

# Virgin Hardwood Forest Soils of the Southern Appalachian Mountains: II. Weathering, Mineralogy, and Chemical Properties<sup>1</sup>

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## ABSTRACT

Eight undisturbed soils derived from feldspathic meta-sediments in the Joyce Kilmer Memorial Forest were studied. Gibbsite was common throughout all soils, and increased in abundance in the clay fraction with depth. The clay content in most soils decreased with depth, with intergrade 2:1 type minerals occurring as the dominant phyllosilicates 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 type to the clays. The coarse sand fractions were almost entirely quartz, while the fine sands contained quartz, weathered 2:1 minerals, and feldspars. The CEC of the mineral surfaces in these soils was extremely low. Soil CEC was almost entirely derived from organic matter, and was typically < 3 cmol/kg in subsurface horizons. Levels of exchangeable Ca and Mg, acid extractable P, and total-N were very low below surface horizons. These soils have weathered in a wet (>200 cm precipitation) temperate environment and resemble some tropical soils. Erosion could severely damage the natural productivity of these soils. The addition of oxidic mineralogy classes to certain Inceptisol families is recommended.

**Additional Index Words:** Hapludults, Dystrachrepts, Haplumbrepts, meta-sediments, colluvium, residuum.

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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. Even the majority of eastern forest soils studied in recent years supported agricultural production at one time or another. 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). The Joyce Kilmer Memorial Forest in western North Carolina, examined in this study, provides an excellent opportunity to study virgin hardwood forest soils under their original vegetative cover.

Two other 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 aspect on soils weathered from granitic biotite gneiss in southwestern North Carolina, not far from our research area, and found that kaolinite and hydroxy-interlayered 2:1-type minerals were dominant in soils on north-facing slopes while gibbsite was dominant on the warmer 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; Carlisle and Zelazny, 1974; Karathanasis et al., 1983.) 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 Sawney (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 (O'Brien 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 parent material/soil weathering sequences and to relate the chemical and mineralogical properties of undisturbed soils within the Joyce Kilmer Memorial Forest to variations in aspect, parent materials, and vegetation. 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.

## METHODS AND MATERIALS

### Geology and Site Description

Eight soils were sampled from intensive study plots within the Joyce Kilmer Memorial Forest in Graham County, North Carolina. Considerable detail on the watershed, landforms, study site locations, and overall soil distributions is given by Daniels et al. (1987). The classification of each soil is given in Table 1.

The underlying bedrock within the watershed consists primarily of massive metasediments, metasilts, graywackes, and phyllites of the Great Smoky Group (King et al., 1968). Schists are occasionally encountered. The geology of the watershed has not been mapped in detail. Regional

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**Table 1. Classification of soils used in study. Elevation increases with site number on each aspect.**

Site	Classification
<u>North-facing slopes</u>	
1	Typic Haplumbrept, fine-loamy, oxidic, mesic
2	Typic Haplumbrept, coarse-loamy, oxidic, mesic
5	Typic Haplumbrept, coarse-loamy, oxidic, mesic
6	Typic Haplumbrept, coarse-loamy, oxidic, mesic
<u>South-facing slopes</u>	
3	Typic Hapludult, fine-loamy, oxidic, mesic
4	Umbric Dystrachrept, coarse-loamy, oxidic, mesic
7	Umbric Dystrachrept, coarse-loamy, oxidic, mesic
8	Umbric Dystrachrept, coarse-loamy, oxidic, mesic

maps and rock descriptions by Kish et al. (1975) indicate that the parent material belongs to an unnamed member of the Great Smoky Group mapped as the Thunderhead sandstone further north. Fisher et al. (1970) include these strata with the Snowbird group, which extends from the Smokies 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 2. Soils in the watershed are formed in both residuum and colluvium.

The climate of the region is extremely humid and temperate. Yearly rainfall within the watershed probably exceeds 200 cm (Daniels et al., 1987). 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) studied the climate in a similar high elevation watershed nearby and reported that the annual precipitation was 250 cm, and that soil temperature on the south slope was 3.5°C warmer than the north slope in April, 1.0°C in July, and 1.6°C in September, respectively. 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).

