Virgin Hardwood Forest Soils of the Southern Appalachian Mountains: I. Soil Morphology and Geomorphology[1]

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ABSTRACT

Little is known about the characteristics of undisturbed soils in the eastern USA, since few exist. Eight sites with virgin forest soils formed under southern Appalachian hardwood vegetation were studied in the Joyce Kilmer Memorial Forest, an unlogged watershed in western North Carolina. Sites ranged in elevation from 720 to 1200 m with only two on <50% slopes. Generally, soils were quite deep and highly weathered because of high rainfall (>200 cm), weatherable feldspathic parent material, and no accelerated erosion. Average solum depth was 90 cm, while depth to metasandstone bedrock was typically >1.3 m. Deeply weathered saprolites were commonly encountered. Soils on northerly aspects had thick umbric epipedons and more organic matter than soils on south-facing slopes. Organic matter contents of A1 horizons ranged from 45 to 170 g/kg and surface horizons contained moderate coarse and medium crumb structure. Most soils had cambic horizons and clay contents that decreased with depth. Argillic horizons were present only at low elevations on south-facing slopes. While the majority of soils were formed in colluvium, significant amounts of deep soils in residuum occurred on sideslopes and appeared stable. The present-day landforms appear to be significantly influenced by periglacial activity. Windthrow appears to have mixed the surfaces of these soils. Due to their decreasing clay content with depth, oxidic mineralogy, and low CEC, these soils resemble tropical forest soils.

Additional Index Words: **Umbric epipedon, periglacial activity, Haplumbrepts, Dystrochrepts, slope, aspect.**

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THE MAJORITY OF SOILS in the eastern USA formed in equilibrium with forest vegetation, and almost all have been logged or cultivated. Virgin soils that remain are usually 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 eastern USA were disturbed before the recent advances in soil science, 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 have removed a vast majority of the original O and A horizons from the southeastern USA Piedmont (Trimble, 1974) 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, comparative studies to discern the influences of soil-forming factors or effects of land uses over time are difficult since there are no reference benchmark soils.

The Joyce Kilmer Memorial Forest in Graham County, 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, 1980) which remained unlogged only because of a fortuitous combination of ownership changes, and that around 1930 the TVA flooded the main railroad access into it. 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 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 (<600 m) 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 midslope positions were coarser textured and lower in base saturation than soils on lower slopes. Soils on south-facing slopes had thinner A horizons, lower organic matter contents, and higher B horizon 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 radiation, evapotranspiration and soil temperatures on the southern slopes, and associated differences in vegetation, weathering, and oxidation rates.

In a study conducted in Transylvania County, 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 (<1 m). No reference was made as to whether the soils were in residuum or colluvium, but the high rainfall of the area (250 cm) and temperate climate had combined to produce extremely deep soil weathering.

The soils in the Joyce Kilmer area were reconnaissance 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 Bourdeau (1955). 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 impressed 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

