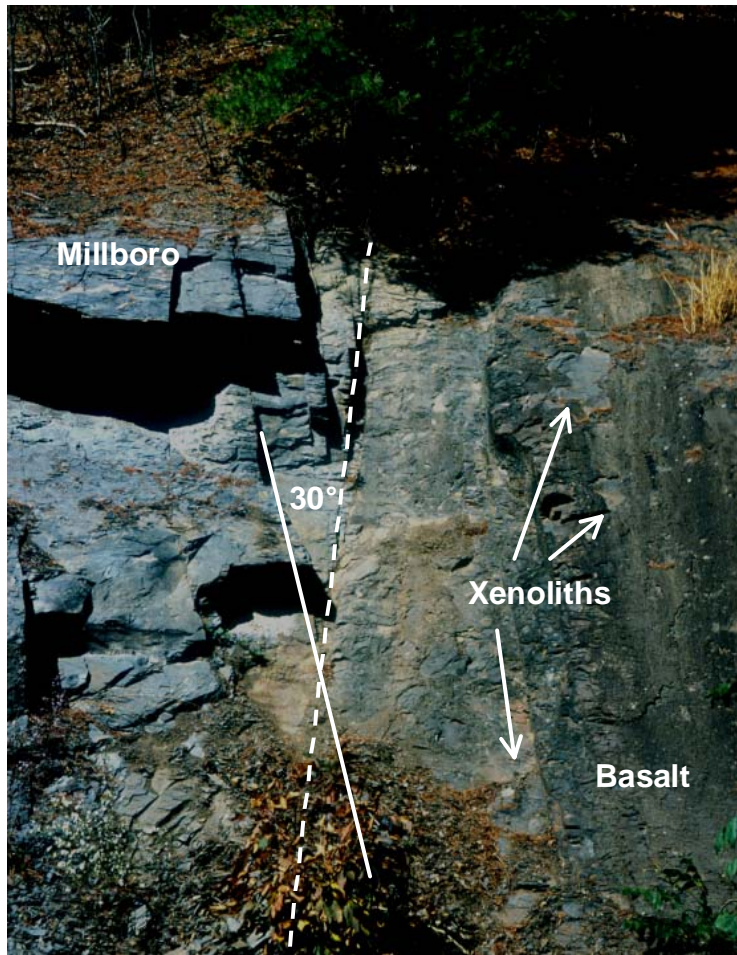


FIELD GUIDE TO THE MIDDLE EOCENE IGNEOUS ROCKS OF PENDLETON COUNTY, WV AND NORTHERN HIGHLAND COUNTY, VA

VA - Prepared for PGS Spring Field Trip, April 26, 2003



Contact between the Millboro Shale and the dike portion of the Sugar Grove basaltic sill-dike. The basalt has been intruded along a joint (dashed line). Notice that a second joint set intersects the first at a 30° angle. Also notice the xenoliths of Millboro caught up in the basalt.

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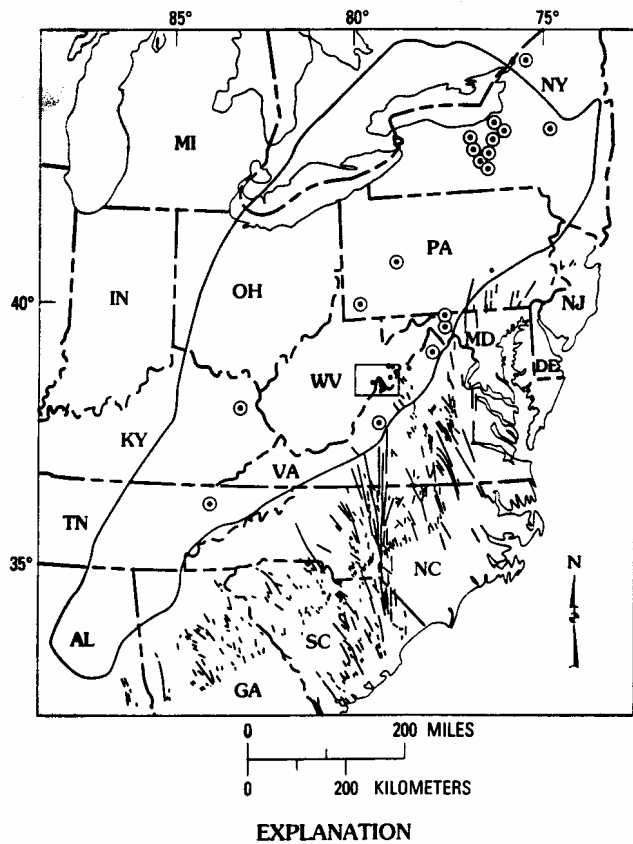
INTRODUCTION

Igneous rocks in the vicinity of Pendleton County, WV and Augusta, Highland, and Rockingham, counties, VA (Figure 1) were first recognized in 1837 (Johnson and others, 1971). N. H. Darton (1894; 1899) described and mapped a number of occurrences of exposed igneous material in the area and reported on their petrology and petrography (Darton and Diller, 1890; Darton and Keith, 1898). Watson and Cline (1913) described the igneous rocks of Augusta County, VA; Garnar (1956) described a complex of basaltic to andesitic rocks across the border in Pendleton County, WV. Over the years, these rocks have been the subject of numerous thesis projects (Dennis, 1934; Garnar, 1951; Kapnick, 1956; Kettren, 1970; Hall, 1975), as well as, a variety of scientific publications (Johnson and Milton, 1955; Fullagar and Bottino, 1969; Dennison and Johnson, 1971; Core and others, 1974; Wampler and Dooley, 1975; Sutter, 1976; Ressetar and Martin, 1980; Gray and Gottfried, 1986; Rader and others, 1986; Southworth and others, 1993)

