the majority of the soils decreased with depth, with hydroxy-interlayered vermiculite (HIV) occurring as the dominant phyllosilicate in surface horizons. Kaolinite was low in all soils, but was more abundant in south facing soils. Gibbsite abundance was not aspect dependent. The silt fractions contained appreciable quantities of weathered 2:1 type minerals similar in makeup to the clays. The coarse sand fractions were almost entirely quartz, while the fine sand contained quartz, weathered 2:1 minerals and feldspars. The CEC of the mineral surfaces in these soils was extremely low due to coatings of Al and Fe oxy-hydroxides. Soil CEC is almost entirely derived from organic matter, and is typically < 3 cmol/kg in subsurface horizons. Levels of exchangeable Ca and Mg, acid extractable P and total-N are very low below surface

horizons. These soils have weathered in an extremely wet (>200 cm ppt.) and temperate environment and highly resemble tropical soils. Erosion could severely damage the natural productivity of these soils. Inceptisol morphology coupled with an oxidic mineralogy class makes proper taxonomic placement of these soils difficult.

3.2 INTRODUCTION

Our understanding of soil chemistry and its relationship to mineralogy and soil weathering processes over time has resulted primarily from the study of agricultural soil systems, and has therefore concentrated on productive, highly managed, and altered systems. Even the majority of eastern forest soils studied in recent years supported agricultural production at one time or another. This is particularly evident in southeastern Piedmont soils which which were heavily eroded prior to reforestation (Trimble, 1974). Many steeply sloping Appalachian forest soils were never cultivated, but most have been logged one or more times, frequently followed by fires and severe erosion (Clarkson, 1964). Often, the soil material that we sample and study from A or Ap horizons is recently exposed and rapidly weathering subsoil material that bears little resemblance to the original surface soil. The common occurence of subangular blocky structure and clay or clay loam texture in the surfaces of many eastern United States soils is the legacy of this history of disturbance. Thus when we attempt to study the effects of land use practices, intensive agriculture or clearcutting on soil properties and nutrient cycles we very seldom have a truly undisturbed system to serve as a comparative "control" treatment.

The Joyce Kilmer Memorial Forest in western North Carolina provides an excellent opportunity to study virgin hardwood forest soils under their original vegetative cover, free from the influences of man, and in particular it allows us to study soil weathering and chemical characteristics down through the profile. This large (> 1600 ha) mountainous watershed contains large expanses of deep, highly productive forest soils (Ch. 2). While the vegetation in the watershed has received some study (Lorimer, 1982, Oosting and Bordeau 1954), the soils have not, except for some general information on pH and organic matter content provided by Oosting and Bordeau (1954). In fact, the chemistry and mineralogy of steeply sloping soils in the southern Appalachians are poorly documented at best.

Two studies conducted in this region have reported stronger weathering on south-facing slopes than north-facing slopes. Franzmeier, et al. (1969) studied the effects of topographic position on steeply sloping soils in the Cumberland Plateau of eastern Kentucky and Tennessee and found argillic horizons on south-facing slopes and weakly weathered cambic horizons on opposing northerly slopes. Soils on northerly slopes had 2° C lower mean annual soil temperature, were considerably wetter year round, and therefore contained more organic matter. Soils in lower slope positions were higher in base saturation, presumably due to downslope water seepage. Losche, et al. (1970) studied the effects of slope aspect on soils weathered from granitic biotite gneiss in southwestern North Carolina, not far from our research area, and found that kaolinite and 2:1-2:2 intergrade minerals were dominant in soils on north-facing slopes while gibbsite was dominant on the hotter south-facing slopes. The soils were almost devoid of exchangeable Ca and Mg below their A horizons due to the extreme leaching environment. They also reported that the finer soil fractions were more highly weathered than the coarser fractions, and that the soils in lower slope positions were more highly weathered.

Intergrade vermiculite-chlorite is commonly reported (Weed and Nelson; 1962, Karanthanis, et al, 1983; Carlisle and Zelazny, 1974) as being the dominant stable surface soil 2:1 type mineral resulting from muscovite weathering in humid regions, while biotite commonly weathers to a kaolinite pseudomorph of the original mica crystal (Harris, et al 1985). A regularly interstratified biotite/vermiculite weathering intermediary (hydrobiotite) is reviewed in detail by Sawnhey (1977), and a similar product results from partial muscovite weathering (Norrish, 1973). Reports of regularly interstratified minerals in southeastern soils are rare, presumably due to the highly weathered stage of the majority of soils studied. Deep feldspar weathering in rock saprolites with recrystallization as kaolinite (Obrien and Buol, 1984) and at the soil/saprolite boundary with recrystallization as gibbsite and halloysite (Calvert, et al. 1980) have been reported in North Carolina Piedmont soils over granitic gneiss. In the latter study gibbsite was not present within the solum, and was considered to be reprecipitated at depth and then resilicated to halloysite.

The overall goal of this study was to determine the parent material/soil weathering sequences and the chemical and mineralogical properties of undisturbed soils within the Joyce Kilmer Memorial Forest, and relate these properties to variations in aspect, parent materials, and vegetation. This paper reports our specific findings regarding soil chemical and mineralogical properties, parent material and weathering. While the data and relationships reported here are certainly specific to the region and parent materials studied, we hope that they will serve as benchmarks for other studies.

3.3 METHODS AND MATERIALS

3.3.1 GEOLOGY AND SITE DESCRIPTION

Eight soils were sampled from intensive study plots within the Joyce Kilmer Memorial Forest in Graham Co., North Carolina. Considerable detail on the watershed, landforms, and overall soil distributions is given in Chapter 2. The topographic characteristics and classification for each of the soils are given in Table 4. The study sites were located along two transects, one at lower elevations (700-900 m) and a second transect at higher elevations (1000-1250 m) within the watershed in an attempt to ascertain the effects of aspect (north- vs south-facing) and elevation on soil properties and weathering. The soils were described and sampled during the summers of 1982 and 1983, and intensive soil transect and vegetative analyses were performed at each site. Hardwood vegetation is dominant at all sites except #3 where the canopy is mixed oak-pine and mountain laurel. The species distribution varies from site to site, however, as do the form and properties of the associated litter layers (Ch. 4).

The underlying bedrock within the watershed consists

Table 4. Topographic characteristics and classification of soils and study sites.

Site	Elev.	Aspect	Slope	
	m		%	
			North Facing Slopes	
1	732	N-NE	22	Typic Haplumbrept, Fine Loamy, Oxidic, Mesic
2	857	NE	53	Typic Haplumbrept, Coarse Loamy, Oxidic, Mesic
5	1068	E-NE	59	Typic Haplumbrept, Coarse Loamy, Oxidic, Mesic
6	1220	NE	57	Typic Haplumbrept, Coarse Loamy, Oxidic, Mesic
			South Facing Slopes	
3	738	S-SE	31	Typic Hapludult, Fine Loamy, Oxidic, Mesic
4	863	S-SW	55	Umbric Dystrochrept, Coarse Loamy, Oxidic, Mesic
7	1043	S-SW	60	Umbric Dystrochrept, Coarse Loamy, Oxidic, Mesic
8	1220	S	54	Umbric Dystrochrept, Coarse Loamy, Oxidic, Mesic

primarily of massive metasandstones, metasiltstones, graywackes and phyllites of the Great Smoky Group (King, et al. 1968). Schists are occasionally encountered, but the parent material is dominantly meta-sedimentary. The geology of the watershed has not been mapped in detail, but regional maps and rock descriptions by Kish, et al. (1975), indicate that the parent material belongs to an as yet unnamed member of the Great Smoky Group which is mapped as the Thunderhead sandstone further north. Fisher, et al (1970) include these strata with the snowbird group, which extends from the Smokys well into northern Georgia. Rocks similar to these underlie a majority of the Great Smoky Mountains National Park. Petrographic analyses of the major rock types underlying the watershed are presented in Table 5. The rocks are dominated by quartz and feldspars with frequent carbonate cementation. Hematite, pyrite, and chalcopyrite are common, particularly in the finer textured rocks, and have caused major water quality problems in recent road cuts just to the south of the watershed. The phyllosilicate content of the rocks is quite variable, but reaches 30 to 40% in some metasiltstones and phyllites. The soils within the watershed are formed in both residuum and colluvium, and the present day landforms appear to be a result of periglacial stripping at higher elevations coupled with deposition on footslopes, in coves, and along drainageways

Table 5. Petrographic analysis of major rock types in watershed.

Mineral	%	Descriptions
		Feldspathic Metasandstone
Quartz	48	Dominantly polycrystalline and intergranular.
Orthoclase	34	Large grains, some altered to clays.
Plagioclase	4	Fragmented and subangular.
Hematite	6	Anhedral, vein aggregate, infiltrates Feldspars.
Muscovite	4	Primary phase, lacks foliation.
Mixed Phylosilicates	4	Hydrothermal ppts, or alteration products.
		Calcite cemented Metasandstone
Quartz	75	Mixture of angular monocrystalline grains and polycrystalline intergranular cements.
Biotite	11	Some partial alteration.
Pyrite	2	Intimately associated with chalcopyrite.
Orthoclase	3	Partially altered.
Plagioclase	2	Grain boundaries corroded.
Calcite	7	Secondary intergranular and void filling cement.
		Metasandstone
Quartz	34	Primarily subangular, detrital, and monocrystalline.
Plagioclase	16	Subangular and detrital.
Orthoclase	2	Subangular and detrital.
Muscovite	10	Weakly foliated.
Mixed Phyllosilicates	23	Alteration products of muscovite and feldspars.
Hematite	15	Anhedral, in veins and filling voids.

at lower elevations (Ch. 2).

The climate of the region is extremely humid and temperate, and the yearly rainfall within the watershed probably exceeds 200 cm. The two nearest National Weather Service stations report 146 cm (Tapoco) and 158 cm (Andrews) of average annual precipitation, but both of these stations are low in elevation (600 m) and precipitation in the watershed is certainly much higher. The rainfall is evenly distributed year-round, and average yearly air temperature is 13^{o} C. We sampled and described these soils over the summers of 1982, 1983, and 1984, and never found the soils dry, even in upper horizons after a protracted regional summer drought in 1982. We believe that these soils, particularly those on north-facing slopes, may never dry appreciably below their immediate surface horizons. Losche et al. (1970) made a detailed study of the climate in a similar high elevation watershed nearby, and reported that annual precipitation was 250 cm, and that soil temperature on the south slope was 3.5^{o} C warmer than the north slope in April, 1.0^{o} C in July, and 1.6^{o} C in September. Differences in soil temperatures in mountainous watersheds are even greater in mid-winter when the sun shines on north-facing slopes for only short periods of time at low angles (Lee, 1963).

3.3.2 Sampling and Analytical Methods

Bulk samples of all delineated mineral horizons were taken from soil pits and air dried and sieved in the laboratory. An additional composite sample was taken from the upper 0-7.5 cm of mineral soil at each site in conjunction with our litter layer sampling (Chapter 4). This sample allows uniform site to site comparison of surface soil characteristics independent of A horizon morphologies, which varied greatly. In all cases the 7.5 cm depth was completely within the A horizon. The morphological and physical properties of all soils are detailed in chapter 2. Percent organic matter was estimated by the Walkley-Black technique (with a carbon:OM conversion factor of 1.75) and pH was measured in the supernatant portion of a 1:1 soil:water paste. Exchangeable bases were extracted with M NH_4OAc (pH 7), and exchangeable Al into M KCl. Bases were analyzed by atomic absorption spectroscopy, and Al by titration. The CEC was calculated as the sum of exchangeable bases plus KCl exchangeable Al. Whole soil acidity was also estimated by reaction with pH 8.2 $BaCl_2$-TEA. All procedures for exchangeable bases and acidity were performed according to U.S. Soil Survey procedures (USDA-SCS, 1984). Iron oxides were extracted in Dithionite-Citrate-Bicarbonate (DCB) and analyzed by atomic absorption. Total soil N was estimated by a standard micro-kjeldahl technique, and soil P was extracted in dilute double acid and analyzed by a

Murphy-Riley (1962) technique.

Regression analyses of CEC against organic matter in A horizon samples was performed using Theil-Sen regression (Hollander and Wolfe, 1973), a non-parametric rank regression technique. This method was employed because the data contained one moderate outlier, and the residuals were not normally distributed.

The particle size distribution of each horizon was determined by sieving (sand) and pipette analysis (silt and clay). Sand mineralogy was determined by petrographic analysis on <40 and >40 mesh sand fractions, and x-ray diffraction (on selected whole samples). Silt mineralogy was determined by x-ray diffraction of randomly oriented slides, and interpretations based on integrated peak areas. Clay samples were oriented on ceramic tiles by the method of Rich (1969), and saturated with K and Mg plus glycerol. Potassium saturated samples were analyzed by x-ray diffraction at 25, 110, 300, and 550^{o}C. Magnesium plus glycerol samples were analyzed at 25 and 110^{o} C. All x-ray analyses were performed with a Diano scanning diffractometer linked to a LSI-11 computer with CuKα radiation and a graphite monochromoter. The % quartz and total 2:1 mineral assemblage were estimated from x-ray diffractograms. Gibbsite and kaolinite were quantified by differential scanning calorimetry (DSC) using a Dupont 1090 Thermal Analyzer and standard Reynolds synthetic gibbsite and poorly crystalline Georgia kaolinite minerals.

3.4 RESULTS AND DISCUSSION

These soils are enigmatic in that they simultaneously possess characteristics of both highly weathered and young soils. Seven out of the 8 soils studied classify as Inceptisols, yet they are all in the oxidic mineralogy class. An easily weatherable feldspathic and calcitic parent material coupled with very high rainfall has led to very deep solution weathering and leaching of these soils, but 2:1 type minerals are still common in their surfaces, and 2:2 type minerals virtually absent. Gibbsite, micas, and feldspars commonly occur together in these soils, with minimal accumulations of kaolinite, an unusual combination for southeastern United States soils. By studying the mineral suites of the sand, silt and clay fractions collectively, however, the major weathering processes and resultant products and soil chemical properties are quite understandable.

3.4.1 CLAY MINERALOGY

The clay mineral suites of all soils were fairly similar, reflecting rapid weathering of their feldspathic parent materials to great depths. The clay mineralogy of the major A, B and C (where present) horizon from each soil are shown in Fig. 9. The surface horizons were dominated by hydroxy-interlayered vermiculite (HIV) and vermiculite, and in some instances, regularly interstratified mica-vermiculite (RMV). The proportions of vermiculite and HIV decrease with depth as mica increases (Fig. 10), particularly in the predominantly residual soils (Ch. 2). The deep (145-386 cm) CR horizon of soil 2 was the only horizon studied with a distinct 1.0 um mica peak, all other C and CR horizons were dominated by either vermiculite or RMV. Many of the surface horizons also contain significant quantities of mica and RMV, believed to be derived from physical weathering of silts to clays high in the profile. The regularly interstratified mica-vermiculite generates distinct diffraction peaks at 2.4, 1.2 and occasionally 0.8 nm, and is most common in intermediately weathered Bw and transitional BC or CB horizons. The colluvial soils (1, 6 and the solum of 7) show similar 2:1 mineral weathering trends, but contain higher proportions of vermiculite and interstratified minerals in their subsoils (Fig. 11). Smectite and interstratified smectite/vermiculite commonly occurs in the subsoils of these colluvial soils, but are not regular constituents of the residual soils. The x-ray diffractograms for all soils and horizons are in Appendix 3.

Gibbsite commonly occurs in the surfaces of all

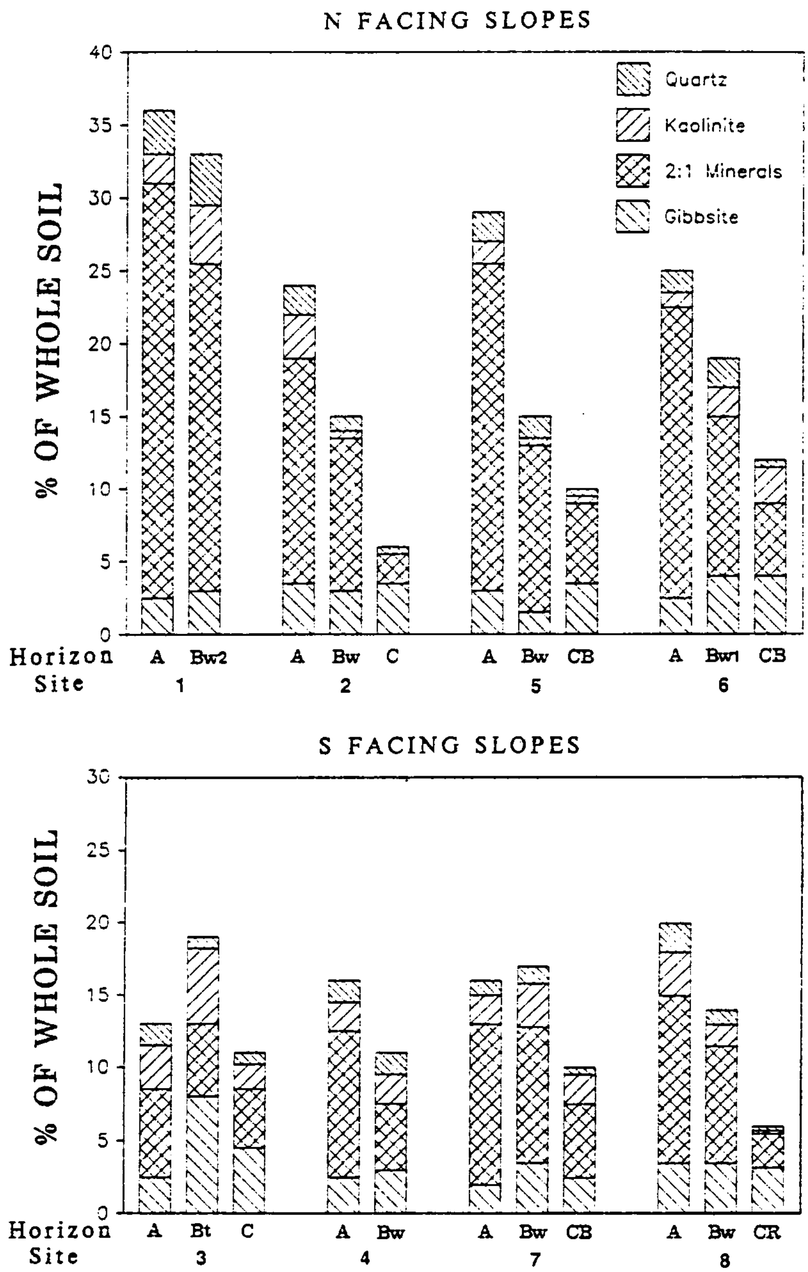

Figure 9. Clay mineralogy of major A, B, and C horizons. Soils 1 and 4 did not contain a C horizon.

