PEDOGENESIS AND GEOMORPHIC IMPLICATIONS OF SOILS DEVELOPED ON BLUE RIDGE ALLUVIAL FANS, VIRGINIA

by

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

DOCTOR OF PHILOSOPHY
in
Crop and Soil Environmental Sciences

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December, 1995
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(ABSTRACT)

Alluvial fans along the western footslopes of the Blue Ridge province, Virginia range over a linear distance of at least 200 km and spread westward up to 4.8 km. Certain soils formed on the fans appear old and highly weathered. Little detailed physical, chemical, or mineralogical data is available about the soils. Concepts about their origin, age, and genesis are vague. This research was conducted in Botetourt, Augusta, Rockingham, and Page counties, Virginia with the intent to gain information about soil properties and to clarify genetic concepts. The objectives were to 1) characterize selected alluvial fan soils distributed along mountain footslopes, 2) show two depositional units compose the sola by using multivariate data analysis procedures, 3) determine the genesis of the soils, and 4) find out if weathered rock bulk density (ρ_{rb}) and free Fe (Fe_r) are different among sites and, if so, what soil and/or rock properties correlate to ρ_{rb}.

Transitional horizons, fragipans, and weakly to moderately developed argillic horizons compose the upper depositional unit (unit A). Reticulate redoximorphic features and highly weathered quartzite rocks are found in the 2Bt horizons (unit B) where clay approaches 60 percent at 2m.

Up to 25 pedons were sampled within a 50 m^2 grid at four sites. Paired samples from the pedons were analyzed by principal component analysis (PCA). The PCA loadings show significant soil properties contribute about equally to the first principal component. The second principal component loadings show clay-free properties best define the discontinuites. Discriminant functions clearly separate unit A from unit B ($P < 0.001$).

Clay and free Fe abruptly increase at the discontinuity. Hydroxy-interlayered vermiculite (HIV) dominates unit A clay fractions; whereas, kaolinite is abundant in unit B. Gibbsite is higher in unit B than unit A. Weathered ρ_{rb} is not different among five sites on a bajada within the central part of the study area, but it is different from five other sites on either end of the study area. Free Fe variation among rocks within sites accounts for 70.6% of the variation, but the variation among sites is only 12.7%. Weathered ρ_{rb} most strongly, although negatively ($r = -0.76$), correlates to clay-fraction HIV.

Time and climate are considered the most influential factors controlling soil development on the Blue Ridge fans. A substantial but unknown amount of time passed before unit A was deposited over unit B. Clay percentages, clay mineralogy, and chemical properties indicate the soils formed from materials additional to the quartzite rocks. Vestiges of these materials are no longer present in the soils. Rock weathering patterns suggest the soil weathering environment has changed. The fan soils are similar to other soils in Virginia dated to late Miocene. The alluvial fan soils are probably related to the dated soils, and they may also relate to other soils reported on transported deposits elsewhere in the southern Appalachians.

Acknowledgements

Before VPI and SU, there was my wife. Cathy, you made many personal and professional sacrifices to move with me to southwest Virginia. Your gifts of love, support, encouragement, and your desire for adventure made this degree possible. Our daughter, Hannah, is a great pleasure, never failing to tell me to get off the "compooter" and play. My enduring love goes to each of you.

My utmost appreciation goes to Dr. James C. Baker for bearing with me to the completion of this dissertation. Jim, your patience and support at times seemed unreal, but were always a soothing relief. Thanks for taking me on. Without you an important door in my life would still be closed.

To Dr. William J. Edmonds, anything I say will be far short of enough. Bill, your insights into soils ring in my head every day when I am on my map. Your enthusiasm and influence are unmatched. They will guide me through my career. After coming to VPI, I heard you respectfully called many things. I can only call you Friend. Thanks for helping me "get in the road!"

I am equally grateful to Dr. Lucian Zelazny, Dr. Jim Campbell, and Dr. Lee Daniels for serving as committee members and for teaching me. It was an honor to work with each of you.

Many other people were involved in this project

personally and professionally, and I share my thanks with them. They are Dr. Thomas W. Simpson, Dr. Mark H. Stolt, Velva Groover, W.T. Price, Louise Price, Sue Brown, Margaret B. Gearhart, Allison Housley, Harry Behl, Phil Cobb, Gary Whitley, Dean Gall, Gerald Doval, and known and unknown landowners. A special debt of gratitude for friendship is owed to all fellow students with whom I associated.

By far the greatest lessons for achievement came from my parents. Rather than constrain me to western Kentucky, they encouraged me to pursue opportunities. One valuable lesson came from my mother: "Can't never could."

A final message of appreciation is extended to Dr. John Mikulcik, my first soils professor. He was the first to spark my interest in soils. Perhaps his most important lesson came not from his classroom but from across his office desk. "Brute strength and awkwardness -- they will get you through!" That's a fact!

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Chapter 1

Introduction

Alluvial fans are extensive along the Blue Ridge province of Virginia. Found along the mountain footslopes, they extend westward into the Great Valley portion of the Valley and Ridge province. Thus, the fans form a transition zone between the two physiographic provinces. Other surficial deposits such as colluvium and river alluvium also occur throughout the Valley and other areas of the Commonwealth. Taken together, these deposits depict an active period of surficial geomorphic evolution.

For many years the deposits were recognized and studied from a geomorphic perspective. Their sedimentology was analyzed in attempts to determine the main mechanisims responsible for deposition. Physical properties, mainly color, texture, and weathered quartzite rocks, were used to estimate the age of the deposits. Many of the geology studies incorporated soils into the analyses, but no studies thoroughly investigated the soils from the soil science perspective. When studied alone, soils yield information about the weathering environment and pedogenic processes. When sedimentological data are combined with information about geographically associated soils, it should be possible to construct a chronological sequence for deposition. When viewed in conjunction with regional studies, the soils can improve our concepts about regional relationships among soils and surficial deposits.

This dissertation specifically addresses the distribution, characterization, and genesis of old, weathered soils formed on the humid-temperate alluvial fans along the western footslopes of the Blue Ridge in Virginia. Two other important features common to the fan soils are investigated, albeit geomorphological in nature but within a soil science context. The first feature is the discontinuities within the sola evident at many locations. The second feature is the highly weathered Antietam quartzite rocks prevalent in the soils throughout the region. Both features have profound impacts upon theories concerning depositional processes and the time factor for soil development. This dissertation points out the need for more soils research on alluvial fans and related deposits in Virginia and the southeastern United States.

Chapter 2

Literature Review

Surficial deposits are commonly divided into three major groups: residual, transitional, and transported deposits (Hunt, 1986). Residual deposits are the unconsolidated and partly weathered mineral materials accumulated in place by disintegration of consolidated rock. Transitional deposits are composed of material moved primarily under the influence of gravity. Such deposits are emplaced by landslides, debris avalanches, and mudflows. By their nature these processes are destructive and can remove hundreds of thousands of cubic meters of regolith per square kilometer (Williams and Guy, 1973). The more time-consuming colluvial processes also form transitional deposits. These processes include slopewash caused by raindrop impact, overland flow and stem flow erosion, windthrow of trees, frost heave, animal and human activity, and any other local disturbance of the ground surface that dislodges soil material. Transported deposits are derived from material moved by water, ice, or wind. These processes imply that the materials may be moved a considerable distance from their source. Hunt (1986) includes alluvial fans in this category.

Alluvial fans are fan- or cone-shaped sedimentary bodies that accumulate at the base of a mountain front or other upland area downslope from the point where streams emerge from the uplands (Bull, 1977). Where the mountain front is relatively straight, a series of alluvial fans coalesce to form a bahada (Fairbridge, 1968). The Blue Ridge province in Virginia from Roanoke northward is a classic example of a linear range. Alluvial fans apron the Blue Ridge throughout most of central Virginia (Hack, 1965).

Many studies focused on the sedimentology and geomorphology of modern and ancient alluvial fans in arid, humid-glacial, humid-tropical, and humid-periglacial environments (Kochel and Johnson, 1984; Nilsen, 1985). Few studies concentrated on humid-temperate alluvial fans. As with the geology studies, little research has centered on the soils formed in the humid-temperate alluvial fans. The most prominent studies about arid alluvial fan soils were the work of Gile (1970; 1975a; 1975b) and Gile and Hawley (1966; 1968; 1972). Other contributions include those by Eghbal and Southard (1993) and Gile (1995).

Deposits formed by one or a combination of the aforementioned processes occur throughout the Appalachian Mountains of the eastern United States. Several authors of geology and geomorphology literature believe the deposits are the result of infrequent catastrophic rainfall (Hack and Goodlett, 1960; Williams and Guy, 1973; Kochel et al., 1982; Kochel and Johnson, 1984; Kochel and Simmons, 1986; and Neary et al., 1986). Others believe the deposits are relict features inherited from Pleistocene or late Tertiary periglacial climates (King, 1950; Michalek, 1968; Haselton, 1973; Raymond, 1977; Potter and Moss, 1968; Smith, 1953; Denny, 1956). Certainly there is evidence that episodic mass wasting occurred and still occurs in the Appalachians. It is not difficult to imagine mass wasting during climatic variations since many writers documented boulder streams and patterned ground in the present-day Appalachians (Mills, 1988; Haselton, 1973; Raymond, 1977; Braun, 1989; Clark and Ciolkosz, 1988) and paleosols and organic material beneath Piedmont colluvium (Eargle, 1940; 1977; Whitehead and Barghoorn, 1962). In the southern Appalachians, boulder streams and patterned ground are described as possible relicts of a colder climate (Clark, 1968), and they are active processes in northern regions today. Mills (1982) stated that even if most footslope deposits resulted by debris flow rather than periglacial activity such as gelifluction, the possibility that deposition was to some extent controlled by climate is not eliminated. He (Mills, 1982) suggested debris flows may be larger or more frequent under certain climatic regimes than under others. Definitive answers about the main processes responsible for emplacement probably await correlation of the deposits to river alluvium and a better understanding of stratigraphy and depositional chronology.

Soils in Virginia formed on the alluvial fans range from very young soils to apparently very old soils. Some of the old soils are highly rubified and exhibit redoximorphic patterns presumed to take a long time to form. Also, quartzite rocks embedded in the soils have undergone extreme chemical weathering. Many clasts almost completely disarticulate when struck and most have complex weathering patterns. The clasts attest to the stability and antiquity of the deposits.

Landform and stratigraphic observations can help one understand transport processes. In the humid-temperate region of central Virginia, Kochel and Johnson (1984) examined alluvial fans thought to have been constructed by large infrequent rainstorms. Inactive fans prograde westward from the Blue Ridge province into the Valley and Ridge province. In most areas they form a bajada overlying Lower Cambrian clastic sediments of the Chilhowee Group and Lower Cambrian carbonates of the Shady and Rome Formations. Kochel and Johnson (1984) described the plan view fan morphology as having downslope- arcuate contours and convex-upward cross profiles. According to Bloomer and Werner (1955), fans spread up to 4.8 km from the Blue Ridge. They (Bloomer and Werner, 1955) described the deposits as crudely stratified, bouldery gravel mountain wash derived from Antietam quartzite. The observations of Bloomer and Werner (1955) basically agree with Kochel and Johnson (1984) who provide more detail on the sedimentology and stratigraphy. Their (Kochel and Johnson, 1984) observations taken from gravel quarries indicate proximal-distal fining of the sediments over 2 or 3 km with over 80% of the deposits supported by subrounded, imbricated, cobble-size rocks in a sand matrix. On the proximal portion of the fans mud-supported boulder-grade facies do not have a preferred clast fabric. Kochel and Johnson (1984) believed the cobble-grade facies to be high-gradient braided stream deposits of the Pleistocene and perhaps the early Holocene. They interpreted the boulder-grade facies as debris flow deposits such as the ones they studied on the eastern front of the Blue Ridge.

Eastern slope fans deposited by Hurricane Camille, August 1969 (Williams and Guy, 1973) do not have typical fan shapes because most of the sediments were confined to narrow basins between interfluves. Typical fan shapes occur where sediments escaped confinement. These sediments were deposited on older fan surfaces that had been stable for a long time. Kochel and Johnson (1984) reported coarse clasts weathered to grus in the pre-1969 material. Clast imbrication in the recent deposits was poorly developed or nonexistent. This information combined with indistinct stratification, sharp contacts between depositional units, absence of current structures, superelevation of debris lines, and inversely graded bedding led Kochel and Johnson

(1984) to conclude a debris flow origin for the pre-1969 deposits. Another important discovery was the presence of intact, pre-1969 soil units and weathered granitic boulders in the 1969 sediments. These features were believed unable to withstand abrasive tractive forces associated with stream transport. Debris or mud flow processes apparently cushioned the soil units against rupture. Thus, their presence provided additional evidence for debris flow origin.

A study of New River alluvium (Mills and Wagner, 1985) also noted the presence of weathered clasts that disintegrated when touched. The study determined the areal and verticle distribution and the relationship between elevations and weathering intensity of deposits. They (Mills and Wagner, 1985) used the clasts to determine if terrace soils were reworked through erosion or dissolution of underlying carbonate rock. They (Mills and Wagner, 1985) concluded such clasts could not have been moved after weathering and therefore, were essentially in the same place as when deposition ceased.

Velbel (1987) reported on debris flow, alluvial channel, and overbank deposits on local alluvial fans bordering the Little Tennessee River near Otto, North Carolina. Six units were defined; two were interpreted as debris flows. The debris flow units were poorly sorted and the sediment ranged from fine-earth to cobble size. Clasts were subangular to subrounded. Internal fabric, structure, or textural grading were not detected. Two other units were weakly cross-stratified and had poorly plane-laminated fine sands with bleaching and prismatic structure at the top. One unit was interpreted as an arid paleosol developed on a fluvial deposit for two reasons. First, the bleached zone appeared to have natric character. Second, the red color of the sediments immediately beneath it suggested hematite as the dominant iron mineral. Thus, it was hypothesized that the unit formed during a relatively warm and/or dry climate. However, no chemical data was presented for the proposed natric feature.

In his geomorphology study of the Shenandoah Valley, Hack (1965) acknowledged the region must have been greatly affected by Pleistocene climates even though the region is several hundred kilometers south of the glacial margin. However, he (Hack, 1965) supported the hypothesis that the surficial deposits are related to more than Pleistocene conditions. Instead, he (Hack, 1965) believed gravel deposition as alluvial aprons or pediments is a process continuous through time and is related to bedrock resistance within a drainage basin. The Shenandoah Valley is within the Valley and Ridge Province and is bisected by Massanutten Mountain. The valley is bordered to the east by the Blue Ridge. The gradient of streams descending from resistant areas decrease as the streams enter the lower relief areas of the valley (Hack, 1957; 1960; 1965). Since the debris cannot be immediately carried away by the low gradient streams, it is stored as alluvial aprons until it is reduced by weathering and erosion to smaller particles capable of being carried to the valley streams. The area of the deposits is proportional to the area of the drainage system in the mountains as well as to the difference in rock resistance and relief between the mountain and lowland areas (Hack, 1965).

The stream gradient on the deposits is generally steeper than lowland streams because the average size of the stream load decreases away from the mountain (Hack, 1957; 1965). Deposits tend to spread laterally through time because the sandstone and quartzite stream load is more resistant to corrasion and corrosion than the softer valley rocks (Hack, 1965). Through time the alluvial aprons evolved into a series of gravelly flood plains, terraces, and dissected terraces (Hack, 1965). After being abandoned by the stream, the deposits on softer rocks remain stable over a relatively long time. Ancestral New River and Shenandoah River alluvium in Virginia attest to the advanced weathering stage achieved by alluvium overlying carbonate rocks (Harris et al., 1980; Mills and Wagner, 1985; Mills, 1986; Bell, 1986).

At the Mountain Lake area, southwestern Virginia, Mills (1988) conducted a thorough investigation into the surficial geology and geomorphology. His Unit 5 (sandstone-rich colluvium) is positioned mainly on gently sloping noses, hilltops, and other landscapes above modern drainageways. Mills (1981; 1988) suggested the older colluvium in the region resulted from landscape reversal. That is, the older colluvium once armored hollow floors. Ridges between hollows were destroyed by lateral migration of the hollow walls and the floors covered with bouldery colluvium became the new interfluves. Although this theory excludes such deposits from this dissertation, the soil weathering characteristics and the proposed initial emplacement of the materials are interesting. Mills (1988) exhaustively studied the colluvium's sedimentology in an attempted to segregate relict colluvium produced by periglacial conditions from that derived from debris avalanches and flows. After subdividing the colluvium into five different topographic environments, he (Mills, 1988) examined particle size distribution, clast roundness, clast fabric, clast weathering, and matrix color. Lower noses were found to have more clay, rounder clasts, and weaker clast fabrics than the other four positions. Unfortunately, these results provided little toward defining the origin of the material. Weak clast fabric is characteristic of debris flows but cannot be used alone to prove this origin. Soils on the lower noses also had stronger chromas, finer mantles as expressed by clast size, and higher percentages of weathered sandstone mainly from the Juniata Formation. These results suggest advanced weathering for the lower nose soils. Mills (1988) believed the colluvium to be pre-Illinoian probably of debris flow origin.

On the Allegheny Plateau of north central Pennsylvania, Denny (1956) discussed the presence of alluvial and colluvial deposits outside the Wisconsin drift border. Some of the deposits were parent material for pre-Wisconsin paleosols. Ancient soils were overlain by periglacial deposits 1 to 2 m thick emplaced by either mass movement or mass movement aided by flowing water as evidenced by the heterogenous or partially stratified character of material. Waltman et al. (1990), working across level to gently sloping plateau summits, examined these soils more closely to establish their stratigraphy, properties, and origin. At the type localities studied by Denny (1956), Waltman et al. (1990) determined the red substrata formed in saprolitic sedimentary bedrock. At other locations the red substrata formed in colluvium. Rubified, strongly weathered sandstones and conglomerates were described in the lower colluvium. From the pedon descriptions (Waltman et al., 1990), the upper colluvium in most cases exhibited weaker horizonation than the substratum, which had strongly expressed argillic horizons. Denny (1956) observed a highly weathered paleosol derived from till. Approximately 5 m of the material was red (2.5 YR 4/8) reticulately mottled clay loam. The total thickness of the exposure was approximately 12 m. Because the red substrata had a significantly higher mean clay content than the overlying material, and because the red color could not be attributed to red-bed parent materials, but instead to a probable strong oxidizing environment prior to burial, Waltman et al. (1990) concurred with Denny (1956) that the red substrata were paleosols. They (Waltman et al., 1990) interpreted the paleosol as pre-Wisconsin colluvium and sandstone residuum and assigned it the name Pine Creek.

Ciolkosz et al. (1979) estimated that approximately 27 percent of the unglaciated Valley and Ridge province of Pennsylvania is covered by colluvium at simple side slope positions and by more complex fan deposits of the major and secondary ridges. Soils formed in these materials have been stable long enough to achieve a substantial degree of pedogenesis as indicated by argillic horizon development, fragipan formation, leaching, and clay mineral weathering. Verticle texture variations occur in these soils because of changes in parent materials and clay elluviation. Soil color was reported to change across discontinuities. They (Ciolkosz et al., 1979) reported no fabric analysis data but they did describe the sandstone fragments as flat and variable in size, which seemed to indicate a local source and little sorting. They (Ciolkosz et al., 1979) did not report the weathering characteristics of the sandstone. Since the soils exhibited stability, Ciolkosz et al. (1979) suggested the material moved downslope as a mass in a periglacial environment during Wisconsin time.

Graham and Buol (1990) and Graham et al. (1990) focused their investigations on slope processes and genesis of soils on the Blue Ridge Front in North Carolina. Geomorphic processes that produced colluvium were debris avalanches, soil creep, slope wash, and solution loss. Their studies seem to indicate these soils are probably younger than those described by Ciolkosz et al. (1979) and Waltman et al. (1990). After excluding the A and E horizons of soils formed in soil creep and slope wash, the colluvium in North Carolina had fairly uniform colors and did not have the red hues typical of the residual soils of the study. Whereas the red substrata (n = 62) of Waltman et al. (1990) had a mean clay content of 27.3%, the mean clay content of B horizons (n = 25) in North Carolina colluvium (Graham and Buol, 1990) was 17.6%. Field argillans were less pronounced in the North Carolina colluvium than in the Pennsylvania colluvium (Ciolkosz et al., 1979). Neither pedogenic features such as fragipans or redoximorphic features nor stratification in any of the colluvial deposits were reported by Graham and Buol (1990).

In the Grandfather Mountain and Roan Mountain areas and the Dellwood quadrangle, all in the Blue Ridge of North Carolina, Mills (1982) used three measures of weathering intensity to ascertain relative dates of 135 foot slope deposits. Through discriminant analysis of B horizon clay percentage, oxidation as reflected by hue, and clast weathering, he (Mills, 1982) classified the sites into younger and older colluvium. In the Roan Mountain area he (Mills, 1982) was able to make an intermediate age division. The study implied the distinct groups of colluvium probably represented depositional events concentrated in but not confined to certain time intervals. He (Mills, 1982) concluded footslope deposition was intermittent through time probably as a result of Quaternary climatic cycles. Substantial weathering occurred between episodes with the most weathered deposits being mid-Wisconsinan or older.

Farther south, along the Blue Ridge Escarpment in northwest South Carolina, Mills (1977) examined colluvial deposits containing weathered igneous and metamorphic rocks. Upper, steeper slopes were covered by Young Colluvium containing relatively unweathered clasts. Soil profiles expressed little soil development. On gentler lower slopes, Older Colluvium lacking stratification or sorting overlaid still an older, more weathered deposit termed Buried Colluvium. Coarse-grained clasts in the Older Colluvium were weathered to grus; whereas, finer-grained amphibolite clasts had only a thin weathering rind. The clast:matrix ratio used to study particle-size distributions in the deposits decreased from the Older Colluvium to the Buried Colluvium [Mills, (1977) defined the size limit for the ratio at 8 mm]. Redder hues were observed in the Buried Colluvium than in the Older unit. The deep soil profiles were attributed to post-depostional weathering, implying long periods of landscape stability. Partly because of these characteristics, Mills (1977) believed Pleistocene processes emplaced the Old Colluvium but cautioned against eliminating the catastrophic rainfall theory. He (Mills, 1977) estimated the relative age of the Young Colluvium as probably Holocene or late Wisconsin, the Older Colluvium as probably early Wisconsin or older, and the Buried Colluvium as probably Illinoian or older.

A few generalizations can be drawn from the geomorphic studies reviewed above. First, soils with some degree of similarity are reported throughout the central and southern Appalachians on alluvial and colluvial landscapes. Similar characteristics among the soils include at least moderately well developed soil profiles, textures, rubified horizons, and weathered coarse fragments. Secondly, whether the soils are related through time is unknown, but the studies indicate some of the soils have reached similar states of development, suggesting they may be related in time. Thirdly, regardless of whether the deposits are related by a common time such as the Pleistocene, or whether they were emplaced sequentially by infrequent eposodic events, depositional events were apparently separated by enough time to allow for soil development before more sediment was delivered. Fourthly, stratification within depositional units is not visible in the soil profiles. Soil weathering and formation probably obliterated stratifcation and weatherable coarse fragments. From personal observations, transported deposits in Virginia associated with the Blue Ridge province appear to have reached similar morphological and pedological stages. However, their relationship within the Commonwealth and to similar deposits and soils in surrounding states remains basically unresolved.

Alluvial fans in Virginia offer the opportunity to study several facets of soil genesis as they relate to the geomorphic nature of the deposits. Other than the work by Ciolkosz et al. (1979) and Waltman et al. (1990), little characterization and pedological research has been conducted on the soils in the eastern USA. Although the transported deposits have been long recognized, no studies specific to soil genesis have been conducted on them. Old river alluvium from the New River (Harris et al., 1980), the James River (Howard et al., 1993), and the Shenandoah River (Bell, 1986) has similar characteristics as the fan soils.

Below the solum in a deposit, evidence for one or more discontinuities may be less tenuous than in the solum where pedogenesis occurred. In Virginia, landscape position and emplacement processes imply discontinuities may exist in the sola. Soils on mountain sideslopes and footslope are candidates for colluvial influence. Where the soils are farther away from the mountain on more gentle slopes they may be subjected to inundation with sediments by processes more dramatic than colluviation. An abrupt texture change in both the coarse fraction and the fine-earth fraction is evident in many of the soils along with contrasting hues between upper and lower sola. Verification of a discontinuity in the upper sola would add to understanding the complex geomorphic nature of these soils.

A number of papers discuss useful methods for confirming parent material uniformity, discontinuities, pedogenic changes, relative weathering intensity, or weathering intervals between deposition (Sudom and St. Arnaud, 1971; Wang and Arnold, 1973; Foss and Rust, 1968; Chapman and Horn, 1968; Marshall and Haseman, 1942; Alexander et al., 1962; Khangarot et al., 1971; Beavers et al., 1963; Fanning and Jackson, 1967; Smith and Buol, 1968). These works generally relied on elemental determination of Zr or K or molecular ratios of Ca, Fe, or Ti over Zr expressed as oxides. Clay mineral and particle size differences with depth, heavy mineral ratios, and resistant mineral ratios as well as stone lines and other obvious features were used to make genetic interpretations. Depth distribution curves of the soil properties were usually presented to illustrate either soil homogeneity or discontinuous soil properties.

Severely weathered quartzite and sandstone clasts are common features to the Virginia alluvial fan soils. Inherent Fe is a minor constituent on the rocks (Stead and Stose, 1943; Sweet and Wilkes, 1986) but free Fe stains produced unique weathering patterns within the stones. Peltier (1949) described similar patterns in clasts associated with Susquehanna River terraces in Pennsylvania. Mills (1988) reported unique rock weathering patterns in surficial deposits of the Mountain Lake area of Virginia. Mills (1988) found evidence for sequential rather than simultaneous rind development, and suggested that multiple rinds may reflect a changing clast environment fostered by either climatic change or by movement of the clasts into a different soil horizon by means of windthrow or other disruption of the soil profile. Howard et al. (1993) studied an alluvial chronosequence of the James River in the Inner Coastal Plain of Virginia. Surfaces estimated to have began formation near the beginning of late Miocene time (10.8 - 13.0 myr B.P.) contained quartzite clasts with ferruginous weathering rinds greater than 1 cm thick, or that were partially or totally disarticulated and crumbled into loose sand.

The clasts associated with the alluvial fans soils appear as though a reversal in rind formation has occurred, with reduced Fe now being leached from the clasts. Redox conditions are verified by strongly contrasting redoximorphic features often present in the soils. Whether the free Fe was derived from within the clasts or translocated into the clasts from the soil matrix is an interesting point. I believe the weathered quartzite rocks are one of the key features implying long-term soil formation and landscape stability.

Gile and Hawley (1966) concluded from a study of alluvial-fan piedmont soils in southern New Mexico that soils formed in those sediments should be examined over large areas prior to genetic interpretation. Likewise, Daniels (1988) stressed the need to understand the field stratigraphic and geomorphic relations of soils to make laboratory data meaningful. In the initial stages of a soil investigation it may be just as advantageous to focus on particular soils within a soilscape. As the investigation unfolds, then, information obtained from geographically associated soils can be incorporated. If necessary, theories and interpretations should be revised.

The literature, including soil surveys, show old soils on Blue Ridge alluvial fans are extensive. However, regional relationships among the soils are not clearly established. It is hoped this study will show a correlation between the old alluvial-fan soils. Further, this research should serve as a framework for future investigations which should focus on the relationship of these soils to geographically associated soil bodies as well as correlate the soils to the old river terrace soils and colluvial soils in the Virginia Valley and Ridge province. Finally, this research may lead to correlating the Virginia soils to similar soils and deposits in surrounding states, thus enhancing theories about the surficial geomorphic evolution of the southeastern USA.

Chapter 3

DISTRIBUTION AND CHARACTERIZATION OF SELECTED BLUE RIDGE ALLUVIAL-FAN SOILS IN VIRGINIA

(ABSTRACT)

Typic Paleudults and Typic Fragiudults lay along the western footslopes of the Blue Ridge Province, central Virginia. They developed on alluvial fans, and more than one depositional unit occurs at most locations. Because detailed information is limited, this study was conducted to show the distribution of the soils as well as their characteristics, and describe their relation to one another and possibly other soils on transported deposits in Virginia. I examined pedon morphology and physical, chemical, and mineralogical properties of selected soils spread across a linear distance of approximately 200 km. Transitional horizons, fragipans, and/or weakly to moderately developed argillic horizons commonly occur in the upper, most recent depositional unit (unit A). Family placement is influenced by the thickness and amount of development in this unit. Reticulate redoximorphic features and highly weathered quartzite clasts are found in the thick, lower argillics (unit B) where clay contents approach 60%. Kaolinite and hydroxy-interlayered vermiculite (HIV) are abundant clay-fraction minerals. Up to 12% gibbsite is present. Low cation-exchange capacities and very low base saturations reflect the soils' weathered nature. Soils with similar properties and features reported

elsewhere in Virginia date to late Miocene. The western Blue Ridge fan soils appear to be part of a surficial geomorphic continuum from the footslopes to the rivers flowing through the Valley and Ridge. They may relate to southern Appalachian colluvial soils as well.

INTRODUCTION

Alluvial fans and colluvial mantles are surficial deposits widespread throughout the central and southern Appalachian Mountains, USA (Graham et al., 1990; Velbel, 1987; Mills, 1977; Hack, 1965). Alluvial fans along the western flank of the Blue Ridge in Virginia are intriguing because the soils suggest they are very old, stable landforms.

Although the fans in Virginia are well documented (Henika, 1981; Gathright et al., 1977; Werner, 1966), their origin is unclear. Early research suggests the fans are relict features from Pleistocene periglacial conditions; some ancient gravels in Georgia might date to late Tertiary climates (King, 1950). Though well south of the glacial margin, Hack (1965) acknowledged the Shenandoah Valley must have been affected greatly by Pleistocene climates even though he believed fan formation to be a process continuous through time. Additional research documents patterned ground (Clark, 1968) and other periglacial activity (Clark and Ciolkosz, 1988) such as boulder streams (Mills, 1988), and Piedmont organic deposits covered by several meters of colluvium (Eargle, 1940; 1977; Whitehead and Barghoorn, 1962). The organic deposits contain pollen from plants which have a more northerly distribution or which in the southeast are largely confined to the mountains. All these features reflect a cooler climate than exists today in the Appalachians.

Infrequent catastrophic rainfalls are sometimes given credit for constructing the alluvial fans (Neary et al., 1986; Kochel and Johnson, 1984; Williams and Guy, 1973; Hack and Goodlett, 1960). These rare events occur when tropical storm paths and topographic barriers at the Blue Ridge and Allegheny Front create climatic variability (Jacobson et al., 1989).

Tectonic activity is the third mechanism considered for creating the fans. Destabilized regolith moved downslope as equilibrium reestablished after uplift. Poag and Sevon (1989) reported a significant pulse of uplift during the middle Miocene in the central Appalachians. Self (1993) proposed Appalachian uplift as the mechanism for Late Tertiary-Early Quaternary sedimentation in the Lower Mississippi Valley and Gulf Coastal Plain. Even though Cenozoic uplift is well documented in the Applachians, it is difficult to ascribe Blue Ridge fan formation to this mechanism because little research has focused on this cause.

Reguardless of how the fans formed, stable mineral suites and highly weathered quartzite rocks suggest intense weathering and soil formation through a long period of time. Geomorphology literature reports the alluvial fans (Henika, 1981; Gathright et al., 1977; Werner, 1966; Hack, 1965), but the soils are rarely mentioned. A few studies of highly weathered soils were done in Virginia, but the soils occurred on river terraces (Howard et al., 1993; Bell, 1986; Harris et al., 1980). Each study described one or more of the following characteristics, all of which are common to soils on Blue Ridge fans: significant soil development, stable mineral assemblages, and weathered quartzite rocks.

Based on the information provided by these studies (Howard et al., 1993; Bell, 1986; Harris et al., 1980), I believe the alluvial fans and the river terraces may be geomorphically related. Furthermore, the soils formed on these two landforms may present a relationship with colluvial soils in Virginia (Mills, 1988) and nearby states (Waltman et al., 1990; Mills, 1982; 1977) representing one or more very active periods within the evolutionary process of the central and southern Appalachians.

However, for the alluvial-fan soils, detailed characterization data are unavailable. The data are needed before drawning conclusions about relationships between the alluvial-fan soils and the terrace and colluvial soils. Therefore, the objectives of this study are to: (i) characterize selected alluvial-fan soils and show their distribution along the western footslopes of the Blue Ridge, and (ii) evaluate the effectiveness of the data toward correlating the alluvial-fan soils with other transported soils in Virginia.

MATERIALS AND METHODS

Study Area Description

Study sites are within Botetourt, Augusta, Rockingham, and Page counties along the western flank of the Blue Ridge province, central Virginia (Fig. 3.1). The sites are on stable interfluves with slopes ranging from 2 to 10 percent. They lay between 300 and 575 m elevations (Table 3.1). Figures 3.2 - 3.9 are examples of the soils studied. Inactive fans prograde westward up to 4.8 km from the Blue Ridge into the Valley and Ridge province (Bloomer and Werner, 1955). They are composed mainly of crudely stratified, bouldery gravel derived from Antietam quartzite, which forms the hog-back northwestern front of the Blue Ridge (Bloomer and Werner, 1955). In the central Virginia area the fans form a bajada overlying Lower Cambrian clastic sediments of the Chilhowee Group and Lower Cambrian carbonates of the Shady and Rome Formations (Kochel and Johnson, 1984). Fan thicknesses are estimated to be from 15 m to >50 m (King, 1950). The sites are in mixed hardwood forests, show no signs of recent deposition, and are drained by incised streams.

Downslope-arcuate contours on U.S. Geological Survey (1977; 1979; 1985; 1987) 7.5 minute topographic quadrangles were used to identify alluvial fans. In the field, highly

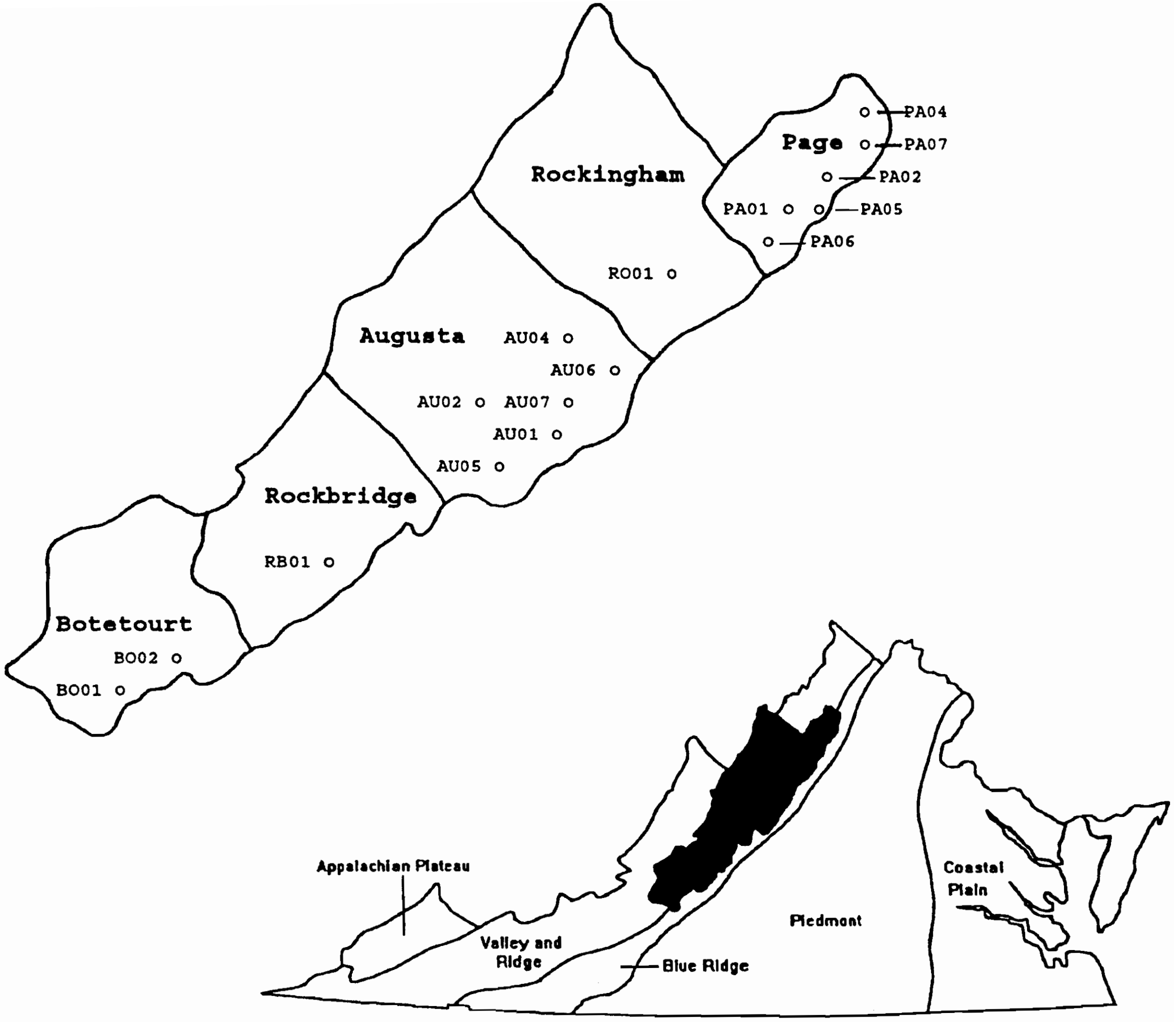

Figure 3.1. This map shows the locations for the sites.

Table 3.1. Partial morphological descriptions and site characteristics of the selected pedons.

Horizon	Depth	Color (moist)	Texture†	Redoximorphic features‡	Slope	Elevation
	(cm)				-- % --	(m)
			BO01			
A	0-5	10YR 5/2	sl		10	482
BE	33-50	10YR 6/4	l			
Bt1	50-64	7.5YR 5/4	l			
Bt2	64-99	5YR 5/8	l			
2Bt3	99-143	5YR 5/8	c	c1p 10YR 6/8		
2Bt4	143-200	2.5YR 4/6	c	c2p 10YR 5/6 c2p 10YR 6/6		
			BO02			
A	0-3	10YR 4/2	sl		7	402
Bt1	48-66	7.5YR 5/6	l	c2d 10YR 6/3		
2Bt2	66-94	5YR 5/6	c			
2Bt4	128-170	2.5YR 4/6	vcbc	m3p 10YR 5/6 f2p 10YR 6/2		
2Bt5	170-240	2.5YR 4/6	vcbcl	f2p 10YR 6/2 m2p 10YR5/6		
			AU01			
A	0-15	10YR 4/3	sl		2	536
Bt1	45-90	2.5YR 4/6	gr scl			
Bt2	90-180	2.5YR 4/6	vgr scl			

Table 3.1. (cont.) Partial morphological descriptions and site characteristics of the selected pedons.

Horizon	Depth (cm)	Color (moist)	Texture†	Redoximorphic features‡	Slope -- % --	Elevation (m)
			AU02			
A	0-5	10YR 4/2	l		2	439
BE	12-28	7.5YR 5/6	grsl			
Bt1	28-67	5YR 4/8	grl			
Bt2	67-100	2.5YR 4/6	vgr cl			
			AU04			
Ap	0-12	10YR 5/2	l		3	402
EB	23-58	10YR 6/3	grsl			
2Bt1	58-117	5YR 5/4	cbc	c2d 7.5YR 6/8		
2Bt2	117-161	7.5YR 5/8	vcbc	f2d 10YR 7/1		
			AU05			
Ap	0-7	10YR 5/2	sl		5	567
EB	29-42	10YR 5/4	l			
2Bt1	42-71	5YR 5/8	cl			
2Bt2	71-128	2.5YR 4/8	c			
			AU06			
A	0-10	10YR 4/2	sl		10	433
BE	31-56	10YR 5/8	sl			
2Bt1	56-96	2.5YR 4/6	sc			
2Bt3	135-150	5YR 5/6	cl			

Table 3.1. (cont.) **Partial morphological descriptions and site characteristics of the selected pedons.**

Horizon	Depth	Color (moist)	Texture†	Redoximorphic features‡	Slope	Elevation
	(cm)				-- % --	(m)
			AU07			
A	0-5	10YR 3/1	sl		1	573
Bt1	11-32	10YR 6/3	sl			
Bt2	32-48	10YR 6/3	l	m2f 10YR 6/4		
				f2d 10YR 6/1		
Bx	48-81	10YR 6/4	sl	c1d 5YR 5/6		
				m2d 10YR 6/1		
2Bt1	81-114	5YR 5/6	cl	f2d 7.5YR 5/6		
				m2p 10YR 7/1		
				f2d 10YR 6/6		
3Bt4	156-192	2.5YR 4/6	cbc	c1d 5YR 5/6		
			RO01			
A	0-6	10YR4/2	sl		2	353
Bt1	18-40	10YR 5/4	sil			
Bt2	40-76	10YR 5/4	cl			
E′	76-94	10YR 6/3	l	c1f 10YR 5/4		
2Bt1	90-112	7.5YR 5/6	vcbc	f2d 10YR 3/6		
2Bt3	156-200	10R 3/6	excbcl	m2p 10YR 6/8		
				f2p 10YR 6/1		
			PA02			
A	0-14	10YR 5/4	l		6	317
Bt1	54-80	5YR 5/6	vgrscl	f2d 2.5YR 4/6		
2Bt2	80-124	10R 4/6	vgrc	f1p N 7/		
2Bt3	124-150	10R 3/6	vgrc	f1p N 7/		

Table 3.1. (cont.) Partial morphological descriptions and site characteristics of the selected pedons.

Horizon	Depth	Color (moist)	Texture†	Redoximorphic features‡	Slope	Elevation
	(cm)				-- % --	(m)
			PA05			
Ap	0-2	10YR 3/1	sil		10	360
E2	18-44	10YR 6/3	grsl			
Btx	44-64	10YR 5/4	cbl			
2Bt1	64-82	7.5YR 5/6	grc	c2d 2.5YR 3/6		
2Bt5	173-205	2.5YR 4.6	c	c2p 10YR 5/6 c2p 10YR 6/2		
			PA07			
A	0-18	10YR 5/2	sil		4	296
Bt1	41-63	7.5YR 5/6	cl	c1d 5YR 4/8 c1d 10YR6/3		
Bt4	160-205	10R 3/6	c	c1p 7.5YR 5/8 c2p 10YR 8/1		

† sl = sandy loam; l = loam; c = clay; cl = clay loam; scl = sandy clay loam; sc = sandy clay; sil = silt loam; cb = cobbly; vcb = very cobbly; excb = extremely cobbly; gr = gravelly; vgr = very gravelly.

‡ f = few; c = common; m = many; 1 = fine; 2 = medium; 3 = coarse; f = faint; d = distinct; p = prominent.

Figure 3.2. This photograph is Site BO01. Tape intervals are approximately 0.3m.

Figure 3.3. A close-up of Site BO01 shows a weak stone line and the well-developed 2Bt horizon. Tape intervals are approximately 0.3m.

Figure 3.4. This soil is Site AU01.

Figure 3.5. Site AU04 has four depositional layers. Tape intervals are approximately 0.3m.

Figure 3.6. This is Site AU07. Tape intervals are 0.5m.

Figure 3.7. This close-up of Site AU07 shows the weak structure of unit A. Tape intervals are 0.5m.

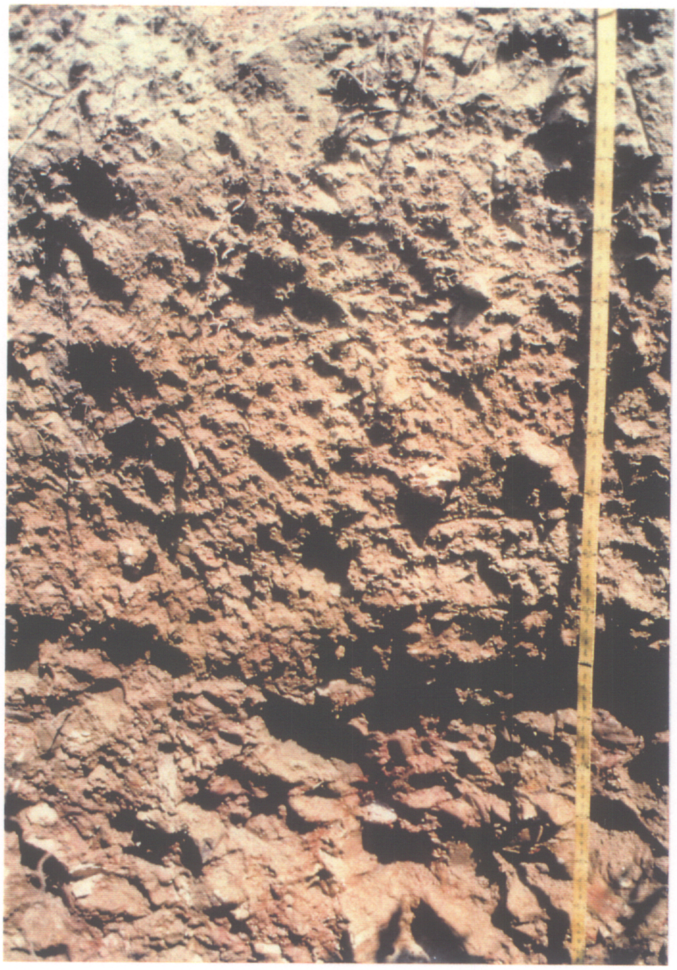

Figure 3.8. This photograph of Site R001 clearly shows the moderately developed unit A above unit B. Tape length is approximately 1.5m.

Figure 3.9. This is Site PA05. Tape length is approximately 1.3m

weathered Antietam quartzite clasts, identifiable by the fossilized worm borrows, *Scolithus linearis*, were one of the criteria for site selection because the clasts appear to have weathered *in situ*. Another criteria was the deep argillic horizons. These two features commonly occur together.

Geographically associated soils classify as Typic Hapludults (fine-loamy or clayed, mixed, mesic); Aquic Hapludults (fine-loamy, mixed, mesic); Typic or Aquic Fragiudults (fine-loamy, mixed, mesic); and Typic Dystrochrepts (loamy-skeletal, siliceous, mesic) (Hockman, 1982; Hockman, 1979). The Typic Dystrochrepts may represent younger deposits from more recent geomorphic activity, therefore, I excluded them from this study. However, I do not wish to deemphasize their importance to the geomorphic development of the region.

Procedures

Pedons were described and sampled according to standard procedures (Soil Survey Staff, 1984). Particle-size distribution was determined by the pipette method of Gee and Baulder (1986). Exchangeable bases were extracted with 1 *M* NH_4OAc, pH 7.0, and exchangeable Al with 1 *M* KCl. Extractions were analyzed by atomic absorption spectrophotometry (Soil Survey Staff, 1984). Exchangeable acidity was determined by $BaCl_2$-TEA. Cation-exchange capacities were calculated by sum of bases plus exchangeable acidity and by sum of bases plus exchangeable Al. The pH was determined by a 1:1 soil to water mixture. Dithionite-citrate-bicarbonate-extractable free Fe was determined by the method of Holmgren (1967). Qualitative clay mineralogy (<2.0 μm) was determined with a Diano XRD 8300 AD x-ray diffractometer (Diano Corp., Woburn, MA) with CuKα radiation (20mA, 40kV) after particle-size fractionation by centrifugation (Kittrick and Hope, 1963). Kaolinite and gibbsite were quantified by differential scanning calorimetry with a DuPont 1090 Thermal Analyzer (TA Instruments, New Castle, DE), using poorly crystalline Georgia kaolinite and Reynolds synthetic gibbsite as standards. Other minerals were estimated by comparing XRD peak areas relative to those of kaolinite.

RESULTS

Study sites are concentrated in central Virginia (Fig. 3.1). Complete pedon descriptions are given in Tables A.1 - A.15. In Augusta and Rockingham counties the fans coalesce into nearly level to gently sloping bajadas (Kochel and Johnson, 1984). Deposits in these counties were described by Kochel and Johnson (1984) as high-gradient braided stream deposits with crude fining-upward sequences. The weathered coarse fragments of 2Bt horizons at Site RO01 are moderately imbricated (Table A.9), supporting the braided stream description. Bajadas also occur in Botetourt and Page counties, but they are not as extensive spatially as the Augusta and Rockingham fans. In Botetourt County, fans rarely exceed 1.6 km widths (Henika, 1981) and in Page County their widths are even less. Slope gradient is steeper in Botetourt and Page (Table 3.1) as one would expect from material transported shorter distances from the source.

Only one site was observed in Rockbridge County during reconnaissance investigations. Fans may never have existed in the county or, alternatively, they were removed by geologic erosion. The James River flows northeast through Botetourt County, and after its confluence with the southwesterly-flowing Maury River, turns southeast through the Blue Ridge. Both rivers flow along the footslopes of the Blue Ridge and perhaps hastened the removal of unconsolidated deposits by transporting the material out of the region. This area could have been part of the source for the alluvium studied by Howard et al. (1993).

Soil classification for the pedons (Table 3.2) is representative of soils formed on the stable fans. Nearly all pedons are Paleudults, reflecting the stability of the fans. Stolt et al. (1994) classified one pedon in the region as a Plinthic Paleudult. The soils typically display at least two depositional units as evidenced by abrupt clay increases and abrupt sand and silt decreases (Table 3.3). The surface and some of the argillic of unit B must have been

Table 3.2. Classification for the selected soils on the alluvial fans.