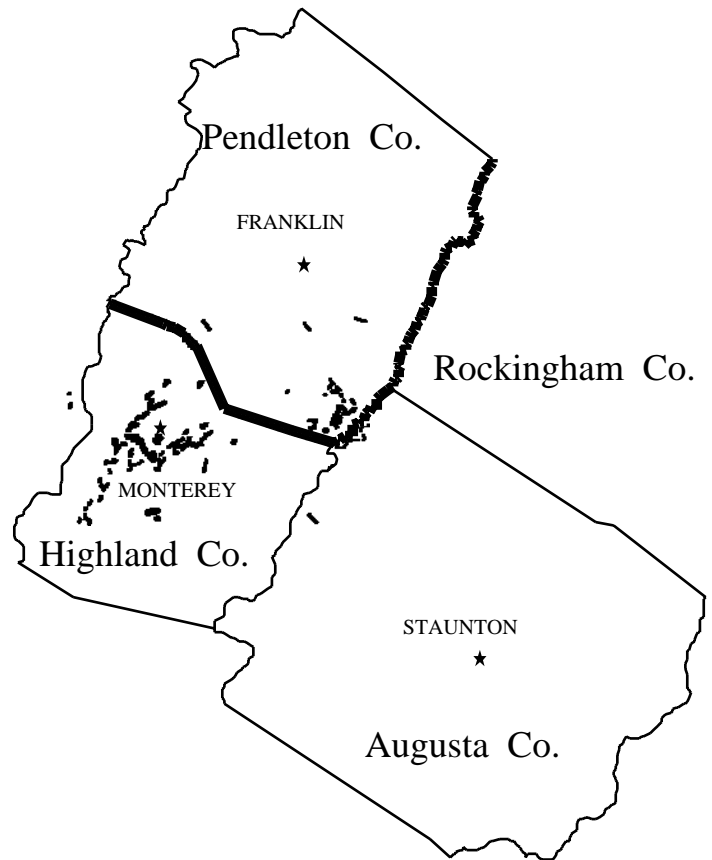
The igneous rocks of the area are observed to intrude and crosscut exposed Paleozoic sedimentary units ranging in age from Ordovician through Devonian (Figure 2). The first suggestion for the age of these rocks was Late Paleozoic or younger based on crosscutting relationships observed in the field. From the late 1800's until the 1960's, these rocks were thought to be of Mesozoic age (Darton and Diller, 1890; Johnson and Milton, 1955; Zartman and others, 1967), related to rift-associated igneous activity as the Atlantic Ocean basin opened following the Appalachian Orogeny. Subsequent workers (Fullagar and Bottino, 1969; Wampler and Dooley, 1975; Ressetar and Martin, 1980; Southworth and others, 1993), demonstrated the Eocene age of the majority of the igneous rocks in the area (there are Middle Jurassic dikes immediately to the east and south) by radioisotopic and paleomagnetic techniques. The generally accepted middle Eocene age (~ 47 ma) makes these the "youngest igneous rocks in the eastern United States" (Southworth and others, 1993, p. 4).

PETROLOGY

The Eocene igneous rocks of the area are a bit unusual in their textures in that many of them exhibit the fine-grained or aphanitic appearance usually associated with extrusive or volcanic igneous rocks (Figure 3 presents a highly simplified scheme for classifying and naming igneous rocks). In fact, these rocks are, for the most part, intrusive, having been injected into fractured and structurally deformed country rocks. The igneous bodies in the area consist of dikes, sills, plugs, and, perhaps, *diatremes* (Figure 4). Of this group, only the diatremes may have actually been erupted onto the land surface. The rest owe their fine-grained textures to intrusion close to the surface and relatively rapid cooling. It should be noted that many of the Eocene igneous rocks of the area are porphyritic. This indicates that the magmas associated with these rocks were not injected directly after melting, but rather, experienced extended periods of *stasis* prior to their final emplacement. This allowed well-formed crystals of various minerals to grow which were later carried along with the magma as it was emplaced near the surface and were preserved in the rapidly cooling groundmass.



- ⊙ Kimberlites
- ≡ Dikes (Jurassic)
- ∨ Dikes, sills, plugs, and diatremes (Middle Eocene)



Expanded view of the area enclosed by the small rectangle in the figure to the left.

Figure 1. Regional map of the Appalachian basin showing the distribution of late Paleozoic to Cretaceous kimberlites along the basin axis; Early Jurassic diabase dike swarms in the Appalachian Piedmont and Blue Ridge; Late Jurassic alkalic dikes in the eastern portion of the basin in the Shenandoah Valley, VA; and the middle Eocene dikes, sills, plugs, and diatremes in the central Appalachian Valley and Ridge province (enclosed with rectangle).
(Modified from Southworth and others, 1993, Figures 1 and 17, p. 2 and 19)

Generalized Stratigraphic Column for the Study Area			
Age	Group	Formation	Thickness
EOCENE		Ugly Mtn. & Trimble Knob Igneous Cmplx.	???
MISSISSIPPIAN		Price	400'
DEVONIAN	Helderberg	Hampshire	2650'
		Foreknobs	2650'
		Brallier	2900'
		Millboro	620'
		Tioga Bentonite	10'
		Needmore	100'
		Oriskany	120'
			400'
SILURIAN		Tonoloway	300'
		Wills Creek	200'
		Williamsport	20'
		McKenzie -Rochester	210'
		Keefer	10'
		Rose Hill	300'
		Tuscarora	200'
ORDOVICIAN		Juniata	400'
		Oswego	75'
		Reedsville	1,600'

Figure 2. Generalized stratigraphic column for southern Pendleton Co., WV. Formation names are those in current use by the West Virginia Geological and Economic Survey. **NOTE:** to the north of the area, the Ordovician Martinsburg Shale replaces the Reedsville.