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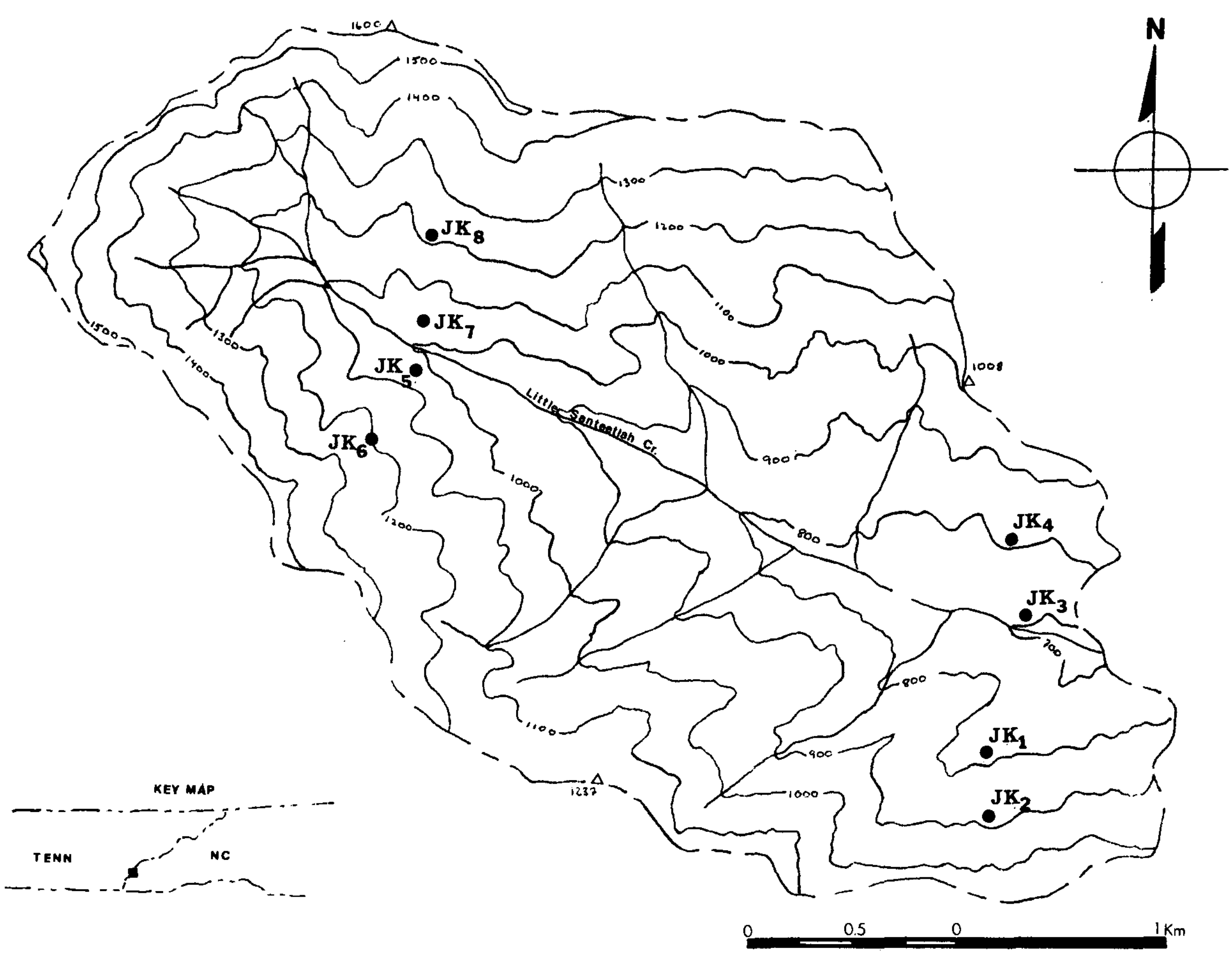

Fig. 1. Map of the Little Santeetlah Creek watershed and the location of sampling sites in the Joyce Kilmer Memorial Forest. Elevations in m.

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 are certainly specific to the parent material and region studied, we believe that they reveal many important aspects of original soils in the Appalachians.

MATERIALS AND METHODS

Study Area Description

The Joyce Kilmer Memorial Forest lies just southwest of the Great Smoky Mountains National Park in a steeply sloping watershed (Fig. 1) incised into rocks of the Precambrian Great Smoky Group (King et al., 1968). The bedrock is composed primarily of massive metasandstones, with lesser amounts of metasiltstones, graywackes, and phyllites. Metasandstones within the watershed are commonly feldspathic, and some contain appreciable amounts of carbonates. Many of the finer-textured metasiltstones and phyllites contain pyrite. 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 given by Daniels et al. (1987). Little Santeetlah Creek drains the watershed, and elevations range from 700 to >1600 m on the watershed divide. 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 trees in moister sites exceed 50 m in height and 1.3 m in diameter. Daniels (1985) presents considerably detail on the vegetation present at all study sites.