Site	**Family**
BO01	coarse-loamy, siliceous, mesic Typic Paleudults
BO02	clayey, mixed, mesic Typic Paleudults
AU01	loamy-skeletal, siliceous, mesic Typic Hapludults
AU04	clayey, mixed, mesic Typic Paleudults
AU05	clayey, mixed, mesic Typic Hapludults
AU06	clayey, mixed, mesic Typic Paleudults
AU07	coarse-loamy, siliceous, mesic Aquic Fragiudults
RO01	fine-loamy, siliceous, mesic Typic Paleudults
PA02	clayey-skeletal, mixed, mesic Typic Paleudults
PA05	coarse-loamy, siliceous, mesic Typic Fragiudults
PA07	clayey, kaolinitic, mesic Typic Paleudults

Table 3.3. Particle-size distributions from the control sections of the selected alluvial-fan soils.

Site	Horizon	Depth	Sand	Silt	Clay
		(cm)		%	
BO01	Bt1	50-64	48.0	41.3	10.7
	Bt2	64-99	49.0	35.7	15.3
	2Bt3	99-143	25.1	29.8	45.1
BO02	Bt1	48-66	40.7	43.1	16.2
	2Bt2	66-94	23.3	24.6	52.1
	2Bt3	94-128	30.2	28.3	41.5
AU01	Bt1	45-90	58.3	8.7	33.0
	Bt2	90-122	75.1	3.4	21.5
AU02	Bt1	28-67	43.7	35.8	20.5
	Bt2	67-100	36.1	24.0	39.9
AU04	2Bt1	58-117	26.8	17.1	56.1
AU05	2Bt1	42-71	32.6	29.3	38.1
	2Bt2	71-128	34.5	10.1	55.4
AU06	2Bt1	56-96	48.7	15.1	36.2
	2Bt2	96-135	45.7	20.4	33.9
AU07	Bt1	11-32	52.0	40.8	7.2
	Bt2	32-48	51.3	38.1	10.6
RO01	Bt1	18-40	41.4	52.4	6.2
	Bt2	40-74	25.7	35.8	38.5
PA02	Bt1	54-80	60.6	16.1	23.3
	2Bt2	80-124	29.6	21.6	48.8
PA05	E2	18-44	46.4	48.1	5.5
PA07	Bt1	41-63	29.2	38.2	32.6
	Bt2	63-94	17.5	26.3	56.2

truncated prior to or during deposition of unit A because there is no evidence of an old A-horizon. Complete particle-size data are shown in Table A.16. Table A.17 gives coarse fragment (>2.0 mm) percentages for selected horizons.

Family particle-size classes (Table 3.2) are dictated by the amount of development in the unit A. Coarse-loamy soils occur where unit A is moderately developed, or where fragipans are present. Thin eluvial horizons, transitional horizons, and argillic horizons with weak structure and few clay films are common features of this unit (Table 3.1). Otherwise, clayey particle-size classes occur when unit B dominates the control section because unit A is too weakly developed to influence family placement.

For the upper 2Bt horizons, yellowish red, strong brown, and reddish brown matrix colors (Table 3.1) indicate the Fe mineralogy of these horizons might be converting from Fe oxides to Fe oxyhydroxides. These colors are compared to the red or dark red hues of the lower 2Bt horizons which suggest hematite is the dominant Fe mineral. Unit B may have existed during periods when the mean annual soil temperature was warmer than the present-day mesic soil temperature regime. Warm interstadial periods existed after each Pleistocene glaciation. Hack (1965) noted the oxidized condition of residual soils in his comprehensive report about the Shenandoah Valley region. To him (Hack, 1965) this indicated the soils had been through a period when Fe sesquioxides were formed and concentrated by lateritic weathering. By his estimates of downwasting, the thick residuum could have survived from a time long before the Wisconsin.

Clay percentages of the lower Bt horizons (Table 3.4) are strikingly similar given the extent of the study area. Such similarity may indicate unit B materials were deposited within a relatively short geologic time and had somewhat equivalent composition. Another feature shared by the soils is the highly weathered, subangular to subrounded quartzite clasts. The clasts are generally cobble-size, but range from pebble- to boulder-size. The rocks are easily broken with a hammer; some even can be broken by hand. These size and shape observations correspond to those of Kochel and Johnson (1984), who reported more than 80% of Blue Ridge fans contained cobbles which, where imbricated, indicated a southwesterly paleoflow.

Redoximorphic features are found in some pedons (Table 3.1). Stolt et al. (1994) studied these strongly contrasting features and found they form where horizons are dense or where the water table fluctuates. Howard et al. (1993) observed the same type redoximorphic features in old river terrace soils. They (Howard et al., 1993) believed the features signified impeded drainage because soil pores were completely plugged with clay. They (Howard et al., 1993)

Table 3.4. Particle-size distribution of the lower argillic horizons.

Site	Horizon	Depth	Sand	Silt	Clay
		(cm)	-----------	%	-----------
BO01	2Bt4	143-200	29.07	30.22	40.71
BO02	2Bt4	128-170	33.67	24.20	42.13
AU01	Bt2	90-122	75.10	3.45	21.45
AU02	Bt2	67-100	36.10	24.00	39.90
AU04	2Bt2	117-161	41.80	13.55	44.65
AU05	2Bt2	71-128	34.45	10.15	55.40
AU06	2Bt3	135-150	43.00	18.18	38.82
AU07	2Bt3	142-156	29.38	21.06	49.56
RO01	2Bt2	112-156	33.03	24.86	42.10
PA02	2Bt3	124-150	38.55	13.40	48.05
PA05	2Bt3	106-151	38.08	21.45	40.47
PA07	Bt3	94-160	16.40	23.92	59.68

also suggested the redoximorphic features reflected horizon degradation.

No weatherable minerals are present in any pedon control section; only <2.0 mm quartz. In all pedons (Table 3.5), kaolinite and HIV are the predominant control section clayminerals, with up to 78% kaolinite and 46% HIV. Gibbsite ranges from zero to 12.5% for the sites. Most soils have >4.0% gibbsite. For pedons BO01, BO02, and RO01, where HIV is less abundant, mica is present in the clay fraction implicating HIV as a weathering product of the mica. The general mineral sequence follows the order kaolinite > HIV > gibbsite.

In the chemical control sections (Table 3.6), exchangeable bases are very low, while extractable Al and extractable acidity are high (Table 3.6; Table A.18). The pH values show the soils are strongly to very strongly acid. This accounts for the high exchangeable Al. The chemical properties emphasize the extent to which the soils are weathered. The chemical data correspond well with the abundant HIV, the gibbsite, and the weathered quartzite.

The clay content, the clay mineral suite, and the amount of extractable Al and free Fe argue for a source of parent material in addition to the Antietam quartzite. Werner (1966) described the Antietam as remarkably homogeneous, uniform white to blueish-gray quartzose sandstone beds. Gathright et

Table 3.5. Clay (<2.0 μm) mineralogy† of the control sections from the selected sites.

Site	**KAO**	**GIB**	**HIV**	**QTZ**	**INT**	**MICA**	**Fe‡**
	%						
BO01	38.2	7.8	21.8	11.9	8.9	15.9	4.39
BO02	33.9	12.5	19.5	11.1	10.3	8.8	4.57
AU01	42.7	10.4	41.0	2.4	--	--	1.56
AU04	48.1	7.7	44.0	--	--	--	1.01
AU05	44.6	10.5	35.0	7.3	--	--	2.00
AU06	47.8	3.4	42.0	3.6	--	--	1.61
AU07	7.7	4.4	45.9	9.6	25.9	5.8	2.67
RO01	21.7	6.7	28.4	15.6	--	23.8	5.21
PA02	36.5	Tr	45.6	7.3	--	4.0	3.04
PA05	14.6	1.3	40.3	27.8	--	15.4	4.06
PA07	78.7	--	14.0	--	--	2.8	4.28

† KAO = kaolinite; GIB = gibbsite; HIV = hydroxy interlayered vermiculite; QTZ = quartz; INT = 2:1 intergrade.

‡ Free Fe on a whole soil basis

Table 3.6. Characterization of the chemical control sections.

Site	Depth	pH	Σ Exchange-able bases	Exchange-able acidity†	Cation exchange capacity	Exchange-able Al	ECEC‡
	(cm)		--------------	cmol_c kg^{-1}	--------------		---- % ----
BO01	175	5.14	0.30	14.4	14.70	9.35	9.65
BO02	173	5.00	0.12	10.7	10.82	4.85	4.97
AU01	170	5.04	0.13	4.8	4.93	1.45	1.58
AU04	183	4.92	0.13	8.2	8.33	4.95	5.08
AU05	167	5.00	0.47	9.9	10.07	4.65	5.12
AU06	181	4.88	0.89	13.0	13.89	5.65	6.54
AU07	123	5.16	0.55	13.2	13.75	5.40	5.95
RO01	165	4.85	0.32	16.0	16.32	8.40	8.72
PA02	179	5.38	1.97	9.0	10.97	4.75	6.72
PA05	119	5.01	0.80	12.6	13.40	5.05	5.85
PA07	166	5.05	3.34	11.6	14.94	3.85	7.19

†Cation exchange capacity = (sum of bases + exchangeable acidity).

‡ECEC = effective cation exchange capacity = (sum of bases + exchangeable Al).

al. (1977) described the formation as tan to white metamorphosed feldspathic sandstone interlayered with green and pink laminated phyllite and argillite. Rocks composed of these minerals could impart the observed properties to the soils.

Geologic formations of the central Virginia Blue Ridge run essentially in a continuous line with the mountain range. The primary source for fan material, besides the Antietam, is the Harpers formation (Henika, 1981; Gathright et al., 1978; Gathright et al., 1977; Werner, 1966). The Harpers Formation is composed of greenish to bluish gray, quartz-chlorite-sericite or biotite phyllite with thin to massive layers of metamorphosed sandstone. The Harpers is an additional plausible parent material for the soils. Sericite and chlorite are sources of Al, biotite is a source for Fe, and the feldspars and biotite are precursers for kaolinite, gibbsite, and HIV. This is quite likely an over-simplified senario for the mineral transformations which produced the soils. But if, in fact, the parent materials were composed of these minerals and rocks, the senario offers a better understanding about how the observed soil properties were derived.

DISCUSSION

Comparison to Other Locations

Despite recent studies of the alluvial fans (Kochel and

Johnson, 1984), much uncertainty exists about their origin and ages. There seems to be common agreement that a colder, possibly periglacial climate existed in the region during the Pleistocene (Conners, 1986). However, determining the paleoclimatic influences on the geomorphic processes and landforms is complicated by the difficulty encountered when transferring information from one location to another, by our meager understanding of contemporary geomorphic processes, and by extrapolating present processes to uncertain past climatic conditions (Conners, 1986).

Reqardless of the emplacement processes and past conditions, my data suggest similarity among the soils investigated. Similarity might result from the materials having been emplaced at about the same time and the soils having formed from similar parent material during similar environmental conditions. Also, my data compare well to data from other studies conducted in the region.

Harris et al. (1980) found sand and silt fractions of a high-terrace Typic Paleudult dominated by quartz. Clay composed 54 to 60% of the whole soil, and the control section was dominated by kaolinite (40%) and HIV (45%). The near absence of gibbsite was attributed to the antigibbsite effect of HIV. Crushable quartzite clasts observed in the soil suggested prolonged or intense leaching of Si. The study site for Harris et al. (1980) is approximately 100 km southwest of my study area.

Howard et al. (1993) also studied a terrace chronosequence in Virginia. Their study area was southeast of mine, associated with the James River on the Inner Coastal Plain. Plinthic Paleudults on the highest terrace were very strongly developed, had duripan and ferricrete development, and contained disarticulated quartzite clasts. The soils belonged to the clayey, kaolinitic, thermic family. One pedon had 10.9% gibbsite. Although not stated, the clasts were likely derived from the Blue Ridge because the James River flows through the mountain province. Howard et al. (1993) placed the formation of the high terraces into late Miocene time (10.8 to 13.0 myr ago).

Bell (1986) studied the morphology and stratigraphy of terraces formed by the South Fork of the Shenandoah River, Central Appalachian region. Of the five terraces she (Bell,1986) identified, the highest surface (T5; >23 m AMRL) was deep and intensely weathered. With increasing age, all terraces exhibited mean increases in silt and clay and increased rubification. Terrace Five showed a clay increase with depth. Older deposits no longer contained unweathered parent material, and kaolinite was the dominant clay mineral. Bell (1986) noted considerable downcutting followed each major deposition, but could not provide absolute dates for the terraces.

Kochel and Simmons (1986) described red paleosols with rotted quartzite clasts several meters below the surface at all the sites they investigated. They (Kochel and Simmons, 1986) suggested such soil development and rock weathering should require either a very long time under present climatic conditions and/or a warm, more humid paleoclimate during which chemical weathering would be hastened.

If it is accepted that the soils described in the above studies (Howard et al., 1993; Bell, 1986; Kochel and Simmons, 1986; Harris et al., 1980) are similar to the soils on the alluvial fans, then they seem to suggest a relationship between the river terraces and the fans. The soils may also imply one or more periods existed when the mountain landscapes were quite unstable and supplied large amounts of sediment to streams. As material washed from the mountains, some washed to the streams and settled on floodplains. The sediment not reaching a river collected to form the alluvial fans.

Rather than advocating the theory of single depositions spaced randomly through time, Mills (1982) thought it more reasonable to attribute footslope deposits in North Carolina to a large number of depositional events relatively closely spaced in time (within an interval of several thousand years). He believed this because the deposits seemed much to voluminous to be accounted for by one event. This theory reasonably applies to the alluvial fans because of their similarity and extent throughout central Virginia.

It seems sustained, high-energy water flow would have been necessary to carry the sediments, particularly the rocks, the distances they were transported. Unit A is different from unit B in that it is relatively coarse fragment-free. Unit A could have been emplaced by infrequent rainfall events like those Kochel and Johnson (1984) advocate or by other mechanisms such as creep on steeper slopes. The solum thicknesses I observed also correspond to the thicknesses that Kochel and Johnson (1984) recorded.

In conclusion, the deep, highly weathered soils formed on alluvial fans along the western footslopes of the Blue Ridge are similar to each other based on the degree of development, chemistry, and mineralogy. Points of similarity include silt and sand percentages of unit A; high clay percentages of unit B; abundant clay-fraction kaolinite, HIV, and gibbsite; low pHs and ECECs; and high exchangeable Al. Nearly all soils are Typic Paleudults. Some are Fragiudults with palic clay distributions.

The alluvial-fan soils are possibly related to terrace soils of the New, the Shenandoah, and the James rivers because the terrace soils have properties much like the fan soils. No definitive ages other than those offerred by Howard et al. (1993) have been determined for the fan soils.

The late Miocene age suggested by Howard et al. (1993) seems probable for the alluvial-fan soils because of the chemical and mineralogical composition of the thick argillics and the presence of intensely weathered quartzite rocks. Future work should clarify the relationship between the alluvial fans and the river terraces.

Chapter 4

STATISTICAL VERIFICATION OF SOIL DISCONTINUITIES IN VIRGINIA

(ABSTRACT)

Soil discontinuities, defined by significant texture, mineralogical, and/or age differences, are usually verified from a small number of pedons without gaining information about their spatial extent. Their extent has important implications for both land use and soil genesis/geomorphology interpretations. Along the western footslopes of the Virginia Blue Ridge, Typic Paleudults and Typic Fragiudults formed on alluvial fans appear to have at least two depositional sequences in the sola. Soil texture differences and abrupt color changes suggest discontinuities are present. The objective was to determine if discontinuities occur in the soils by validating their presence spatially at four locations. Stratified systematic unaligned sampling within a 50 m^2 area, the Wilcoxon Signed-Rank test, principal component analysis (PCA), and discriminant analysis (DA) were used to verify the discontinuities. Of 25 soil properties evaluated by the Wilcoxon Signed-Rank test, 21 at Site 1, 18 at Site 2, 14 at Site 3, and 16 at Site 4 were significantly different at the 10% level of probability. After PCA of the significantly-different properties, principal component loadings showed the properties contributed about equally to the first principal component. The second component loadings

found clay-free properties to be the best indices for defining the discontinuities. Discriminant analysis of scores from the first five principal components showed the components contributed from 91 to 96% to the discriminant functions. Discriminant functions clearly separated unit A from unit B at each site. Hotelling's T^2 test showed the distances were significant ($P \leq 0.001$) between unit A and unit B multivariate means. After removing the portion of the distance, which separates multivariate means, contributed by the most influential PC, the distance at every pedon was still greater than the minimum Mahalanobis' distance necessary to say statistically that a discontinuity exist. Thus, discontinuities are present at the four locations, and they can be observed spatially by significant textural differences and clay-free properties. Soil discontinuities should be expected during any investigations of the Blue Ridge alluvial fans in central Virginia.

INTRODUCTION

Soil discontinuities are defined by significant changes in particle-size distribution or mineralogy that indicate a difference in the material from which the horizons formed, and/or a significant difference in age (Soil Survey Staff, 1992). Since discontinuities impact our concepts of both soil genesis and landscape evolution, we need to know the spatial extent of surficial geomorphic events. Information gained regarding the spatial extent could aid mapping by correlating soils to specific geomorphic surfaces.

Several methods can be used to confirm parent material uniformity, discontinuities, or intervals between deposition (Wang and Arnold, 1973; Sudom and St. Arnaud, 1971; Chapman and Horn, 1968; Foss and Rust, 1968; Beavers et al., 1963). The methods depend upon depth-distributions of elemental Zr, Ti, and K or molecular ratios of CaO/ZrO_2 or TiO_2/ZrO_2 to decide where within the soil profile the discontinuity occurs. Recently, Bartenfelder and Karathanasis (1991) used quartz thermal activation energy to find lithological and age discontinuities in Kentucky soils. Stone lines (Ruhe, 1959; Parizek and Woodruff, 1957) and abrupt color changes with depth (Waltman et al., 1990) also corroborate soil discontinuities. Although the methods confirmed discontinuities, most studies used a small number of pedons to verify the discontinuity. The discontinuity was interpreted where the largest data value difference occurred between two points, but the values at the two points were not usually tested for significance.

The sedimentological nature of some alluvial fans in central Virginia suggests they should have soil discontinuities. For example, Kochel and Johnson (1984) reported cobble and pebble imbrication and crude upward-fining sequences in alluvial fans near the Blue Ridge province. Geomorphology studies from central and northern Virginia separated depositional events on fan surfaces. The deposits were referred to as gravel units (Kochel and Johnson, 1984; King, 1950; 1949), sedimentation units (Kochel and Simmons, 1986), or alluvial aprons (Hack, 1965). However, none of the research attempted to separate geomorphic events within the sola.

Multivariate procedures for data analysis such as cluster analysis enhance our ability to establish natural groups (Edmonds et al., 1985). Discriminant analysis and principal component analysis reduce large data sets to a few variables which best describe the natural groups (Edmonds and Lentner, 1987; Seelig et al., 1991). Nonparametric statistical methods are tools for determining the influence variables can have on properties and classification of soils (Edmonds and Martens, 1990).

Because previous research did not recognize discontinuities in the soils of the region, but soil features suggest discontinuities occur in the soils, the objective was to determine if discontinuities occur in soils formed in alluvial fans near the western slopes of the Blue Ridge by validating their presence spatially at four locations with a sampling scheme coupled with nonparametric and multivariate statistics.

MATERIALS AND METHODS

Site Locations and Characteristics

Study areas are near the western slopes of the Blue Ridge in Botetourt (Site 1, Fig. 3.2), Augusta (Site 2, Fig. 3.6), Rockingham (Site 3, Fig. 3.8), and Page (Site 4, Fig. 3.9) counties, Virginia. Sites 1, 2, and 4 are in mixed hardwood forest, and Site 3 is in pasture. Slopes range from 1 to 10% (Table 4.1). Site 1 occurs on the proximal segment of a fan; whereas, Site 3 occurs on the distal end of a fan. Sites 2 and 4 occupy approximately mid-fan positions. All sites are on stable interfluves. Each site has weak to moderate soil development in the upper solum. Lower sola are well developed, deep argillic horizons, some with strongly contrasting redoximorphic features and all with highly weathered quartzite clasts. The four sites were selected after reconnaissance investigations revealed similar soils throughout the study area. Statistical analyses were not used prior to site selection to verify discontinuites at the

Table 4.1. Partial characterization data and site characteristics of a typical pedon from each of the four study sites.

Feature	Site			
	1	**2**	**3**	**4**
Unit A horizon	Bt2	Bx	E′	Btx
and depth (cm)	64-99	48-81	74-90	44-64
Unit B horizon	2Bt3	2Bt1	2Bt1	2Bt1
and depth (cm)	99-143	81-114	90-112	64-82
Unit A thickness (cm)	99	81	90	64
Texture				
unit A	loam	sandy loam	loam	loam
unit B	clay	clay loam	clay	clay
Sand (g kg^{-1})				
unit A	477	525	382	474
unit B	236	401	229	273
Silt (g kg^{-1})				
unit A	370	439	435	425
unit B	313	297	332	321
Color				
unit A	5YR 5/8	10YR 6/4	10YR 6/3	10YR5/4
unit B	5YR 5/8	5YR 5/6	7.5YR 5/6	7.5YR 5/6
Lower 2Bt color	2.5YR4/6	2.5YR 4/6	10R 3/6	2.5YR 4/8
Lower 2Bt texture	clay	clay	clay loam	clay
Lower 2Bt depth (cm)	143-200	156-192	156-200	106-151

sites.

Sample Number Estimation

The first step prior to sampling was to decide upon the appropriate confidence level with which to say a discontinuity is present. An 85% confidence level was decided upon by extending the definition of a consociation, which states limiting inclusions should not exceed 15% (Soil Survey Staff, 1993). With the formula $(1-\alpha)100\%$, where $\alpha = 0.15$, the confidence level becomes 85%. I did this because I considered a pedon with no significant evidence of a discontinuity as an inclusion.

Secondly, the size sample needed to test the hypothesis that discontinuities occur in the soils can be found from the following equation

$$n = pq\left[\frac{Z_{\left(\frac{\alpha}{2}\right)}}{E}\right]^2 \qquad \textbf{[1]}$$

where n is the number of samples necessary, p is the probability of successfully observing a discontinuity, $q = (1-p)$ or the probability of failing to observe a discontinuity, Z is the area under the standard normal curve, and E is the predetermined maximum acceptable error of the point estimate (Freund and Smith, 1986). Equation [1] will be used to find the appropriate sample size for future discontinuity investigations in the region.

Equation [1] is used when information about p is available. When information is not available, each pedon stands a 0.50 chance of either having or failing to have a discontinuity. So, without information about p, pq = (0.50)(0.50) = 0.25 and

$$n = \frac{1}{4}\left[\frac{Z_{\left(\frac{\alpha}{2}\right)}}{E}\right]^2 \qquad \textbf{[2]}$$

Equation [2] was used to determine the number of samples to collect. I chose $E = 0.15$ (which yields 1.44 as the table value for $Z_{\alpha/2}$) because it allowed me to calculate a feasible number of samples without unnecessarily exceeding the sample size. After Eq. [2] is solved, $n = 24$ pedons at each site. For convenience, I sampled 25 pedons except where coarse fragments prohibited auger sampling, in which case less than 25 profiles were sampled.

Field Methods

A 5 x 5 matrix of 10 m^2 sampling cells at each site served as the base for randomly sampling a single pedon in each 10 m^2 cell. The sampling design, called stratified systematic nonaligned (Campbell, 1987), is shown in Fig. 4.1. It prevents sample clustering, and it maintains randomness. Pedon locations were assigned within each cell by subdividing each cell into 3.33 m intervals along both the X and Y axes. A random numbers table was used to assign pedon coordinates within each cell.

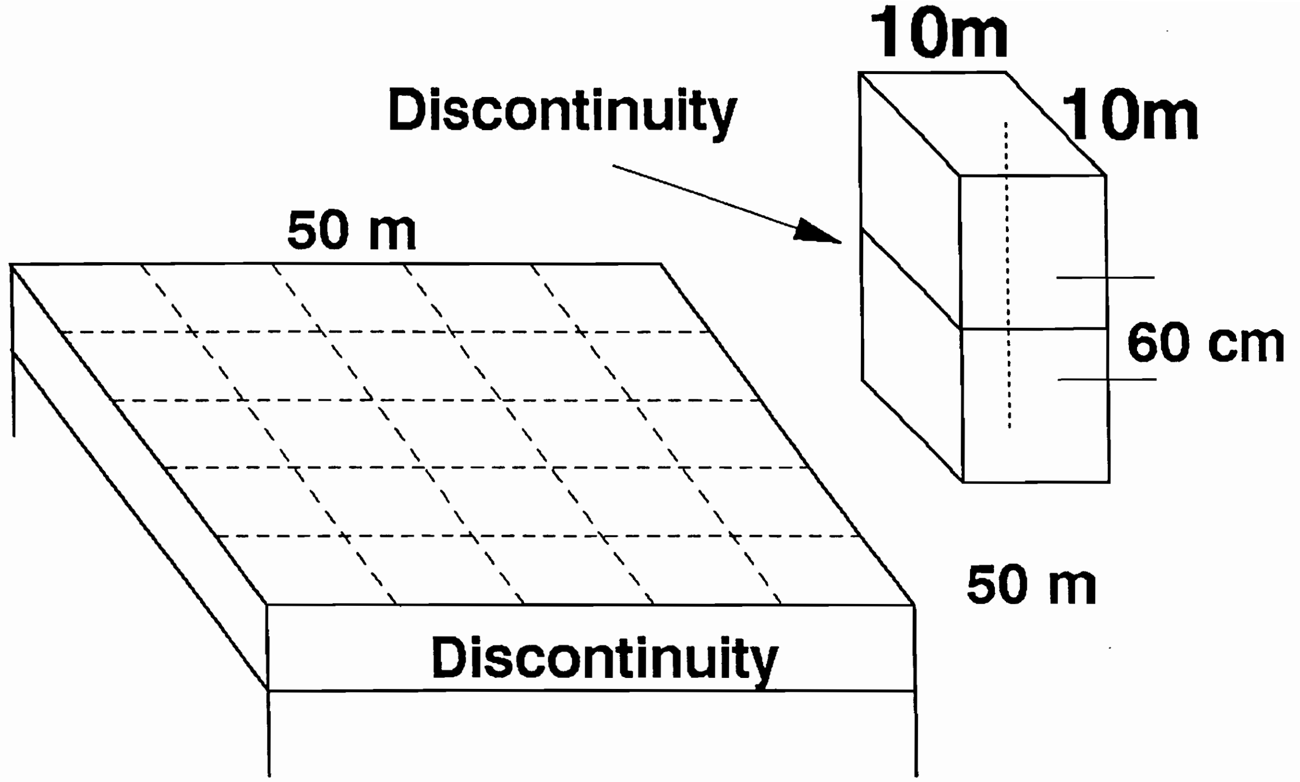

Figure 4.1. The schematic diagram shows the stratified systematic nonaligned sampling grid. The inset represents one cell.

Color and texture changes were the primary indicators suggestive of the discontinuities. Samples were taken with a hand auger (diam. = 7.6cm) about 30 cm above and 30 cm below the discontinuity (Fig. 4.1). The interval between samples was wide enough to minimize soil mixing at the discontinuity. Henceforth, the phase above the discontinuity will be called unit A, and the phase below the discontinuity will be called unit B.

Laboratory Methods

Samples were air-dried, sieved to remove rock fragments >2.0 mm, and ground to pass a 2.0 mm sieve. Particle-size samples were deferrated by the method of Holmgren (1967) and washed free of salts prior to particle-size analysis (PSA) by pipet and sieve (Gee and Bauder, 1986). On different subsamples, dithionite-citrate bicarbonate (DCB) Fe was quantified by atomic absorption spectrophotometry. The Fe was assumed to be part of the clay fraction for particle-size calculations.

Another 10g whole-soil subsample was deferrated before heavy mineral extraction. After sedimentation of the >2.0 μm fraction, the clay was siphoned and discarded. Sand and silt were separated by wet-sieving. Sand- and silt-sized heavy minerals (SG >2.88) were extracted with bromoform (SG = 2.88-2.90) in 100 ml polyproplyene centrifuge tubes. Sand-sized heavy minerals were separated by sedimentation in the tubes;

silt-sized heavy minerals were separated centrifugally based on centrifuge time and speed equations given by Tanner and Jackson (1947). After the heavy minerals settled, tube bottoms were placed in liquid N_2, freezing the bottom liquid and leaving a supernatant with the light fraction. The light-mineral fraction was decanted, filtered, and washed with acetone to remove excess bromoform. The heavy-mineral fraction was treated likewise after the bromoform thawed. Both fractions were measured gravimetrically.

Twenty-five measurements (Table 4.2) from the PSA and the heavy mineral analyses were considered for statistical analysis. Several clay-free ratios were included to evaluate weathering trends within the pedons.

Statistical Methods

The UNIVARIATE procedure (SAS Institute Inc., 1985a) was used to calculate probabilities ($P = 0.10$) associated with the Shapiro-Wilk W-statistic. This test determined if the data were random samples from normal distributions.

The unit A sample was paired with the unit B sample for each pedon because they were exposed to the same climatic treatment effects (i.e., rainfall and temperature). Since a significant difference between the units is implied by a discontinuity, I used the Wilcoxon Signed-Rank test to evaluate the difference between unit A and unit B. This test obtains the differences between pairs of observations, ranks

Table 4.2. Definitions of symbols used in the analyses.

VCS = very coarse sand
CS = coarse sand
MS = medium sand
FS = fine sand
VFS = very fine sand
TOTS = total sand
CSI = coarse silt
MSI = medium silt
FSI = fine silt
TOTSI = total silt
CFS = clay-free sand
SIND† = sand index, (((MS+FS)/TOTS)*100)
TSTSI = total sand/total silt
CFMS = clay-free medium sand
CFFS = clay-free fine sand
CFVFS = clay-free very fine sand
CFMSFS = CFMS/CFFS
CFMSVFS = CFMS/CFVFS
HVSI = heavy silt
HVS = heavy sand
HSILSI = heavy silt/light silt
HSLS = heavy sand/light sand
HWH = >0.002 mm heavy minerals, whole-soil basis
LWH = >0.002 mm light minerals, whole-soil basis
HLWH = HWH/LWH

† (Hoover and Ciolkosz, 1988)

the absolute values of the differences from smallest to largest, assigns to each rank the sign of the difference whose absolute value yielded that rank, sums the ranks with positive signs, and sums the ranks with negative signs. For this test,

$$H_O\text{: } \boldsymbol{\theta} = 0 \qquad \textbf{[3]}$$

against

$$H_A\text{: } \boldsymbol{\theta} \neq 0 \qquad \textbf{[4]}$$

where θ is the median of the population of differences. If H_O is true, we expect the sum of the ranks with positive signs to be about equal to the sum of the ranks with negative signs (Daniel, 1990). The Signed-Rank test does not assume standard normal populations, but it does assume the distribution of the population of differences is symmetric (Daniel, 1990).

The Signed-Rank test is appropriate for paired samples when the data are interval (i.e., there is a fixed unit of measurement, e.g. PSA presented as g kg^{-1}) or ratio (i.e., there is a true zero, indicating an absence of the trait being measured, e.g. CFS/CFSI). The UNIVARIATE procedure (SAS Institute Inc., 1985a) was used to calculate probabilities (P = 0.10) associated with the Wilcoxon Signed-Rank test. To maintain open data sets, CSI was omitted from all sites; VCS and HLWH was omitted from Site 1; HSILSI was omitted from

Site 2; CFMSVFS was omitted from Site 3; and LWH was omitted from Site 4.

A Hodges-Lehmann estimate of the median difference based on Walsh averages and Tukey's distribution-free confidence intervals was calculated for each property (Tables B.1 - B.4). Where applicable, the Moses distribution-free ranklike test can test for equal dispersion

$$H_O = \gamma^2 = \frac{\sigma^2{}_2}{\sigma^2{}_1} = 1 \qquad [5]$$

against

$$H_A\colon \gamma^2 \neq \frac{\sigma^2{}_2}{\sigma^2{}_1} \neq 1 \qquad [6]$$

between the specified property above and below the discontinuity (Hollander and Wolfe, 1973). The Virginia Tech Nonparametric Statistics Package (Pirie, 1988) was used to calculate Hodges-Lehmann estimates, confidence intervals, and probabilities associated with the Moses ranklike test for dispersion.

Multivariate Methods

The RANK option (SAS Institute Inc., 1985b), which gives results with the same $\bar{X}$ and s^2, was used to rank the data before PCA because multivariate procedures are based on assumptions of normally distributed data. Ranks order observations by magnitude without indicating how much the difference is between ranks. This lets us make more-than less-than statements about pairs (Spence et al., 1990), and focus on whether unit A is consistently different from unit B across the landscape.

Principal component analysis considered all properties from a site simultaneously, and generated one principal component score for each sample. It computed a variance-covariance matrix (Tables B.5 - B.8) expressed as a series of eigenvectors, or principal components, in multidimensional space. The number of components equaled the number of variables. Eigenvalues represented vector lengths (Davis, 1986). The principal component (PC) became the new variable and the score became the measurement of the new variable. Principal component analysis removed all correlation among variables because the eigenvectors were mutually orthogonal. The PCA was applied to data from each individual grid. Scores from the first five PCs were used to calculate discriminant functions for each site.

Principal component loadings are coefficients of the linear equation which define the eigenvector. Loadings reflect the relative importance of a variable within a principal component, but they do not reflect the importance of the component itself (Davis, 1986). Loadings can be used to select properties (Edmonds et al., 1986) that best define the discontinuity. The PRINCOMP procedure (SAS Institute

Inc., 1985b) was used to calculate principal components from the original ranked variables, loading values of the variables, and PC scores.

Since PCA is not a statistical method, but a mathematical manipulation (Davis, 1986), it does not test significance. Discriminant analysis is a statistical procedure, which was used to determine statistical significance between unit A and unit B PC scores.

Discriminant analysis created a linear function from the two groups of PC scores of the form

$$R = \lambda_1\psi_1 + \lambda_2\psi_2 + \ldots + \lambda_m\psi_m \qquad [7]$$

where λ = coefficients of the discriminant equation, ψ = the variables (principal components) which characterize units A and B, and m = the number of these variables. The function produced the maximum difference and the least variance between unit A and unit B. Also, it transformed the PC scores for a given observation to a single discriminant score (Davis, 1986). Multivariate means (R_A and R_B) of units A and B were found by the equations

$$R_A = \lambda_1\bar{A}_1 + \lambda_2\bar{A}_2 + \ldots \lambda_m\bar{A}_m \qquad [8]$$

and

$$R_B = \lambda_1\bar{B}_1 + \lambda_2\bar{B}_2 + \ldots \lambda_m\bar{B}_m \qquad [9]$$

where $\bar{A}_x$ and $\bar{B}_x$ are the multivariate means of PC scores for units A and B for PRIN_x.

Substitution of the midpoint between the two group means for units A and B in Eq. [7] gave the discriminant index (R_0).

The resulting equation was

$$R_0 = \lambda_1 \frac{\bar{A}_1 + \bar{B}_1}{2} + \lambda_2 \frac{\bar{A}_2 + \bar{B}_2}{2} + \ldots + \lambda_m \frac{\bar{A}_m + \bar{B}_m}{2} \qquad \textbf{[10]}$$

The multivariate distance between R_A and R_B is Mahalanobis' distance (D^2) (Davis, 1986). The hypothesis of no significant difference between R_A and R_B ($D^2 = 0$ or $R_A = R_B$) was tested by Hotelling's T^2, which can be transformed to an F test.

The amount of separation between R_A and R_B contributed by a single PC score (i) can be estimated by

$$D_i = \frac{\bar{A}_i - \bar{B}_i}{D^2} 100 \qquad \textbf{[11]}$$

(Edmonds et al., 1987). Discriminant functions, scores, and D^2 were calculated by the DISCRM program (Davis, 1986).

The minimum, or critical, Mahalanobis' distance (D^2_{min}) needed to say a discontinuity occurred at a given site was calculated by solving the following equation for D^2

$$F = \left(\frac{n_a + n_b - m - 1}{(n_a + n_b - 2)m}\right)\left(\frac{n_a n_b}{n_a + n_b}\right) D^2 \qquad \textbf{[12]}$$

with m and $(n_a + n_b - m - 1)$ degrees of freedom where F = the critical $F_{(0.10)}$ determined using Table S (Rohlf and Sokal, 1969), m = the number of variables and n = the number of observations (Davis, 1986).

Next, pedon scores were subtracted to find the difference between unit A and unit B for each pedon. Then D_i was estimated for the first PC with Eq. [11], the distance multiplied by D_i, and the product subtracted from the score distance at the corresponding pedon. The final value was the score distance minus the contribution of the most-contributing PC. The final value was compared to D^2_{min} to determine q for each site. Finally, with this information we used Eq. [1] to determine the actual number of samples required to verify discontinuities at other locations within the region.

RESULTS AND DISCUSSION

Nearly level to strongly sloping fan surfaces (Table 4.1) are dissected by intermittent and perennial streams generally 600 to 1200 m apart (U.S. Geological Survey, 1977; 1979; 1985; and 1987). Unit A thicknesses are fairly consistent across the sites except for Site 4, which is thinner. At all sites, unit A typically has more silt and sand than the adjacent underlying horizons of unit B. The E′ horizon at Site 3 indicates lateral water flow across the contact with unit B. Imbricated rocks in the lower solum of

Site 3 suggest emplacement by a stream. The upper sola were emplaced by an unknown process. Texture and color differences mark the discontinuity at all sites. Red hues in the lower sola emphasize the age differences between the two units.

Statistical Analysis

Table 4.2 defines the variables used in this study. From Table 4.3 one can see the Shapiro-Wilk test indicates several properties have nonnormal distributions at the 10% level of probability. Nonnormal distributions may arise when little variation occurs in the property being considered and when the property is heavily skewed. For example, small variation in sand sizes could be caused by similar depositional energies across the landscape, or by little variation in the source material.

After exclusion of the aforementioned variables to maintain open data sets, 19 properties from Site 1, 17 from Site 2, 13 from Site 3, and 15 from Site 4 are significantly different at the 10% level of probability by the Wilcoxon Signed-Rank analysis (Table 4.3). These are the properties which were ranked and to which PCA was applied.

Several clay-free properties and SIND are statistically significant, suggesting two depositional units with different particle-size distributions occur at the sites. Clay distribution is subject to pedogenic change and may mask

Table 4.3. Soil properties†, p-values for Shapiro-Wilk (W) test of normality and p-values associated with Wilcoxon Signed-Rank (S) test for determining if members of paired observations differ.

	Site							
	1		2		3		4	
	$\alpha(W)$	$\alpha(S)$	$\alpha(W)$	$\alpha(S)$	$\alpha(W)$	$\alpha(S)$	$\alpha(W)$	$\alpha(S)$
VCS	0.5346	0.0046	0.3116	0.6995	0.7975	0.0313	0.0655	0.1563
CS	0.7356	0.0001	0.1311	0.0001	0.1533	0.6875	0.1936	0.7422
MS	0.1153	0.0001	0.7965	0.0001	0.1082	0.0625	0.5720	0.4609
FS	0.1691	0.0001	0.6564	0.0001	0.5838	0.0313	0.3926	0.0391
VFS	0.7281	0.0001	0.8612	0.0001	0.1755	0.0625	0.3543	0.0156
TOTS	0.1307	0.0001	0.1084	0.0001	0.1954	0.0625	0.7866	0.0547
MSI	0.0061	0.0001	0.0688	0.0001	0.3707	0.0313	0.5813	0.0078
FSI	0.0246	0.0001	0.0697	0.0001	0.0680	0.1563	0.1013	0.0078
TOTSI	0.4363	0.0001	0.6605	0.0001	0.8502	0.0313	0.2867	0.0078
CFS	0.0914	0.0001	0.0453	0.4684	0.2725	1.0000	0.1392	0.0391
SIND	0.5787	0.0001	0.8603	0.0001	0.2515	0.0313	0.3160	0.0547
TSTSI	0.4698	0.0001	0.2570	0.3698	0.6043	1.0000	0.5187	0.0391
CFMS	0.7132	0.0001	0.7651	0.1434	0.4627	0.6875	0.6019	0.0781
CFFS	0.3154	0.0001	0.4576	0.0009	0.0209	0.0313	0.8420	0.3828
CFVFS	0.3421	0.0005	0.8452	0.0001	0.9662	0.0313	0.8684	0.1484
CFMSFS	0.6212	0.3189	0.1023	0.0050	0.8647	0.1563	0.1006	0.0781
CFMSVFS	0.4135	0.0005	0.7368	0.0001	0.4774	0.0938	0.0495	0.0781
CFFSVFS	0.9454	0.0101	0.2076	0.0001	0.3272	0.3272	0.3836	0.1953
HVSI	0.1014	0.2387	0.0005	0.0009	0.7358	0.2188	0.0666	0.3125
HVS	0.0922	0.0340	0.1010	0.8600	0.0970	0.0313	0.9346	0.0547

Table 4.3. (cont.) Soil properties†, *p*-values for Shapiro-Wilk (*W*) test of normality and *p*-values associated with Wilcoxon Signed-Rank (*S*) test for determining if members of paired observations differ.

	Site							
	1		2		3		4	
	$\alpha(W)$	$\alpha(S)$	$\alpha(W)$	$\alpha(S)$	$\alpha(W)$	$\alpha(S)$	$\alpha(W)$	$\alpha(S)$
HSILSI	0.0398	0.2387	0.0001	0.0009	0.7120	0.2188	0.0573	0.3125
HSLS	0.0785	0.0328	0.1248	0.8961	0.0947	0.0313	0.9339	0.0781
HWH	0.1012	0.9480	0.0009	0.1245	0.6154	0.8438	0.0001	0.0156
LWH	0.8796	0.0001	0.9615	0.0001	0.9267	0.0625	0.7814	0.0078
HLWH	0.0254	0.0930	0.0002	0.0008	0.8235	0.2188	0.0043	0.7422

† Soil properties are keyed to Table 2.

inherited lithologic differences. Clay-free properties are reliable indices for evaluating parent material uniformity (Hoover and Ciolkosz, 1988). The indices should remain fairly constant with depth in soils formed from uniform parent material.

Hodges-Lehmann estimates of the true median for the significantly different properties are shown in Tables B.1 - B.4. For each site we are 89.99% confident the intervals contain the true median. The Moses Ranklike test tests for equal dispersion or variance when sample sizes are large enough, as they are for Sites 1 and 2. Clearly, there is lack of evidence for dispersion differences for several properties at these sites. At best there is only marginal evidence ($P = 0.04$) against H_o, meaning we do not have sufficient evidence to state variation is higher for a given property in unit A than in unit B. This suggests the method of deposition, particle sorting, and/or the source area is probably the same for both units. It can also mean laboratory variation is about the same as well.

Principal Component Analysis

A measure of the amount of information conveyed by each PC is its variance. Table 4.4 presents the proportion each of the first five eigenvalues contribute to the total variance. The first component alone contributes between 56 and 72%. The first five PCs account cummulatively for 91% of

Table 4.4. Proportions of the total variance contributed by the principal components.

Eigenvector	Eigenvalue	Proportion	Cumulative
		%	%
Site 1			
PRIN1	10.67	56	56
PRIN2	2.36	12	68
PRIN3	1.57	8	76
PRIN4	1.48	8	84
PRIN5	1.27	7	91
PRIN6-19	--	--	9
Site 2			
PRIN1	10.34	61	61
PRIN2	1.90	11	72
PRIN3	1.35	8	80
PRIN4	1.25	7	87
PRIN5	0.76	4	92
PRIN6-17	--	--	8
Site 3			
PRIN1	9.34	72	72
PRIN2	1.47	11	83
PRIN3	0.92	7	90
PRIN4	0.40	3	93
PRIN5	0.36	3	96
PRIN6-13	--	--	4
Site 4			
PRIN1	8.37	56	56
PRIN2	2.36	16	72
PRIN3	1.78	12	84
PRIN4	0.85	6	90
PRIN5	0.73	5	95
PRIN6-15	--	--	5

the total variance in the original properties at Site 1, 92% at Site 2, 96% at Site 3, and 94% at Site 4. After the fifth component, the remaining components contribute little to the total variance. Table B.9 shows the proportion of variance contributed by all eigenvalues.

Scores of the first PCs (Table 4.5) indicate positive scores for unit A and negative scores for unit B. Scores for all PCs appear in Tables B.10 - B.13. The mathematics behind PCA are beyond the scope of this dissertation. Briefly, scores are derived from linear equations with coefficients unique to each depositional unit. Because nearly all PRIN1 scores are positive for unit A, each specific original property within unit A is similar among pedons at a site. The same is true for unit B, since nearly all scores are negative. Scores also indicate a given specific property differs between the two units among pedons.

The magnitudes and signs of the PC loadings indicate the contribution of a soil property to the variance expressed by a given principal component (Edmonds et al., 1986). Many properties with loadings between 0.22 and 0.29 (Table 4.6) contribute about equally to the total variance of the first component (PRIN1). Thus the first component does not adequately distinguish the most suitable properties for detecting the discontinuities. The second component loadings (PRIN2) reveal various clay-free properties are the best

Table 4.5. Principal component scores for each site comparing unit A with unit B. These scores were used for discriminant analysis.

	Site 1, Unit A					Site 1, Unit B				
Pedon	**PRIN1**	**PRIN2**	**PRIN3**	**PRIN4**	**PRIN5**	**PRIN1**	**PRIN2**	**PRIN3**	**PRIN4**	**PRIN5**
1	1.47	0.69	0.45	-0.07	-1.47	-4.89	0.43	0.54	0.83	-0.33
2	3.86	-1.72	-0.91	1.85	-0.32	-1.49	1.07	0.21	-1.36	1.69
3	2.56	2.85	-0.14	0.14	0.18	-3.87	0.80	-0.85	0.62	1.07
4	2.50	1.89	2.49	-0.24	-0.20	-3.18	1.21	-1.83	-0.83	-0.14
5	2.19	-2.31	-1.11	1.67	-0.40	-2.35	0.64	0.41	-0.74	0.09
6	2.83	-1.53	0.06	2.00	0.14	-0.67	-0.84	0.83	0.69	-3.74
7	1.87	1.68	-1.42	0.27	-1.12	-4.50	-0.75	2.20	-0.15	0.20
8	-0.09	2.79	-0.22	0.57	-1.27	-6.17	0.41	-0.61	-0.36	-0.66
9	3.84	-0.48	0.64	-2.94	0.72	-4.94	-1.97	0.97	-0.91	-0.06
10	2.50	-1.15	0.83	1.95	1.67	-1.89	-3.01	0.26	-1.97	-1.44
11	4.36	-1.95	0.29	-1.84	0.18	-2.98	-1.16	2.94	1.43	-0.29
12	3.71	-1.25	-1.20	-0.53	0.33	-0.16	-3.20	0.24	1.93	0.92
13	2.09	0.18	0.65	1.16	-1.82	-4.92	-0.47	-0.49	-1.21	-0.29
14	0.50	3.32	1.35	1.34	-0.26	-5.09	-0.14	-1.76	-0.43	-1.46
15	2.42	0.61	-1.55	-0.10	0.83	-3.51	0.00	0.96	-0.34	0.83
16	3.96	-0.19	-0.62	-0.51	0.23	-1.85	1.85	1.25	-0.61	-1.31
17	3.16	-1.52	1.88	-0.40	-1.12	-5.85	-0.94	0.19	0.30	1.73
18	1.56	-0.42	-1.27	1.33	0.05	-2.71	-0.26	-0.35	1.87	1.18
19	3.99	0.52	-1.57	0.52	0.66	-0.44	3.02	-0.30	-0.32	1.21
20	4.11	-0.89	-0.17	-1.34	-0.77	-4.78	-0.70	0.46	0.54	1.31
21	3.62	1.13	2.67	-0.17	-0.18	1.72	-0.15	-0.42	-3.87	0.37
22	3.63	-0.29	0.49	0.01	1.09	-1.75	1.80	-0.21	-0.01	1.07
23	4.15	0.94	1.44	-0.20	2.05	-0.40	2.26	-2.29	0.83	-1.74
24	2.43	-0.56	-0.33	-0.14	-1.06	-2.15	-0.67	-1.68	-0.30	1.15
25	2.56	0.47	-1.13	0.69	0.89	-0.93	-2.02	-2.28	-0.62	-0.38

Table 4.5. (cont.) Principal component scores for each site comparing unit A with unit B. These scores were used for discriminant analysis.

	Site 2, Unit A					Site 2, Unit B				
Pedon	**PRIN1**	**PRIN2**	**PRIN3**	**PRIN4**	**PRIN5**	**PRIN1**	**PRIN2**	**PRIN3**	**PRIN4**	**PRIN5**
1	4.08	-1.27	-0.62	-0.07	1.74	-1.85	0.29	2.05	-0.47	1.29
2	2.22	2.66	0.76	0.16	0.76	-1.39	-1.08	1.28	-2.14	0.86
3	1.35	-1.04	0.76	1.88	-0.72	-1.61	1.95	2.60	-0.17	0.36
4	1.63	0.65	-0.13	0.48	0.72	-3.48	1.59	0.02	0.01	0.20
5	2.88	0.89	-2.19	0.00	0.56	-0.79	0.73	-1.38	1.11	-0.07
6	2.35	-0.02	0.67	0.63	0.69	-1.51	-3.32	0.69	-1.90	0.70
7	1.25	-0.06	2.15	1.28	-0.23	-3.94	1.17	0.70	-1.06	0.90
8	3.09	-0.51	2.23	-1.48	-0.53	-3.12	-3.28	-0.17	-0.80	-0.32
9	3.05	-0.21	-0.47	-0.27	-0.07	-4.28	-0.34	-1.85	0.50	0.44
10	3.71	-0.04	-1.02	1.05	0.29	-4.27	-0.39	-0.81	-0.54	0.05
11	2.80	1.66	-0.15	0.42	1.01	-3.67	0.60	-0.64	-0.29	-0.49
12	4.01	0.09	-1.06	0.35	0.34	-3.57	0.80	0.69	0.14	-0.09
13	2.91	-1.26	0.23	0.31	-0.69	-3.64	-0.10	0.21	1.53	-1.50
14	3.01	1.08	0.08	0.26	-0.68	-2.19	-1.28	0.18	1.30	1.39
15	4.04	-1.35	-0.23	-2.00	0.38	-4.66	0.66	-1.25	-0.32	0.22
16	3.06	2.75	0.63	-0.24	-0.16	-2.07	0.31	-1.48	-1.94	-1.69
17	4.62	-0.94	0.19	-0.50	-2.05	-3.45	0.71	1.74	0.73	-2.05
18	4.32	1.10	-0.93	0.15	-0.82	-2.65	2.43	-1.53	-2.10	0.23
19	2.76	-1.75	-1.61	0.37	-0.30	-4.19	-1.14	-0.22	0.15	0.09
20	1.96	-1.76	0.95	2.05	0.81	-2.40	-0.06	-1.25	1.63	0.16
21	3.88	0.04	0.09	-1.70	-1.19	-4.24	-0.92	0.12	1.49	-0.57

Table 4.5. (cont.) Principal component scores for each site comparing unit A with unit B. These scores were used for discriminant analysis.