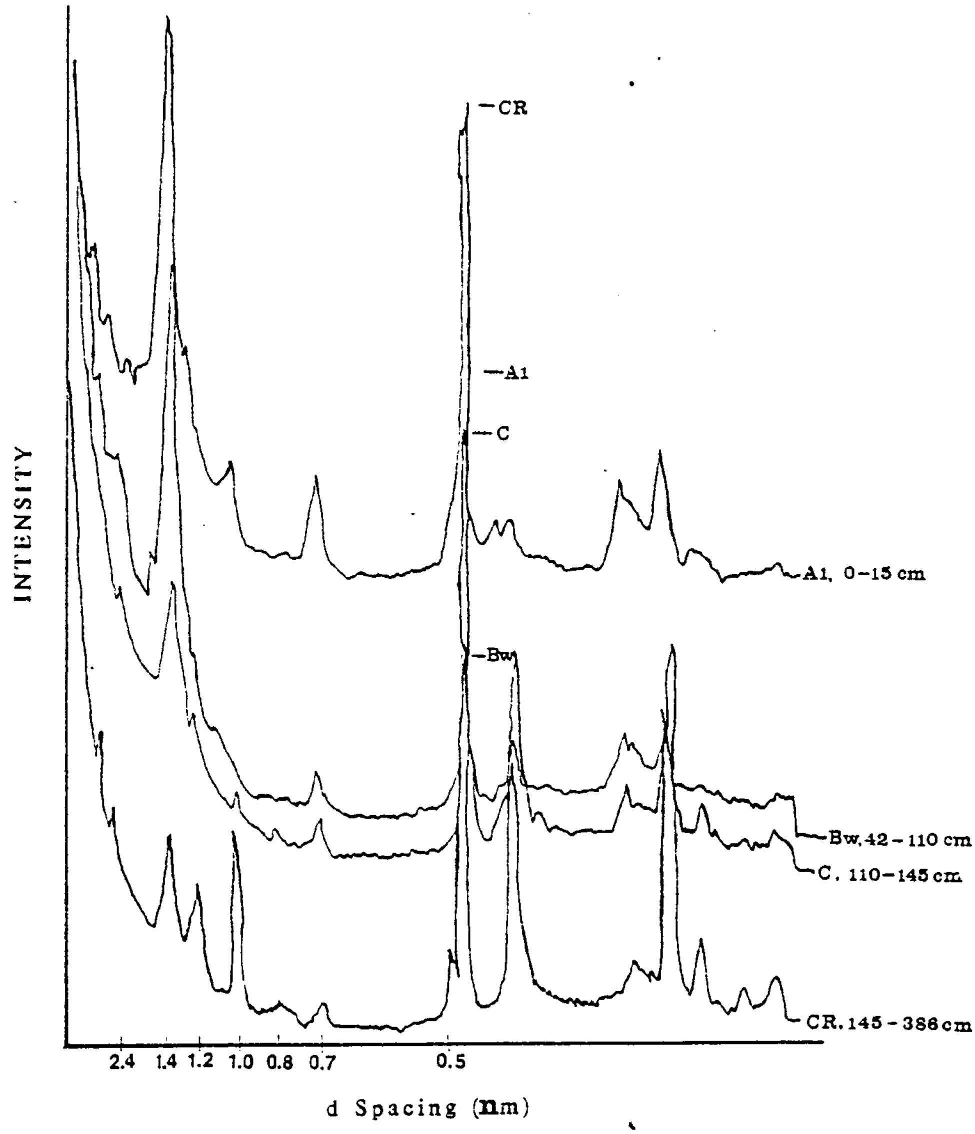

Figure 10. X-ray diffractograms of soil 2 clay fractions. Samples were saturated with Mg and glycerol and run at 25°C.

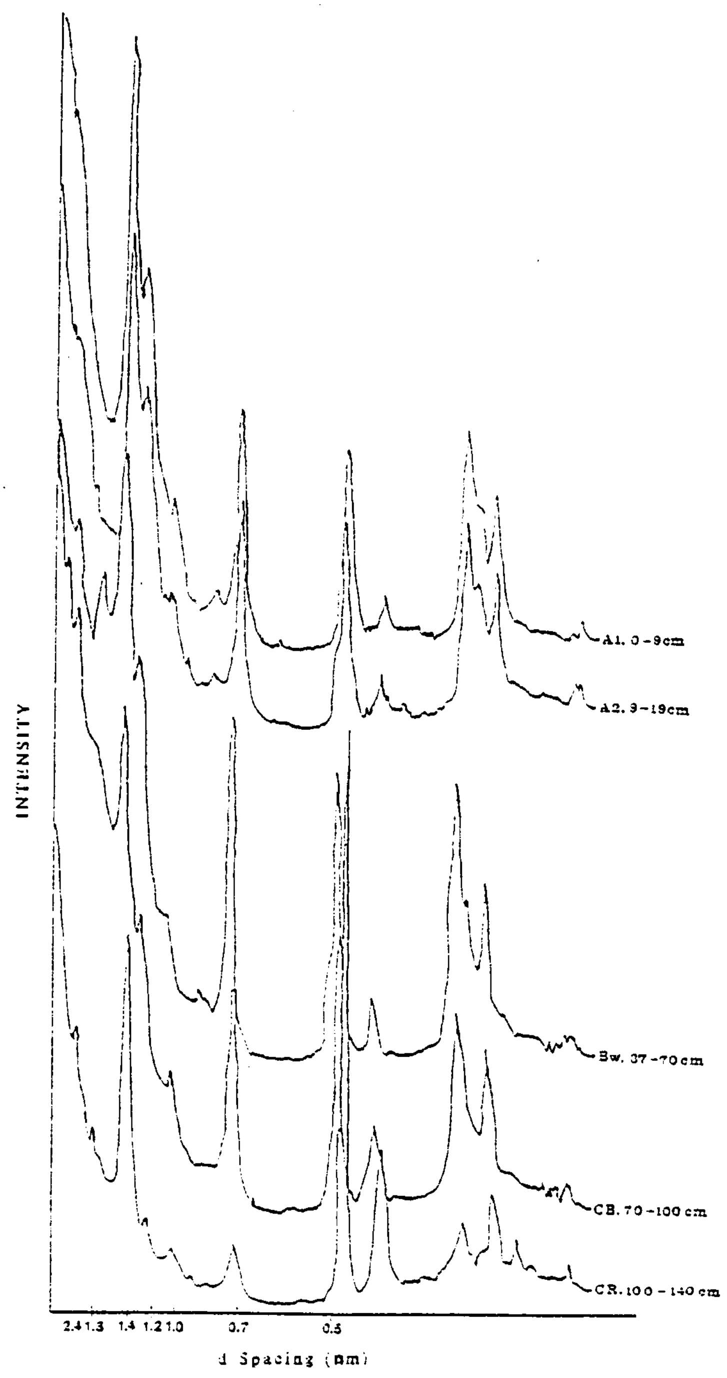

Figure 11. X-ray diffractograms of soil 7 clay fractions. Horizons above 70 cm are colluvial and below 70 cm residual. Samples were saturated with Mg and glycerol and run at 25°C.

soils, and its proportion of total clay content increases regularly with depth in residual profiles. The gibbsite content in the colluvium shows a more irregular distribution, particularly within the solum, but does increase with depth overall. Feldspar dissolution and gibbsite formation have occurred to great depths. Soil 2 was weathered quite deeply in residuum, and contained over 50% gibbsite in the clay fraction at depths > 3m. The gibbsite contents in the subsoil and saprolite horizons are quite high, exceeding 45% in several instances. Compared with these high gibbsite contents, the proportions of kaolinite are low. South-facing soils are higher in kaolinite than opposing north-facing soils, but not in gibbsite as reported by Losche et al (1970). The quartz content in the clay fraction ranged from 5 to 11% and showed no significant trends with depth. Traces of feldspars are present in almost all horizons, and are more pronounced with depth.

Total clay contents are higher in north-facing soils than south-facing soils, perhaps due to greater leaching and hydrolysis weathering of silts on the wetter slopes. The clay contents of all profiles except soils 3 and 7 decrease with depth from the surface, reflecting intensive weathering from the surface down, and deep leaching of any soluble or dispersable components completely through the profile. Gibbsite is apparently generated by rapid dissolution of feldspars in place and then reprecipitation. When the decreasing clay content with depth is taken into account, the total amount of gibbsite in whole soil throughout these profiles does not change significantly with depth (Fig. 9). In most profiles, the gibbsite is really diluted by increasing amounts of 2:1 type minerals as it approaches the surface. Other researchers (Calvert, et al 1980) have reported that gibbsite forms only at depth as Al is released from feldspars in deep weathering fronts, and that in surface horizons kaolinite formation is the primary sink for Al. Our data indicate that either the gibbsite remains in place following direct conversion from feldspars and is essentially diluted as the soil weathers down into the parent material, or that additional gibbsite is forming in surfaces rather than kaolinite.

The various 2:1 minerals present in the clay fraction are weathered by chemical and physical processes primarily from the silt and sand fractions. The regularly interstratified minerals are weathering intermediaries between muscovite and vermiculite, but the source of smectite in several horizons is unknown. Perhaps it is a product of size and charge reduction of highly weathered vermiculite fragments (millot, 1970), which would account for its presence only in the more highly weathered colluvial materials. Pedogenic chlorite is present in only trace amounts in surfaces of several south-facing soils, although HIV is common in all surface and many subsurface horizons. The low amounts of kaolinite in these soils, particularly on north-facing slopes may be due to the fact that these soils seldom, if ever, dry out, thereby limiting secondary kaolinite precipitation. The increased abundance of kaolinite on south-facing slopes and in the uppermost horizons of several north-facing soils may be due to more intense weathering and drier soil conditions which allow more kaolinite formation.

3.4.2 SILT AND SAND MINERALOGY

The silt fractions of these soils are dominated by quartz, mica, vermiculite, and interstratified/ intergrade minerals (Table 6). The ratio of quartz:2:1 type minerals is highest in the surface horizons, and decreases with depth. The majority of subsurface horizons are dominated by 2:1 type minerals, and should therefore be quite reactive. The silt fraction is physically and chemically weathering to supply phyllosilicates to the clay fraction, particularly in the surface horizons. Significant losses of 2:1 minerals from the silts by dissolution may be occurring as well. The silt fraction demonstrates a similar weathering sequence with depth to that of the clays. Minerals with 1.4 nm peaks dominate the surface 2:1 minerals, and grade into regularly interstratified

Table 6. Silt mineralogy for major A, B, and C horizons (where present) A horizon mineralogy determined on composite (0-7.5 cm) samples from each site. Estimated by X-ray diffraction peak areas.

Site	Horizon	Mineral Suite*
	North Facing Slopes	
1	A	Q>>V>M>K>F>G
	Bw2	Q≈RMV>V>M>K>F>G
2	A	Q>>>M>V>G>F>RMV
	Bw	V>M>Q>G>RMV>F
	C	M≈G≈Q>F>V>RMV
5	A	V≈M≈Q>RMV>F>G
	Bw	V>M≈Q>RMV>F>G
	CB	M≈RMV>Q>G>F
6	A	Q>M>V>RMV>F>G
	Bw1	M≈V≈RMV>Q>G>K>F
	CB	M>RMV≈Q>G>K>F
	South Facing Slopes	
3	A	Q>M>V≈RMV>G>F>K
	Bt	RMV>V≈Q>G>F>K
	C	RMV>G≈Q>M>V>K>F
4	A	Q>M≈V>RMV>G>K>F
	Bw	RMV>M≈Q>G>K>F
7	A	Q≈M>RMV≈V>F
	Bw	RMV>V>M>Q>K>G>F
	CB	
8	A	Q>M>RMV>V>F>G
	Bw	RMV>M>V>Q>K>G>F
	CR	M>RMV>V>G≈Q>K>F

* Q = Quartz
V = Vermiculite + HIV
M = Mica
K = Kaolinite
F = Feldspars
G = Gibbsite
RMV= Regularly Interstratified Mica/Vermiculite

mica-vermiculite and mica with depth (Fig. 12). Gibbsite is absent from the surface horizons silts, but increases with depth, particularly in soils with residual subsurface horizons. Kaolinite is found in the subsurface silts, especially on southern aspects.

The coarse and fine sand fractions are all dominated by quartz, and show a distinct mica to vermiculite weathering sequence with depth (Table 7). Total 2:1 mineral content increases with depth in the fine sands, and the majority of the mica-like grains are altered to either vermiculite or some other mica weathering product. X-ray diffraction analyses of several sand fractions revealed the presence of significant amounts of regularly interstratified mica-vermiculite and 1.4 um minerals in this fraction. Feldspars commonly occur in the fine sands and show no consistent weathering trends, probably due to the fact that feldspar weathering occured rapidly to great depths, leaving only remnants in the upper horizons. Zircon, epidote, and tourmaline occurred in all profiles in smaller amounts.

3.4.3 WHOLE SOIL WEATHERING

As silt and sand sized grains approach the surface they are subjected to intense dissolution and hydrolysis weathering mechanisms, and the lack of stable 1.4 um minerals in the surface clays may indicate that even

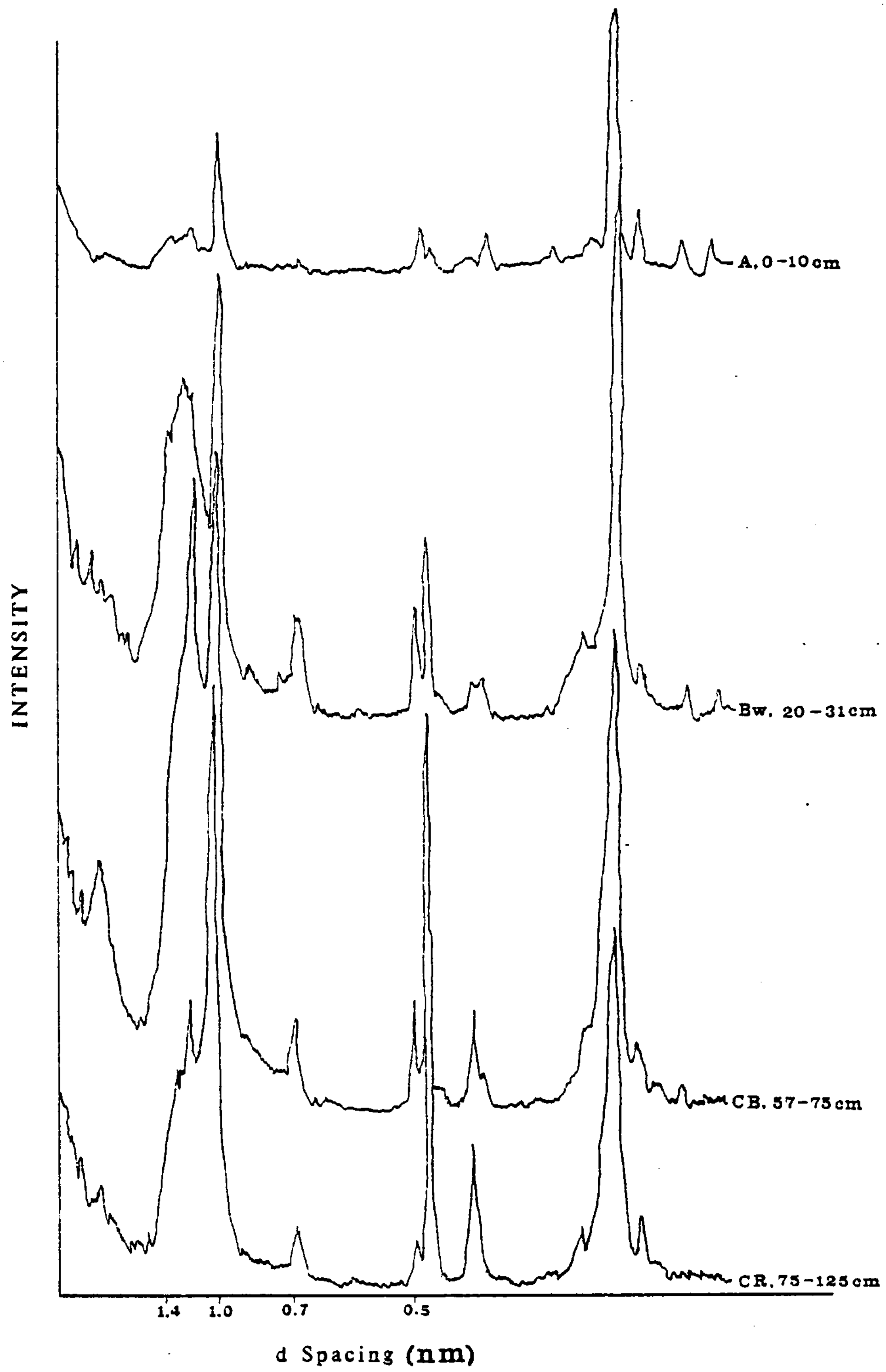

Figure 12. X-ray diffractograms of soil 8 silt fractions. Samples were saturated with Mg and glycerol and run at 25°C.

Table 7. Sand mineralogy for major A, B and C horizons (where present). A horizon mineralogy determined on 0-7.5 cm composited samples from each site. Numbers in parentheses are % of point counts (150 counts for the 2-0.42 mm and 200 counts for the 0.42 - 0.05 mm fractions).

Site	Horizon	% of 0.42-0.05 mm mineral suite								% of 2-0.42 mm mineral suite							
		Qtz.	Kspar	Plag.	Musc.	2:1's	Opaques	Heavy Min.	Rock Frag.	Qtz.	Kspar	Plag.	Musc.	2:1's	Opaques	Heavy Min.	Rock Frag.
									North Facing Slopes								
1	A	75	TR	6	7	6	3	2	1	83	0	0	0	0	6	1	10
	Bw2	37	TR	8	26	27	1	TR	1	89	1	1	0	0	0	1	8
2	A	65	5	6	4	1	2	2	15	77	0	0	0	1	4	0	18
	Bw	79	5	2	TR	8	4	0	2	91	0	0	0	0	3	0	6
	C	74	8	2	TR	9	4	0	3	98	0	0	0	0	2	0	0
5	A	71	22	2	0	3	0	2	0	81	13	0	0	6	0	0	0
	Bw	79	12	1	0	6	1	1	0	95	3	0	0	1	0	1	0
	CB	50	7	1	2	25	1	13	1	99	1	0	0	0	0	0	0
6	A	67	14	1	0	12	1	5	0	85	9	0	0	5	0	1	0
	Bw1	57	20	3	0	19	0	1	0	100	0	0	0	0	0	0	0
	CB	66	17	0	0	14	0	3	0	97	2	0	0	1	0	0	0
									South Facing Slopes								
3	A	70	5	6	13	2	2	0	2	82	2	1	0	0	0	0	15
	Bt	63	8	7	2	19	0	0	1	90	0	0	0	0	0	0	9
	C	69	7	2	4	16	0	0	2	95	0	0	0	0	0	0	5
4	A	86	3	3	0	7	0	1	0	93	1	1	0	4	0	1	0
	Bw	75	0	1	1	18	1	4	0	99	0	0	0	1	0	0	0
7	A	64	10	2	0	21	1	2	0	96	2	0	0	1	0	1	0
	Bw	55	12	3	0	29	0	1	0	96	2	0	0	1	0	1	0
	CB	57	13	2	1	21	0	7	0	94	1	0	0	3	1	1	0
8	A	55	10	2	0	30	1	2	0	88	1	0	0	8	0	1	2
	Bw	71	6	1	0	15	3	0	6	95	1	0	0	2	0	2	0
	CR	31	3	2	1	61	0	0	2	99	0	0	0	0	0	1	0

vermiculites and HIV are not stable over long periods of time and dissolve before they are completely interlayered. The presence of feldspar indicates that these soils are really relatively young, or that the soil is rapidly weathering downward as fast as the feldspars can be dissolved. The lack of large amounts of kaolinite even though gibbsite is common indicates that these profiles are undergoing desilication, in a fashion similar to tropical soils. Karanthanasis, et al. (1983) studied the comparative stabilities of kaolinite, gibbsite and vermiculite in a wide range of southeastearn Ultisols and concluded that in weathered surface soils, HIV may be more stable than gibbsite or kaolinite, which would explain the lack of kaolinite in these soils, but not the high gibbsite contents. Apparently, the anti-gibbsite effect (Jackson, 1963) of Al interlayering in vermiculites is not active in these soils. These soils are weathering rapidly in a considerably wetter environment, however, and dissolved Si levels may remain so low that even HIV deteriorates over time. This would also explain the almost total lack of chlorite. The decreasing clay contents with depth in these soils also support the hypothesis of rapid weathering and desilication from the surface down, and due to the extremely wet climate, the present mineral suite may an equilibrium form since argillic horizon formation is unlikely without wet/dry cycles to flocculate and reprecipitate clays in subsurfaces (Barshad, 1967).