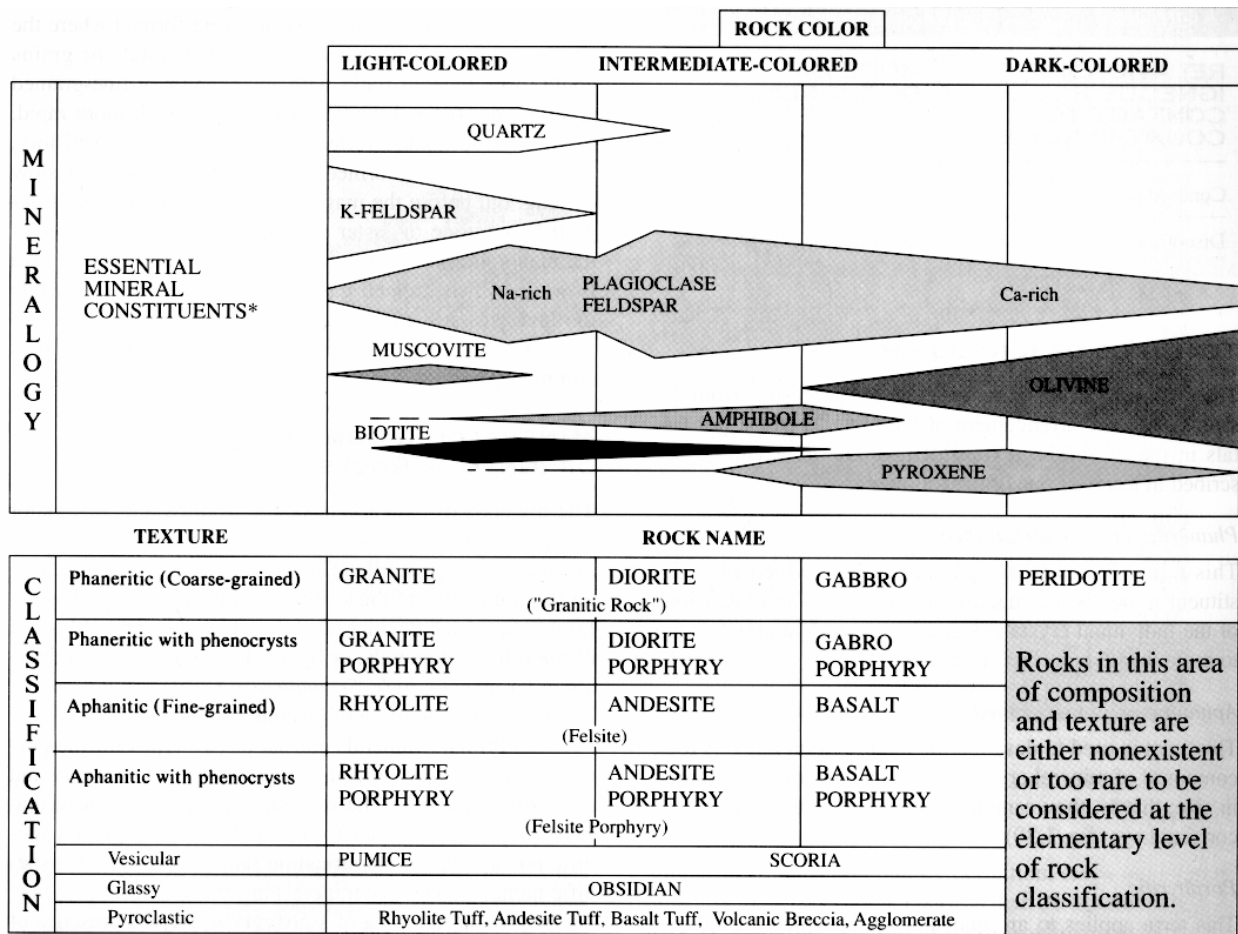


Figure 3. Simplified naming diagram for igneous rocks based on their texture and mineral composition. (Modified from Zumberge and others, 1999, Table 1.7, p. 28)