	Site 3, Unit A					Site 3, Unit B				
Pedon	**PRIN1**	**PRIN2**	**PRIN3**	**PRIN4**	**PRIN5**	**PRIN1**	**PRIN2**	**PRIN3**	**PRIN4**	**PRIN5**
1	2.93	1.15	-0.04	-1.06	0.50	-2.63	-0.11	-0.16	-0.38	0.39
2	3.67	-0.96	-0.43	-0.42	-0.18	-1.13	-1.85	0.48	-0.34	0.30
3	3.19	-0.92	0.95	0.12	0.52	-3.70	1.77	0.25	0.06	-0.17
4	-0.24	-0.55	-0.84	1.48	0.28	-2.18	1.40	1.72	0.23	0.13
5	3.98	0.57	0.33	0.23	-1.50	-3.61	-1.71	0.52	-0.03	-0.57
6	2.58	0.95	-0.76	0.60	0.61	-2.85	0.24	-2.03	-0.48	-0.34

	Site 4, Unit A					Site 4, Unit B				
Pedon	**PRIN1**	**PRIN2**	**PRIN3**	**PRIN4**	**PRIN5**	**PRIN1**	**PRIN2**	**PRIN3**	**PRIN4**	**PRIN5**
1	1.13	1 54	1.17	0.27	1.52	-0.29	-2.76	1.84	-1.66	0.79
2	3.63	-0.26	-0.33	0.85	0.50	-3.30	-1.04	0.90	0.00	0.40
3	3.41	0.61	1.34	-0.62	-2.05	-3.63	-0.60	0.99	0.39	-0.02
4	2.15	1.08	1.04	1.44	0.73	-0.77	-2.42	-1.72	0.01	-0.81
5	3.43	-1.11	-1.33	0.36	-0.14	-2.95	1.05	-0.47	-0.68	-0.29
6	1.21	-1.03	-1.86	0.18	0.38	-2.60	-0.10	-1.32	-0.39	0.62
7	0.59	0.47	-1.23	0.76	-0.31	-0.49	3.44	-1.46	-1.73	0.22
8	3.66	0.20	1.55	-0.56	-0.48	-5.20	0.95	0.91	1.37	-1.07

Table 4.6. Loading values for the soil properties† onto the first and second principal components.

Site 1			Site 2		
Variable	**PRIN1**	**PRIN2**	**Variable**	**PRIN1**	**PRIN2**
CS	0.26	-0.13	CS	0.18	0.21
MS	0.28	0.01	MS	0.24	0.24
FS	0.28	0.00	FS	0.29	-0.12
VFS	0.25	0.29	VFS	0.29	-0.14
TOTS	0.29	0.07	TOTS	0.28	0.07
MSI	0.25	-0.01	MSI	0.25	0.06
FSI	0.08	0.21	FSI	0.22	0.03
TOTSI	0.19	-0.07	TOTSI	0.27	0.17
CFS	0.27	0.18	SIND	0.19	0.15
SIND	0.20	-0.33	CFFS	0.18	-0.47
TSTSI	0.27	0.17	CFVFS	0.25	-0.28
CFMS	0.24	0.02	CFMSFS	-0.21	0.42
CFFS	0.24	0.00	CFMSVFS	-0.25	0.32
CFVFS	0.16	0.50	CFFSVFS	-0.17	-0.03
CFMSVFS	0.17	-0.29	HVSI	-0.21	-0.29
CFFSVFS	0.12	-0.43	LWH	0.29	0.17
HVS	-0.16	0.24	HLWH	-0.22	-0.28
HSLS	-0.16	0.24			
LWH	0.26	-0.00			

Table 4.6. (cont.) Loading values for the soil properties† onto the first and second principal components.

Site 3			Site 4		
Variable	**PRIN1**	**PRIN2**	**Variable**	**PRIN1**	**PRIN2**
VCS	-0.24	0.06	FS	0.27	0.33
MS	0.28	0.19	VFS	0.27	0.25
FS	0.30	-0.02	TOTS	0.16	0.52
VFS	0.30	0.16	MSI	0.28	0.06
TOTS	0.30	0.10	FSI	0.30	0.04
MSI	0.28	0.18	TOTSI	0.32	-0.09
TOTSI	0.26	0.41	CFS	-0.24	0.41
SIND	0.24	-0.20	SIND	0.20	0.06
CFFS	0.21	-0.47	TSTSI	-0.24	0.41
CFVFS	0.26	-0.37	CFMS	-0.29	0.18
HVS	-0.30	0.22	CFMSFS	-0.26	-0.20
HSLS	-0.30	0.23	CFMSVFS	-0.30	-0.06
LWH	0.27	0.44	HVS	0.22	-0.20
			HWH	0.13	0.09

† Soil properties are keyed to Table 2.

indicies for detecting the discontinuities. For example, at Site 1 unit A is separated from unit B by high CFVFS (0.50) and low CFFSVFS (-0.43) ratios. At Site 2, unit A and unit B are separated by CFFS, CFMSFS, and CFMSVFS. At Site 3, the two units are separated mainly by TOTSI, CFFS, and LWH. Total sand, CFS, and TSTSI separate the units at Site 4. Sand and silt variables are logical separators since unit A at the sites has more sand and silt than unit B. Loading values for the variable onto all the PCs are given in Tables B.14 - B17.

Discriminant Analysis

Scores from the first five PCs were used to develop discriminant functions for each site. Function coefficients calculated by multiple linear regression (Davis, 1986) are shown in Table 4.7 along with the percentage contributions the PCs make to the discriminant functions. The first component contributes the most by adding between 82 and 98% to the discriminant functions. Discriminant indices are equal to 0.0000 because the sum of unit A PC scores for PRIN_x is equal to but opposite the sum of unit B PC scores for PRIN_x. When the sums are substituted into Eq. [10] for $\bar{A}_x$ and $\bar{B}_x$, R_0 equals 0.0000.

Discriminant scores clearly separate unit A from unit B at each site (Fig. 4.2 - 4.5). Numerical score values are given in Table B.18. Within a pedon, smaller differences

Table 4.7. Discriminant functions based on principal components for discriminating unit A from unit B at each site.

Variable	Coefficient	Percent Added	R_A	R_0	R_B	α(F)†
			Site 1			
PRIN1	2.3684	95.29	6.9471	0.0000	-6.9471	<0.001
PRIN2	0.4295	0.70				
PRIN3	0.3643	0.33				
PRIN4	1.2229	3.53				
PRIN5	-0.2711	0.15				
			Site 2			
PRIN1	6.4654	97.89	19.8347	0.0000	-19.8347	<0.001
PRIN2	0.3711	0.06				
PRIN3	0.2567	0.02				
PRIN4	2.6684	2.02				
PRIN5	-0.1919	0.01				
			Site 3			
PRIN1	8.1702	89.99	24.3925	0.0000	-24.3925	<0.001
PRIN2	0.7911	0.13				
PRIN3	-4.0469	2.19				
PRIN4	11.0184	7.15				
PRIN5	3.1874	0.54				
			Site 4			
PRIN1	5.2202	82.29	15.2700	0.0000	-15.2700	<0.001
PRIN2	1.4437	1.78				
PRIN3	0.4196	0.11				
PRIN4	7.1442	15.76				
PRIN5	0.4847	0.06				

† *P*-values associated with Hotelling's T^2 test of the equality of the multivariate means.

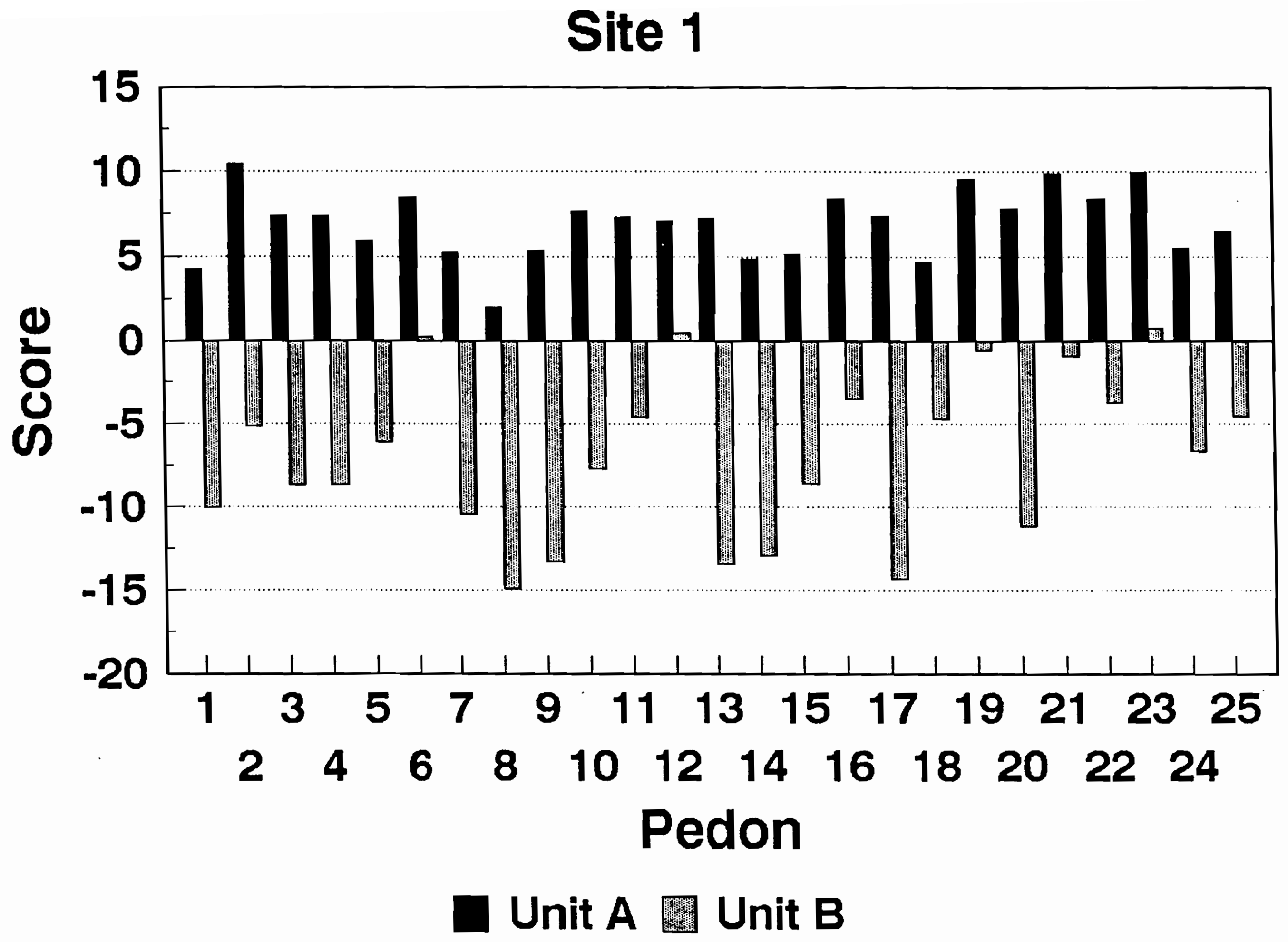

Figure 4.2. Discriminant scores from Site 1 separate unit A from unit B.

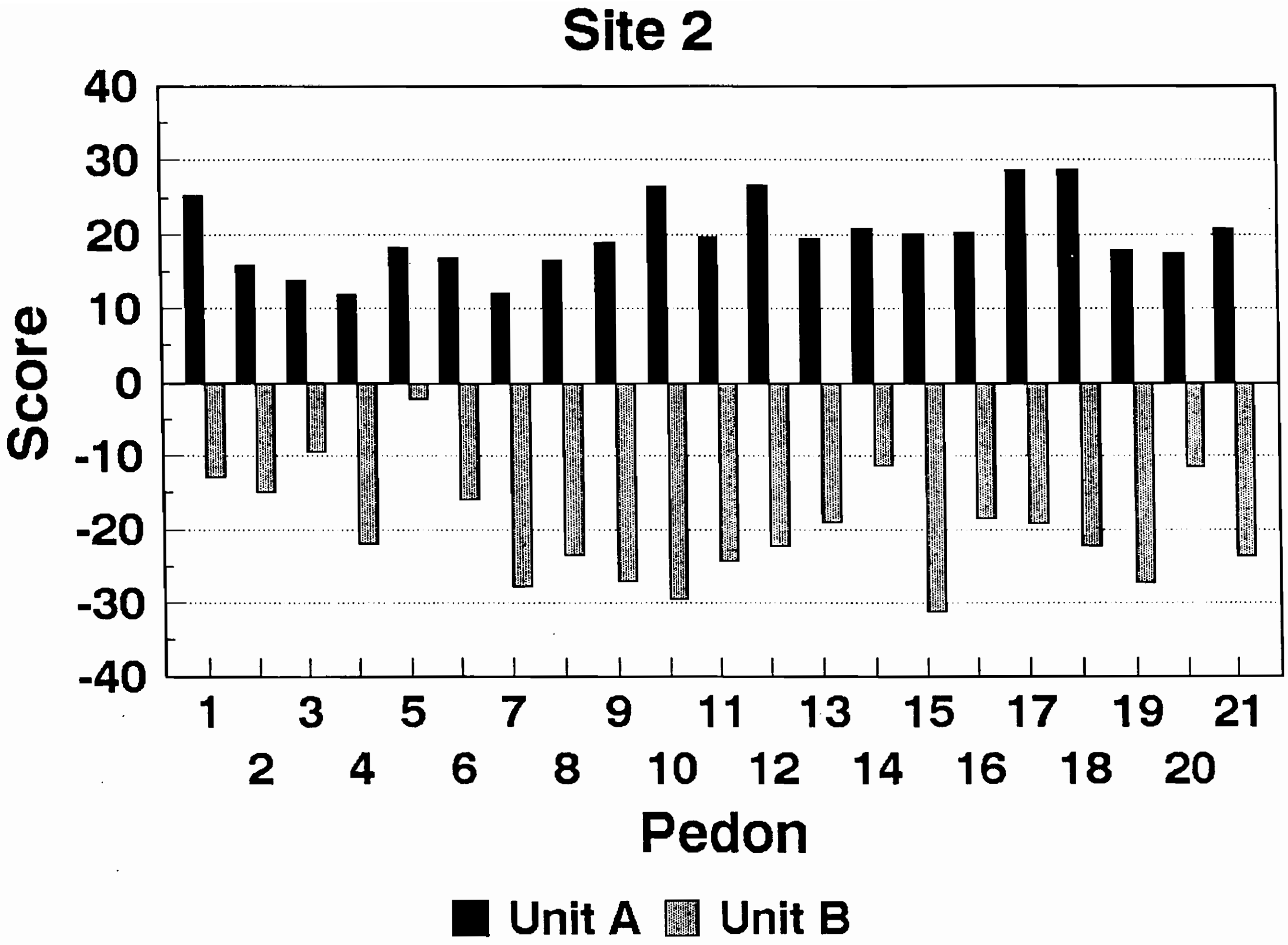

Figure 4.3. Discriminant scores from Site 2 separate unit A from unit B.

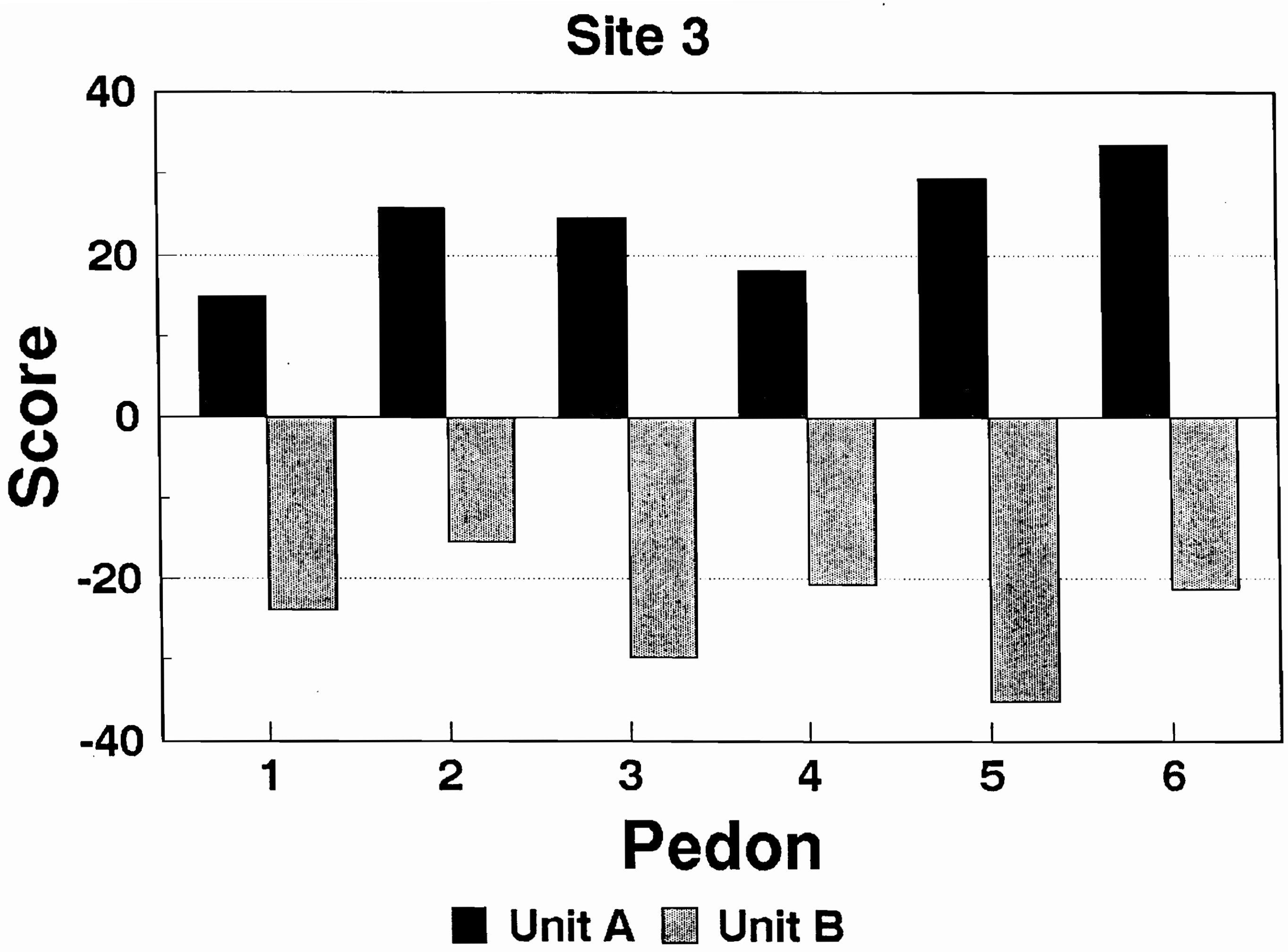

Figure 4.4. Discriminant scores from Site 3 separate unit A from unit B.

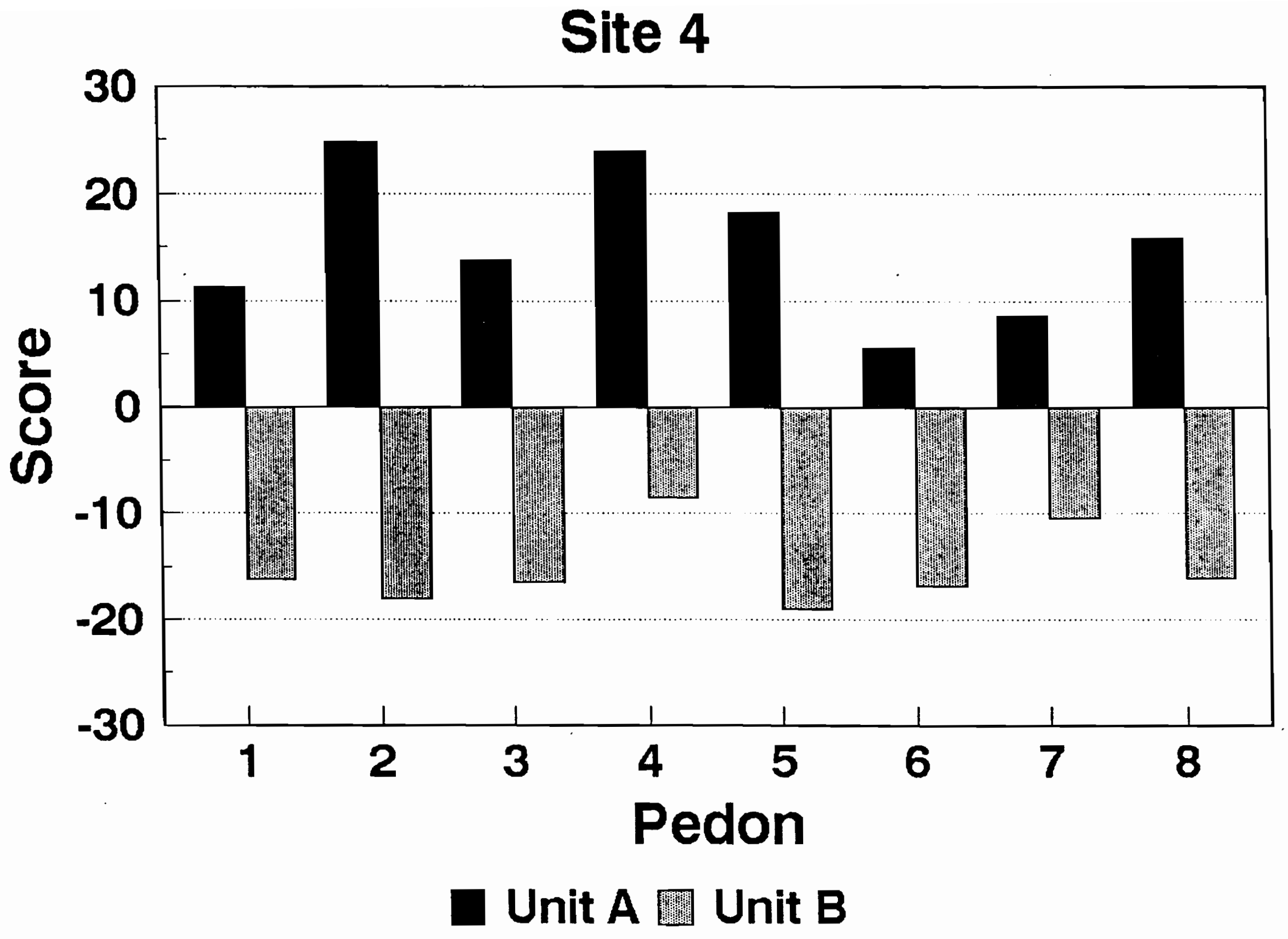

Figure 4.5. Discriminant scores from Site 4 separate unit A from unit B.

between scores for unit A and unit B indicate more similarity between the two units than where score differences are larger. For example, at Site 1 (Fig. 4.2) pedon 17 has a larger difference than pedon 18 at Site 1. Small differences emphasize the importance for making more than one observation in an area because the discontinuity might not be apparent within every pedon. Similarity can result when soil from the two units is combined by treethrow, animal burrowing, or other physical disturbances.

Hotelling's T^2 test (Table 4.7) shows the distance between the multivariate means R_A and R_B at each site is strongly significantly different at the 0.10% level of probability, proving a discontinuity is present at each site. The critical $F_{(0.10)}$, $D^2_{\min}$, and D_i for each site are shown in Table 4.8. The initial intent was to say with at least 85% confidence a discontinuity occurs at each site. But instead I chose to calculate the critical F at the 10% level of probability rather than the 15% level to make $D^2_{\min}$ less conservative and strengthen the conclusion that discontinuities occur.

The new distances (Table 4.9) still exceed $D^2_{\min}$ for all pedons (Table 4.8). Thus, $q = 0$ at all sites. From Eq. [1] $E = 0$ and $n = 0$ for all sites. This implies sampling at other locations in the region is probably unnecessary when unit A thickness approaches 1m.

Table 4.8. **Degrees of freedom, critical $F_{(0.10)}$, Mahalanobis' distance (D^2), D^2_{min}, and, D_i calculated using the first principal component, and used to determine the probability of observing a discontinuity in a pedon.**

	Site 1	**Site 2**	**Site 3**	**Site 4**
df	5,44	5,36	5,6	5,10
$F_{(0.10)}$	1.99	2.02	3.11	2.52
D^2	13.98	39.67	48.79	30.54
D^2_{min}	1.1500	0.9356	0.1157	0.2267
D_i (%)	40.24	15.14	11.01	15.76

Table 4.9. Distances between discriminant scores corrected for D_i to determine the probability of observing a discontinuity at each site.

Pedon	Site 1	Site 2	Site 3	Site 4
1	8.5705	32.3530	34.5804	23.2090
2	9.3131	26.1583	36.6713	36.1523
3	9.5826	19.7605	48.2971	25.6088
4	9.6237	28.7280	34.5747	27.3916
5	7.1909	17.4490	57.5145	31.5025
6	4.9541	28.0086	48.8450	18.9073
7	9.4024	33.9266		16.1307
8	10.0827	34.0356		26.9129
9	11.1408	38.9580		
10	9.1939	47.4697		
11	7.1377	37.4104		
12	3.9622	41.4720		
13	12.3531	32.7442		
14	10.6011	27.2591		
15	8.1877	43.5503		
16	7.1374	32.9982		
17	12.9345	40.6710		
18	5.5947	43.2671		
19	6.0675	38.2217		
20	11.3652	24.7329		
21	6.4837	37.7567		
22	7.2529			
23	5.5501			
24	7.2868			
25	6.6097			

CONCLUSIONS

Discontinuities occur in soils formed in surficial deposits near the western slopes of the Blue Ridge. They can be validated spatially with nonparametric and multivariate statistics. Discriminant analysis found unit A to be significantly different from unit B at all sites. Discriminant scores vary among pedons, supporting the idea that several pedons are required to accurately identify the discontinuity.

Soil morphology is a reliable indicator for locating discontinuites in the alluvial fan soils. Nonnormal distributions for some properties and the Moses Ranklike test for equal dispersion show the source material and methods of deposition were probably similar for both units. Principal component loadings suggest texture properties, particularly clay-free properties, are good indicies for detecting discontinuities. Because discontinuities are present at these locations near the Blue Ridge, it is important to treat the soils as an entity apart from other depositional units when investigating the surficial geology of the region.

Chapter 5

PEDOGENESIS OF DEEPLY WEATHERED SOILS DEVELOPED ON BLUE RIDGE ALLUVIAL FANS, VIRGINIA

(ABSTRACT)

Highly weathered soils along the western footslopes of the Blue Ridge province, central Virginia have characteristics indicative of long-term weathering. This study was conducted to investigate the genesis of these deep, highly weathered soils. Five pedons were selected and studied by standard characterization methods and micromorphological observation. Two depositional phases are present in the soils. For the upper unit (unit A), transitional, argillic, and fragipan horizon bulk densities (ρ_b) range from 1.69 to 2.09 Mg m^{-3} with up to 53% silt. It is believed the fragipans formed at a chronologic discontinuity. At the discontinuity, clay increases abruptly by 20 to 36% from overlying horizons. Free Fe increases from less than 21 g kg^{-1} in the upper unit to as much as 66 g kg^{-1} in adjacent underlying horizons. Many prominent clay films surround peds of the thick, unit B argillic horizons. Clay maxima at 2m range from 33 to 63%. Hydroxy-interlayered vermiculite (HIV) dominates unit A clay mineralogy; whereas, kaolinite is abundant in unit B. Gibbsite notably increases at the discontinuity suggesting either an intense weathering environment prior to burial by unit A or the argillic acted as a sink for Al leached from unit A. Physical and mineralogical properties indicate the

soils developed from sediments and/or lithologies additional to the weathered quartzite found in the sola. Time and climate were the most influential factors controlling soil development, as these soils may have evolved during varying climates.

INTRODUCTION

Sequential pedogenesis is common to alluvial fans in the western and southwestern USA (Eghbal and Southard, 1993; Gile, 1966). Pedogenesis is interrupted or altered by periodic sedimentation across fan surfaces and begins anew each time sediment is delivered. Sedimentation is a response to a climatic event; the soils record the dominant climatic regime during which they formed.

In Virginia, Paleudults developed on alluvial fans along the western footslopes of the Blue Ridge province. Like western alluvial fans, several studies document sedimentology for central Virginia alluvial fans (Kochel and Johnson, 1984; Hack, 1965). Most of the work focused on the deposits' implications toward the geomorphic evolution of the region. However, little attention has been given to the genesis of the soils and how it can help decipher some of the geomorphic history.

Some studies in eastern states investigated soils found on other surficial deposits. In Pennsylvania, Waltman et al. (1990) described soils on the Allegheny Plateau with substratum morphologies that, by their profile descriptions, appear similar to those in Virginia. They (Waltman et al., 1990) interpreted the substratum as truncated paleosols derived from pre-Wisconsin colluvium and residuum from sandstone units capping plateau summits. Substratum color varied with landscape position and drainage, with well drained soils having red to yellowish red matrixes.

In the Valley and Ridge province of Pennsylvania, Hoover and Ciolkosz (1988) investigated colluvium at the base of primary ridges. One to 3 m of brown (10YR to 7.5YR) colluvium typically overlay red (7.5YR to 2.5YR) colluvium. Fragipans occurred in the red colluvium at nearly all sites, and one was described in the brown colluvium at one of the better drained sites. Because the underlying layer had red colors and sandstone fragments with red rinds, and because the brown colluvium formed benches and lobate landforms characteristic of solifluction lobes, the red layer was interpreted as a relict from a previous weathering environment.

Other southern Appalachians studies focused on colluvial deposits and their possible connection to climatic variations. Multiple colluvial generations were identified, and due emphasis was placed on weathering characteristics. In the Grandfather Mountain and Roan Mountain areas and the Dellwood quadrangle, all in the North Carolina Blue Ridge, Mills (1982) analyzed percent clay, hue, and clast weathering of B horizons. With discriminant analysis, 135 footslope deposits were separated into either two or three groups; young, intermediate, and old colluvium. The implications of the study were that the distinct groups probably represent depositional events concentrated in but not confined to certain time intervals. Farther south, along the Blue Ridge Escarpment of northwest South Carolina, Mills (1977) examined colluvial exposures containing weathered igneous and metamorphic rocks. Three distinct units were defined. Soil profiles in the youngest unit expressed little development. The oldest, lowermost unit had red, deep soils; coarse grained lithologies were thoroughly weathered to grus. All of these features were attributed to a long period of post-depositional weathering.

Since we have limited information about soil formation on the central Virginia alluvial fans, my objective was to study the genesis of selected alluvial fan soils by obtaining physical, chemical, mineralogical, and micromorphological data.

MATERIALS AND METHODS

Geomorphology

From Kochel and Simmons (1986), the following summerizes the geomorphology of the alluvial fans. Inactive fans form an extensive bajada along the western footslopes of the Blue Ridge, and they are best developed along the southeastern margin of the Shenandoah Valley. Powerful braided streams appear responsible for emplacing the sediments. Antietam quartzite is the dominant rock in the deposits, and overall sorting is poor. No post-settlement depositional activity is evident. The upper gravel unit has a tan, sandy matrix and unweathered quartzite clasts. A paleosol underlies this facies. It has a red matrix and rotted quartzite clasts.

Procedures

Distinct downslope arcuate contours define the alluvial fan landforms on which the sites occur (U.S.Geological Survey, 1977; 1979; 1985, 1987). Figure 5.1 shows the site locations. Figures 3.2, 3.6, 3.8, and 3.9 show four of the five sites studied. Pedons were described and sampled according to standard procedures (Soil Survey Staff, 1984). Particle-size distribution was determined by the pipette method of Gee and Baulder (1986). Bulk density was measured on triplicate natural clods using the saran-coated method (Brasher et al., 1966) and water adsorption. Exchangeable bases were extracted with 1 *M* NH_4OAc, pH 7.0, and exchangeable Al with 1 *M* KCl. Extractions were analyzed by atomic absorption spectro- photometry (Soil Survey Staff, 1984). Exchangeable acidity was determined by $BaCl_2$-TEA. Base saturation percentages were calculated by the sum of cations. Organic C was determined by the Walkley-Black method (Grewling and Peech, 1960) and soil pH by a 1:1 soil/water mixture. Dithionite-citrate-bicarbonate-extractable free Fe was determined by the method of Holmgren (1967).

Qualitative clay mineralogy (<2.0 μm) was determined

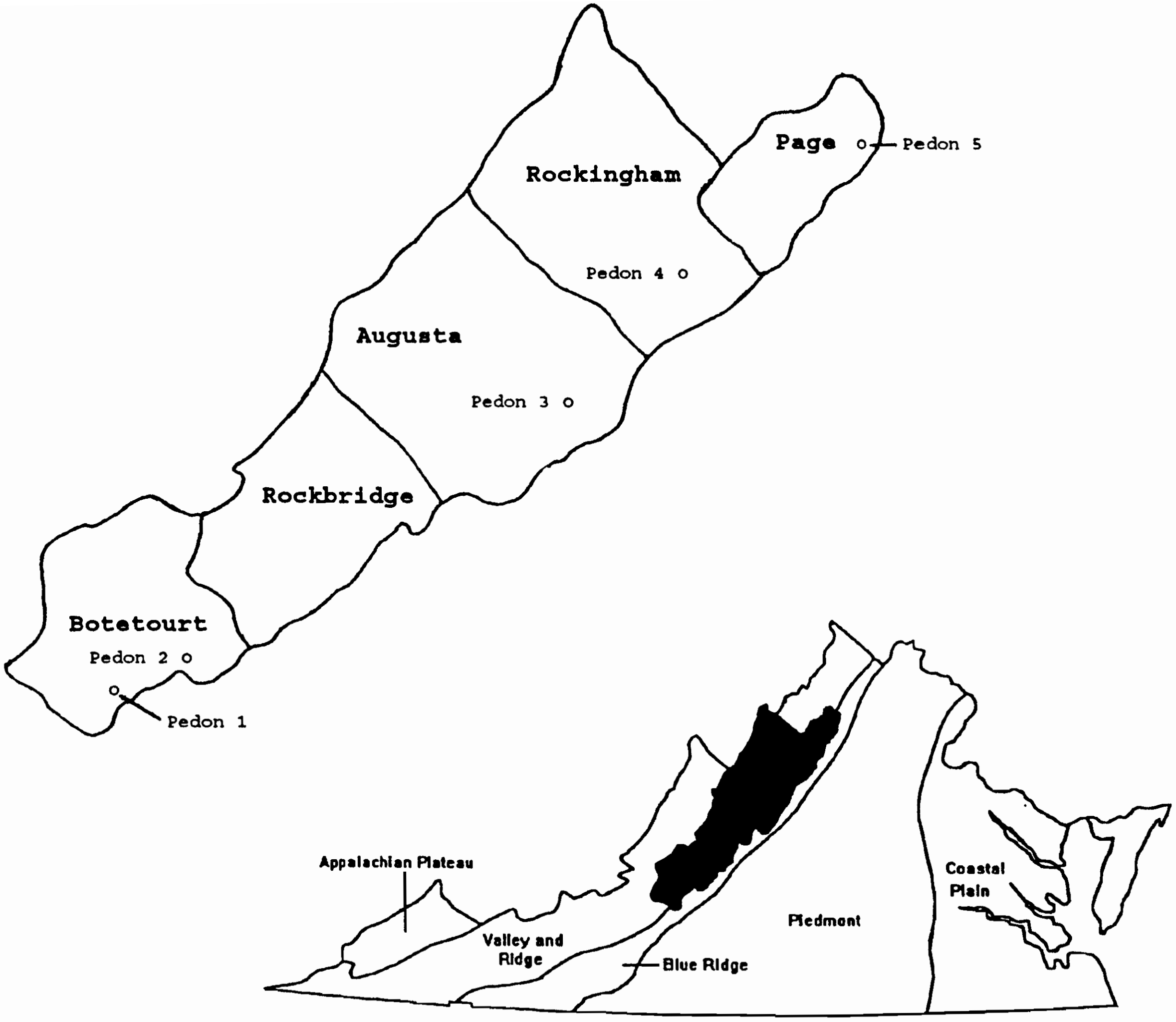

Figure 5.1. This map shows the locations for the five pedons.

using a Diano XRD 8300 AD x-ray diffractometer (Diano Corp., Woburn, MA) with CuKα radiation (20mA, 40kV) after particle-size fractionation by centrifugation (Kittrick and Hope, 1963). Kaolinite and gibbsite were quantified by differential scanning calorimetry with a DuPont 1090 Thermal Analyzer (TA Instruments, New Castle, DE), using poorly crystalline Georgia kaolinite and Reynolds synthetic gibbsite as standards. Other minerals were estimated by comparing XRD peak areas relative to those of kaolinite.

Micromorphology thin sections were prepared from oriented clods. To reduce cracking during drying, clods were air-dried to a constant weight at 25° C, and then oven-dried at 95° C prior to impregnation with an epoxy resin. Micromorphological descriptions were made using the terminology of Bullock et al. (1985). Oriented clay and voids, and coarse/fine ratios separated at 20 μm ($c/f_{20\mu m}$) were estimated from traverse line counts at 63x magnification.

RESULTS AND DISCUSSION

Relatively sharp Munsel color contrasts and abrupt textural changes separate unit A from unit B (Table 5.1). Even though abrupt particle-size changes occur within all pedons, clay-free total sand and other clay-free sand fraction indices (Table 5.2) do not always clearly demonstrate the discontinuities. Chapter 4 showed discontinuities do occur in the soils, and clay-free

Table 5.1. Partial morphological descriptions of the selected pedons.

Horizon	Depth (cm)	Color (moist)	Texture†	Structure‡	Consistence§	Boundary¶	Redoximorphic features#	Notes††
Pedon 1 **coarse-loamy, siliceous, mesic Typic Paleudults**								
A	0-5	10YR 5/2	sl	1fgr	mfr	cs		
E	5-33	10YR 7/4	l	1fsbk	mfr	cs		2% cf
BE	33-50	10YR 6/4	l	1msbk	mfr	cs		2% cf
Bt1	50-64	7.5YR 5/4	l	1msbk	mfr	gs		f2 clay films; 2% cf
Bt2	64-94	5YR 5/8	l	2msbk	mfr	gs		c2 clay films; 5% cf
2Bt3	99-143	5YR 5/8	c	2msbk	mfi	gs	c1p 10YR 6/8	m3 clay films; 5% cf
2Bt4	143-200	2.5YR 4/6	c	2msbk	mfr	gs	c2p 10YR 5/6	m3 clay films
2Bt5	200-240	2.5YR 4/6	cl	2msbk	mfr	gs	m2p 10YR 5/6	m3 clay films
2Bt6	240-280	2.5YR 4/6	cl	2msbk	mfr	gs	m2p 10YR 5/6	m3 clay films
2Bt7	280-307	2.5YR 4/6	cl	2msbk	mfr		m2p 10YR 5/6	m3 clay films
Pedon 2 **clayey, mixed, mesic Typic Paleudults**								
A	0-3	10YR 4/2	sl	1fgr	mvfr	aw		2% cf
E	3-27	10YR 6/3	sl	1csbk	mfr	cw		2% cf
EB	27-48	10YR 6/3	sl	1msbk	mfr	cw	c2d 7.5YR 5/6	2% cf
Bt1	48-66	7.5YR 5/6	l	1msbk	mfr	cw		c2d 10YR 6/3 clay depletions on faces of peds; c2 clay films; 2% cf
2Bt2	66-94	5YR 5/6	c	2msbk	mfr	cw		m3 clay films; 2% cf
2Bt3	94-128	2.5YR 4/6	c	2msbk parts to 1mpl	mfr	aw	c2p 10YR 5/6	m3 clay films; 10% cf
2Bt4	128-170	2.5YR 4/6	vcbc	2csbk parts to 1mpl	mfr	gw	m2p 10YR 5/6 f2p 10YR 6/2	m3 clay films; 45% cf
2Bt5	170-240	2.5YR 4/6	vcbcl	2csbk parts to 1mpl	mfr		m2p 10YR 5/6 f2p 10YR 6/2	m3 clay films; 45% cf

Table 5.1. (cont.) Partial morphological descriptions of the selected pedons.

Horizon	Depth (cm)	Color (moist)	Texture†	Structure‡	Consis- tence§	Boundary¶	Redoximorphic features#	Notes
				Pedon 3				
				coarse-loamy, siliceous, mesic Aquic Fragiudults				
A	0-5	10YR 3/1	sl	2mgr	mvfr	cs		
E	5-11	10YR 6/3	sl	1msbk	mfr	cs		
Bt1	11-32	10YR 6/3	sl	1msbk	mfr	cs		
Bt2	32-48	10YR 6/3	l	1msbk	mfr	cs		few 10YR 6/1 clay depletions on faces of peds
Bx	48-81	10YR 6/4	sl	2msbk parts to 2fpl	mfi	cs	c1p 5YR 5/6	many 10YR 6/1 clay depletions on faces of peds
2Bt1	81-114	5YR 5/6	cl	2msbk	mfr	gs	f2p 10YR 6/6	many 10YR 7/1 clay depletions on faces of peds
2Bt2	114-142	2.5YR 4/6	c	2csbk	mfr	gs	c2d 7.5YR 5/6	m2 clay films
2Bt3	142-156	2.5YR 4/6	c	2csbk	mfr	gs	c2d 7.5YR 5/6	m2 clay films
3Bt4	156-192	2.5YR 4/6	vcbc	2msbk	mfr		c1d 5YR 5/6	m2 clay films; 50% cf
				Pedon 4				
				fine-loamy, siliceous, mesic Typic Paleudults				
Ap	0-6	10YR 4/2	sl	1fgr	mfr	as		
E	6-18	10YR 6/3	sil	1msbk	mfr	gw		2% cf
Bt1	18-40	10YR 5/4	sil	1msbk	mfr	cs		2% cf
Bt2	40-74	10YR 5/8	cl	1msbk	mfr	as		c2 clay films; 5% cf
E′	74-90	10YR 6/3	l	1msbk	mfr	as	c1f 10YR 5/4	5% cf
2Bt1	90-112	7.5YR 5/6	vcbc	1fsbk	mfr	cs	f2d 10YR 3/6	c2 clay films; 10% cf
2Bt2	112-156	10R 3/6	excbc	2fsbk	mfr	ds	m2p 7.5YR 5/6 m2p 10YR 6/8 f2p 10YR 6/1	m3 clay films; 70% imbricated cf

Table 5.1. (cont.) Partial morphological descriptions of the selected pedons.

Horizon	Depth (cm)	Color (moist)	Texture†	Structure‡	Consistence§	Boundary¶	Redoximorphic features#	Notes
Pedon 4 (cont.)								
fine-loamy, siliceous, mesic Typic Paleudults								
2Bt3	156-200	10R 3/6	excbcl	2fsbk	mfr	ds	m2p 7.5YR 5/6 m2p 10YR 6/8 f2p 10YR 6/1	m3 clay films; 70% imbricated cf
Pedon 5								
coarse-loamy, siliceous, mesic Typic Fragiudults								
Ap	0-2	10YR 3/1	sil	1fgr	mvfr	as		2% cf
E1	2-18	10YR 6/3	grl	1fsbk	mfr	gs		2% cf
E2	18-44	10YR 6/3	grsl	1msbk	mfr	gs		5% cf
Btx	44-64	10YR 5/4	cbl	2cpr parts to 1msbk	mfi	gs		c2 clay films; 5% cf
2Bt1	64-82	7.5YR 5/6	grc	2msbk	mfi	gs	c2d 2.5YR 3/6	m3 clay films; 5% cf
2Bt2	82-106	7.5YR 5/6	vgrc	2msbk	mfr	ds	m2d 5YR 5/6 f2d 10YR 6/6 c2p 10YR 6/2	m3 clay films; 25% cf
2Bt3	106-151	2.5YR 4/8	grc	3thpl parts to 2msbk	mfr	gs	m2p 7.5YR 5/8 m2p 10YR 6/6 c3p 10YR 6/2	m3 10YR 5/3 clay films; 35% cf
2Bt4	151-173	2.5YR 3/6	c	3thpl parts to 2msbk	mfr	gs	m2p 10YR 4/3 c2p 10YR 7/8 c2p 10YR 6/2	m3 clay films; 5% cf
2Bt5	173-205	2.5YR 4/6	c	3mpr parts to 2thpl	mfr		c2p 10YR 5/6 c2p 10YR 6/2	m3 10YR 4/4 clay films; 2% cf

† sl = sandy loam, l = loam, c = clay, cl = clay loam, sil = silt loam; v = very; ex = extremely, gr = gravelly; cb = cobbly.

‡ 1 = weak, 2 = moderate, 3 = strong; f = fine, m = medium, c = coarse, th = thick; gr =granular, sbk = subangular blocky, pl = platy, pr = prismatic.

§ m = moist; vfr = very friable, fr = friable, fi = firm.

¶ a = abrupt, c = clear, g = gradual, d = diffuse; s = smooth, w = wavy.

f = few, c = common, m = many; 1 = fine, 2 = medium, 3 = coarse; f = faint, d = distinct, p = prominent.

†† f = few, c = common, 3 = many; 1 = faint, 2 = distinct, 3 = prominent.

Table 5.2. Particle-size distribution, bulk density, and clay-free ratios of the selected pedons.

Horizon	Depth	S	Si	C	FC†	ρ_{ad}	$\rho_{0.033}$	TS_{cf}‡	MF_{cf}§	MFV_{cf}¶
	(cm)	------------ %	------------	------------	------------	--- Mg m^{-3}	---			
					Pedon 1					
A	0-5	55.5	36.1	8.4	3.3	--	--	60	60	86
E	5-33	51.8	40.7	7.5	4.2	1.38	1.11	56	56	86
BE	33-50	51.0	40.4	8.6	5.5	1.71	1.54	56	57	89
Bt1	50-64	47.0	42.2	10.7	12.4	1.93	1.74	53	53	88
Bt2	64-94	47.7	37.0	15.3	12.2	1.93	1.72	56	53	81
2Bt3	94-143	23.6	31.3	45.1	26.5	1.64	1.46	43	48	95
2Bt4	143-200	29.1	30.2	40.7	31.2	1.67	1.52	49	54	88
2Bt5	200-240	30.4	31.8	37.8	25.4	--	--	49	50	86
2Bt6	240-280	35.5	32.5	31.9	21.8	--	--	52	57	90
2Bt7	280-307	29.4	35.2	35.4	24.4	--	--	45	51	85
					Pedon 2					
A	0-3	52.1	41.8	6.1	6.4	--	--	55	52	86
E	3-27	50.5	47.3	2.2	4.4	1.68	1.55	52	48	91
EB	27-48	46.8	48.4	4.8	8.5	1.69	1.57	49	48	89
Bt1	48-66	38.6	45.2	16.2	23.3	1.60	1.45	46	47	87
2Bt2	66-94	22.0	25.9	52.1	39.1	1.49	1.31	46	46	87
2Bt3	94-128	28.6	29.8	41.5	34.0	1.55	1.48	49	43	85
2Bt4	128-170	33.7	24.2	42.1	38.4	1.75	1.56	58	45	86
2Bt5	170-240	38.1	28.6	33.3	41.1	1.74	1.55	57	42	81

Table 5.2. (cont.) Particle-size distribution, bulk density, and clay-free ratios of the selected pedons.

Horizon	Depth	S	Si	C	FC†	ρ_{ad}	$\rho_{0.033}$	TS_{cf}‡	MF_{cf}§	MFV_{cf}¶
	(cm)	------------	------ %	------	------------	--- Mg	m^{-3} ---			
					Pedon 3					
A	0-5	53.1	43.4	3.5	1.0	--	--	55	72	78
E	5-11	52.9	42.5	4.5	3.7	1.50	1.41	55	78	88
Bt1	11-32	52.0	40.8	7.2	4.3	1.63	1.49	56	79	89
Bt2	32-48	51.0	38.3	10.6	8.5	1.85	1.67	57	80	90
Bx	48-81	52.5	43.9	3.6	16.6	1.91	1.74	54	77	86
2Bt1	81-114	40.8	29.7	30.2	36.5	1.71	1.61	58	76	83
2Bt2	114-142	31.0	24.5	44.5	49.2	1.55	1.39	56	75	84
2Bt3	142-156	29.4	21.1	49.6	43.9	1.57	1.43	58	74	82
3Bt4	156-192	33.1	17.1	49.9	31.3	1.65	1.46	66	77	84
					Pedon 4					
Ap	0-6	46.9	47.4	5.7	7.3	--	--	50	72	85
E	6-18	42.9	53.0	4.2	7.3	1.79	1.68	45	75	91
Bt1	18-40	41.4	52.4	6.2	16.7	1.86	1.77	44	74	92
Bt2	40-74	25.7	35.8	38.5	30.2	1.59	1.56	42	71	90
E′	74-90	38.3	43.5	18.2	14.5	1.80	1.74	47	73	91
2Bt1	90-112	22.9	33.2	43.8	39.8	1.39	1.35	41	72	88
2Bt2	112-156	33.0	24.9	42.1	43.9	1.67	1.72	57	53	66
2Bt3	156-200	38.2	23.0	38.8	36.8	1.74	1.83	62	58	69

Table 5.2. (cont.) Particle-size distribution, bulk density, and clay-free ratios of the selected pedons.

