The Geological Society of America
Field Guide 16
2010

Soils, geomorphology, landscape evolution, and land use in the Virginia Piedmont and Blue Ridge

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ABSTRACT

The object of this field trip is to examine the geology, landforms, soils, and land use in the eastern Blue Ridge and western Piedmont geologic provinces in Orange County in central Virginia. A complex mix of igneous, sedimentary, and metamorphic bedrocks, ranging in age from Mesoproterozoic to Triassic (possibly some Jurassic) underlie the area. Soils are equally varied with a total of 62 series mapped in Orange County alone. The area being relatively stable tectonically, landforms generally reflect the resistance to weathering of the bedrock. Area landforms range from a low ridge over Catoctin greenstone to a gently rolling Triassic basin. Soils examined on the trip represent three orders: Ultisols, Alfisols, and Inceptisols. Residual soils clearly reflect the compositions of the parent rocks and saprolites are common. Map patterns of forested versus nonforested lands bear a striking resemblance to the distribution patterns of the different soil and bedrock types. Our work has shown that the vast majority of the land in central Virginia, even that forested today, shows evidence of past clearing and cultivation. However, the harsh demands of growing tobacco wore out the less fertile and more erodible soils by the mid-nineteenth century resulting in their abandonment and the subsequent regeneration of the vast tracts of hardwood forests we see today. Only the most productive soils remain in agriculture.

REGIONAL GEOLOGY

Virginia can be divided into five geologic provinces (Fig. 1). Our trip will include portions of the Blue Ridge and Piedmont provinces in central Virginia.

Blue Ridge Province

The oldest rocks in Virginia are found in the Blue Ridge Province, a complex basement massif. The core of the massif is composed of Mesoproterozoic crystalline rocks, some >1 Gy (Southworth et al., 2009). During the Grenvillian orogeny, granitic intrusions and associated metamorphism affected the core. Moving outward from the core, rocks of Neoproterozoic age form the flanks of the massif. Here a series of sedimentary rocks derived from the weathering of the core—ranging from alluvial conglomerates to marine shales—were deposited along with volcanic ash. These rocks make up the Swift Run Formation on the west side and the Lynchburg Group on the east side of the eroded core (Fig. 2). Subsequently, basalt flows associated with

Sherwood, W.C., Hartshorn, T., and Eaton, L.S., 2010, Soils, geomorphology, landscape evolution, and land use in the Virginia Piedmont and Blue Ridge, *in* Fleeger, G.M., and Whitmeyer, S.J., eds., The Mid-Atlantic Shore to the Appalachian Highlands: Field Trip Guidebook for the 2010 Joint Meeting of the Northeastern and Southeastern GSA Sections: Geological Society of America Field Guide 16, p. 31–50, doi: 10.1130/2010.0016(02). For permission to copy, contact editing@geosociety.org. ©2010 The Geological Society of America. All rights reserved.

the opening of the proto–Atlantic Ocean flowed out over the sedimentary units. Later, these basalts were metamorphosed to form the greenstones of the Catoctin Formation.

Following the rifting and associated basalt flows, clastic sediments associated with the proto–Atlantic Ocean margin covered portions of the flows. These make up the Chilhowie Group, which occupy the western flank of the Blue Ridge Mountains and the Candler Formation east of Southwest Mountain. Metamorphism that altered the Catoctin basalts to greenstone affected the siliceous clastic rocks producing mainly quartzites, phyllites, and schists (Rader and Evans, 1993).

Topographically, the Blue Ridge Mountains with elevations of up to 1200 m (4000 ft) dominate the western portion of the Blue Ridge Province. These mountains are composed of a mix of basement rocks, Catoctin greenstone, and Chilhowie metasediments. Today, the Shenandoah National Park occupies much of the Blue Ridge Mountain crest in northwestern Virginia. Moving eastward from the Blue Ridge Mountains toward the core of the Blue Ridge Province, a number of monadnocks or inselbergs are evident in the western portion of the province. Farther east, the land is gently rolling until it reaches a low ridge composed of Catoctin greenstone that forms the eastern edge of the Blue Ridge Province.

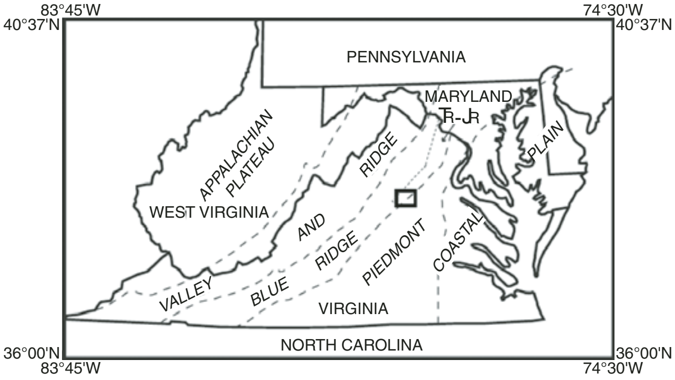

Figure 1. Generalized geologic provinces (Appalachian Plateau, Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain) of Mid-Atlantic States. Inset rectangle shows location of this field trip.

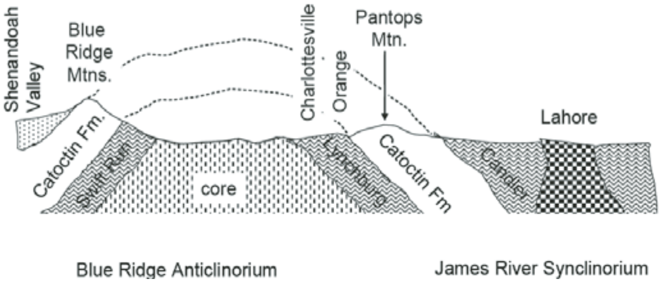

Figure 2. Simplified cross section of the Blue Ridge anticlinorium (modified from Sherwood and Eaton, 1993, p. 57).

Structurally, the Blue Ridge has been variously described as an anticlinorium with the flanks held up by the relatively resistant Catoctin greenstone and the oldest formations in the center (Fig. 2).

Other interpretations involve a series of thrust faults to account for the surface pattern of rock types (Fig. 3). It is generally agreed that the rocks of the Blue Ridge Province are allochthonous, having been thrust northwestward over the Paleozoic rocks of the Valley and Ridge.

Piedmont Province

The Piedmont Geologic Province borders the Blue Ridge Province to the southeast. Today's complex bedrock geology reflects an equally complex geologic past. Basically, the rocks of the Virginia Piedmont are composed of a series of allochthonous terranes that have accreted to the North American plate by the closing of the ancient proto–Atlantic Ocean. Figure 4 is a generalized geologic map showing the extent of the individual terranes.

The western Piedmont terrane is composed of early Paleozoic igneous and metasedimentary rocks associated with the suture zone with the Blue Ridge Province. Rocks of the western Piedmont are thought to be composed of fragments of the divergent continental margin created during the opening of the proto-Atlantic and later metamorphosed to greenschist and amphibolite facies (Rankin, 1975).

To the southeast of the western Piedmont terrane lies the Chopawamsic volcanic belt (Fig. 4). This belt is composed of a series of volcanic and plutonic rocks that appear to have originated as an island arc offshore in the proto–Atlantic Ocean (Pavlides, 1980). The Lahore pluton (Figs. 2 and 5; Pavlides, 1982) at Stop 6 is one of the several mafic intrusions occurring within the Chopawamsic Belt in Virginia. Converging forces caused the arc to collide with the North American plate. Both the western Piedmont and Chopawamsic volcanic terranes have been intruded by late Paleozoic granites, and undergone several episodes of deformation and metamorphism, producing an exceedingly complex geology.

Today the Piedmont is characterized by a gently rolling landscape incised by numerous streams and a few large rivers. Deep weathering and saprolites are common, and bedrock outcrops are scarce, occurring mainly in the beds and banks of streams.

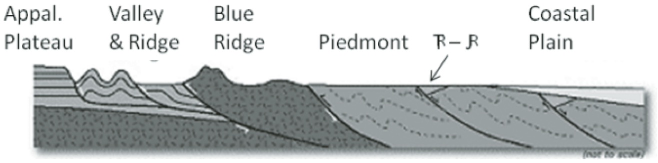

Figure 3. Cross section of the regional geological (modified from Bailey, 2006).

Culpeper Mesozoic Basin

Subsequent to the closing of the proto-Atlantic, tensional stresses began to affect Earth's crust in what is now eastern North America. During the Triassic, rifting at several points created a series of grabens and half-grabens. The largest of these features in Virginia is the Culpeper Basin. The Culpeper Basin extends from just south of Orange County northward into Maryland, a distance of more than 148 km (Lindholm, 1979). The rocks of the basin have traditionally been associated with the Triassic Newark Group (Fig. 5). For many years the Culpeper and related basins were referred to as Triassic basins. Pollen studies (Cornet, 1977), however, determined the rocks to range from Upper Triassic to Lower Jurassic in age.

As rifting occurred, sediment eroding from the adjoining highlands was rapidly transported into the basins. Thick beds of sand, silt, and clay were deposited throughout the basins, and coarse conglomerates formed near the border faults. Red beds deposited in shallow fresh water and on broad alluvial plains are the most common rock types found in the Culpeper Basin (Lindholm, 1979). In general, the sedimentary sequence exhibits coarse clastic rocks at the base fining upward to the Bull Run shale.

In Virginia, most of the conglomerates are found contiguous to the normal faults bordering the west side of the basin. However, near the south end of the basin, north of Barboursville, Lindholm (1979) reported conglomerates to be more extensive along the southeast side. One of the authors (Sherwood) also described well-developed conglomerate along the southeast border of the basin north of the Rappahannock River in Fauquier County.