The watershed forms a symmetric oval with its main axis oriented NNW-SSE. Thus, 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° 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. Average monthly temperature and precipitation for the Tapoco station (15 km NW) are given below:

Month	J	F	M	A	M	J	J	A	S	O	N	D
Temp. (°C)	0	5	8	17	17	23	24	22	19	14	9	3
Precip. (cm)	13	14	15	12	11	12	16	13	8	7	12	13

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 opposite side. Each site was designated on a map before entering the watershed. Pit location was selected in what we considered to be a typical soil for that immediate area and the soils were described according to the *U.S. Soil Survey Handbook* (1981). Soils in rocky drainage ways and recent stream deposits were excluded, since they were minor components of the overall soil body. Large bulk samples were taken from each delineated horizon for laboratory analyses. Three bulk density cores were taken with a 5-cm diam sampler from the center of each major A, B, and C horizon. 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.

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 five sampling points each at 30-m intervals from pit center. At each point, three observations were taken with a 1.25-m soil probe, and a

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

Site	Elevation	Aspect	Slope	0–7.5 cm organic matter	Total litter weight
	m		%	g kg^{-1}	Mg ha^{-1}
			North-facing slopes		
1	732	N-NE	22	183.8	18.66
2	857	NE	53	144.1	17.37
5	1068	E-NE	59	154.8	16.86
6	1220	NE	57	148.3	25.19
			South-facing slopes		
3	738	SE	31	80.5	15.37
4	863	S-SW	55	77.7	22.98
7	1043	S-SW	60	106.6	16.13
8	1220	S	54	101.9	17.50

Table 2. Selected physical and chemical characteristics of mineral horizons. All soils were covered with thin litter layers.