Horizon	Depth (cm)	S	Si	C	FC†	ρ_{ad}	$\rho_{0.033}$	TS_{cf}‡	MF_{cf}§	MFV_{cf}¶
		%				Mg m^{-3}				
					Pedon 5					
Ap	0-2	39.4	56.9	3.7	3.6	--	--	41	67	76
E1	2-18	44.0	47.3	8.6	2.9	1.51	1.48	48	69	81
E2	18-44	45.1	49.4	5.5	4.4	1.97	1.89	48	68	82
Btx	44-64	47.4	42.5	10.1	10.2	2.09	1.93	53	66	80
2Bt1	64-82	27.3	32.1	40.6	28.1	1.80	1.70	46	65	79
2Bt2	82-106	28.9	26.2	44.9	41.4	1.69	1.62	52	59	73
2Bt3	106-151	38.1	21.5	40.5	20.3	1.78	1.75	64	60	69
2Bt4	151-173	15.6	21.4	63.0	32.0	1.57	1.46	42	53	64
2Bt5	173-205	8.4	30.0	61.6	42.3	1.46	1.45	22	46	67

† FC = fine clay (percent of total clay)
‡ TS_{cf} = clay-free total sand
§ MF_{cf} = clay-free medium + fine sand
¶ MFV_{cf} = clay-free medium + fine + very fine sand

properties are good indicators for discontinuities when more than one pedon is used to verify their presence. Because unit A and unit B developed from similar parent material, it is better to view the disconti- nuities as chronologic (Smeck et al., 1989) rather than lithologic. The type of discontinuity does not reduce the importance of its presence.

Among pedons, unit A ranges from 64 to 94 cm thick and is weakly to moderately developed. In the field, the upper horizons of Pedons 1 and 3 were thought to be cambic horizons, but clay increases were enough to redesignate the horizons as E-Bt sequences. Fine clay (<20 μm) distributions support this interpretation (Table 5.2), but also suggests the upper argillics are young. Waltman et al. (1990) cited either limited duration of post-Wisconsinan weathering or mixing by windthrow as reasons for weak development in Snowden Hill soils, each of which are plausible explanations for weak horizonation of the unit A phase in the alluvial fan soils.

In Table 5.2, air-dried bulk densities (ρ_b) are compared with ρ_b equilibrated to 0.033 MPa. Those at 0.033 MPa are consistently lower than air-dried ρ_b but their pattern of change mimics ρ_b. For each pedon, the highest ρ_b occurs in unit A and among pedons it ranges from 1.38 to 2.09 Mg m^{-3}. At each location, except Pedon 5, the horizon with the highest ρ_b has the highest silt content.

Fragipans were found in Pedons 3 and 5. A ped from Pedon 5 (Fig. 5.2) shows the coarse fragipan structure. Sand and silt data suggest these horizons are lower horizons of unit A. Fragipan ρ_b are high at Pedons 3 and 5, but high ρ_b are not uncommon at the other sites, particularly near the discontinuity. Possibly, hydrous oxides of Si and Al leached from above were immobilized upon contact with the finer-textured unit B. Subsequent hydrous oxides precipitated, possibly forming the fragipans from the bottom up.

Smeck et al. (1989) proposed fragipan formation at weathering discontinuities. Weathering discontinuites originate two ways. In the first, weathered horizons overlie relatively unweathered horizons such as occurs where weathering intensity decreases with depth in uniform material. In the second way, relatively unweathered horizons overlie weathered horizons such as occurs by the shallow burial of preexisting soils. Evidence from their examples (Smeck et al., 1989) illustrating the second method indicated hydrous oxides moved into the preexisting soil before precipitating rather than stopping at the discontinuity. Perhaps the best evidence for downward leaching and immobilization of constituents in the alluvial-fan soils is the higher base saturation in the fragipan horizons (Pedons 3 and 5) and Mg enrichment in horizons near the discontinuity at the other sites (Table 5.3). Waltman et al. (1990) found fragipans above stonelines

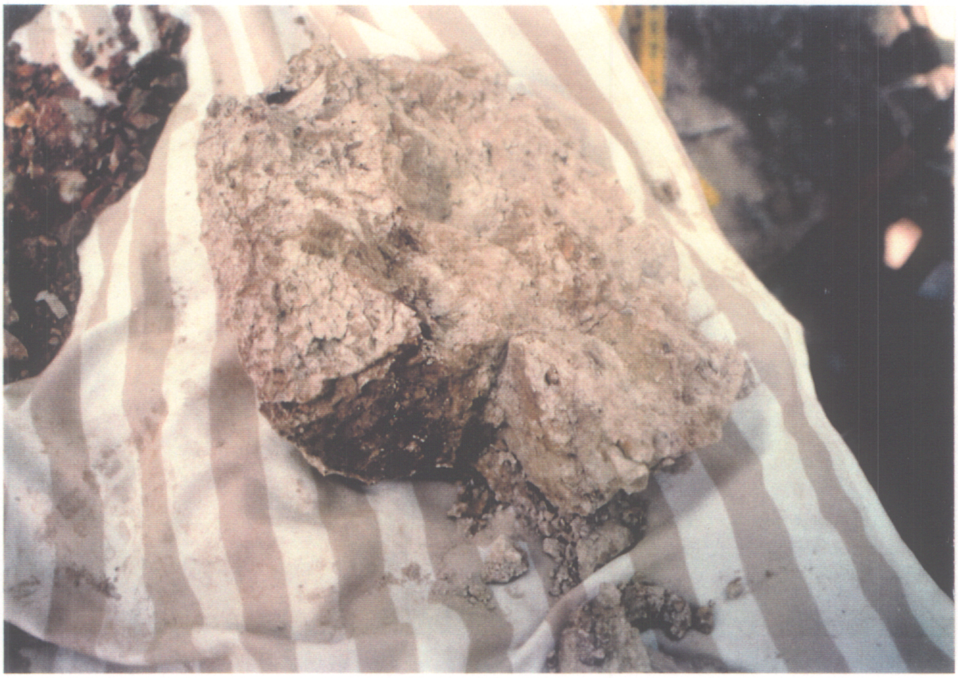

Figure 5.2. Coarse structure is evident from this ped of the Btx of Pedon 5.

Table 5.3. Chemical properties of the selected pedons.

Horizon	Exchangeable cations Ca	Exchangeable cations Mg	Exchangeable cations K	Exchange-able acidity	SCEC†	Exchange-able Al	NCEC‡	ECEC§	Base saturation	Organic C	pH
	$\text{cmol}_c\ \text{kg}^{-1}$								%	g kg^{-1}	
						Pedon 1					
A	0.18	0.11	0.14	10.6	11.03	3.0	7.9	3.4	3.94	32.7	4.11
E	0.03	0.03	0.03	3.4	3.48	1.0	2.2	1.1	2.29	3.7	4.87
BE	0.03	0.03	0.04	1.9	2.00	1.1	2.2	1.2	4.99	1.5	4.91
Bt1	0.05	0.03	0.06	2.3	2.44	1.8	2.9	1.9	5.93	0.0	4.72
Bt2	0.09	0.32	0.09	5.7	6.20	2.9	4.4	3.4	8.06	0.7	4.91
2Bt3	0.03	0.30	0.09	15.2	15.63	9.1	15.0	9.5	2.75	0.3	5.12
2Bt4	0.03	0.21	0.07	14.4	14.71	9.3	14.0	9.6	2.07	0.0	5.14
2Bt5	0.03	0.13	0.05	13.3	13.51	8.5	13.9	8.7	1.51	0.0	5.13
2Bt6	0.03	0.11	0.04	13.2	13.39	7.6	10.2	7.8	1.38	0.7	5.04
2Bt7	0.03	0.11	0.06	15.2	15.40	8.6	15.0	8.8	1.30	0.6	5.05
						Pedon 2					
A	0.19	0.19	0.13	6.5	7.00	2.2	6.9	2.7	7.21	32.7	4.29
E	0.13	0.14	0.02	2.7	3.00	0.7	2.4	1.0	10.01	3.9	4.92
EB	0.07	0.07	0.04	5.4	5.58	1.7	3.6	1.9	3.31	2.5	4.88
Bt1	0.09	0.16	0.10	7.7	8.04	3.0	5.6	3.3	4.29	3.8	4.82
2Bt2	0.05	0.49	0.08	14.1	14.73	4.4	13.4	5.0	4.28	1.4	5.14
2Bt3	0.05	0.20	0.05	12.1	12.40	4.3	10.4	4.6	2.46	0.6	5.14
2Bt4	0.03	0.11	0.05	9.7	9.89	4.4	7.9	4.6	1.97	0.0	5.15
2Bt5	0.03	0.05	0.04	10.7	10.83	4.8	10.6	5.0	1.19	0.0	5.00
						Pedon 3					
A	0.07	0.12	0.17	7.3	7.67	1.7	6.5	2.1	4.83	45.4	4.08
E	0.02	0.03	0.08	4.4	4.53	1.7	3.7	1.8	2.87	8.5	4.71
Bt1	0.02	0.02	0.05	2.6	2.69	1.2	2.2	1.3	3.53	3.9	4.90
Bt2	0.03	0.02	0.05	2.4	2.49	1.6	2.1	1.7	3.81	2.0	4.82
Bx	0.07	0.40	0.08	3.7	4.26	2.1	3.9	2.7	13.15	1.1	4.98
2Bt1	0.21	0.63	0.13	10.4	11.37	4.0	7.5	5.0	8.53	1.1	5.09
2Bt2	0.05	0.31	0.19	13.2	13.75	5.4	11.2	5.9	4.03	1.1	5.16
2Bt3	0.04	0.25	0.17	16.2	16.66	5.2	14.6	5.7	2.79	1.2	5.23
3Bt4	0.02	0.18	0.12	15.4	15.78	5.2	12.8	5.5	2.09	1.7	5.18

Table 5.3. (cont.) Chemical properties of the selected pedons.

Horizon	Exchangeable cations Ca	Mg	K	Exchange-able acidity	SCEC†	Exchange-able Al	NCEC‡	ECEC§	Base saturation	Organic C	pH
	----------	----------	----------	---------- $\mathrm{cmol_c\ kg^{-1}}$	----------	----------	----------	----------	%	$\mathrm{g\ kg^{-1}}$	
						Pedon 4					
Ap	1.46	0.28	0.25	9.3	11.29	1.1	6.3	3.1	17.66	22.7	4.61
E	0.22	0.07	0.05	2.7	3.04	1.1	2.6	1.4	11.20	2.4	4.95
Bt1	0.99	0.19	0.08	3.0	4.26	0.7	3.6	1.9	29.66	1.4	5.04
Bt2	1.58	1.12	0.18	12.4	15.29	4.1	11.2	7.0	18.90	2.9	5.00
E'	0.12	0.19	0.11	5.5	5.92	2.0	5.2	2.4	7.10	0.6	5.18
2Bt1	0.30	0.64	0.26	16.3	17.51	6.9	16.1	8.1	6.91	1.0	5.05
2Bt2	0.09	0.22	0.19	17.2	17.70	9.5	13.5	10.0	2.82	1.9	4.89
2Bt3	0.07	0.10	0.15	16.0	16.32	8.4	13.6	8.7	1.99	0.9	4.85
						Pedon 5					
Ap	0.50	0.29	0.43	23.9	25.12	4.0	15.7	5.2	4.87	75.9	4.06
E1	0.02	0.03	0.09	6.2	6.34	1.2	3.2	1.3	2.21	12.5	4.88
E2	0.03	0.03	0.07	2.5	2.63	1.1	2.2	1.2	5.11	3.1	4.87
Btx	0.11	0.32	0.09	3.8	4.32	1.5	2.4	2.0	12.17	1.0	4.91
2Bt1	0.07	0.71	0.15	13.6	14.53	5.1	12.3	6.1	6.43	1.0	5.16
2Bt2	0.20	0.92	0.17	16.6	17.91	6.1	11.6	7.4	7.28	1.7	5.03
2Bt3	0.13	0.53	0.14	12.6	13.41	5.1	11.0	5.8	6.01	0.7	5.01
2Bt4	0.05	0.52	0.07	17.5	18.15	7.6	13.7	8.2	3.58	1.3	5.13
2Bt5	0.05	0.53	0.07	12.9	13.55	8.1	14.8	8.7	4.80	0.9	5.07

† SCEC = cation-exchange capacity by sum of bases + exchangeable acidity.

‡ NCEC = cation-exchange capacity by 1N NH_4OAc, pH 7.

§ ECEC = cation-exchange capacity by sum of bases plus 1N KCl-extractable Al.

and felt they marked a separate colluvial deposit atop the underlying paleosol.

Upper argillic horizons of unit B tend to be yellower (7.5YR-5YR) than the lower horizons (2.5YR). This implies free Fe mineralogy at the weathering front is converting to hydrated Fe compounds such as goethite. Stolt et al. (1994) found hematite composed 7 to 16% of the redox concentration clay mineralogy. They (Stolt et al., 1994) found goethite in both redox concentrations and depletions. Since free Fe contents in the first 2Bt horizons are not substantially different from the lower horizons, Fe apparently has not illuviated from these horizons. For the first 2Bt horizons, total clay (Table 5.2) and free Fe (Table 5.4) do not strongly indicate these horizons are degrading. Fine clay is lower for these horizons than underlying argillics and is the only property hinting that the horizons are in an early stage of degredation.

Antietam quartzite is well documented as the dominant rock of the fans (Kochel and Johnson, 1984; Bloomer and Werner, 1955), and it is the only rock found in the soils I studied. Given this, the clay loam and clay textures are anomolous. Seemingly, the underlying fan unit was composed of additional rock types which are no longer present, having been completely weathered chemically and altered pedologically. This hypothesis also accounts for the

Table 5.4. Clay (<2.0 μm) mineralogy† of the selected pedons.

Horizon	K	HIV	G	I	V	M	Q	Fe‡
	g kg^{-1}							
Pedon 1								
A	100	575	-	246	-	-	73	5
E	126	471	15	202	-	105	72	8
BE	250	230	15	125	-	200	180	9
Bt1	297	279	13	119	-	194	84	14
Bt2	414	199	6	80	-	146	135	21
2Bt3	450		5	-	250	151	50	94
2Bt4	522		-	-	51	333	50	44
2Bt5	536		-	-	134	282	-	47
2Bt6	447		-	-	240	275	-	37
2Bt7	403		-	-	264	275	38	38
Pedon 2								
A	120	449	25	299	-	-	104	3
E	140	403	72	173	-	88	117	8
EB	214	371	74	158	-	85	87	11
Bt1	350	222	104	95	-	85	122	22
2Bt2	325	181	137	106	-	87	113	49
2Bt3	394	171	124	114	-	102	54	41
2Bt4	333	165	95	110	-	184	55	58
2Bt5	387	95	130	63	-	199	80	46
Pedon 3								
A	100	558	7	-	-	109	224	2
E	13	654	24	280	-	-	24	4
Bt1	55	463	48	308	-	45	75	6
Bt2	105	455	39	195	-	75	124	7
Bx	171	316	72	211	-	133	86	11
2Bt1	300	200	50	133	-	150	139	27
2Bt2	344	92	94	75	-	246	111	38
2Bt3	228	419	87	50	-	-	171	43
3Bt4	397	239	77	159	-	-	81	45

Table 5.4. (cont.) Clay (<2.0 μm) mineralogy† of the selected pedons.

Horizon	K	HIV	G	I	V	M	Q	Fe‡
	g kg^{-1}							
				Pedon 4				
Ap	55	630	30	157	-	61	60	6
E	67	644	29	88	-	63	98	11
Bt1	155	392	36	44	-	173	178	21
Bt2	284	105	76	-	-	311	188	36
E′	75	346	79	-	-	158	131	38
2Bt1	220	665	49	-	-	85	88	66
2Bt2	357	157	56	150	-	161	75	44
2Bt3	448	148	29	34	-	254	32	52
				Pedon 5				
Ap	55	570	9	-	244	40	76	6
E1	26	704	18	176	-	25	45	7
E2	146	403	13	-	-	154	278	6
Btx	185	597	10	-	-	122	77	9
2Bt1	648	24	5	-	-	136	136	50
2Bt2	500	171	1	-	-	176	85	48
2Bt3	565	121	-	-	-	185	88	41
2Bt4	662	-	-	69	-	154	63	52
2Bt5	666	-	-	17	-	207	54	55

† K = kaolinite; HIV = hydroxy interlayered vermiculite; G = gibbsite; I = 2:1 intergrade; V = vermiculite; M = mica; Q = quartz.

‡ Free Fe on a whole soil basis

chemical and mineralogical composition of these soils, discussed below. Hack (1965) described a Shenandoah River terrace 61 m above modern river level composed of quartzite boulders in a reddish-brown clay matrix. To him (Hack, 1965) the composition suggested weathering had completely altered once-present igneous boulders. For this study, Pedon 1 is 91 m, Pedon 2 is 46 m, Pedon 3 is 152 m, Pedon 4 is 9 m, and Pedon 5 is 49 m above major rivers. With the possible exception of Pedon 4, the soils are not on stream terraces, but they are part of the continuum of surficial deposits in the region. Therefore, it is probable that the alluvial-fan composition was similar to that of the river terraces.

Soils with contasting redoximorphic features are common on the alluvial fans throughout the region. Well-expressed reticulate patterns are among the features. A ped from Pedon 5 (Fig. 5.3) exemplifies the reticulate pattern. Stolt et al. (1994) examined these features to determine their genesis. Pedons 2 and 5 of this study were included in the study of Stolt et al. (1994). The dominant mechanism responsible for redox depletions appeared to be Fe reduction within planer voids and subsequent Fe movement into ped interiors. This process explains the presence of Fe masses and nodules within the peds. A secondary redox pattern indicated Fe reduction within peds and Fe oxidation on ped surfaces. Both mechanisms were attributed to water table

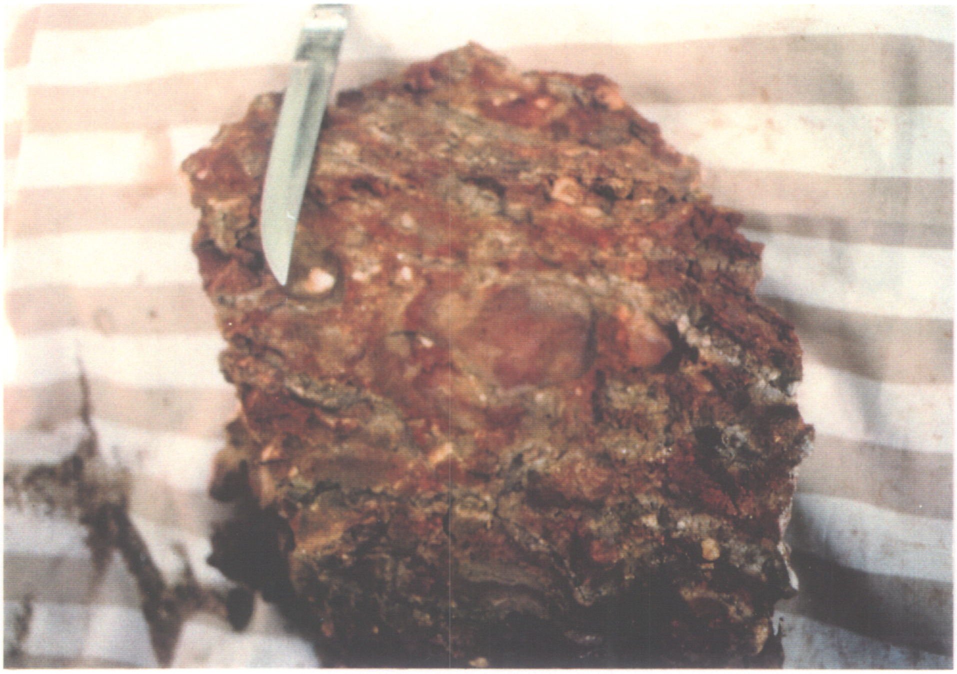

Figure 5.3. Well-expressed reticulate redoximorphic patterns are shown by the ped from the 2Bt3 of Pedon 5.

fluctuations and enhanced by high ρ_b, very low saturated hydraulic conductivity, and higher clay contents of redox depletions relative to the surrounding matrix.

Exchangeable Al provides most of the exchangeable acidity to the soils (Table 5.3). Because the sand fractions of all horizons are 1000 g kg^{-1} quartz, the Al source must be 2:1 layer silicates in the clay fractions or possibly in the silt fractions. Aluminum is obviously highest in the lower argillic horizons. Norfleet et al. (1993) suggested argillic horizons may act as sinks for Al weathered and leached from overlying horizons and, when suitable concentrations are reached, precipitates as crystalline gibbsite. This may be the case for Pedons 2, 3, and 4 because there is a tendency toward more gibbsite and HIV and less kaolinite in the lower argillics than Pedons 1 and 5, which tend to have more exchangeable Al.

Low effective CECs are another indication that the soils are extremely weathered. The ECECs are lower than the SCECs and the NCECs because the exchangeable Al was extracted at soil pH. This shows the actual acidity present in the soils. Even though NCEC and ECEC data are low, none of the pedons have kandic horizons.

Hydroxy interlayered vermiculite dominates upper horizon clay fractions (Table 5.4). Its inverse relationship with kaolinite is a common occurrence in most southeastern soils

(Karathanasis et al., 1983). Often studies of weathered soils find no consistent gibbsite trend with depth (Karathanasis et al., 1983; Harris et al., 1980). (Intensely weathered soils of Norfleet et al. (1993) are an exception). High gibbsite concentrations at depth could represent polygenetic soil formation of Pleistocene or possibly pre-Pleistocene age (Bryant and Dixon, 1963, as cited by Karathansis et al., 1983). Pedons 2, 3, and 4 exhibit a notable gibbsite increase with depth that generally occurs at the discontinuity suggesting the possibility of an intense weathering environment prior to burial by the upper unit.

At the onset of this research, I expected to find a high amount of HIV in the lower argillic horizons because these horizons appear quite old. However, this hypothesis was not proven because, with depth, HIV becomes less abundant. In fact, vermiculite and mica are the dominant 2:1 layer silicates in Pedons 1 and 5. On the other hand, the high quantities of kaolinite could be an indication of extreme age or past climatic conditions. Harris et al. (1980) found a high amount of kaolinite in a New River terrace Typic Paleudult. They (Harris et al., 1980) suggested prolonged or intense desilication and alumination could have lead to the transformation of 2:1 intergrade to 1:1 layer silicates. Since the alluvial fans are near the area studied by Harris et al. (1980), the alluvial-fan soils probably developed under similar external conditions.

On a chronosequence of James River terraces in Virginia, Howard et al. (1993) found kaolinite increased with age except for a dramatic decline in the oldest terrace soil (Plinthic Paleudults, 13myr). The decrease signaled the ultimate stage of chemical weathering where kaolinite and HIV were converted into gibbsite. Howard et al. (1993) also found gibbsite increased with age, although gibbsite content was highly variable within a given alloformation.

Micromorphology

Micromorphology observations and measurements contrast soil development in the two depositional units (Table 5.5). Unit A has weak subangular blocky structure, or structure is absent. The close- and single-spaced coarse/fine related distribution patterns and the $c/f_{20\mu}$ ratios reflect the coarser textures of the unit A. Figure 5.4 (Pedon 1), Fig. 5.5 (Pedon 3), Fig. 5.6 (Pedon 4), and Fig. 5.7 (Pedon 5) show for comparison the related distribution patterns for a unit A horizon and a unit B horizon.

Moderate medium subangular blocky structure is common in the lower, older argillic horizons, but fine structure occurs, too. Much lower $c/f_{20\mu}$ ratios for unit B correspond to the double- and open-spaced porphyric distribution patterns. These horizons have more oriented clay and planer voids and fewer vughs than unit A horizons. The subangular

Table 5.5. Partial micromorphological descriptions of selected horizons.

Horizon	Depth	Oriented clay	Planar voids	Vughs	c/f ratio†	Microstructure‡	coarse/fine related distribution patterns
	(cm)	----------	%	----------			
Pedon 1							
BE	35-50	7.0	0.0	93.0	0.94	absent	single spaced porphyric
Bt1	50-64	17.0	7.0	76.0	0.94	absent/1vf,fsbk	single to double spaced porphyric
Bt2	64-94	45.0	24.0	31.0	0.78	2msbk	single spaced porphyric
2Bt3	99-143	50.0	42.0	8.0	0.24	2f,msbk	single to double spaced porphyric
2Bt4	143-200	47.0	39.0	14.0	0.28	2f,msbk	single to double spaced porphyric
Pedon 2							
2Bt2	66-94	33.5	30.5	36.0	0.50	absent/1msbk	single to double spaced porphyric
2Bt3	94-128	37.5	40.5	22.0	0.45	2msbk	single spaced porphyric
2Bt4	128-170	42.5	40.0	17.5	0.28	2vf-msbk	single to double spaced porphyric
Pedon 3							
Bt2	32-48	11.5	1.5	87.0	1.16	1msbk	close to single spaced porphyric
Bx	48-81	46.0	11.5	42.5	0.94	absent/1msbk	close to single spaced porphyric
2Bt1	81-114	52.5	32.0	15.5	0.34	2msbk	single to double spaced porphyric
2Bt2	114-142	46.0	44.0	10.0	0.29	2msbk	single to double spaced porphyric
2Bt3	142-156	48.0	42.0	10.0	0.25	2,3fsbk	single to double spaced porphyric
Pedon 4							
Bt	40-74	22.0	16.5	61.5	0.75	1msbk	single to double spaced porphyric
E′	74-90	1.5	2.5	96.0	0.30	1msbk	single spaced porphyric
2Bt1	90-112	55.5	17.5	27.0	0.49	2msbk	single to double spaced porphyric
2Bt2	112-156	49.0	46.5	4.0	0.09	2,3msbk	double to open spaced porphyric
2Bt4	156-200	42.0	51.0	7.0	0.34	2fsbk	single to double spaced porphyric

Table 5.5. (cont.) Partial micromorphological descriptions of selected horizons.

Horizon	Depth	Oriented clay	Planar voids	Vughs	c/f ratio†	Microstructure‡	coarse/fine related distribution patterns
	(cm)	----------	% ----------				
					Pedon 5		
Btx	44-64	48.0	16.0	36.0	1.27	1fsbk	single spaced porphyric
2Bt3	106-151	51.0	45.0	4.0	0.38	2f,msbk	single spaced porphyric
2Bt4	151-173	53.0	46.0	1.0	0.05	2f,msbk	double spaced porphyric
2Bt5	173-205	49.0	47.0	4.0	0.05	2f,msbk	double to open spaced porphyric

† Coarse/fine ratio, divided at 20 μm.

‡ 1 = weak, 2 = moderate, 3 = strong; vf = very fine, f = fine, m = medium; sbk = subangular blocky.

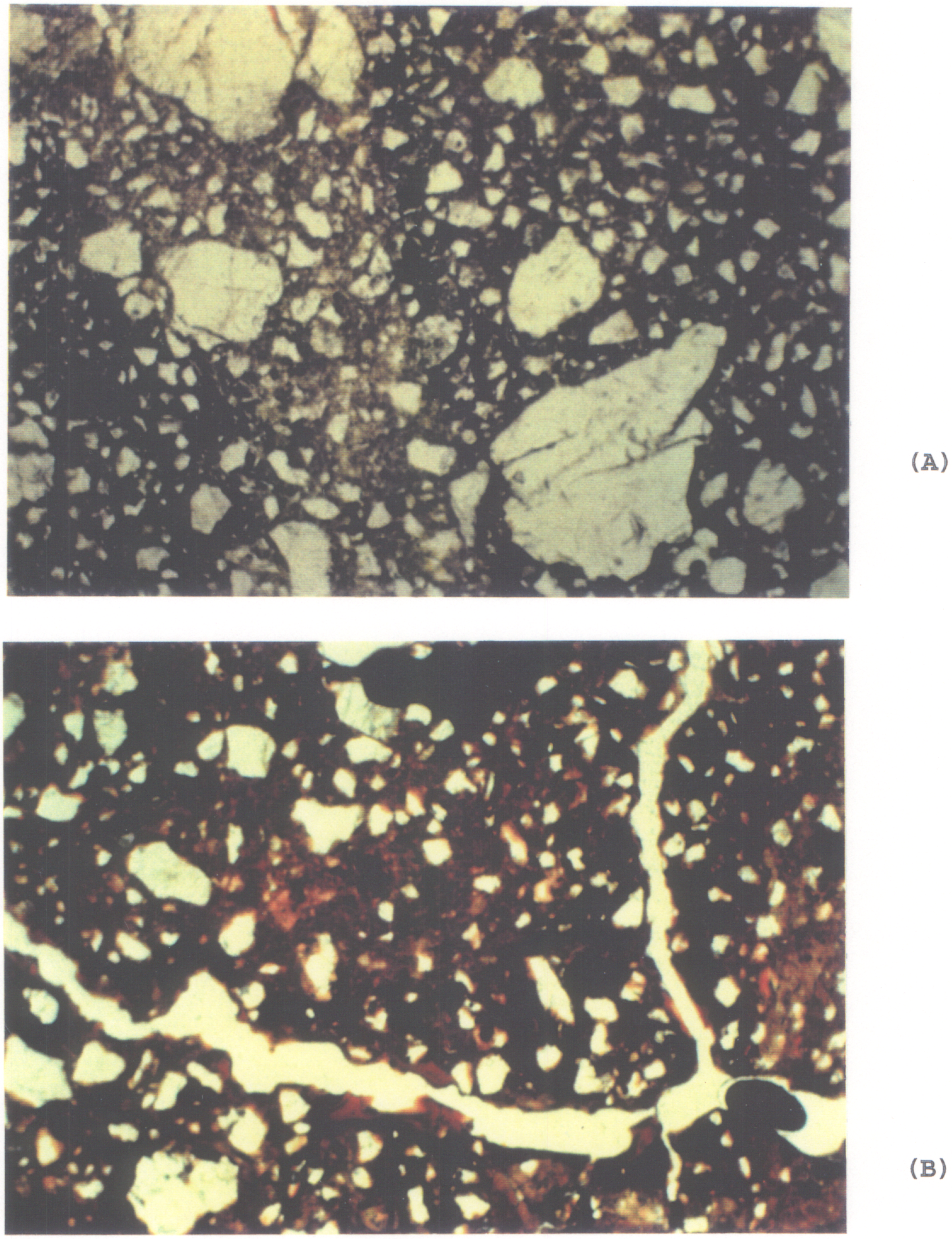

Figure 5.4. Vertical thin sections of Pedon 1 taken in plane-polarized light. Magnification is 40x. (A) BE horizon (B) 2Bt3 horizon.

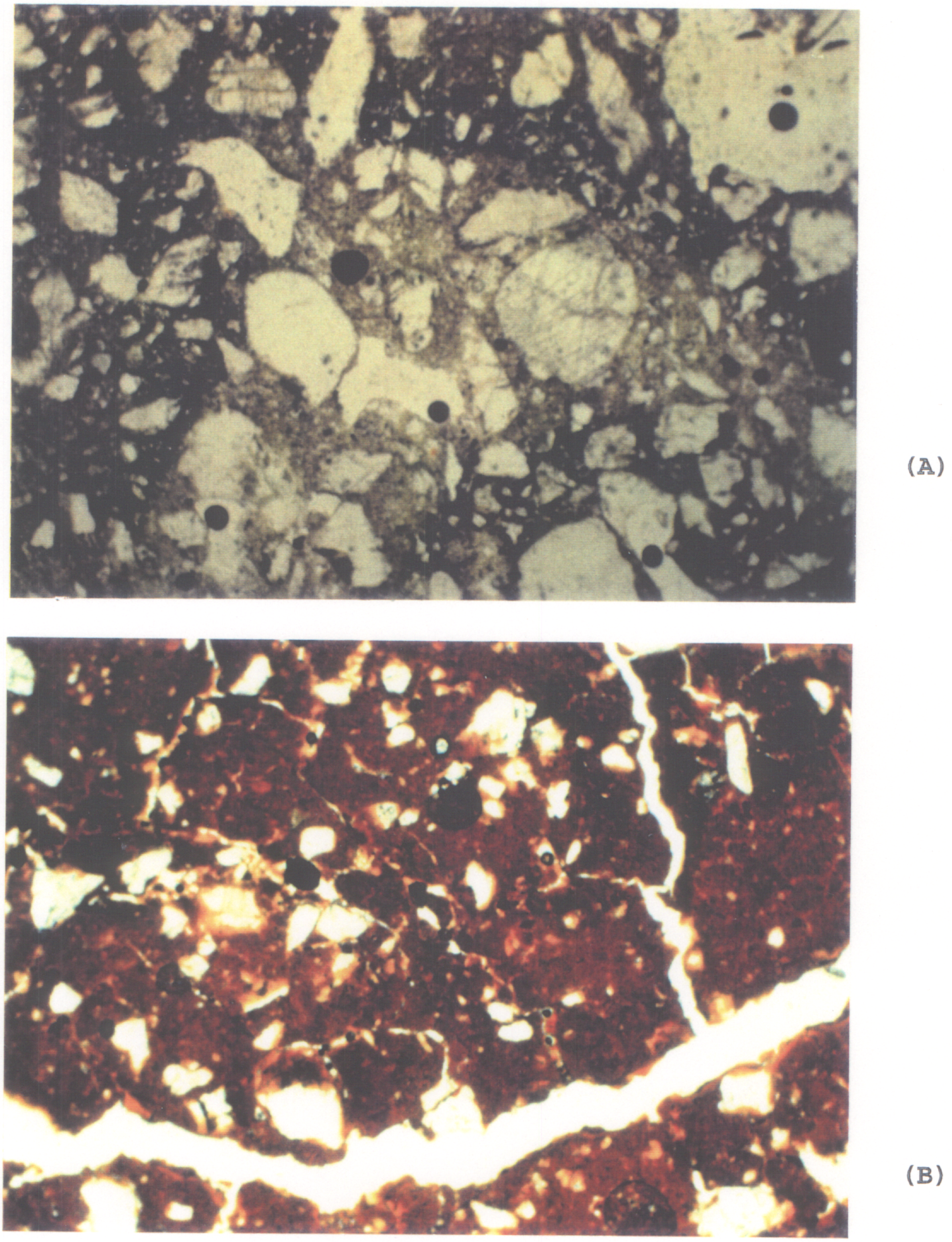

Figure 5.5. Vertical thin sections of Pedon 3 taken in plane-polarized light. Magnification is 40x. (A) Bx horizon (B) 2Bt2 horizon.

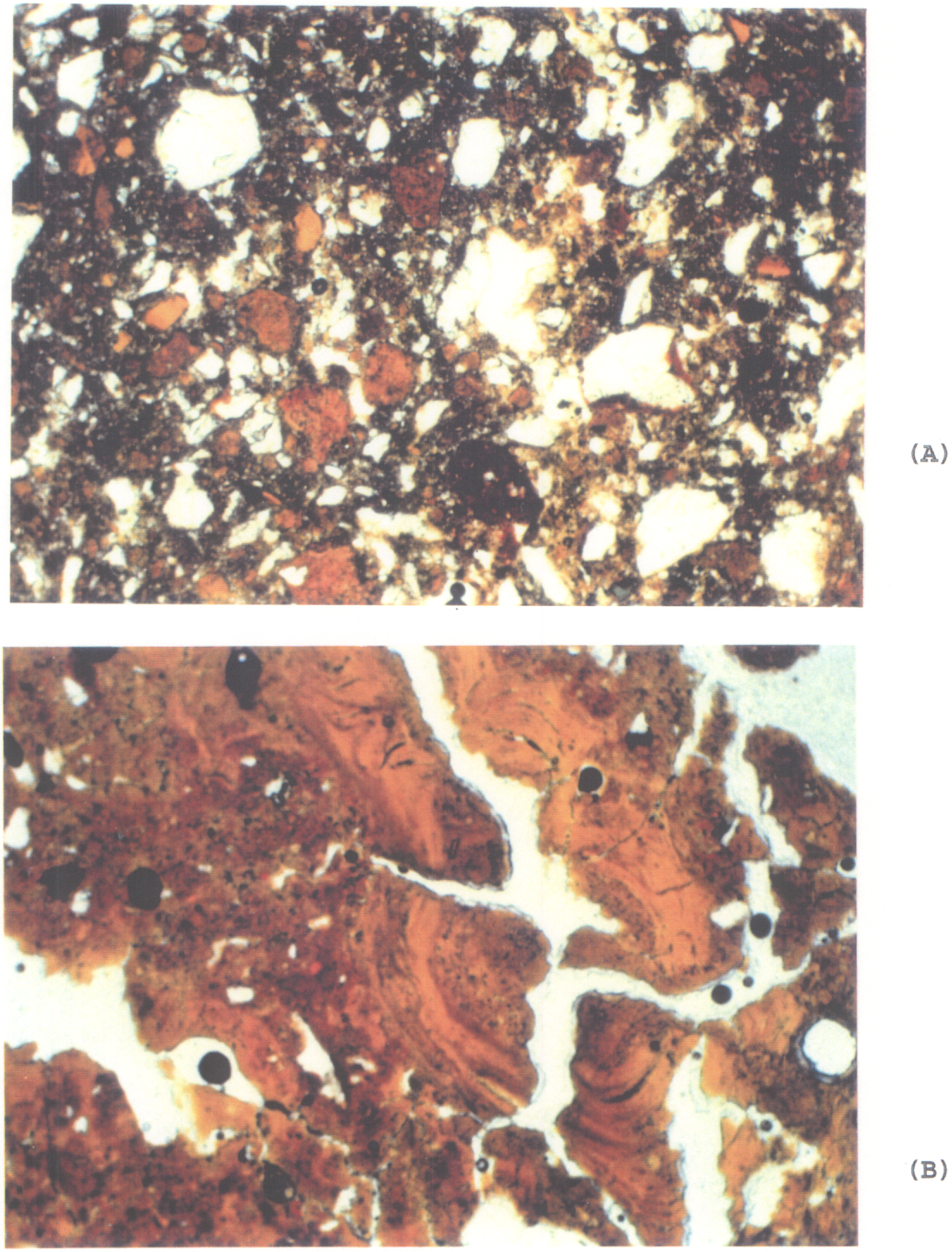

Figure 5.6. Vertical thin sections of Pedon 4 taken in plane-polarized light. Magnification is 40x. (A) Bt1 horizon (B) 2Bt2 horizon.

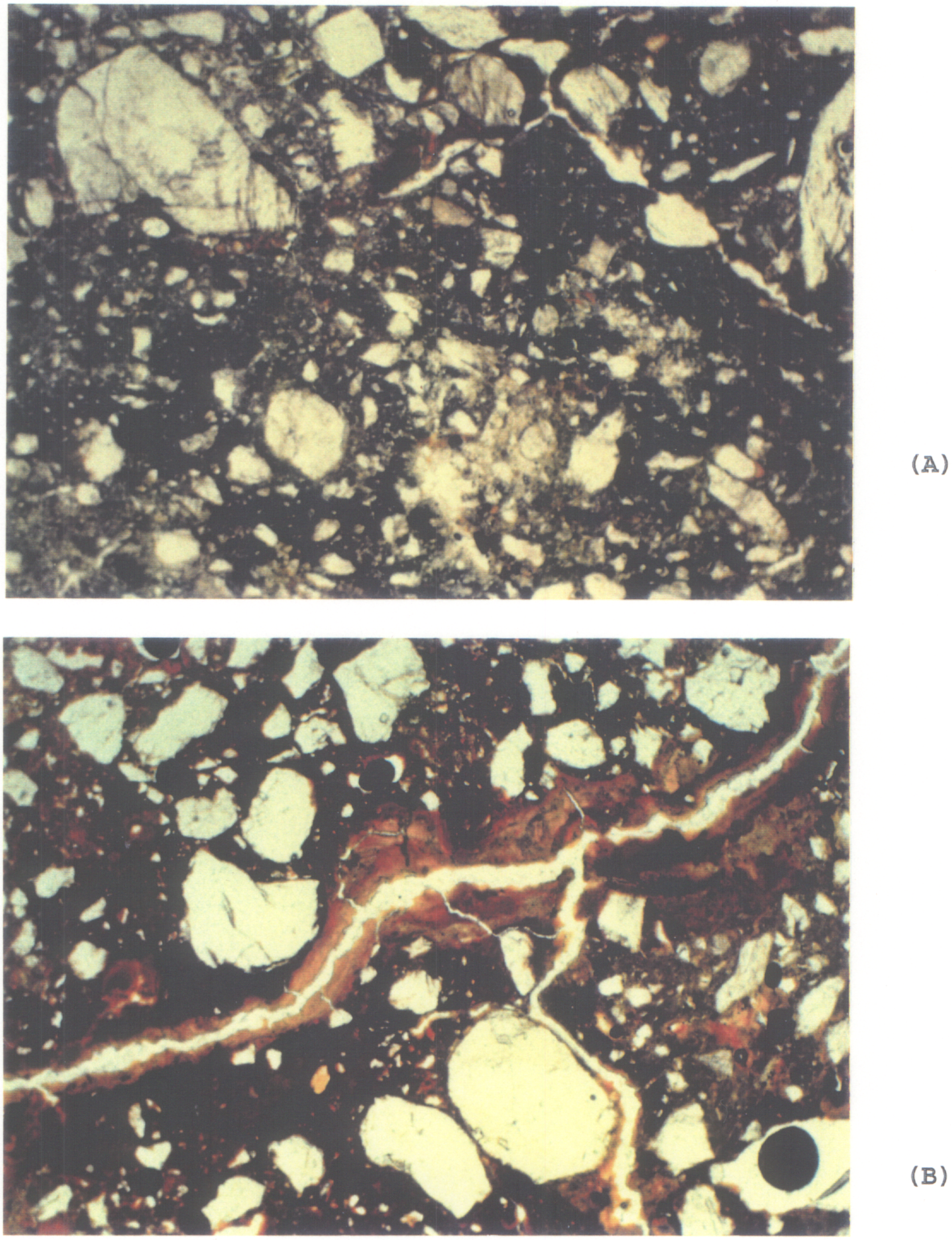

Figure 5.7. Vertical thin sections of Pedon 5 taken in plane-polarized light. Magnification is 40x. (A) Btx horizon (B) 2Bt3 horizon.

blocky peds partially accommodate one another, being separated by planer voids lined with oriented clay. Oriented clay and planer voids remain relatively constant with depth. These features, as well as free Fe contents (Table 5.4), accentuate the depths to which the soils developed and suggest landscape stability for a long period of time.

No evidence was found for mixing between the depositional units which one might expect to happen as a result of depositional processes. Also, in unit B thin sections, no weathered fragments of other lithologies were found. Assuming the soil matrix was derived from other rocks, their absence from thin section indicates they are completely weathered and obliterated by soil formation.

Stolt et al. (1994) found yellowish brown (10YR 5/6) clay coating voids within 2.5YR 4/6 nodules. The coatings were most likely goethite illuviated from above or formed within the redox patterns. I found the same features in Pedon 3 (Fig. 5.5), Pedon 4 (Fig. 5.6), and Pedon 5 (Fig. 5.7). Stolt et al. (1994) suggested the present soil environment is more conducive to goethite formation than hematite formation. Nodules transected by the 10YR 5/6 coatings are probably relict and the hematite is undergoing dissolution. Figure 5.6-B is interpreted as a former pore plugged with micro-laminated clay now reopened by a planer void.

Pedogenic Interpretations

Of the soil forming factors acting upon the Blue Ridge alluvial fans, the most influential ones are time and climate. The burden of proof rests upon the highly weathered quartzite clasts and the absence of other lithologies which could have produced the particle-size distributions, chemical properties, and mineralogical suites. These same factors also produced the thick, red, acid argillic horizons.

Barron (1989) used general circulation models to examine climate evolution of the Appalachians from the Carboniferous to the Present through consideration of large scale changes in paleogeography. His (Barron, 1989) simulations demonstrate the Appalachians, through the Cenozoic era, were a region of higher precipitation compared to the other mid-latitude regions. The best simulation was for the Eocene. The simulations predicted mean annual precipitation ≥ 6 mm d^{-1} (≥ 86 in yr^{-1}) for the Appalachians through at least the Miocene epoch. The focused precipitation during the Cenozoic may have been responsible for building the alluvial fans.

After emplacement, unit B sediments weathered through a period warmer and more humid than present-day conditions. Floral data suggests the Eocene of North America was characterized by increased warmth and humidity (Frakes, 1979 as cited by Barron, 1989). Warm temperatures and high rainfall would promote leaching and hasten initial soil development, including hematite formation. Higher gibbsite contents in Pedons 2, 3, and 4 may be a vestige of greater weathering intensity than current conditions can generate. Age plots for the James River chronosequence study (Howard et al., 1993) suggested rates of soil morphological development were relatively rapid initially, but slowed after an indeterminant time interval.

The alluvial fans were stable for a long time, and the landscapes were probably quite similar to those we see today. Deep argillics formed as weatherable rocks altered to kaolinite, gibbsite, and vermiculite. Quite possibly, the lower sola have existed during and continued to develop through more than one climatic period. If the soils corrolate with those of Howard et al. (1993), whose oldest soils are mid to late Miocene, they have endured the four glacial periods, three interglacials, and warm a period (Blancan) prior to the Nebraskan. Thermic soil temperatures likely prevailed during any or all of the interglacials since intervening interglacial periods probably were a bit warmer worldwide than present day average temperatures (Plummer and McGeary, 1982). The warm interglacials aided continued development of unit B.

A long hiatus occurred before the unit A sediments were deposited. Emplacement likely truncated the preexisting soils. For steeper landscapes, Graham et al. (1990)

identified soil creep and slope wash as mechanisms for transporting soil or rock debris down slope. Graham et al. (1990) cited overland flow as an uncommon erosive agent in forests of the eastern United States because of dense canopy cover, continuous litter layers, and high infiltration rates. Nevertheless, this mechanisim is the best explanation for the emplacement of unit A sediments on the nearly level segments of the alluvial fans. Unit A sediments seem to be locally-derived preweathered material. For this reason, the discontinuities are interpreted as chronologic rather than as lithologic discontinuities. Clay could have been winnowed from the sediments during transport or, alternatively, it was never a main component of the sediments. Unit A for Pedon 5 may be alluvium because of the site's proximity to the Shenandoah River (2 km) and location on the distal edge of a fan.

Silica and Al leached through unit A and precipitated at the discontinuity becoming bonding agents for fragipan formation. Also, Al leached from upper sediments either interlayered vermiculite or moved downward into lower argillics and possibly crystallized as gibbsite. Presently, the free Fe compounds in the first 2Bt horizons appear to be converting to goethite as suggested by the yellow hues. Some time during formation reductive processes became more active in some of the soils. Evidence for the changing moisture regime includes redox depletions and yellowish brown clay coating planer voids within red matrices.

Chapter 6

QUARTZITE ROCK WEATHERING IN VIRGINIA BLUE RIDGE ALLUVIAL-FAN SOILS

(ABSTRACT)

Highly weathered quartzite cobbles are imbedded in alluvial-fan soils along the western footslopes of the Virginia Blue Ridge. These widespread rocks are intriguing because their weathering patterns and physical condition suggest long-term exposure to weathering processes. This study was conducted to compare weathered rock bulk densities (ρ_{rb}) among sites and to determine if ρ_{rb} correlates to rock and/or soil properties. From 10 locations, 93 rocks were collected. Rock bulk density was compared using the Kruskal-Wallis nonparametric procedure. Rock free Fe (Fe_r) was compared with a two-level nested analysis of variance for unequal sample sizes. Pearson's correlation coefficients were determined for ρ_{rb} verses several soil and rock properties. Among five sites, weathered ρ_{rb} ranges from 2.17 to 2.32 Mg m^{-3} and is not significantly different. These sites lie on a bajada. Weathered ρ_{rb} is different at the other sites and ranges from 2.39 to 2.52 Mg m^{-3}. Variation among rocks within sites yields 72.8 percent of the Fe_r variation making it impossible to suggest a within-site weathering senario. Rock free Fe variation among sites is only 13.1 percent, which suggests similar weathering processes controlled rock alteration

throughout the study area. The correlation coefficient (r = -0.73) indicates an inverse weathering relationship between ρ_{rb} and Fe_r. Rock bulk density is most strongly, but also negatively (r = -0.76), correlated with clay fraction hydroxy-interlayered vermiculite (CLAYHIV). No direct interaction is known between the two properties, but their correlation indicates rock weathering in the soils is related to weathering environment intensity and probably residence time of the rocks in the soil. It appears ρ_{rb} and Fe_r are good parameters with which to study weathering and possibly age relationships among Blue Ridge alluvial-fan soils. The parameters could prove useful for correlating fan deposits with colluvial and river terrace deposits in Virginia.

INTRODUCTION

Rocks weathered in transported deposits conceivably should be useful for evaluating the soil weathering environment. The rocks may differentiate depositional sequences and thus correlate geomorphic surfaces. As with any soil feature, weathered rocks offer only relative estimates about the length of time for development. Even so, they provide a direct, internal means for correlation. Mills (1988) advocated relative age classifications, stating that even though in most cases they represent arbitrary division of a continuum, they should be used when possible.