Much stronger weathering and profile differentiation on south-facing slopes than north-facing slopes was reported in a nearby watershed by Losche et al (1970). They also found the soils in lower landscape positions to be more highly weathered, and that the finer size fractions of all soils were more highly weathered than the coarser fractions. While these soils displayed strong morphological differences due to aspect, gibbsite was slightly more common in north-facing soils and kaolinite more common in south-facing soils, the reverse of the relationship reported by Losche, et al.. Their study area was underlain by granite gneiss, however, a parent material much more likely to weather to kaolinite, and one which lacks the large feldspar content that in these soils weathers directly to gibbsite. Slope position or elevation per se do not appear to strongly influence mineralogy and weathering, except in that the extrememly low and high elevation soils in these watersheds tend to be colluvial, and therefore are more highly weathered since they were probably derived from pre-weathered soils. The soils on north-facing slopes are higher in overall clay content, however, presumably due to greater water movement through their profiles and concomittant solution/hydrolysis weathering. All size fractions of these soils exhibit similar weathering trends within the 2:1 mineral suites, and the fact that the clay fraction contains more gibbsite is simply a function of the fact that when gibbsite precipitates, it is more likely to be fine than coarse.

3.4.5 Cation Exchange, Nutrient levels and Acidity

Levels of exchangeable Ca and Mg are virtually undetectable (Table 8) below the organic matter enriched surfaces where they are being concentrated and cycled by the forest (Ch. 4). Potassium is apparently weathering directly from feldspars, and is more abundant in most horizons. Aluminum almost completely saturates the exchange complex of these soils, except for the uppermost surface horizons where base cycling is active and organic matter contents are high. Soil pH ranges from 4.2 to 5.8, but the majority of horizons are buffered between 5.1 and 5.3 by high Al levels. The pH of soil 7 is considerably lower than the other soils, and ranges from 4.1 in the surface to 5.5 in the subsoil, and may be formed from more pyritic parent materials. The effective CEC of the mineral fraction is apparently quite low, even though abundant 2:1 type minerals are present in these soils. The relationship between percent organic matter and CEC of the A horizons is quite linear with an intercept near 0 (Fig. 13). The correllation of CEC with clay content in these horizons is poor. The CEC of the subsurface horizons is frequently < 4 and in several cases < 2 cmol/kg. Linear extrapolation of

Table 8. Chemical and selected physical characteristics of mineral horizons.

Site	Horizon	Depth	pH	Organic Matter	Ca	Mg	K	Al	CEC	Base Sat.	$BaCl_2$-TEA Acidity	Ext. Fe_2O_3	Acid Extract. P	Total N	Textural Class
		cm		%	-------------		cmol/Kg		-------------	%	cmol/kg	%	ppm	%	
							North Facing Slopes								
1	A1	0- 13	5.8	16.1	11.10	2.00	1.00	0.15	14.25	99	28.6	3.7	0.8	0.30	cl
	A2	13- 30	5.3	10.7	1.98	0.61	0.44	1.70	4.73	64	33.6	3.8	0.8	0.22	cl
	AB	30- 43	5.2	3.8	0.18	0.11	0.18	1.95	2.42	19	24.0	4.1	0.8	0.11	sil
	Bw1	34- 64	5.2	1.0	0.29	0.22	0.20	3.75	4.46	16	15.8	4.3	0.8	0.07	cl
	Bw2	64-128	5.3	0.7	0.29	0.23	0.17	4.25	4.94	14	14.9	4.2	1.2	0.05	cl
	R	128+													
2	A1	0- 15	5.2	8.6	3.27	0.56	0.37	1.20	5.40	78	31.8	3.1	1.2	0.32	l
	A2	15- 42	5.0	2.6	0.02	0.02	0.05	1.80	1.89	5	16.9	3.0	1.0	0.07	l
	Bw	42-110	5.2	1.1	0.03	0.07	0.03	1.73	1.86	7	10.4	3.0	0.8	0.05	sl
	C	110-145	5.4	0.2	0.03	0.02	0.04	0.25	0.34	26	2.8	1.6	1.6	0.02	sl
	CR	145-386	5.6	0.1	0.03	0.07	0.06	0.15	0.31	52	1.0	1.2	4.8	0.01	ls
	R	386+													
5	A1	0- 6	4.1	17.0	3.95	0.99	0.60	4.75	10.29	54	47.3	3.1	2.0	0.58	cl
	A2	6- 20	4.5	8.7	0.36	0.17	0.33	4.05	4.91	18	36.5	3.2	1.4	0.32	l
	A3	20- 31	5.0	5.8	0.17	0.08	0.23	3.25	3.73	13	29.1	3.1	0.8	0.26	l
	BA	31- 50	4.9	2.9	0.08	0.03	0.24	2.75	3.10	11	20.8	3.2	0.8	0.14	l
	Bw	50- 94	5.1	1.3	0.07	0.03	0.19	2.45	2.74	10	14.1	3.0	1.2	0.11	l
	CB	94-141	5.4	0.7	0.08	0.03	0.13	1.55	1.79	13	10.1	1.7	3.8	0.09	sl
	CR	141-170	5.5	0.2	0.05	0.02	0.03	0.80	0.90	11	3.5	0.8	7.8	0.02	ls
6	A1	0- 12	4.8	12.8	0.35	0.26	0.29	3.80	4.70	19	37.2	2.8	1.2	0.52	l
	A2	12- 27	5.0	8.6	0.03	0.07	0.16	2.85	3.11	8	27.4	2.8	1.2	0.20	l
	AB	27- 52	4.9	4.2	0.03	0.05	0.10	2.70	2.88	8	23.0	2.9	1.2	0.13	l
	Bw1	52- 93	5.0	1.1	0.03	0.10	0.07	2.60	2.80	7	11.0	3.1	0.8	0.11	l
	Bw2	93-118	5.1	0.6	0.02	0.17	0.11	3.25	3.55	8	10.0	2.8	1.0	0.06	l
	CB	118-150	5.1	0.3	0.04	0.11	0.05	2.15	2.34	8	6.6	1.4	2.0	0.03	sl
	C	150-170+	5.4	0.2	0.06	0.03	0.03	1.05	1.17	10	4.4	0.1	2.0	0.04	sl

Table 8. cont.

Site	Horizon	Depth	pH	Organic Matter	Ca	Mg	K	Al	CEC	Base Sat.	$BaCl_2$-TEA Acidity	Ext. Fe_2O_3	Acid Extract. P	Total N	Textural Class
		cm		%	------------cmol/kg				--------------	%	cmol/kg	%	ppm	%	
						South Facing Slopes									
3	A	0- 12	4.7	4.5	0.08	0.10	0.13	2.60	2.91	10	14.1	2.5	2.0	0.13	sl
	Bw	12- 33	5.2	0.7	0.05	0.14	0.11	1.15	1.45	20	14.2	3.1	1.2	0.06	sl
	Bt	33- 84	5.2	0.3	0.03	0.42	0.12	0.80	1.37	41	4.7	3.7	0.8	0.07	sl
	C	84-126	5.3	0.1	0.06	0.20	0.06	0.65	0.97	33	4.0	3.1	1.2	0.03	sl
	R	126+													
4	A	0- 14	4.6	6.3	0.13	0.21	0.24	3.70	4.28	13	19.0	2.5	2.0	0.18	l
	Bw	14- 63	5.1	0.6	0.03	0.22	0.13	1.25	1.63	23	6.6	3.4	1.2	0.07	l
	R	63+													
7	A1	0- 9	5.0	9.2	0.19	0.17	0.28	3.50	4.14	18	26.7	2.2	2.4	0.30	l
	A2	9- 19	4.7	3.9	0.05	0.05	0.16	2.25	2.51	10	18.0	2.4	3.0	0.16	l
	BA	19- 37	4.8	1.4	0.03	0.05	0.10	2.35	2.53	7	10.5	2.4	1.6	0.05	l
	Bw	37- 70	4.8	0.6	0.05	0.12	0.10	2.85	3.12	9	9.4	2.5	1.2	0.06	l
	CB	70-100	4.9	0.8	0.10	0.13	0.17	2.00	2.40	17	7.3	1.4	6.8	0.06	sl
	CR	100-140+	5.2	0.1	0.03	0.05	0.04	0.25	0.37	32	2.4	0.6	86.0	0.01	ls
8	A	0- 10	4.7	10.6	0.03	0.20	0.36	3.85	4.44	13	31.2	2.1	1.4	0.35	l
	BA	10- 20	4.9	3.3	0.03	0.06	0.23	2.10	2.42	13	13.9	2.2	1.0	0.19	l
	Bw	20- 31	5.3	1.3	0.04	0.04	0.20	1.80	2.08	13	10.1	2.2	1.2	0.08	sl
	BC	31- 57	5.3	0.6	0.05	0.07	0.15	1.80	2.07	13	8.3	2.2	1.2	0.13	sl
	CB	57- 75	5.4	0.4	0.03	0.05	0.11	1.45	1.64	12	7.8	1.6	14.0	0.07	sl
	CR	75-125	5.1	0.1	0.03	0.02	0.12	0.95	1.12	15	4.5	1.2	9.8	0.01	sl
	R	125+													

the regression line shown in Fig. 13 would indicate that the CEC of the organic fraction is 57 cmol/kg, a very low value. The cation exchange sites on the mineral surfaces are apparently coated with gibbsite and iron oxides rendering them virtually neutral. The low apparent CEC of the organic matter is due either to complexation with nonexchangeable Al and Fe, the fact that the organic matter may be highly degraded and stable, or more likely, a combination of the above. Levels of $BaCl_2$-TEA acidity are very high in almost all A and B horizons due to the high levels and deep incorporation of organic matter. When this acidity measure is used in calculating base saturation, the resulting values for all horizons are extremely low, many $< 1\%$.

Total N levels are of course directly correlated with organic matter, and therefore N levels drop sharply below the organic enriched A horizons. Extractable soil P levels are quite low througout the solum, but are quite high in several of the saprolites. Apatite is common in many of the rocks of the Great Smoky Group, and is probably the source of this P. The trees commonly root into the C horizons in these soils, and this deep P is probably plant available. Both of these elements are concentrated and cycled by the forest community, and held against leaching and fixation in primarily organic forms at the surface. Further detail on the relationships among vegetation,

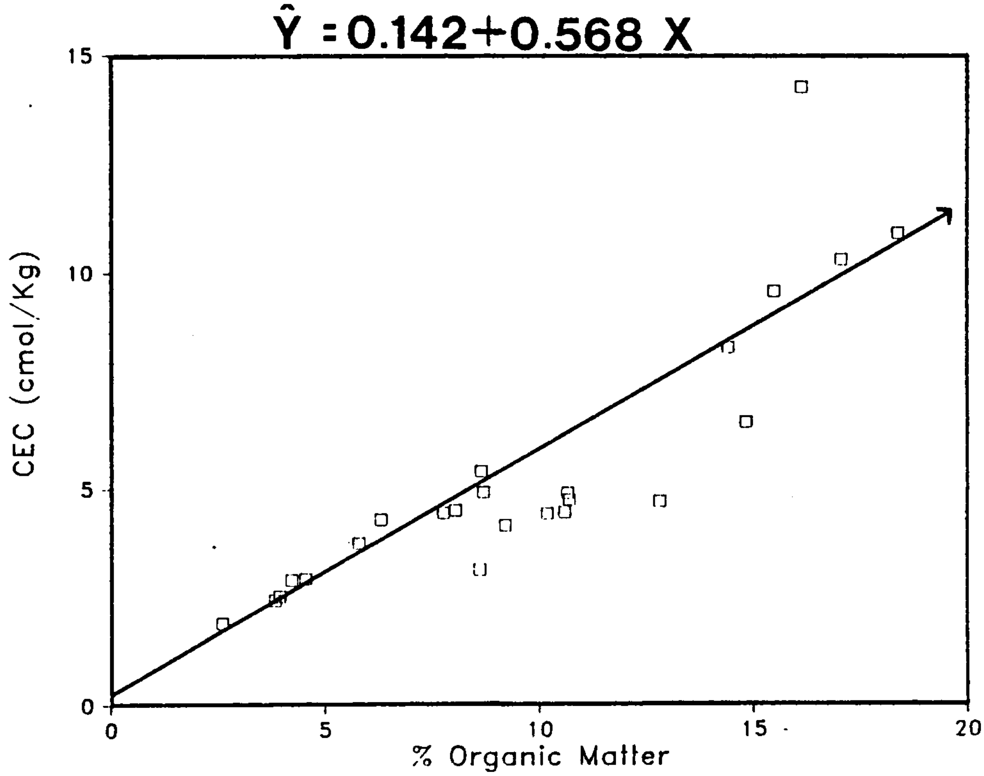

Figure 13. Fitted regression line ($\hat{Y}$) of % organic matter (X) versus CEC (Y) for all A horizons and composite samples.

litter layers and nutrient availability in these soils is given in Chapter 4.

3.4.6 Extractable Iron Oxides.

Extractable Fe (by DCB) decreased with depth in most soils, but showed a more uniform distribution and higher subsoil levels in the colluvium (1, 6 and and the solum of 7) The two lowest south-facing soils (3 and 4) both had a maximum of extractable Fe in their B horizons. Hotter, south-facing slopes did not show higher levels of extractable Fe as expected, and in fact the north-facing soils were consistently higher than their opposing south-facing soils. There does appear to be a trend of decreasing extractable Fe with elevation, however. The overall levels of extractable Fe were rather high for brown, weakly developed soils, ranging from 2.1 to 4.3 % within the sola. Apparently, much of the Fe is included in the Fe and Al oxy-hydroxide complex that coat mineral surfaces, and therefore does not redden the soil. The DCB solution can be a potent extractor of organic matter as well, and it is possible some of the Fe in the extract was paired with organic functional groups.

3.4.7 Problems with Soil Classification at the Order, Family, and Series Level.

Based on morphology and base saturation alone, these soils classify (Ch. 2) as Umbric Dystrochrepts (4, 7 and 8), Typic Haplumbrepts (1, 2, 5 and 6) and a Typic Hapludult (3). The mineralogical class for all of the soils is oxidic, however, and in the majority the critical ratio of % Fe_2O_3 + % gibbsite to % clay is > 0.3 in the mineralogical control section. In fact, the extremely low CEC of the thick subsurface cambic horizons would qualify them as oxic horizons, if their weatherable mineral content was ignored. With Their low CEC, oxidic mineralogy, and decreasing clay content with depth, these soils closely resemble the highly weathered soils of the tropics, and with further weathering will eventually be indistinguishable from them. The Inceptisol order is designed to encompass weakly developed soils whose genesis has been limited by some external factor. There are presently no established Haplumbrept or Dystrochrept series with oxidic mineralogy classes. These soils are deep, well weathered, represent an intermediate weathering stage between Inceptisols and Oxisols, and very likely will never pass through a form definable as an Ultisol. Soil Taxonomy presently has no "niche" for soils like these, but there is current discussion about the establishment of a new diagnostic horizon (Kandic) to include low charge argillic horizons.

3.7 CONCLUSIONS

Assuming that these soils have been relativly stable since only the late pleistocene, their depth and degree of weathering is remarkable. The moderately soluble feldspathic metasandstone has been dissolved to great depths in a very wet climate, and depth to hard rock in primarily residual soils is frequently > 3 m. The weathering processes in these soils are essentially the same that have generated the Oxisols by constant leaching, dissolution of soluble minerals, and desilication. The fact that these soils are undisturbed allows us to make some conclusions regarding mineral weathering sequences without the complications of man's disturbance.

Readily soluble feldspars are dissolved to great depths, but a few resistant crystals remain throughout the weathered zone. Gibbsite is the major weathering product of feldspar dissolution. Mica is weathered to vermiculite through several regularly interstratified intermediates and hydroxy-interlayered vermiculite forms in the surfaces and upper B horizons and is the most stable phyllosilicate. In this weathering sequence Chlorite is virtually absent from surface horizons, either due to young age, or dissolution of its interlayered vermiculite precursor. Kaolinite is found in only small amounts in these soils, possibly due to the fact that heavy rainfall leads to desilication, and these soils never dry sufficiently to allow secondary kaolinite to precipitate. Soils that are predominantly residual show regular weathering trends and decreasing extractable Fe levels with depth. Colluvial soils have irregular gibbsite distributions within their sola, their ratio of 1.4 nm minerals to mica is greater throughout the profile, and they contain smectite in their subsurface horizon. These materials were probably weathered somewhat before deposition, with the smectite being an ephemeral weathering product of vermiculite. The strong effects of aspect and slope position on soil chemistry and mineralogy reported by Losche et al (1970) and Franzmeier et al (1969) were not seen in this study, perhaps due to differences in parent materials and the constant vegetative cover over time, or the lack of a weathering equilibrium state in their soils. The soils studied by these other researchers were logged, and may have been exposed to pronounced temperature fluctuations and possibly to severe erosion before the forest canopy recovered.

The ability of these soils to hold and exchange nutrient cations is totally dependent upon their organically enriched surface horizons. The mineral fraction of these soils appears to contribute very little to cation exchange. This fact in conjunction with the low levels of nutrients below the A horizons makes these soils extremely susceptible to severe losses in productivity following even moderate erosion. The maintenance of organic matter levels in these soils is absolutely essential to nutrient supply and retention, even more so than in most humid-temperate soils because of their relativley inert mineral fraction. Weathering of feldspars, and other traces of primary minerals following an erosion event would certainly re-supply some cations but the loss of the majority of nutrients from the surface would take long periods of time to replenish. Extreme erosion, flash flooding, and mass wasting were common in the high rainfall areas of the southern Appalachians following logging around the turn of the century. It is therefore possible that a severe loss in soil productivity occurred concomitantly. In the future we will expand our studies into surrounding logged watersheds, using the Joyce Kilmer area as a control, and attempt to determine the long term effects of site disturbance of soil properties, productivity and nutrient budgets.

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Chapter IV

Interrelationships among Vegetation, Litter Layers, and Mineral Soils

4.1 ABSTRACT

Virtually no undisturbed forests and soils remain in the East, and very little is known of their original properties. Effects of aspect (N vs. S), elevation, and tree species on litter layers and underlying soil properties were studied in eight undisturbed southern Appalachian hardwood stands in western North Carolina. The vegetation ranged from mixed mesophytic cove hardwoods at lower elevations on north-facing slopes to mixed oak/hickory on south-facing slopes. Many individual trees in the coves exceed 1.3 m in DBH and 50 m in height. American chestnut (Castanea dentata) once dominated south-facing slopes, and was a major component of the cove forests as well. Total litter production averaged 3494 kg/ha/yr and did not vary by aspect or elevation. The forest floor was typified by thin leaf (L) layers and well expressed fermentation (F) and humus (H) layers. Total litter weights (L+F+H) averaged 16.9 Mg/ha and showed no consistent aspect or elevation effects. One site with a significant proportion of mountain laurel and white pine

cover did contain much more total litter (24.3 Mg/ha), the majority of which was concentrated in a thick H layer. All humus layers were duff-mulls with considerable mixing of organic matter into mineral soil below the H layer. Whole soil organic matter levels were much greater on north-facing than south-facing slopes, and increased with elevation on both aspects. Whole soil organic matter contents in excess of several hundred Mg/ha were common. Nitrogen, K, and Ca levels were much higher in annual litter fall, litter layers, and surface soils on north-facing slopes, while P levels did not vary significantly by aspect. Phophorus, K, and Ca are concentrated in litter layers and immediate surface soil, while the majority of total-N is mixed deeply into the underlying mineral soil with organic matter. Compared with other Appalachian forest soil systems, these appear to have a greater proportion of cations in their litter layers than mineral soil, which is similar to tropical systems.

4.2 INTRODUCTION AND LITERATURE REVIEW

Mature forest ecosystems usually contain well developed forest floors or litter layers whose properties are dependent on a wide variety of factors including forest type, climate, and disturbance history. The forest floor, along with its underlying organically enriched A horizons plays an important role in nutrient retention and cycling within forest communities, and is one of the most important components of the dynamic equilibrium among vegetation, climate and soil properties over time.