Site	Horizon	Depth	Coarse frag.	Sand	Silt	Clay	Bulk density	Organic matter	pH	CEC	Base sat.	Effective CEC
		cm	%				Mg m^{-3}	g kg^{-1}		cmol$_c$ kg^{-1}	%	cmol$_c$ kg^{-1}
						North-facing slopes						
1	A1	0–13	1.4	24	43	33	0.76	161	5.77	42.8	33	14.2
	A2	13–30	1.0	24	44	32		107	5.34	36.7	8	4.7
	AB	30–43	0.7					38	5.21	24.5	2	2.4
	Bw1	43–64	1.5	29	40	31	1.24	10	5.21	16.5	4	4.5
	Bw2	64–128	0.9	31	36	33		7	5.30	15.6	4	4.9
	R	128+										
2	A1	0–15	6.0	40	41	19	0.98	86	5.21	31.9	14	5.4
	A2	15–42	4.7	44	42	14		26	5.02	16.9	1	1.9
	Bw	42–110	9.3	53	32	15	1.32	11	5.16	10.4	1	1.9
	C	110–145	12.7	69	25	6	1.48	2	5.45	2.9	3	0.3
	Cr	145–386	0.8	73	24	3		1	5.60	0.9	2	0.3
	R	386+										
5	A1	0–6	1.3	30	41	29		170	4.12	52.9	10	10.3
	A2	6–20	6.8	33	43	24	0.74	87	4.50	37.4	2	4.9
	A3	20–31	0.2	36	46	18		58	4.96	29.6	2	3.7
	BA	31–50	0.3	36	48	16		29	4.89	21.2	2	3.1
	Bw	50–94	0.6	42	43	15	1.05	13	5.14	14.4	2	2.7
	CB	94–141	0.9	56	34	10		7	5.38	10.4	2	1.8
	Cr	141–170+	0.1	72	27	1	1.75	3	5.51	3.6	3	0.9
6	A1	0–12	3.7	40	37	23		128	4.81	38.1	2	4.7
	A2	12–27	0.6	38	42	20	0.99	86	5.02	27.7	1	3.1
	AB	27–52	3.1	44	40	16		42	4.89	23.2	1	2.9
	Bw1	52–93	0.8	45	36	19		11	5.03	11.3	2	2.8
	Bw2	93–118	2.8	46	36	18	1.33	6	5.11	10.4	3	3.6
	CB	118–150	2.2	59	29	12		3	5.14	6.8	3	2.3
	C	150–170+	1.7	65	29	6	1.51	2	5.44	4.6	3	1.2
						South-facing slopes						
3	A	0–12	8.9	58	29	13	1.21	45	4.71	14.5	2	2.9
	Bw	12–33	9.7	54	32	14		7	5.24	14.6	2	1.4
	Bt	33–84	1.3	55	26	19	1.40	3	5.19	5.3	11	1.4
	C	84–126	0.2	63	26	11	1.54	1	5.33	4.3	7	1.0
	R	126+										
4	A	0–14	34.0	49	38	13	1.24	63	4.59	19.6	3	4.3
	Bw	14–63	10.7	49	40	11	1.65	6	5.06	7.0	5	1.6
	R	63+										
7	A1	0–9	2.4	46	38	16		92	4.97	27.4	2	4.1
	A2	9–19	3.8	49	36	15	0.96	39	4.71	18.3	1	2.5
	BA	19–37	2.4	48	37	15		14	4.80	10.7	2	2.5
	Bw	37–70	3.5	49	34	17	1.35	6	4.80	9.7	3	3.1
	CB	70–100	0.9	63	26	10		8	4.95	7.7	5	2.4
	Cr	100–140+	38.0	81	16	3	1.69	1	5.20	2.6	4	0.4
8	A	0–10	4.8	46	35	19	1.06	106	4.68	31.9	2	4.4
	BA	10–20	10.1	49	35	16		33	4.88	14.3	2	2.4
	Bw	20–31	6.2	53	33	14	1.28	13	5.31	10.4	3	2.1
	BC	31–57	3.7	57	29	14		6	5.29	8.6	3	2.1
	CB	57–75	0.3	60	28	12		3	5.38	8.0	2	1.6
	Cr	75–125	0.1	72	22	6	1.62	1	5.09	4.7	4	1.1
	R	125+										

composite description of average horizon depths was recorded. Additional data on parent material, geomorphic setting, and any aberrant 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 distributions and data reported reflect the proportion of actual sites sampled.

Bulk soil and litter samples were immediately air-dried upon return to the laboratory. The air-dry soil samples were sieved through a 2-mm sieve to remove coarse fragments. Coarse fragment contents are expressed by weight. 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 (<2 mm) organic C was determined by a Walkely-Black method (Peech et al., 1947). Whole soil organic matter levels (Mg/ha) were determined for each soil by summing values for each horizon after multiplying organic matter content × bulk density × horizon volume. Horizon volumes were corrected for coarse fragment content. Soil pH was determined in the supernatant portion of a 1:1 soil/water paste. Cation exchange capacity (CEC) 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.

RESULTS AND DISCUSSION

Soil Morphology and Classification

Considering the fact that all but two sampling sites occurred on slopes >50% (Table 1), these soils are surprisingly deep and free of coarse fragments (Table 2). Average solum depth was 90 cm and average depth of the A horizons was 25 cm. Depth to hard rock was frequently >1.3 m. Deeply weathered sandstone saprolites were common. The colors and overall solum depths were quite similar at all sites (Table 3). Seven soils contained cambic horizons with clay contents that decreased with depth. Soils on the north-facing slopes were Typic Haplumbrepts, while three of the four 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 acidic high organic matter soils, and the effective CEC was generally <5 cmol/kg. All profiles were placed in the oxidic mineralogy class. Greater detail on the chemical and mineralogical characteristics and classification of these soils is given by Daniels et al. (1987).