Lithologies of the clasts making up the conglomerates change along the faults reflecting the source rocks being weathered and transported into the basin. Examination of the western border conglomerate, ~10 km north of our Stop 2 at Barboursville, found it to contain a variety of clasts, including cream-colored shale, vein quartz, phyllite, greenstone, and granite (Sherwood, 2003). In general, the beds within the basin dip to the west indicating periodic or subsequent movement along the

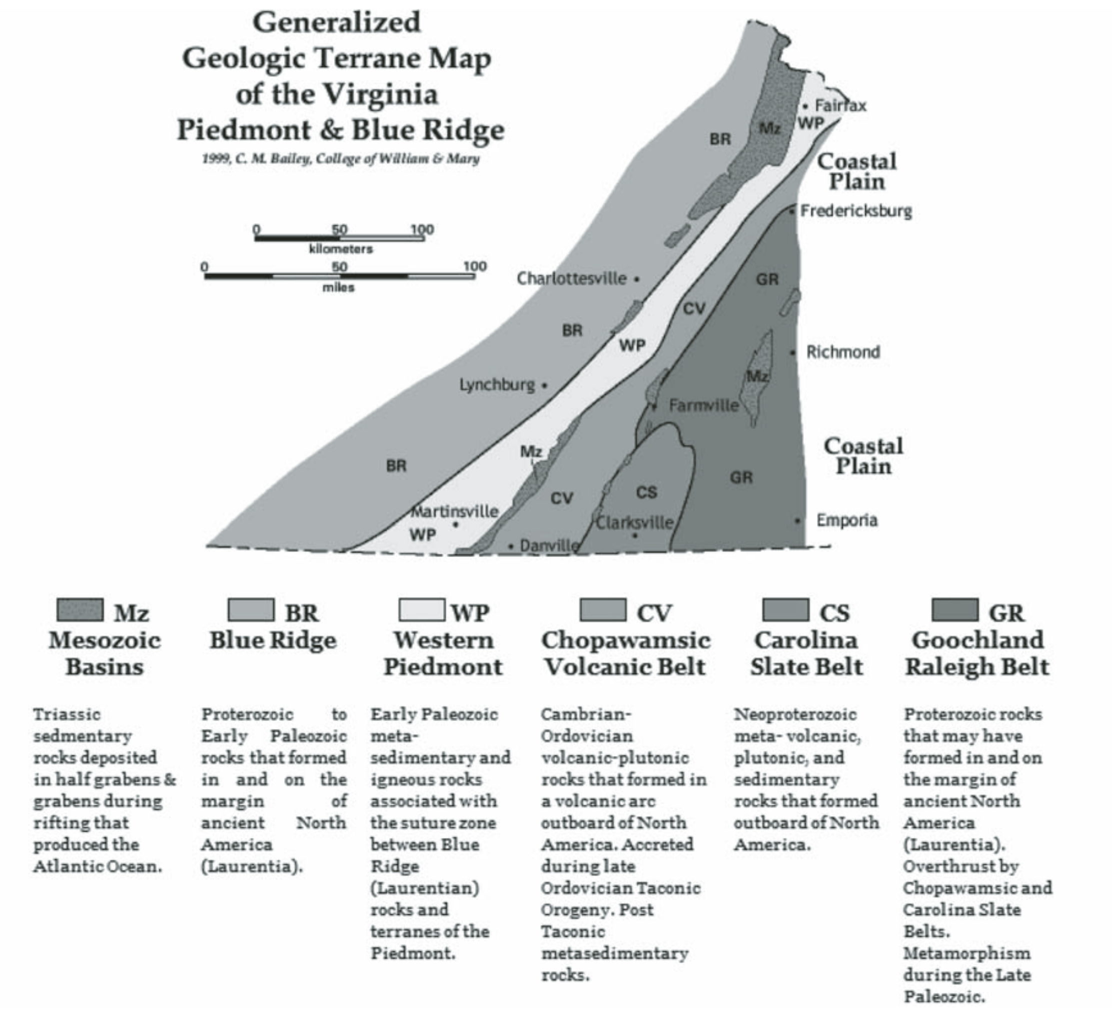

Figure 4. Terrane map of the Piedmont and Blue Ridge provinces, Virginia (modified from Bailey, 2006).

western faulted edge. Early dinosaur tracks have been observed at several exposures within the basin (Roberts, 1928).

Farther north across the Rapidan River, the Culpeper Basin contains numerous mafic igneous intrusions and several basaltic lava flows. The mafic intrusions are predominately diabase or "trap rock." These intrusions serve as the major sources of crushed stone in northern Virginia. In some cases, contact metamorphism caused by the intrusions result in zones of hornfels extending as much as hundreds of meters into the surrounding sedimentary rocks.

REGIONAL SOILS

The "diversity and complexity of the geology in central Virginia are accompanied by an equally diverse and complex mantle of residual soils" (Plaster and Sherwood, 1971, p. 2813). On today's field trip, we will focus on the uppermost two meters of the regolith. This depth will allow observations of the critical A and B horizons or solum on which modern soil classification is based. As we know, soils reflect the variable influences of soil-forming state factors (Jenny, 1941), including climate, organisms, relief, parent material, and time. A major focus of this field trip will be on parent material and time (age of the soils). Pavich (1986) framed this field trip well, when he wrote "… how climate affects the rock weathering is complexly dependent upon soil and rock structure."

In the Virginia Blue Ridge and Piedmont, soil properties show great fidelity to the underlying lithology. The most common soil order in the Piedmont is the Ultisol (Buol, 1973; Fig. 6), highly weathered soils with low base saturation. Base saturation is a measurement of the percentage of a soil's cation exchange capacity (negatively charged edges) that is occupied by the base cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}. Ultisols predominate over metasedimentary rocks and felsic intrusions. A second well-developed soil order, the Alfisols, consists of intermediately weathered soils with high base saturation; Alfisols are typically mapped over mafic and ultra-mafic parent materials, such as gabbro and diabase (Genthner, 1990), as will be seen at Stop 6. Other common orders mapped in this area are Inceptisols and Entisols; these are both relatively unweathered soils showing little or no morphologic profile differentiation, and are commonly mapped on steep slopes, highly dissected uplands, or floodplains.

While the current landscape appears stable, and the soil properties we observe and use to classify the soils (texture, color, quantity, and types of clays) are consistent with long residence times, portions of the Piedmont landscape may have been less

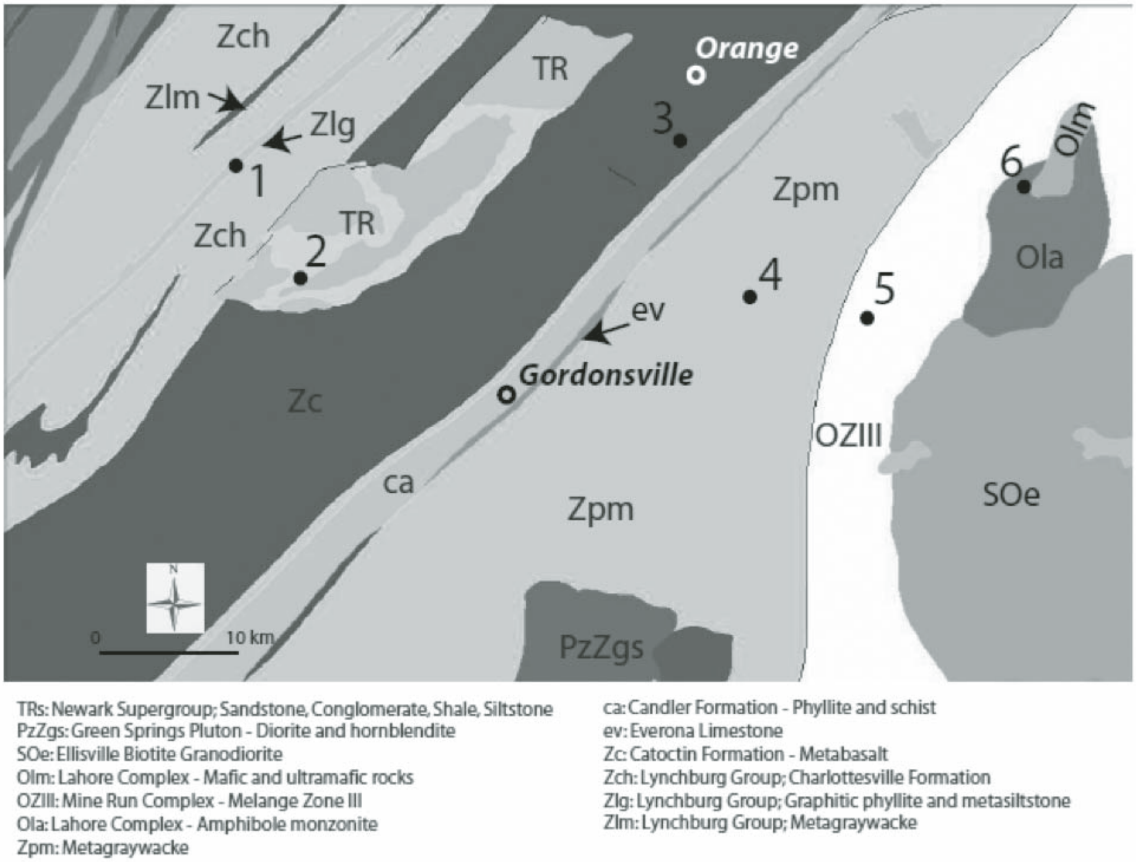

Figure 5. Geological units in the field trip area, with individual stops (1–6) indicated (modified from Dicken et al., 2008).

stable in the past. For example, ~60% of soil parent material along a 22-km pipeline trench in Culpeper and Orange counties was interpreted to be colluvium, while 10% was alluvium (Whittecar, 1985). However, the regional fidelity between lithology and soil properties (and land use), implies large areas of the Piedmont landscape are residual soils, formed in place.

Soil Properties and Nomenclature

On this field trip, a number of soil properties will be highlighted, including Munsell colors, textures, B horizon thicknesses, clay mineralogy, as well as base saturation.

As a quick guide to the overarching importance of soil texture, Table 1 shows a number of properties associated with five of the 12 polygons that are commonly found on texture triangles, calculated using an online hydraulic properties calculator (http://www.pedosphere.com/resources/texture/triangle_us.cfm?192,220).

Most of the field trip sites we visit today exhibit very old soils. As Pavich et al. (1989, p. 48) have noted, Piedmont soils "show relatively the same amount of development" as post-Miocene soils (Markewich et al., 1987; Owens et al., 1983). For example, quartz dissolves and illite transforms to vermiculite in soils >100 k.y., and >1 m thick sola can be 1–2 Ma (Markewich et al., 1987). While a comparison with Coastal Plain soils suggests Piedmont soils are "no older than Pliocene (5 Ma) and probably no older than Pleistocene (2 Ma)," a number of studies suggest that specific geomorphic features such as the oldest James River terraces are 10 Ma or older (e.g., Howard et al., 1996). Residence times are to some extent a reflection of the balance between soil

TABLE 1. SELECT HYDRAULIC PROPERTIES ASSOCIATED WITH A SUBSET OF SOIL TEXTURAL CLASSES

Textural polygon	Midpoint % clay (<2 µm)	Midpoint % silt (2–50 µm)	Typical bulk density (1.32 g cm^{-3})	Saturated hydraulic conductivity (cm h^{-1})	Saturated volumetric water content (cm^3 water cm^{-3} soil)	Field capacity (cm^3 water cm^{-3} soil)	Wilting point (cm^3 water cm^{-3} soil)	Plant available water (cm^3 water cm^{-3} soil)
Clay loam	33	34	1.32	0.31	0.50	0.32	0.18	0.14
Silt loam	12	66	1.44	2.37	0.46	0.28	0.10	0.18
Sandy loam	14	23	1.51	1.60	0.43	0.21	0.10	0.11
Loamy sand	5	11	1.68	6.40	0.37	0.15	0.06	0.08
Sandy clay	43	7	1.31	0.13	0.50	0.33	0.23	0.10

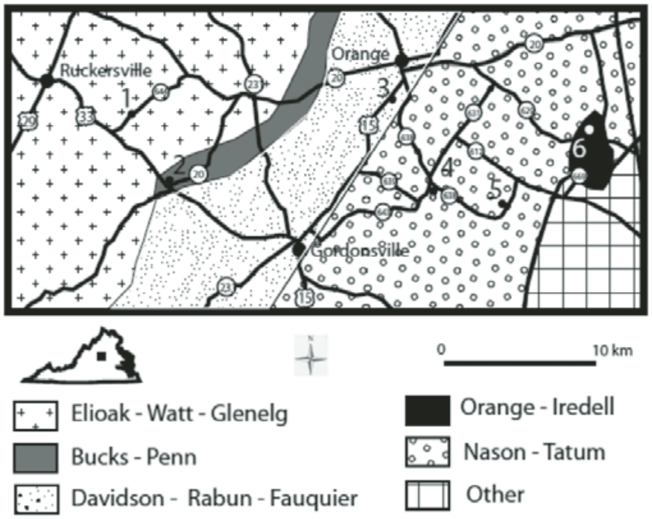

Figure 6. Simplified soils map of the field trip area, showing broad soil series zones: Stop 1 will feature an example of a soil mapped as the Watt series (Inceptisol soil order), Stop 2 the Bucks-Penn series (Alfisol, Ultisol), Stop 3 the Davidson series (Ultisol), Stop 4 the Nason-Tatum series (Ultisols), Stop 5 the Wehadkee series (Inceptisol), and Stop 6 the Iredell series (Alfisol).

production rates and total denudation (physical erosion + chemical weathering) rates. However, the quantification of these rates is not by any means straightforward.