4.2.1 Litter Layers

The dynamics of forest floor litter layers are of critical importance to the cycling of nutrients and long term stability of forest ecosystems. The forest floor serves not only as a source of energy and nutrients for a bewildering array of macro and micro fauna and flora, but the continuing addition and decay of litter represents a revolving fund of essential nutrients, particularly nitrogen (N), phosphorus (P) and sulfur (S) for higher plants (Pritchett, 1979). The various layers of the forest floor can be separated into L, F, and H layers based on their relative degree of decomposition. The L or leaf layer is composed of relatively fresh and undecomposed remains of plants and animals. This layer is essentially the same as the Oi horizon in current soil survey nomenclature (Soil Survey Staff, 1981). The F or fermentation layer is composed of partially decomposed plant remains that are still somewhat recognizable. This layer corresponds to the Oe horizon. The humus layer (H) consists largely of stable, highly decomposed organic matter which has almost entirely passed through the guts of soil fauna, and is amorphous. Appreciable amounts of mineral matter may be mixed into the lower H layer in some soils, making its sharp delineation from the underlying mineral A1 horizon difficult. This zone is usually typified by a friable crumb structure, and is dėlineated as an Oa or A1 horizon by conventional soil nomenclature. Like any type of soil feature or horizon, not all soils contain L, F and H layers, but they do serve as a convenient guide for the description and further classification of forest floors.

Variations in climate and vegetation lead to various combinations and morphologies of these layers in world soils. The H layer along with the more decomposed portions of the F layer constitute what is generally regarded as the humus layers which have been subjected to various classification schemes. (Heiberg and White, 1941). Two major end-members, mor humus and mull humus, have been universally recognized, however. Mor humus is characteristic of coniferous vegetation over acid soils, and is characterized by a sharp boundary with underlying mineral materials. Mull humus is charactarized by a diffuse boundary and extensive mixing with the underlying mineral soil. Mulls are commonly found under deciduous vegetation and often over soils with more moderate pH and base status. Fungi are the dominant microbial decomposers in mors, while bacteria are much more common in mulls.

Litter decomposition in mulls is controlled by earthworms and soil arthropods (Edwards, et al, 1970) which shred, transform and mix the organic materials deep into the underlying soil. Mors are decomposed primarily in place by fungi and leaching, and are subjected to much less faunal activity and mixing.

The majority of forest humus layers in the world exhibit some properties of both mull and mor, and therefore most classification systems have recognized a continuum between the two. These intermediate types of layers have been collectively called moder (Kubiena, 1953) by Europeans and duff mulls by Americans. The latter classification is largely due to a report by Hoover and Lunt (1952) to the Soil Science Society of America which proposed the following scheme for classification of forest humus types:

Mulls:	Firm, Sand, Coarse, Medium, Fine, Twin.
Duff Mulls:	Thick, Thin.
Mors:	Granular, Felty, Greasy, Thin, Imperfect.

Under this classification mulls contain no distinct H layer, and humus is completely mixed into the underlying mineral soil. Duff mulls possess a distinct H layer over an underlying mull horizon, and mors have virtually no mixing of organic and mineral horizons. Individual classes within each category are based on easily recognizable morphological features, and while somewhat complex, this

Table 9. Estimates of litter production and accumulation for various ecosystems. Annual values include additions from stems and boles falling. (Atjay, et al, 1979)

Cover type	Annual litter fall	Total Accum.
	Kg/ha	
Tropical rain	18,500	6,500
Temperate	8,500	30,000
Boreal (closed)	6,000	35,000
Grass savanna	15,000	3,500
Herb/lichen tundra	1,450	5,000
Desert	1,250	1,000

system is widely used, particularly in research.

4.2.2 Litter Production

In a steady state forest ecosystem, net litter fall is approximately equal to total net productivity, and therefore varies with vegetation type in response to climatic and geological conditions. Total litter fall (leaf + limbs + boles) in various ecosystems world wide ranges from 1,250 to 18,500 Kg/ha/yr (Ajtay, et al, 1979, Table 9). These values are gross regional estimates, however, and higher rates for various cover types have been reported in many areas, including the temperate southeastern United States (Bray and Gorham, 1964). Net annual production in the Coweeta watershed has been reported by Day and Monk (1977) at 8,754 kg/ha, with 4,195 kg/ha falling as annual leaf and twig litter. The highest litter fall occurs in highly productive tropical rain forests, but extremely fast turnover of fallen litter occurs, leading to little litter or nutrient accumulation on the forest floor. Boreal forests on the other hand produce much less litter, but accumulate more litter and nutrients on the forest floor because of much slower decay rates. The total litter that falls is a complex assemblage of plant parts, but the majority is leaf litter. Cromack and Monk (1975) report the following distribution for a hardwood forest in the Coweeta watershed: Leaves (64%);

stems <2.5 cm (16%); stems >2.5 cm (7%); nuts (10%); and various debris (3%). Annual root death certainly contributes much to total organic matter additions as well, but is extremely hard to estimate in forest systems.

The southern Appalachian forest is one of the most productive in the United States, and produces some of the heaviest reported annual litterfalls. Harmon (1980) studied litter production and dynamics at low elevations in the Great Smoky Mountains National Park and found that leaf litter production in closed stands varied from 3500 to 4500 Kg/ha/yr regardless of species composition or topography. Lower rates were associated with earlier successional stages, but up to 2/3 or more of a mature canopy could be removed before a significant reduction in litter production occurred the following season. This was due to vigorous expansion of suppressed and unaffected dominant trees into the openings.

4.2.3 Factors Affecting Litter Accumulation and Decomposition

The total amount of litter on the forest floor varies tremendously worldwide, primarily in response to climate. On a local basis, however, a number of other factors including microclimate, local vegetation type, the palatability of litter substrates to decomposers, and disturbance history control the form and amount of organic materials on and in the soil.

Total weight loss during the first year can be quite large. Shanks and Olson (1961) studied leaf litter breakdown in the southern Appalachians under hardwoods and conifers, and found that in one year hardwood litter lost between 35 and 46% of its original weight, while conifers lost 29 to 40%. The decomposition rates for both cover types decreased with altitude due to temperature gradients. During the first year, decomposition follows what has been called a "3 component curve" (Seastedt, et al, 1981). During and immediately after litter fall, there is a rapid loss of soluble ions (particularly K) and organic compounds (1st component). Decomposition then slows over the winter (2nd component), but total losses in the first 3 months may still exceed 20%. Rapid decomposition resumes again in the spring, and is controlled primarily by the activity of soil fauna (3rd component). Decomposition rates during the second year are usually similar to the first, but the total weight loss is much less due to a lower amount of initial substrate left from the first year. In boreal regions, decompostion may not slow down as much during winter due to the dominance of abiotic decomposition processes (McBayer and Cromack, 1980).

Recognizing this exponential decay function of litter materials over time, Jenny, et al (1949) and Olson (1963) used the equation $dx/x = -Kdt$ or $\ln X_1 = \ln X_0 - Kt$ to derive the decay constant (K), where X_0 is the initial amount of litter or organic matter, and X_1 is the final amount at time t (usually set at 1 year). Thus a value of K of .25 would indicate 25% decompostion per year, and 3/K is the approximate number of years that it will take for 95% decomposition of the material. While K is a very useful tool for comparing specific turnover rates from site to site, it is not predictive. Meentemeyer (1978) studied a wide range of temperate and boreal environments and developed a regression model to predict K based on cumulative annual evapotranspiration (AET via Thornthwaite and Mather, 1955) and the relative digestibility of the litter (% lignin). His equation: ($Y = -1.31369 + 0.05350X_1 + 0.18472X_2$); where Y =annual % weight loss, X_1 = AET in mm and X_2 = AET/% lignin, has been widely used, but does not predict well for extremely arid or disturbed ecosystems. It does point out, however, that between broad climatic zones AET is the basic controller of decomposition, but within zones, the relative digestibility of the litter is the most important factor.

While a significant portion of litter decomposition in the southern Appalachians can be attributed solely to physical processes such as leaching, the soil biota, particularly microarthropods and worms regulate the overall rate of decay and organic matter incorporation. The direct consumption of litter by arthropods is quite low (1 to 20%), but the indirect effects are profound (Crossly, 1976). Soil microarthropods pass from 20 to 100% of the forest floor litter through their bodies per year (Webb, 1976), and in the process fragment it, increase its relative surface area, convert it to fecal pellets, mix it with mineral soil, and regulate microfloral populations. Various mites, orbatids, and collembola feed on and spread fungal and bacterial assemblages associated with litter decay. Microcosm studies (Ausmus and Witkamp, 1973) have shown that systems containing arthropods have a larger and more stable microbial biomass than those lacking them. The exact mechanisms of interaction among soil arthropods, fungi and bacteria are extremely difficult to experimentaly delineate (Crossly, 1976) but their importance is irrefutable. A number of investigators (Seastedt and Crossly, 1983, Wittkamp and Crossley, 1966) have shown that litter decomposition rates can be drastically reduced by killing or simply excluding (by using fine nylon mesh bags) arthropods from the litter. In many soils, earthworms may be as important as arthropods in regulating decomposition and incorporation of organic matter into mull horizons (Anderson, 1978).

The equilibrium form and properties of the forest floor are then dependent upon the balance between litter production rates and decomposition rates, and the nature of the litter itself. Under extremely cold or wet conditions, decomposition may almost be completely inhibited, leading to thick peat or duff accumulations. In Appalachian ecosystems the overall accumulation of litter, and the relative distribution of it between F and H layers varies with cover type. Harmon (1980) found pine-oak forests were greater than pure oak forests in both total litter and F layer biomass, and that cove forests were lowest of all. Humus layers were slow to form, and their total biomass depended on stand composition, altitude, and disturbance history (fire or logging). The differences in accumulation among cover types are probably due to differences in litter digestibility, since all of the covers were approximately equal in litter production, and we would expect higher turnover rates on the hotter sites (pine-oak>pure oak>cove forests). Cove hardwoods often are higher in bases than mesic oaks and pines (Day and Monk, 1977), and are often lower in polyphenolics and lignin. Increases in polyphenolic materials are known to inhibit arthropod activity (Edwards and Heath, 1963), and high lignin and/or C:N ratios will also directly slow overall decompostion rates (Cromack and Monk, 1975). Therefore, the final amount of litter on a given soil is governed by a complex set of factors, not the least of which is litter palatibility.

4.2.4 The Forest Floor and Nutrient Retention

The total nutrient content of forest floors varies significantly by climate, vegetation type and the associated rates of litter production and decomposition (Table 10). The pre-fall nutrient concentrations of Appalachian hardwoods vary appreciably (Table 11) by species, so the relative nutrient content of a given litter layer is highly species dependent. Leaf nutrient contents drop appreciably just before leaf fall due to translocation within the plant (Day and Monk, 1977), and K is particularly susceptible to leaching before and after leaf fall. As decomposition proceeds, C and H losses are directly proportional to weight loss, while N concentrations increase due to immobilization in microfloral and faunal biomass. Nitrogen levels may also increase due to N-fixation in decaying wood (Cornby and Waide, 1973), or other exogenous N additions (Anderson, 1978). In general concentrations of N and P are highest in F layers, and then drop in the highly decomposed H layers. Concentrations of K, Ca, and Mg drop as litter is decomposed due to lower microbial immobilization and subsequent leaching. The litter layers and associated surface soil organic matter are the major source of plant available N, P and S over time, and hold it against leaching (N and S) and fixation by mineral colloids (P and

Table 10. Forest floor weights and nutrient content from several ecosystems. (adapted from Pritchett, 1979 and personal data)

Forest type	Layer	Weight(O.D.)	N	P	K	Ca	Mg
		Kg/ha	%				
Spruce	L	2,900	1.17	0.14	0.24	1.23	0.31
(Russia)	F	8,200	1.45	0.11	0.13	1.18	0.30
	H	10,100	1.32	0.09	0.09	0.76	0.30
Birch	L	1,100	1.37	0.21	0.31	1.36	0.32
(Russia)	F	6,100	1.66	0.21	0.18	1.38	0.32
	H	10,900	1.18	0.17	0.05	1.25	0.27
Hem./maple	L	5,800	0.69	0.06	0.07	0.38	0.02
(New Eng.)	F	44,900	1.49	0.10	0.10	0.21	0.03
	H	31,400	1.17	0.09	0.60	0.10	0.04
S. Pines	L	10,200	0.52	0.05	0.06	0.44	0.12
(SE USA)	H	22,800	0.54	0.06	0.04	0.42	0.09
Mixed cove	L	439	1.27	0.07	0.33	1.43	0.15
hardwoods	F	9,269	1.80	0.10	0.26	1.95	0.23
(Kilmer #6)	H	10,073	1.28	0.12	0.69	0.81	0.42

Table 11. Live leaf nutrient contents (% D.W.) for various hardwood species before litter-fall in Aug., (Day and Monk, 1977)

Species	N	P	K	Ca	Mg
Quercus prinus	2.22	0.18	1.09	0.59	0.19
Acer rubrum	1.67	0.16	0.53	0.62	0.20
Liriodendron tulip.	2.22	0.18	1.04	1.39	0.61
Robinia pseudoacacia	4.00	0.23	1.11	0.49	0.47
Oxydendrum arboreum	2.00	0.19	0.78	0.96	0.27

some S). Calcium, Mg, and K on the other hand may be supplied both through organic decay or exchange from mineral colloids.

As shown in Table 12, the forest floor contains an appreciable amount of the total N, K and Ca in Appalachian hardwood forest systems (Henderson, et al, 1978), and is instrumental in the retention and subsequent cycling of all major soil-supplied nutrients over time. Each nutrient has its own complex cycle, which is interrelated with factors affecting litter dynamics, relative levels and cycles of other nutrients, and the pattern of disturbance in the ecosystem. Careful treatment of each is beyond the scope of this paper, but Howell, et al (1975) provide an excellent review for southeastern ecosysystems.

The objectives of this study were to characterize the vegetation, litter layers and soil/litter nutrient pool associated with an undisturbed and highly productive southern Appalachian hardwood forest ecosystem and to compare it to reported properties of other southern Appalachian forests. The vast majority of soils in the East formed in equilibrium with forest vegetation, and almost all have been disturbed by man in one way or another. Little is known about soil properties of climax Eastern U. S. ecosystems and effects of logging and other past disturbances. A number of investigators have attempted to study effects of logging on forest ecosystems

Table 12. Partitioning of N, K, and Ca in two southern Appalachian hardwood forest ecosystems. (Henderson, et al, 1978)

	N		K		Ca	
Location	Coweeta	Walker Branch	Coweeta	Walker Branch	Coweeta	Walker Branch
	Kg/ha					
Vegetation	995	470	400	340	830	980
Litter layers	140	310	20	20	130	430
Soil (Exchangeable)	117	75	510	170	940	710

in isolated watersheds like Hubbard Brook (Bormann, et al. 1974) and the Coweeta Hydrologic Laboratory (Swank and Douglass, 1977), but all of the forests involved were logged at one time or another and have returned in a second generation stand. Thus while these studies have certainly determined short term disturbance effects on already disturbed systems, the true long term effects of logging undisturbed systems remain unknown, as do the properties of the soils and litter layers associated with them.

4.3 MATERIALS AND METHODS

4.3.1 Site Description

The Joyce Kilmer Memorial Forest in Graham County, North Carolina contains over 1600 ha of virgin hardwood timber and associated soils contained within a steeply sloping watershed. Elevations range from 700 to 1600 m within the watershed, and the majority of the landscape is steeply sloping. The underlying bedrock is massive meta-sandstones and meta-siltstones of the Great Smoky Group, and detailed information on geology of the area is provided in chapter 2. The soils within the watershed are surprisingly deep, and the majority are classified as Inceptisols (Table 13). A complete description of soil geomorphology within the watershed and the morphological, physical, chemical and mineralogical properties of the soils at each site is given in chapters 2 and 3. The climate of the watershed is humid-temperate, with precipitation estimated to exceed 200 cm/yr. The native vegetation within the watershed will be described in detail in this chapter.

4.3.2 Field Sampling Methods

Eight intensive study sites were located along two transects, one across the lower portion (700-900 m) of the watershed and one across the upper portion (1000-1250 m),

Table 13. Topographic characteristics, classification and A horizon depth of studied soils.

Soil	Elev.	Aspect	Slope	Classification	A Horizon Depth	Solum Depth
	m		%		---------cm---	----------
				North Facing Slopes		
1	732	N-NE	22	Typic Haplumbrept Fine-Loamy, Oxidic, Mesic	43	128
2	857	NE	53	Typic Haplumbrept Coarse Loamy, Oxidic, Mesic	42	110
5	1068	E-NE	57	Typic Haplumbrept Coarse Loamy, Oxidic, Mesic	31	94
6	1220	NE	59	Typic Haplumbrept Coarse Loamy, Oxidic, Mesic	52	118
				South Facing Slopes		
3	738	SE	31	Typic Hapludult Fine Loamy, Oxidic, Mesic	12	84
4	863	S-SW	55	Umbric Dystrochrept Coarse Loamy, Oxidic, Mesic	14	63
7	1043	S-SW	60	Umbric Dystrochrept Coarse Loamy, Oxidic, Mesic	19	70
8	1220	S	54	Umbric Dystrochrept Coarse Loamy, Oxidic, Mesic	20	57

in conjunction with soil geomorphology and weathering studies described in chapter 2. The transects were designed to provide southerly aspects on one side of the watershed and northerly aspects on the opposing slope, thereby sampling differing soils and associated vegetative communities. The topographic characteristics and classification of the soils at each site are given in Table 13.

At each site, centered on the soil pit, all woody vegetation within a 400 m^2 circle was documented by species, dbh, height, and crown class. Basal areas (m^2/ha) and stem densities (stems/plot) are estimated from these data, and are not corrected for slope. Estimates of the type and extent of understory vegetation < 2.54 cm dbh were also made within the plots.

Litter layers (L, F and H) were carefully separted at 5 arbitrarily set 0.1 m^2 plots, and then composited. Larger stems (>2.54) were occasionally encountered, and were not sampled as leaf litter. An additonal composite sample was taken from the upper 0-7.5 cm of mineral soil below the bottom of the H layer. This sample allowed direct comparison of litter layer properties with their underlying surface soils, and allows uniform site to site comparison of surface soil characteristics since morphology and depth of the A horizons (Ch. 2) varied a great deal across sites. Five nylon mesh litter traps were installed at litter sampling locations in August 1983, and collected in January 1985. A great deal of additional information on vegetation, soil, and landscape relationships within the watershed was gathered during transect studies and extensive exploratory work during the summers of 1982, 1983 and 1984.

4.3.3 Analytical Methods

All samples were oven dried at 70°C and ground in a Wiley mill. All litter and soil parameters are expressed on an oven dry basis, and are not corrected for slope. Planar hectare weights can be obtained by multiplying all values by 1/cos O, where O is the slope angle from horizontal in degrees. The maximum correction for the steepest site, if applied, is 1.15. Ash content was determined at 470 C for all samples, and all weights are expressed with ash. Percent organic matter in litter was calculated as 1 - % ash, and soil organic matter and determined by a modified Walkely-Black procedure (Nelson and Sommers, 1982) Total-N was determined by a modified micro-Kjeldahl procedure (Bremner and Mulvaney, 1982). Total P, K, Ca, Mg, and S were determined following a nitric/perchloric acid digestion by ammonium-molybdate colorimetry for P (Murphy and Riley, 1962), atomic absorption for K, Ca, and Mg, and a turbidimetric technique (Tabatabai and Bremner, 1970) for S. Extractable

K, Ca, Mg, and P in the soil samples were determined by the techniques described in Chapter 3, and total levels of organic matter and available nutrients in the entire profiles at sites 3 and 6 were calculated based on data presented in Chapters 2 and 3. Whole soil nutrient and organic matter values reported are corrected for coarse fragment content and bulk density, but not slope.