### Analytical Methods

Detail on the sampling methodology and morphological and physical properties of all soils are detailed by Daniels et al. (1987). Soil organic matter was estimated by a modified (Peech et al., 1947) Walkley-Black technique (with a carbon/organic matter 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 1 M NH<sub>4</sub>OAc (pH 7), and exchangeable Al into 1 M KCl. Bases were analyzed by atomic absorption spectroscopy, and Al by titration. The cation exchange capacity (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<sub>2</sub>-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 spectroscopy. Poorly crystalline materials were estimated by dark extraction in acid ammonium oxalate (Hodges and Zelazny, 1980). Total soil N was estimated by a standard micro-Kjeldahl technique, and soil P was extracted in dilute double acid and analyzed by the Murphy and Riley (1962) technique.

Regression analysis of CEC against organic matter in A horizon samples was performed with Theil-Sen regression (Hollander and Wolfe, 1973), a nonparametric rank regression technique. This method was employed because the data

**Table 2. Petrographic analysis of major rock types in watershed.**

Mineral	Percent	Descriptions
<u>Feldspathic Metasandstone</u>		
Quartz	48	Dominantly polycrystalline and intergranular.
Orthoclase	34	Large grains, some altered to clays.
Plagioclase	4	Fragmented and subangular.
Hematite	6	Anhedra, vein aggregate, infiltrates Feldspars.
Muscovite	4	Primary phase, lacks foliation.
Mixed	4	Hydrothermal ppts, or alteration products.
<u>Phyllosilicates</u>		
<u>Calcite cemented Metasandstone</u>		
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.
<u>Metasiltstone</u>		
Quartz	34	Primarily subangular, detrital, and monocrystalline.
Plagioclase	16	Subangular and detrital.
Orthoclase	2	Subangular and detrital.
Muscovite	10	Weakly foliated.
Mixed	23	Alteration products of muscovite and feldspars.
<u>Phyllosilicates</u>		
Hematite	15	Anhedra, in veins and filling voids.

contained one moderate outlier, and residuals were not normally distributed.

Sand mineralogy was determined by petrographic analysis on 2.0 to 0.42 mm and 0.42 to 0.05 mm (<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 after heating at 25, 110, 300, and 550°C. Magnesium plus glycerol samples were analyzed after heating at 25 and 110°C. All x-ray analyses were performed with a Diano scanning diffractometer linked to a LSI-11 computer with Cu K- $\alpha$  radiation and a graphite monochromator. The percent 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, employing standard Reynolds synthetic gibbsite and poorly crystalline Georgia kaolinite minerals as standards.

The data reported for A horizons in Fig. 1, and Tables 3 and 4, are from the top 7.5 cm of mineral soil for all profiles, to allow for uniform comparison of surface mineralogy. These samples were higher in clay in some cases than the complete surface horizons, which were considerably thicker. (Daniels et al., 1987).

### RESULTS AND DISCUSSION

These soils are enigmatic in that they simultaneously possess characteristics of both highly weathered and young soils. Seven out of the eight soils studied classify as Inceptisols (Daniels et al., 1987), yet they are all in the oxidic mineralogy class. An easily weatherable feldspathic/calcitic parent material coupled with very high rainfall led to very deep weathering and leaching of these soils, but 2:1-type minerals were still common in their surfaces. Chlorite-type minerals were virtually absent. Gibbsite, micas, and feldspars commonly occurred together in these soils, with minimal accumulations of kaolinite, an unusual combination

for the southeastern USA. 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 understandable.

### 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. 1. Noncrystalline materials are not accounted for in these estimates. The surface horizons were dominated by hydroxy-interlayered 2:1 minerals and vermiculite, and in some instances, regularly interstratified mica-vermiculite (RMV). The proportions of vermiculite and interlayered 2:1 minerals decreased with depth as mica increased (Fig. 2),

particularly in the soils predominantly in residuum (2, 3, 5, and 8). The deep (145–386 cm) Cr horizon of soil 2 was the only horizon studied with a distinct 1.0 nm 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 and chemical weathering of silts to clays high in the profile. The RMV 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 soils in colluvium (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. 3). Smectite and interstratified smectite/vermiculite commonly occur in the subsoils, but are not regular constituents of the soils in residuum.