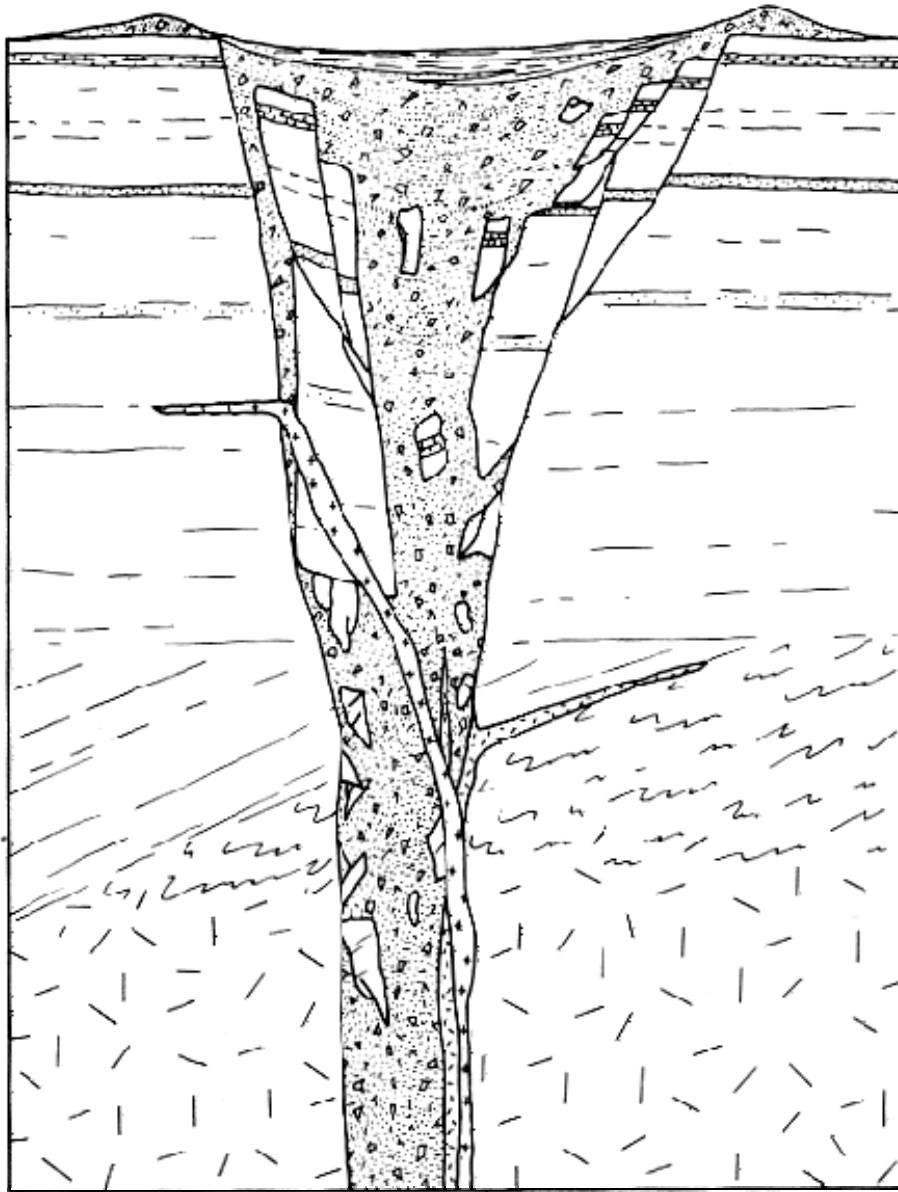


Figure 4. Idealized model of a diatreme. Igneous material is forcefully and explosively emplaced, shattering and brecciating existing country rock. Material may be ejected from the diatreme but much of this ejecta falls back into the crater. Diatreme breccia contains angular fragments of both volcanic and country rock along with a large amount of ash. This material may be matrix- or clast-supported depending on the ash content and the rock ultimately produced by this event may show evidence of “welding” of grains because much of the associated volcanic material is ejected at near molten temperatures.

(Modified from Best, 1982, Figure 6-6, p. 209)

The composition of the Eocene intrusives is somewhat variable ranging from rhyolite or rhyodacite to basalt (Figure 5). These volcanic rock names are appropriate because of the fine-grained textures of the intrusives and reflect compositional differences in the amount of quartz, plagioclase feldspar, and mafic minerals present.