Saprolite

The first part of this field guide described the geological setting for the soils we will see today. In addition to the underlying bedrock, however, this part of Virginia is underlain by meters of saprolite (Pavich, 1985; Genthner, 1990), in some cases exceeding 50 m (Pavich et al., 1989). Importantly, however, this saprolite thickness shows great spatial variability (Fig. 7), with greater thicknesses reported over felsic lithologies and thinner saprolites over mafic lithologies, such as the amphibole monzonite that underlies our last Stop (Stop 6: Iredell soil series).

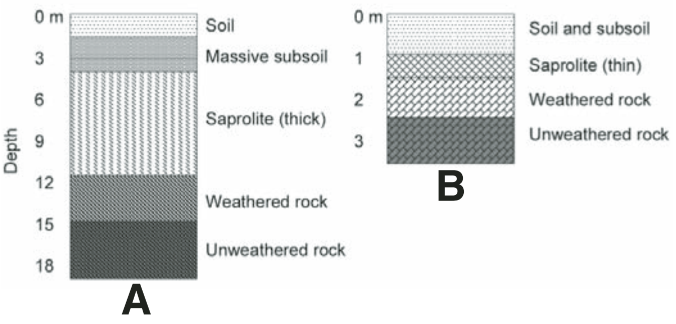

Figure 7. Variation in regolith thickness developed over more felsic rock such as foliated metasedimentary and granitic rocks (left, regolith A; ~19 m) and more mafic rock such as diabase (right, regolith B; ~4 m) in northern Virginia (modified from Pavich et al., 1989, p. 5). Note the shift in vertical scale between regolith A and B.

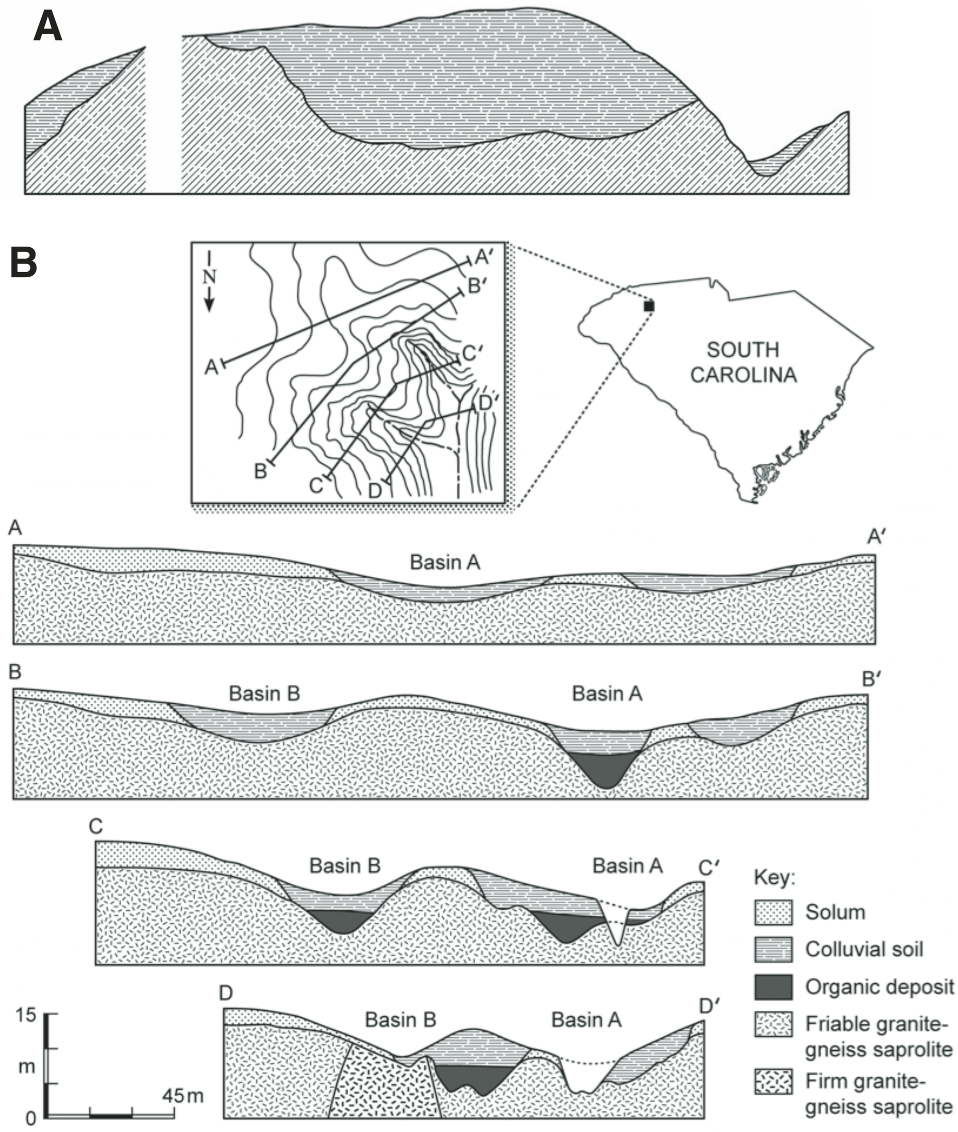

Figure 8 (*continued on following page*). Piedmont regolith cross sections: (A) Catawba Valley, North Carolina (modified from Kerr, 1881, p. 347), (B) northern South Carolina (modified from Eargle, 1940, p. 337), (C) Fairfax County, Virginia (modified from Pavich et al., 1989, p. 44).

The extreme thickness of the regolith in the southern Piedmont has been a matter of historical interest to both geologists and soil scientists alike. W.C. Kerr (1881) remarked: "To a foreign geologist, entering the Middle and South Atlantic States for the first time, a hundred miles or more from the coast, the most striking and novel feature of the geology is the great deal of earth which almost everywhere mantles and conceals the rocks" (p. 345). Kerr provided some of the earliest cross sections of Piedmont soils (Fig. 8A), and called attention to what he termed "three kinds of earthy layers, each having a different structure and origin" (p. 345). Roughly translated, these are the soils, saprolite, and unweathered rock. Kerr used these strata, and their relationships with the geomorphic and soil surface, to suggest that "the present topography of the surface is the result of *extensive erosion, subsequent to the accumulation of these deposits*" (p. 347, italics his). He alludes to inverted topography, and also goes on to invoke "frost drift" as the mechanism most clearly responsible for the locations of colluvial material

Eargle (1940, 1977) further explored the question of the origin of the soil mantle. He suggested that lateral soil transport was responsible for what he termed "episodic accumulation." This included burial of organic-rich paleosols, not just in hollows, but occasionally on topographically high points (Fig. 8B). Some variations within individual soil types were attributed to "the partial assortment of materials during soil migration" (Eargle, 1940, p. 337–338), a description similar to that used by Milne ("differential reassortment of mass"; 1935a, 1935b, 1936) to describe the genesis of African catenas. These translocation concepts have been expanded upon (e.g., Morison, 1948; Sommer et al., 2000) to argue that, just as eluvial and illuvial processes (such as the transfers of clays) can be invoked to explain vertical differentiation of soil profiles, so too can these processes be invoked to explain lateral differentiation of catenas. More recently, Pavich et al. (1989, Fig. 8C) have observed similar discrepancies between the upper boundaries of soils and saprolite.

These observations by Kerr and Eargle, and those of Pavich et al. (1989; Fig. 6C), together point to a fundamental topographic mismatch between the top of the regolith and the top of the saprolite. This mismatch suggests residual interpretations of the origin of Piedmont soils might be incomplete, and are

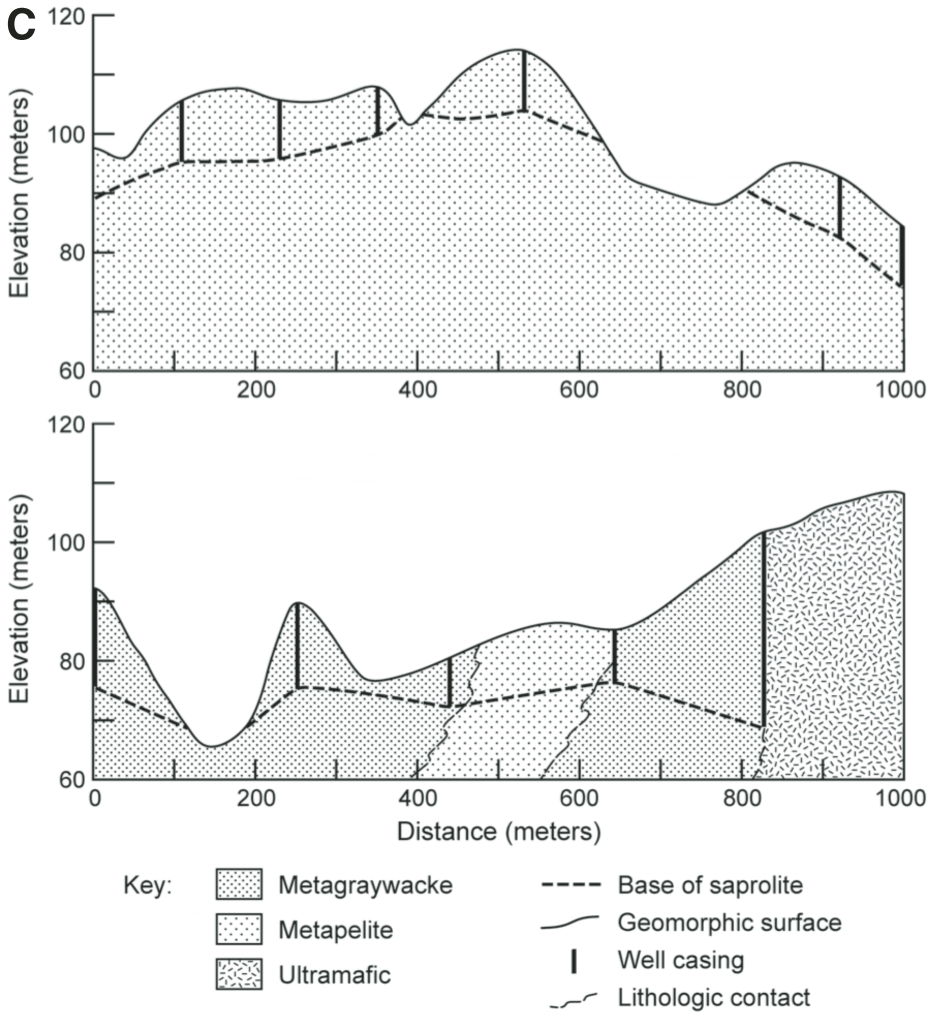

Figure 8 (*continued*).

consistent with the ideas that parent material has been translocated and that topographic inversion has occurred in many areas of the Piedmont.