Gibbsite commonly occurs in the surfaces of all 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 >3 m. The gibbsite contents in the clay of 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-

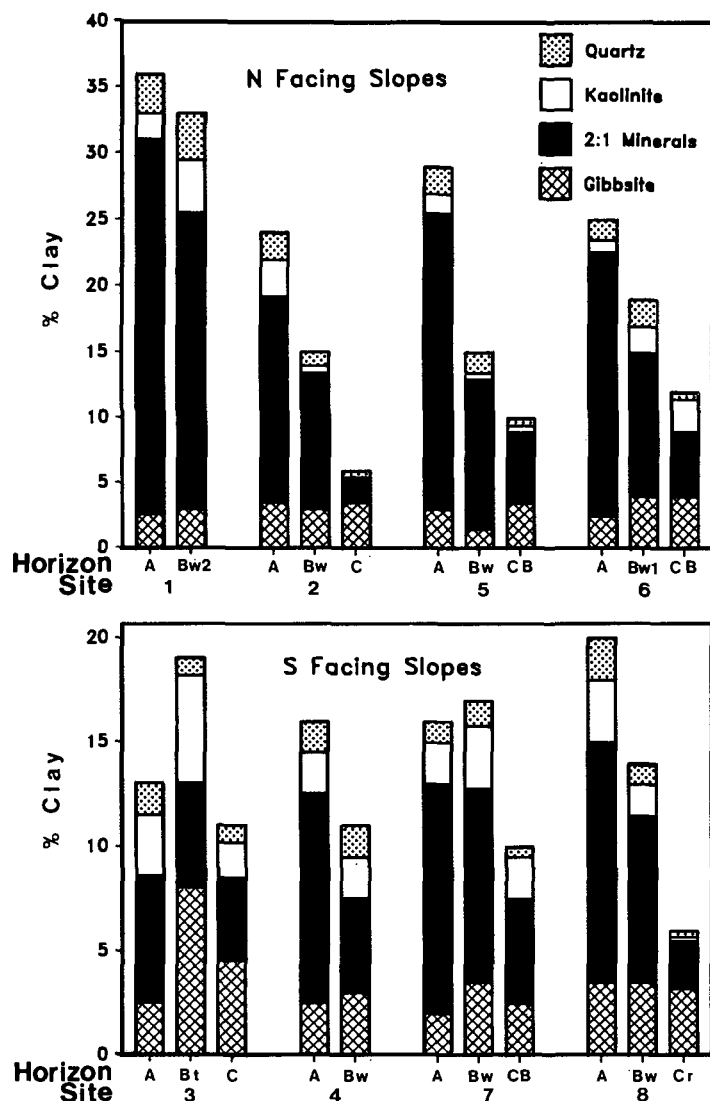


Fig. 1. Mineralogy of clay fractions of major A, B, and C horizons expressed as a percent of the air-dry sample weight on a whole-soil basis. The sum of the minerals shown for each horizon is the percent clay. Soils 1 and 4 had no C horizons. A horizon samples were from the upper 7.5 cm of the mineral portion of each soil and their total clay content may not match the clay content given for the corresponding A horizon of Table 2 of Daniels et al. (1987).

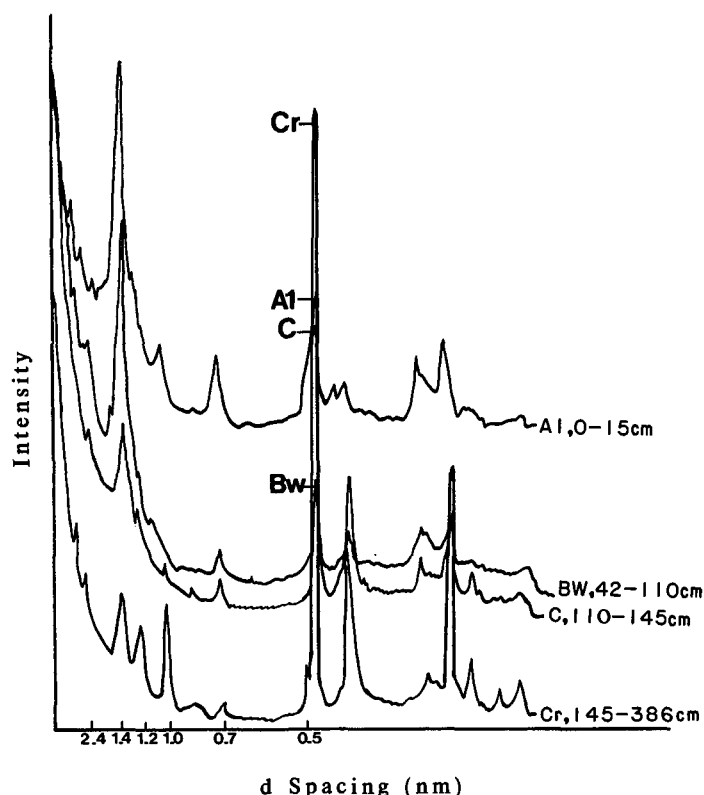


Fig. 2. X-ray diffractograms of soil 2 clay fractions. Samples were saturated with Mg and glycerol and run at 25°C. This soil is weathered deeply into metasandstone residuum.