4.4 RESULTS AND DISCUSSION

4.4.1 Vegetation

Due to diversity in altitudes and aspects sampled, the vegetation varied greatly from site to site (Table 14). For the sake of brevity, I will discuss only major woody vegetation since it dominates total litter production and quality. All sites contained a number of large individual trees spread among many smaller ones, but the vegetation at site 1 was particularly impressive. This site lies on the gently sloping floor of poplar cove and was dominated by tulip poplar (Liriodendron tulipifera), basswood (Tilia americana), silverbells (Halesia carolina), beech (Fagus grandifolia), and other mixed mesophytic cove species. The extraordinarily high basal area reported (114 m^2/ha) is an artifact of our pit placement, but Lorimer (1976) reported a value of 55 m^2/ha in the same area in poplar dominated stands, and 72 m^2/ha for nearby mixed hemlock/poplar stands. The forest immediately surrounding

Table 14. Total stems/400 m^2 plot, basal area, and species of overstory trees present at each site.

Species	Site 1 DBH <5cm	Site 1 DBH >5cm	Site 1 Basal Area	Site 2 DBH <5cm	Site 2 DBH >5cm	Site 2 Basal Area	Site 5 DBH <5cm	Site 5 DBH >5cm	Site 5 Basal Area	Site 6 DBH <5cm	Site 6 DBH >5cm	Site 6 Basal Area
	Stems		m^2/ha	Stems		m^2/ha	Stems		m^2/ha	Stems		m^2/ha
Acer rubrum (red maple)	2	--	--	--	--	---	--	--	--	--	15	13.06
Acer saccharum (sugar maple)	3	--	--	7	13	2.06	--	1	0.58	--	2	1.94
Aesculus octandra (sweet buckeye)	4	1	0.03	1	1	0.30	--	3	0.74	--	--	---
Betula lenta (black birch)	--	--	--	--	1	0.36	--	--	--	--	6	0.92
Carpinus carolinia (iron wood)	9	1	0.07	--	--	---	--	--	--	--	--	---
Carya cordiformis (bitternut hickory)	--	1	0.15	--	1	10.21	--	--	--	--	--	---
Cornus florida (flowering dogwood)	4	4	0.32	10	--	---	--	--	--	--	--	---
Halesia carolina (mountain silverbells)	--	5	6.12	--	10	12.41	--	5	0.99	--	14	17.02
Fagus grandifolia (american beech)	39	5	9.02	--	--	---	1	3	4.89	--	--	---
Fraxinus americana (white ash)	--	1	0.65	--	--	---	--	--	--	--	--	---
Fraxinus pennsylvanica (green ash)	10	--	--	--	--	---	--	--	--	--	--	---
Liriodendron tulipifera (tulip poplar	2	3	93.20	1	1	0.10	--	--	--	--	3	11.62
Magnolia acuminata (cucumber tree)	--	--	--	--	--	---	--	--	--	--	2	3.05
Magnolia fraseri (fraser magnolia)	--	1	0.40	--	--	---	--	--	--	--	--	---
Oxydendrum arboreum (sourwood)	--	--	--	--	--	---	--	--	--	--	1	1.56
Quercus prinus (chestnut oak)	--	--	--	--	--	---	--	--	--	--	3	3.85
Quercus rubra (red oak)	--	--	--	--	--	---	--	--	--	--	1	2.32
Robinia pseudoacacia (black locust)	--	--	--	--	--	--	--	2	6.53	--		5.88
Tilia americana (basswood)	35	2	4.19	--	--	--	1	--	7.47	--	--	---
Tsuga canadensis (eastern hemlock)	5	1	0.07	--	--	--	--	3	7.15	--	2	0.22
Totals	113	25	114.2	19	27	25.4	2	17	28.3	0	49	61.4

Table 14 cont.

Species	Site 3			Site 4			Site 7			Site 8		
	DBH		Basal Area	DBH		Basal Area	DBH		Basal Area	DBH		Basal Area
	<5cm	>5cm		<5cm	>5cm		<5cm	>5cm		<5cm	>5cm	
	Stems		m^2/ha	Stems		m^2/ha	Stems		m^2/ha	Stems		m^2/ha
Acer rubrum (red maple)	8	12	11.91	9	16	3.89	--	19	6.14	4	18	5.41
Acer saccharum (sugar maple)	--	--	---	--	--	---	--	1	0.02	--	--	--
Carya glabra (pignut hickory)	--	2	1.13	--	1	5.16	--	2	0.13	--	3	1.62
Carya tomentosa (mockernut hickory)	--	--	---	--	--	---	--	1	1.14	--	--	--
Cornus florida (flowering dogwood)	--	1	0.06	3	5	0.92	--	--	---	1	2	0.20
Kalmia latifolia (mountain laurel)	42	7	0.81	3	--	---	--	2	---	--	--	--
Nyssa sylvatica (black gum)	3	1	0.08	2	--	---	--	--	---	--	1	0.07
Oxydendrum arboreum (sourwood)	3	16	3.64	--	10	2.52	1	4	1.57	--	--	--
Pinus strobus (white pine)	--	8	3.54	--	3	1.61	--	--	---	--	--	--
Quercus alba (white oak)	2	9	18.81	--	--	---	--	2	10.01	--	--	--
Quercus rubra (red oak)	--	1	5.11	--	--	---	--	3	4.98	1	9	7.86
Quercus coccinea (scarlet oak)	--	1	3.65	--	1	1.09	--	--	---	--	--	--
Quercus prinus (chestnut oak)	--	--	---	--	2	10.35	--	--	---	--	2	9.97
Quercus velutina (black oak)	--	5	3.50	--	6	2.59	--	--	---	--	--	--
Robinia pseudoacacia (black locust)	--	--	---	--	--	---	--	--	---	--	2	8.23
Tsuga canadensis (eastern hemlock)	3	3	0.36	2	1	0.67	--	--	---	--	--	--
Totals	61	66	52.6	19	45	28.8	1	34	23.9	6	37	33.3

site 1 contains numerous large tulip poplars (Fig. 14) which tower to > 50 m above a multi-tiered canopy (Fig. 15), and are often > 1.3 m in diameter. The large poplar and hemlock (Tsuga canadensis) are limited to the cove floors and major stream bottoms, and therefore were not present at any other sites on steeper sideslopes. Sites 2 and 6, which are much lower in basal area than site 1, are dominated by mountain silverbells (Halesia carolina), a species which attains large size only in this region, and is generally limited to moist north-facing sites. Site 5 contains primarily mixed-mesophytic species along with several large black locusts (Robinia pseudoacacia). The herbaceous and understory vegetation at all north-facing sites was lush and diverse.

South-facing sites were dominated by mixed oak-hickory-maple forests. Large amounts of downed chestnut logs, profuse chestnut stump sprouts, and low basal areas at sites 4, 7 and 8 indicate that these stands were once dominated by the American chestnut and are in the process of recovery (Woods and Shanks, 1959). Red maple (Acer rubrum) was common on these sites, but seldom as a dominant tree. Site 3 was covered with a dense thicket of mountain laurel, penetrated by white pine(Pinus strobus) and several large white oaks (Quercus alba), making it quite distinctive from others in this study. This was the lowest, south-facing site in this study, and

Figure 14. Large tulip poplar (Liriodendron tulipifera) trees around site 1. Many trees in this cove are > 1.3 m in diameter and 50 m in height.

Figure 15. Scale diagram of the vegetation at site 1, showing canopy architecture, and the massive nature of the poplars. Diagram by Lenoor Oosterhuis.


Liriodendron tulipifera
Liriod. tulip.
Liriod. tulip.
Liriodendron tulipifera
Liriodendron tulipifera
Halesia carolina
Fagus grand.
Fagus grand.
Hal. car.
Fagus grandifolia
Halesia car.
Liriod. tulip.
Fagus grandifolia
Halesia carolina
Hal. car.
Hal. car.
Hal. car.
Cornus florida
Hal. car.
Fagus grand.
Cornus florida
Fagus gr.
Carp. car.
Fagus grand.
Carp. car.
Fagus grand.
Carpinus car.
Fagus grand.
Halesia car.
Fagus grand.
March 1984
W.L.D.
P.L.G.
P.J.N.
L.O.
0
10
20
30
40
50

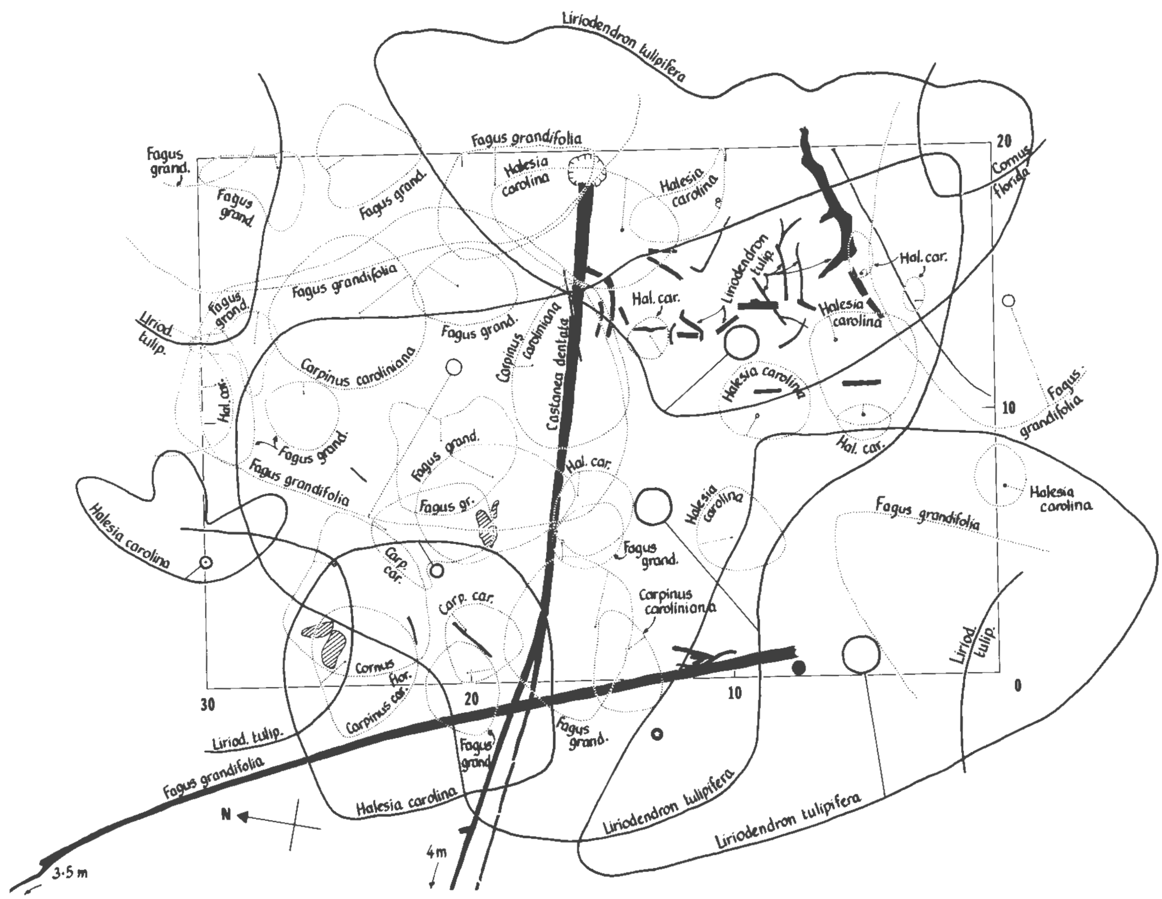

Figure 16. Scale diagram of the vegetation at site 1, top view. Note the numerous downed boles on the plot, and the extension of the canopy of the large tulip poplar (Liriodendron tulipifera) at the upper right into the canopy space vacated by the downed American chestnut (Castanea dentata).

is surrounded by large areas of mixed pine/oak forests, while the remaining south-facing slopes in the watershed are covered with mixed oak/hickory. The herbaceous and understory layers on south-facing slopes were thinner and less diverse than those on north-facing slopes.

The forest floor in all parts of the watershed is littered with numerous downed trees (Figs. 16 and 17), so much so that walking away from established trails can be quite difficult. The extremely wet and temperate climate leads to very fast decompositon rates, and downed boles virtually disappear in several years, leaving deep pockets of humus on the surface (Harmon, 1980) and windthrow mounds (Ch. 2). The downed wood is the combined result of natural mortality of large over-mature trees and the chestnut blight. The chestnut was not only a dominant member of the mesic forests on upper slopes, but commonly occurred as a dominant tree in the cove associations as well (Fig. 16). Thus, when we consider these virgin forest communities and soils, we must realize that they have been exposed to considerable disturbance by the chestnut blight (Woods and Shanks, 1959), and to local patches of windthrow by severe storms (Lorimer, 1976). As these large trees fall, they frequently clear out large (up to .3 ha/tree) areas of the canopy and understory, allowing suppressed and newly germinating tree seedlings to fill the openings. In this fashion forest succession occurs in a patchwork pattern, and the community contains all ages of trees in various stages of growth and maturity rather than a pure stand of large over-mature trees.

The upper rim (> 1300 m) of the watershed is underlain primarily by very resistant quartzitic rocks, and the soils are quite thin. This, in conjunction with the harsh high elevation climate, has led to stunted beech-maple-oak forests frequently underlain by thick grass. Many of the exposed ridges are covered in heath slicks, dominated by catawba rhododendron (Rhododendron Catawbiense) flame azaelea (Rhododendron calendulaceum) mountain laurel, and many species of Vaccinium (blueberries). These communities are literally growing directly in their own thick litter layers which have accumulated to > 0.75m in many places over hard rock, and have thin spodic or placic horizons below them.

Figure 17. Downed log and dense herbaceous vegetation near site 2. Large amounts of downed wood were present around all sites, and most trees decay quite rapidly in this very moist environment. Trees like this one often serve as "nurse logs" for germinating tree seedlings, providing support and nutrition as they decay.

4.4.2 Annual Litter Additions and Quality

Annual leaf litter additions at all sites (table 15) averaged 3494 kg/ha and agreed well with values reported by Harmon (1980), and Cromack and Monk (1975) for similar southern Appalachian forests. These values underestimate total annual litter additions, however, for several reasons. Large branches, boles, and litter that fell over the spring and summer were not estimated, and the leafy litter may have lost up to 20% of its dry weight by the time we collected it in January (Seastedt, et al, 1981). The reasons for the two low values (1986 kg/ha at site 7, and 2730 kg/ha at site 6) are unknown, but may be due to litter blowing out of the traps on steep slopes, or simple random variability in the field. Species, aspect, and elevation appeared to have no consistent affect on total litter production. This agrees with the results reported by Harmon (1980) for a much larger sample population in the Smoky Mountains. Litter on north-facing slopes was consistently higher in N, P, K, and Ca content however, presumably due to the higher nutrient content of the cove hardwoods (Day and Monk, 1977). Calcium and particularly K are subject to rapid leaching from both the canopy and fresh litter, and are underestimated. For example, Cromack and Monk (1975) reported 18.0 kg/ha (K) and 44.5 kg/ha (Ca) as total annual litter additions at Coweeta, and that an additional 31 kg/ha of K reached the forest floor as

Table 15. Estimated annual leaf litter fall and nutrient additions.

Site	Annual Litter Fall	Ash	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	kg/ha	%						kg/ha				
					North Facing Slopes							
1	3461	5.47	0.57	0.076	0.15	1.47	0.14	19.62	2.64	5.16	51.15	4.82
2	4599	4.84	0.38	0.049	0.14	1.20	0.14	17.38	2.25	6.62	55.18	6.42
5	4028	4.13	0.58	0.069	0.12	1.11	0.13	23.01	2.79	5.22	44.95	5.22
6	2730	7.31	0.46	0.045	0.09	0.86	0.14	12.67	1.23	2.45	23.64	3.81
					South Facing Slopes							
3	3701	3.35	0.31	0.051	0.06	0.77	0.12	11.55	1.89	2.21	28.58	4.42
4	3866	4.34	0.31	0.040	0.08	0.90	0.16	12.00	1.57	3.08	35.13	6.16
7	1986	3.80	0.33	0.050	0.08	0.88	0.12	6.59	0.99	1.58	17.61	2.37
8	3583	2.16	0.20	0.024	0.07	0.51	0.09	7.16	0.87	2.49	18.21	3.57

throughfall after leaching from the canopy and intact leaves. Our data (Table 15) are considerably lower. These data do represent the status of the fresh litter in mid-winter, however, and can be used as a comparative estimate of annual additions.

4.4.3 Litter Layer Properties

The litter layers at all sites were characterized by very thin leaf layers, and well developed fermentation and humus layers (Table 16). These samples were taken in mid-summer, and L layer weights are quite low when compared with annual litter additions, indicating that the first year decomposition rates may be well in excess of the 35 to 46% reported by Shanks and Olson (1961), but similar to the 70% reported by Cromack and Monk (1975). The lower part of the humus layers were was mixed into the underlying mineral soil forming a deep, mull humus with high ash content, particularly on north facing slopes. A distinct H layer was present at all sites over the mull layer, so all of these layers would classify as duff-mulls (Hoover and Lunt, 1952). The exact delineation of the humus/soil boundary in these soils is difficult, but in most cases a distinct change from very light organic granules to medium crumb structure and a higher bulk density were noted.

Total litter weights did not vary appreciably from site

Table 16. Litter Layer weights and nutrient properties.

Site	Layer	Dry Weight	Ash	Total N	Total P	Total K	Total Ca	Total Mg	Total S	N	P	K	Ca	Mg	S
		kg/ha	%	%						kg/ha					
							North Facing Slopes								
1	L	402	0.8	0.54	0.035	0.12	1.81	0.12	0.064	2.17	0.14	0.48	7.28	0.48	0.26
	F	10,890	15.3	1.49	0.094	0.43	3.36	0.28	0.120	162.26	10.24	46.82	365.90	30.49	13.07
	H	6,922	48.3	1.22	0.122	0.11	2.39	0.65	0.101	84.45	8.45	7.61	165.43	44.99	6.99
	Total	18,214								248.88	18.83	54.91	538.61	75.96	20.32
2	L	606	4.5	1.10	0.079	0.60	2.97	0.35	0.096	6.67	0.48	3.64	17.99	2.12	0.58
	F	7,812	11.8	1.54	0.098	0.23	4.51	0.42	0.136	120.30	7.66	17.97	352.32	32.81	10.62
	H	6,922	53.0	1.13	0.115	0.42	2.34	0.75	0.092	78.22	7.96	29.07	161.97	51.92	6.37
	Total	15,340								205.19	16.10	50.68	532.28	86.85	17.57
5	L	440	7.3	1.27	0.070	0.33	1.43	0.15	0.037	5.58	0.31	1.45	6.29	0.66	0.16
	F	9,270	9.7	1.80	0.101	0.26	1.95	0.23	0.075	166.86	9.36	24.10	180.75	21.32	6.95
	H	10,073	29.7	1.28	0.116	0.69	0.81	0.42	0.044	128.93	11.68	69.51	81.59	42.31	4.43
		19,783								301.37	21.35	95.06	268.63	64.29	11.54
6	L	339	2.7	1.18	0.075	0.16	1.25	0.12	0.041	4.00	0.25	0.54	4.23	0.41	0.14
	F	5,538	16.5	1.38	0.079	0.24	1.28	0.18	0.048	76.42	4.37	13.29	70.88	9.97	2.66
	H	7,469	55.1	1.34	0.090	0.59	0.45	0.33	0.052	100.07	6.72	44.06	33.61	24.65	3.88
	Total	13,346								180.49	11.34	57.89	108.72	35.03	6.68

Table 16 cont.