Systematic differences in saprolite thickness across the Piedmont can be traced to the underlying lithologies, because "despite the mass loss due to dissolution of less resistant minerals (such as plagioclase and biotite), the quartz and muscovite remain relatively unaltered, and grain-to-grain contacts of muscovite retain structural integrity" (Pavich et al., 1989). Thus, the prolonged and intense chemical weathering of felsic materials leads to the formation of a quartz- and/or muscovite-rich skeleton that allows for continued solutional ("plasma" sensu Pédro, 1983) losses, leading to great saprolite thicknesses. Weathering of mafic materials, by contrast, produces collapse of the profile, yielding much thinner saprolites.

In a study of the Maryland Piedmont, Costa and Cleaves (1984) suggested saprolite thickness reflected parent material mineralogy and degree of metamorphism. They also suggested the mineralogy of the saprolite reflected landscape setting: kaolinite and quartz dominated drier, upland portions of catenas, whereas kaolinite, quartz, and smectites dominated wetter, lower portions of catenas.

The Piedmont, while upstream of a passive margin, is not tectonically quiescent. Tertiary marine formations such as the Miocene Calvert Formation now lie as much as 150 m above sea level, implying uplift of 20 m/m.y. (Darton, 1951). Furthermore, fall line compressional faults have thrust crystalline rocks over younger sedimentary rocks, and these faults have been active during the Cenozoic (Mixon and Newell, 1977; Prowell, 1976). Long-term lowering of the Potomac Valley (~15 m/ m.y.) through the Piedmont has been suggested to reflect a combination of "slow flexural uplift of the Atlantic margin from offshore sediment unloading, isostatic response to denudation, and protracted late Cenozoic sea-level fall" (Reusser et al., 2004, p. 499). Genthner (1990) has suggested that the eastern Blue Ridge and Piedmont's rolling hillslopes led Hack (1960) and Pavich (1986) to believe they represent an equilibrium landscape: erosion rates appear to be matching long, slow uplift rates.

FIELD TRIP ITINERARY

This field guide will emphasize U.S. soil taxonomic classifications instead of, for example, World Reference Base classifications (the WRB is successor to the Food and Agriculture Organization's classification system), because the U.S. system names have, in our opinion, a higher information density. And it is worth remembering Lewis Carroll's (1871) thinly veiled explanation for why we classify soils:

> "What's the use of their having names," the Gnat said, "if they won't answer to them?"
>
> "No use to *them*," said Alice, "but it's useful to the people that name them, I suppose. If not, why do things have names at all?"

Introduction

Today's trip will cover portions of the eastern Blue Ridge and western Piedmont geologic provinces, and the Culpeper Mesozoic basin in Orange County, Virginia (Figs. 1 and 9). The object will be to examine relationships between bedrock geology, soils, and historic uses of the land.

Over the years, the authors have studied the historic patterns of land use and their relationships to the bedrock geology and soils of Virginia. Central Virginia presents an ideal outdoor laboratory for studies of this type because of the sharply juxtaposed and contrasting bedrock geology, and soils and the relatively long (human) historical context. The long residence times of the soils, in some cases >1 m.y., have allowed for the clear expression of normally nuanced climate, biotic, relief, and parent material effects on soil-landscape relationships. Finally, the general area remains relatively free of intensive urbanization so historic land use patterns largely reflect long-term agricultural and silvicultural land uses.

Figure 10 shows the land use patterns that have developed over the past four hundred years. Basically, areas cleared of forest cover are assumed to be underlain by soils worthy of the effort involved in clearing and maintaining the land in nonforest

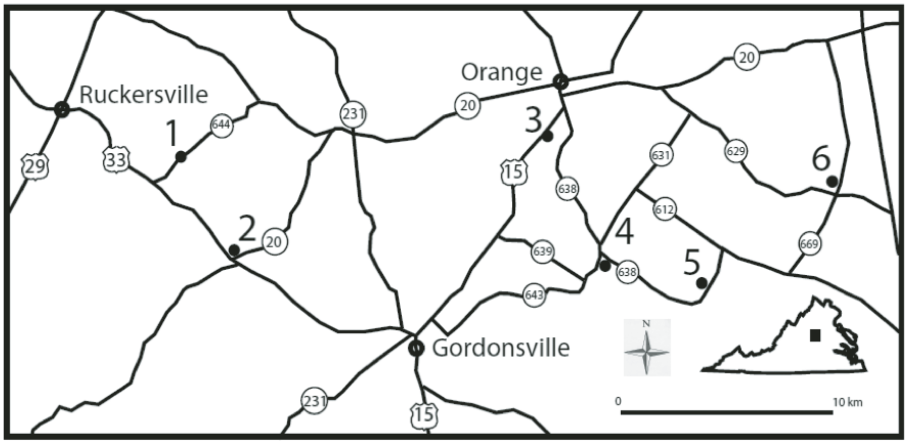

Figure 9. Road map of field trip area, with the six stops indicated.

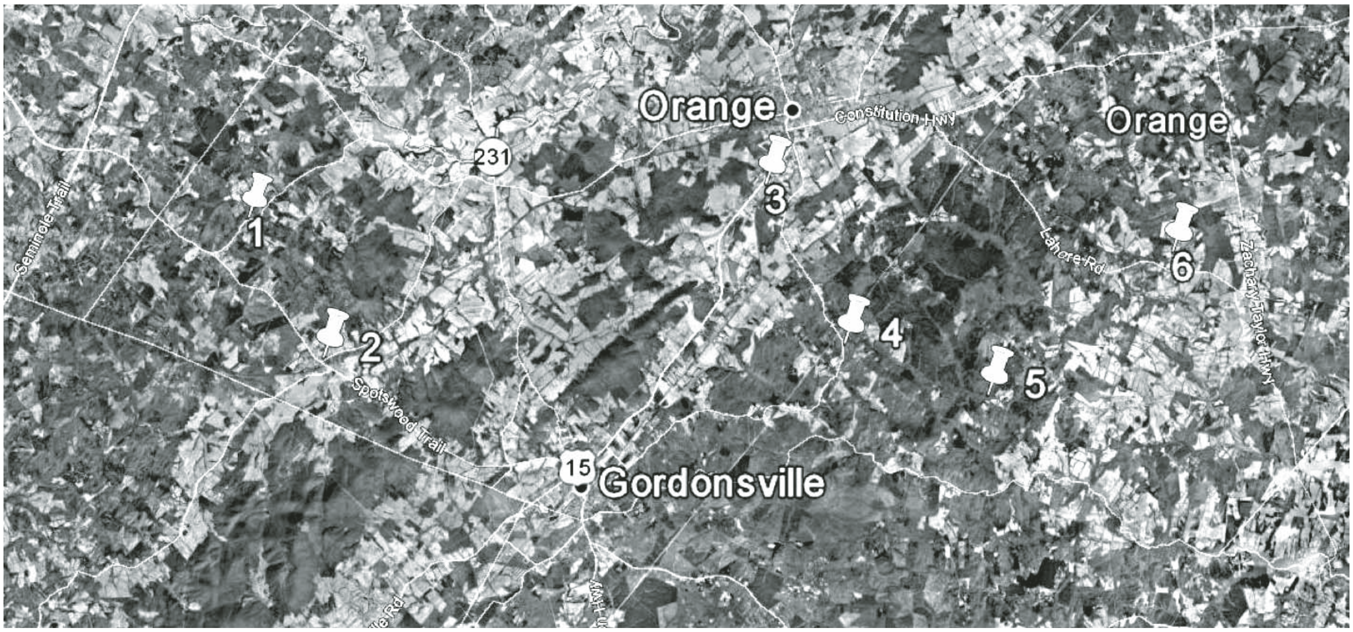

Figure 10. Satellite map showing land use in the vicinity of each of our stops.

(mainly agricultural) use. Forested areas, on the other hand, could either be underlain by soils with significant limitations for other uses or be the product of decades of afforestation following nineteenth and/or twentieth century clearing and abandonment. Having said this, we are acutely aware that modern views value forests for many different reasons. Consequently, in the future the old systems of land values may change, and future patterns of land use in this region may well change with them.

In a nutshell, Stops 3 and 4 are underlain by Ultisols, Stop 6 by Alfisols, and Stops 1 and 5 are graphite schist- and floodplain-associated Inceptisols, respectively; Stop 2 includes soils mapped as Ultisols (Bucks soil series) and Alfisols (Penn soil series) (Table 2).

Miles	
0.0	Ruckersville.
3.5	From Ruckersville proceed east on Rt. 33 to Eheart.
4.6	Turn left on Rt. 644, proceed to intersection with Rt. 657.

Stop 1. EHEART

Local Geology

Stop 1 is located over the Lynchburg Formation named for exposures of schist and gneiss near Lynchburg, Virginia by Jonas (1927). Rocks of the Lynchburg are Neoproterozoic in age, existing between the Grenville basement and the overlying Catoctin Formation (Fig. 4). The predominant rock types making up the Lynchburg in the vicinity of Stop 1 are biotite-muscovite schists and phyllites, interfingered with bands of graphite schist.

Stratigraphic treatment of the graphite-rich rocks at Stop 1 has differed among the various investigators over the years. Jonas (1927) referred to these rocks as the Johnson Mill member of the Lynchburg Formation. Nelson (1962) gives them formational status as the Johnson Mill Graphite Slate Formation. Allen (1963) refers to a graphite schist facies of the Lynchburg Formation.

While it is generally agreed that the schists and phyllites of the Lynchburg Formation are sedimentary in origin, the origin of the carbon concentrated in the graphite schist presents an

TABLE 2. SALIENT FEATURES OF THE SIX STOPS

Stop	Soil order	Parent rock	Soil series	Piedmont acres (000)	Orange County acres (%)	Notes
1	Inceptisol	Graphite schist	Watt	2.7	660 (0.3)	85% forested
2	Ultisol/Alfisol	Triassic siltstone	Bucks/Penn	65/367	3700 (1.7)/1800 (0.8)	Productive agricultural soil
3	Ultisol	Greenstone	Davidson	553	21,900 (10.0)	All-purpose soil
4	Ultisol/Ultisol	Schist and phyllite	Tatum/Nason	720/430	24,100 (11.0)/43,800 (20.0)	Highly erosive and acidic; ubiquitous
5	Inceptisol	Alluvium	Wehadkee	655	1300 (0.6)	Redoximorphic features
6	Alfisol	Amphibole monzonite	Iredell	231	440 (0.2)	Shrink-swell clays, high base saturation

Note: Orange County has an area of 875 km^2, or ~219,000 acres.

intriguing question. A search of the existing literature resulted in no evidence that this topic has been addressed in a systematic way. Rumors have circulated for many years to the effect that the rocks contained ~8% graphite and mining had been considered at one time.