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 increasing depth.

Total clay contents were 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 dispersible 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 on a whole soil basis throughout these profiles does not change significantly with depth (Fig. 1). In most profiles, the gibbsite is greatly 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 hydroxy-interlayered 2:1 minerals are 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 for more kaolinite formation.

**Silt and Sand Mineralogy**

The silt fractions of these soils are dominated by quartz, mica, vermiculite, and interstratified/intergrade minerals (Table 3). The ratio of quartz/2:1 type minerals is highest in the surface horizons, and de-

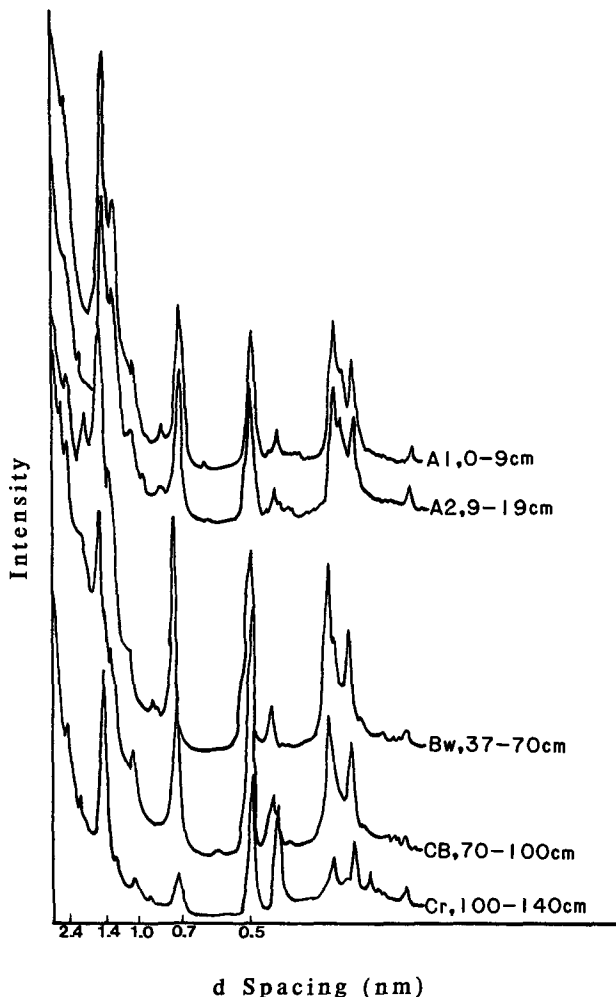


Fig. 3. X-ray diffractograms of soil 7 clay fractions. Horizons above 70 cm are in colluvium and below 70 cm in residuum. Samples were saturated with Mg and glycerol and run at 25°C.

Table 3. 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†
<u>North-facing slopes</u>		
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
<u>South-facing slopes</u>		
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
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 + Intergrade 2:1 Minerals; M = Mica; K = Kaolinite; F = Feldspars; G = Gibbsite; and RMV = Regularly Interstratified Mica/Vermiculite.