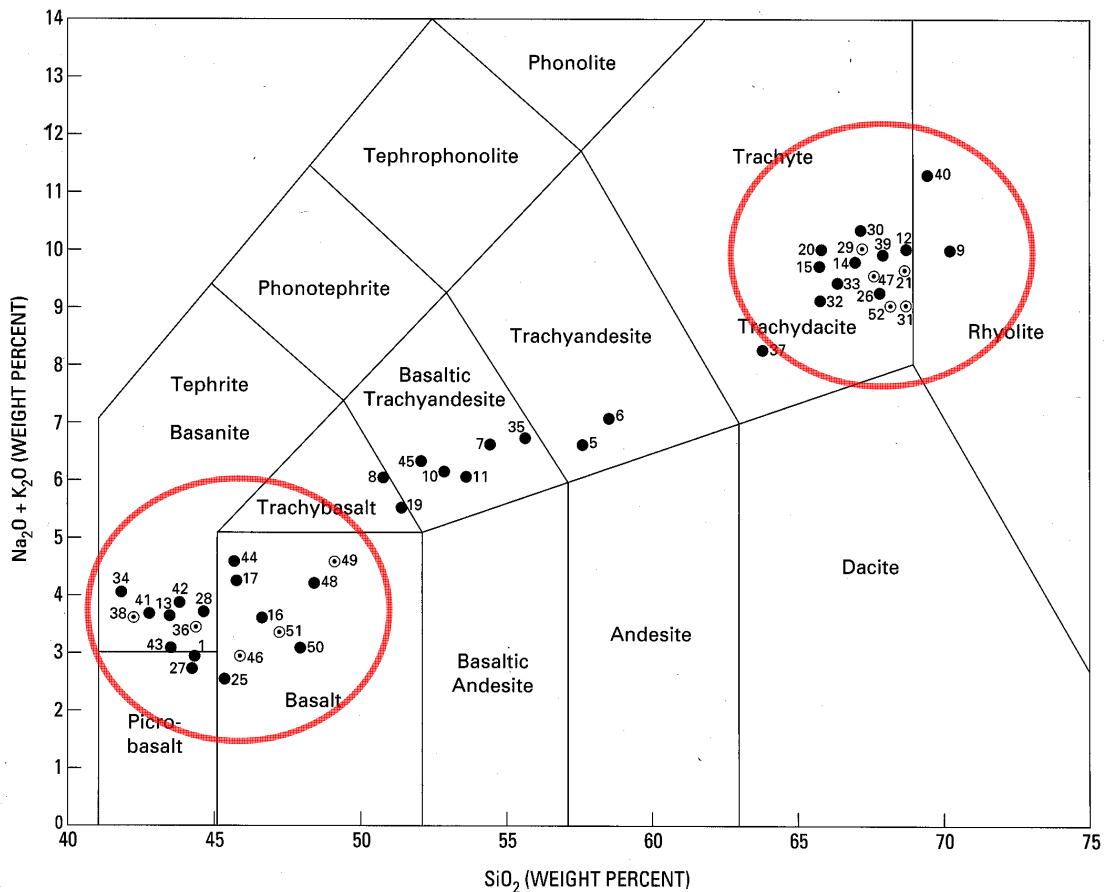


Figure 5. Compositional range for Eocene igneous rocks from the Pendleton Co. - Highland Co. area. Majority of rocks fall into either the basaltic or rhyolitic (actually rhyodacitic) field. *(Modified from Southworth and others, 1993, Fig. 6, p. 7.)*

There appear to have been two centers of Eocene igneous activity in the area (Southworth and others, 1993), one centered in the vicinity of Trimble Knob in Monterey, Virginia and a second centered around Ugly Mountain across the border in West Virginia. The more mafic igneous activity was associated with Trimble Knob; the more felsic activity with Ugly Mountain. Does this imply two distinctly different magma sources for these igneous rocks or are they merely the product of differentiation of a single magma over time? During the field trip, you will see that the two types of igneous rocks are in close proximity. With the exception of Trimble Knob itself, age dates for both types of igneous rocks overlap (Southworth and others, 1993) so that if there were two different magmas present, they must have been stimulated by contemporaneous igneous activity.

GEOCHEMISTRY

In general, trace element geochemical analyses of the middle Eocene igneous rocks of the area indicate enrichment of lighter elements and depletion of heavier elements compared to the mid-ocean ridge basalt standard (MORB) of Taylor and McLennan, 1985 (Figure 6). Compared to Taylor and McLennan's (1985) Chondrite standard, mafic rocks of the area are enriched in all trace elements except scandium (Figure 7). Trace element analyses of the felsic and volcanoclastic (diatreme) rocks of the area show the same trend (Figures 8 and 9) when compared to the Chondrite standard.

Major elements barium, chromium, sodium, zinc, manganese, strontium, calcium, aluminum, and potassium are enriched (4 to 55 x) in the area's igneous rocks compared to background values (McDowell, 2001) for sedimentary country rocks in the area. The major element thorium is depleted (0.5 x) in the igneous rocks. In general, there appears to have been little transfer of metals from the igneous intrusives into the sedimentary country rocks. This suggests a *dry* emplacement of many of the intrusives with the fluid phase in the magma being gases rather than liquids like water.