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 170 to 86 g/kg on the northerly

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, fine-loamy, oxidic, mesic
	A2	13–30	10YR3/3	cl	1f&msbk	mvfr	gs	
	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, coarse-loamy, oxidic, mexic
	A2	15–42	10YR3/3	l	1mcr/1fsbk	mvfr	gs	
	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+						
5	A2	6–20	10YR3/2	l	2mcr/2msbk	mfr	cw	Typic Haplumbrept, coarse-loamy, oxidic, mesic
	A3	20–31	10YR3/3	l	1f&msbk	mvfr	cw	
	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, coarse-loamy, oxidic, mesic
	AB	27–52	10YR3/3	l	1f&msbk	mvfr	gs	
	Bw1	52–93	10YR4/4	l	1msbk	mvfr	ds	
	C	150–170+	2.5YR6/4	sl	o-m	mfr		
					South-facing slopes			
3	A	0–12	10YR4/3	sl	1mcr/1msbk	mvfr	cs	Typic Hapludult, fine-loamy, oxidic, mesic
	Bt	33–84	7.5YR5/6	sl/scl	1msbk	mvfr	gw	
	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, coarse-loamy, oxidic, mesic
	Bw	14–63	10YR5/6	l	1msbk	mvfr	as	
	R	63+	Dark Gray Fine Grained Metasandstone Bedrock					
7	A1	0–9	10YR3/2	l	2mcr/1msbk	mfr	cs	Umbric Dystrochrept, coarse-loamy, oxidic, mesic
	A2	9–19	10YR4/4	l	1m&fsbk	mvfr	gw	
	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, coarse-loamy, oxidic, mesic
	BA	10–20	10YR4/4	l	1f&msbk	mvfr	cs	
	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					

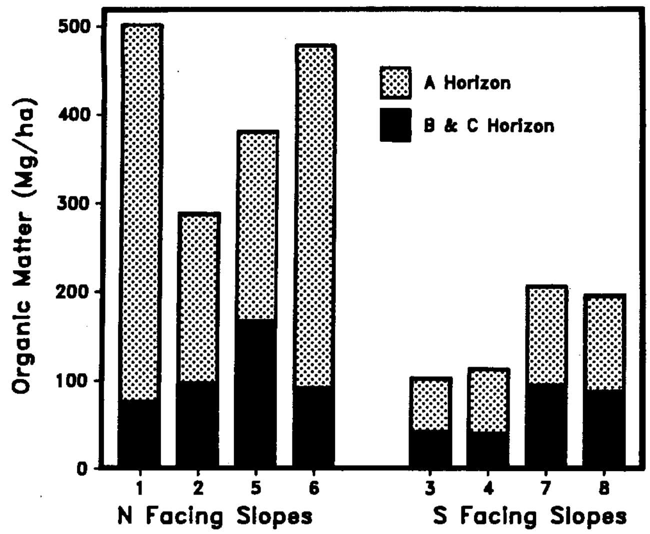

Fig. 2. Whole soil organic matter contents. Organic matter is incorporated deeply into these soils, particularly on north-facing slopes.

Fig. 3. Coarse crumb structure in the A horizon of a soil near site 1. This structure type dominated higher organic matter mineral horizons.

aspects and from 106 to 45 g/kg on opposing south-facing slopes. Total A horizon depth ranged from 52 cm in the highest north-facing soil 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. 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 reported by Losche et al. (1970).

The surface horizons, particularly those on north aspects, contained striking moderate to strong, medium, and coarse crumb structure (Table 3 and Fig. 3). 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 channels 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 contained 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 (>1.3 m) 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. 4). However, several soils did contain sub-rounded coarse fragments in their upper horizons. Soils 1, 4, and 6 were weathered entirely from 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. 4).

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. A few 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. Slope creep was only evident in extremely steep (>75%) shallow soils where phyllite strata dipped parallel to the surface. The majority of the watershed is underlain by massive metasandstones, however, and their dip does not appear to control slope stability. Due to the maturity of the forest cover, dead standing trees and windthrows were numerous, and windthrow mounds were common at all sites, generating an undulating microtopography. Windthrow mounds were much more extensive on north-facing slopes, particularly at higher elevations.