Table 4. 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 percent of point counts (150 counts for the 2-0.42 nm 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.	K feldspar	Plag.	Musc.	Other 2:1's	Opauques	Heavy min.	Rock frag.	Qtz.	K feldspar	Plag.	Musc.	Other 2:1's	Opauques	Heavy min.	Rock frag.
<u>North-facing slopes</u>																	
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	1	8	
2	A	65	5	6	4	1	2	2	15	77	0	0	0	1	4	18	
	Bw	79	5	2	TR	8	4	0	2	91	0	0	0	3	0	6	
	C	74	8	2	TR	9	4	0	3	98	0	0	0	2	0	0	
5	A	71	22	2	0	3	0	2	0	81	13	0	0	6	0	0	
	Bw	79	12	1	0	6	1	1	0	95	3	0	0	1	0	0	
	CB	50	7	1	2	25	1	13	1	99	1	0	0	0	0	0	
6	A	67	14	1	0	12	1	5	0	85	9	0	0	5	0	0	
	Bw1	57	20	3	0	19	0	1	0	100	0	0	0	0	0	0	
	CB	66	17	0	0	14	0	3	0	97	2	0	0	1	0	0	
<u>South-facing slopes</u>																	
3	A	70	5	6	13	2	2	0	2	82	2	1	0	0	0	15	
	Bt	63	8	7	2	19	0	0	1	90	0	0	0	0	0	9	
	C	69	7	2	4	16	0	0	2	95	0	0	0	0	0	5	
4	A	86	3	3	0	7	0	1	0	93	1	1	0	4	0	0	
	Bw	75	0	1	1	18	1	4	0	99	0	0	0	1	0	0	
7	A	64	10	2	0	21	1	2	0	96	2	0	0	1	0	0	
	Bw	55	12	3	0	29	0	1	0	96	2	0	0	1	0	0	
	CB	57	13	2	1	21	0	7	0	94	1	0	0	3	1	0	
8	A	55	10	2	0	30	1	2	0	88	1	0	0	8	0	2	
	Bw	71	6	1	0	15	3	0	6	95	1	0	0	2	0	0	
	Cr	31	3	2	1	61	0	0	2	99	0	0	0	0	1	0	

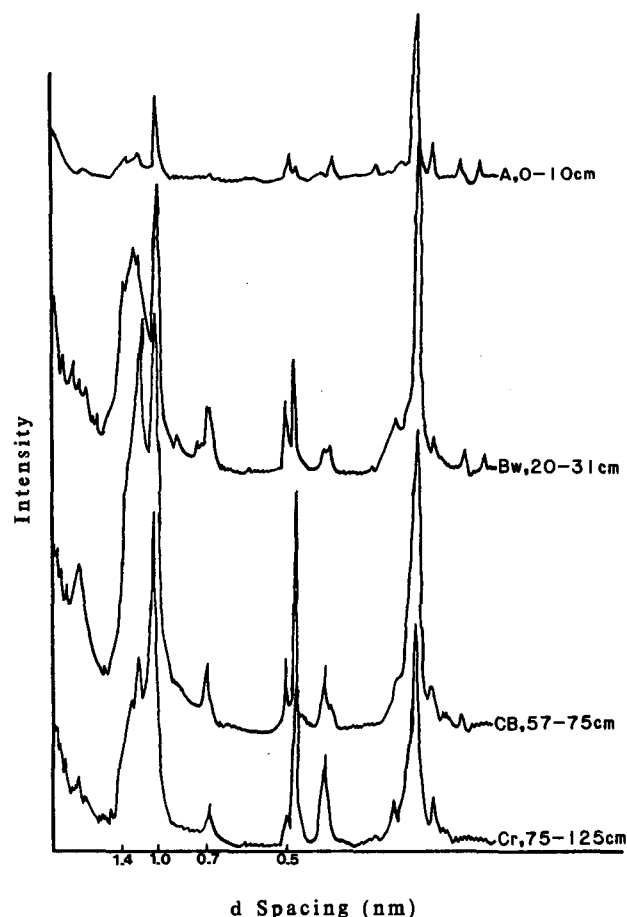


Fig. 4. X-ray diffractograms of soil 8 silt fractions. Samples were saturated with Mg and glycerol and run at 25°C.

creases 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 surface horizons. Significant losses of 2:1 minerals from silts by dissolution may be occurring as well. The silt fraction demonstrates a similar weathering trend with depth to that of the clays. Minerals with 1.4-nm peaks dominate the surface 2:1 minerals, and grade into RMV and mica with depth (Fig. 4). Gibbsite is absent from the surface horizon silts, but increases with depth, particularly in soils completely formed in residuum. 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 4). 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 sand fractions revealed the presence of significant amounts of RMV and 1.4-nm 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 occurred rapidly to great depths, leaving only remnants in the upper horizons. Zircon, epidote, and tourmaline occurred in all profiles in smaller amounts.