Chemical weathering rinds progress inward from the rock surface. Colman and Pierce (1981) measured weathering rinds on andesitic and basaltic stones in the Western United States. From their (Colman and Pierce, 1981) research, they placed glacial deposits within time intervals for glacial advances that corresponded well to oxygen-isotope records. Colman and Pierce (1981) also addressed how the factors of soil formation influence the rate of weathering-rind development. Because their paper was about the influence of time, they designed sampling procedures to reduce or isolate variation contributed by the other factors.

For three Quaternary Allier River terraces in France, Veldkamp et al. (1990) analyzed chemical composition of weathered alkali basalt pebbles. They (Veldkamp et al.,

1990) compared the bulk density of weathering rinds with that for unweathered cores as a measure of weathering intensity. They concluded differences in weathering intensity between the two oldest terraces were predominantly caused by chemical composition of the alkali basalt pebbles.

Mills (1988) presented a schematic diagram of weathering rinds observed on sandstone found in southwestern Virginia colluvium. Some patterns suggested, by yellow or white external rinds against red interiors, Fe reduction along the outer perimeter of the stones. The rocks with the best developed, multiple rinds were on colluvium-capped noses. But even within a single horizon at an individual site rinds varied greatly. Mills (1988) suggested the multiple rinds may reflect a change in the rock-weathering environment, either climatic or physical such as tree throw.

Other studies from Virginia mentioned weathered siliceous rocks as components of transported deposits although rock weathering was not the research focus. Harris et al. (1980) identified crushable quartzite in a New River terrace (about 84 m above river level) as partial evidence for separating it from the next lower terrace. Likewise, Howard et al. (1993) found disarticulated quartzite clasts in Plinthic Paleudults formed in James River alluvium. In their chronosequence study (Howard et al., 1993), rock competency decreased as geomorphic surfaces became progressively older.

Mills and Wagner (1985) also studied weathering intensity of high terraces along the New River downstream from Harris et al. (1980). They noted sandstone clasts so weathered that they disintergrated when touched. Hack (1965) studied alluvial terraces of the Shenandoah River and its tributaries during his geomorphology investigations of the Shenandoah Valley. Terrace remnants of the Middle River were present as high as 60 m above the river. Although the high remnants were small, at such different elevations, and the soils too much alike for him to correlate the terraces, Hack noted the degree of boulder weathering and the amount of terrace dissection increased with elevation. Several other studies describe Antietam quartzite as the dominant lithology of fluvial deposits along the western footslopes of the Blue Ridge (Henika, 1981; Gathright et al., 1977; Bloomer and Werner, 1955).

The ubiquity of the rocks reported throughout central Virginia suggests a period of regolith instability during the geologic history of the region. Although Hack (1965) believed erosional-depositonal processes are continuous through time, the weathered condition of the rocks suggested to him it had been a long time since the last major episode of deposition. The rocks potentially provide information about depositional processes, time intervals between depositions, and the weathering environment during which they weathered. Also, they may be useful for correlating the alluvial fans with other transported deposits in the Commonwealth.

Since the rock weathering process implies transformation and loss of constituents, the response to the process should be decreased ρ_{rb}. Quantification and comparison of this parameter, and Fe_r, may improve theories and interpretations about the geomorphic history of a region.

The objectives of this investigation were to: i) use ρ_{rb} to compare fan soils from several locations along the western flank of the Blue Ridge; and ii) determine if weathered ρ_{rb} correlates to any rock or soil properties.

MATERIALS AND METHODS

The study region is along the western footslopes of the Blue Ridge province in Botetourt, Augusta, Rockingham, and Page counties, Virginia (Fig. 6.1). The alluvial fans were interpreted by Kochel and Johnson (1984) and Kochel and Simmons (1986) as braided stream deposits with insignificant debris flow activity (Kochel and Simmons, 1986). The soils typically depict at least two episodes of deposition in the upper 2m. The discontinuity generally occurs between 0.5 to 1m. Above the discontinuity the soils have more sand and silt than below the discontinuity. Clay percentages below the discontinuity range between 35 and 55%.

Rocks in the soils are quartzite from the Antietam

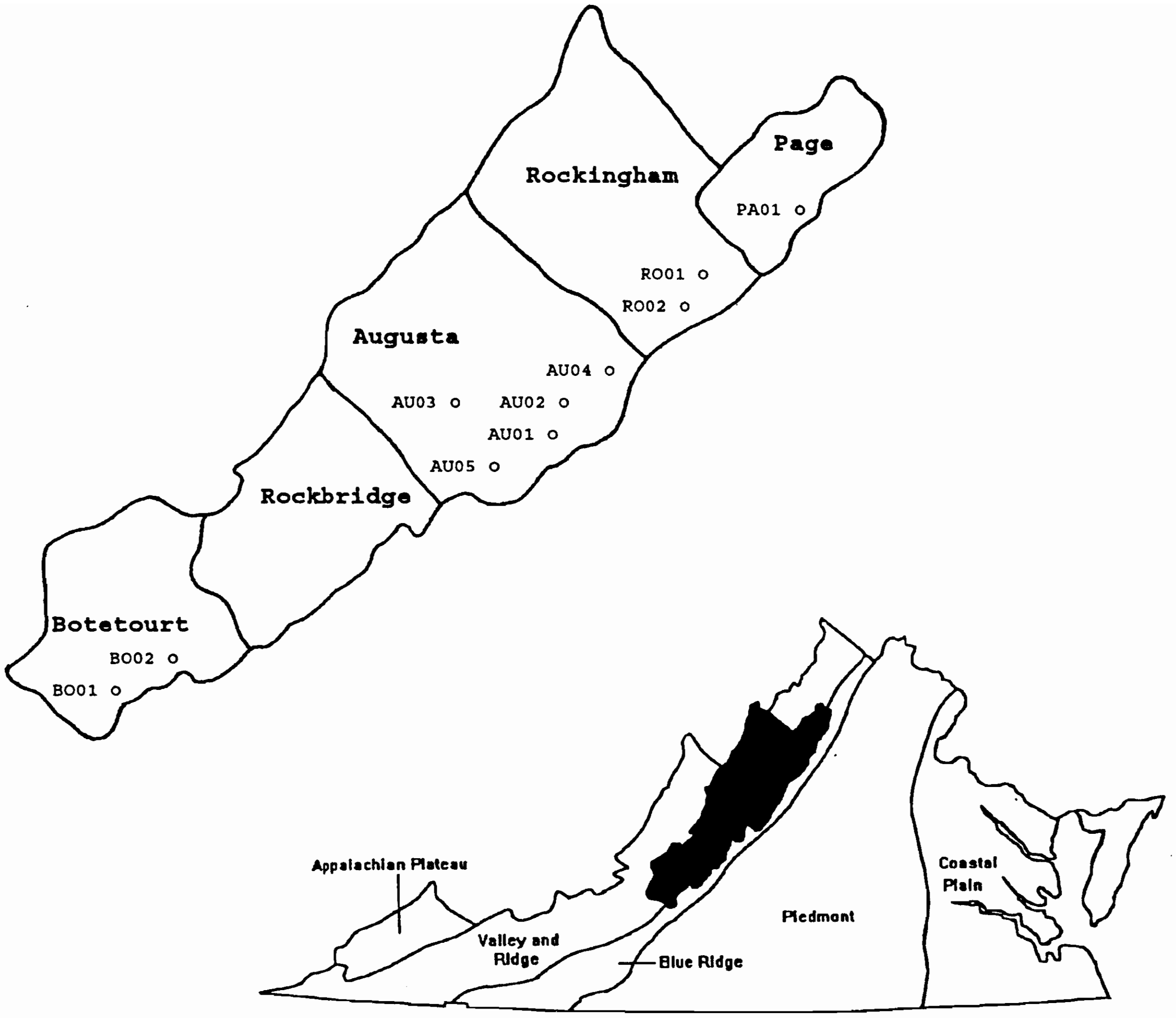

Figure 6.1. This map shows the locations of collection sites for the weathered rocks.

Formation. It forms the hogback northwestern front of the Blue Ridge. At most locations the formation is homogeneous, uniformly arenaceous, white to bluish-gray, quartzites and well-indurated quartzose sandstone cemented by secondary silica (Sweet, 1981; Bloomer and Werner, 1955). Chemical composition ranges from 96.5 to 99.6% SiO_2, 0.01 to 0.33% Fe_2O_3, and 0.30 to 1.86% Al_2O_3 (Harris, 1972; Sweet, 1981; Sweet and Wilkes, 1986).

Soil and rock samples were collected (from below the discontinuity if present) at depths between 1.5 and 1.75 m. Sites were excavated pits and freshly exposed road cuts in or near mixed hardwood forests. Complete descriptions for sites BO01, BO02, AU01, AU02, AU04, RO01, and PA01 can be found in Appendix A. For this study site AU02 corresponds to Table A.8, site AU04 corresponds to Table A.7, and site PA01 corresponds to Table A.13. Complete descriptions for AU03, AU05, and RO02 are not available, but site locations are footnoted in Table C.1.

Particle-size distribution of soil (<2.0 mm) surrounding the rocks was determined using the the pipet method (Soil Survey Staff, 1984). Soil free Fe was determined by the dithionite-citrate-bicarbonate (DCB) method of Holmgren (1967), and Fe extracts were analyzed by atomic absorption spectrophotometry. Qualitative clay mineralogy (<2.0 μm) was determined using a Diano XRD 8300 AD x-ray diffractometer

(XRD) (Diano Corp., Woburn, MA) with Cu$k\alpha$ radiation (20 mA, 40 kV) after particle-size fractionation by centrifugation (Kittrick and Hope, 1963). Kaolinite and gibbsite were quantified by differential scanning calorimetry (DSC) with a DuPont 1090 Thermal Analyzer (TA Instruments, New Castle, DE) using poorly crystalline Georgia kaolinite and Reynolds synthetic gibbsite as standards. The remaining clay-size minerals were estimated by comparing XRD peak areas relative to those of kaolinite.

Rock Sampling and Analysis

From each pedon, 8 to 10 rocks with approximately 12 cm diam. were collected within a horizontal distance of 1.0 m. Rock sampling was random and unbiased with respect to lithology, rock integrity, and degree of weathering because rocks were not broken apart in the field to observe these characteristics before selection.

In the laboratory, after air-drying for several weeks, the rocks were washed free of excess soil, dried, and the external appearance was described. Bulk density was measured on each rock using a modified method of Brasher et al. (1966). (The rocks were not coated with saran, but a hairnet was used to suspend the rocks in water). Unweathered Antietam rocks were collected from four creeks within the study area. Bulk density was measured on these rocks to obtain an estimate of the intial ρ_{rb}.

After measuring ρ_{rb}, the weathered rocks were broken apart, and the internal weathering characteristics were described. When broken, many of the weathered rocks fell into disarticulated sand. Five subsamples were obtained from each rock for DCB Fe analysis (Holmgren, 1967) and for grain-size analysis by sieving. Hard rocks were broken to pass a 2.0 mm sieve and subsampled for Fe analysis. Thin sections were prepared from the hard samples and grain-size estimates were made by the line count method by measuring grains with a Zeiss polarizing microscope equiped with a micrometer. Rock Fe extracts were analyzed by an inductively coupled plasma spectrometer equipped with a Jarrell-Ash ICAP 9000 simultaneous spectrometer.

Statistical Analysis

The Kolmogorov-Smirnov procedure (Hollander and Wolfe, 1973) was used to test for normality of bulk density measurements within sites. Rock bulk density among sites was compared using the Kruskal-Wallis procedure, the nonparametric counterpart to analysis of variance. Calculations were performed using the Virginia Tech Nonparametric Statistical Package (Pirie, 1988).

Rock free Fe measurements were compared using a two-level nested analysis of variance for unequal sample sizes (Sokal and Rohlf, 1969). Iron observations (Y_{ijk}) were assumed to be explainable by the linear model:

$$Y_{ijk} = \mu + S_i + R \subset S_{ij} + \epsilon_{ijk} \qquad [1]$$

where μ represents an overall mean; S_i represents the effect due to a particular site; $R \subset S_{ij}$ represents the effect due to a particular rock within a site; and ϵ_{ijk} represents the residual or error variance. The analysis of variance procedure was used to compute mean squares (MS) necessary for estimating amount of total variance contributed by each component in the experimental design.

Pearson's correlation coefficients were calculated for ρ_{rb} verses soil free Fe, sand, silt, and clay; rock free Fe, coarse sand, medium sand, and fine sand; clay-size kaolinite, gibbsite, and HIV; and elevation (SAS Institute Inc., 1985a).

RESULTS AND DISCUSSION

Soil Properties

Clay percentages and Munsell color (Table 6.1) for the soil horizons suggest advanced soil weathering. Clay percentages are unusual for soils containing only quartzite rocks. Other lithologies were present and have since weathered away (Chapter 5). Another possibility is that the original sediments held substantial fine-earth transported to the present location. If they were ever present, all signs of depositional stratification were overcome by soil horizonation.

Kaolinite and HIV are the primary components of the clay (Table 6.2). Moderate amounts of muscovite in some horizons

Table 6.1. Horizon physical properties† and external site characteristics of the pedons from which the rocks were sampled.

Site	Horizon	Depth	Color	VCS	CS	MS	FS	VFS	TS	Si	Clay	Slope	Elev.‡
		(cm)						%					(m)
BO01	2Bt4	143-200	2.5YR 4/6	1.42	1.98	1.68	13.98	10.01	29.07	30.22	40.71	10	482
BO02	2Bt4	128-170	2.5YR 4/6	0.81	3.75	3.65	11.56	13.90	33.67	24.20	42.13	7	402
AU01	Bt2	90-122	2.5YR 4/6	3.44	10.41	28.10	13.74	2.73	58.42	13.97	27.61	2	536
AU02	2Bt3	142-156	2.5YR 4/6	0.82	4.12	12.41	9.44	2.59	29.38	21.06	49.56	2	439
AU03	2Bt2	90-132	5YR 4/8	0.31	1.74	5.74	11.69	5.13	24.61	15.46	59.93	3	457
AU04	2Bt2	117-161	7.5YR 5/8	0.81	4.66	10.03	20.16	10.83	46.49	25.52	27.99	3	402
AU05	2Bt3	115-152	10YR 5/6	0.83	3.62	8.17	8.37	4.65	25.64	26.35	48.01	5	396
RO01	2Bt2	112-156	10R 3/6	4.51	6.59	7.21	10.39	4.33	33.03	24.86	42.10	2	353
RO02	Bt2	76-120	2.5YR 4/8	0.52	3.41	6.81	8.98	6.92	26.64	32.45	40.91	3	335
PA01	2Bt2	82-106	10R 4/6	2.45	5.29	8.66	8.45	4.06	28.91	26.21	44.88	10	360

† VCS = very coarse sand; CS = coarse sand; MS = medium sand; FS = fine sand; VFS =very fine sand; TS = total sand; SI = silt.

‡ Elev. = elevation.

Table 6.2. Clay (<2.0 μm) mineralogy† of the horizons from which rocks were sampled.

Site	Horizon	Depth	KAO	HIV	GIB	2:1 intergrade	MUS	QTZ	Fe
		(cm)	----------------			g kg^{-1}	----------------		
BO01	2Bt4	143-20	522	51	--	--	333	50	44
BO02	2Bt4	128-170	333	165	95	184	184	55	58
AU01	Bt2	90-122	427	409	107	--	--	24	33
AU02	2Bt3	142-156	228	419	87	50	--	171	43
AU03	2Bt2	90-132	308	411	164	50	--	--	67
AU04	2Bt2	117-161	488	241	43	--	--	95	133
AU05	2Bt3	115-152	347	440	40	100	--	33	50
RO01	2Bt2	112-156	357	157	57	150	161	75	44
RO02	Bt2	76-120	255	472	41	200	--	--	33
PA01	2Bt2	82-106	500	171	--	--	176	85	48

† KAO = kaolinite; HIV = hydroxy interlayered vermiculite; GIB = gibbsite; MUS = muscovite; QTZ = quartz; Fe = free Fe on a whole soil basis.

suggest it as a likely precursor to the HIV. Even with the high amount of HIV, which can be a sink for hydroxy-Al, gibbsite still occurs in the horizons. Harris et al. (1980) found no trend with age or depth for gibbsite in their chronosequence study even though Al sources (mica and feldspar) were available in the sand fractions. However, gibbsite did show a trend toward increasing abundance with age in the James River terraces studied by Howard et al. (1993). The stable clay mineral suite of this study compliments the high clay contents, and supports the theory for long-term soil weathering (Kochel and Simmons, 1986) and landscape stability.

Rock Properties

Figures 6.2 - 6.5 show redoximorphic patterns imprinted on the rocks. The patterns, representative of all sites, are inherent from the surrounding soil matrix. Hues correspond to soil matrix colors shown in Table 6.1. Secondary colors on rock surfaces are brownish yellow (10YR 6/6), yellow (10YR 7/6), and pink (5YR 7/4). The subangular to subrounded rocks, rather than having smooth surfaces like most fluvially transported rocks, have pitted surfaces which resulted from Si dissolution. Individual sand grains can be rubbed from the exterior surfaces and exposed interior surfaces.

Rock interiors have a variety of rind patterns and colors which starkly contrast with the vitreous luster of

Figure 6.2. A representative rock from BO01. Bar length is 10 cm.

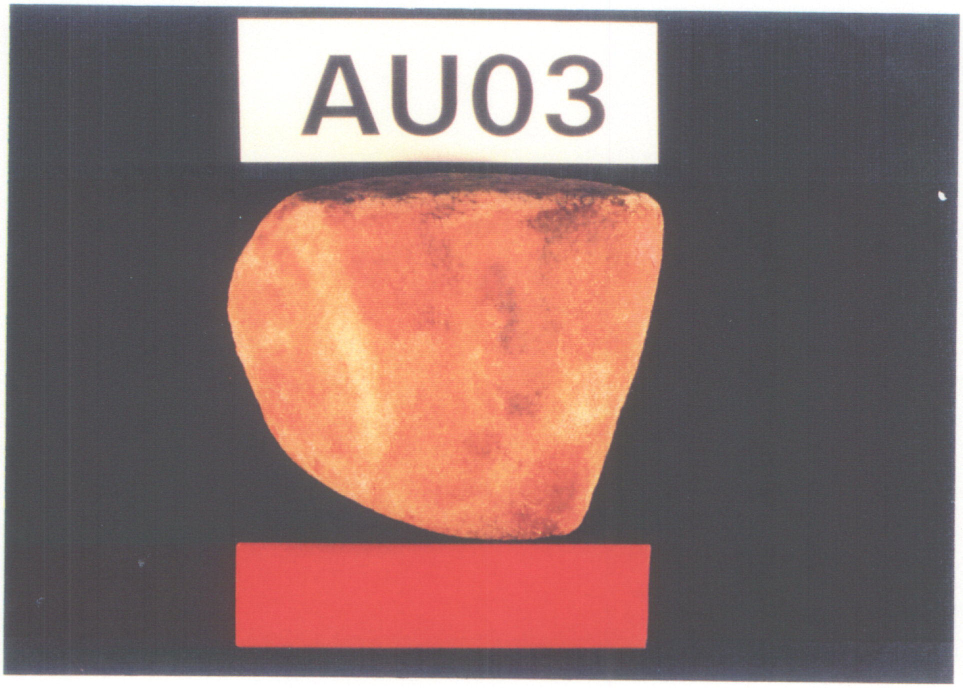

Figure 6.3. A representative rock from AU03. Bar length is 10 cm.

Figure 6.4. A representative rock from RO01. Bar length is 10 cm.

Figure 6.5. A representative rock from PA01. Bar length is 10 cm.

unweathered Antietam quartzite (Appendix C.1). The rocks typically are completely oxidized to their center. In most cases, progressing outward, red and pink colors change to yellow, suggesting the presence of hydrated Fe compounds. The yellow rind grades to the white and gray color of the unstained rock. This indicates Fe reduction and translocation from the outermost part of the rocks. A rock from PA01 (Fig. 6.6) typifies this pattern. It also has a concentration of apparently less hydrated Fe adjacent to the yellow rind. The striations visible on rocks from PA01 (Fig. 6.6) and RO02 (Fig. 6.7) are burrows made by *Skolithus linearis* when the original quartz sands were Cambrian offshore bar to tidal delta deposits (Schwab, 1972, as cited by Henika, 1981).

The rind patterns may signal a change in the soil weathering environment. Mills (1988) described multiple rinds on Tuscarora Quartzite, a component of Valley and Ridge colluvial deposits in southwest Virginia. He (Mills, 1988) said multiple rinds may reflect a changing clast environment caused by either climatic change or by movement of the clasts within the soil by physical disruption such as tree fall. Similar patterns on medium-grained, white sandstone were also described by Peltier (1949) on Pleistocene terraces of the Susquehanna River, Pennsylvania.

Figure 6.6. A rock from PA01 shows the internal weathering pattern and a *Scolithus linearis* burrow. Bar length is 10 cm.

Figure 6.7. A rock from RO02 shows a *Scolithus linearis* burrow in relief after the external rock surface weathered away. Bar length is 10 cm.

Box plots for very coarse sand (Fig. 6.8), coarse sand (Fig. 6.9), medium sand (Fig. 6.10), fine sand (Fig. 6.11), and very fine sand (Fig. 6.12) developed from the sieve and thin section measurements indicate median medium sand generally is greater than median coarse sand. Substantial amounts of fine sand also are present in the rocks. Extended boxes and long whiskers indicate dispersion is great for all three fractions at each site, an inherited property implying the poorly sorted nature of the quartzite. Quantiles for rock sand-size measurements are given in Table C.2.

Rock Analyses

With the physical and mineralogical properties of the soil and the physical condition of the quartzite rocks indicating advanced soil weathering, it is reasonable to expect ρ_{rb} to also reflect the weathering. I used the Kruskal-Wallis test to compare ρ_{rb} between sites because sample distribution was nonnormal by the Kolmogorov-Smirnov test (Table 6.3). Comparisons indicate the Augusta County sites and one Rockingham County site are not different. These sites are on the fluvially dominated bajada discussed by Kochel and Johnson (1984). The similarity indicates the materials could have been deposited about the same time. The remaining sites are outside the area studied by Kochel and Johnson (1984) and occur on steeper slopes. Steeper slopes may allow water to pass through the soil more quickly than

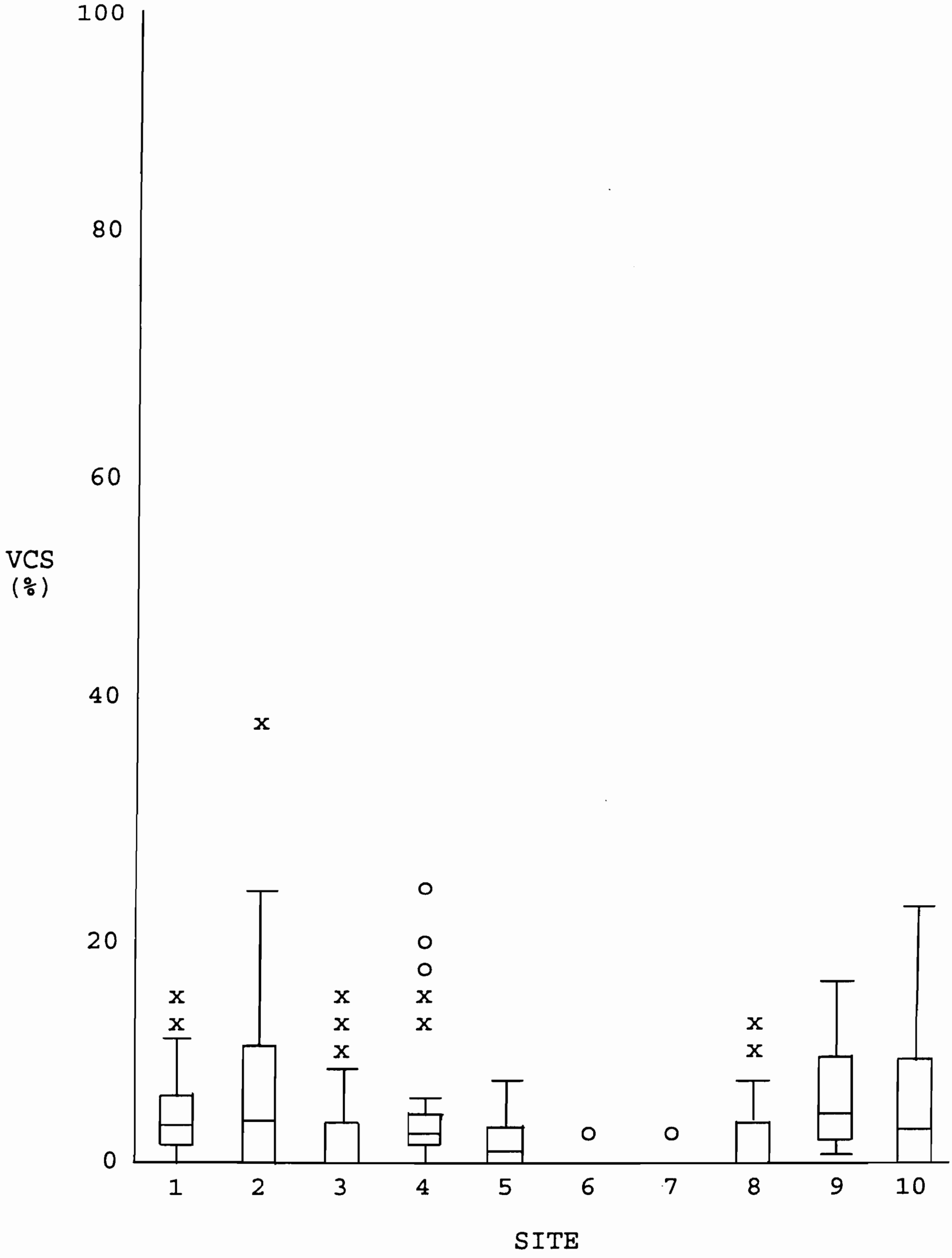

Figure 6.8. Box plots show the dispersion of the very coarse sand fractions from the weathered rocks.

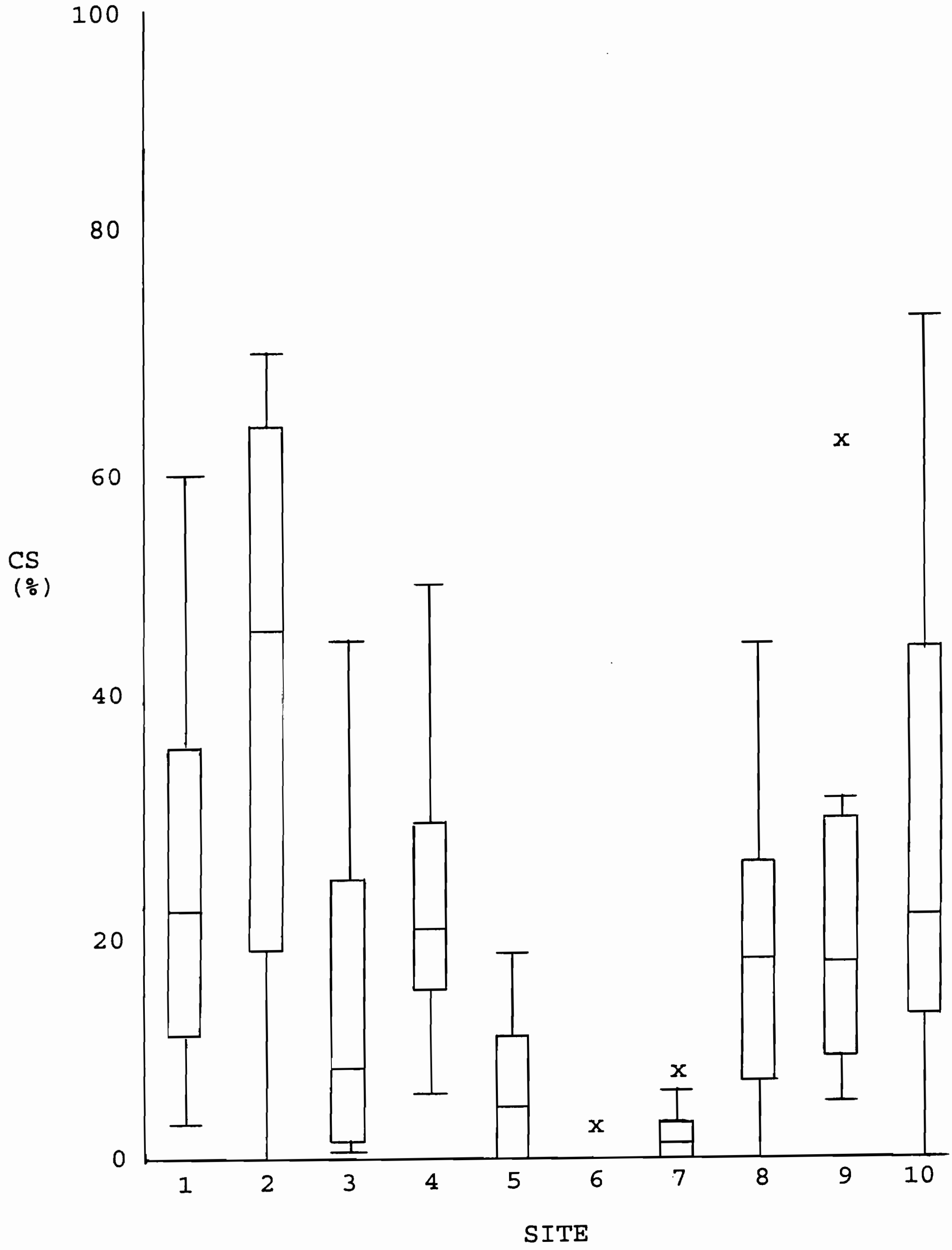

Figure 6.9. Box plots show the dispersion of the coarse sand fractions from the weathered rocks.

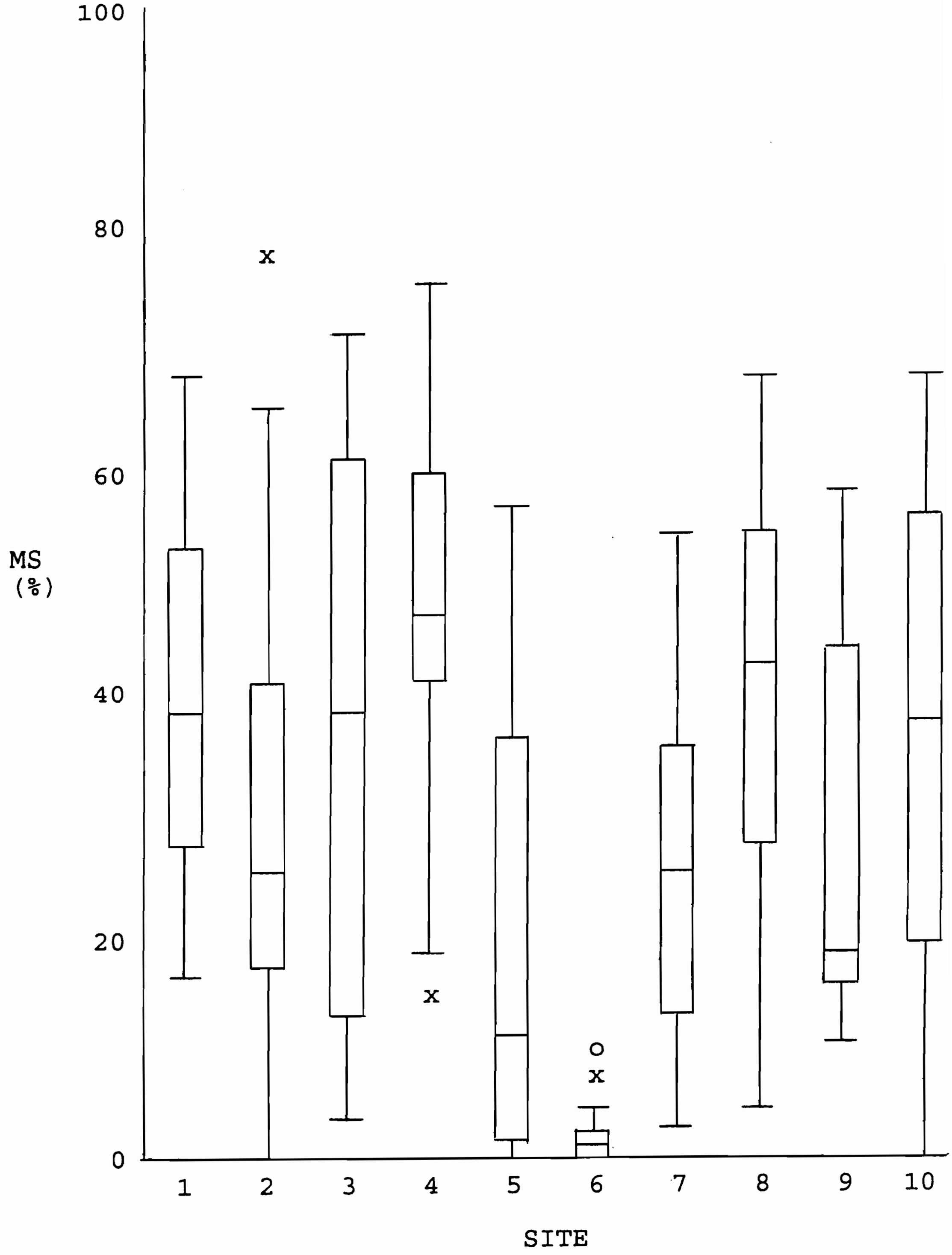

Figure 6.10. Box plots show the dispersion of the medium sand fractions from the weathered rocks.

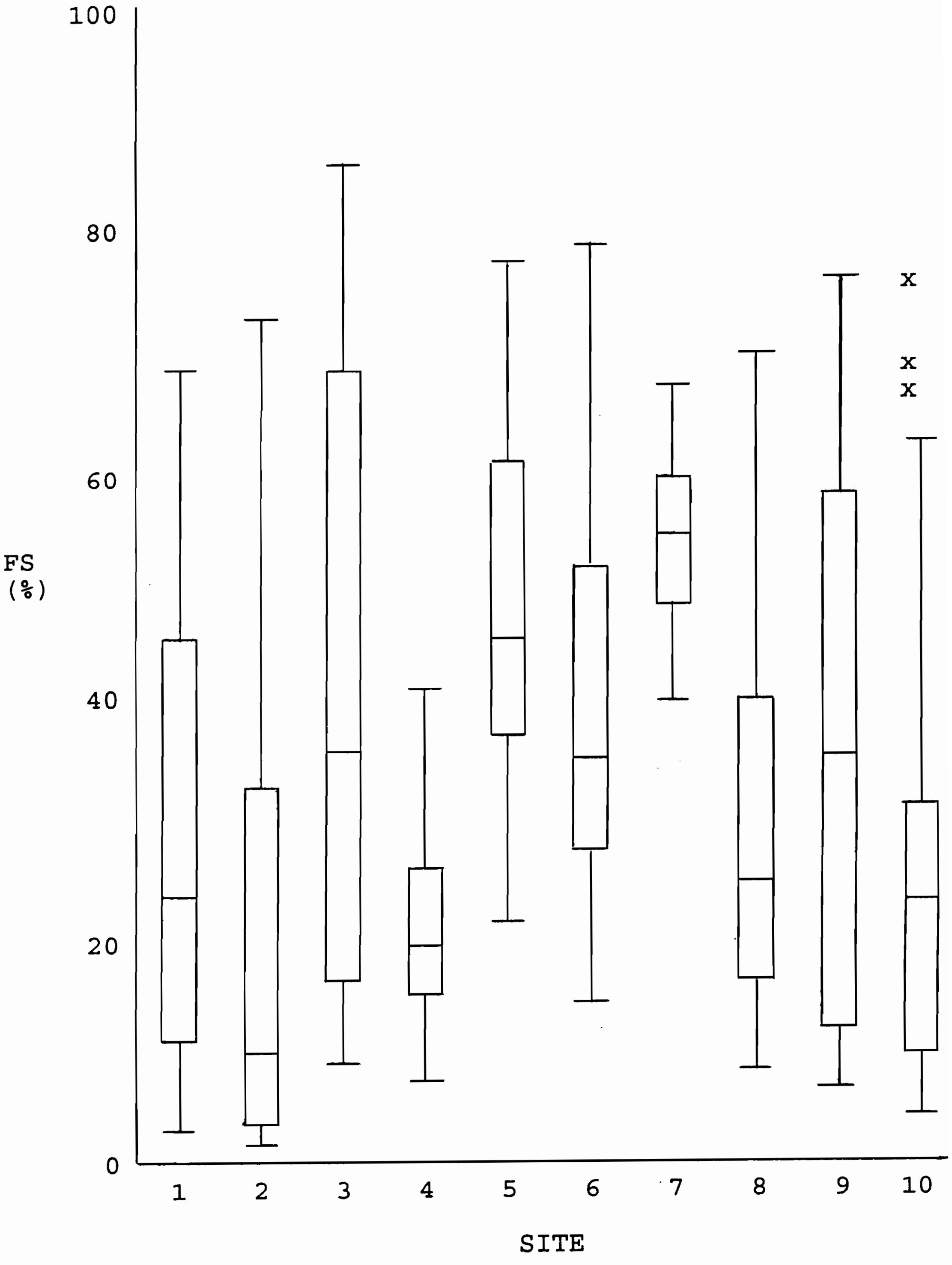

Figure 6.11. **Box plots show the dispersion of the fine sand fractions from the weathered rocks.**

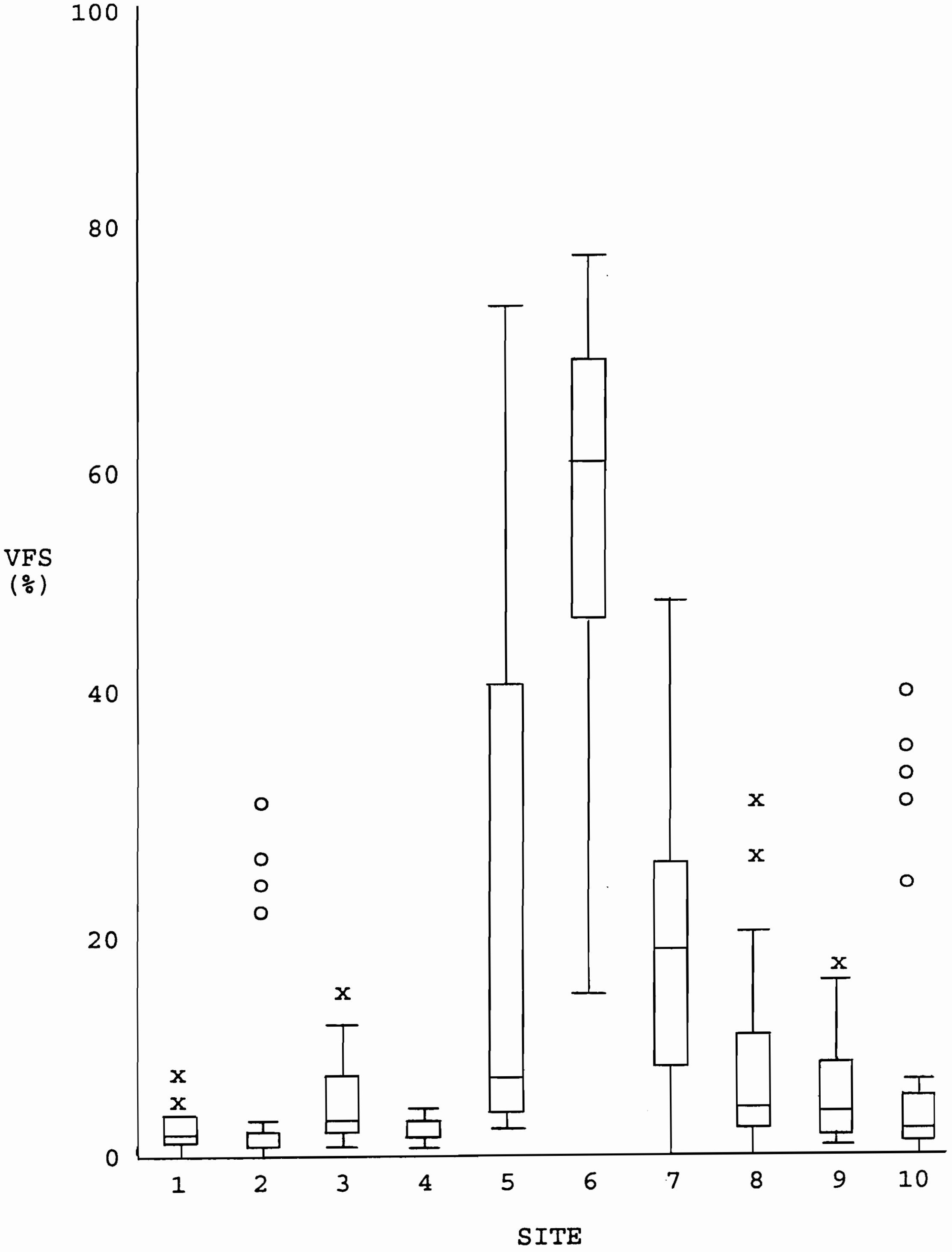

Figure 6.12. Box plots show the dispersion of the very fine sand fractions from the weathered rocks.

Table 6.3. **Alpha-levels associated with the Kolmogorov-Smirnov procedure for testing the normality of sample distribution and Kruskal-Wallis comparisons of the median bulk densities for the weathered and unweathered rocks.**

Weathered Rocks			Unweathered Rocks	
Site	α(DNS)	ρ_b†	Site	ρ_b
		Mg m^{-3}		Mg m^{-3}
AU03	<0.01	2.21a	AU01	2.57a
AU04	<0.01	2.22a	AU02	2.58a
RO02	<0.01	2.17a	AU04	2.59a
AU01	<0.01	2.29a	PA01	2.59a
AU05	<0.01	2.31a		
AU02	<0.01	2.32a		
RO01	<0.01	2.39b		
BO01	<0.01	2.44b		
PA01	<0.01	2.45b		
BO02	<0.01	2.52c		

† Values followed by the same letter are not significantly different.

flatter slopes. Thus, the rocks have less reaction time with water. Actual ρ_{rb} values for each rock are shown in Table C.3.

Bulk density is not different for the unweathered rocks (Table 6.3) collected from nearby stream beds. Whether the values (2.57-2.59 Mg m^{-3}) reflect the actual ρ_b or a consistentunderestimate is unknown.

Since Fe_r is expected to increase as weathering progresses, the rocks provide the opportunity to compare Fe_r and rock weathering within and among sites. From the analysis of variance, sampling and laboratory procedures contribute some variability to the observations of rocks. Variance within the rocks, or error variance (Table 6.4), is 14.05%, indicating fairly consistent sampling and laboratory techniques for measuring the Fe_r. Low error variance means we can observe real differences in the Fe_r content.

The bulk of the variation (72.82%) represents variation among rocks within sites. The large contribution to total variance from among rocks within sites makes it impossible to suggest a weathering senario within each pedon. Two possible but untested hypotheses for the high variability are i) inherent Fe in the rock was highly variable and, ii) assuming some of the Fe was translocated into the rock, textural differences between rocks caused variable transport. The high variability among Fe_r within sites supports the need to take many samples within the level where the most variability

Table 6.4. Analysis of variance for DCB-extractable Fe in the weathered rocks.

Source of Variation	df	Mean square	$P > F$	Parameter estimates†	Contribution to total variance (%)
Among sites	9	0.4989	0.01	$\sigma^2_\epsilon + n'_0\sigma^2_{RCS} + (nb)_0\sigma^2_S$	13.13
Among rocks (within sites)	83	0.2348	<0.005	$\sigma^2_\epsilon + n_0\sigma^2_{RCS}$	72.82
Within rocks (replicates)	372	0.0077		σ^2_ϵ	14.05

† $n'_0 = 2.4534$, $(nb)_0 = 46.4635$, $n_0 = 5.2761$.
$s^2 = 0.0077$ estimates σ^2_ϵ.
$s^2_{RCS} = (\mathrm{MS}_{RCS} - \mathrm{MS}_\epsilon)/n_0 = 0.04304$ estimates σ^2_{RCS}.
$s^2_S = [\mathrm{MS}_S - \mathrm{MS}_\epsilon - n'_0(s^2_{RCS})]/(nb)_0 = 0.0083$ estimates σ^2_S.

is expected (Sokal and Rohlf, 1969). Many samples assure accurate representation of the parameter and interpretation of the results.

Although differences among sites and differences within sites are significantly different, differences among sites contribute much less to the total variance (13.13%) than the differences within sites. This indicates the rocks at each site, though spread over a distance of several km, have undergone similar weathering processes and/or were similar lithologies.

Multiple comparisons of mean Fe_r (Table 6.5) among sites place the sites into six separate groups. Although not in the identical order, the groups generally correspond to the ρ_{rb} groupings shown in Table 6.3. The Fe_r values increase as ρ_{rb} decrease. The Fe_r values, ranging from 1.0 to 3.8 g kg^{-1}, are comparable to the Fe values given by Sweet (1981) and Harris (1972) and, therefore, do not strongly support the hypothesis that some of the free Fe was transported into the rocks from the surrounding soil matrix. Actual free Fe for each rock subsample is shown in Table C.4.

Correlation coefficients show the relationship between median ρ_{rb} and several soil and rock related features (Table 6.6). Clay-fraction HIV, ROCKFE, ROCKCS and ROCKFS are the significant properties correlated to ρ_{rb}. The negative relationship between ρ_{rb} and Fe_r ($r= -0.73$) was expected from

Table 6.5. Duncan's multiple comparisons of Fe_r from rocks among sites.

Site	Mean Fe_r†
	g kg^{-1}
AU02	3.8a
AU04	3.7a
RO02	3.1b
AU01	2.9bc
AU03	2.8bc
AU05	2.6c
PA01	1.9d
BO01	1.5e
RO01	1.1f
BO02	1.0f

† Values followed by the same letter are not significantly different.

Table 6.6. **Pearson's coefficients (r) for correlating median rock bulk density to the selected variables and the probability of whether the sample correlation coefficient could have come from a population with a correlation coefficient of zero.**

Variable†	**r**	**α(R)**
SOILFE	-0.33	0.36
SOILSAND	-0.10	0.79
SOILSILT	0.15	0.67
SOILCLAY	0.02	0.96
CLAYKAO	0.34	0.33
CLAYGIBB	-0.32	0.37
CLAYHIV	-0.76	0.01
ROCKFE	-0.73	0.01
ROCKCS	0.71	0.02
ROCKMS	0.46	0.18
ROCKFS	-0.64	0.04
ELEV	-0.01	0.66

† SOIL = <2.0 mm fraction; CLAY = <2.0 μm fraction; FE = dithionite-citrate bicarbonate extractable free Fe; KAO = kaolinite; GIBB = gibbsite; HIV = hydroxy interlayered vermiculite; ROCK = rock samples; CS = coarse sand; MS = medium sand; FS = fine sand; ELEV = elevation.

the multiple comparisons. Also, rock texture is an important factor affecting the rate at which rocks weather. Fine-grained rocks should weather more slowly than coarse-grained rocks and, consequently should have lower bulk density. However, my data indicate the sites with finer-textured rockshave lower ρ_{rb}. This suggests more intergrain pore space is created as the rocks weather resulting in lower ρ_{rb}.

Surprisingly, all the soil fine-earth fractions are not correlated to ρ_{rb}. This implies soil texture had little influence on rock weathering. Colman and Pierce (1981) found slightly faster rind development on rocks embedded in finer-textured till than in coarser outwash. However, they (Colman and Pierce, 1981) suggested the effect may be complicated by different vegetation communities supported by the different soils.

Although no direct physical or chemical interaction is known between clay-fraction HIV and ρ_{rb}, it is interesting that this relationship is the most strongly correlated ($r = -0.76$). This appears to indicate rock weathering is related to the intensity of the weathering environment. Rock bulk density is poorly correlated to clay fraction kaolinite and gibbsite (Table 6.6).

CONCLUSIONS

Soils formed on Blue Ridge alluvial fans of central Virginia can be compared using the bulk density of weathered quartzite found in the soils. It appears rock texture influenced rate of rock weathering more than the fine-earth fraction of the surrounding soil matrix. Intensity of the weathering environment and residence time of rocks in the soil also seem to control the degree of rock weathering as indicated by moderately strong correlation between CLAYHIV and ρ_{rb}. This study strongly suggests ρ_{rb}, Fe_r, and CLAYHIV measurements are promising properties for which to evaluate soil-geomorphic relationships among Blue Ridge alluvial fans. The properties may prove useful in future efforts to correlate the alluvial fan-soils with soils developed on other transported deposits of central Virginia.

Chapter 7

CONCLUSIONS AND SUMMARY

Typic Paleudults and Typic Fragiudults are widely distributed on alluvial fans spread across the western footslopes of the Blue Ridge province, Virginia. Nearly all the sites investigated have a discontinuity in the solum underlain by a thick, well developed, red argillic horizon. The soils are strongly to very strongly acid, have low effective CECs, and have high amounts of kaolinite, HIV, and gibbsite. All of the sites contain weathered Antietam quartzite rocks, many of which readily disarticulate to sand when struck with a hammer. Physical, chemical, and mineralogical properties show the similarity among the soils as well as emphasize their degree of development.

The upper, most recent deposit, unit A, is usually 1 m thick or less. Taxonomic classification of the soils is influenced by the thickness and amount of development of unit A. Coarse-loamy or fine-loamy soils occur when unit A is moderately developed. Clayey soils occur when the unit is thin and weakly developed.