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

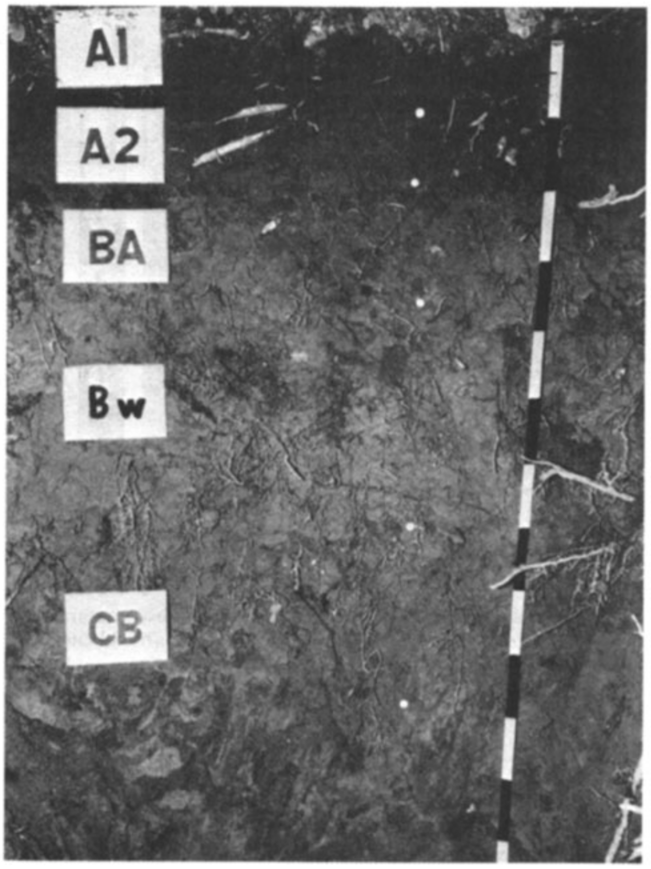

Fig. 4. Profile of soil 7. The C and Cr horizons below 70 cm are highly weathered metasandstone saprolite, while the solum above 70 cm is weathered in colluvium. Measuring tape is divided into 10-cm increments.

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 intermittent drainage ways that feed into it. The other two dominantly colluvial soils (4 and 6), which 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 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 rapid weathering, have led to deeply weathered profiles. We believe that these soils were deeply weathered initially by hydrolysis/dissolution of feldspars and carbonates, and that the fine silts and clays are generated by accelerated physical and chemical weathering processes in surface horizons. Soils on north-facing slopes were 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 (10–15 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 (Barshad, 1964).

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 (Franzmeier 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 soils in colluvium 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. Bulk densities generally remain below 1.4 Mg/m^3 through the porous B horizons, before increasing in the C or Cr horizon saprolites.

Soil Transect Studies

The eight 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 (16–20 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. The frequency distributions of solum depths for each sampling site are presented in Fig. 5. Based on the summed observations from all sites, 7% of the land surface was bare rock outcrop, 18% was covered by extremely shallow soils in stony drains or braided stream deposits, 36% was covered by soils in colluvium with varying depths, and 39% of the soils appeared to be primarily residual with some surface mixing.

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 also occur in the soil landscape. Numerous yellowish-red Typic Hapludults were also observed during the transect studies around sites 3 and 4, primarily over Fe-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. 5) revealed that except for the fact that we excluded extremely shallow soils in stony drains and over rock outcrops, the eight soils chosen for intensive study do represent the dominant soils in the land-