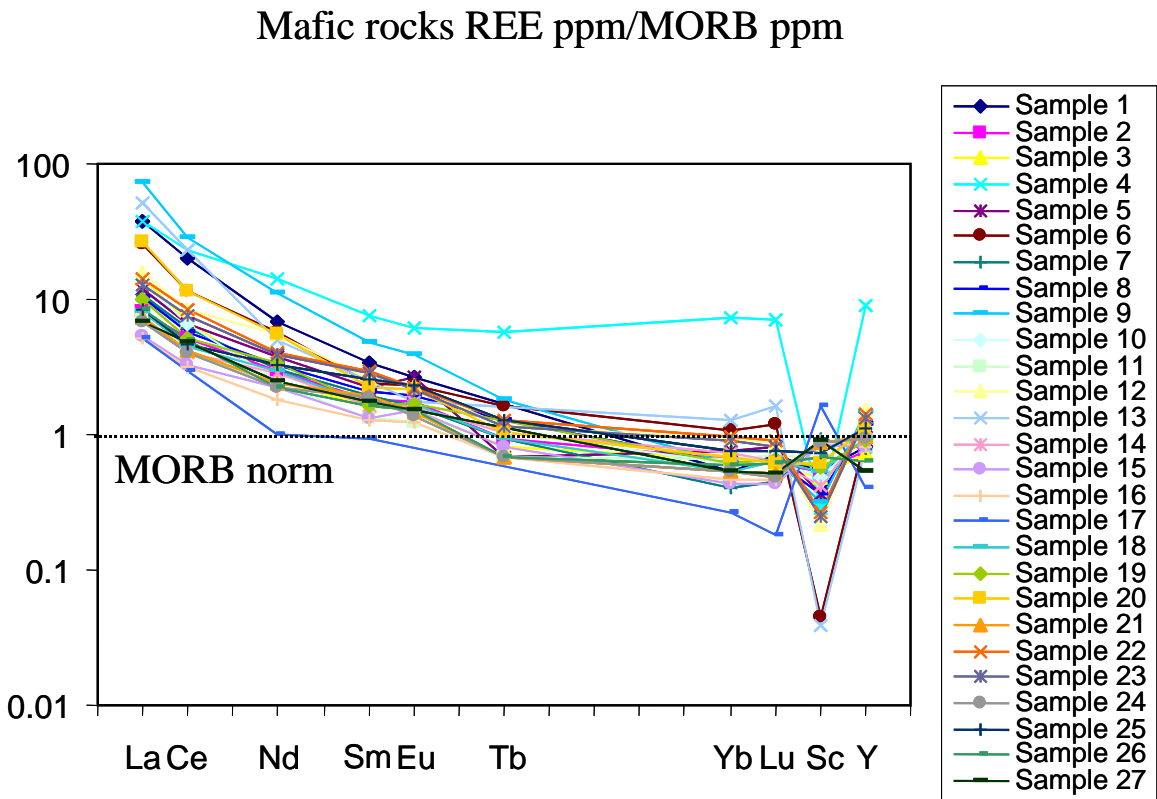


Figure 6. Normative plot – Normalized rare-earth element (REE) concentrations from mafic rock samples plotted against MORB Standard of Taylor and McLennan, 1985. Lighter trace elements are enriched; heavier trace elements are depleted relative to the standard.

Mafic rocks REE ppm/Chondrite ppm

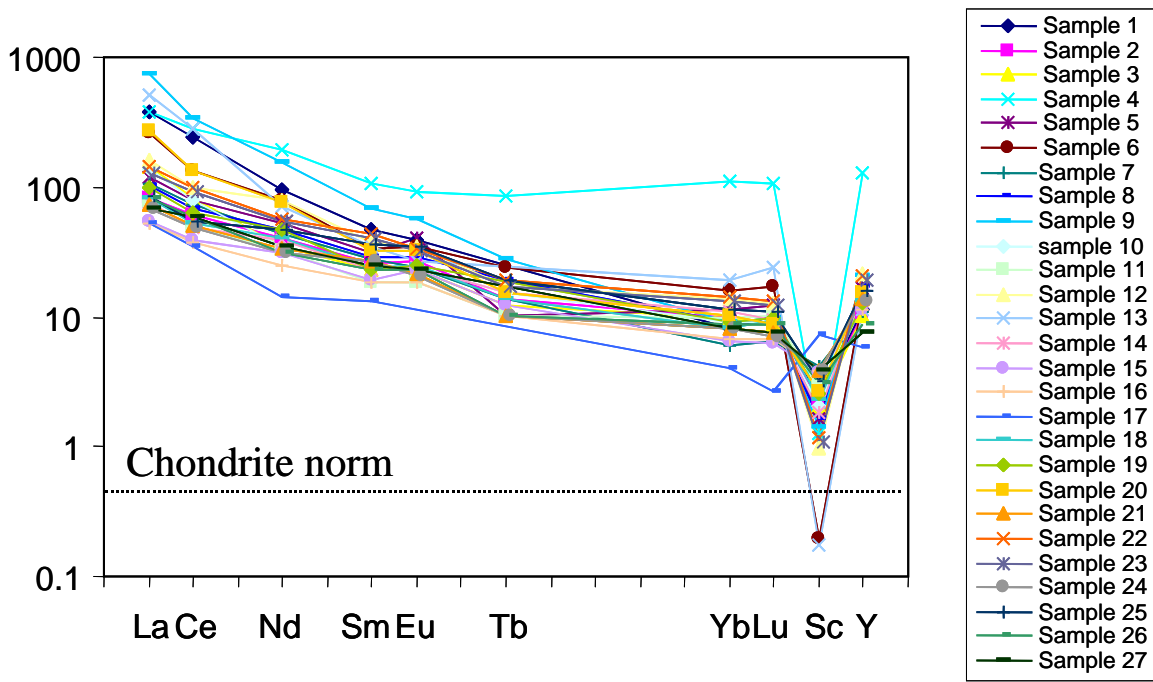


Figure 7. Normative plot – Normalized rare-earth element (REE) concentrations from mafic rock samples plotted against Chondrite Standard of Taylor and McLennan, 1985. All elements except scandium are enriched compared to the standard.