Soils

Here we will observe a soil mapped as part of the *Watt* soil series, also formally known as ("afka") a loamy-skeletal, mixed, semiactive, mesic *Typic Dystrudept*, meaning (U.S. soil taxonomic classifications are read from right to left, and the formative elements of the *subgroup* are in italics).

Order→Inc*ept*isol (weakly developed, "infantile" soil)

Suborder→*Ud*ept (udic soil moisture regime: wetter than ustic [semiarid grasslands or savannas], drier than perudic [precipitation exceeds evapotranspiration in every month of the year])

Great group→*Dystr*udept (low base saturation)

Subgroup→*Typic* Dystrupdept (insufficiently distinguished [morphologically or chemically] to merit classification as another subgroup).

Watt (A) horizons are typically dark-gray (5Y 2/1), channery silt loams, dominated by graphitic schist fragments, and can be extremely acid with very low base saturation. Watt soils are commonly mapped over rocks with traces of sulfides, which results in very low pH values. Watt B horizons are thin, show an increase in rock fragments with depth, and bedrock is typically within 0.5–1 m of the surface. Because of the dark parent material, "in most places, the C horizon is darker colored than the solum" (Official Series Description, Natural Resources Conservation Service [NRCS]). The areal extent of Watt soils was derived with an online Soil Extent Mapping Tool (link [e.g., http://www.cei.psu.edu/soiltool/semtool.html?seriesname = WATT] at the official series description web site): Watt soils cover 2700 acres across the Piedmont, and 745 acres (0.3%) across Orange County.

The Watt soil we will examine is interfingered at a very fine spatial scale with the Glenelg soil series, afka fine-loamy, mixed, semiactive, mesic Typic Hapludults (Table 3). From the official Glenelg series description: "Depth to bedrock is 2–3 m or more. Rock fragments range from 0 to 35% throughout the solum and 5–55% in the C horizon. Fragments are mostly hard white quartz or schist and range from gravel or channers to stones in size. Stone content ranges from 0 to 5%. Mica content increases sharply in the lower part of the solum and substratum. Unlimited reaction ranges from very strongly acid to slightly acid."

Land Use

Due to its shallow depth to bedrock, high acidity (pH <5), and low organic matter content, the Watt series exhibits severe limitations for most land uses. In Orange County, over 80% of the Watt remains in forest cover (see Fig. 10). Even the quality of the forests is generally poor. Acid-tolerant tree species such as chestnut oak, hickory, and maple predominate, but growth rates are slow. The understory contains dogwood and wild blueberries. The Orange County Soil Survey notes the best trees to plant on Watt soils for pulp wood or timber production are loblolly and short leaf pines.

Use of the Watt soil for agriculture in Virginia is almost nonexistent and is generally not recommended. All of the characteristics noted above plus excessive drainage create poor conditions for crops and even hay or pasture. U.S. Department of Agriculture (USDA) tables (Carter et al., 1971) for the Watt do not even list expected yields for the principal grains and hay, and rate its use for pasture as lowest of the 63 soils mapped in Orange County (U.S. Department of Agriculture, 1971).

Potential for development also has the Watt series receiving low ratings. The principal limitation is the shallow depth which makes it unsuitable for common on-site sewage disposal systems that use septic tanks and drain fields. Alternative systems can be used but are expensive and require a high level of maintenance. Watt soils can also present significant engineering problems, such as the necessity for blasting during excavations for foundations, deep ditches, or road cuts. They also provide inadequate fill material and exhibit poor compactibility.

TABLE 3. SELECTED PROPERTIES OF THE WATT SOIL SERIES

Horizon	Lower depth (cm)	Colors[1]	Textures	Other
A1	5	5Y 2/1	Channery[2] silt loam	20% graphitic schist gravels (>2 mm); very strongly acid[3]
A2	23	5Y 3/2	Channery silt loam	25% graphitic schist gravels; very strongly acid
Bw	35	5Y 4/2	Channery silt loam	40% graphitic schist gravels; very strongly acid
C	65	5Y 2/1	Very channery silt loam	55% graphitic schist gravels; very strongly acid
R	65+		(Rock)	

Note: See http://ortho.ftw.nrcs.usda.gov/cgi-bin/osd/osdlist.cgi.

[1] All colors are moist and follow Munsell notation: e.g., 5Y 2/1 is hue 5Y, value 2, chroma 1.

[2] Textures are modified according to the contribution (by volume) and type of rock fragments >2 mm: for <15% gravels or channers (prismoidal or subprismoidal, flat) rock fragments, there is no modifier; 35% > volume > 15%, "gravelly" or "channery"; 60% > volume > 35%, "very gravelly" or "very channery" (Schoeneberger et al., 2002, p. 2–31).

[3] Reaction classes or field pH values are as follows: very strongly acid: 5.0 > pH > 4.5; strongly acid: 5.5 > pH > 5.1; moderately acid: 6.0 > pH > 5.6; slightly acid: 6.5 > pH > 6.1; neutral: 7.3 > pH > 6.6; slightly alkaline: 7.8 > pH > 7.4; moderately alkaline: 8.4 > pH > 7.9 (Schoeneberger et al., 2002, p. 2–70).

Miles	
6.2	From Stop 1, proceed east on Rt. 657 to left on Rt. 33.
8.0	Barboursville intersection of Rt. 33 and Rt. 20.

Stop 2. BARBOURSVILLE

Local Geology

Stop 2 places us at the far south end of the Culpeper Mesozoic basin described earlier under Regional Geology. For many years the basin was thought to be continuous to a point just south of Barboursville, where it ends at a transverse fault. More recent investigations, however, have uncovered a distinct break in the basin ~13 km north of Stop 2, just west of Orange Court House. Whether this relatively small area, separate from the main basin, will continue to be considered as a part of the Culpeper Basin or will assume a new name in the future has not been determined at this writing.

The rocks underlying Stop 2 are known as the Bull Run shale (Roberts, 1928) or Bull Run Formation (Lindholm, 1979). They exhibit the characteristic color of most sedimentary rocks found in the Mesozoic basins throughout the eastern states. It has been variously described as red, pinkish-red, or pinkish purple and, once seen, the color can be recognized instantly. Lithologically, the rocks at Stop 2 are predominately shales and siltstones. Fresh and even slightly weathered exposures exhibit white specks of plagioclase feldspar, and desiccation cracks are common. Early dinosaur tracks have been found at a number of exposures farther north within the basin.

Soils

Just north of the intersection of Rt. 20 and Rt. 33, we will meet soils that have been mapped as part of the *Penn* and *Bucks* soil series (Table 4). Penn soils are afka fine-loamy, mixed, superactive, mesic *Ultic Hapludalfs*.

- Order→*Alf*isol (clay-rich, high base saturation)
  - Suborder→*Ud*alf (udic soil moisture regime)
    - Great group→*Hapl*udalf (insufficiently distinguished [morphologically or chemically] to merit classification as another great group)
      - Subgroup→*Ultic* Hapludalf (sufficiently leached that base saturation is lower than for a Typic Hapludalf).

Penn surface horizons are dark reddish brown (5YR 3/3), silt loams, and have relatively low base saturation. Subsurface horizons show increases in gravels (>2 mm) or channers, as well as a pronounced color shift to redder hues (2.5YR 4/4) that reflect the underlying parent material, often reddish shale, siltstone, or fine-grained sandstone of Triassic–Jurassic age (145–250 m.y. B.P.). Penn soils are closely related to the Bucks soil series, differing primarily in terms of depth to bedrock (Penn <1 m) and base saturation (Penn > Bucks). (Bucks soils are afka as fine-loamy, mixed, active, mesic *Typic Hapludults*.)

Across the Piedmont, Penn soils cover 367,000 acres, while the Bucks soils cover 65,000 acres; across Orange County, Penn soils comprise 1800 acres (0.8%), while Bucks soils comprise 3700 acres (1.7%) (U.S. Department of Agriculture, 1971).

Land Use

Soils of the Bucks and Penn series are the most commonly mapped units within the Mesozoic basins of Virginia. They are also among the most productive soils and often occur together in close proximity on the landscape. Although the Orange County Soil Survey maps Stop 2 as Bucks, our experience has shown that we may well encounter Penn.

Both Bucks and Penn soils are intensively farmed throughout the rural portions of the Culpeper Basin. The land use pattern in Figure 9 clearly shows the preponderance of clear land in a band extending to the northeast from Stop 2. Several soil attributes account for this intensive utilization.

TABLE 4. SELECTED PROPERTIES OF THE PENN AND BUCKS SOIL SERIES

Horizon	Lower depth (cm)	Colors	Textures	Other
Penn soil series				
Ap	25	5YR 3/3	Silt loam	5% channers (>2 mm); slightly acid
Bt1	45	5YR 5/4	Silt loam	8% channers; slightly acid; few clay films
Bt2	57	2.5YR 4/4	Silt loam	10% channers; moderately acid; few clay films
Bt3	66	2.5YR 3/4	Channery loam	20% channers; moderately acid; few clay films
Cr	84	10R 4/3	Very channery loam	40% channers; moderately acid; very few clay films
R	84+	10R 3/3	(Rock)	95% angular flagstones
Bucks soil series				
Ap	20	10YR 4/4	Silt loam	Strongly acid
BA	45	7.5YR 4/4	Heavy silt loam	Very strongly acid
Bt1	75	5YR 4/4	Heavy silt loam	Very strongly acid; discontinuous clay films
Bt2	105	2.5YR 3/4	Silt loam	Very strongly acid; discontinuous clay films
2C	126	2.5YR 3/4	Shaly silt loam	35% shale fragments; strongly acid
2R	126+	2.5YR 3/2	(Fractured shale)	

Topographically both series occupy nearly level to gently sloping landscapes where erosion is limited. They are well drained and sufficiently deep to bedrock to allow good root development. The Penn series, being an Alfisol, has, by definition, a relatively high base saturation. Although the Bucks series is classified as an Ultisol, the presence of fresh or only partially weathered plagioclase feldspar in the bedrock and subsoil provide nutrients and acid neutralization. The Orange County Soil Survey states: "These (Bucks Series) are among the best soils for farming in Orange County." Although timber trees thrive on Bucks and Penn soils, forest acreage tends to be limited because the land is usually cleared for other uses.

As often is the case with good agricultural soils, the Bucks and Penn soils are also well suited for engineering and urban development. Consequently, pressures to build on these soils are high, and many highly productive farms throughout the Culpeper Basin are disappearing under concrete and asphalt.

Miles	
15.6	Proceed north on Rt. 20 to right on Rt. 639.
19.2	Proceed east on Rt. 639 to Rt. 15 (by Montpelier, home of James Madison).
21.2	Turn left on Rt. 15 and proceed to Agriculture Experiment Station.

Stop 3. Northern Piedmont Agricultural Research and Extension Center (NPAREC)

Local Geology

Stop 3 is located on the eastern limb of the Blue Ridge Anticlinorium near the eastern edge of the Blue Ridge Province (Fig. 2).

Here the bedrock is the Catoctin Formation, comprised of a thick series of basaltic lava flows subsequently metamorphosed to greenstone. Thickness of the formation is reported by Nelson (1962) to exceed 7 km at the Orange County line 12 km to the southwest of Stop 3, while thickness values reported by others working farther south are somewhat less.