Site	Layer	Dry Weight	Ash	Total N	Total P	Total K	Total Ca	Total Mg	Total S	N	P	K	Ca	Mg	S
		kg/ha	%	%						kg/ha					
							South Facing Slopes								
3	L	878	2.7	1.24	0.077	0.14	1.20	0.11	0.038	10.89	0.68	1.23	10.54	0.96	0.34
	F	7,715	9.5	1.36	0.088	0.18	1.19	0.11	0.045	104.92	6.79	13.89	91.80	8.49	3.47
	H	15,671	26.8	1.35	0.087	0.26	0.24	0.12	0.065	211.56	13.64	40.75	37.61	18.80	10.19
	Total	24,264								327.37	21.11	55.87	139.95	28.25	14.00
4	L	774	3.6	0.80	0.059	0.12	1.08	0.10	0.038	6.19	0.45	0.93	8.36	0.77	0.29
	F	10,083	15.8	1.31	0.083	0.19	1.27	0.17	0.055	132.09	8.36	19.16	128.05	17.15	5.55
	H	3,908	33.8	1.31	0.098	0.35	0.32	0.19	0.057	51.19	3.83	13.68	12.51	7.43	2.23
	Total	14,765								189.47	12.64	33.77	148.92	25.35	8.07
7	L	1,265	2.6	1.01	0.076	0.12	1.21	0.11	0.038	12.78	0.96	1.52	15.30	1.39	0.48
	F	6,964	19.8	1.38	0.107	0.29	1.22	0.22	0.045	96.10	7.45	20.19	84.95	15.32	3.13
	H	5,599	61.1	0.83	0.083	0.78	0.28	0.48	0.032	46.47	4.65	43.67	15.68	43.59	1.79
	Total	13,828								155.35	13.06	65.38	115.93	60.30	5.40
8	L	973	2.7	1.18	0.065	0.11	0.89	0.14	0.043	11.48	0.63	1.07	8.65	1.36	0.42
	F	7,603	13.3	1.51	0.082	0.17	0.89	0.18	0.041	114.80	6.23	12.93	67.67	13.69	3.12
	H	6,816	48.5	1.09	0.091	0.47	0.22	0.38	0.040	74.29	6.20	32.04	14.99	25.90	2.73
	Total	15,392								200.57	13.06	46.04	91.30	40.95	6.27

to site, except for site 3, where under mountain laurel and oak/pine vegetation, an extremely thick humus layer was present. This is probably due to the higher lignin content and lower palatability (Cromack and Monk, 1975) of this litter compared to the cove and mixed hardwoods present at the other sites. Harmon (1980) reported that while total litter production in forests in the Smokys was not affected by species, aspect, or altitude, significant differences in F layer and total litter accumulations did occur under different cover types. The lack of differences across vegetation types in this study may indicate that the litters from these species vary little in their decomposition rates, net production rates are similar, or perhaps we did not sample enough sites with enough diversity in litter digestibility to make the differences obvious.

The Ca and K contents of the litter layers on north-facing slopes were higher than those on south-facing slopes due to higher levels in the annual litter additions (Table 15). Nitrogen and P levels showed no consistent differences even though annual inputs were higher on north-facing slopes. Phosphorus contents in the litter were quite low in general (<0.10 %), and similar levels in litter at the Coweeta watershed were interpreted by Cromak and Monk (1975) as indicative that the ecosystem was P-limited. The presence of significant levels of subsoil P at many of our sites, however, lends doubt to this interpretation. In general, N contents were highest in F layers, while P levels were highest in H layers. Higher levels of N in the F layers are probably due to their intermediate stage of decompositon, combined with microbial immobilization of N as it is leached and mineralized from L layers. The H Layers were usually high in ash, and significant portion of total-P in these high-ash H layers may have been associated with inorganic Fe and Al compounds. Both N and P are rapidly immobilized into microbial biomass as they are mineralized from the litter, while Ca, Mg, and K are much more mobile and may be leached or remain in an exchangeable form on mineral and organic surfaces. Sulfur levels did not show consistent differences among sites except for the fact that overall levels were slightly higher in the litter at sites 1 and 2.

4.4.4 Litter/Soil Relationships

While different sites did not vary significantly in litter accumulation, they did vary dramatically in organic matter incorporation into underlying mineral soil (Fig. 18) These mineral soils contain large amounts of organic matter, often incorporated deeply into their B horizons. Higher levels in north-facing slopes may be due to decreased faunal activity on hotter slopes (Seastedt and

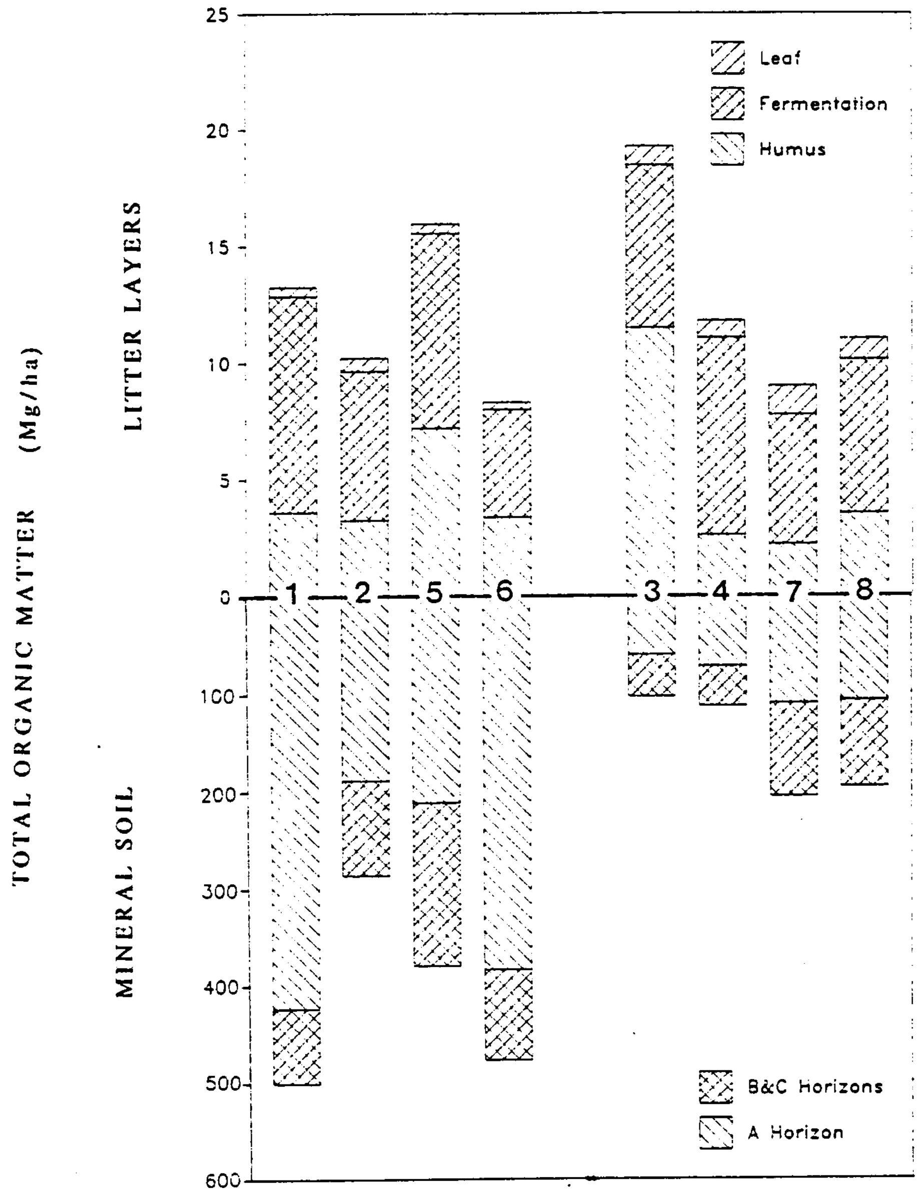

Figure 18. Total organic matter (ash free) in the litter layers at each site, and in the underlying soil horizons.

Crossly, 1981), and more importantly, lower organic matter oxidation rates. Assuming that the soils in the vicinity of all sites were similar in depth and organic matter content to those described in chapter 1, they contain hundreds of metric tons of organic matter/ ha, while the litter layers contain less than 20 (ash free). These whole soil organic matter contents greatly exceed the entire above-ground biomass measured (139 kg/ha) in the Coweeta watershed (Day and Monk, 1977). When we exclude the gently sloping soil (1) in poplar cove, whole soil organic matter levels increase with altitude on both aspects. Even at site 3 where a thick H layer had developed, whole soil organic matter exceeded litter organic matter by an order of magnitude.

The differences in soil organic matter levels and incorporation coupled with the differences in litter quality on opposing aspects exert a dominant influence on the chemical properties of surfaces of their underlying mineral soils (Table 17). The surface 0-7.5 cm of mineral soils on north-facing slopes are all higher in organic matter content, total-N, extractable bases, CEC, and base saturation than south-facing slopes. Not only are these soil surfaces higher in nutrient content, they are much higher in organic matter dependent CEC (Ch. 2) and are therefore more capable of holding mobile Ca and K against leaching. Thus, while the species adapted to grow on the

Table 17. Chemical characteristics of the upper 7.5 cm of mineral soil at the 8 study sites.

Site	Ash	O.M.	Total N	C/N	pH	Extractable Cations Ca	Mg	K	Al	CEC	Base Sat.	Ext. P
	%					cmol/kg					%	ppm
					North Facing Slopes							
1	71.9	18.38	0.71	14.8	5.32	7.85	1.70	0.90	0.45	10.90	96	1.2
2	79.3	14.41	0.47	17.5	4.98	5.07	1.19	0.55	1.45	8.26	82	2.6
5	74.5	15.48	0.62	14.3	4.14	3.41	0.80	0.60	4.75	9.56	50	2.0
6	77.0	14.83	0.40	21.2	4.80	1.05	0.61	0.48	4.40	6.54	32	1.6
					South Facing Slopes							
3	86.2	8.05	0.22	20.9	4.62	0.19	0.20	0.30	3.80	4.49	15	2.0
4	86.3	7.77	0.29	15.3	4.86	0.26	0.21	0.26	3.70	4.43	16	2.6
7	82.5	10.66	0.35	17.4	4.50	0.81	0.40	0.33	3.35	4.89	31	3.4
8	81.7	10.19	0.35	16.6	4.64	0.15	0.25	0.36	3.65	4.41	17	1.6

north slopes have higher N and cation levels in their litter, they also have much higher levels of these nutrients available to them for uptake. Extractable P levels, however, do not differ by aspect in the surface soil, just as they do not differ in the litter layers.

The distribution of N, P, and cations between litter and mineral soil at sites 3 and 6 is presented in table 18. These two sites represent extremes in aspect, elevation, vegetation, and litter layer properties. Total soil N levels in the high elevation north-facing site (6) are twice those of site 3, but site 3 retains twice as much N in its litter layers above the soil. Litter and total soil levels of K, Ca, and Mg vary little between sites, but are concentrated deeper in the subsoil at site 3 due to the lack of organic matter and CEC in the soil surface to intercept and hold leaching cations. While the total P in litter at both sites appears to be much higher than that extractable from mineral soil, the deep C horizon at site 6 contains a large amount of extractable P, apparently weathering from apatite in the parent material (Ch. 3). The ratios of total litter K and Ca to exchangeable soil K and Ca are much higher than those reported (Table 12) by Henderson, et al, (1978) at Coweeta (W. NC) and Walker Branch (E. TN). Due to the high rainfall and extreme leaching environment, these forest systems may be concentrating the majority of these

Table 18. Total nutrient content of litter layers, and total soil N, exchangeable K, Ca and Mg and acid extractable P levels in soils 3 and 6.

	Soil 3					Soil 6				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	kg/ha					kg/ha				
Total in Litter Layers	327	21.1	55.9	139.9	28.3	180	11.3	57.9	108.7	35.0
A horizons	1,720	2.6	66.9	21.1	15.8	9,264	6.4	466.8	103.8	63.5
B horizons	6,421	8.6	436.2	95.4	397.5	7,292	7.0	271.2	42.1	124.2
C horizons	1,920	7.7	149.8	76.8	153.7	2,500	14.7	120.2	53.1	68.5
Total in min. soil	10,061	18.9	652.9	193.3	567.0	19,056	28.1	858.2	199.0	256.2

nutrients in the live biomass and litter, much like a tropical rain forest.

It is difficult to accurately estimate the total nutrient pool and biomass on these sites for the obvious reason that the vegetation cannot be cut and sampled. These stands are also uneven aged with many large irregularly shaped trees whose total volume may be impossible to accurately estimate. Day and Monk (1977) estimated the standing biomass in the Coweeta watershed at 139 Mg/ha, and estimated that it contained 551 kg of Ca, 232 kg of K and 48 Kg/ ha of Mg. That forest is still quite young, however, and Whittaker (1966) has estimated the biomass of older cove hardwood stands in the Smokys at 500 to 610 Mg/ha. If some accurate estimate of standing biomass and nutrient content in these forest stands could be made, the data presented here could be integrated with it and data from the directly adjacent logged and disturbed watersheds to produce an unbiased study of logging effects, with a truly undisturbed control treatment.

4.5 CONCLUSIONS

Aspect strongly controls vegetation type within this watershed, and therefore the nutrient content of the annual litter additions and properties of the underlying surface soils. Cove hardwoods and other mixed mesophytic tree associations produce litter much higher in N and cation content, and over time they have enriched their surrounding soils with these nutrients when compared to the forests on south-facing slopes. Annual litter additions and total litter accumulations vary little from site to site, while whole soil organic matter levels and depth of incorporation show strong aspect and elevation effects, indicating that the activity of soil fauna are much greater on the cooler slopes. Whole soil organic matter levels are very high in these soils, particularly on north-facing slopes, and they contain much more total-N in soil than in litter layers. Calcium, K and P on the other hand are concentrated in litter layers and immediate surface horizons, and the ratios of litter to soil levels of these nutrients are much higher than those commonly reported for other southern Appalachian forests.

While this is regarded as a virgin forest, it has been subjected to significant disturbances by windthrows over time and particularly by the chestnut blight, which wiped out a major component of the forest in all landscape positions. Particularly on south-facing slopes, where it appears that the vast majority of the canopy was removed, it is hard to judge just how much of the differences in litter layer properties that we have observed due to aspect are due to long term vegetative effects, and how much may be an artifact of the elevated temperatures and associated decreased faunal activity, lower soil moisture, and temporary lack of litter production in the 1940's.

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Chapter V

SUMMARY AND CONCLUSIONS

As a whole these virgin soils are deep, highly weathered, and very high in organic matter content. While significant amounts of relatively thin soils exist over shallow rock outcrops, rocky drainageways and stream cuts, a major portion of the landscape is underlain by predominantly residual soils. These landscapes show no evidence of slow slope creep, the mechanism generally thought to be responsible for the large accumulations of colluvium on foot slopes, in coves and along drainageways in the Appalachians. Rather, these landforms appear to have been created by solifluction and periglacial mass wasting, and have been relatively stable since. These soils, particularly those formed in residuum on middle elevation side slopes may have been completely weathered to a depth of several meters in less than 15,000 years. High rainfall, soluble feldspathic parent material, long term organic matter decay, and a constant and massive network of reinforcing tree roots have apparently combined to create deep stable soils in a relatively short period of time.

By far the most outstanding morphological feature of these soils is their deep, organically enriched surface horizons with coarse crumb structure. They are the combined product of hardwood vegetation and litter, soil mixing by fauna, and a very wet climate over time. The close inter-dependence of aspect, vegetation, and soil properties is dramatic at all sites, especially in surface soil and litter properties. The vegetation patterns within the watershed are strongly controlled by aspect, with cove and mixed mesophytic hardwoods on north-facing slopes and mixed oak/hickory stands on south-facing slopes. The fact that the soil and vegetation patterns have apparently co-evolved over time, demonstrates the difficulty in separating the effects of the various soil forming factors on the equilibrium form of a soil. These soils, particularly those on north-facing slopes contain more organic matter below ground than most Appalachian forests contain above ground. This organic matter is the major source of CEC, and is critical for the retention of K and Ca against leaching. Nitrogen is mixed quite deeply into these soils along with the organic matter, but P, K, and Ca are concentrated in the litter layers and surface soil when compared to other Appalachian ecosystems. We can only wonder about the effects of logging, erosion, and fires on steeply sloping soils when the southern Appalachians were logged around the turn of the century.

The joint occurence of gibbsite and easily weatherable minerals with only limited amounts of kaolinite in these soils seems strange at first, but in this high rainfall environment, weathering may be occurring so fast that this is the equilibrium mineral suite. The lack of drying may preclude the formation of secondary kaolinite, and intense desilication and hydrolysis weathering of the 2:1 type minerals may prevent 2:2 type minerals from forming. Even the sand and silt fractions in these soils are highly weathered, with the majority of micas being transformed to 1.4 um minerals in both fractions. The very low effective CEC's of these soils are hard to explain in light of large amounts of whole soil vermiculite, unless the mineral surfaces are completely coated with Fe and Al oxy-hydroxide complexes.

With their decreasing clay contents with depth, low CEC's, oxidic mineralogies, and concentration of cations and P away from the soil in litter and biomass, these soils highly resemble tropical Oxisols. This coupled with Inceptisol morphology makes classification of these soils by Soil Taxonomy enigmatic. Because of these properties, these soils are quite different from the majority of soils in the United States. Despite the unique nature of these soils, we hope that these data and the findings relating soil forming factors and equilibrium soil conditions will be of value in the study of other soil systems.

APPENDIX I

SOIL DESCRIPTIONS

Joyce Kilmer #1

Horizon	Depth (cm)	Description
A1	0-13	Very dark gray (10 YR 3/1) to very dark grayish brown (10 YR 3/2) clay loam; moderate to strong coarse crumbs breaking to fine and medium crumbs; very friable; many very fine roots, and common vertical and horizontal fine and medium roots; common tubular and vesicular pores; clear smooth boundary.
A2	13-20	Dark brown (10 YR 3/3) clay loam; weak fine and medium subangular blocks; very friable; common very fine, fine, medium and coarse vertical and horizontal roots; few vesicular and common tubular pores; gradual smooth boundary.
AB	30-43	Brown (10 YR 4/3) silt loam; weak fine and medium subangular blocks, very friable to friable; common medium and coarse vertical and horizontal roots; common tubular and vesicular pores; gradual smooth boundary.
Bw1	43-64	Dark yellowish brown (10 YR 4/4) clay loam; weak fine and medium subangular blocks; very friable to friable; common medium and coarse vertical and horizontal roots; common tubular and vesicular pores; gradual smooth boundary.
Bw2	64-128	Dark yellowish brown (10 YR 4/6) to yellowish brown (10 YR 5/6) clay loam; weak fine and medium subangular blocks; very friable to friable; common medium and coarse vertical and horizontal roots; few tubular and common vesicular pores; abrupt smooth boundary.
R	128+	Metasandstone rock. The rock/soil contact slants from 103 cm to >150 cm from right to left. Clay accumulation just above rock contact.

Notes: Location - Lower Poplar Cove (see map)
Vegetation - Mixed mesophytic cove hardwoods
Physiography - Long gentle convex cove floor
Slope - 22%
Elevation - 732 m
Aspect - NNE

Weak structure in B horizon with porous peds. Lack of structure is probably due to lack of wetting and drying cycles in this moist position. The B horizon is riddled with old insect burrows and root channels. This has led to deep incorporation of more A horizon material. Due to a lack of a C or CR horizon this soil is probably formed in old colluvium. The R is the top of a large boulder. The B horizon is riddled with roots.

Joyce Kilmer #2

Horizon	Depth (cm)	Description
A1	0-15	Black (10 YR 2/1) to very dark grayish brown (10 YR 3/2) loam; moderate coarse crumbs breaking to moderate to strong, fine and medium crumbs; very friable; many very fine and fine roots and common medium vertical and horizontal roots; many tubular and common vesicular pores; clear smooth boundary.
A2	15-42	Dark brown (10 YR 3/3) loam; weak medium crumbs, and weak fine subangular blocks; very friable; common fine, and many very fine and medium vertical horizontal roots; and common coarse vertical and horizontal roots; common tubular and vesicular pores; gradual smooth boundary.
Bw	42-110	Dark yellowish brown (10 YR 4/4) loam; weak fine and medium subangular blocks; friable; few fine, common medium, and common coarse vertical roots; common tubular and vesicular pores; gradual wavy boundary.
C	110-145	Dark yellowish brown (10 YR 4/6), black (10 YR 7/1) and brownish yellow (10 YR 7/1) sandy loam; structureless, massive; firm in place, fragments are friable; few fine, medium and coarse vertical roots; many vesicular and few tubular pores; clear wavy boundary.
CR	145-386	Light gray (10 YR 7/1) and black (10 YR 2/1) loamy sand; structureless, massive; firm in place, chunks are friable; few medium and fine vertical roots; common vesicular pores; abrupt smooth boundary. Water at rock contact.
R	386+	Hard metasandstone bedrock.