Felsic rocks REE ppm/Chondrite ppm

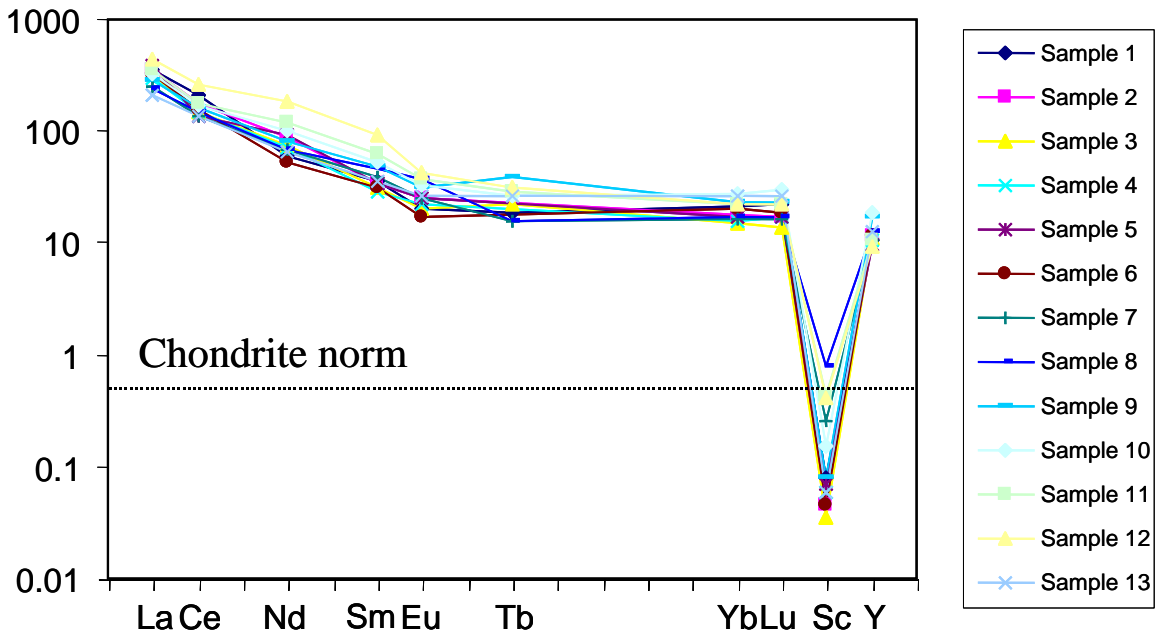


Figure 8. Normative plot – Normalized rare-earth element (REE) concentrations from felsic rock samples plotted against Chondrite Standard of Taylor and McLennan, 1985. All elements except scandium are enriched compared to the standard.

Diatreme? REE ppm/Chondrite ppm

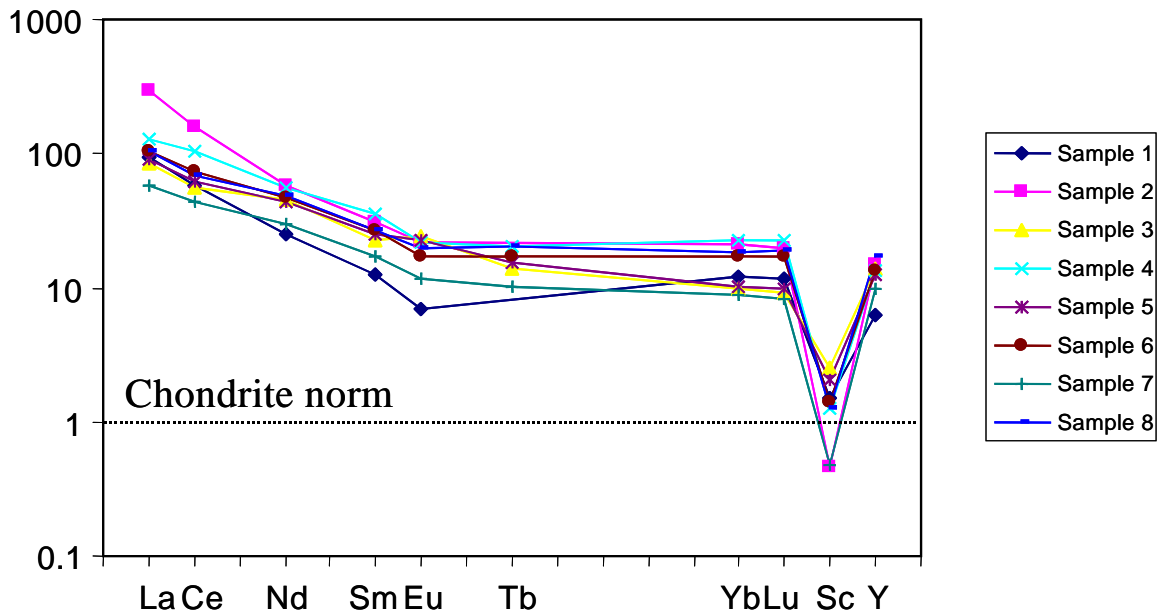


Figure 9. Normative plot – Normalized rare-earth element (REE) concentrations from diatreme rock samples plotted against Chondrite Standard of Taylor and McLennan, 1985. All elements except scandium are enriched compared to the standard.

EXPLANATIONS AND IMPLICATIONS

And, finally . . . just what was happening to this part of North America during the middle Eocene? Any explanation will have to address the following points: 1) the east coast of North America was a passive continental margin in the Eocene just as it is today; 2) to facilitate the igneous activity in the area, pre-existing, through-going faults and fractures were either reactivated or put under extensional stress; 3) deep-seated, upper mantle-derived magma was rapidly intruded along zones of weakness with little assimilation of country rock; 4) the porphyritic nature of many of the igneous rocks suggests a multi-stage cooling history *but*, the nearly ubiquitous presence of aphanitic groundmass implies that the final stage was rapid; and 5) today, there is no apparent expression of extrusive igneous activity.

We have evaluated a number of possible explanations from a variety of sources: 1) rift volcanism associated with the opening of the Atlantic – *the igneous activity is too young*; 2) convergence of regional lineaments and pre-existing faults and fractures resulting from reactivation of basement structures – *why does the passive margin undergo extensional stress and why does magmatism occur during the middle Eocene and no other time?*; 3) sediment loading of the continental shelf reactivates pre-existing faults and fractures – *same questions as for 2*); 4) asteroid impact in Chesapeake Bay reactivates pre-existing faults and fractures – *impact is too young (35 ma) except for Trimble Knob basalt*; 5)

rearrangement of global plate motion in the Tertiary reactivates pre-existing faults and fractures – *was this intense enough to both break the crust and produce magmatism?*; 6) North American Plate overrides the hinge of a subducting Pacific Plate producing reactivation of pre-existing structures and magmatism as the Pacific Plate melted – *hmmmmmm?* The last explanation (Grand, 1994) appears to have merit.