Greenstone is the dominate rock type within the Catoctin Formation and in the vicinity of Stop 3. Fresh bedrock is mainly a grayish-green to dark-yellowish green, fine grained, somewhat schistose, chlorite and actinolite-bearing lithology with common epidosite segregations. Rocks displaying amygdaloidal features usually occur at the tops of the individual flows where vesicles are filled with an assortment of minerals. White quartz, jasper, epidote, and pink orthoclase feldspar fillings are common. These rocks are much sought after by rock and mineral collectors who saw and polish them producing striking display specimens. Unfortunately, for any collectors along on this trip, amygdaloidal zones have not been described at this specific locality.

Associated and interbedded with the metabasalt are conformable beds of metasedimentary rocks. Impure quartzites and arkosic sandstones appear to be the most common of these. However, metasiltstone and phyllite are also reported (Rader and Evans, 1993). These units range from a few cm to 100 m in thickness but are usually less than 20 m. Most occur as lenses with limited horizontal extent.

A conglomerate unit up to 400 m thick and containing greenstone clasts was described by Nelson (1962) as occurring within the Catoctin in Albemarle County, 12 km to the southwest of Stop 3. A number of other geologists (Furcron, 1939; Espenshade, 1986; Kline et al., 1990) have described greenstone breccia within the Catoctin. Finally Lambeth (1901) described "alaskite" dikes intruding the Catoctin in the vicinity of Thomas Jefferson's Monticello some 40 km to the southeast. These dikes composed of nearly pure microcline have a striking pink color that weathers to orange. One of the authors (Sherwood) determined the foundation and basement walls at Thomas Jefferson's Monticello to be constructed of this stone.

Soils

Just south of the town of Orange along Rt. 15 lies the NPAREC. Here, we will meet a soil that has been mapped as part of the *Davidson* soil series, afka a fine, kaolinitic, thermic *Rhodic Kandiudult* (Table 5).

Order→*Ult*isol (clay-rich, low base saturation)
Suborder→*Ud*ult (udic soil moisture regimes)
Great group→*Kandi*udult (distinguishable chemically by low-activity clays, meaning the clay cation exchange capacity is <16 $\text{cmol}_+ \text{ kg clay}^{-1}$)
Subgroup→*Rhodic* Kandiudult (very red).

Davidson surface horizons are typically dark red (2.5YR, 5YR), clay loams, dominated by kaolinite, and very acid, and thus, have very low base saturation (<13%). Subsurface horizons are dark red (10R 3/6), and occasionally contain stone lines. Davidson soils form from rocks high in ferromagnesian minerals

TABLE 5. SELECTED PROPERTIES OF THE DAVIDSON SOIL SERIES

Horizon	Lower depth (cm)	Colors	Textures	Other
Ap	18	5YR 3/3	Loam	Strongly acid
Bt1	30	2.5YR 3/6	Clay loam	Strongly acid; few clay films; few black concretions (Mn^{4+})
Bt2	58	10R 3/6	Clay	Strongly acid; few clay films; few Mn^{4+}
Bt3	132	10R 3/6	Clay	Strongly acid; common clay films
Bt4	180	2.5YR 3/6	Clay	Strongly acid; many clay films; mottles

Note: The term "mottles" was replaced in 1995 by "redox features"; more specifically, the term "depletions" is used for gray areas and "concentrations" for red, yellow, or brown areas.

(e.g., greenstone); bedrock is typically >1.8 m (Genthner, 1990). Davidson soils comprise ~553,000 acres across the Piedmont, and 23,000 acres (10%) in Orange County (U.S. Department of Agriculture, 1971).

Land Use

The soils formed from the Catoctin greenstone have long been considered to be among the most desirable in the Blue Ridge and Piedmont of Virginia. Many of the earliest land patents from the King of England were underlain by the Catoctin Formation. Figure 9 shows intense use of the land on either side of Southwest Mountain where the Davidson and related greenstone soils are free of forest cover. This is strong evidence that the early settlers recognized the greenstone-derived soils. A list of the antebellum families living over the Catoctin contains many FFVs (First Families of Virginia). Even today some of the most beautiful estates in Virginia are located here. The homes of four United States Presidents—Jefferson, Madison, Monroe, and Taylor—are all located over greenstone soils within 45 km of this stop.

Although many of these homes have commanding views of the surrounding countryside, doubtless the principal draw was the productivity of the greenstone-derived soils that underlie the flanks of Southwest Mountain. Only the steepest slopes were unsuitable for crop production. The Davidson, Rabun, and Fauquier series that form from weathered greenstone are all deep, well drained, and productive. A state soil scientist recently measured over 6 m of B horizon at a site underlain by Davidson soil only 6 km south of Stop 3. During the colonial period and even after, much of this acreage was devoted to crops, particularly tobacco, corn, and wheat. The Orange County Soil Survey estimates corn, wheat, alfalfa, and pasture yields from Davidson soils as among the highest in the County. Today pastures and hay production predominate.

The same properties that make the Davidson, Rabun, and Fauquier soils excellent for agriculture apply to tree growth. Hardwoods, particularly poplars and oak species grow rapidly in these soils. The Landmark Forest at Montpelier just over the ridge to the west of this stop has been essentially undisturbed for ~100 yr. It contains impressive specimens of the forenamed trees. Tulip poplars with 1.5-m diameters at breast height and oaks with 1.2-m diameters are common there.

Greenstone-derived soils also have few limitations for a range of nonagricultural uses. Their deep profiles and well-drained properties are ideal for conventional on-site wastewater systems such as those involving septic tanks and drain fields. Consequently, development pressures for single homes, subdivisions, and commercial enterprises are great. The fact that most of the land over the greenstone is in “strong hands” (i.e., families with a tradition of far-sighted management of the land) may be a factor that limits runaway development over these soils.

Davidson soils also exhibit more than adequate engineering properties (Parker et al., 1983). Despite high silt and clay content that classifies them as A-7–5 in the American Association of State Hightway and Transportation Officials (AASHTO) system, and as MH in the Unified system, the clay fractions are high in kaolinite. Kaolinite-rich soils are the most stable for engineering uses of the clay-rich soils. They exhibit low shrink-swell potential and moderate optimum moisture, shear strength, liquid limits, plasticity indices, and California bearing ratio (CBR) values. Consequently these soils are commonly used for fill material and other engineering purposes.

Miles	
23.2	Proceed south on Rt. 15 to left (east) on Rt. 639.
26.3	Turn left on Rt. 643.
27.2	Proceed to the intersection of Rt. 643 and 638.

Stop 4. The Flat Woods

Local Geology

Stop 4 is located in the western Piedmont (see Fig. 4). After leaving Stop 3 we proceeded southward parallel to the strike of the Catoctin Formation, then turned eastward at Madison Run. At that point we left the Catoctin and crossed the Mountain Run fault and the Candler Formation. The Candler Formation, of Cambrian age, lies stratigraphically above the Catoctin. Major rock types within the Candler are phyllite, metasiltstone, metatuff, and dolomitic marble. At the top of the formation at this point is the Everona Limestone. Mack (1965) describes the Everona as ~55 m of dark-blue, thin-bedded, slatey limestone containing thin stringers of calcite. Weathering of the limestone has created a distinct, narrow valley that can be traced for several kilometers along the strike of the formation. Note we cross through the valley just east of the railroad. As is usually the case with limestone, the narrow valley has been cleared and farmed since the colonial period (see Fig. 10). The limestone was also mined at several sites during the mid 1800s for the production of hydrated lime.

The bedrock at Stop 4 overlies the Candler Formation. The Virginia State Geologic Map (Rader and Evens, 1993) refers to these rocks as “Stratified rocks of the western Piedmont.” Lithologically they are a complex of metagraywacke, quartzose schist, phyllite, and mélange. The metagraywackes have been highly sheared and altered to quartzose chlorite and biotite schist with some blue quartz. According to Pavlides (1980) these rocks grade upward into a sequence of metavolcanic and metasedimentary rocks correlated with the Chopawamsic Formation of northern Virginia.

Soils

Here we will meet a soil that has been mapped as part of the Tatum soil series, afka a fine, mixed, semiactive, thermic *Typic Hapludult* (Table 6). Tatum surface horizons are typically brown (7.5YR 4/4), silt loams, contain 25% quartz and sericite schist channers, and have low base saturation. Subsurface horizons are much redder (2.5YR 5/6) clay loams. Tatum soils typically overlie sericite, schist, phyllite, or other fine-grained metamorphic rock. Nason soils are very closely related to Tatum soils, with an identical classification, but with the principal difference being subsoil horizons are less red (5YR to 10YR; Table 7). Tatum and Nason soils together cover 1.15 million acres (0.72M and 0.43M acres, respectively) of the Piedmont, and 24,000 (11%) and 45,000 (20%) acres, respectively, of Orange County (U.S. Department of Agriculture, 1971).

Land Use

Tatum and Nason soils cover vast areas of the western and central Piedmont of Virginia. In Orange County alone, the two series comprise >30% of the total land area with about three quarters of the land area in forests (Fig. 9). Acid tolerant vegetation predominates, with chestnut oaks, Virginia pine, black gum, and blueberries common. During the colonial period and even up to the Civil War most of these soils were cleared and farmed, principally for tobacco. However, due to their acidity, low natural fertility, and highly erodible nature, most of the land quickly became exhausted and was abandoned.

The Piedmont, in fact, has been the locus of considerable research on past soil erosion rates (e.g., Ireland et al., 1939; Trimble, 1985). In 1995, it was suggested that current soil erosion rates were unsustainable relative to soil production rates and expensive to remedy (Pimentel et al., 1995). Follow-on letters and studies from economists (e.g., Crosson, 1995) led to an exchange of letters, which triggered yet another response from Trimble and Crosson (2000), titled "U.S. soil erosion rates—Myth and reality." In this article, Trimble and Crosson (p. 250) wrote "We do not seem to have a truly informed idea of how much soil erosion is occurring in this country, let alone of the processes of sediment movement and deposition." Recent studies have estimated that farmland denudation is occurring at rates of between ~600 and ~4000 m/m.y. (Wilkinson and McElroy, 2007; Montgomery, 2007), and that these rates are approximately two orders of magnitude larger than soil production rates. It will be important on this field trip to relate current land uses, including abandonment following attempts at agriculture, to soil properties.

During the nineteenth century, as the soils were exhausted large numbers of the settlers moved westward in their quest for "new land." The worn-out and heavily eroded fields were left to nature, where the old field succession of Virginia pine, black locust, blackberries, and broom sedge followed. Within a few years the Virginia pines came to dominate. Even today, fields abandoned during the twentieth century contain thick stands of this species. However, Virginia pines are shade intolerant and relatively short-lived trees. After about seventy years the pines begin to die off and young shade-tolerant hardwoods such as oaks, hickory, poplar, maple, and ash take over. Today, hardwood forests predominate over Tatum and Nason soils in the Virginia Piedmont.

In the twenty-first century, with readily available lime and fertilizers, some Tatum and Nason soils can be successfully farmed, and this is the case on a modest scale in Orange County. However, stringent management practices, particularly to control erosion, are required.