#### 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-nm minerals in the surface clays may indicate that

even vermiculites and intergrade 2:1 minerals 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 down into the saprolite as fast as the soluble minerals can be dissolved. The lack of large amounts of kaolinite, even though gibbsite is common, indicates that these profiles are undergoing desilication. Karathanasis et al. (1983) studied the comparative stabilities of kaolinite, gibbsite, and vermiculite in a wide range of southeastern Ultisols and concluded that in weathered surface soils, hydroxy-interlayered vermiculite 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, particularly near the surface. These soils are weathering rapidly in a considerably wetter environment, however, and dissolved Si levels may remain so low that even interlayered minerals deteriorate over time. These soils formed on steep slopes with rapid vertical and downslope subsurface flow of percolating water that drives weathering reactions with high rates of hydrolysis/dissolution, and rapid flushing of weathering products (Velbel, 1985). This constant flushing also explains 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 represent a dynamic steady-state since argillic horizon formation is unlikely without wet/dry cycles to flocculate and reprecipitate clays in subsurfaces (Barshad, 1964).

Much stronger weathering and profile differentiation on south-facing 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 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—a parent material much more likely to weather to kaolinite, and one which lacks the large feldspar content that in these soils apparently weathers directly to gibbsite. Slope position or elevation per se do not appear to strongly influence mineralogy and weathering, except in that the extremely low and high elevation soils in these watersheds tend to be in colluvium, and therefore are more highly weathered since they were probably derived from preweathered materials. The soils on north-facing slopes are higher in overall clay content, however, due to greater water movement through their profiles and concomitant 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 simply reflects the fact that when gibbsite precipitates, it is more likely to be fine than coarse.

### Cation Exchange, Nutrient Levels, and Acidity

Exchangeable Ca and Mg are virtually undetectable (Table 5) below the organic matter enriched surfaces where they are being concentrated and cycled by the forest vegetation. 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 that of the other soils, ranges from 4.1 in the surface to 5.5 in the subsoil, and may have been influenced by more pyritic parent materials. The effective CEC of the mineral fraction is quite low, even though abundant 2:1 type minerals are present in these soils. The relationship between organic matter and CEC of the A horizons is quite linear with an intercept near 0 (Fig. 5). The correlation 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 the regression line shown in Fig. 5 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, Fe oxides, and amorphous materials 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<sub>2</sub>-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 throughout 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, litter layers, and nutrient availability in these soils is given by Daniels (1985).

### Extractable Iron Oxides and Noncrystalline Materials

DCB extractable Fe (Table 5) decreased with depth in most soils, but showed a more uniform distribution and higher subsoil levels in the colluvium (1, 6, 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. Warmer south-facing slopes did not show higher levels of extractable Fe as expected, and in fact

Table 5. Chemical and selected physical characteristics of mineral horizons. All soils were covered with thin litter layers.