Notes: Location - Poplar Cove, upper slope
Physiography - Sideslope of narrow ridge spur
Elevation - 857 m
Slope 53%
Aspect - N E
Vegetation - Mixed mesophytic hardwoods

This is a deep residual soil, weathered in place, with an uninterrupted A-B-C-CR-R horizon sequence. Soils like this occupy at least 2/3 of the surrounding area. The only rocky areas are in washed out drains and at the tips of ridges. The soils surrounding this one have been disturbed and hummocked by windthrows every 50 to 100 feet. The pit is located about 100' above where the slope breaks from 20 to 30% to > 50%. There were a few rock fragments in the solum, but they occupy less than 5% of the total volume. Roots riddled the entire profile to > 1.5 m. Several fine and medium roots were found at a depth of 73 m. The R-CR contact was saturated with water.

Joyce Kilmer #3

Horizon	Depth (cm)	Description
A	0-12	Brown (10 YR 4/3) sandy loam; weak, medium crumbs breaking to weak medium and fine subangular blocks, very friable; common very fine, fine, medium, and coarse roots; common tubular and few vesicular pores; clear smooth boundary.
Bw	12-33	Yellowish brown (10 YR 5/8) sandy loam; weak medium subangular blocks; very friable; few fine and very fine, and common medium and coarse vertical and horizontal roots; many vesicular and common tubular pores; gradual smooth boundary.
Bt	33-84	Strong brown (7.5 YR 5/6) sandy loam; weak medium subangular blocks; few very fine and fine, and common medium and coarse vertical and horizontal roots; many vesicular and common tubular pores; gradual wavy boundary.
C	84-126	Yellowish brown (10 YR 5/6) sandy loam with common, coarse, distinct gray (10 YR 5/1) mottles; structureless, massive; friable; common medium vertical roots; many vesicular pore; abrupt wavy boundary.
R	126+	Very dark gray (10 YR 3/1), fine grained, metasandstone.

Notes: Location - Slope opposite Poplar Cove
Physiography - convex sideslope
Slope - 31%
Aspect - SE
Elevation - 738 m

This is a deep, well developed and leached soil with a rather thin A horizon. The A and B horizon contain angular coarse fragments indicating colluvial influence. The C horizon contains several pockets of highly weathered gray rock saprolite. Rooting is fairly even throughout the solum with some roots at > 100 cm.

Joyce Kilmer #4

Horizon	Depth (cm)	Description
A	0-14	Dark yellowish brown (10 YR 3/4) loam; weak fine crumbs and subangular blocks; very friable; many very fine and fine, and common medium and coarse vertical and horizontal roots; common tubular and vesicular pores; clear smooth boundary.
Bw	14-63	Yellowish brown (10 YR 5/6) loam; weak medium subangular blocks; very friable; common very fine, fine, medium and coarse vertical and horizontal roots; common vesicular and few tubular pores; abrupt smooth boundary.
R	63+	Dark gray (10 YR 4/1), fine grained meta-sandstone.

Notes: Location - Slope opposite poplar cove
Physiography - Convex sideslope
Slope - 55%
Aspect - S-SW
Elevation - 863 m

This is a steep colluvial soil with many angular coarse fragments in the A and B horizons. Thickly rooted throughout the profile.

Joyce Kilmer #5

Horizon	Depth (cm)	Description
A1	0- 6	Very dark brown (10 YR 2/2) clay loam; strong medium and coarse crumbs; very friable; many very fine and fine, and common medium and coarse vertical and horizontal roots; many tubular and common vesicular pores; clear wavy boundary.
A2	6-20	Very dark grayish brown (10 YR 3/2) loam; moderate medium crumbs and subangular blocks; friable to firm; many very fine and fine, and common medium and coarse vertical and horizontal roots; many tubular and common vesicular pores; clear wavy boundary.
A3	20-31	Dark brown (10 YR 3/3) loam; weak fine and medium subangular blocks; friable; common very fine, fine, medium and coarse vertical and horizontal roots; many tubular and common vesicular pores; clear wavy boundary.
BA	31-50	Dark yellowish brown (10 YR 4/4) loam; weak fine and medium subangular blocks; friable; few fine and common medium and coarse vertical and horizontal roots; common tubular and vesicular pores; gradual smooth boundary.
Bw	50-94	Yellowish brown (10 YR 5/6) loam; weak fine and medium subangular blocks; very friable; common fine and medium vertical roots; many vesicular and tubular pores; gradual wavy boundary.
CB	94-141	Mottled yellowish brown (10 YR 5/4) and dark gray (10 YR 4/1) sandy loam; structureless, massive; fragments are friable; common fine vertical roots; many vesicular and few tubular pores; gradual wavy boundary.
CR	141-170+	Gray (10 YR 5/1) loamy sand; structureless, massive; fragments are friable; no roots; many vesicular pores.

Notes: Physiography - Convex sideslope, upper watershed
Elevation - 1068 m
Slope - 59%
Aspect - E-NE

Deep well drained soil which is primarily residual with some colluvial influence in the upper horizons. A1, A2 and A3 horizons are delineated on differences in structure.

Joyce Kilmer #6

Horizon	Depth (cm)	Description
A1	0-12	Very dark brown (10 YR 2/2) loam; moderate coarse crumbs breaking to strong fine and medium crumb structure; friable; many coarse, and common very fine, fine and medium vertical and horizontal roots; common vesicular and tubular pores; clear smooth boundary.
A2	12-27	Very dark brown (10 YR 2/2) loam; moderate to strong fine and medium subangular blocks; friable; common very fine, fine, and medium roots, and many coarse vertical and horizontal roots; common tubular and vesicular pores; gradual smooth boundary.
AB	27-52	Dark brown (10 YR 3/3) loam; weak fine and medium subangular blocks; very friable; common very fine, fine, medium, and coarse vertical and horizontal roots; many vesicular and common tubular pores; gradual smooth boundary.
Bw1	52-93	Dark yellowish brown (10 YR 4/4) loam; weak medium and coarse subangular blocks; very friable; common fine and medium vertical and horizontal roots; many vesicular and common tubular pores; diffuse smooth boundary.
Bw2	93-118	Dark yellowish brown (10 YR 4/4) loam; weak fine and medium subangular blocks; very friable; few fine vertical roots; many vesicular and few tubular pores; clear wavy boundary.
CB	118-150	Yellowish brown (10 YR 5/4) sandy loam; structureless, massive; very friable; few fine vertical roots; many vesicular pores; clear wavy boundary.
C	150-170+	Light yellowish brown (2.5 Y 6/4) sandy loam; structureless, massive; very friable; few fine vertical roots; many vesicular pores.

Notes: Location - Upper sideslope high in the watershed
Elevation - 1220 m
Slope - 57%
Aspect - E-NE
Physiography - Convex sideslope

This is a deep soil which tongues down between two large boulders in colluvial material (We think). The soil immediately to the right is 65 cm deep. The overall area is 60-75% soils of this depth and nature. There are several large (>5 cm) areas of filled root voids in the B with OM darkened material. B horizons are delineated based on texture and structure.

Joyce Kilmer #7

Horizon	Depth (cm)	Description
A1	0- 9	Very dark grayish brown (10 YR 3/2) loam; moderate medium crumbs and weak medium subangular blocks; friable; many very fine, and common fine, medium and coarse vertical and horizontal roots; common tubular and few vesicular pores; clear smooth boundary.
A2	9-19	Dark yellowish brown (10 YR 4/4) loam; weak, fine and medium subangular blocks; very friable; common very fine, fine and medium vertical and horizontal roots; many vesicular pores; gradual wavy boundary.
BA	19-37	Dark yellowish brown (10 YR 4/6) loam; weak medium and fine subangular blocks; very friable; common fine, medium, and coarse vertical and horizontal roots; many vesicular pores; gradual smooth boundary.
BW	37-70	Yellowish brown (10 YR 5/6) loam; weak medium subangular blocks; very friable; common fine and medium vertical roots; many vesicular pores; gradual wavy boundary.
CB	70-100	Light yellowish brown (10 YR 6/4) sandy loam; structureless, massive; common fine vertical roots; many vesicualr pores; clear irregular boundary.
CR	100-140+	Gray (10 YR 5/1) loamy sand; structureless, massive; firm in place; few fine roots; many vesicular pores.

Notes: Physiography - Convex sideslope
Elevation - 1043
Slope - 60%
Aspect - S-SW

Deep residual soil with a minor colluvial influence. Rooting to CR horizon. There are Patches of A horizon material in the upper B horizon. There is a rock-outcrop about 110' along the slope, and this also appears to be an old chestnut stand.

Joyce Kilmer #8

Horizon	Depth (cm)	Description
A	0-10	Very dark grayish brown (10 YR 3/2) loam; moderate to strong, medium crumbs; friable; common very fine, fine, medium and coarse vertical and horizontal roots; common tubular and vesicular pores; clear wavy boundary.
BA	10-20	Dark yellowish brown (10 YR 4/4) loam; weak fine and medium subangular blocks; very friable; many very fine and fine, and common medium and coarse vertical and horizontal roots; common tubular and vesicular pores; clear smooth boundary.
Bw	20-31	Dark yellowish brown (10 YR 4/6) sandy loam weak fine and medium subangular blocks loam; very friable; common very fine, fine, medium and coarse vertical roots; many vesicular and common tubular pores; clear smooth boundary.
BC	31-57	Yellowish brown (10 YR 5/6) sandy loam; weak medium subangular blocks; very friable; common very fine, fine, medium, and coarse vertical roots; many vesicular and few tubular pores; clear wavy boundary.
CB	57-75	Brown (10 YR 5/3) sandy loam; structureless, massive; very friable; few fine and common medium vertical roots; many vesicular and few tubular pores; clear wavy boundary.
CR	75-125	Grayish brown (10 YR 5/2) sandy loam; structureless, massive; friable; few fine vertical roots; many vesicular pores; abrupt wavy boundary.
R	125+	Fine grained meta sandstone/siltstone.

Notes: Physiography - Convex sideslope in upper watershed
Slope - 54%
Aspect - S
Elevation - 1220 m

Residual soil with stong colluvial influence in surface. Heavy rooting to top of CR horizon. Common metasiltstone channers in upper 40 cm. Many filled root voids to C horizon. Old chestnut stand with eroded O horizon. Surface of O is obviously subjected to water run off and loss of litter.

APPENDIX II

SOIL TRANSECT STUDIES DATA

JK1 - Transect Summary Aspect - 36° Elev. - 2750'

Transect	OBS	A	B	C	R	Notes
#1-216°	1)	0-9	9-38	38+	---	
	2)	0-18	---	---	18+	Rocky Drain
	3)	0-15	15-45	45+	---	
	4)	0-3	---	---	3+	Over Rock
	5)	0-4	---	---	4+	Colluvium
#2-306°	1)	0-2	---	---	2+	Rocky Drain
	2)	0-4	4-32	32+	---	
	3)	0-4	4-45	45+	---	Stripped A?
	4)	0-8	8-38	38+	---	
	5)	0-2	---	---	2+	Rocky Drain
#3-36°	1)	0-3	---	---	3+	Colluvium
	2)	0-5	---	---	5+	Colluvium
	3)	0-8	8-22	22+	---	
	4)	0-4	---	---	4+	Colluvium
	5)	0-4	---	---	4+	Colluvium
#4-126°	1)	0-8	8-25	26+	---	
	2)	0-13	---	13+	---	Colluvium
	3)	0-4	---	---	4+	Colluvium
	4)	0-3	3-16	---	16+	
	5)	Rock	Outcrop	---	---	

JK2 - Transect Summary Aspect - 20° Elev - 2500'

Transect	OBS	A	B	C	R	Notes
#1-200°	1)	0-21	21+	---	---	Colluvial
	2)	0-7	7-30	30+	---	
	3)	0-5	---	---	5+	Colluvial
	4)	0-8	8-34	---	34+	Colluvial
	5)	0-8	---	---	8+	Colluvial
#2-290°	1)	0-8	8-26	---	26+	
	2)	0-10	---	---	10+	Colluvium
	3)	0-6	---	---	6+	Colluvium
	4)	Stream	---	---		Drain
	5)	0-5	---	---	5+	Drain Braided Colluvium
#3-20°	1)	0-11	11-31	---	31+	
	2)	0-10	10-33	33-44	44+	
	3)	0-10	10-44	44-58	58+	
	4)	0-9	9-31	---	31+	
	5)	Stream				Drain
#4-110°	1)	0-11	11-26	---	26+	
	2)	0-3	---	---	3+	Drain
	3)	0-10	10-40	40-48	48+	
	4)	0-15	15-53	---	53+	
	5)	0-6	---	---	6+	Colluvium

JK3 - Transect Summary Aspect - 150° Elev. - 2280

Transect	OBS	A	B	C	R	Notes
#1-334°	1)	0-4	4-31	31^{+}	---	
	2)	0-4	4-39	39^{+}	---	Colluvial
	3)	0-4	4-23	---	23^{+}	
	4)	0-5	5-37	---	37^{+}	
#2-64°	1)	0-4	4-29	29-37^{+}	---	
	2)	0-4	4-39	39^{+}	---	Colluvial
	3)	0-2	2-5	------	5^{+}	Colluvial
	4)	0-4	4-38	38^{+}	---	
#3-154°	1)	0-5	5-23	23-28	28^{+}	
	2)	0-4	4-19		19^{+}	
	3)	0-4	----	4-26	26^{+}	Drain
	4)	0-6	6-20	------	20^{+}	Drain
#4-244°	1)	0-5	5-33	33-66^{+}	---	
	2)		Braided Stream Deposits			Drain
	3)			"		Drain
	4)			"		Drain

JK4 Transect Summary Aspect - 160° Elev. - 2600

Transect	OBS	A	B	C	R	Notes
#1 - 340°	1)	0- 3	3- 7	-----	7+	Shallow to Rock
	2)	0- 4	4-12	12-20	20+	
	3)	0- 5	5-24	24-36+	--	
	4)	0-13	13-50	50-55	--	Colluvial
	5)	0- 8	-----	8-24	--	Colluvial
#2 - 70°	1)	0- 5	5-15	-----	15+	Deep & Red Over Metasis
	2)	0- 7	7-33	33-66+	--	
	3)	0- 5	5-14	-----	14+	
	4)	0- 6	6-40	-----	40+	Colluvial
	5)	0-16	16-48	-----	48+	Drain
#3 - 160°	1)	0- 5	5-18	-----	18+	
	2)	0- 8	8-58	58+	--	
	3)	0- 7	7-40	-----	40+	Colluvial
	4)	0- 1	1-29	29+	--	
	5)	0- 4	4-10	-----	10+	Rock Outcrop
#4 - 250°	1)	0- 9	9-28	28-40+	--	Colluvial
	2)	0- 5	----	5-10	10+	Colluvial
	3)	0- 4	4-32	32-60	--	
	4)	0- 3	----	3-11	11+	Colluvial
	5)	0- 3	----	3-10	10+	Rock Outcrop

JK5 - Transect Summary Aspect - 130° Elev. - 3800'

Transect	OBS	A	B	C	R	Notes
#1-130°	1)	0-15	15-27	27+	---	
	2)	Rock	Outcrop	---	---	Rock Outcrop
	3)	0-18	18-23	---	23+	Colluvial
	4)	Rocky	Drain	---	---	Drain
	5)	0-10	10-34	34+	---	Colluvial
#2-220°	1)	0-21	21-36	36+	---	
	2)	0-6	---	---	6+	Drain
	3)	0-19	---	---	19+	Drain
	4)	0-16	16-29	29+	---	
	5)	Rock	Outcrop	---	---	Rock Outcrop
#3-310°	1)	0-6,	---	6+	6+	Colluvial
	2)	Rock	Outcrop	---	---	Rock Outcrop
	3-5)	Impenetratable		---	---	
#40-40°	1)	0-18	18-32	---	32+	
	2)	0-4	4-40	40+	---	Colluvial
	3)	0-5	5-28	28+	---	
	4)	0-4	4-28	28+	---	
	5)	0-6	6-30	30+	---	

JK6 Transect Summary Elev. 3380' Aspect 50°

Transect	OBS	A	B	C	R	Notes
#1-50°	1)	0-12	12-39	---	39+	
	2)	0-10	10-36	36+	---	
	3)	Rock	Outcrop		---	Rock Outcrop
	4)	Braided	Stream		Deposit	Drain
	5)	Braided	Stream		Deposit	Drain
#2-140°	1)	Rocks	In	Drain	---	Drain
	2)	0-11	---	---	11+	Drain
	3)	0-12	12-32	---	32+	Drain
	4)	Rock	Outcrop	---	---	Rock Outcrop
	5)	Rock	Outcrop	---	---	Rock Outcrop
#3-230°	1)	0-16	16-48	48+	---	
	2)	0-10	10-28	28+	---	
	3)	Rock	Outcrop -	Cliff	---	Rock Outcrop
#4-320°	1)	0-10	10-36	36+	---	
	2)	0-8	8-15	---	15+	Colluvial
	3)	0-9	9-16	---	16+	Colluvial
	4)	0-8	8-22	22-26	26+	
	5)	0-10	10-20	---	20+	Drain

JK7 Transect Summary Aspect 210° Elev. 3350'

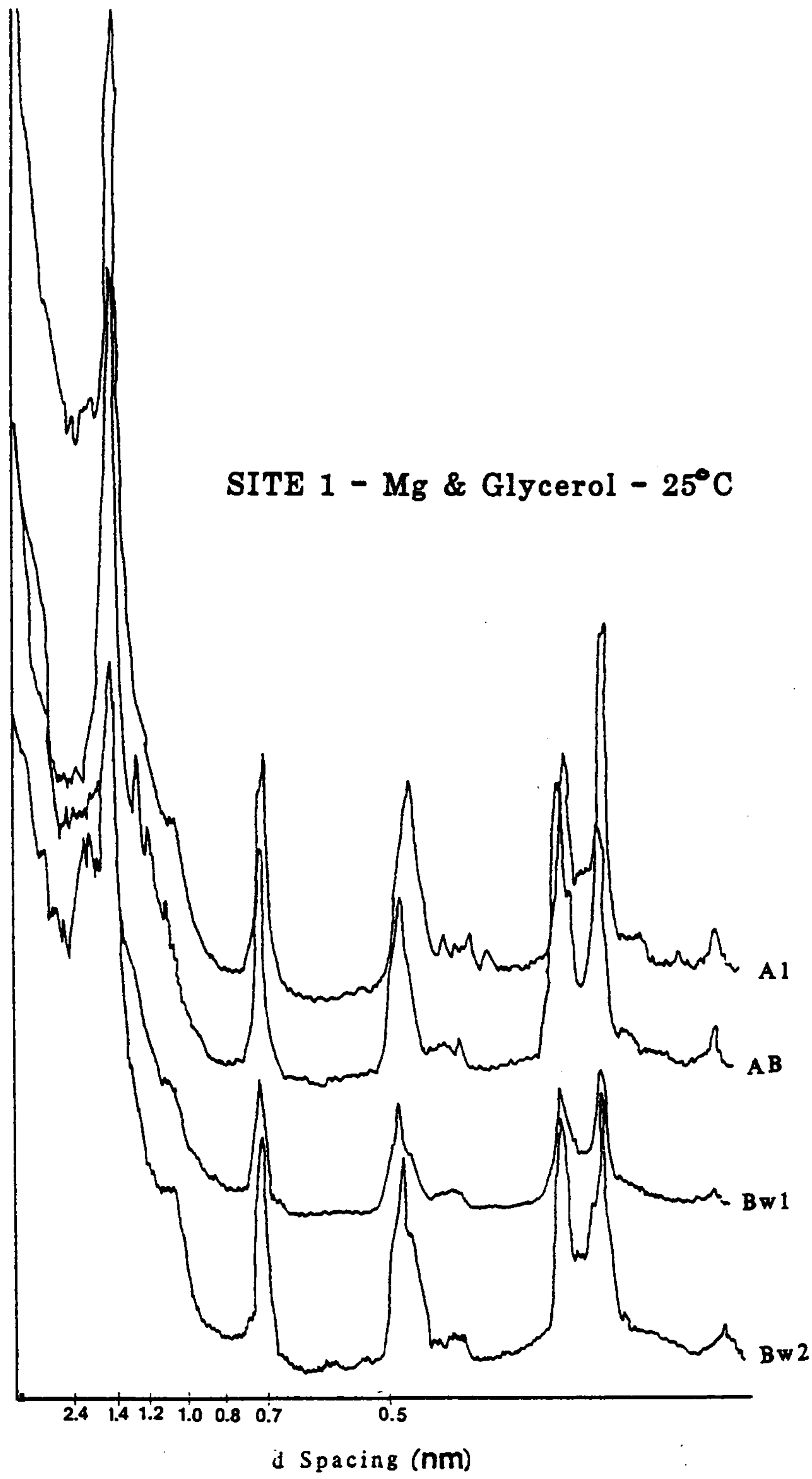
Transect	OBS	A	B	C	R	Notes
#1-30°	1)	0-8	8-27	27-66+	---	
	2)	0-5	5-26	26-48+	---	Colluvial
	3)	0-6	6-18	18-31	31+	
	4)	0-6	6-31	31-45+	---	
	5)	0-5	5-22	22-33	33+	
#2-120°	1)	Rocky	Area			Colluvial
	2)	0-10	10-30	30+	---	
	3)	Rock	Outcrop			Rock Outcrop
	4)	Rocky	Drain			Drain
#3-210°	1)	0-10	10-34	34+	---	
	2)	0-8	8-48	---	48+	Colluvial
	3)	Braided	Stream	Deposit		Drain
#4-300°	1)	0-9	9-32	32-60+	---	
	2)	0-12	12-25	25+	---	Colluvial
	3)	Rocky	Drain	---		Drain
	4)	0-8	8-30	---	30+	
	5)	0-10	10-36	36-60+	---	