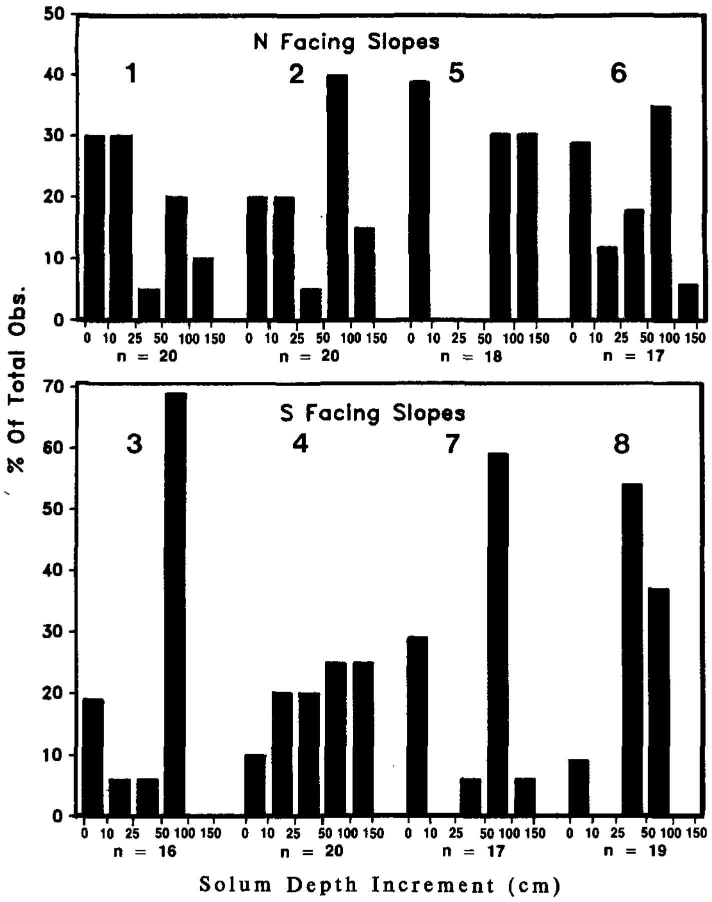

Fig. 5. Histogram of solum depths encountered in transect studies at each site. Shallow soils (<50 cm) were dominantly formed in colluvium while the deeper soils (>50 cm) were formed in a mixture of residuum and colluvium.

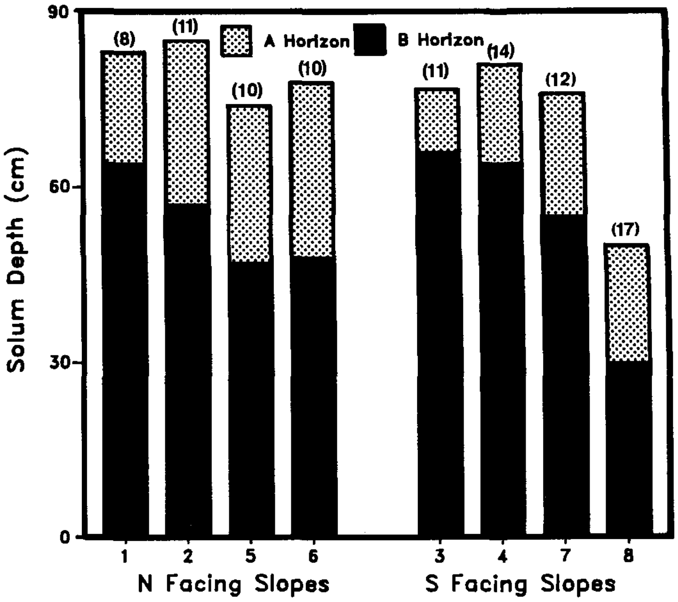

Fig. 6. Average solum depths of deeper soils (those containing A and B horizons) encountered in transect studies around each site. Note the close correspondence with overall horizon depths described in the pit studies. Number of observations each are in parentheses.

scape. The average solum depth and A horizon thickness of deep soils (sola >50 cm) observed on transects at each site (Fig. 6) mirrors the overall trends observed in the pit studies.