After paired sampling of several pedons within a 50 m^2 area, principal component analysis and discriminant analysis of several soil properties clearly identify discontinuities in the soils. Principal component loadings indicate clay-free properties are usually the most effective properties for identifying the discontinuities. Several pedons within an area should be examined to spacially verify the discontinuity. The Moses Ranklike test indicates no evidence for dispersion differences between unit A and unit B. This suggests method of deposition, particle-sorting, and/or source area is about the same for both units. Because dispersion is not different, the discontinuity is interpreted as a chronologic rather than as a lithologic discontinuity.

Clay, free Fe, and extractable Al occur in anomolous amounts for what one would expect of soils derived from quartzite. Therefore, the original materials of the lower unit, unit B, must have contained other lithologies and/or fine-earth additional to the quartzite. Any vestige of other sources has long since weathered to soil. The Harpers Formation most likely contributed to the fan sediments. It runs continuously along the Blue Ridge like the Antietam Formation. Sericite, chlorite, biotite, and feldspars in the Harpers could produce soil properties and mineral suites like the ones observed on the alluvial fans.

Fan sediments probably began accreting during the Cenozoic era, possibly as early as the Eocene epoch, when the Appalachians are predicted to have received ≥ 6 mm d^{-1} mean annual precipitation. Unit B soils began forming when the last sediment was deposited. This was probably during the Miocene epoch. High rainfall, along with warm temperatures, leached the sediments and initiated soil formation.

After unit B was deposited, a substantial period of time passed. During this time the climate may have changed from warm to cool temperatures, possibly more than once. Warm interglacial temperatures aided soil development, producing the deep argillics. The past weathering environment intensity for unit B is reflected by red hues, more gibbsite in some pedons relative to unit A, and thoroughly weathered quartzite rocks with red internal hues and pitted external surfaces.

The rocks are intriguing features common to all the soils. They may well be the most useful feature for correlating the old soils to one another as well as to geographically associated soils. Rock bulk density is inversely correlated to Fe_r in the rocks ($r = -0.73$) and to HIV from the clay fraction ($r = -0.76$). Both findings illustrate the infuence of the weathering environment without discounting the importance of time. Soil particle-size fractions are not correlated to ρ_{rb}, but ρ_{rb} is correlated to coarse and fine sand rock fractions. This indicates soil textural composition had less influence on rock weathering than the rock physical properties.

Long after unit B materials were emplaced, unit A sediments were deposited. Soil morphology is weak to moderate in this unit. Hydrous oxides of Si and Al leached through unit A and precipitated at the contact with unit B.

They served as a cementing agent between the silt particles, thus aiding fragipan development at some locations. Some time during soil development reductive processes became more pronounced. Evidence for this is matrix redox depletions, yellowish brown clay coatings along planer voids within the red matrixes, and gray and yellow outer rinds surrounding red centers of the weathered quartzite rocks.

The soils record a long, complex history of soil formation and geomorphic evolution which began in the Cenozoic era. They imply sustained rainfall events occurred throughout central Virginia punctuated by Blue Ridge erosion and corresponding alluvial fan accretion. Secondly, unit B characteristics imply the soils formed in similar materials. They formed by similar, intense external and internal conditions during the same length of time. Thirdly, unit B soils likely correlate with Shenandoah, James, and New river terrace soils and southwestern Virginia colluvial soils. Finally, unit A sediments were implaced following a long time period. Probably deposited during the Pleistocene epoch, these sediments also demonstrate the widespread occurrence of the event marking their deposition.

Much work remains before solid theories can be fashioned reqarding the relationship of the alluvial-fan soils to other soils on transported deposits in Virginia. Just for the fan soils alone, more information is needed regarding Fe mineralogy of the red argillics and silt mineralogy of the whole solum. The origin and relative age of the unit A cappings are still an enigma and should be studied. It would be interesting to know why fragipans form in some of the soils but not others. The geomorphic relationship of the old fan soils to geographically associated soils should be investigated. For this investigation, a first approach to separating landforms on the fan surface could be to conduct a trend surface analysis with elevation data. Multivariate analysis of soil properties among landforms may help understand within-fan soil relationships. Without question, more studies should compare the alluvial fan soils to colluvial soils and river terrace soils both in Virginia and in the southern Appalachians. These studies and others would greatly enhance what we know about the surficial evolution of the southeastern United States.

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Appendix A

Table A.1. Description for Site BO01, Botetourt County.

Topographic Quadrangle: Villamont
Location: About 4200 feet, 158 degrees southeast of the junction of VA-640 and VA-711 and about 4300 feet, 140 degrees southwest of the junction of VA-640 and VA-647 at Nace.
Date: September 27, 1991
Described by: C. M. Ogg and M. H. Stolt
Vegetation: mixed hardwood
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 152 m
Elevation: 482 m
Slope: 10 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description to 200 cm; auger description to 307 cm. A weak stone line occurs at about 1m below the surface.

Ap - 0 to 5 cm; Gray (10YR 5/1) sandy loam; weak fine granular structure; very friable; many fine and medium roots and common coarse roots; many fine pores; clear smooth boundary; extremely acid.

E - 5 to 33 cm; Very pale brown (10YR 7/4) loam; weak fine subangular blocky structure; friable; common fine, medium, and coarse roots; common fine pores; 2 percent coarse fragments; clear smooth boundary; very strongly acid.

BE - 33 to 50 cm; Light yellowish brown (10YR 6/4) loam; weak medium subangular blocky structure; friable; common fine and medium roots; common fine vesicular pores; 2 percent coarse fragments; clear smooth boundary; very strongly acid.

Bt1 - 50 to 64 cm; Brown (7.5YR 5/4) loam; weak medium subangular blocky structure; friable; few fine and medium roots; common fine pores; 2 percent coarse fragments; gradual smooth boundary; very strongly acid.

Bt2 - 64 to 99 cm; Yellowish red (5YR 5/8) loam; moderate medium subangular blocky structure; friable; common discontinuous clay films on faces of peds; few fine roots; few fine pores; 5 percent coarse fragments; gradual smooth boundary; very strongly acid.

Table A.1. (cont.) Description for Site BO01, Botetourt County.

2Bt3 - 99 to 143 cm; Yellowish red (5YR 5/8) clay; common fine prominent brownish yellow (10YR 6/8) iron masses in the matrix; moderate medium subangular blocky structure; firm; many continuous clay films on faces of peds; few fine roots; few fine pores; 5 percent coarse fragments; gradual smooth boundary; strongly acid.

2Bt4 - 143 to 200 cm; Red (2.5YR 4/6) clay; common medium prominent yellowish brown (10YR 5/6) and brownish yellow (10YR 6/6) iron masses in the matrix; moderate medium subangular blocky structure; friable; many continuous clay films on faces of peds; gradual smooth boundary; strongly acid.

2Bt5 - 200 to 240 cm; Red (2.5YR 4/6) clay loam; many medium prominent yellowish brown (10YR 5/6) and brownish yellow (10YR 6/6) iron masses in the matrix; moderate medium subangular blocky structure; friable; many continuous clay films on faces of peds; gradual smooth boundary; strongly acid.

2Bt6 - 240 to 280 cm; Red (2.5YR 4/6) clay loam; many medium prominent yellowish brown (10YR 5/6) and brownish yellow (10YR 6/6) iron masses in the matrix; moderate medium subangular blocky structure; friable; many continuous clay films on faces of peds; gradual smooth boundary; strongly acid.

2Bt7 - 280 to 307 cm; Red (2.5YR 4/6) clay loam; many medium prominent yellowish brown (10YR 5/6) and brownish yellow (10YR 6/6) iron masses in the matrix; moderate medium subangular blocky structure; friable; many continuous clay films on faces of peds; gradual smooth boundary; strongly acid.

Table A.2. Description for Site BO02, Botetourt County.

Topographic Quadrangle: Villamont
Location: About 5200 feet, 156 degrees southeast of the junction of VA-606 and VA-640 (southeast of Camp Bethel).
Date: October 10, 1991
Described by: M. H. Stolt
Vegetation: mixed hardwood
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 213 m
Elevation: 402 m
Slope: 7 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Roadcut exposure.

A- 0 to 3 cm; Dark grayish brown (10YR 4/2) sandy loam; weak fine granular structure; very friable; many fine and medium roots; many fine pores; 2 percent coarse fragments; abrupt wavy boundary; extremely acid.

E - 3 to 27 cm; Pale brown (10YR 6/3) sandy loam; weak coarse subangular blocky structure; friable; common fine and medium roots; common fine pores; 2 percent coarse fragments; clear wavy boundary; very strongly acid.

EB - 27 to 48 cm; Pale brown (10YR 6/3) sandy loam; common medium distinct strong brown (7.5YR 5/6) iron masses in the matrix; weak medium subangular blocky structure; friable; common fine and medium roots; common fine pores; 2 percent coarse fragments; clear wavy boundary; very strongly acid.

Bt1 - 48 to 66 cm; Strong brown (7.5YR 5/6) loam; common medium distinct pale brown (10YR 6/3) clay depletions on faces of peds; weak medium subangular blocky structure; friable; common discontinuous clay films on faces of peds; common fine and medium roots; common fine pores; 2 percent coarse fragments; clear wavy boundary; very strongly acid.

Table A.2. (cont.) Description for Site BO02, Botetourt County.

2Bt2 - 66 to 94 cm; Yellowish red (5YR 5/6) clay; moderate medium subangular blocky structure; friable; many continuous yellowish red (5YR 4/6) clay films on faces of peds; few fine and medium roots; few fine pores; 2 percent coarse fragments; clear wavy boundary; strongly acid.

2Bt3 - 94 to 128 cm; Red (2.5YR 4/6) clay; common medium prominent yellowish brown (10YR 5/6) iron masses in the matrix; moderate medium subangular blocky structure parting to weak medium platy structure; friable; many continuous clay films on faces of peds; few fine roots; few fine pores; 10 percent coarse fragments; abrupt wavy boundary; strongly acid.

2Bt4 - 128 to 170 cm; Red (2.5YR 4/6) very cobbly clay; many medium prominent yellowish brown (10YR 5/6) iron masses in the matrix; few medium prominent light brownish gray (10YR 6/2) iron depletions in the matrix; moderate coarse subangular blocky structure parting to weak medium platy structure; friable; many continuous clay films on faces of peds; few fine pores; 45 percent coarse fragments; gradual wavy boundary; strongly acid.

2Bt5 - 170 to 240 cm; Red (2.5YR 4/6) very cobbly clay loam; many medium prominent yellowish brown (10YR 5/6) iron masses in the matrix; few medium prominent light brownish gray (10YR 6/2) iron depletions in the matrix; moderate coarse subangular blocky structure parting to weak medium platy structure; friable; many continuous clay films on faces of peds; few fine pores; 45 percent coarse fragments; very strongly acid.

Table A.3. Description for Site AU01, Augusta County.

Topographic Quadrangle: Big Levels
Location: From VA-644, west 2.7 miles on Forest Service Road 42 (Coal Road). The site is south of the road on the southwest rim of the quarry. 2500 feet east of Kennedy fields campground. (VA -644 is in the Sherando Quadrangle).
Date: August 5, 1989
Described by: Charles M. Ogg
Vegetation: Oak, blueberry
Parent Material: alluvial fan
Physiography: Blue Ridge
Relief: 518 m
Elevation: 527 m
Slope: 2 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Soil described at a fresh exposure on the quarry wall.

A - 0 to 15 cm; Brown (10YR 4/3) sandy loam; weak fine granular structure; very friable; common fine and medium roots; many fine pores abrupt smooth boundary; very strongly acid.

E - 15 to 45 cm; Yellowish brown (10YR 5/6) gravelly sandy loam; weak fine subangular blocky structure; friable; common fine and medium roots; many fine pores; 25 percent coarse fragments; abrupt smooth boundary; very strongly acid.

Bt1 - 45-90 cm; Red (2.5YR 4/6) gravelly sandy clay loam; moderate medium subangular blocky structure; friable; slightly sticky; slightly plastic; common discontinuous clay films on faces of peds; common fine and medium roots; common fine pores; 34 percent coarse fragments; gradual smooth boundary; strongly acid.

Bt2 - 90 to 122 cm; Red (2.5YR 4/6) very gravelly sandy clay loam; moderate medium subangular blocky structure; friable; slightly sticky; slightly plastic; common discontinuous clay films on faces of peds; few fine; common fine pores; 55 percent coarse fragments; strongly acid.

Table A.4. Description for Site AU02, Augusta County.

Topographic Quadrangle: Waynesboro West
Location: About 200 feet, 87 degrees east of the junction of VA-634 and VA-624 and about 1600 feet, 130 degrees east-southeast of the junction of VA-633 and VA-634.
Date: August 5, 1989
Described by: Charles M. Ogg
Vegetation: Oak, pine
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 15 m
Elevation: 439 m
Slope: 2 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description.

Ap - 0 to 5 cm; Dark grayish brown (10YR 4/2) loam; weak fine granular structure; very friable; many fine and medium roots; many fine pores; 2 percent coarse fragments; clear smooth boundary; very strongly acid.

E - 5 to 12 cm; Light yellowish brown (10YR 6/4) gravelly sandy loam; weak fine granular structure; very friable; many fine and medium roots; many fine pores; 20 percent coarse fragments; clear wavy boundary; very strongly acid.

BE - 12 to 28 cm; Strong brown (7.5YR 5/6) gravelly sandy loam; weak medium platy structure; friable; slightly sticky; slightly plastic; common fine and medium roots; common fine pores; 26 percent coarse fragments; clear wavy boundary; very strongly acid.

Bt1 - 28 to 67 cm; Yellowish red (5YR 4/8) gravelly loam; moderate medium subangular blocky structure; friable; slightly sticky; slightly plastic; common continuous brown/dark brown (10YR 4/3) clay films on faces of peds; common fine and medium roots; common fine pores; 24 percent coarse fragments; gradual smooth boundary; strongly acid.

Bt2 - 67 to 100 cm; Red (2.5YR 4/6) very gravelly clay loam; moderate medium subangular blocky structure; friable; slightly sticky; slightly plastic; common continuous brown/dark brown (10YR 4/3) clay films on faces of peds; few fine roots; few fine pores; 55 percent coarse fragments; strongly acid.

Table A.5. Description for Site AU04, Augusta County.

Topographic Quadrangle: Crimora
Location: About 1800 feet, 145 degrees south-southeast of the junction of VA-340 and VA-672 and about 2250 feet, 64 degrees east-northeast of the junction of VA-340 and VA-619.
Date: May 15, 1991
Described by: Charles M. Ogg
Vegetation: hardwoods beside fence
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 85 m
Elevation: 402 m
Slope: 3 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Fresh exposure behind the maintainence shop at Waynesboro North 340 campground.

Ap - 0 to 12 cm; Grayish brown (10YR 5/2) loam; weak fine granular structure; friable; many fine roots; many fine pores; 5 percent coarse fragments; abrupt smooth boundary; very strongly acid.

E - 12 to 23 cm; Pale brown (10YR 6/3) sandy loam; weak medium subangular blocky structure; friable; many fine roots; many fine pores; 5 percent coarse fragments; clear smooth boundary; very strongly acid.

EB - 23 to 58 cm; Pale brown (10YR 6/3) gravelly sandy loam; moderate medium subangular blocky structure; friable; many fine roots; many fine pores; 15 percent coarse fragments; gradual smooth boundary; very strongly acid.

Bt1 - 58 to 117 cm; Reddish brown (5YR 5/4) cobbly clay; common medium distinct reddish yellow (7.5YR 6/8) mottles; strong fine subangular blocky structure; friable; sticky; plastic; many continuous clay films on faces of peds; common fine roots; many fine pores; 20 percent coarse fragments; gradual smooth boundary; strongly acid.

Table A.5. (cont.) Description for Site AU04, Augusta County.

2Bt2 - 117 to 161 cm; Strong brown (7.5YR 5/8) very cobbly clay; few medium prominent light gray (10YR 7/1) mottles; moderate medium subangular structure; friable; sticky; plastic; many continuous clay films on faces of peds; many fine pores; 40 percent coarse fragments; gradual smooth boundary; very strongly acid.

3Bt3 - 161 to 207 cm; Yellowish red (5YR 5/8) cobbly sandy loam; few medium prominent light gray (10YR 7/1) mottles; weak medium subangular blocky structure; slightly sticky; slightly plastic; few clay bridges between sand grains; 35 percent coarse fragments; very strongly acid.

4C - 207 to 248 cm; Yellow (10YR 7/8) sandy clay loam; common medium prominent yellowish red (5YR 5/8) mottles, massive structure; friable; few clay flows; very strongly acid.

Table A.6. Description for Site AU05, Augusta County.

Topographic Quadrangle: Vesuvius
Location: West of VA-608, about 4200 feet, 200 degrees south-southwest of the junction of VA-666 and VA-608 and about 4300 feet, 38 degrees north-northeast of the junction of VA-667 and VA-608.
Date: May 13, 1991
Described by: Charles M. Ogg
Vegetation: Hickory
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 40 m
Elevation: 567 m
Slope: 5 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Auger description to 128 cm. Roadcut description from 128 to 177 cm.

Ap - 0 to 7 cm; Grayish brown (10YR 5/2) sandy loam; weak fine granular structure; friable many fine roots; many fine pores; abrupt smooth boundary; very strongly acid.

E - 7 to 29 cm; Pale brown (10YR 6/3) sandy loam; weak medium subangular blocky structure; friable; many fine roots; many fine pores; clear smooth boundary; very strongly acid.

EB - 29 to 42 cm; Yellowish brown (10YR 5/4) loam; moderate medium subangular blocky structure; friable; many fine roots; many fine pores; clear smooth boundary; very strongly acid.

2Bt1 - 42 to 71 cm; Yellowish red (5YR 5/8) clay loam; moderate medium subangular blocky structure; friable; common fine roots; many fine pores; gradual smooth boundary; very strongly acid.

2Bt2 - 71 to 128 cm; Red (2.5YR 4/8) clay; moderate medium subangular blocky structure; friable; common fine roots; many fine pores; gradual smooth boundary; strongly acid.

2Bt3 - 128 to 177 cm; Red (2.5YR 4/8) sandy clay; moderate medium subangular blocky structure; friable; common fine roots; many fine pores; gradual smooth boundary; strongly acid.

Table A.7. Description for Site AU06, Augusta County.

Topographic Quadrangle: Waynesboro East

Location: About 250 feet, 105 degrees east southeast of the junction of VA-611 and VA-619 and about 8000 feet, 103 degrees east southeast of the junction of VA-611 and VA-340.

Date: May 23, 1991

Described by: Charles M. Ogg

Vegetation: hardwoods

Parent Material: alluvial fan

Physiography: Blue Ridge

Relief: 366 m

Elevation: 433 m

Slope: 10 percent

Erosion: Class 1

Drainage: well

Ground water: deep

Moisture: moist

Remarks: Roadcut exposure adjacent to Shenandoah National Park near Sawmill Run ranger station.

A - 0 to 10 cm; Dark grayish brown (10YR 4/2) sandy loam; weak fine granular structure; friable; many fine roots; many fine pores; abrupt smooth boundary; strongly acid.

E - 10 to 31 cm; Light yellowish brown (10YR 6/4) sandy loam; weak fine subangular blocky structure; friable; many fine roots; many fine pores; clear smooth boundary; strongly acid.

BE - 31 to 56 cm; Yellowish brown (10YR 5/8) sandy loam; weak medium subangular blocky structure; friable; many fine roots; many fine pores; gradual smooth boundary; strongly acid.

2Bt1 - 56 to 96 cm; Red (2.5YR 4/6) sandy clay; moderate medium subangular blocky structure; friable; sticky; plastic; many continuous clay films on faces of peds; common fine roots; common fine pores; gradual smooth boundary; very strongly acid.

2Bt2 - 96 to 135 cm; Red (2.5YR 4/6) sandy clay loam; common fine prominent light yellowish brown (10YR 6/4) mottles; moderate medium subangular blocky structure; friable; sticky; plastic; many continuous clay films on faces of peds; common fine pores; gradual smooth boundary; very strongly acid.

Table A.7. (cont.) Description for Site AU06, Augusta County.

2Bt3 - 135 to 150 cm; Yellowish red (5YR 5/6) clay loam; moderate medium subangular blocky structure; friable; sticky; plastic; many continuous clay films on faces of peds; common fine pores; very strongly acid.

Table A.8. Description for Site AU07, Augusta County.

Topographic Quadrangle: Vesuvius
Location: About 4000 feet, 186 degrees south of the junction of VA-666 and VA-608 and about 5400 feet, 45 degrees northeast of the junction of VA-667 and VA-608 near Pkin.
Date: November 21, 1991
Described by: Charles M. Ogg and Mark H. Stolt
Vegetation: hardwoods
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 97 m
Elevation: 573 m
Slope: 1 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description.

A - 0 to 5 cm; Very dark gray (10YR 3/1) sandy loam; moderate medium granular structure; very friable; many fine and medium roots; many fine pores; clear smooth boundary; extremely acid.

E - 5 to 11 cm; Pale brown (10YR 6/3) sandy loam; weak medium subangular blocky structure; friable; many fine and medium roots; many fine pores; clear smooth boundary; very strongly acid.

Bt1 - 11 to 32 cm; Pale brown (10YR 6/3) sandy loam; few fine faint light yellowish brown (10YR 6/4) mottles; weak medium subangular blocky structure; friable; many fine and medium roots; common fine pores; clear smooth boundary; very strongly acid.

Bt2 - 32 to 48 cm; Pale brown (10YR 6/3) loam; many fine faint light yellowish brown (10YR 6/4) mottles; few light gray (10YR 6/1) clay depletions; weak medium subangular blocky structure; friable; common fine and medium roots; few fine vesicular pores; clear smooth boundary; very strongly acid.

Bx - 48 to 81 cm; Light yellowish brown (10YR 6/4) sandy loam; common fine distinct light yellowish red (5YR 5/6) mottles; many light gray (10YR 6/1) clay depletions on faces of peds; moderate medium subangular blocky structure parting to moderate thin (3mm) platy structure; firm; few fine roots; common fine vesicular pores; gradual smooth boundary; very strongly acid.

Table A.8. (cont.) Description for Site AU07, Augusta County.

2Bt1 - 81 to 114 cm; Yellowish red (5YR 5/6) clay loam; few medium distinct strong brown (7.5YR 5/6) and brownish yellow (10YR 6/6) mottles; many medium prominent light gray (10YR 7/1) clay depletions on faces of peds; many discontinuous clay films on faces of peds; moderate medium subangular blocky structure; friable; few fine pores; gradual smooth boundary; strongly acid.

2Bt2 - 114 to 142 cm; Red (2.5YR 4/6) clay; common medium distinct strong brown (7.5YR 5/6) mottles; moderate coarse subangular blocky structure; friable; many discontinuous clay films on faces of peds; few fine pores; gradual smooth boundary; strongly acid.

2Bt3 - 142 to 156 cm; Red (2.5YR 4/6) clay; common medium distinct strong brown (7.5YR 5/6) mottles; moderate coarse subangular blocky structure; friable; many discontinuous clay films on faces of peds; few fine pores; gradual smooth boundary; strongly acid.

3Bt4 - 156 to 192 cm; Red (2.5YR 4/6) cobbly clay; common fine distinct yellowish red (5YR 5/6) mottles; moderate medium subangular blocky structure; friable; many discontinuous clay films on faces of peds; few fine pores; 50% coarse fragments; gradual smooth boundary; strongly acid.

Table A.9. Description for Site RO01, Rockingham County.

Topographic Quadrangle: McGaheysville
Location: On VA-754, about 0.3 miles beyond VA-958 at Rocky Bar. About 119 degrees east southeast of the junction of VA-958 and VA-754 and 197 degrees south southwest of the junctions of VA-649 and U.S. Route 340 at Island Ford. About 1000 feet south southeast of the junction of VA-754 and drive entrance. About 300 feet south southeast of log cabin porch.
Date: August 18, 1991
Described by: Charles M. Ogg, Mark H. Stolt, W. J. Edmonds, Harry Behl
Vegetation: pine, oak, locust, chinkapin
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 85 m
Elevation: 353 m
Slope: 2 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description

Ap - 0 to 6 cm; Dark grayish brown (10YR 4/2) sandy loam; weak fine granular structure; friable; many fine roots; many medium pores; 2 percent coarse fragments; abrupt smooth boundary; very strongly acid.

E - 6 to 18 cm; Pale brown (10YR 6/3) silt loam; weak medium subangular blocky structure; friable; many fine roots; common medium pores; 2 percent coarse fragments; gradual wavy boundary; very strongly acid.

Bt1 - 18 to 40 cm; Yellowish brown (10YR 5/4) silt loam; weak medium subangular blocky structure; friable; common fine roots; common fine pores; 2 percent coarse fragments; clear smooth boundary; very strongly acid.

Bt2 - 40 to 74 cm; Yellowish brown (10YR 5/8) clay loam; weak medium subangular blocky structure; friable; common discontinuous clay films on faces of peds; common fine roots; common fine pores; 5 percent coarse fragments; abrupt smooth boundary; very strongly acid.

Table A.9. (cont.) Description for Site RO01, Rockingham County.

E′ - 74 to 90 cm; Pale brown (10YR 6/3) loam; common fine faint yellowish brown (10YR 5/4) mottles; weak medium subangular blocky structure; friable; few fine roots; few fine pores; 5 percent coarse fragments; abrupt smooth boundary; strongly acid.

2Bt1 - 90 to 112 cm; Strong brown (7.5YR 5/6) very cobbly clay; few medium distinct dark yellowish brown (10YR 3/6) mottles; weak fine subangular blocky structure; friable; common continuous clay films on faces of peds; few fine pores; 40 percent coarse fragments; clear smooth boundary; very strongly acid.

2Bt2 - 112 to 156 cm; Dark red (10R 3/6) extremely cobbly clay; many medium prominent strong brown (7.5YR 5/6) and brownish yellow (10YR 6/8) mottles; few medium prominent gray (10YR 6/1) and light brownish gray (10YR 6/2) iron depletions in the matrix; moderate fine subangular blocky structure; friable; many continuous clay films on faces of peds; few fine pores; 60 percent imbricated coarse fragments; diffuse smooth boundary; very strongly acid.

2Bt3 - 156 to 200 cm; Dark red (10R 3/6) extremely cobbly clay loam; many medium prominent strong brown (7.5YR 5/6) and brownish yellow (10YR 6/8) mottles; few medium prominent gray (10YR 6/1) and light brownish gray (10YR 6/2) iron depletions in the matrix; moderate fine subangular blocky structure; friable; many continuous clay films on faces of peds; few fine pores; 60 percent imbricated coarse fragments; very strongly acid.

Table A.10. Description for Site PA01, Page County.

Topographic Quadrangle: Big Meadows
Location: About 800 feet, 146 degrees south southeast of the junction of VA-611 the entrance to Harper Valley subdivision and 44 degrees northeast of the junction of VA-611 and VA-631.
Date: July 25, 1989
Described by: Charles M. Ogg
Vegetation: fescue
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 189 m
Elevation: 292 m
Slope: 3 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description. The site is at the base of Hershberger Hill.

A - 0 to 18 cm; Brown (10YR 4/3) loam; weak fine granular structure; friable; many fine roots; many fine pores; abrupt smooth boundary; strongly acid.

Bt1- 18 to 30 cm; Dark brown (10YR 4/4) sandy clay loam; moderate medium subangular blocky structure; friable; many fine roots; many fine pores; 2 percent coarse fragments; clear smooth boundary; strongly acid.

Bt2 - 30 to 61 cm; Yellowish brown (10YR 5/6) clay loam; few fine faint brownish yellow (10YR 6/8) mottles; moderate medium subangular blocky structure; friable; slightly sticky; slightly plastic; common prominent dark yellowish brown (10YR 3/4) clay films on faces of peds; common fine roots; common fine pores; 2 percent coarse fragments gradual smooth boundary; strongly acid.

Bt3 - 61 to 76 cm; Brownish yellow (10YR 6/6) clay loam; common medium faint brownish yellow (10YR 6/8) redox concentrations in the matrix; moderate medium platy structure; friable; sticky; slightly plastic; common prominent dark yellowish brown (10YR 3/4) clay films on faces of peds; few fine roots; few fine pores; 2 percent coarse fragments: gradual smooth boundary; strongly acid.

Table A.10. (cont.) Description for Site PA01, Page County.

2Bt4 - 76 to 100 cm; Yellowish brown (10YR 5/6) gravelly sandy clay loam; common medium prominent strong brown (7.5YR 5/6) redox concentrations in the matrix; moderate medium platy structure; friable; sticky; slightly plastic; common prominent dark yellowish brown (10YR 3/4) clay films on faces of peds; few fine roots; few fine pores; 32 percent coarse fragments; gradual smooth boundary; very strongly acid.

2Bt5 - 100 to 124 cm; Brownish yellow (10YR 6/6) very gravelly sandy clay loam; common medium prominent red (2.5YR 4/6) and light brownish gray (2.5Y 6/2) reticulate redoximorphic features in the matrix; moderate medium platy structure; friable; sticky; plastic; common prominent dark yellowish brown (10YR 3/4) clay films on faces of peds; few fine roots; few fine pores; 55 percent coarse fragments; strongly acid.

Table A.11. Description for Site PA02, Page County.

Topographic Quadrangle: Luray
Location: About 2500 feet, 166 degrees south southeast of the junction of U.S. 211 and VA-611 and 124 degrees east southeast of the junction of U.S. 211 Bus. and U.S. 211 BPY.
Date: July 25, 1989
Described by: Charles M. Ogg
Vegetation: Oak, maple
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 283 m
Elevation: 317 m
Slope: 6 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description.

A - 0 to 14 cm; Yellowish brown (10YR 5/4) loam; weak fine granular structure; friable; many fine and medium roots; many fine and medium pores; clear smooth boundary; very strongly acid.

E - 14 to 54 cm; Pale brown (10YR6/3) very gravelly loam; weak medium subangular blocky structure; friable; few fine roots; common fine pores; 55 percent coarse fragments; gradual smooth boundary; very strongly acid.

Bt1 - 54 to 80 cm; Yellowish red (5YR 5/6) very gravelly sandy clay loam; few medium distinct red (2.5YR 4/6) iron concentrations in the matrix; moderate medium subangular blocky structure; friable; slightly sticky; slightly plastic; few fine roots; few fine pores; 58 percent coarse fragments gradual smooth boundary; strongly acid.

2Bt2 - 80 to 124 cm; Red (10R 4/6) very gravelly clay; few fine prominent light gray (N 7/) redox depletions in the matrix; moderate medium subangular blocky structure; friable; slightly sticky; slightly plastic; common continuous yellowish red (5YR 4/6) clay films on faces of peds; few fine roots; few fine pores; 40 percent coarse fragments; gradual smooth boundary; strongly acid.

Table A.11. (cont.) Description for Site PA02, Page County.

2Bt3 - 124 to 150 cm; Dark red (10R 3/6) gravelly clay; few fine prominent light gray (N 7/) redox depletions in the matrix; moderate medium subangular blocky structure; friable; slightly sticky; slightly plastic; many continuous yellowish red (5YR 4/6) clay films on faces of peds; few fine roots; few fine pores; 25 percent coarse fragments; strongly acid.

Table A.12. Description for Site PA04, Page County.

Topographic Quadrangle: Elkton East
Location: About 1300 feet, 245 degrees southwest of the junction of VA-603 and VA-681 and 334 degrees north northwest of the junction of VA-603 and VA-673.
Date: July 26, 1989
Described by: Charles M. Ogg
Vegetation: oak, hickory
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 182 m
Elevation: 341 m
Slope: 5 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description.

A - 0 to 5 cm; Dark gray (10YR 4/1) sandy loam; weak fine granular structure; very friable; many medium and coarse roots; many fine and medium pores; 5 percent coarse fragments; abrupt smooth boundary; very strongly acid.

E - 5 to 27 cm; Pale brown (10YR 6/3) sandy loam; weak fine subangular blocky structure; friable; common medium roots; many fine and medium pores; 5 percent coarse fragments; clear smooth boundary; very strongly acid.

Btx - 27 to 40 cm; Yellowish brown (10YR 5/6) sandy loam; moderate medium subangular blocky structure; firm; few fine roots; common fine pores; 5 percent coarse fragments; gradual smooth boundary; very strongly acid.

2Bt1 - 40 to 56 cm; Strong brown (7.5YR 5/6) very cobbly sandy clay loam; few fine faint brownish yellow (10YR 6/6) redox concentrations in the matrix; moderate medium platy structure; friable; slightly sticky; slightly plastic; common distinct strong brown (7.5YR 5/6) clay films on faces of peds; few fine roots; common fine pores; 40 percent coarse fragments: gradual smooth boundary; strongly acid.

Table A.12. (cont.) Description for Site PA04, Page County.

2Bt2 - 56 to 104 cm; Red (2.5YR 4/6) very cobbly clay; few fine prominent brownish yellow (10YR 6/6) redox concentrations in the matrix; moderate medium platy structure parting to moderate medium subangular blocky peds; friable; slightly sticky; slightly plastic; common prominent yellowish brown (10YR 5/4) clay films on faces of peds; few fine roots; few fine pores; 40 percent coarse fragments; gradual smooth boundary; strongly acid.

2Bt3 - 104 to 130 cm; Strong brown (7.5YR 5/6) very cobbly clay; common fine faint yellowish red (5YR 4/6) redoximorphic concentrations in the matrix; moderate medium platy structure parting to moderate medium subangular blocky peds; friable; slightly sticky; slightly plastic; common distinct yellowish brown (10YR 5/4) clay films on faces of peds; few fine roots; few fine pores; 40 percent coarse fragments; strongly acid.

Table A.13. Description for Site PA05, Page County.

Topographic Quadrangle: Big Meadows
Location: About 3800 feet, 109 degrees east southeast of the junction of VA-611 and the entrance to Harper Valley subdivision and 83 degrees east northeast of the junction of Va-611 and VA-631.
Date: July 27, 1989
Described by: Charles M. Ogg, Mark H. Stolt, and Harry Behl.
Vegetation: oak, hickory
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 152 m
Elevation: 317 m
Slope: 10 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description. The site is at the base of Hershberger Hill.

Ap - 0 to 2 cm; Very dark gray (10YR 3/1) silt loam; weak fine granular structure; very friable; many fine roots; many medium pores; 2 percent coarse fragments; abrupt smooth boundary; extremely acid.

E1 - 2 to 18 cm; Pale brown (10YR 6/3) gravelly loam; weak fine subangular blocky structure; friable; many fine roots; many medium pores; 20 percent coarse fragments; gradual smooth boundary; very strongly acid.

E2 - 18 to 44 cm; Pale brown (10YR 6/3) gravelly sandy loam; weak medium subangular blocky structure; friable; many fine roots; many medium pores; 25 percent coarse fragments; gradual smooth boundary; very strongly acid.

Btx - 44 to 64 cm; Yellowish brown (10YR 5/4) cobbly loam; moderate coarse prismatic structure parting to weak medium subangular blocky structure; firm; common discontinuous clay films on faces of peds; few fine roots; many fine vesicular pores; 33 percent coarse fragments; gradual smooth boundary; very strongly acid.

2Bt1 - 64 to 82 cm; Strong brown (7.5YR 5/6) gravelly clay; common medium distinct dark red (2.5YR 3/6) iron concentration in the matrix; moderate medium subangular blocky structure; firm; many continuous clay films on faces of peds; few fine roots; few fine pores; 33 percent coarse fragments; gradual smooth boundary; strongly acid.

Table A.13. (cont.) Description for Site PA05, Page County.

2Bt2 - 82 to 106 cm; Strong brown (7.5YR 5/6) very gravelly clay; many medium distinct yellowish red (5YR 5/6) and few medium distinct brownish yellow (10YR 6/6) iron concentrations in the matrix; common medium prominent light grayish brown (10YR 6/2) redox depletions; moderate medium subangular blocky structure; friable; many continuous brown (7.5YR 5/4) clay films on faces of peds; few fine roots; few fine pores; 55 percent coarse fragments; diffuse smooth boundary; very strongly acid.

2Bt3 - 106 to 151 cm; Red (2.5YR 4/8) gravelly clay; many medium prominent strong brown (7.5YR 5/8) and brownish yellow (10YR6/6) iron concentrations in the matrix; common coarse prominent light grayish brown (10YR 6/2) redox depletions; strong thick platy structure parting to moderate medium subangular blocky structure; friable; many continuous brown (10YR 5/3) clay films on faces of peds oriented parallel to the soil surface and many continuous pale brown (10YR 6/3) clay films on broken surfaces; common fine pores; 30 percent coarse fragments; clear smooth boundary; very strongly acid.

2Bt4 - 151 to 173 cm; Red (2.5YR 3/6) clay; many medium prominent dark brown (10YR 4/3) and brownish yellow (10YR 6/6) and common medium prominent yellow (10YR 7/8) iron concentrations in the matrix; common medium prominent light grayish brown (10YR 6/2) redox depletions; strong thick platy structure parting to moderate medium subangular blocky structure; friable; many continuous clay films on faces of peds; common fine pores; 5 percent coarse fragments; gradual smooth boundary; strongly acid.

2Bt5 - 173 to 205 cm; Red (2.5YR 4/6) clay; common medium prominent yellowish brown (10YR 5/6) and yellow (10YR 7/8) iron concentrations in the matrix; common medium prominent light grayish brown (10YR 6/2) redox depletions; strong medium prismatic structure parting to strong thin platy structure; friable; many continuous dark yellowish brown (10YR 4/4) clay films on faces of peds; common fine pores; 2 percent coarse fragments; gradual smooth boundary; very strongly acid.

Table A.14. Description for Site PA06, Page County.

Topographic Quadrangle: Luray
Location: About 3200 feet, 175 degrees southeast of the junction of VA-689 and VA-669 at Fairview and 64 degrees east northeast of the junction of VA-689 and VA-642 near Antioch Church.
Date: July 28, 1989
Described by: Charles M. Ogg
Vegetation: hickory
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 152 m
Elevation: 286 m
Slope: 3 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description.

A - 0 to 5 cm; Dark gray (10YR 4/1) silt loam; weak fine granular structure; friable; common fine and medium roots; many fine and medium pores; abrupt smooth boundary; very strongly acid.

E - 5 to 14 cm; Pale brown (10YR 6/3) silt loam; moderate medium platy structure; friable; common fine roots; common fine pores; clear smooth boundary; very strongly acid.

Btx - 14 to 22 cm; Pale brown (10YR 6/3) silt loam; moderate coarse platy structure parting to moderate medium subangular blocky peds; firm; few faint clay films on faces of peds; common fine roots; common fine pores; 2 percent coarse fragments; clear smooth boundary; very strongly acid.

2Bt1 - 22 to 47 cm; Strong brown (7.5YR 5/6) clay; moderate medium subangular blocky structure; friable; sticky; plastic; common distinct clay films on faces of peds; few fine roots; common fine pores; gradual smooth boundary; strongly acid.

2Bt2 - 47 to 87 cm; Yellowish red (5YR 4/8) clay; few fine distinct reddish yellow (7.5YR 6/8) redox concentrations in the matrix; moderate medium subangular blocky structure; friable; slightly sticky; slightly plastic; common distinct red (2.5YR 4/6) clay films on faces of peds; few fine roots; common fine pores; 2 percent coarse fragments; gradual smooth boundary; strongly acid.

Table A.14. (cont.) Description for Site PA06, Page County.

2Bt3 - 87 to 120 cm; Red (2.5YR 4/8) clay; common medium prominent strong brown (7.5YR 5/8) redoximorphic concentrations in the matrix; moderate medium subangular blocky structure; friable; slightly sticky; sslightly plastic; common prominent brown/dark brown (7.5YR 4/2) clay films on faces of peds; few fine roots; few fine pores; 2 percent coarse fragments; strongly acid.

Table A.15. Description for Site PA07, Page County.

Topographic Quadrangle: Luray
Location: About 3500 feet, 18 degrees north northeast of the junction of VA-658 and VA-611 and about 5000 feet 90 degrees east of the junction of VA-658 and VA-656.
Date: May 23, 1991
Described by: Charles M. Ogg
Vegetation: pasture
Parent Material: alluvial fan
Physiography: Valley and Ridge
Relief: 61 m
Elevation: 296 m
Slope: 4 percent
Erosion: Class 1
Drainage: well
Ground water: deep
Moisture: moist
Remarks: Pit description from a basement cut.

Ap - 0 to 18 cm; Grayish brown (10YR 5/2) silt loam; weak fine granular structure; friable; many fine roots; many medium pores; abrupt smooth boundary; very strongly acid;

BE - 18 to 41 cm; Pale brown (10YR 6/3) silt loam; weak medium subangular blocky structure parting to weak thin platy structure; friable; many fine roots; many medium pores; clear smooth boundary; very strongly acid;

Bt1 - 41 to 63 cm; Strong brown (7.5YR 5/6) clay loam; common fine distinct yellowish red (5YR 4/8) and pale brown (10YR 6/3) iron concentrations in the matrix; moderate medium subangular blocky structure; friable; sticky; plastic; many continuous clay films on faces of peds; common fine roots; common fine pores; gradual smooth boundary; very strongly acid;

Bt2 - 63 to 94 cm; Yellowish red (5YR 4/8) clay; common fine distinct strong brown (7.5YR 4/2) iron concentrations in the matrix; strong medium subangular blocky structure; friable; sticky; plastic; many continuous clay films on faces of peds; common fine pores; gradual smooth boundary; very strongly acid;

Table A.15. (cont.) Description for Site PA07, Page County.

Bt3 - 94 to 160 cm; Red (2.5YR 4/6) clay; common fine distinct light yellowish brown (2.5YR 6/4) and common fine distinct reddish brown (5YR 5/4) iron concentrations in the matrix; strong medium subangular blocky structure; friable; sticky; plastic; many continuous clay films on faces of peds; common fine pores; gradual smooth boundary; very strongly acid;

Bt4 - 160 to 205 cm; Mottled clay; many medium prominent dark red (10R 3/6) and common fine prominent strong brown (7.5YR 5/8) iron concentrations in the matrix; common medium prominent white (10YR 8/1) and common fine prominent light brownish gray (2.5YR 6/2) redox depletions in the matrix; strong medium subangular blocky structure; friable; sticky; plastic; many continuous clay films on faces of peds; common fine pores; strongly acid.

Table A.16. Particle-size distribution† of selected horizons from the alluvial-fan soils.

Horizon	Depth	VCS	CS	MS	FS	VFS	TOTS	CSI	MSI	FSI	TOTSI	C
	(cm)						%					
						BO01						
A	0-5	1.11	6.89	7.19	25.91	14.44	55.54	12.72	17.63	5.71	36.06	8.40
E	5-33	1.60	5.56	9.67	19.19	15.78	51.80	14.85	17.72	8.09	40.66	7.54
BE	33-50	1.00	4.74	9.25	19.98	16.07	51.05	14.25	18.04	8.09	40.37	8.58
Bt1	50-64	1.31	4.52	8.54	16.57	16.07	47.00	16.06	17.80	8.39	42.25	10.75
Bt2	64-99	2.31	6.54	8.25	16.90	13.68	47.69	17.75	14.01	5.23	36.99	15.33
2Bt3	99-143	0.20	0.94	1.96	9.29	11.23	23.62	17.26	11.05	2.97	31.29	45.08
2Bt4	143-200	1.42	1.98	1.68	13.98	10.01	29.07	17.79	9.65	2.78	30.22	40.71
2Bt5	200-240	1.22	3.13	1.81	13.29	10.95	30.39	19.28	9.15	3.37	31.80	37.81
2Bt6	240-280	1.52	1.88	3.60	16.60	11.93	35.53	19.39	9.16	3.97	32.52	31.94
2Bt7	280-307	1.53	2.91	4.13	10.77	10.05	29.39	21.21	10.27	3.72	35.20	35.41
						BO02						
A	0-3	1.61	5.73	8.05	19.21	17.50	52.11	17.23	18.66	5.89	41.78	6.12
E	3-27	0.50	3.79	5.90	18.35	21.96	50.50	19.98	18.44	8.83	47.25	2.25
EB	27-48	1.20	3.82	5.52	17.07	19.18	46.78	21.53	19.35	7.56	48.45	4.77
Bt1	48-66	2.02	3.01	3.91	14.32	15.33	38.59	23.96	17.09	4.17	45.22	16.20
2Bt2	66-94	0.61	2.23	2.02	8.16	8.98	21.99	12.82	9.17	3.89	25.87	52.13
2Bt3	94-128	1.02	3.39	1.76	10.63	11.85	28.65	20.58	7.35	1.89	29.82	41.53
2Bt4	128-170	0.81	3.75	3.65	11.56	13.90	33.67	16.75	6.62	0.83	24.20	42.13
2Bt5	170-240	3.46	3.89	2.97	13.24	14.56	38.11	18.31	7.95	2.38	28.64	33.25
						AU01						
Ap	0-15	1.55	9.05	26.00	21.30	5.60	63.50	8.64	10.99	6.78	26.41	10.09
E	15-45	1.20	7.55	25.95	24.30	6.10	65.10	3.72	12.62	6.89	23.23	11.67
Bt1	45-90	1.95	11.60	28.00	14.00	2.80	58.35	1.91	3.94	2.78	8.65	33.00
Bt2	90-122	1.10	10.00	40.20	20.80	3.00	75.10	0.30	2.31	0.84	3.45	21.45
						AU02						
BE	12-28	0.40	4.33	13.91	24.70	11.39	54.74	17.24	15.60	9.17	42.01	9.17
Bt1	28-67	0.10	2.78	11.64	20.39	8.75	43.66	18.49	9.98	7.32	35.81	20.54
Bt2	67-100	0.21	2.63	8.11	19.38	5.69	36.02	16.59	5.25	2.20	24.04	39.94

Table A.16. (cont.) Particle-size distribution† of selected horizons from the alluvial fan soils.

Horizon	Depth	VCS	CS	MS	FS	VFS	TOTS	CSI	MSI	FSI	TOTSI	C
	(cm)	------	------	------	------	------	%	------	------	------	------	------
						AU04						
Ap	0-12	0.85	7.75	14.40	18.55	8.05	49.60	13.68	18.80	6.10	38.58	11.82
E	12-23	1.30	4.30	15.65	20.35	11.25	52.85	10.45	21.68	8.78	40.92	6.23
EB	23-58	0.65	4.30	17.10	21.40	11.90	55.35	7.07	19.19	10.18	36.44	8.21
Bt1	58-117	0.70	2.80	7.40	10.70	5.20	26.80	8.16	4.90	4.01	17.07	56.13
2Bt2	117-161	1.70	5.90	14.50	13.90	5.80	41.80	3.80	5.03	4.72	13.55	44.65
3Bt3	161-207	7.10	19.85	27.75	12.05	4.35	71.10	1.42	2.27	7.54	11.23	17.67
4C	207-248	0.25	2.85	12.85	24.05	14.30	54.30	2.70	8.11	6.86	17.67	28.02
						AU05						
Ap	0-7	0.75	6.00	23.65	24.40	7.15	61.95	8.15	15.96	5.81	29.92	8.13
E	7-29	0.50	4.95	21.25	22.60	7.80	57.10	8.36	15.88	9.69	33.93	8.97
EB	29-42	0.35	4.65	20.10	18.45	6.60	50.15	2.23	18.89	10.94	32.07	17.78
2Bt1	42-71	0.10	3.10	13.70	11.70	4.00	32.60	6.64	14.82	7.87	29.32	38.08
2Bt2	71-128	0.45	3.55	9.95	16.10	4.40	34.45	0.23	6.78	3.13	10.15	55.40
2Bt3	128-177	1.70	12.10	15.40	17.10	3.20	49.50	0.22	5.00	1.99	7.21	43.28
						AU06						
A	0-10	1.50	6.20	12.50	28.30	16.60	65.10	5.34	14.02	6.25	25.61	9.29
E	10-31	1.30	7.10	10.25	29.75	15.25	63.65	7.51	13.08	5.10	25.69	10.66
BE	31-56	0.95	5.80	11.60	29.30	15.05	62.70	0.98	13.43	8.09	22.50	14.80
2Bt1	56-96	1.05	4.90	10.95	20.20	11.65	48.75	1.47	8.38	5.22	15.07	36.18
2Bt2	96-135	0.60	4.35	10.55	19.80	10.40	45.70	9.48	5.84	5.10	20.42	33.88
2Bt3	135-150	0.60	4.10	9.35	18.65	10.30	43.00	7.18	6.14	4.86	18.18	38.82

Table A.16. (cont.) Particle-size distribution† of selected horizons from the alluvial fan soils.