Site	Horizon	Depth cm	pH	Organic matter g kg <sup>-1</sup>	Ca	Mg	K	Al	CEC	Base sat. %	BaCl <sub>2</sub> - TEA acidity	Ext. Fe <sub>2</sub> O <sub>3</sub> † g kg <sup>-1</sup>	Acid extract. P mg kg <sup>-1</sup>	Total N g kg <sup>-1</sup>	Textural class
											cmol <sub>c</sub> kg <sup>-1</sup>				
<u>North-facing slopes</u>															
1	A1	0-13	5.8	161	11.10	2.00	1.00	0.15	14.25	99	28.6	37	0.8	3.0	cl
	A2	13-30	5.3	107	1.98	0.61	0.44	1.70	4.73	64	33.6	38	0.8	2.2	cl
	AB	30-43	5.2	38	0.18	0.11	0.18	1.95	2.42	19	24.0	41	0.8	1.1	sil
	Bw1	43-64	5.2	10	0.29	0.22	0.20	3.75	4.46	16	15.8	43	0.8	0.7	cl
	Bw2 R	64-128 128+	5.3	7	0.29	0.23	0.17	4.25	4.94	14	14.9	42	1.2	0.5	cl
2	A1	0-15	5.2	86	3.27	0.56	0.37	1.20	5.40	78	31.8	31	1.2	3.2	l
	A2	15-42	5.0	26	0.02	0.02	0.05	1.80	1.89	5	16.9	30	1.0	0.7	l
	Bw	42-110	5.2	11	0.03	0.07	0.03	1.73	1.86	7	10.4	30	0.8	0.5	sl
	C	110-145	5.4	2	0.03	0.02	0.04	0.25	0.34	26	2.8	16	1.6	0.2	sl
	Cr R	145-386 386+	5.6	1	0.03	0.07	0.06	0.15	0.31	52	1.0	12	4.8	0.1	ls
5	A1	0-6	4.1	170	3.95	0.99	0.60	4.75	10.29	54	47.3	31	2.0	5.8	cl
	A2	6-20	4.5	87	0.36	0.17	0.33	4.05	4.91	18	36.5	32	1.4	3.2	l
	A3	20-31	5.0	58	0.17	0.08	0.23	3.25	3.73	13	29.1	31	0.8	2.6	l
	BA	31-50	4.9	29	0.08	0.03	0.24	2.75	3.10	11	20.8	32	0.8	1.4	l
	Bw	50-94	5.1	13	0.07	0.03	0.19	2.45	2.74	10	14.1	30	1.2	1.1	l
	CB	94-141	5.4	7	0.08	0.03	0.13	1.55	1.79	13	10.1	17	3.8	0.9	sl
	Cr	141-170+	5.5	3	0.05	0.02	0.03	0.80	0.90	11	3.5	8	7.8	0.2	ls
6	A1	0-12	4.8	128	0.35	0.26	0.29	3.80	4.70	19	37.2	28	1.2	5.2	l
	A2	12-27	5.0	86	0.03	0.07	0.16	2.85	3.11	8	27.4	28	1.2	2.0	l
	AB	27-52	4.9	42	0.03	0.05	0.10	2.70	2.88	8	23.0	29	1.2	1.3	l
	Bw1	52-93	5.0	11	0.03	0.10	0.07	2.60	2.80	7	11.0	31	0.8	1.1	l
	Bw2	93-118	5.1	6	0.02	0.17	0.11	3.25	3.55	8	10.0	28	1.0	0.6	l
	CB C	118-150 150-170+	5.1 5.4	3 2	0.04 0.06	0.11 0.03	0.05 0.03	2.15 1.05	2.34 1.17	8 10	6.6 4.4	14 1	2.0 2.0	0.3 0.4	sl sl
<u>South-facing slopes</u>															
3	A	0-12	4.7	45	0.08	0.10	0.13	2.60	2.91	10	14.1	25	2.0	1.3	sl
	Bw	12-33	5.2	7	0.05	0.14	0.11	1.15	1.45	20	14.2	31	1.2	0.6	sl
	Bt	33-84	5.2	3	0.03	0.42	0.12	0.80	1.37	41	4.7	37	0.8	0.7	sl
	C R	84-126 126+	5.3	1	0.06	0.20	0.06	0.65	0.97	33	4.0	31	1.2	0.3	sl
4	A	0-14	4.6	63	0.13	0.21	0.24	3.70	4.28	13	19.0	25	2.0	1.8	l
	Bw R	14-63 63+	5.1	6	0.03	0.22	0.13	1.25	1.63	23	6.6	34	1.2	0.7	l
7	A1	0-9	5.0	92	0.19	0.17	0.28	3.50	4.14	18	26.7	22	2.4	3.0	l
	A2	9-19	4.7	39	0.05	0.05	0.16	2.25	2.51	10	18.0	24	3.0	1.6	l
	BA	19-37	4.8	14	0.03	0.05	0.10	2.35	2.53	7	10.5	24	1.6	0.5	l
	Bw	37-70	4.8	6	0.05	0.12	0.10	2.85	3.12	9	9.4	25	1.2	0.6	l
	CB Cr	70-100 100-140+	4.9 5.2	8 1	0.10 0.03	0.13 0.05	0.17 0.04	2.00 0.25	2.40 0.37	17 32	7.3 2.4	14 6	6.8 86.0	0.6 0.1	sl ls
8	A	0-10	4.7	106	0.03	0.20	0.36	3.85	4.44	13	31.2	21	1.4	3.5	l
	BA	10-20	4.9	33	0.03	0.06	0.23	2.10	2.42	13	13.9	22	1.0	1.9	l
	Bw	20-31	5.3	13	0.04	0.04	0.20	1.80	2.08	13	10.1	22	1.2	0.8	sl
	BC	31-57	5.3	6	0.05	0.07	0.15	1.80	2.07	13	8.3	22	1.2	1.3	sl
	CB	57-75	5.4	3	0.03	0.05	0.11	1.45	1.64	12	7.8	16	14.0	0.7	sl
	Cr R	75-125 125+	5.1	1	0.03	0.02	0.12	0.95	1.12	15	4.5	12	9.8	0.1	sl

† DCB extractable Fe expressed as Fe<sub>2</sub>O<sub>3</sub>.

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 increasing elevation. The overall levels of extractable Fe were rather high for brown, weakly developed soils, ranging from 21 to 43 g/kg within the sola.