Soil Genesis and Geomorphology

Geomorphological research in the central and southern Appalachians (Clark, 1968) and southern Pennsylvania (Denny, 1951) indicates that mass wasting of these landscapes, particularly at higher elevations, may have occurred by periglacial mechanisms 10 to 40 000 yr ago. The landscape and surfaces within this watershed exhibit many of the same features described by these authors, and do not appear to be the result of gradual colluvial processes. The region south of the ice-sheet, while not glaciated, was under a much colder climate than present, and the vegetation 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 lower in the landscape, 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 appears to have caused the thin mantle of colluvium over much of the lower sideslopes, the thick colluvial deposits at sites 1 and 6, and the extremely coarse boulder trains in the bottoms of most drainageways. 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 preweathered before stripping and deposition) surrounded by large (>1 m) rounded boulders and cobbles derived from resistant quartzitic metasandstones higher in the landscape.

Neary et al. (1986) recently reported storm-induced debris avalanching in western North Carolina. While it is possible that similar episodic events may have generated some of the deposits we encountered in concave landscape positions, the extensive blankets of colluvium that occur on convex sideslopes could not have been generated by this mechanism. These soils are extensively reinforced with tree roots and show no evidence of recent movement in themselves or the massive trees around them, which are commonly 300- to 400-yr old (Lorimer, 1980). The shallow colluvial soil at site 4 contains high amounts of angular coarse fragments and reflects either short range colluvial movement, or perhaps a series of windthrows.

The presence of very deep residuum on extremely steep slopes (<50%) is surprising. Five of the eight soils examined from pits contained deeply weathered saprolites in their C and Cr horizons, and the transect studies indicated that slightly more than one third of the entire landscape is underlain by deep residuum. Most of these soils did contain some evidence of local colluvial activity or mixing in their upper horizons. 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 windthrow of large trees. 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 in primarily residual materials vs. those that are obviously in colluvial ones. The only exception is the soil in colluvium at site 1 which is considerably finer in texture as discussed earlier. The colluvial soil materials differ somewhat mineralogically, in that they contain smectites in their B horizons (Daniels et al., 1987). 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 deep 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 upper landscape is correct, soils in residuum at higher elevations have either weathered completely from hard rock, or more likely from partially weathered saprolite exposed at the surface after stripping. The presence of rounded coarse fragments in surfaces of many soils in residuum at lower elevations is 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. 4). Apparently, extreme weathering conditions, a weatherable and massive parent material, and constant vegetative cover have combined to produce deeply weathered soils in residuum 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 by the fact that these porous soils pass water rapidly, preventing saturation and loss of slope stability. The importance of vegetation in reinforcing the slopes against wasting is demonstrated by the numerous reports of slope failure and flash flooding in the southern Appalachians after logging around 1900 (Hursh, 1941). Aguilar and Arnold (1985) recently reported very similar findings regarding slope stability and the importance of periglacial solifluction as a source of colluvium in a virgin timber stand in northern Pennsylvania. While this study occurred a good deal further south, we believe that the same mechanisms have been an important influence on this landscape.

CONCLUSIONS

The outstanding characteristics of these undisturbed soils were their overall depth, thick dark surface horizons, distinctive coarse crumb structure, and uniformity in thickness, texture, and color. Significant amounts of deep stone-free soils in residuum commonly occurred on extremely steep slopes, with little evidence of recent movement other than local surface mixing due to windthrows. Deep saprolites were common beneath these soils. The majority of soils in the watershed, however, were formed in colluvial debris on sideslopes and along footslopes, and in the broad boulder trains and valley fills apparently left by periglacial activity. 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 occurred along the backbones of secondary spur ridges, and occasionally as cliff lines in the upper reaches of the watershed. The extremely high rainfall and moderate year round temperatures in this area have led to accelerated soil weathering and extremely deep weathering profiles. Due to their decreasing clay content with depth, oxidic mineralogy, low CEC levels, and very low base saturations, these soils somewhat 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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