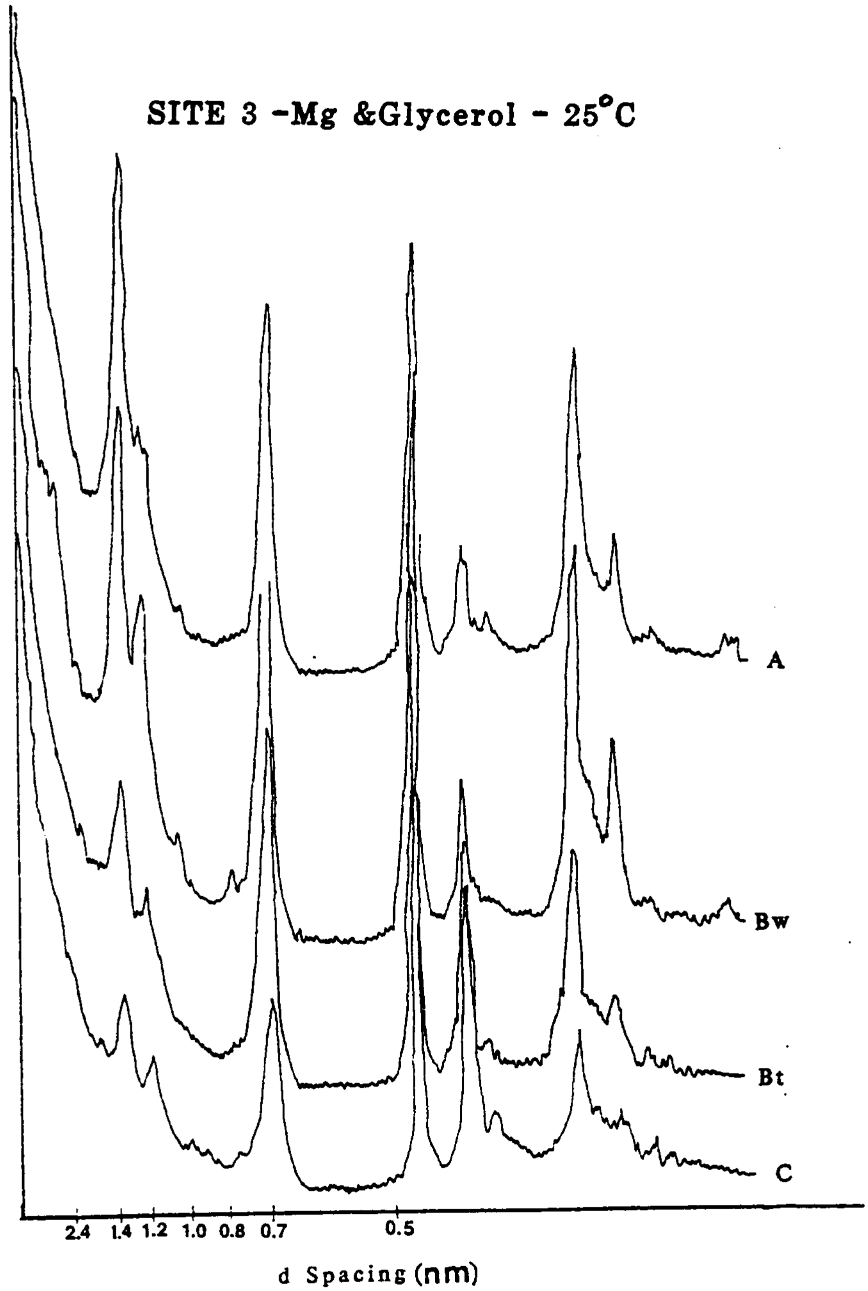
JK8 Transect Summary Aspect 210° Elev. 3700'

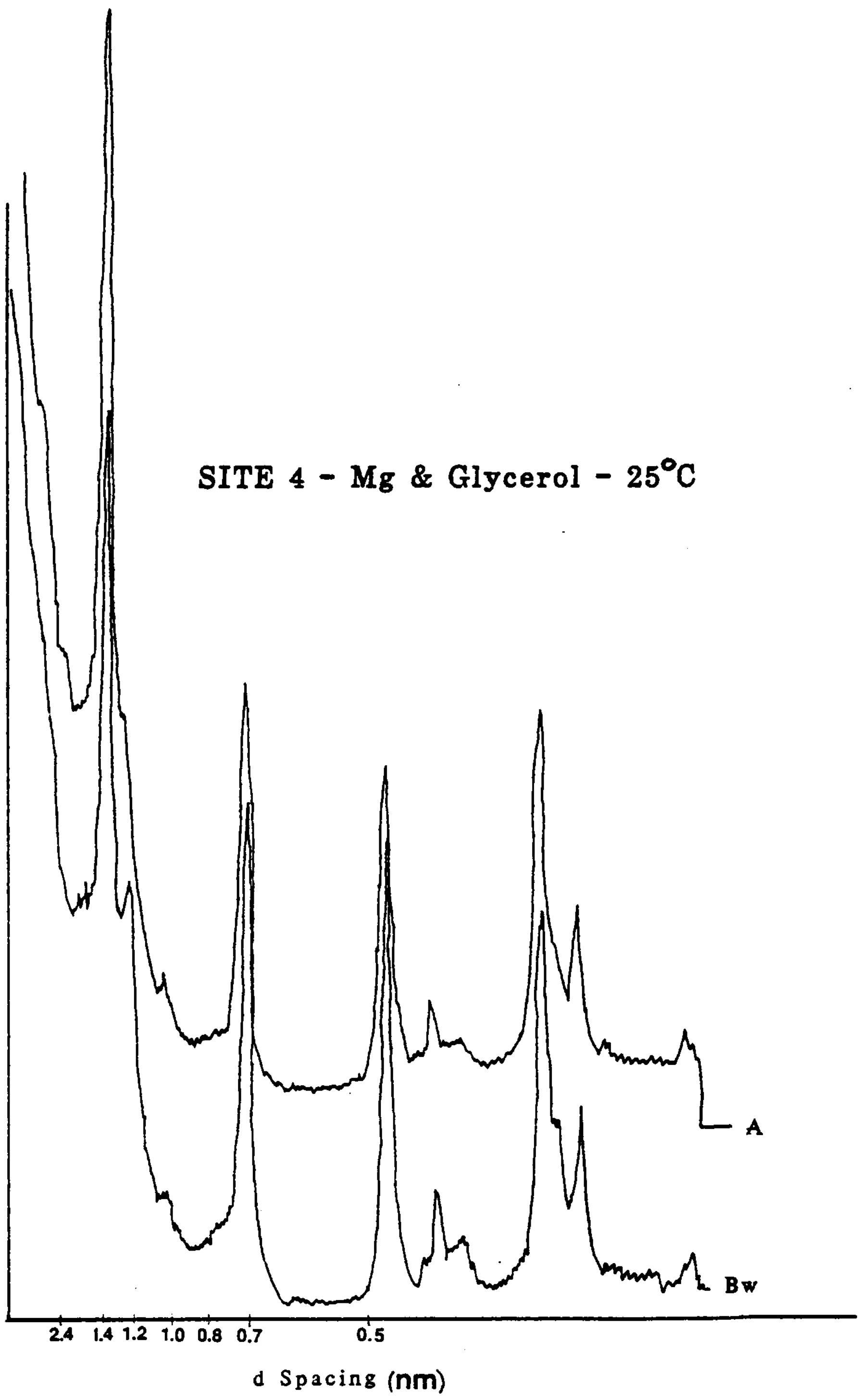
Transect	OBS	A	B	C	R	Notes
#1-210°	1)	0-8	8-32	32-45+	---	
	2)	0-9	9-25	25-30	30+	
	3)	0-7	7-13	---	13+	Colluvial
	4)	0-6	6-25	25-39	39+	
	5)	0-7	7-17	---	17+	Colluvial
#2-300°	1)	0-12	12-23	---	23+	
	2)	0-10	10-20	---	20+	Colluvial
	3)	0-6	6-30	30-38	38+	
	4)	0-5	---	---	5+	Colluvial
#3-30°	1)	0-8	8-14	---	14+	Colluvial
	2)	0-6	6-13	---	13+	Colluvial
	3)	0-8	8-16	16-27	27+	
	4)	0-10	10-18	18-22	22+	
	5)	0-8	8-15	---	15+	Colluvial
#4	1)	0-8	8-24	---	24+	
	2)	0-8	8-15	---	15+	Colluvial
	3)	Rock	Outcrop	---	---	
	4)	0-6	6-15	15-22	22+	
	5)	0-8	8-18	18-23	23+	Drain

APPENDIX III

X-RAY DIFFRACTOGRAMS


SITE 1 - Mg & Glycerol - 25°C
A1
AB
Bw1
Bw2
2.4
1.4
1.2
1.0
0.8
0.7
0.5
d Spacing (nm)


SITE 3 -Mg &Glycerol - 25°C
A
Bw
Bt
C
2.4
1.4
1.2
1.0
0.8
0.7
0.5
d Spacing (nm)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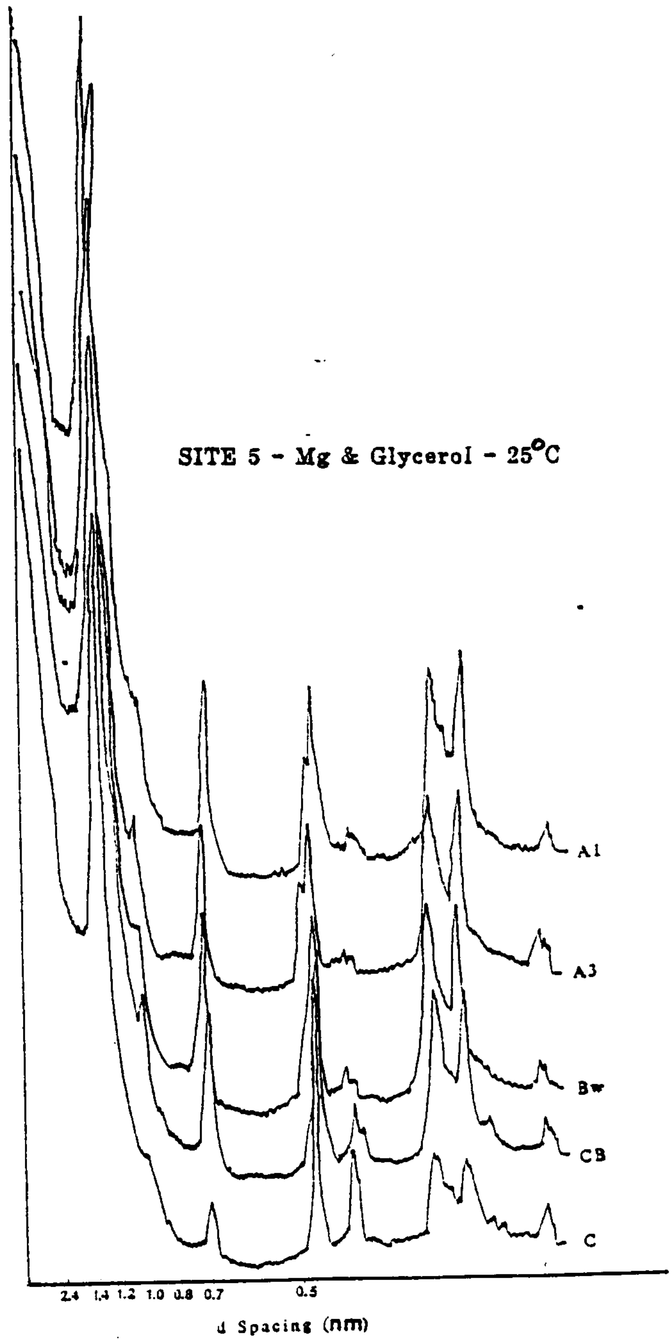
A
Bw
2.4 1.4 1.2 1.0 0.8 0.7 0.5
d Spacing (nm)


SITE 5 - Mg & Glycerol - 25°C
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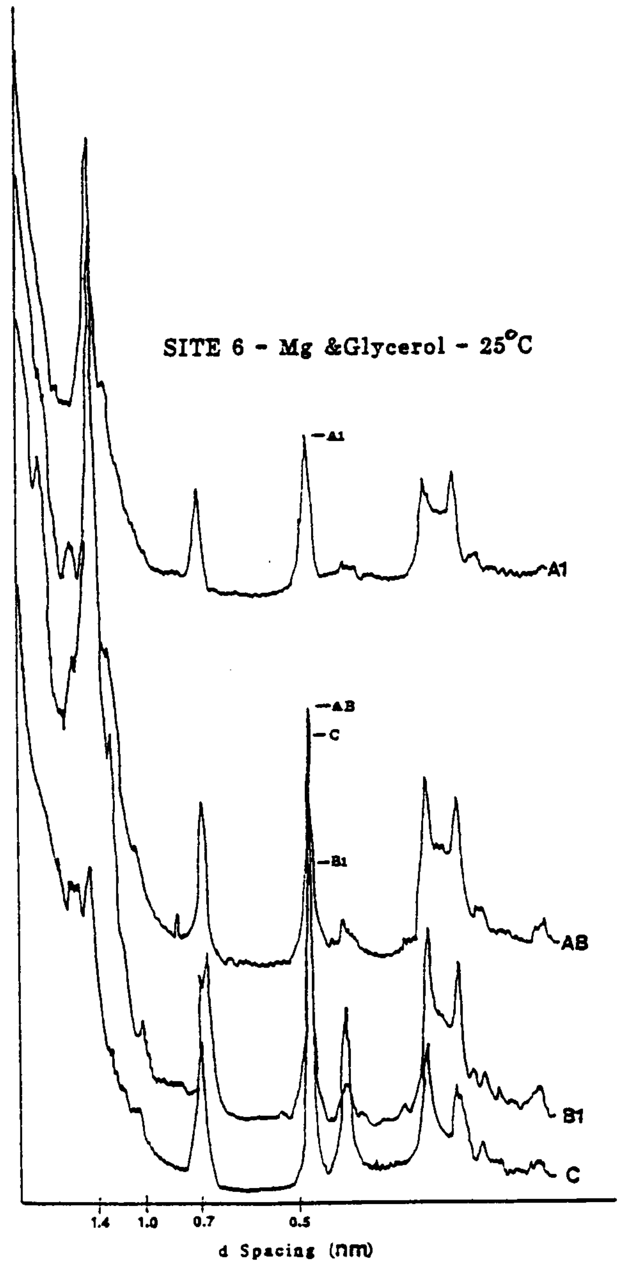
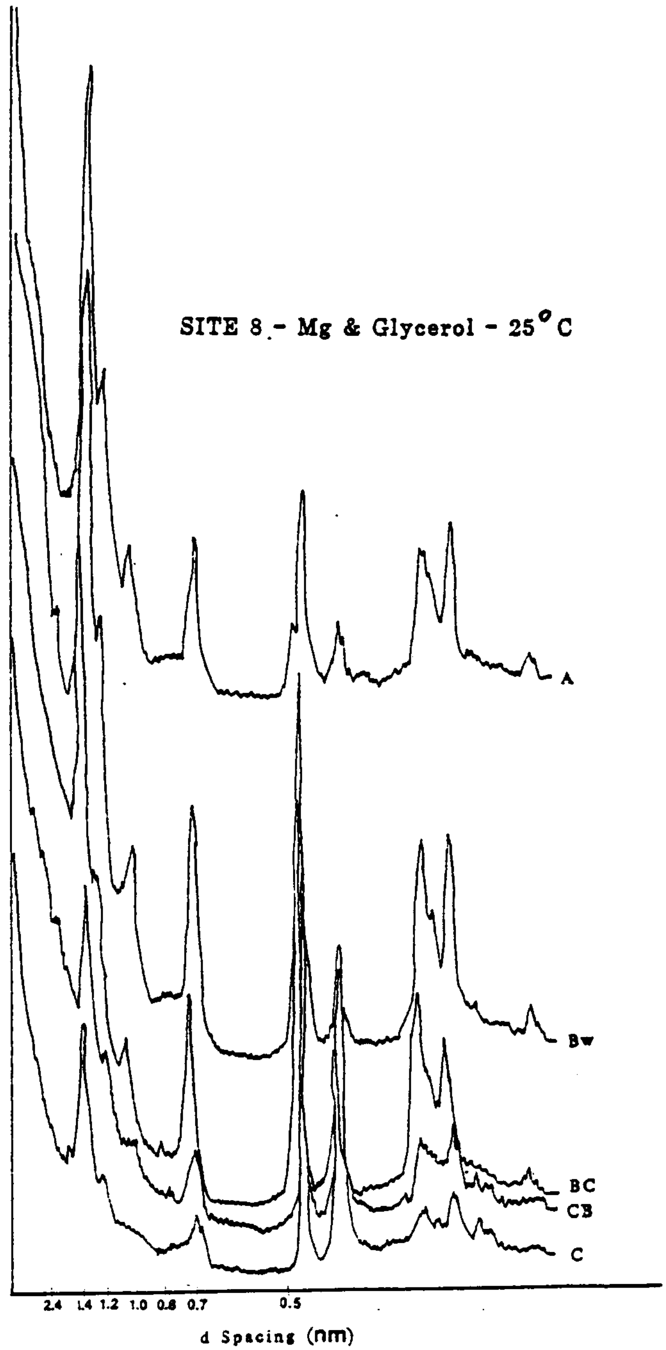
A3
Bw
CB
C
2.4 1.4 1.2 1.0 0.8 0.7
0.5
d Spacing (nm)


SITE 6 - Mg &Glycerol - 25°C
A1
AB
C
B1
A1
AB
B1
C
1.4
1.0
0.7
0.5
d Spacing (nm)


SITE 8 - Mg & Glycerol - 25°C
A
Bw
BC
CB
C
2.4
1.4
1.2
1.0
0.8
0.7
0.5
d Spacing (nm)

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