Tatum and Nason soils are normally deep and well drained so they usually pass the "perc" test required for conventional septic-tank and drain-field waste water systems. These properties together with lax local zoning regulations and low land prices have resulted in an explosion of strip development along the secondary roads in the "flat woods" area. This condition will be evident as we proceed to our next stop. Thirty years ago these roads traversed virtually unbroken forests.

Miles	
31.3	Proceed east on Rt. 638 to bridge over Cooks Creek.

Stop 5. Floodplain of Cooks Creek

Local Geology

The bedrock at Stop 5 lies within the Copowamsic volcanic belt. As noted earlier, this belt is one of the allochthonous terranes making up the western and central portions of the Virginia Piedmont. Pavlides (1990) mapped the rocks here as part of the Malange Zone III of the Mine Run Complex, probably of Ordovician age. Pavlides recognized three distinct malange zones within the Mine Run Complex. While the matrix rocks are predominately schists and phyllites, the zones are differentiated on the basis of the degree of deformation and the compositions of the included blocks of other lithologies. In Zone III many of the matrix rocks are highly deformed and contain abundant euhedral magnetite. Exotic blocks of mafic composition include amphibolite, ultramafics, serpentinite, and talc. Some blocks contain more than one rock type. Nonmafic blocks composed of biotite gneiss are also present.

Despite the interesting bedrock in this area, the principal purpose of Stop 5 is to examine the geomorphology (Fig. 9). At this point, Cooks Creek, a tributary to the North Anna River, has abandoned its former channel and moved ~100 m to the south. In so doing, the stream has left a well-defined abandoned channel and a nearly level wetland floodplain that sustains standing water in wet sessions. It also left a stretch of cut bank that resembles a large amphitheater.

Soil

Where Rt. 638 crosses Cooks Creek, we will visit a floodplain soil that is framed by an amphitheater with ~20 m of relief, reflecting millennia of incision. This *Wehadkee* soil series, afka a fine-loamy, mixed, active, nonacid, thermic *Fluvaquentic Endoaquept*, has grayish-brown (10YR 5/2) surface horizons, with some mica flakes, and moderate base saturation (Table 8). Some redoximorphic features are evident in subsurface horizons, and the irregular decrease in organic carbon with depth leads to the "Fluvaquentic" subgroup classification. Wehadkee soils develop from sediments derived from schist, gneiss, granite, phyllite, and other metamorphic and igneous rocks. For this particular soil at this stop, the parent material represents material transported by Cooks Creek to this location. The Wehadkee series comprises

TABLE 6. SELECTED PROPERTIES OF THE TATUM SOIL SERIES

Horizon	Lower depth (cm)	Colors	Textures	Other
Oe	5–0	(Litter/twigs)	(Mucky peat)	(Evergreen litter)
A	10	7.5YR 4/4	Gravelly silt loam	25% qpssc; 5% cobbles (75–250 mm); very strongly acid
Bt1	33	5YR 4/6	Gravelly silty clay loam	18% qpssc; very strongly acid; few clay films
Bt2	79	2.5YR 5/6	Silty clay loam	5% qpssc; strongly acid; common clay films
BC	107	5YR 5/8	Silty clay loam	Very strongly acid; mottles
C	137	5YR 6/4, 5YR 5/8	Channery silt loam saprolite	20% ssc; strongly acid; mottles
Cr	157		Highly fractured sericite schist	Strongly acid
R	157+		Unweathered, slightly fractured sericite schist	

Note: Qpssc—quartz pebbles and sericite schist channers; ssc—sericite schist channers.

TABLE 7. SELECTED PROPERTIES OF THE NASON SOIL SERIES

Horizon	Lower depth (cm)	Colors	Textures	Other
Oi	3–0	(Litter/twigs)	(Peat)	(Deciduous forest litter)
A	3	10YR 3/2	Silt loam	Strongly acid
E	23	10YR 5/4	Silt loam	Very strongly acid
Bt1	38	10YR 5/8	Silty clay loam	5% quartz gravels; very strongly acid; few clay films
Bt2	51	7.5YR 5/8	Silty clay	5% quartz gravel; very strongly acid; few clay films
Bt3	71	5YR 4/8	Silty clay	5% schist gravels; very strongly acid; common clay films; mottles
Bt4	97	5YR 4/6	Channery silty clay loam	25% schist gravels; very strongly acid; common clay films; mottles
C	127	5YR 4/6, 2.5YR 5/6, 7.5YR 5/6	Channery silt loam saprolite	25% schist gravels; very strongly acid; mottles
Cr	157		Weathered, fractured sericite schist	

TABLE 8. SELECTED PROPERTIES OF THE WEHADKEE SOIL SERIES

Horizon	Lower depth (cm)	Colors	Textures	Other
Ap	20	10YR 5/2	Fine sandy loam	Few mica flakes; moderately acid
Bg1	43	10YR 4/1	Loam	Few mica flakes; moderately acid; common Fe^{3+} masses
Bg2	102	10YR 6/1	Sandy clay loam	Common mica flakes; moderately acid; common Fe^{3+} masses
Cg	127	10YR 6/1	Sandy loam	Common mica flakes; moderately acid; common Fe^{2+} masses; prominent Fe^{3+} masses

~655,000 acres of the Piedmont, 62,000 of those in Virginia (1%), and 1300 (0.6%) of those in Orange County (U.S. Department of Agriculture, 1971).

Land Use

Like most of the land over Wehadkee soils in Orange County, Stop 5 is forested. Wetland tolerant tree species common here are river birch, sycamore, alder, maple, iron wood, and willow oak. In addition, fine specimens of tulip poplar are present. Poplar, a desirable timber species, can grow rapidly and attain immense size under the conditions found here. Noncanopy vegetation includes spice bush, button bush, and ferns. While tree growth can be rapid in Wehadkee soils, harvesting can present problems during wet seasons. Many forms of wildlife such as deer, muskrat, raccoon, wild turkey, and a variety of other birds flourish in areas with Wehadkee soils.

Surprisingly, some 40% of the Wehadkee soils in Orange County have been cleared and used for pasture. The carrying capacity of these soils, at 80 cow-acre-days per year ranks about midway when compared to other soils within the County. However, during very dry years, pastures on Wehadkee soils are desirable, providing good forage when the grasses on the upland soils do not. A very small acreage over the Wehadkee soils in Orange County is devoted to growing crops, mainly corn. Again these fields can aid farmers during dry years, but generally cropping on Wehadkee soils is not recommended.

Because of the seasonally high water table and susceptibility to flooding, Wehadkee soils are not recommended for development.

Miles	
32.6	Proceed east on Rt. 638 to intersection with Rt. 612, turn right on Rt. 612.
34.7	Proceed east on Rt. 612 to intersection with Rt. 669, turn left on Rt. 669.
38.8	Proceed north on Rt. 669 to Stop 6, 0.2 miles north of Lahore.

Stop 6. Lahore

Local Geology

Stop 6 is over the Lahore pluton (see Fig. 2). The pluton was named by Pavlides (1990) for the small village of Lahore located immediately to the south of our stop. It was intruded into malange zone III during the Ordovician. It is one of a number of mafic intrusions emplaced within the Central Virginia volcanic-plutonic belt. Pavlides (1990) recognized three distinct lithologies within the pluton. These are:

1. (1) amphibole monzonite, mesocratic, medium-grained amphibole monzonite, and amphibole-quartz monzonite. A foliation is defined by the alignment of tabular feldspar crystals;
2. (2) pyroxene monzonite with color ranging from dark gray to black. The rock is massive to weakly foliated and consists of large augite and plagioclase grains (some zoned) and opaque oxides; and
3. (3) mafic and ultramafic rocks consisting of partially serpentinized pyroxenite and diopside.

Stop 6 is located over lithology type 1—amphibole monzonite. The landscape over the Lahore pluton is very gently rolling to nearly level. This topography is in subtle contrast to that in the surrounding countryside, where hill slopes are somewhat steeper and stream valleys are narrower and more pronounced. The average land elevation over the pluton is slightly lower than that surrounding the intrusion. This difference is even more pronounced over the famous Green Springs intrusion, located ~18 km southwest of Lahore. Because of its slightly lower elevation, the Green Springs area is often referred to as the Green Springs basin.

Soils

Just north of Lahore Road off Rt. 669, we will meet a soil mapped as the series, afka a fine, mixed, active, thermic, *Oxyaquic Vertic Hapludalf* (Table 9). Iredell surface horizons are typically dark grayish-brown (2.5Y 4/2), sandy loam, with few gravels, and with moderate base saturation. Subsurface horizons show strong increases in shrink-swell–prone clays (presence of slickensides) as well as base saturation. In the Virginia Piedmont, Iredell soils are most closely associated with mafic plutons, such as diabase, monzonite, diorite, and gabbro. Iredell soils cover ~231,000 acres across the Piedmont, and 427 acres (0.2%) of Orange County (U.S. Department of Agriculture, 1971). Unlike any of the other soils on this field trip, some of the soil pH values are >7.9, an unusual feature for soils in humid climates with long residence times.

The taxonomic classification of Iredell soils provided above is specific to a location, per the official series description, 71 m "north of a fire hydrant, across the road from the Southside School, [1.6 km] south of Chester, South Carolina, along U.S. Highway 72." This classification indicates the mineralogy is mixed, a characterization that is also likely to apply to our specific Iredell soil (Plaster and Sherwood, 1971), since several clay minerals were found in the B horizon (Fig. 11). Note that while montmorillonite increases sharply in the C horizon, this increase is only relative to other clay minerals. In fact, total clay shows a precipitous decline below the argillic B horizon, so it is possible that there could have been more montmorillonite present in the B horizon than in the C horizon, because of the >5-fold difference in total clay content (Fig. 11).

Not too surprisingly for an Alfisol, there is a pronounced increase in clay with depth, followed by a sharp decrease with depth (Fig. 11A). From the A_2 horizon (sample I-1, 25–37 cm) to the B horizon (samples I-2 and I-3, 37–91 cm) to the C horizon (samples I-4 through I-6, 91–183 cm), clay-sized material (<2 µm) changed from 18% to 66% to 12%. Just as striking as this clay bulge is the shift in clay mineralogy (Fig. 11B), from clays dominated by quartz and vermiculite, to illite in the B horizon, to montmorillonite in the C horizon. The dominance of clay-sized quartz at the surface of the profile was attributed to

TABLE 9. SELECTED PROPERTIES OF THE IREDELL SOIL SERIES

Horizon	Lower depth (cm)	Colors	Textures	Other
Ap1	13	2.5Y 4/2	Sandy loam	1% fine pebbles; slightly acid; few black concretions (Mn^{4+})
Ap2	18	10YR 4/2	Loam	Neutral; few Mn^{4+}
Btss1	28	10YR 4/3	Clay	Slightly acid; common clay films, slickensides; many Mn^{4+}
Btss2	51	10YR 4/3	Clay	Neutral; common clay films, slickensides, Mn^{4+}; few weathered feldspar crystals
Btg	61	2.5Y 4/2	Silty clay	Neutral; common clay films, slickensides, Mn^{4+}; few weathered feldspar crystals
BC	69	5Y 4/3	Loam	Common saprolite; neutral; common clay films; mottles
C1	81	fmdgg, vpb, and yb (m)	Loam	80% saprolite; neutral; few clay films
C2	112	fmdgg, vpb, b, and yb (m)	Sandy loam	90% saprolite; moderately alkaline; few clay films
C3	157	fmdgg, yb, b, and vpb	Sandy loam	90% saprolite, 10% hard rock fragments; moderately alkaline

Note: b—black; fmdgg—finely mottled dark greenish gray; m—mottled; vpb—very pale brown; yb—yellowish brown.

intense leaching (eluviation) that is characteristic of a udic soil moisture regime (Plaster and Sherwood, 1971) and very long soil residence times.