Poorly crystalline materials (as estimated by weight loss after acid-oxalate extraction in soils 1 through 4) range from 0.7 to 8.5% on a whole soil basis (Table 6). If we assume that the majority of these materials are in the clay fraction, a significant portion of the clays may be amorphous. Higher levels of noncrystalline materials in the wetter north-facing soils (1 and 2) and very low ratios of SiO<sub>2</sub>:Al<sub>2</sub>O<sub>3</sub> (particularly in the surface horizons) support our hypothesis that these soils are undergoing desilication.

### Problems of Classification

Based on morphology and base saturation alone, these soils classify (Daniels et al., 1987) 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<sub>2</sub>O<sub>3</sub> + % 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 were ignored. With their low CEC, oxidic mineralogy, and decreasing clay content with depth, these soils resemble highly weathered Tropepts in many ways.

The Inceptisol order was designed to encompass

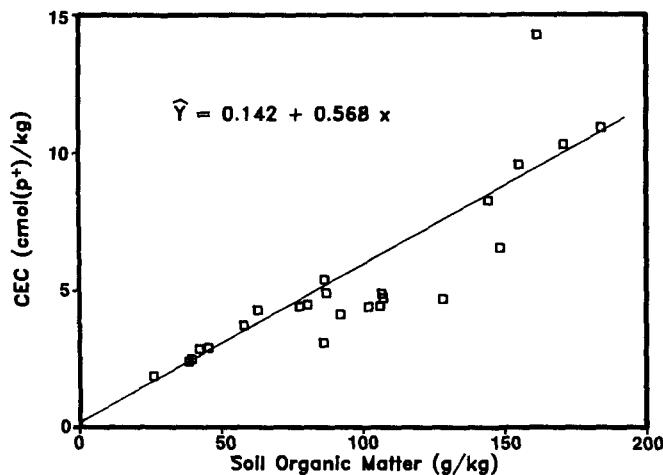


Fig. 5. Fitted regression line ( $\hat{Y}$ ) of g/kg organic matter ( $X$ ) vs. CEC ( $Y$ ) for all A horizons and composite samples. Note the intercept near 0.

weakly developed soils whose genesis has been limited by some external factor. There are presently no established Haplumbrept or Dystrubrept series with oxidic mineralogy classes. These soils are deep, well-weathered, represent an intermediate weathering stage between relatively unweathered Inceptisols and Oxisols, and very likely will never pass through a form definable as an Ultisol. Soil Taxonomy should allow for oxidic mineralogy classes within Inceptisols for these situations.

### CONCLUSIONS

Assuming that these soils have been relatively 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 >2m. These soils appear to have undergone constant leaching, dissolution, and desilication. As a result, kaolinite appears unstable while gibbsite is common. 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 constant vegetative cover over time, or the lack of a weathering steady-state in their soils. The soils studied by these other researchers were logged, and may have been exposed to pronounced temperature fluctuations and possibly severe disturbance before the forest canopy recovered.

The ability of these soils to hold and exchange nutrient cations is primarily 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 essential to nutrient supply and retention, even more so than in most humid-temperate soils because of the relatively inert mineral fraction. Weathering of feld-

Table 6. Percent noncrystalline materials and  $\text{SiO}_2:\text{Al}_2\text{O}_3$  ratio for mineral horizons at sites 1, 2, 3, and 4.

Site	Horizon	Depth, cm	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	Noncrystalline, % whole soil
<u>North-facing slopes</u>				
1	A1	0-13	0.21	5.8
	A2	13-30	0.43	6.7
	AB	30-43	0.46	7.6
	Bw1	34-64	0.31	7.5
	Bw2	64-128	0.24	3.9
2	A1	0-15	0.05	4.8
	A2	15-42	0.11	3.6
	Bw	42-110	0.24	3.2
	C	110-145	0.39	1.5
	Cr	145-386	0.82	1.3
<u>South-facing slopes</u>				
3	A	0-12	0.49	1.4
	Bw	12-33	1.00	0.8
	Bt	33-84	1.43	0.8
	C	84-126	1.52	0.7
4	A	0-14	0.68	2.0
	Bw	14-63	0.73	0.9

spars, and other traces of primary minerals following an erosion event, would certainly resupply some cations and P, 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. There is currently great concern over the influence of acidic deposition on the long-term productivity of the southern Appalachian forest. This research points out that erosion and logging practices also deserve attention.

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