Horizon	Depth	VCS	CS	MS	FS	VFS	TOTS	CSI	MSI	FSI	TOTSI	C
	(cm)	%										
						AU07						
A	0-5	0.81	11.00	23.19	14.83	3.25	53.08	15.87	19.39	8.18	43.44	3.48
E	5-11	0.30	6.13	20.58	20.78	5.12	52.91	13.07	22.50	6.97	42.55	4.54
Bt1	11-32	0.70	4.87	15.31	26.05	5.07	52.01	12.53	20.11	8.18	40.82	7.17
Bt2	32-48	0.40	4.49	18.95	21.96	5.20	51.01	11.01	19.86	7.48	38.35	10.64
Bx	48-81	1.01	6.39	22.49	18.06	4.58	52.52	21.33	13.44	9.12	43.89	3.59
2Bt1	81-114	0.51	5.53	17.50	13.44	3.10	40.08	12.18	10.65	6.89	29.71	30.21
2Bt2	114-142	0.82	4.13	12.91	10.26	2.91	31.02	12.37	7.86	4.24	24.47	44.51
2Bt3	142-156	0.82	4.12	12.41	9.44	2.59	29.38	9.62	8.23	3.22	21.06	49.56
3Bt4	156-192	0.61	4.64	14.66	10.78	2.39	33.08	7.60	5.91	3.55	17.06	49.86
						RO01						
Ap	0-6	1.31	5.85	11.38	22.34	6.05	46.93	19.37	20.68	7.36	47.41	5.65
E	6-18	0.60	3.04	14.28	17.79	7.15	42.87	20.39	21.67	10.92	52.97	4.16
Bt1	18-40	0.40	2.79	12.64	18.16	7.41	41.40	20.24	21.10	11.06	52.41	6.19
Bt2	40-74	0.61	2.06	7.86	10.30	4.91	25.73	15.80	13.28	6.72	35.80	38.46
E’	74-90	0.40	2.94	11.90	15.93	7.07	38.25	13.04	19.60	10.89	43.52	18.23
2Bt1	90-112	0.51	2.18	7.61	8.94	3.71	22.95	16.52	9.86	6.87	33.25	43.80
2Bt2	112-156	4.51	6.59	7.21	10.39	4.33	33.03	10.42	6.66	7.79	24.86	42.10
2Bt3	156-200	1.23	10.60	10.70	11.31	4.37	38.20	9.33	7.65	6.04	23.01	38.78
						PA01						
Bt1	18-30	1.40	6.80	11.40	13.20	8.70	41.50	6.50	24.11	10.03	40.64	17.86
Bt2	30-61	1.40	3.90	7.80	12.30	7.50	32.90	8.22	14.89	9.37	32.48	34.62
2Bt4	76-100	5.00	13.10	13.50	9.20	3.60	44.40	9.52	5.25	12.29	27.06	28.54
2Bt5	100-124	14.30	23.90	11.90	7.50	1.70	59.30	5.60	2.71	2.50	10.87	29.83
						PA02						
E	14-54	0.80	6.50	14.50	17.80	11.00	50.60	2.76	19.61	14.18	36.56	12.84
Bt1	54-80	3.80	13.90	20.60	15.40	6.90	60.60	0.08	11.16	4.90	16.14	23.26
2Bt2	80-100	1.80	6.80	7.80	8.60	4.60	29.60	7.88	9.36	4.36	21.61	48.79
2Bt3	100-124	0.65	3.60	8.00	13.75	12.55	38.55	8.05	2.66	2.69	13.40	48.05

Table A.16. (cont.) Particle-size distribution† of selected horizons from the alluvial fan soils.

Horizon	Depth	VCS	CS	MS	FS	VFS	TOTS	CSI	MSI	FSI	TOTSI	C
	(cm)						%					
						PA04						
Btx	27-40	1.21	5.14	14.73	18.86	8.78	48.72	19.04	20.08	8.67	47.79	3.49
2Bt2	56-104	1.99	3.97	3.97	10.49	3.86	23.73	14.22	11.15	4.28	29.65	46.61
						PA05						
A	0-2	1.12	8.13	13.32	13.11	3.76	39.44	23.33	22.97	10.60	56.90	3.66
E1	2-18	1.11	7.29	11.71	18.54	5.38	44.02	14.73	21.33	11.28	47.35	8.63
E2	18-44	1.10	6.99	8.19	22.42	6.39	45.09	15.27	21.70	12.42	49.39	5.52
Btx	44-64	1.51	7.98	15.91	15.31	6.68	47.39	12.81	20.10	9.62	42.54	10.07
2Bt1	64-82	0.61	5.21	8.97	8.87	3.68	27.33	9.26	13.99	8.84	32.09	40.58
2Bt2	82-106	2.45	5.29	8.66	8.45	4.06	28.91	12.00	8.89	5.32	26.21	44.88
2Bt3	106-151	2.64	8.96	13.12	9.98	3.38	38.08	12.37	5.04	4.04	21.45	40.47
2Bt4	151-173	1.43	4.09	4.30	3.89	1.84	15.56	15.26	2.45	3.69	21.40	63.04
2Bt5	173-205	0.82	1.92	1.51	2.44	1.72	8.42	17.00	7.83	5.18	30.01	61.57
						PA06						
E	5-14	1.21	4.53	11.07	12.68	5.34	34.83	28.57	23.92	10.04	62.52	2.64
Bt2	47-87	0.55	1.88	3.10	5.99	2.22	13.75	21.18	7.38	4.34	32.90	53.34
Bt3	87-120	1.02	2.73	4.32	4.43	2.16	14.66	21.87	6.33	4.19	32.57	52.95
						PA07						
Ap	0-18	1.10	5.80	11.90	14.20	9.10	42.10	17.50	28.23	8.31	54.04	3.86
BE	18-41	0.80	5.15	9.95	14.70	9.05	39.65	17.61	25.03	10.07	52.71	7.64
Bt1	41-63	0.65	4.00	8.10	9.40	7.05	29.20	12.90	17.65	7.68	38.23	32.57
Bt2	63-94	0.90	2.80	3.60	5.65	4.55	17.50	12.52	9.35	4.46	26.34	56.16
Bt3	94-160	1.25	2.60	3.55	4.60	4.40	16.40	11.02	8.87	4.03	23.92	59.68
Bt4	160-205	0.70	1.90	2.70	3.70	4.40	13.00	2.78	8.44	5.32	16.55	70.45

†VCS = very coarse sand; CS = coarse sand; MS = medium sand; FS = fine sand; VFS = very fine sand; TOTS = total sand; CSI = coarse silt; MSI = medium silt; FSI = fine silt; TOTSI = total silt; C = clay; Text. = texture.

Table A.17. Coarse fragment (>2.0mm) percentages of selected horizons from selected sites.

Horizon	Depth	Fraction (mm)						
		>50.8	50.8- 38.1	38.1- 25.4	25.4- 19.0	19.0- 9.5	9.5- 2.0	Total
	(cm)	%						
		AU01						
E	15-45	14.4	0.0	1.2	0.4	4.4	5.6	26.0
Bt1	45-90	0.0	15.0	6.1	2.9	4.9	4.8	33.7
Bt2	90-180	19.7	2.1	12.5	4.7	8.2	7.2	54.4
		AU02						
BE	12-28	13.1	1.9	8.4	0.5	0.9	0.9	25.7
Bt1	28-67	10.3	6.7	2.0	1.6	2.4	1.2	24.2
Bt2	67-100	14.6	11.4	13.9	4.3	4.6	3.6	52.4
		RO01						
E	6-18	0.0	0.0	0.0	0.0	1.2	0.6	1.8
Bt1	18-40	0.0	0.0	0.0	0.0	1.1	0.6	1.7
E'	76-94	0.0	0.0	0.5	0.5	1.0	1.0	3.0
2Bt3	112-156	48.8	3.1	0.3	2.8	1.4	3.5	59.9
		PA01						
Bt1	18-30	0.0	0.0	0.6	0.0	0.6	1.3	2.5
Bt3	61-76	0.0	0.0	0.0	0.0	0.5	1.5	2.0
2Bt4	76-100	0.0	4.4	2.2	3.6	9.3	12.4	31.9
2Bt5	100-124	0.0	4.4	5.2	8.4	17.2	20.0	55.2

Table A.17. (cont.) Coarse fragment (>2.0mm) percentages of selected horizons from selected sites.

Horizon	Depth	Fraction (mm)						
		>50.8	50.8-38.1	38.1-25.4	25.4-19.0	19.0-9.5	9.5-2.0	Total
	(cm)	%						
				PA02				
E	14-54	9.2	8.4	11.8	5.9	12.2	7.6	55.1
Bt1	54-80	9.2	16.8	11.2	5.6	8.8	6.0	57.6
2Bt2	80-124	5.0	10.0	6.7	2.5	6.7	8.3	39.2
2Bt3	124-150	6.7	10.0	2.1	1.7	1.7	2.9	25.1
				PA04				
Btx	27-40	0.0	2.7	5.8	0.5	3.6	0.9	13.5
2Bt2	56-104	29.0	4.0	0.5	1.0	1.5	4.5	40.5
				PA05				
E1	2-18	9.5	0.0	7.0	1.0	3.5	4.5	25.5
Btx	44-64	33.1	6.5	10.9	2.7	3.8	8.7	65.7
2Bt1	64-82	12.2	6.9	6.5	2.4	2.4	2.9	33.3
2Bt3	106-151	8.2	13.8	14.2	6.0	6.4	6.7	55.3
				PA06				
Btx	14-22	0.0	0.0	0.0	0.0	1.0	2.1	3.1
Bt2	47-87	0.0	0.0	2.7	1.6	0.5	1.1	5.9
Bt3	87-120	0.0	9.5	1.6	1.6	0.5	1.1	14.3

Table A.18. Chemical characterization of selected horizons from the alluvial fan soils.

Horizon	Depth	Exchangeable cations			Exchange-able acidity	Cation exchange capacity	Exchange-able Al	Base saturation	pH
		Ca	Mg	K					
	(cm)	----------	----------	----------	cmol$_c$ kg^{-1}	----------	----------	%	
					AU01				
Ap	0-15	0.05	0.04	0.10	7.00	7.19	1.75	2.64	4.65
E	15-45	0.04	0.02	0.04	2.00	2.10	1.00	4.76	4.66
Bt1	45-90	0.15	0.49	0.15	6.60	7.39	2.35	10.69	5.12
Bt2	90-122	0.04	0.05	0.04	4.80	4.39	1.45	2.64	5.04
					AU02				
BE	12-28	0.04	0.09	0.07	4.00	4.20	1.35	4.76	4.95
Bt1	28-67	0.26	0.43	0.12	8.00	8.81	3.15	9.19	5.02
Bt2	67-100	0.02	0.49	0.13	12.00	12.64	3.95	5.06	5.30
					AU04				
Ap	0-12	2.59	0.56	0.40	19.00	22.55	1.15	15.74	4.87
E	12-23	0.07	0.04	0.11	7.00	7.22	1.15	3.05	5.00
EB	23-58	0.07	0.02	0.07	3.00	3.16	1.45	5.06	4.88
Bt1	58-117	0.43	0.85	0.31	15.80	17.39	5.35	9.14	5.15
2Bt2	117-161	0.11	0.18	0.08	12.60	12.97	6.35	2.85	4.92
3Bt3	161-207	0.04	0.05	0.03	5.60	5.72	5.60	2.10	4.94
4C	207-248	0.04	0.05	0.04	8.20	8.33	4.95	1.56	4.92

Table A.18. (cont.) Chemical characterization of selected horizons from the alluvial fan soils.

Horizon	Depth	Exchangeable cations Ca	Exchangeable cations Mg	Exchangeable cations K	Exchangeable acidity	Cation exchange capacity	Exchangeable Al	Base saturation	pH
	(cm)	----------------	----------------	cmol$_c$ kg^{-1}	----------------	----------------	----------------	%	
					AU05				
Ap	0-7	2.59	0.88	0.14	10.00	13.61	0.45	26.52	5.08
E	7-29	0.06	0.04	0.02	2.00	2.12	1.05	5.66	4.88
EB	29-42	0.04	0.05	0.04	4.80	4.93	1.75	2.64	4.77
2Bt1	42-71	0.30	0.56	0.08	9.60	10.54	4.25	8.92	4.94
2Bt2	71-128	0.03	0.21	0.06	13.00	13.30	4.84	2.26	5.13
2Bt3	128-177	0.18	0.25	0.04	9.60	10.07	4.65	4.67	5.00
					AU06				
A	0-10	3.55	0.64	0.18	5.00	9.37	0.10	46.64	5.36
E	10-31	0.59	0.19	0.09	1.20	2.07	0.35	42.03	5.45
BE	31-56	0.35	0.21	0.05	0.60	1.21	1.00	50.41	5.28
2Bt1	56-96	0.24	0.44	0.07	9.00	9.75	5.05	7.69	4.80
2Bt2	96-135	0.16	0.59	0.08	9.60	10.43	5.05	7.96	4.92
2Bt3	135-150	0.21	0.59	0.09	13.00	13.89	5.65	6.61	4.88
					PA01				
Bt1	18-30	2.36	0.13	0.04	3.00	5.53	0.15	45.75	5.32
Bt2	30-61	2.34	0.64	0.11	7.40	10.49	2.65	29.46	5.10
2Bt4	76-100	0.93	0.67	0.15	9.20	10.95	3.95	15.98	4.90
2Bt5	100-124	0.12	0.49	0.15	8.60	9.36	3.35	8.12	5.02

Table A.18. (cont.) Chemical characterization of selected horizons from the alluvial fan soils.

Horizon	Depth	Exchangeable cations			Exchange-able acidity	Cation exchange capacity	Exchange-able Al	Base saturation	pH
		Ca	Mg	K					
	(cm)	----------------	----------------	----------------	$cmol_c\ kg^{-1}$	----------------	----------------	%	
					PA02				
E	14-54	0.08	0.04	0.08	2.40	2.60	1.05	7.69	4.94
Bt1	54-80	0.62	0.51	0.12	3.20	4.45	1.75	28.09	5.10
2Bt2	80-100	0.08	0.64	0.13	13.60	14.45	6.15	5.88	5.38
2Bt3	100-124	0.80	1.07	0.10	9.00	10.97	4.75	17.96	5.38
					PA04				
Btx	27-40	0.02	0.03	0.10	3.20	3.35	1.75	4.48	4.80
2Bt2	56-104	0.13	0.76	0.20	20.00	21.09	9.45	5.17	5.24
					PA06				
E	5-14	0.06	0.02	0.06	5.00	5.14	1.45	2.72	4.76
Bt2	47-87	0.28	1.95	0.48	15.20	17.91	7.15	15.13	5.28
Bt3	87-120	0.03	1.21	0.39	17.60	19.23	7.05	8.48	5.36
					PA07				
Ap	0-18	0.15	0.05	0.18	5.00	5.38	1.45	7.06	4.68
BE	18-41	0.26	0.10	0.20	4.40	4.96	2.25	11.29	4.72
Bt1	41-63	1.40	0.80	0.22	9.20	11.62	3.25	20.83	4.84
Bt2	63-94	1.05	1.28	0.17	14.60	17.10	5.05	14.62	4.75
Bt3	94-160	1.16	1.46	0.18	12.00	14.80	4.25	18.92	5.00
Bt4	160-205	1.53	1.64	0.17	11.60	14.94	3.85	22.36	5.05

Appendix B

Table B.1. **Hodges-Lehmann estimates, confidence intervals, and dispersion *P*-values for Site 1, Botetourt County.**

Variable	Hodges-Lehmann Estimate	89.99998 Confidence Interval	Dispersion *P*-value
CS	-1.58500	(-1.94000, -1.21000)	0.04312
MS	-3.97500	(-4.49000, -3.55000)	0.04312
FS	-8.21001	(-9.32500, -6.74000)	0.07962
VFS	-5.69500	(-6.83000, -4.66000)	0.07962
TOTS	-19.58499	(-22.23999, -16.38499)	0.04312
MSI	-6.58500	(-7.64000, -5.48000)	0.50018
FSI	-0.92500	(-1.96500, -0.14000)	0.68584
TOTSI	-7.39500	(-9.17499, -5.67000)	0.13802
CFS	-7.37499	(-9.81500, -5.29501)	0.04312
SIND	-2.93001	(-3.64999, -2.20000)	0.13802
TSTSI	-0.30500	(-0.39000, -0.22000)	0.17262
CFMS	-2.09000	(-2.76000, -1.50500)	0.04312
CFFS	-3.50500	(-4.60500, -2.46500)	0.07962
CFVFS	-1.74000	(-2.58500, -0.87000)	0.04312
CFMSVFS	-0.07500	(-0.11000, -0.04000)	0.04312
CFFSVFS	-0.08500	(-0.14500, -0.03000)	0.04312
HVS	0.66000	(0.15000, 1.17500)	0.07962
HSLS	0.00070	(0.00015, 0.00120)	0.04312
LWH	-267.15503	(-308.69482, -227.84998)	0.04312

Table B.2. Hodges-Lehmann estimates, confidence intervals, and dispersion *P*-values for Site 2, Augusta County.

Variable	Hodges-Lehman Estimate	89.99998 Confidence Interval	Dispersion *P*-value
CS	-0.57500	(-0.76500, -0.39500)	0.46520
MS	-6.83500	(-7.70000, -5.73500)	1.00000
FS	-8.59499	(-9.59999, -7.64000)	1.00000
VFS	-2.64000	(-2.88000, -2.44000)	0.46520
TOTS	-18.90500	(-20.42499, -17.18001)	0.06788
MSI	-10.48999	(-11.70000, -9.33500)	0.46520
FSI	-4.85500	(-6.23500, -3.73500)	1.00000
TOTSI	-15.21001	(-17.45000, -12.91000)	0.06788
SIND	-1.69500	(-2.19000, -1.23500)	1.00000
CFFS	-1.78000	(-2.97000, -1.09500)	0.46520
CFVFS	-1.19000	(-1.42000, -0.95000)	0.06788
CFMSFS	0.17500	(0.10000, 0.24000)	0.46520
CFMSVFS	1.24000	(0.87000, 1.62500)	0.14412
CFFSVFS	0.58000	(0.37500, 0.76500)	0.14412
HVSI	24.95999	(9.40999, 67.60500)	0.06788
HSILSI	0.02680	(0.00975, 0.07610)	0.06788
LWH	-345.05493	(-378.20996, -309.87988)	0.06788
HLWH	0.00905	(0.00440, 0.03040)	0.06788

Table B.3. Hodges-Lehmann estimates and confidence intervals for Site 3, Rockingham County.

Variable	Hodges-Lehman Estimate	89.99998 Confidence Interval
VCS	0.84500	(0.31500, 1.53000)
MS	-4.89500	(-6.17000, -1.7000)
FS	-8.32500	(-12.25500, -4.29000)
VFS	-3.66500	(-4.61000, -1.68000)
TOTS	-16.69000	(-22.31999, -5.18500)
MSI	-11.79500	(-15.73000, -6.41000)
TOTSI	-19.85500	(-29.72000, -5.94000)
SIND	-8.64500	(-13.50500, -2.39999)
CFFS	-2.84000	(-6.46000, -1.69000)
CFVFS	-1.51000	(-2.19500, -0.86500)
HVS	2.94000	(1.65000, 5.27500)
HSLS	0.00295	(0.00170, 0.00535)
LWH	-343.42017	(-540.96509, -165.63013)

Table B.4. Hodges-Lehmann estimates and confidence intervals for Site 4, Page County.

Variable	Hodges-Lehman Estimate	89.99998 Confidence Interval
FS	-6.68000	(-9.94499, -2.82499)
VFS	-2.68000	(-3.54000, -1.47000)
TOTS	-8.06000	(-13.97000, -1.55501)
MSI	-14.68499	(-16.04999, -11.55000)
FSI	-5.49500	(-9.40500, -3.75000)
TOTSI	-22.64499	(-27.88000, -17.43999)
CFS	10.11250	(1.89500, 15.61000)
SIND	-4.71250	(-9.39000, -0.66500)
TSTSI	0.40500	(0.09000, 0.75500)
CFMS	4.36250	(1.06500, 8.00000)
CFMSFS	0.29250	(0.08500, 0.75500)
CFMSVFS	1.23500	(0.14500, 4.22000)
HVS	-1.86000	(-3.14000, -0.52000)
HSLS	-0.00188	(-0.00320, -0.00050)
HWH	-2.85500	(-15.44999, -1.50000)

Table B.5. Correlations of the variables used to calculate principal components for Site 1, Botetourt County.

	RCS	RMS	RFS	RVFS	RTOTS
			r		
RCS	1.0000	0.8178	0.7645	0.5925	0.8082
RMS	0.8178	1.0000	0.8044	0.7816	0.8929
RFS	0.7645	0.8044	1.0000	0.7989	0.9525
RVFS	0.5925	0.7816	0.7989	1.0000	0.8691
RTOTS	0.8082	0.8929	0.9525	0.8691	1.0000
RMSI	0.6674	0.8359	0.6781	0.6539	0.7489
RFSI	0.2115	0.2881	0.2598	0.3732	0.2730
RTOTSI	0.6166	0.6211	0.6230	0.6343	0.6103
RCFS	0.6886	0.7929	0.8410	0.7936	0.8896
RSIND	0.5024	0.5925	0.6910	0.3192	0.6007
RTSTSI	0.6863	0.7952	0.8378	0.7895	0.8862
RCFMS	0.7173	0.8878	0.6030	0.5907	0.7239
RCFFS	0.5940	0.5808	0.8940	0.6364	0.7939
RCFVFS	0.2452	0.4744	0.4905	0.7741	0.5726
RCFMSVFS	0.6440	0.6800	0.3642	0.1873	0.4475
RCFFSVFS	0.4320	0.2582	0.5371	0.0197	0.3689
RHVS	-0.5224	-0.4205	-0.3930	-0.2995	-0.4050
RHSLS	-0.5196	-0.4219	-0.3994	-0.3028	-0.4093
RLWH	0.7773	0.8440	0.8470	0.8109	0.8653

	RMSI	RFSI	RTOTSI	RCFS	RSIND
			r		
RCS	0.6674	0.2115	0.6166	0.6886	0.5024
RMS	0.8359	0.2881	0.6211	0.7929	0.5925
RFS	0.6781	0.2598	0.6230	0.8410	0.6910
RVFS	0.6539	0.3732	0.6343	0.7936	0.3192
RTOTS	0.7489	0.2730	0.6103	0.8896	0.6007
RMSI	1.0000	0.2334	0.5739	0.6763	0.5242
RFSI	0.2334	1.0000	0.3939	0.1761	-0.0173
RTOTSI	0.5739	0.3939	1.0000	0.2830	0.3869
RCFS	0.6763	0.1761	0.2830	1.0000	0.4851
RSIND	0.5242	-0.0173	0.3869	0.4851	1.0000
RTSTSI	0.6752	0.1685	0.2789	0.9994	0.4903
RCFMS	0.7463	0.1435	0.3056	0.7889	0.4943
RCFFS	0.4907	0.1629	0.3295	0.8271	0.6634
RCFVFS	0.4164	0.2901	0.1396	0.7443	-0.0189
RCFMSVFS	0.5906	0.0477	0.3387	0.3626	0.5323
RCFFSVFS	0.2138	-0.0158	0.2707	0.2351	0.8216
RHVS	-0.4317	0.0217	-0.3561	-0.3825	-0.3329
RHSLS	-0.4316	0.0255	-0.3600	-0.3855	-0.3356
RLWH	0.7365	0.3379	0.8651	0.6436	0.5562

Table B.5. (cont.) Correlations of the variables used to calculate principal components for Site 1, Botetourt County.

	RLWH	RTSTSI	RCFMS	RCFFS	RCFVFS
			r		
RCS	0.7773	0.6863	0.7173	0.5940	0.2452
RMS	0.8440	0.7952	0.8878	0.5808	0.4744
RFS	0.8470	0.8378	0.6030	0.8940	0.4905
RVFS	0.8109	0.7895	0.5907	0.6364	0.7741
RTOTS	0.8653	0.8862	0.7239	0.7939	0.5726
RMSI	0.7365	0.6752	0.7463	0.4907	0.4164
RFSI	0.3379	0.1685	0.1435	0.1629	0.2901
RTOTSI	0.8651	0.2789	0.3056	0.3295	0.1396
RCFS	0.6436	0.9994	0.7889	0.8271	0.7443
RSIND	0.5562	0.4903	0.4943	0.6634	-0.0189
RTSTSI	0.6408	1.0000	0.7955	0.8231	0.7427
RCFMS	0.5943	0.7955	1.0000	0.4635	0.4881
RCFFS	0.5964	0.8231	0.4635	1.0000	0.4864
RCFVFS	0.3885	0.7427	0.4881	0.4864	1.0000
RCFMSVFS	0.4607	0.3694	0.7660	0.1626	-0.0978
RCFFSVFS	0.3302	0.2342	0.1329	0.6141	-0.3003
RHVS	-0.4174	-0.3758	-0.4131	-0.3746	-0.1223
RHSLS	-0.4168	-0.3788	-0.4103	-0.3824	-0.1221
RLWH	0.6408	0.6408	0.5943	0.5964	0.3885

	RCFMSVFS	RCFFSVFS	RHVS	RHSLS	RLWH
			r		
RCS	0.6440	0.4320	-0.5224	-0.5196	0.7773
RMS	0.6800	0.2582	-0.4205	-0.4219	0.8440
RFS	0.3642	0.5371	-0.3930	-0.3994	0.8470
RVFS	0.1873	0.0197	-0.2995	-0.3028	0.8109
RTOTS	0.4475	0.3689	-0.4050	-0.4093	0.8653
RMSI	0.5906	0.2138	-0.4317	-0.4316	0.7365
RFSI	0.0477	-0.0158	0.0217	0.0255	0.3379
RTOTSI	0.3387	0.2707	-0.3561	-0.3600	0.8651
RCFS	0.3626	0.2351	-0.3825	-0.3855	0.6436
RSIND	0.5323	0.8216	-0.3329	-0.3356	0.5562
RTSTSI	0.3694	0.2342	-0.3758	-0.3788	0.6408
RCFMS	0.7660	0.1329	-0.4131	-0.4103	0.5943
RCFFS	0.1626	0.6141	-0.3746	-0.3824	0.5964
RCFVFS	-0.0978	-0.3003	-0.1223	-0.1221	0.3885
RCFMSVFS	1.0000	0.3364	-0.3504	-0.3441	0.4607
RCFFSVFS	0.3364	1.0000	-0.2368	-0.2434	0.3302
RHVS	-0.3504	-0.2368	1.0000	0.9982	-0.4174
RHSLS	-0.3441	-0.2434	0.9982	1.0000	-0.4168
RLWH	0.4607	0.3302	-0.4174	-0.4168	1.0000

Table B.6. Correlations of the variables used to calculate principal components for Site 2, Augusta County.

	RCS	RMS	RFS	RVFS	RTOTS	RMSI	RFSI	RTOTSI
	r				r			
RCS	1.0000	0.6612	0.5686	0.4828	0.6962	0.5476	0.4545	0.5479
RMS	0.6612	1.0000	0.7427	0.7084	0.9072	0.7152	0.4747	0.6908
RFS	0.5686	0.7427	1.0000	0.9203	0.9019	0.7240	0.6352	0.7768
RVFS	0.4828	0.7084	0.9203	1.0000	0.8381	0.7635	0.5765	0.7754
RTOTS	0.6962	0.9072	0.9019	0.8381	1.0000	0.7263	0.6020	0.7511
RMSI	0.5476	0.7152	0.7240	0.7635	0.7263	1.0000	0.5576	0.7533
RFSI	0.4545	0.4747	0.6352	0.5765	0.6020	0.5576	1.0000	0.7216
RTOTSI	0.5479	0.6908	0.7768	0.7754	0.7511	0.7533	0.7216	1.0000
RSIND	0.2655	0.7853	0.6774	0.5784	0.7109	0.4756	0.3571	0.5534
RCFFS	0.2903	0.3229	0.7207	0.6224	0.5538	0.3467	0.4488	0.2548
RCFVFS	0.2708	0.5735	0.7598	0.8837	0.6718	0.6968	0.4557	0.5412
RCFMSFS	-0.2499	-0.2287	-0.7477	-0.7053	-0.5181	-0.4673	-0.5327	-0.5103
RCFMSVFS	-0.2468	-0.4128	-0.7897	-0.8835	-0.6181	-0.6783	-0.5963	-0.6746
RCFFSVFS	-0.1809	-0.4999	-0.3773	-0.6449	-0.4337	-0.6261	-0.2534	-0.5066
RHVSI	-0.3572	-0.4814	-0.5176	-0.5221	-0.5452	-0.5369	-0.5962	-0.6939
RLWH	0.6405	0.7857	0.8716	0.8335	0.8739	0.7485	0.7146	0.9543
RHLWH	-0.3989	-0.5182	-0.5448	-0.5372	-0.5836	-0.5534	-0.6010	-0.6715

Table B.6. (cont.) Correlations of the variables used to calculate principal components for Site 2, Augusta County.

	RSIND	RCFFS	RCFVFS	RCFMSFS
	r			
RCS	0.2655	0.2903	0.2708	-0.2499
RMS	0.7853	0.3229	0.5735	-0.2287
RFS	0.6774	0.7207	0.7598	-0.7477
RVFS	0.5784	0.6224	0.8837	-0.7053
RTOTS	0.7109	0.5538	0.6718	-0.5181
RMSI	0.4756	0.3467	0.6968	-0.4673
RFSI	0.3571	0.4488	0.4557	-0.5327
RTOTSI	0.5534	0.2548	0.5412	-0.5103
RSIND	1.0000	0.3260	0.4013	-0.2315
RCFFS	0.3260	1.0000	0.6546	-0.7786
RCFVFS	0.4013	0.6546	1.0000	-0.6443
RCFMSFS	-0.2315	-0.7786	-0.6443	1.0000
RCFMSVFS	-0.3178	-0.6524	-0.8796	0.8498
RCFFSVFS	-0.2164	-0.0272	-0.7363	0.1798
RHVSI	-0.3713	-0.1252	-0.4052	0.3795
RLWH	0.6336	0.3824	0.5979	-0.5529
RHLWH	-0.3956	-0.1862	-0.4333	0.3771

	RCFMSVFS	RCFFSVFS	RHVSI	RLWH
	r			
RCS	-0.2468	-0.1809	-0.3572	0.6405
RMS	-0.4128	-0.4999	-0.4814	0.7857
RFS	-0.7897	-0.3773	-0.5176	0.8716
RVFS	-0.8835	-0.6449	-0.5221	0.8335
RTOTS	-0.6181	-0.4337	-0.5452	0.8739
RMSI	-0.6783	-0.6261	-0.5369	0.7485
RFSI	-0.5963	-0.2534	-0.5962	0.7146
RTOTSI	-0.6746	-0.5066	-0.6939	0.9543
RSIND	-0.3178	-0.2164	-0.3713	0.6336
RCFFS	-0.6524	-0.0272	-0.1252	0.3824
RCFVFS	-0.8796	-0.7363	-0.4052	0.5979
RCFMSFS	0.8498	0.1798	0.3795	-0.5529
RCFMSVFS	1.0000	0.6091	0.4751	-0.6771
RCFFSVFS	0.6091	1.0000	0.3870	-0.4579
RHVSI	0.4751	0.3870	1.0000	-0.7546
RLWH	-0.6771	-0.4579	-0.7546	1.0000
RHLWH	0.4731	0.3783	0.9890	-0.7533

Table B.6. (cont.) Correlations of the variables used to calculate principal components for Site 2, Augusta County.

	RHLWH
	r
RCS	-0.3989
RMS	-0.5182
RFS	-0.5448
RVFS	-0.5372
RTOTS	-0.5836
RMSI	-0.5534
RFSI	-0.6010
RTOTSI	-0.6715
RSIND	-0.3956
RCFFS	-0.1862
RCFVFS	-0.4333
RCFMSFS	0.3771
RCFMSVFS	0.4731
RCFFSVFS	0.3783
RHVSI	0.9890
RLWH	-0.7533
RHLWH	1.0000

Table B.7. Correlations of the variables used to calculate principal components for Site 3, Rockingham County.

	RVCS	RMS	RFS	RVFS	RTOTS
			r		
RVCS	1.0000	-0.4895	-0.5804	-0.6154	-0.5035
RMS	-0.4895	1.0000	0.8531	0.8531	0.8741
RFS	-0.5804	0.8531	1.0000	0.8741	0.9650
RVFS	-0.6154	0.8531	0.8741	1.0000	0.9231
RTOTS	-0.5035	0.8741	0.9650	0.9231	1.0000
RMSI	-0.6434	0.7622	0.8042	0.7622	0.7552
RTOTSI	-0.7063	0.7413	0.6783	0.8042	0.7483
RSIND	-0.7692	0.6294	0.6783	0.5455	0.5524
RCFFS	-0.4406	0.4056	0.7552	0.5245	0.6573
RCFVFS	-0.5245	0.6224	0.7413	0.6993	0.6923
RHVS	0.7902	-0.7273	-0.8042	-0.7762	-0.7552
RHSLS	0.7825	-0.7298	-0.8246	-0.7754	-0.7719
RLWH	-0.5874	0.8322	0.7762	0.8741	0.8531

	RMSI	RTOTSI	RSIND	RCFFS	RCFVFS
			r		
RVCS	-0.6434	-0.7063	-0.7692	-0.4406	-0.5245
RMS	0.7622	0.7413	0.6294	0.4056	0.6224
RFS	0.8042	0.6783	0.6783	0.7552	0.7413
RVFS	0.7622	0.8042	0.5455	0.5245	0.6993
RTOTS	0.7552	0.7483	0.5524	0.6573	0.6923
RMSI	1.0000	0.7692	0.5874	0.4126	0.5944
RTOTSI	0.7692	1.0000	0.5105	0.2378	0.3846
RSIND	0.5874	0.5105	1.0000	0.5315	0.5455
RCFFS	0.4126	0.2378	0.5315	1.0000	0.7552
RCFVFS	0.5944	0.3846	0.5455	0.7552	1.0000
RHVS	-0.7343	-0.6364	-0.7692	-0.6713	-0.8951
RHSLS	-0.7368	-0.6386	-0.7719	-0.7018	-0.8877
RLWH	0.8112	0.9510	0.4476	0.2867	0.4126

Table B.7. (cont.) Correlations of the variables used to calculate principal components for Site 3, Rockingham County.

	RHVS	RHSLS	RLWH
		r	
RVCS	0.7902	0.7825	-0.5874
RMS	-0.7273	-0.7298	0.8322
RFS	-0.8042	-0.8246	0.7762
RVFS	-0.7762	-0.7754	0.8741
RTOTS	-0.7552	-0.7719	0.8531
RMSI	-0.7343	-0.7368	0.8112
RTOTSI	-0.6364	-0.6386	0.9510
RSIND	-0.7692	-0.7719	0.4476
RCFFS	-0.6713	-0.7018	0.2867
RCFVFS	-0.8951	-0.8877	0.4126
RHVS	1.0000	0.9965	-0.6014
RHSLS	0.9965	1.0000	-0.6035
RLWH	-0.6014	-0.6035	1.0000

Table B.8. Correlations of the variables used to calculate principal components for Site 4, Page County.

	RFS	RVFS	RTOTS	RMSI	RFSI
			r		
RFS	1.0000	0.7824	0.8059	0.6294	0.7000
RVFS	0.7824	1.0000	0.6059	0.8206	0.7324
RTOTS	0.8059	0.6059	1.0000	0.4235	0.4559
RMSI	0.6294	0.8206	0.4235	1.0000	0.8559
RFSI	0.7000	0.7324	0.4559	0.8559	1.0000
RTOTSI	0.6647	0.6971	0.3647	0.8382	0.8588
RCFS	-0.2353	-0.3588	0.1971	-0.6059	-0.6088
RSIND	0.5500	0.5647	0.3853	0.6471	0.4647
RTSTSI	-0.2353	-0.3588	0.1971	-0.6059	-0.6088
RCFMS	-0.5941	-0.5118	-0.1735	-0.5471	-0.6676
RCFMSFS	-0.8735	-0.6824	-0.5559	-0.4471	-0.5647
RCFMSVFS	-0.7500	-0.8588	-0.4147	-0.7588	-0.7735
RHVS	0.4118	0.2941	0.1706	0.2529	0.4265
RHSLS	0.4135	0.2899	0.1678	0.2605	0.4312
RHWH	0.2840	0.2163	0.4636	0.1413	0.3885

	RTOTSI	RCFS	RSIND	RTSTSI	RCFMS
			r		
RFS	0.6647	-0.2353	0.5500	-0.2353	-0.5941
RVFS	0.6971	-0.3588	0.5647	-0.3588	-0.5118
RTOTS	0.3647	0.1971	0.3853	0.1971	-0.1735
RMSI	0.8382	-0.6059	0.6471	-0.6059	-0.5471
RFSI	0.8588	-0.6088	0.4647	-0.6088	-0.6676
RTOTSI	1.0000	-0.7853	0.5676	-0.7853	-0.8382
RCFS	-0.7853	1.0000	-0.4765	1.0000	0.7824
RSIND	0.5676	-0.4765	1.0000	-0.4765	-0.2941
RTSTSI	-0.7853	1.0000	-0.4765	1.0000	0.7824
RCFMS	-0.8382	0.7824	-0.2941	0.7824	1.0000
RCFMSFS	-0.5824	0.3029	-0.3353	0.3029	0.7500
RCFMSVFS	-0.7971	0.5706	-0.4118	0.5706	0.7647
RHVS	0.6118	-0.5029	0.2176	-0.5029	-0.6559
RHSLS	0.6196	-0.5107	0.2193	-0.5107	-0.6637
RHWH	0.3929	-0.0662	-0.0294	-0.0662	-0.3503

Table B.8. (cont.) Correlations of the variables used to calculate principal components for Site 4, Page County.

	RCFMSFS	RCFMSVFS	RHVS	RHSLS	RHWH
			r		
RFS	-0.8735	-0.7500	0.4118	0.4135	0.2840
RVFS	-0.6824	-0.8588	0.2941	0.2899	0.2163
RTOTS	-0.5559	-0.4147	0.1706	0.1678	0.4636
RMSI	-0.4471	-0.7588	0.2529	0.2605	0.1413
RFSI	-0.5647	-0.7735	0.4265	0.4312	0.3885
RTOTSI	-0.5824	-0.7971	0.6118	0.6196	0.3929
RCFS	0.3029	0.5706	-0.5029	-0.5107	-0.0662
RSIND	-0.3353	-0.4118	0.2176	0.2193	-0.0294
RTSTSI	0.3029	0.5706	-0.5029	-0.5107	-0.0662
RCFMS	0.7500	0.7647	-0.6559	-0.6637	-0.3503
RCFMSFS	1.0000	0.7706	-0.4706	-0.4739	-0.2443
RCFMSVFS	0.7706	1.0000	-0.4765	-0.4783	-0.2060
RHVS	-0.4706	-0.4765	1.0000	0.9993	0.4680
RHSLS	-0.4739	-0.4783	0.9993	1.0000	0.4595
RHWH	-0.2443	-0.2060	0.4680	0.4595	1.0000

Table B.9. Proportions of the variance contributed by the principal components.

Eigenvector	Eigenvalue	Difference	Proportion	Cumulative
		Site 1		
PRIN1	10.6784	8.31788	0.562021	0.56202
PRIN2	2.3605	0.78710	0.124238	0.68626
PRIN3	1.5734	0.08732	0.082812	0.76907
PRIN4	1.4861	0.20866	0.078216	0.84729
PRIN5	1.2774	0.62782	0.067234	0.91452
PRIN6	0.6496	0.26207	0.034191	0.94871
PRIN7	0.3876	0.16884	0.020398	0.96911
PRIN8	0.2187	0.12990	0.011511	0.98062
PRIN9	0.0888	0.01081	0.004674	0.98530
PRIN10	0.0780	0.02171	0.004105	0.98940
PRIN11	0.0563	0.01299	0.002962	0.99236
PRIN12	0.0433	0.00843	0.002278	0.99464
PRIN13	0.0349	0.00781	0.001835	0.99648
PRIN14	0.0271	0.00778	0.001424	0.99790
PRIN15	0.0193	0.00809	0.001014	0.99891
PRIN16	0.0112	0.00318	0.000589	0.99950
PRIN17	0.0080	0.00689	0.000421	0.99992
PRIN18	0.0011	0.00080	0.000059	0.99998
PRIN19	0.0003	--	0.000017	1.00000
		Site 2		
PRIN1	10.3443	8.43749	0.608488	0.60849
PRIN2	1.9068	0.55583	0.112165	0.72065
PRIN3	1.3510	0.09749	0.079469	0.80012
PRIN4	1.2535	0.48453	0.073734	0.87386
PRIN5	0.7689	0.29012	0.045232	0.91909
PRIN6	0.4788	0.12515	0.028166	0.94725
PRIN7	0.3537	0.10470	0.020805	0.96806
PRIN8	0.2490	0.16240	0.014646	0.98270
PRIN9	0.0866	0.01560	0.005093	0.98780
PRIN10	0.0710	0.02169	0.004175	0.99197
PRIN11	0.0493	0.02291	0.002900	0.99487
PRIN12	0.0264	0.00430	0.001552	0.99642
PRIN13	0.0221	0.00371	0.001299	0.99772
PRIN14	0.0184	0.00671	0.001081	0.99880
PRIN15	0.0117	0.00670	0.000686	0.99949
PRIN16	0.0050	0.00125	0.000292	0.99978
PRIN17	0.0037	--	0.000218	1.00000

Table B.9. (cont.) Proportions of the variance contributed by the principal components.

Eigenvector	Eigenvalue	Difference	Proportion	Cumulative
		Site 3		
PRIN1	9.34808	7.87249	0.719083	0.71908
PRIN2	1.47559	0.54958	0.113507	0.83259
PRIN3	0.92601	0.51756	0.071231	0.90382
PRIN4	0.40845	0.03948	0.031419	0.93524
PRIN5	0.36897	0.10921	0.028382	0.96362
PRIN6	0.25976	0.16439	0.019981	0.98360
PRIN7	0.09536	0.04372	0.007336	0.99094
PRIN8	0.05165	0.00822	0.003973	0.99491
PRIN9	0.04343	0.02700	0.003341	0.99825
PRIN10	0.01643	0.01016	0.001264	0.99952
PRIN11	0.00628	0.00626	0.000483	1.00000
PRIN12	0.00000	0.00000	0.000000	1.00000
PRIN13	0.00000	--	0.000000	1.00000
		Site 4		
PRIN1	8.37154	6.00967	0.558103	0.55810
PRIN2	2.36188	0.57691	0.157458	0.71556
PRIN3	1.78497	0.92907	0.118998	0.83456
PRIN4	0.85590	0.12450	0.057060	0.89162
PRIN5	0.73141	0.33677	0.048760	0.94038
PRIN6	0.39463	0.16896	0.026309	0.96669
PRIN7	0.22568	0.11144	0.015045	0.98173
PRIN8	0.11423	0.04487	0.007616	0.98935
PRIN9	0.06936	0.02508	0.004624	0.99397
PRIN10	0.04428	0.01214	0.002952	0.99693
PRIN11	0.03214	0.01993	0.002142	0.99907
PRIN12	0.01220	0.01069	0.000814	0.99988
PRIN13	0.00152	0.00125	0.000101	0.99998
PRIN14	0.00027	0.00027	0.000018	1.00000
PRIN15	0.00000	--	0.000000	1.00000

Table B.10. Principal component scores for the pedons from Site 1, Botetourt County.

Unit A

Pedon	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
1	1.47284	0.69727	0.45828	-0.07965	-1.47058
2	3.86884	-1.72241	-0.91560	1.85243	-0.32967
3	2.56156	2.85787	-0.14524	0.14936	0.18959
4	2.50746	1.89210	2.49076	-0.24291	-0.20308
5	2.19182	-2.31369	-1.11950	1.67340	-0.40047
6	2.83334	-1.53914	0.06218	2.00994	0.14162
7	1.87325	1.68967	-1.42328	0.27861	-1.12171
8	-0.09897	2.79907	-0.22266	0.57071	-1.27093
9	3.84026	-0.48304	0.64654	-2.94757	0.72679
10	2.50135	-1.15839	0.83476	1.95728	1.67210
11	4.36033	-1.95766	0.29544	-1.84997	0.18702
12	3.71397	-1.25549	-1.20403	-0.53154	0.33545
13	2.09984	0.18845	0.65534	1.16246	-1.82588
14	0.50261	3.32307	1.35842	1.34937	-0.26914
15	2.42659	0.61507	-1.55989	-0.10228	0.83661
16	3.96687	-0.19012	-0.62692	-0.51964	0.23003
17	3.16882	-1.52506	1.88449	-0.40081	-1.12701
18	1.56099	-0.42457	-1.27974	1.33353	0.05824
19	3.99411	0.52196	-1.57494	0.52550	0.66939
20	4.11036	-0.89874	-0.17034	-1.34180	-0.77774
21	3.62300	1.13141	2.67232	-0.17490	-0.18239
22	3.63639	-0.29955	0.49085	0.01245	1.09859
23	4.15570	0.94571	1.44373	-0.20719	2.05170
24	2.43596	-0.56549	-0.33721	-0.14558	-1.06690
25	2.56991	0.47305	-1.13019	0.69027	0.89152

Unit A

Pedon	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
1	1.49476	0.40600	0.16216	-0.11984	0.28883
2	0.65455	0.15601	0.28397	-0.19535	-0.23223
3	0.77046	-0.34524	-0.57015	-0.43587	0.23539
4	-0.92211	-0.92294	-0.52606	-0.17236	0.14935
5	0.82899	1.90174	-0.47871	0.17671	0.44555
6	0.39102	-0.52736	0.07780	0.07459	0.07807
7	-0.89471	0.53295	-0.24418	0.05075	0.04439
8	-0.91827	1.39718	0.12911	0.18927	0.24499
9	-0.18234	-0.14036	-0.12797	0.36034	-0.14427
10	0.13310	0.08200	-0.61435	0.37840	-0.12251
11	0.55592	0.01917	0.21594	-0.21597	0.15971
12	-0.10771	-0.50813	0.66466	-0.17255	-0.06680
13	-0.65974	-1.01432	-0.37944	-0.04131	-0.17099
14	0.20239	0.29837	-0.37596	0.06631	0.10771
15	0.04577	0.12582	0.09709	0.14090	-0.39308
16	1.02537	0.27383	0.48483	-0.16925	-0.33749
17	-1.44038	0.18782	0.93084	-0.26731	0.20777
18	-1.77527	0.30143	-0.03927	0.25123	-0.08830
19	0.59667	0.21635	0.24203	-0.38153	-0.47225
20	-1.34141	-0.27388	-0.64679	-0.49769	-0.06808
21	0.01996	0.16814	-0.47834	-0.33447	0.25250
22	-0.10785	-0.35618	0.99331	-0.19846	-0.08055
23	0.83513	0.55407	-0.08530	-0.32580	0.20337
24	-0.99685	0.68869	-0.09476	-0.03044	0.35535
25	-1.14815	-0.97674	-0.13403	0.14881	-0.49935

Table B.10. (cont.) Principal component scores for the pedons from Site 1, Botetourt County.

Unit B

Pedon	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
1	-4.89214	0.43743	0.54987	0.83454	-0.33984
2	-1.49924	1.07274	0.21749	-1.36601	1.69149
3	-3.87122	0.80440	-0.85657	0.62453	1.07407
4	-3.18902	1.21449	-1.83904	-0.83941	-0.14804
5	-2.35722	0.64912	0.41865	-0.74636	0.09002
6	-0.67909	-0.84151	0.83182	0.69689	-3.74822
7	-4.50743	-0.75940	2.20050	-0.15561	0.20189
8	-6.17746	0.41106	-0.61106	-0.36448	-0.66991
9	-4.94984	-1.97320	0.97911	-0.91981	-0.06564
10	-1.89877	-3.01036	0.26933	-1.97472	-1.44949
11	-2.98718	-1.16908	2.94914	1.43885	-0.29411
12	-0.16214	-3.20110	0.24027	1.93639	0.92066
13	-4.92572	-0.47702	-0.49276	-1.21878	-0.29128
14	-5.09319	-0.14292	-1.76743	-0.43701	-1.46902
15	-3.51290	0.00636	0.96526	-0.34179	0.83483
16	-1.85991	1.85010	1.25186	-0.61951	-1.31196
17	-5.85309	-0.94793	0.19803	0.30541	1.73128
18	-2.71564	-0.26483	-0.35301	1.87906	1.18899
19	-0.44240	3.02974	-0.30008	-0.32368	1.21825
20	-4.78502	-0.70160	0.46040	0.54157	1.31747
21	1.72313	-0.15152	-0.42561	-3.87082	0.37328
22	-1.75399	1.80422	-0.21379	-0.00665	1.07605
23	-0.40360	2.26165	-2.29040	0.83718	-1.74237
24	-2.15108	-0.67327	-1.68134	-0.30166	1.15681
25	-0.93394	-2.02890	-2.28421	-0.62957	-0.38833

Unit B

Pedon	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
1	0.67424	-0.38535	0.48505	-0.40779	-0.14510
2	0.01764	-0.12453	-0.90207	0.45602	0.05280
3	1.56128	-0.05705	0.06601	-0.40326	0.09779
4	0.49967	0.59436	-0.14618	0.18971	-0.05329
5	-1.13828	0.62407	0.36738	0.11503	-0.13314
6	0.75322	-1.29179	0.28396	0.72821	0.15750
7	0.50137	0.45636	-0.27485	0.07906	-0.61172
8	-0.24390	-0.01590	0.24782	-0.53733	-0.13468
9	-0.20922	0.51744	-0.56043	-0.07525	-0.45086
10	0.45388	0.02939	-0.82072	-0.00605	0.04617
11	0.44625	0.49650	-0.07912	0.03173	-0.48177
12	0.29372	0.28452	0.01331	0.54635	0.06802
13	0.18587	0.05317	-0.50661	-0.39500	-0.23026
14	-0.94456	0.39609	0.24208	-0.31621	0.04536
15	-0.57039	0.46108	0.59010	0.09172	-0.13810
16	1.32274	-0.57863	0.69544	0.28283	0.19878
17	-0.19946	0.09252	0.66758	-0.13666	0.74916
18	-0.60314	-0.90938	0.41669	0.00754	0.26149
19	0.64976	-0.47361	-0.03668	0.36649	-0.05848
20	-1.35237	-0.74616	0.05719	0.01994	0.16290
21	0.28700	0.26706	0.75353	0.65030	0.08377
22	-0.29482	-0.12500	0.24304	0.33687	-0.04740
23	0.15242	0.10106	-0.00115	0.18608	-0.32048
24	-0.35573	-0.48728	-0.78811	-0.00922	0.60797
25	1.05348	-1.42322	-0.49967	-0.08021	0.17648

Table B.11. Principal component scores for the pedons for Site 2, Augusta County.