Plaster and Sherwood (1971), in addition to characterizing the particle size distribution and clay mineralogy, also examined the elemental composition of a representative Iredell soil profile and its hornblende metagabbro parent material (Table 10).

The authors then calculated two weathering indices: first, the weathering potential index (WPI; the percentage molar ratio of ΣCaO, MgO, K_2O, Na_2O [ΣBC] minus water to ΣBC plus SiO_2, Al_2O_3, and Fe_2O_3); and second, the base:aluminum (BA) ratio of ΣBC to the molar value of Al_2O_3.

The weathering potential index (Rieche, 1950) has been modified (Short, 1961), and is only one of a great number of weathering indices that have been developed (Birkeland, 1999). Cross-comparisons between weathering indices generally produce comparable results; for WPI, specifically, unweathered materials generally have strongly positive values (Birkeland, 1999: table 3.6, p. 70), while weathered material can have negative values.

Iredell WPI values were similarly positive between gabbro parent material (+19%) and the C horizon composed of saprolite (+16%). WPI values decreased sharply in the B horizon (–36%) and A horizon (–24%), a result attributed in part to the sharply reduced hydraulic conductivity of the clayey B-horizon, which was dominated by 2:1 clays. In effect, as mafic primary minerals weather to secondary minerals, vertical flow paths are effectively rerouted laterally, in effect drying out the lowermost part of the profile. This hydrologic dependence on lithology played a somewhat analogous role in explaining the difference in saprolite

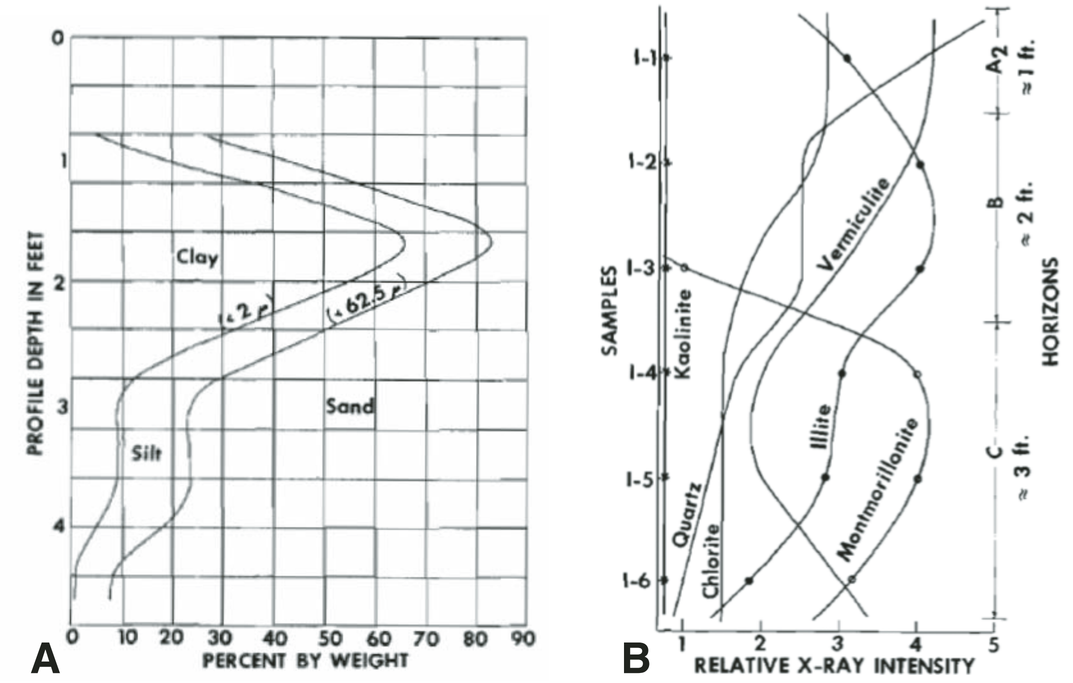

Figure 11. Clay, silt, and sand content (A) and clay mineralogy (B) for a representative Iredell soil profile (Plaster and Sherwood, 1971).

TABLE 10. CHEMICAL COMPOSITION (ALL VALUES %) OF A REPRESENTATIVE IREDELL SOIL, WITH TWO WEATHERING INDICES: WEATHERING POTENTIAL INDEX (WPI) AND THE BASE:ALUMINUM (BA) RATIO

	Lower (cm)	SiO_2	Al_3O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	LOI	Total	WPI	BA
A2	37	54.40	10.40	23.89	1.43	0.00	2.60	0.67	6.65	100	–23.8	0.80
B	91	49.92	21.33	14.93	1.88	1.34	2.06	0.68	9.31	101	–35.8	0.48
C	183	45.89	17.07	10.67	7.90	10.09	1.61	1.55	3.64	98	16.1	2.75
Rock		46.37	16.67	13.70	9.45	7.47	2.05	1.60	2.41	100	19.3	2.56

Note: From Plaster and Sherwood (1971); Plaster (1968). LOI—loss on ignition.

thickness over felsic versus mafic lithologies. BA ratios showed a comparable pattern.

Plaster and Sherwood (1971) raised two questions that we copy here for the purposes of stimulating discussion: (1) Why is there such a dramatic shift in montmorillonite from the B to C horizons? And, (2) Where has the talc identified in the parent material gone? With regards to the depth profile of montmorillonite, Eades (1953) suggested that fine-grained montmorillonite could be eluviated from the B horizon and illuviated into the C horizon.

These elemental depth profiles produced at least two unexpected results. First, it was noted that CaO and MgO might typically be expected, as biologically cycled bases, to show a decrease, not increase, with depth. One possible explanation is that the A2, versus the A1, horizon may not have captured the tree-pumping signal. Second, K_2O:Na_2O ratios decreased sharply with depth, whereas the authors expected to see no increase in Na_2O with depth. This result is consistent with a hydrologic rerouting following in situ formation of low-conductivity clays (see Table 1, which does not account for differences in clay mineralogy). For example, illite, a clay that displays a strong affinity for K, decreases with depth. Another factor may be the addition of K-rich fertilizers at the surface over many decades to increase crop yields.

The WPI values for the Iredell soil show that the saprolite (sample I-5) has experienced little chemical weathering, which Plaster and Sherwood (1971) attributed to the "high concentration of hydrophyllic clays in the B horizon"; the "impermeable nature of this clay-rich zone has hindered the downward migration of water and stands as the major reason for the lack of chemical weathering" of the saprolite (p. 2824).

Land Use

Today, most types of land development in areas underlain by Iredell and related "blackjack" soil series—a catch-all term for Jackland, Whitestore, Orange, Zion, and other high shrink-swell clayey soils—is generally discouraged. Several characteristics of these soils contribute to this policy. First, most of the land will not "perc" due to poor drainage and a seasonally high water table. Second, soils over mafic intrusions usually contain significant amounts of high shrink-swell smectitic clays such as montmorillonite. The taxonomy of the closely related Orange series (fine, smectitic, mesic *Albaquic Hapludalfs*) indicates a 2:1 shrink-swell clay like montmorillonite makes up over 50% of the clays present. Shrink-swell soils are highly unstable for engineering uses such as foundations, fills and other types of construction.

The question then arises, are these soils suitable for agriculture? Tables in the Orange County Soil Survey listing crop yields for the various soil series rate the Orange-Iredell complex in the lowest echelons for corn, wheat, and hay, and low to medium for pasture. Interestingly, the tables give higher yield figures for these same soils on 2%–7% slopes than on 0%–2% slopes. Normally, for most soils the more level slopes are more productive because they are less susceptible to erosion.

The reason for these seemingly illogical values can be summed in a single term—*drainage!* Level landscapes underlain by Iredell and Orange soils exhibit such poor drainage that crops suffer from too much water. Moderate slopes improve drainage and runoff and provide better conditions for crop production. An ancillary problem caused by smectite-rich soils can be harvesting during wet years. When these soils are disturbed while wet, structure is destroyed and they turn to a viscous liquid. It is not unusual for tractors to become mired up to their axles when these conditions occur. Finally, drainage affects chemical weathering processes. As Pavich (1986, p. 587) has noted, "the functional relationships of regolith production and erosion must begin with consideration of the hydrologic processes operating within the soil. The soil acts to partition rainfall into evapotranspiration, runoff, and recharge to the saprolite…. Since water movement is dependent on rock structure, rock weathering rate may be more dependent on soil water balance and rock structure than mineral dissolution kinetics if the rock contains at least one mineral phase that reacts rapidly with dilute, acidic solutions."

Examining the land use patterns in Figure 10, it is evident that despite the latent problems associated with the Iredell soil, the trends are clear. Land underlain by mafic igneous rocks and Iredell or similar soils has been preferentially cleared and farmed over the years. Areas underlain by Tatum and Nason soils are largely forested.

The reason can be traced back to the colonial period of Virginia history. As discussed at Stop 4, settlers whose land was over highly acid and erodible soils such as the Tatum and Nason, literally wore out the land in a few short years. A combination of the demands of tobacco production and poor farming methods were largely responsible. A settler to this area, John Craven, wrote in 1833 "… the whole face of the country presented a scene of desolation that baffles description, farm after farm had been worn out, and washed and gullied, so scarcely an acre could be found in place fit for cultivation.…” Even George Washington described the existing farming methods as “ruinous” and visiting English farmer William Strickland noted “...Virginia farms of the area were much worn out … nearly exhausted … and tobacco and maize … a curse” Strickland (1801).

As noted earlier, these conditions led to a massive out-migration of settlers from the Virginia Piedmont and throughout the southern states and the abandonment of hundreds of thousands of acres of degraded land. Over time, these lands slowly returned to forest. Even today most of these lands remain forested. On the other hand, many of the early settlers over the Iredell, Orange, and related soils formed over the mafic intrusions remained on the land. While the heavy clay soils are difficult to work, they are considerably less erosive and are characterized by naturally high pH and nutrient retention. These properties allowed the land to be successfully farmed for generations, and many families to become relatively prosperous. A number of these families remain on the land today. These areas lack forest cover and appear as light gray in Figure 10. The relationship between the cleared (nonforested) areas and the areal extent of the mafic intrusions is striking. More than one field geologist has noted the contact between the mafic intrusions and the surrounding metasedimentary rocks can be located by following the tree line on the topographic mark of the area.

ACKNOWLEDGMENTS

We thank the following colleagues for their reviews of early editions of this manuscript: Lee Daniels, Greg Hancock, Louis Heidel, Dan Richter, Dave Starner, Aaron Thompson, and Rich Whittecar. Dot McLaren kindly provided assistance with several of the illustrations. Landowners in this area have been particularly generous over the years with granting us access to their properties. We are appreciative of over thirty years of students’ and colleagues’ critiques of portions of this field trip.

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Manuscript Accepted by the Society 2 December 2009