Unit A

Pedon	**PRIN1**	**PRIN2**	**PRIN3**	**PRIN4**	**PRIN5**
1	4.04620	1.33552	-0.72174	-0.28376	1.78037
2	2.34481	-2.14360	1.71540	0.09508	0.81898
3	1.10801	1.82665	1.28731	-1.11685	-0.87672
4	1.66031	-0.42831	0.44732	-0.54453	0.72481
5	3.11884	-1.36360	-1.36376	-1.28512	0.77595
6	2.28965	0.52549	0.96518	-0.19753	0.61599
7	0.88008	1.41122	2.66518	0.01785	-0.27825
8	3.11084	0.75484	0.83930	2.50355	-0.58658
9	3.21280	-0.05642	-0.66412	0.00336	-0.09886
10	3.75256	0.18097	-0.19704	-1.47027	0.30223
11	2.98498	-1.50193	0.67296	-0.53595	0.97757
12	4.18800	-0.27008	-0.63573	-0.88730	0.36259
13	2.85053	1.45885	-0.03354	-0.07319	-0.72629
14	3.17881	-1.00018	0.49026	-0.20013	-0.69996
15	4.13168	0.92382	-1.51579	1.58165	0.57202
16	3.37536	-2.64160	1.19238	0.44227	-0.17082
17	4.84426	0.57707	-0.69628	0.67117	-2.13416
18	4.61153	-1.35340	-0.40136	-0.66960	-0.75603
19	2.78788	1.36415	-1.68354	-1.10034	-0.26708
20	1.64816	2.67180	1.34155	-1.13556	0.52188
21	4.12496	-0.49075	-0.84714	1.50823	-1.04435

Unit A

Pedon	**PRIN6**	**PRIN7**	**PRIN8**	**PRIN9**	**PRIN10**
1	0.05364	-0.68667	-0.48105	0.22845	0.09570
2	0.32797	0.59964	0.65069	-0.27247	0.24147
3	0.36032	0.27200	-0.39770	-0.05663	-0.03434
4	-0.04913	0.43075	-0.00046	-0.19237	-0.45437
5	0.99785	-0.32880	0.09293	-0.08288	-0.22873
6	-0.15927	0.32869	0.64684	-0.03574	-0.26214
7	1.56008	-0.54977	0.57791	-0.10005	0.31355
8	-0.33388	0.68874	-0.15593	-0.52920	-0.02973
9	-0.74534	-0.27885	0.17708	0.30547	-0.51464
10	0.15120	-0.16328	0.25901	0.18336	-0.02625
11	-0.86834	0.14140	-0.22347	-0.34766	0.32627
12	-0.19118	-0.10698	0.42649	0.10709	-0.13837
13	0.39775	0.36364	0.64343	0.24305	-0.18226
14	-0.37632	1.36683	-0.01354	-0.39018	-0.01741
15	0.80719	-0.44554	-0.59192	0.77053	0.10170
16	-0.62670	-0.49088	-0.28303	-0.05192	0.39214
17	-0.78851	-0.31902	-0.49004	0.04271	0.47164
18	0.01478	0.12844	-0.09676	-0.04851	0.40397
19	0.14923	1.12845	-0.35769	-0.10865	-0.46759
20	-0.98136	-0.61548	0.69046	-0.23504	0.18323
21	0.58083	-0.35906	-0.30749	0.07126	-0.00584

Table B.11. (cont.) Principal component scores for the pedons for Site 2, Augusta County.

Unit B

Pedon	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
1	-2.09170	0.39654	1.71717	1.43444	1.26256
2	-1.39216	0.74307	-0.48660	2.56804	0.82689
3	-1.64921	-1.25804	2.61723	1.47813	0.21471
4	-3.43969	-1.63884	0.49847	-0.07438	0.21930
5	-0.71753	-0.90431	-0.37328	-1.70420	-0.08510
6	-1.85223	3.21957	-1.24644	2.05856	0.84322
7	-3.96215	-1.21264	0.46241	1.19681	0.97785
8	-3.30883	2.72062	-1.79096	0.79113	-0.43272
9	-4.32535	-0.15918	-1.38306	-1.41397	0.48339
10	-4.25670	-0.20848	-1.20821	0.06782	0.06136
11	-3.56924	-1.11518	-0.67313	-0.07846	-0.48376
12	-3.59972	-0.73616	0.76134	0.25356	-0.19870
13	-3.88334	0.53615	0.89977	-1.15126	-1.54451
14	-2.52810	1.82508	0.57559	-0.98992	1.26973
15	-4.56841	-1.30312	-1.09430	-0.40892	0.28134
16	-1.67361	-1.73144	-2.47902	0.92566	-1.54686
17	-3.65848	-0.06147	1.94900	0.32950	-2.09419
18	-2.34909	-3.31771	-1.44214	0.77102	0.65766
19	-4.34958	0.95909	-0.55856	-0.17659	0.01194
20	-2.53806	0.18830	-0.13705	-2.06725	0.15777
21	-4.53705	1.27761	0.53499	-1.13272	-0.69517

Unit B

Pedon	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
1	0.31551	-0.63939	-0.20918	-0.19476	-0.17884
2	-0.91577	-0.17445	-0.25389	-0.40226	-0.25158
3	-0.92782	-0.17732	0.25830	0.80110	-0.54012
4	-0.08526	-0.43137	-0.58090	0.10451	0.04821
5	-0.30225	-0.13817	-0.29640	-0.09710	-0.05450
6	1.43964	0.21458	0.36772	-0.36012	0.25067
7	0.15738	-0.07843	-0.70222	-0.20444	-0.10282
8	-1.00677	-0.22354	0.56472	0.05190	0.26230
9	-0.17923	0.74430	0.11277	-0.03833	-0.05731
10	-0.64429	0.19128	-0.28932	-0.06146	0.12012
11	-0.38778	-0.61741	0.68774	-0.16918	0.06228
12	-0.77470	0.16156	-0.40411	0.28443	0.18665
13	0.85362	-0.53765	-0.25409	-0.15356	-0.30964
14	-0.15961	0.37970	-0.10525	-0.20899	0.00031
15	-0.25516	-0.21659	1.57711	0.08961	0.37862
16	-0.16887	-0.97635	0.51307	-0.36822	-0.46285
17	1.01054	0.46503	0.16006	0.21613	-0.07127
18	1.90035	0.83067	0.02596	0.42464	0.16267
19	-0.66803	1.46091	-0.52835	0.47838	0.31965
20	0.45743	-1.30326	-0.91190	-0.31233	0.10510
21	0.06024	-0.03836	-0.49762	0.13936	-0.03567

Table B.12. Principal component scores for the pedons for Site 3, Rockingham County.

Unit A

Pedon	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
1	2.93098	1.15856	-0.04079	-1.06473	0.50908
2	3.67849	-0.96876	-0.43331	-0.42490	-0.18598
3	3.19030	-0.92215	0.95024	0.12622	0.52602
4	-0.24941	-0.55221	-0.84140	1.48000	0.28774
5	3.98772	0.57771	0.33536	0.23149	-1.50793
6	2.58170	0.95324	-0.76102	0.60177	0.61928

Unit A

Pedon	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
1	0.30413	0.09802	-0.14201	0.27886	-0.06403
2	-0.49828	0.04080	0.09812	-0.15551	0.29313
3	0.08993	-0.71947	-0.10514	-0.11918	-0.07740
4	0.09069	0.12237	-0.30950	0.06857	0.02331
5	0.21091	0.16964	-0.12254	0.00588	-0.08179
6	0.02394	0.12885	0.49035	0.09893	-0.04134

Unit B

Pedon	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
1	-2.63831	-0.11051	-0.16411	-0.38373	0.39770
2	-1.13078	-1.85980	0.48628	-0.34036	0.30958
3	-3.70023	1.77477	0.25151	0.06176	-0.17245
4	-2.18074	1.40305	1.72143	0.23173	0.13269
5	-3.61196	-1.70333	0.52713	-0.03462	-0.57498
6	-2.85776	0.24944	-2.03132	-0.48464	-0.34076

Unit B

Pedon	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
1	0.90613	0.20890	-0.19959	-0.08475	0.13689
2	-0.81978	0.45286	-0.06825	0.02182	-0.16099
3	-0.83203	-0.29598	-0.12218	0.24147	0.10183
4	0.06539	0.19790	0.13288	-0.35477	-0.00671
5	0.51249	-0.16538	0.31251	0.27793	0.01978
6	-0.05353	-0.23851	0.03536	-0.27923	-0.14267

Table B.13. Principal component scores for the pedons for Site 4, Page County.

Unit A

Pedon	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
1	1.13033	1.54004	1.17084	0.27021	1.52488
2	3.63641	-0.26547	-0.33662	0.85090	0.50876
3	3.41470	0.61777	1.34265	-0.62563	-2.05005
4	2.15403	1.08435	1.04088	1.44885	0.73842
5	3.34798	-1.11866	-1.33985	0.36492	-0.14860
6	1.21554	-1.03419	-1.86526	0.18790	0.38161
7	0.59956	0.47573	-1.23949	0.76378	-0.31532
8	3.66864	0.20305	1.55691	-0.56641	-0.48346

Unit A

Pedon	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
1	-1.41122	0.15627	0.06443	0.18964	-0.17290
2	0.30400	0.48722	-0.24027	0.13542	0.12562
3	0.42938	-0.33676	-0.00991	0.29349	-0.20068
4	0.80893	-0.64556	0.33204	-0.13687	-0.19125
5	-0.61200	-0.78268	0.33450	0.05852	0.42373
6	0.35360	0.15998	-0.46577	-0.14158	-0.41380
7	0.21825	0.29138	-0.28617	0.30106	0.11453
8	-0.10168	1.00994	0.09278	-0.51006	0.18771

Unit B

Pedon	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
1	-0.29081	-2.76009	1.84346	-1.66886	0.79626
2	-3.30245	-1.04905	0.90849	0.00588	0.40988
3	-3.63155	-0.60982	0.99470	0.39860	-0.02029
4	-0.77006	-2.42472	-1.72784	0.01131	-0.81647
5	-2.95166	1.05363	-0.47559	-0.68058	-0.29435
6	-2.60565	-0.10529	-1.32091	-0.39752	0.62000
7	-0.49570	3.44155	-1.46938	-1.73842	0.22079
8	-5.20932	0.95118	0.91701	1.37507	-1.07205

Unit B

Pedon	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
1	-0.12076	-0.46367	-0.15115	0.01694	-0.06562
2	0.94938	0.10637	0.28282	0.04387	0.10125
3	-0.00485	-0.04854	0.69460	0.18409	0.25630
4	-0.81988	0.04908	0.18936	-0.17316	-0.20276
5	-0.17010	0.54876	0.49906	0.48524	0.08344
6	0.69926	0.17412	0.39972	-0.15624	0.07009
7	0.05255	-0.49160	-0.29953	-0.23715	0.08864
8	-0.57486	-0.21430	-0.04729	-0.35322	-0.03742

Table B.14. Loading values for the variables onto the principal components for Site 1, Botetourt County.

Variable	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
RCS	0.261503	-0.130607	-0.096537	0.074643	0.048432
RMS	0.285961	0.015898	-0.113925	0.096644	0.203862
RFS	0.285153	0.007699	0.232826	0.032246	-0.116108
RVFS	0.253971	0.293030	-0.012067	0.098823	-0.135340
RTOTS	0.294582	0.074463	0.091482	0.026081	-0.011142
RMSI	0.252187	-0.006199	-0.164671	0.082977	0.155361
RFSI	0.085243	0.218005	-0.024212	0.485462	-0.138485
RTOTSI	0.195145	-0.078013	-0.117339	0.511006	-0.257334
RCFS	0.271847	0.181346	0.096375	-0.255533	0.075919
RSIND	0.202707	-0.336679	0.316616	-0.015268	0.098137
RTSTSI	0.271379	0.179989	0.096532	-0.257459	0.088827
RCFMS	0.248411	0.020915	-0.205633	-0.133640	0.404031
RCFFS	0.241990	0.006890	0.382945	-0.197934	-0.197995
RCFVFS	0.164427	0.503284	-0.018824	-0.192894	-0.060293
RCFMSVFS	0.172167	-0.297523	-0.241436	0.081336	0.499674
RCFFSVFS	0.125161	-0.439902	0.457020	0.022806	-0.072890
RHVS	-0.164818	0.247980	0.389076	0.274927	0.396039
RHSLS	-0.165468	0.248128	0.381955	0.276670	0.401575
RLWH	0.269280	-0.007584	-0.033663	0.290841	-0.110347

Variable	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
RCS	0.025466	-0.651231	0.286704	0.164581	-0.415868
RMS	-0.040554	0.037465	-0.149655	-0.275674	-0.357862
RFS	-0.069826	-0.081598	0.016090	-0.182335	0.228603
RVFS	-0.203359	0.057370	-0.235716	-0.137837	0.064282
RTOTS	-0.095769	-0.123734	-0.011183	-0.468141	0.088731
RMSI	-0.082495	0.515124	0.769077	-0.015799	0.001914
RFSI	0.814307	0.079465	-0.023347	-0.097248	-0.024651
RTOTSI	-0.300368	0.007270	-0.066301	0.380929	0.097833
RCFS	0.073499	-0.091353	0.064439	-0.039134	0.087934
RSIND	-0.011544	0.464976	-0.331591	-0.020353	-0.320152
RTSTSI	0.067899	-0.086061	0.046323	-0.018199	0.070457
RCFMS	0.125311	0.025664	-0.219873	0.029355	-0.233440
RCFFS	0.123620	-0.045331	0.107650	0.116529	0.224830
RCFVFS	0.016628	0.162635	-0.114475	0.565303	-0.034337
RCFMSVFS	0.129379	-0.075886	-0.164413	0.114734	0.632824
RCFFSVFS	0.168772	-0.025330	0.082854	0.272133	-0.035440
RHVS	-0.125907	-0.066015	0.063364	0.033491	-0.005021
RHSLS	-0.118880	-0.069411	0.060775	0.051903	-0.017859
RLWH	-0.256062	-0.028632	-0.110204	0.020344	0.032543

Table B.14. (cont.) Loading values for the variables onto the principal components for Site 1, Botetourt County.

Variable	PRIN11	PRIN12	PRIN13	PRIN14	PRIN15
RCS	0.108362	0.142804	0.139059	0.130692	-0.334344
RMS	0.091565	-0.281479	-0.245783	-0.510929	0.110840
RFS	-0.065719	-0.050707	-0.503226	0.049231	-0.364644
RVFS	0.534321	0.005855	0.557645	-0.112069	-0.075922
RTOTS	0.152962	0.357427	-0.281175	0.134310	0.173198
RMSI	0.050141	0.030044	0.056958	-0.023611	-0.044623
RFSI	-0.049062	0.026938	0.037052	0.068828	-0.014222
RTOTSI	0.127691	-0.328105	-0.194776	0.343444	0.241776
RCFS	-0.122924	-0.034156	0.135932	0.255497	0.322759
RSIND	-0.037821	0.127736	0.114850	0.383705	-0.299118
RTSTSI	-0.138781	-0.061915	0.126895	0.283908	0.318320
RCFMS	-0.092569	-0.276503	-0.082112	0.045829	0.112717
RCFFS	-0.083371	-0.512320	0.147993	-0.230178	-0.284403
RCFVFS	0.081459	0.389370	-0.281692	-0.159377	-0.148569
RCFMSVFS	0.112225	0.130980	0.062033	-0.064384	-0.156379
RCFFSVFS	0.241623	0.239289	-0.014517	-0.324747	0.443272
RHVS	0.015795	-0.075431	-0.018754	0.010392	0.068851
RHSLS	-0.029909	0.010166	0.052190	0.020656	-0.088572
RLWH	-0.717883	0.262063	0.267458	-0.286118	0.048852

Variable	PRIN16	PRIN17	PRIN18	PRIN19
RCS	0.073755	0.029275	0.060679	0.004563
RMS	0.444235	0.065019	-0.038631	0.012886
RFS	-0.064813	-0.593760	-0.011212	0.014437
RVFS	-0.143485	-0.250028	0.005609	-0.010273
RTOTS	-0.315420	0.517094	-0.011972	-0.040009
RMSI	-0.064830	-0.028267	0.004443	-0.010089
RFSI	0.001983	-0.013561	0.010059	-0.003919
RTOTSI	0.087873	0.128647	-0.051064	0.013554
RCFS	0.226145	-0.088766	-0.052451	0.721050
RSIND	0.156093	0.102444	0.057141	0.021981
RTSTSI	0.278879	-0.129057	-0.001153	-0.689527
RCFMS	-0.655861	-0.115468	-0.037067	-0.002963
RCFFS	-0.099857	0.433177	0.018032	-0.013534
RCFVFS	0.125830	0.125363	0.035601	0.002889
RCFMSVFS	0.184227	0.083868	0.030437	0.000226
RCFFSVFS	-0.100728	-0.184610	-0.051205	-0.012915
RHVS	-0.018493	-0.003818	0.699843	0.029670
RHSLS	0.005993	0.038691	-0.698348	-0.021932
RLWH	-0.085482	-0.024175	0.042358	-0.004975

Table B.15. Loading values for the variables onto the principal components for Site 2, Augusta County.

Variable	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
RCS	0.186052	0.217153	0.331865	-0.051572	0.675083
RMS	0.249939	0.242487	0.269129	0.285778	-0.045465
RFS	0.292228	-0.122580	0.196482	-0.025556	-0.066884
RVFS	0.292097	-0.148206	-0.030157	0.149864	-0.014951
RTOTS	0.283805	0.075362	0.257670	0.085893	0.014800
RMSI	0.259701	0.064729	-0.090355	0.188603	0.213709
RFSI	0.226614	0.036095	-0.032428	-0.360449	0.125676
RTOTSI	0.271954	0.178044	-0.078839	-0.071589	0.055360
RSIND	0.198103	0.157755	0.354824	0.179304	-0.627734
RCFFS	0.181075	-0.476138	0.285184	-0.163593	-0.038237
RCFVFS	0.251082	-0.282161	-0.181375	0.268204	-0.035035
RCFMSFS	-0.212126	0.420792	0.032586	0.304004	-0.004458
RCFMSVFS	-0.257259	0.327750	0.247472	-0.002767	-0.010495
RCFFSVFS	-0.178353	-0.032836	0.465374	-0.517703	-0.109965
RHVSI	-0.215913	-0.294845	0.319903	0.332223	0.183931
RLWH	0.291675	0.171756	0.027638	-0.100610	0.004541
RHLWH	-0.221670	-0.284560	0.272010	0.320592	0.173021

Variable	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
RCS	-0.240060	-0.087320	-0.099059	0.011982	-0.465727
RMS	-0.111038	0.166814	-0.024351	-0.296451	0.205078
RFS	0.015099	-0.169830	-0.033906	0.206993	0.038287
RVFS	0.004966	-0.152026	-0.194079	0.242739	-0.237868
RTOTS	-0.140384	0.025303	-0.150224	-0.353246	0.517795
RMSI	0.103855	0.006780	0.888947	0.064258	0.076119
RFSI	0.461148	0.718989	-0.087562	-0.105007	-0.104424
RTOTSI	0.476157	-0.273748	-0.108202	0.252167	0.171027
RSIND	0.148459	0.020707	0.107752	-0.058589	-0.498466
RCFFS	-0.280347	0.272353	0.049115	0.305398	0.090054
RCFVFS	-0.228294	0.215976	-0.051439	0.227710	0.062290
RCFMSFS	-0.028795	0.334952	-0.095144	0.602792	0.142559
RCFMSVFS	-0.131481	0.097279	0.045386	0.112631	0.060864
RCFFSVFS	0.019256	-0.129982	0.233961	0.188215	0.173756
RHVSI	0.311026	0.031133	-0.027598	0.024940	0.034308
RLWH	0.156019	-0.237043	-0.177325	0.204134	0.225431
RHLWH	0.409383	-0.055357	-0.062331	-0.066067	0.047547

Table B.15. (cont.) Loading values for the variables onto the principal components for Site 2, Augusta County.

Variable	PRIN11	PRIN12	PRIN13	PRIN14	PRIN15
RCS	-0.078926	-0.007968	-0.200478	0.013021	0.094018
RMS	-0.394360	0.126921	0.233552	0.267518	-0.475058
RFS	0.317198	0.420759	-0.109555	-0.524399	-0.416082
RVFS	0.424434	-0.108417	0.565817	0.399425	0.026339
RTOTS	0.404067	-0.220988	-0.145933	-0.058535	0.398881
RMSI	0.120675	-0.052125	0.060227	0.003099	0.025688
RFSI	0.151207	0.119772	0.054232	0.013594	-0.005757
RTOTSI	-0.434080	-0.124112	0.056192	-0.134011	0.276349
RSIND	-0.040504	-0.093982	-0.192222	-0.041992	0.198299
RCFFS	-0.301255	-0.425521	0.171919	-0.213689	-0.023282
RCFVFS	-0.190745	0.545446	-0.248688	0.222044	0.382966
RCFMSFS	0.179949	-0.211693	-0.232334	0.072103	-0.139617
RCFMSVFS	-0.026782	0.352311	0.577469	-0.320863	0.367880
RCFFSVFS	0.059627	0.185137	-0.125496	0.492738	0.029810
RHVSI	0.017553	-0.064061	-0.074002	-0.057268	0.001690
RLWH	-0.047390	0.046973	-0.050266	0.118790	-0.111033
RHLWH	-0.019596	0.129605	0.050357	0.084185	0.030304

Variable	PRIN16	PRIN17
RCS	0.019126	-0.041566
RMS	-0.158203	-0.058526
RFS	-0.134889	-0.159203
RVFS	-0.137407	-0.040672
RTOTS	-0.030981	-0.084143
RMSI	0.073200	0.032296
RFSI	0.008488	0.030547
RTOTSI	-0.333123	-0.247875
RSIND	0.089624	0.035316
RCFFS	0.160889	-0.030324
RCFVFS	-0.039431	0.029683
RCFMSFS	-0.005383	-0.150948
RCFMSVFS	0.076536	0.131833
RCFFSVFS	-0.168157	-0.085290
RHVSI	-0.407262	0.583616
RLWH	0.578005	0.550040
RHLWH	0.500581	-0.451342

Table B.16. Loading values for the variables onto the principal components for Site 3, Rockingham County.

Variable	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
RVCS	-0.249015	0.060170	0.608194	0.079157	0.358656
RMS	0.285722	0.197456	0.166276	0.177938	0.548127
RFS	0.308243	-0.026492	0.251458	0.300265	-0.067249
RVFS	0.300322	0.160495	0.176956	-0.139363	-0.063185
RTOTS	0.300873	0.102072	0.344662	0.153785	-0.096829
RMSI	0.280232	0.181326	-0.060853	-0.110167	0.102057
RTOTSI	0.263604	0.412309	-0.192607	-0.107774	-0.269564
RSIND	0.246195	-0.203463	-0.434053	0.612146	0.303874
RCFFS	0.217185	-0.476837	0.291360	0.271496	-0.527669
RCFVFS	0.260341	-0.378065	0.188067	-0.479970	0.200681
RHVS	-0.301915	0.229203	0.147215	0.277747	-0.148743
RHSLS	-0.303746	0.234589	0.123691	0.221504	-0.104520
RLWH	0.271355	0.445381	0.051779	-0.008837	-0.175005

Variable	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
RVCS	0.080539	-0.272640	-0.392623	0.346901	-0.162424
RMS	-0.172841	-0.126713	0.604354	-0.127539	-0.251033
RFS	0.151291	0.076829	-0.072798	-0.299257	0.306733
RVFS	-0.317252	0.712661	-0.200977	0.184488	-0.374389
RTOTS	-0.123193	-0.079372	-0.339986	-0.272340	0.297958
RMSI	0.883106	0.139473	-0.038741	0.075333	-0.153448
RTOTSI	-0.144461	-0.454391	-0.082536	0.452951	-0.038818
RSIND	-0.061005	0.087733	-0.226850	0.371559	0.125306
RCFFS	0.090427	-0.150953	0.277085	0.207723	-0.331738
RCFVFS	-0.023923	0.066850	0.207448	0.397157	0.500059
RHVS	0.083499	0.194556	0.221906	0.202943	0.070741
RHSLS	0.059685	0.2865598	0.267709	0.272592	0.369903
RLWH	-0.034267	-0.093041	0.137209	0.019069	0.211832

Variable	PRIN11	PRIN12	PRIN13
RVCS	-0.091480	-0.171512	-0.100461
RMS	0.073356	0.069064	0.137886
RFS	0.489989	-0.510089	-0.168406
RVFS	0.040728	-0.067165	0.004407
RTOTS	-0.113423	0.571180	0.328805
RMSI	-0.033753	0.132829	0.116197
RTOTSI	0.406305	-0.046916	0.189209
RSIND	-0.131570	0.049885	-0.078037
RCFFS	-0.155358	0.003919	0.057722
RCFVFS	0.077119	0.108365	-0.098574
RHVS	0.357659	0.503418	-0.462350
RHSLS	-0.156643	-0.244047	0.569929
RLWH	-0.604619	-0.166688	-0.476838

Table B.17. Loading values for the variables onto the principal components for Site 4, Page County.

Variable	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
RFS	0.278327	0.334339	0.031850	-0.199129	0.126293
RVFS	0.278367	0.255746	-0.174159	-0.035777	-0.072258
RTOTS	0.165026	0.526702	0.126906	0.172319	0.134028
RMSI	0.283467	0.068491	-0.327809	0.248565	-0.087013
RFSI	0.302134	0.048928	-0.096294	0.245153	-0.266462
RTOTSI	0.328508	-0.092460	-0.041553	0.182419	-0.054878
RCFS	-0.246840	0.417933	0.177733	-0.043175	0.019401
RSIND	0.205882	0.069547	-0.328752	0.194434	0.697813
RTSTSI	-0.246840	0.417933	0.177733	-0.043175	0.019401
RCFMS	-0.297791	0.187186	-0.114098	0.240072	0.227533
RCFMSFS	-0.263186	-0.201662	-0.127142	0.526882	0.061643
RCFMSVFS	-0.307769	-0.067597	0.076302	0.249450	0.237666
RHVS	0.227266	-0.204592	0.444819	-0.036879	0.319990
RHSLS	0.228674	-0.208747	0.439739	-0.041802	0.318026
RHWH	0.131909	0.099401	0.486411	0.576289	-0.275671

Variable	PRIN6	PRIN7	PRIN8	PRIN9	PRIN10
RFS	-0.171290	0.290422	0.032978	-0.081025	0.010987
RVFS	0.385142	-0.518667	0.123268	0.253301	-0.452360
RTOTS	-0.137766	0.165346	-0.398552	-0.299162	-0.438331
RMSI	0.267810	0.138645	-0.267970	0.460742	0.196044
RFSI	0.108501	0.531305	0.597598	-0.088943	-0.030710
RTOTSI	-0.038844	0.105133	-0.425292	0.090731	0.316116
RCFS	0.176048	0.040481	-0.008858	0.154752	0.322368
RSIND	-0.272159	-0.244527	0.227501	-0.054983	0.272067
RTSTSI	0.176048	0.040481	-0.008858	0.154752	0.322368
RCFMS	0.369114	0.035205	0.249487	-0.157848	0.009037
RCFMSFS	0.296161	0.061230	-0.261523	-0.326849	-0.095096
RCFMSVFS	-0.306693	0.272952	0.050650	0.651104	-0.388194
RHVS	0.311386	0.057571	0.027971	0.031201	-0.051507
RHSLS	0.302650	0.092783	-0.007112	0.058730	-0.001402
RHWH	-0.275156	-0.390199	0.170642	0.018285	0.139547

Variable	PRIN11	PRIN12	PRIN13	PRIN14	PRIN15
RFS	0.329390	0.655036	-0.296573	0.084560	0.000000
RVFS	0.317741	0.022135	0.130078	0.023834	0.000000
RTOTS	-0.253047	-0.272780	0.075418	-0.025811	0.000000
RMSI	-0.504211	0.207929	-0.164918	-0.003265	0.000000
RFSI	0.041974	-0.161396	0.276906	-0.037741	0.000000
RTOTSI	0.607266	-0.403648	-0.106615	-0.029161	0.000000
RCFS	0.068869	-0.006920	0.252083	-0.040698	0.707107
RSIND	-0.051769	-0.034426	0.229401	-0.028388	0.000000
RTSTSI	0.068869	-0.006920	0.252083	-0.040698	-0.707107
RCFMS	0.067772	-0.237366	-0.680127	0.074994	0.000000
RCFMSFS	0.209839	0.424964	0.303487	0.006043	0.000000
RCFMSVFS	0.174006	-0.011496	0.002077	-0.001607	0.000000
RHVS	-0.040129	0.054908	-0.062573	-0.701177	0.000000
RHSLS	-0.074741	-0.047883	0.099258	0.697450	0.000000
RHWH	-0.050002	0.141970	-0.161337	0.038238	0.000000

Table B.18. Discriminant scores derived from the first five principal components.

Unit A

Pedon	Site 1	Site 2	Site 3	Site 4
1	4.2559	25.2312	14.9194	11.2849
2	10.4443	15.8505	25.7668	24.7838
3	7.3726	13.7221	24.5578	13.8173
4	7.4166	11.9276	18.1549	23.9556
5	5.9445	18.3014	29.4248	18.3046
6	8.4916	16.9577	33.5314	5.5969
7	5.2887	12.0841	8.6003	
8	1.9313	16.5245	15.8165	
9	5.3216	18.8512		
10	7.6710	26.4822		
11	7.2806	19.6819		
12	7.0773	26.6184		
13	7.2094	19.4433		
14	4.8356	20.7368		
15	5.0912	20.1504		
16	8.3872	20.3609		
17	7.3517	28.6586		
18	4.6635	28.6918		
19	9.5712	17.8273		
20	7.8568	17.5861		
21	9.8756	20.8400		
22	8.3799			
23	9.9648			
24	5.5148			
25	6.4805			

Table B.18. (cont.) Discriminant scores derived from the first five principal components.

Unit B

Pedon	Site 1	Site 2	Site 3	Site 4
1	-10.0856	-12.8940	-23.9394	-16.2661
2	-5.1399	-14.9747	-15.4415	-18.1320
3	-8.6625	-9.5639	-29.7147	-16.5825
4	-8.6874	-21.9258	-20.6974	-8.5605
5	-6.0886	-2.2607	-35.2055	-19.0915
6	0.2016	-16.0480	-21.3568	-16.8477
7	-10.4450	-27.8954	-10.5482	
8	-14.9407	-23.5835	-16.1314	
9	-13.3210	-27.0574		
10	-7.7138	-29.4566		
11	-4.6633	-24.4030		
12	0.4471	-22.2527		
13	-13.4618	-19.1429		
14	-12.9040	-11.3856		
15	-8.6098	-31.1698		
16	-3.5563	-18.5246		
17	-14.2932	-19.2686		
18	-4.6984	-22.2947		
19	-0.5819	-27.2136		
20	-11.1612	-11.5594		
21	-0.9740	-23.6529		
22	-3.7569			
23	0.6774			
24	-6.6787			
25	-4.5800			

Appendix C

Table C.1. Munsell colors (dry) for the interiors of the weathered rocks.

BO01

Rock	Color
a	10YR 7/6
b	10YR 7/8
c	10YR 7/4
d	7.5YR 7/8
e	2.5YR 4/8
f	5YR 6/8
g	5YR 5/8
h	7.5YR 7/6
i	7.5YR 7/4

AU02

Rock	Color
a	5YR 5/6
b	5YR 6/6
c	7.5YR 6/6
d	5YR 6/8
e	7.5YR 7/6
f	5YR 4/4
g	5YR 5/8
h	5YR 6/8
i	5YR 5/8
j	2.5YR 5/8

BO02

Rock	Color
a	7.5YR 8/2
b	7.5YR 7/4
c	2.5YR 5/6
d	7.5YR 7/6
e	2.5YR 6/6
f	7.5YR 8/4
g	7.5YR 8/4
h	7.5YR 8/6
i	7.5YR 7/6
j	7.5YR 6/8

AU03†

Rock	Color
a	5YR 7/4
b	5YR 6/8
c	7.5YR 6/6
d	2.5YR 5/6
e	7.5YR 7/4
f	2.5YR 5/6
g	5YR 6/6
h	10YR 6/3

AU01

Rock	Color
a	10YR 8/4
b	5YR 5/8
c	7.5YR 7/8
d	5YR 6/8
e	7.5YR 7/8
f	5YR 5/8
g	2.5YR 4/6
h	5YR 6/6
i	5YR 6/6
j	5YR 4/6

AU04

Rock	Color
a	10YR 6/8
b	5YR 7/4
c	5YR 6/6
d	2.5YR 6/4
e	5YR 6/6
f	5YR 7/4
g	7.5YR 6/6
h	5YR 6/6
i	2.5YR 5/4

Table C.1. (cont.) Munsell colors (dry) for the interiors of the weathered rocks.

AU05‡		**RO02§**	
Rock	**Color**	**Rock**	**Color**
a	5YR 5/6	a	7.5YR 6/8
b	7.5YR 6/8	b	5YR 5/8
c	10YR 7/4	c	5YR 7/4
d	10YR 6/8	d	7.5YR 6/6
e	10YR 7/6	e	7.5YR 5/2
f	2.5YR 3/6	f	7.5YR 6/8
g	7.5YR 8/6	g	7.5YR 5/8
h	7.5YR 7/6	h	5YR 5/8
i	10YR 5/2		

RO01		**PA01**	
Rock	**Color**	**Rock**	**Color**
a	5YR 5/6	a	2.5YR 3/6
b	7.5YR 8/4	b	5YR 6/6
c	7.5YR 7/2	c	7.5YR 7/4
d	7.5YR 8/4	d	5YR 7/4
e	5YR 8/3	e	10YR 7/3
f	5YR 6/2	f	5YR 6/6
g	7.5YR 6/8	g	5YR 7/4
h	5YR 7/3	h	7.5YR 7/2
i	5YR 8/2	i	7.5YR 7/2
j	7.5YR 6/6	j	2.5YR 6/6

† Location for AU03: Sherando Quadrangle; About 2000 feet SE of the junction of VA-633 and VA-610, about 50 feet south of VA-610. Samples taken from a water-line ditch.

‡ Location for AU05: Crimora Quadrangle; From US-340 N, ESE about 4000 feet into Country Estates Mobile Home Park. Site is a roadcut near the powerline.

§ Location for RO02: Grottos Quadrangle. Site is a roadcut on the north side of US-340 N near the entrance to West Sand and Gravel Company.

Table C.2. **Distributions of the sand fractions derived from the combined subsamples of all weathered rocks within sites. These values were used to produce box plots. Values given are percentages.**

Very Coarse Sand (2.0 -1.0 mm)

		Quantiles				
Site	*n*	**Min**	**25%**	**Med**	**75%**	**Max**
BO01	45	0.00	1.36	3.42	5.73	16.00
BO02	50	0.00	0.00	3.62	10.01	38.68
AU01	50	0.00	0.10	0.28	3.42	12.68
AU02	50	0.27	0.87	2.39	4.10	22.58
AU03	40	0.00	0.00	0.89	3.06	7.25
AU04	45	0.00	0.00	0.00	0.00	1.00
AU05	45	0.00	0.00	0.00	0.00	1.01
RO01	50	0.00	0.00	0.00	3.65	11.00
RO02	40	0.72	1.65	4.16	9.03	15.61
PA01	50	0.00	0.00	2.89	8.99	21.87

Coarse Sand (1.0 - 0.5 mm)

		Quantiles				
Site	*n*	**Min**	**25%**	**Med**	**75%**	**Max**
BO01	45	3.00	10.36	21.77	36.07	59.27
BO02	50	0.00	17.75	46.04	63.43	70.05
AU01	50	0.20	1.53	7.78	24.07	45.11
AU02	50	5.44	14.59	19.74	29.46	49.69
AU03	40	0.00	0.00	4.36	10.44	17.80
AU04	45	0.00	0.00	0.00	0.00	1.98
AU05	45	0.00	0.00	1.00	3.00	8.00
RO01	50	0.00	6.75	17.00	25.96	44.55
RO02	40	4.48	8.48	16.82	29.10	62.28
PA01	50	0.00	12.20	21.00	44.23	72.77

Medium Sand (0.5 - 0.25 mm)

		Quantiles				
Site	*n*	**Min**	**25%**	**Med**	**75%**	**Max**
BO01	45	15.76	26.99	38.64	52.65	67.65
BO02	50	0.00	16.19	24.95	41.06	79.00
AU01	50	3.26	12.49	38.50	60.99	71.32
AU02	50	14.56	41.46	46.88	59.14	75.74
AU03	40	0.00	0.71	10.64	36.25	56.44
AU04	45	0.00	0.00	0.97	2.41	9.00
AU05	45	2.65	12.42	25.00	36.00	54.00
RO01	50	4.00	27.50	42.99	54.25	67.74
RO02	40	10.01	14.74	18.03	44.61	58.00
PA01	50	0.00	18.60	37.85	55.50	68.00

Table C.2. **(cont.) Distributions of the sand fractions derived from the combined subsamples of all weathered rocks within sites. These values were used to produce box plots. Values given are percentages.**

Fine Sand (0.25 -0.1 mm)

		Quantiles				
Site	*n*	**Min**	**25%**	**Med**	**75%**	**Max**
BO01	45	2.55	10.10	22.84	45.00	69.13
BO02	50	1.34	3.04	9.38	32.64	73.00
AU01	50	8.55	15.73	35.56	68.62	86.72
AU02	50	7.44	14.68	19.01	25.87	41.15
AU03	40	21.00	37.31	45.39	60.48	78.19
AU04	45	14.00	27.00	35.00	51.50	79.21
AU05	45	40.00	48.08	54.46	59.00	67.00
RO01	50	7.98	15.90	24.50	40.25	70.00
RO02	40	6.69	11.50	35.35	57.73	76.68
PA01	50	3.90	9.11	22.52	30.93	75.00

Very Fine Sand (0.1 - 0.05 mm)

		Quantiles				
Site	*n*	**Min**	**25%**	**Med**	**75%**	**Max**
BO01	45	0.00	0.96	1.73	3.09	8.00
BO02	50	0.00	0.35	0.74	1.48	31.00
AU01	50	0.82	1.80	2.41	6.57	14.66
AU02	50	0.75	1.74	2.13	2.78	3.80
AU03	40	2.74	3.76	6.52	40.75	74.00
AU04	45	14.00	46.27	60.00	69.00	78.00
AU05	45	0.00	7.50	18.00	25.37	48.08
RO01	50	0.00	2.00	4.00	10.25	30.00
RO02	40	0.85	1.53	3.27	7.91	18.06
PA01	50	0.00	0.96	2.01	4.89	42.00

Table C.3. Bulk density (ρ_{rb}, Mg m^{-3}) of the weathered rocks studied in Chapter 6.

BO01

RockID	ρ_{rb}
a	2.46
b	2.44
c	2.57
d	2.47
e	2.45
f	2.22
g	1.96
h	2.61
i	2.48

BO02

RockID	ρ_{rb}
a	2.49
b	2.54
c	2.49
d	2.57
e	2.32
f	2.57
g	2.53
h	2.52
i	2.49
j	2.57

AU01

RockID	ρ_{rb}
a	2.37
b	2.23
c	2.37
d	2.37
e	2.25
f	2.33
g	2.09
h	2.11
i	2.51
j	1.93

AU02

RockID	ρ_{rb}
a	2.27
b	2.32
c	2.42
d	2.32
e	2.37
f	2.37
g	2.31
h	2.12
i	2.27
j	2.34

AU03

RockID	ρ_{rb}
a	2.54
b	2.37
c	2.27
d	2.22
e	2.18
f	2.03
g	2.02
h	2.19

AU04

RockID	ρ_{rb}
a	2.31
b	2.45
c	1.97
d	2.20
e	2.28
f	2.14
g	2.29
h	2.32
i	2.26

AU05

RockID	ρ_{rb}
a	2.35
b	2.31
c	2.04
d	2.43
e	2.50
f	2.20
g	2.13
h	2.13
i	2.41

RO01

RockID	ρ_{rb}
a	2.40
b	2.50
c	2.53
d	2.29
e	2.45
f	2.35
g	2.38
h	2.46
i	2.33
j	2.28

RO02

RockID	ρ_{rb}
a	2.37
b	1.72
c	2.51
d	2.41
e	2.29
f	1.94
g	2.04
h	2.05

PA01

RockID	ρ_{rb}
a	2.26
b	2.41
c	2.53
d	2.32
e	2.48
f	2.49
g	2.35
h	2.51
i	2.43
j	2.76

Table C.4. Actual Fe_r from the weathered rocks used for the analysis of variance.

Site BO01		Site BO02		Site AU01	
RockID	%Fe	RockID	%Fe	RockID	%Fe
a	0.101	a	0.044	a	0.084
a	0.121	a	0.038	a	0.098
a	0.105	a	0.050	a	0.085
a	0.178	a	0.070	a	0.068
a	0.137	a	0.067	a	0.080
b	0.075	b	0.142	b	0.159
b	0.076	b	0.118	b	0.156
b	0.075	b	0.083	b	0.089
b	0.076	b	0.129	b	0.185
b	0.077	b	0.150	b	0.128
c	0.031	c	0.062	c	0.250
c	0.032	c	0.099	c	0.218
c	0.030	c	0.101	c	0.269
c	0.036	c	0.091	c	0.198
c	0.039	c	0.111	c	0.222
d	0.095	d	0.051	d	0.141
d	0.116	d	0.055	d	0.196
d	0.100	d	0.051	d	0.138
d	0.104	d	0.064	d	0.151
d	0.100	d	0.066	d	0.243
e	0.180	e	0.143	e	0.197
e	0.183	e	0.153	e	0.228
e	0.159	e	0.144	e	0.265
e	0.162	e	0.164	e	0.303
e	0.198	e	0.205	e	0.289
f	0.150	f	0.145	f	0.214
f	0.128	f	0.136	f	0.210
f	0.185	f	0.182	f	0.135
f	0.204	f	0.002	f	0.193
f	0.232	f	0.206	f	0.243
g	0.805	g	0.103	g	0.950
g	0.547	g	0.105	g	0.668
g	0.522	g	0.095	g	0.429
g	0.560	g	0.091	g	0.590
g	0.519	g	0.137	g	0.350

Table C.4. (cont.) Actual Fe_r from the weathered rocks used for the analysis of variance.

Site BO01		Site BO02		Site AU01	
RockID	%Fe	RockID	%Fe	RockID	%Fe
h	0.066	h	0.078	h	0.253
h	0.001	h	0.074	h	0.428
h	0.051	h	0.086	h	0.247
h	0.081	h	0.073	h	0.408
h	0.070	h	0.111	h	0.416
i	0.053	i	0.103	i	0.092
i	0.055	i	0.107	i	0.099
i	0.045	i	0.109	i	0.104
i	0.041	i	0.103	i	0.114
i	0.054	i	0.113	i	0.109
		j	0.122	j	0.765
		j	0.114	j	0.829
		j	0.116	j	0.890
		j	0.124	j	0.879
		j	0.138	j	0.700

Site AU02		Site AU03		Site AU04	
RockID	%Fe	RockID	%Fe	RockID	%Fe
a	2.249	a	0.060	a	0.480
a	1.148	a	0.051	a	0.451
a	0.969	a	0.059	a	0.446
a	1.754	a	0.055	a	0.462
a	0.748	a	0.059	a	0.439
b	0.115	b	0.160	b	0.497
b	0.099	b	0.195	b	0.553
b	0.185	b	0.171	b	0.507
b	0.085	b	0.205	b	0.508
b	0.126	b	0.202	b	0.506
c	0.146	c	0.360	c	0.365
c	0.129	c	0.405	c	0.238
c	0.164	c	0.453	c	0.249
c	0.212	c	0.338	c	0.264
c	0.181	c	0.250	c	0.251

Table C.4. (cont.) Actual Fe_r from the weathered rocks used for the analysis of variance.

Site AU02		Site AU03		Site AU04	
RockID	**%Fe**	**RockID**	**%Fe**	**RockID**	**%Fe**
d	0.132	d	0.593	d	0.424
d	0.117	d	0.373	d	0.436
d	0.122	d	0.589	d	0.511
d	0.151	d	0.522	d	0.425
d	0.125	d	0.568	d	0.433
e	0.148	e	0.282	e	0.449
e	0.143	e	0.240	e	0.352
e	0.096	e	0.250	e	0.328
e	0.159	e	0.322	e	0.325
e	0.135	e	0.256	e	0.369
f	0.354	f	0.575	f	0.486
f	0.229	f	0.421	f	0.207
f	0.168	f	0.557	f	0.324
f	0.215	f	0.542	f	0.309
f	0.165	f	0.496	f	0.490
g	0.542	g	0.224	g	0.207
g	0.446	g	0.211	g	0.208
g	0.591	g	0.212	g	0.228
g	0.509	g	0.195	g	0.213
g	0.521	g	0.296	g	0.244
h	0.569	h	0.088	h	0.210
h	0.452	h	0.082	h	0.233
h	0.205	h	0.080	h	0.229
h	0.186	h	0.093	h	0.189
h	0.691	h	0.080	h	0.258
i	0.557			i	0.514
i	0.512			i	0.476
i	0.568			i	0.456
i	0.478			i	0.599
i	0.487			i	0.531
j	0.257				
j	0.197				
j	0.179				
j	0.169				
j	0.264				

Table C.4. (cont.) Actual Fe_r from the weathered rocks used for the analysis of variance.

Site AU05		Site RO01		Site RO02	
RockID	%Fe	RockID	%Fe	RockID	%Fe
a	0.237	a	0.200	a	0.067
a	0.271	a	0.215	a	0.084
a	0.273	a	0.193	a	0.094
a	0.178	a	0.186	a	0.095
a	0.197	a	0.185	a	0.089
b	0.206	b	0.058	b	0.929
b	0.212	b	0.050	b	0.976
b	0.199	b	0.062	b	1.243
b	0.188	b	0.051	b	1.135
b	0.202	b	0.061	b	1.449
c	0.120	c	0.049	c	0.049
c	0.107	c	0.047	c	0.031
c	0.125	c	0.050	c	0.030
c	0.130	c	0.053	c	0.031
c	0.116	c	0.054	c	0.046
d	0.315	d	0.188	d	0.111
d	0.339	d	0.190	d	0.103
d	0.322	d	0.219	d	0.078
d	0.308	d	0.189	d	0.091
d	0.499	d	0.239	d	0.106
e	0.132	e	0.069	e	0.106
e	0.127	e	0.065	e	0.104
e	0.157	e	0.070	e	0.126
e	0.160	e	0.075	e	0.104
e	0.119	e	0.064	e	0.127
f	0.616	f	0.132	f	0.214
f	0.505	f	0.326	f	0.219
f	0.700	f	0.121	f	0.159
f	0.322	f	0.104	f	0.223
f	0.882	f	0.077	f	0.231
g	0.152	g	0.057	g	0.557
g	0.154	g	0.053	g	0.465
g	0.138	g	0.064	g	0.656
g	0.158	g	0.064	g	0.414
g	0.155	g	0.111	g	0.499

Table C.4. (cont.) Actual Fe_r from the weathered rocks used for the analysis of variance.

Site AU05		Site RO01		Site RO02	
RockID	**%Fe**	**RockID**	**%Fe**	**RockID**	**%Fe**
h	0.300	h	0.128	h	0.291
h	0.276	h	0.136	h	0.206
h	0.297	h	0.137	h	0.269
h	0.256	h	0.139	h	0.241
h	0.282	h	0.132	h	0.244
i	0.209	i	0.016		
i	0.288	i	0.018		
i	0.240	i	0.023		
i	0.285	i	0.028		
i	0.172	i	0.022		
		j	0.108		
		j	0.127		
		j	0.110		
		j	0.125		
		j	0.112		

Site PA01		Site PA01	
RockID	**%Fe**	**RockID**	**%Fe**
a	0.669	d	0.205
a	0.748	d	0.177
a	0.680	d	0.216
a	0.720	d	0.227
a	0.708	d	0.232
b	0.249	e	0.097
b	0.204	e	0.125
b	0.210	e	0.105
b	0.234	e	0.106
b	0.243	e	0.123
c	0.085	f	0.131
c	0.060	f	0.136
c	0.056	f	0.154
c	0.080	f	0.147
c	0.061	f	0.135

Table C.4. (cont.) Actual Fe_r from the weathered rocks used for the analysis of variance.

Site PA01

RockID	%Fe
g	0.218
g	0.202
g	0.203
g	0.213
g	0.189
h	0.048
h	0.052
h	0.075
h	0.077
h	0.074
i	0.052
i	0.065
i	0.052
i	0.058
i	0.046
j	0.139
j	0.166
j	0.119
j	0.121
j	0.151

Vita

Charles Morgan Ogg was born on July 22, 1962 in Hopkinsville, Kentucky. He obtained both primary and secondary education in the Christian County school system. He graduated from Christian County High School in May 1980.

Charlie completed a Bachelor of Science in Agriculture degree at Murray State University, Murray, Kentucky in December 1984. He earned a Master of Science in Agronomy, with an emphasis in Soil Genesis and Classification, from Clemson University, Clemson, South Carolina in August 1988.

Charlie began his doctoral program at Virginia Polytechnic Institute and State University, Blacksburg, Virginia in August 1988. He began work as a Soil Scientist with the U.S.D.A. Soil Conservation Service (now Natural Resources Conservation Service) in June 1993 at Darlington, South Carolina. He is currently mapping soils with the Darlington County Soil Survey Party.

Charlie is a member of Sigma Xi scientific research society, Gamma Sigma Delta honor society of agriculture, Phi Sigma Society, Alpha Zeta agricultural honorary fraternity, and Soil Science Society of America. He is a licensed member of the Registered Professional Soil Classifiers of the State of South Carolina. He is married to the former Catherine Jamieson, and they have one daughter, Mary Hannah.

Charles M. Ogg