THE FIELD TRIP

Stop 1 (30 minutes): **Trimble Knob** – Basaltic volcanic neck or plug surrounded by volcanoclastic material – photo opportunity



Figure 10. Trimble Knob in Monterey, VA - a basaltic volcanic neck or plug.

Trimble Knob (Figure 10) is an obvious igneous feature. It has been variously described as a volcanic neck, a plug, and as a diatreme (Rader and others, 1986). The basalt here may have been more viscous than typical basalt lavas seen today in Hawaii or Iceland. Although this feature resembles basaltic cinder cones in the western United States, no cinders, ash beds, or lava flows are present.

Like many of the igneous bodies you will see today, the basalt core of Trimble Knob is surrounded or *mantled* by lithified volcanoclastic material, hence the interpretation of the feature as a diatreme. The suggestion is, that rapid and violent emplacement of the basalt to a near-surface position associated with the rapid release of fluids, shattered the country

rock adjacent to the basalt body. This produced a chaotic collection of fragments of country rock, basalt, and a finely comminuted matrix of rock flour, all of which lithified (Figure 11). Southworth and others, 1993 give a date of 35.0 ± 0.5 Ma for the basalt of Trimble Knob making it the youngest of all igneous rock units you will see today.

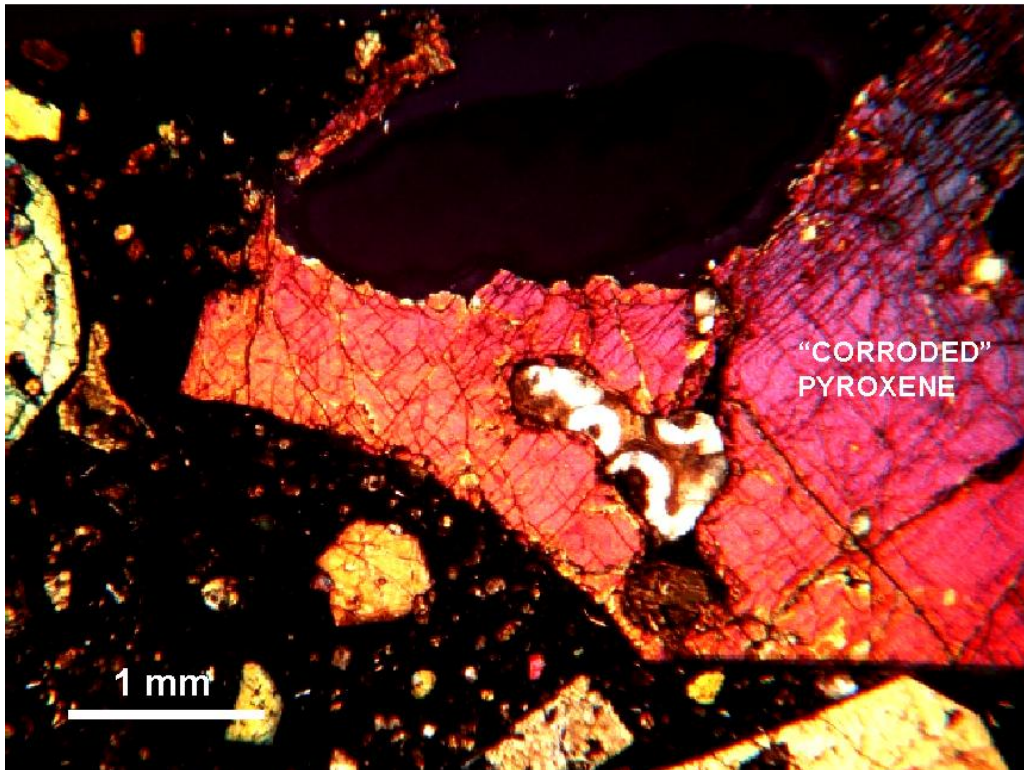


Figure 11. Color photomicrograph of diatreme material from Trimble Knob. Dark, very fine-grained matrix is typical. The botryoidal mineral filling the cavity within the pyroxene is an unidentified zeolite. Crossed polars.

Stop 2 (30 minutes): Bullpasture Mountain landslide – Geological hazard associated with older igneous activity

Looking north across US 250, you see an exposure of two Devonian shale units, the Needmore (to the west) and the Millboro (to the east). Adding to the already difficult task of keeping steeply dipping and strongly jointed rock units from breaking loose and falling onto the highway is the presence of the Tioga Bentonite. This altered, Devonian volcanic ash marks the contact between the Needmore and the overlying Millboro (Figure 12). Like all bentonites, the Tioga becomes very slippery when saturated with water. In 1998, a large volume of Millboro Shale collapsed onto the highway. The Virginia Department of Transportation attempted to stabilize the slope by removing all rock



Figure 12. Landslide initiated in the Tioga Bentonite, US 250, east of Monterey, VA. Strata of the Millboro Shale are sliding downhill along a waterlogged Tioga Bentonite. Concrete barriers have been erected to keep slide material off the highway. Ballast on the right covers an earlier Millboro slide scar.

material directly above the Tioga and covering the bare surface with rock ballast (Figure 13). Unfortunately, the contact between the Tioga and the Needmore is not a simple one. Several layers of volcanic ash are intercalated with the upper Needmore and the slip surface shown in Figure 12 is only one of a number of potential points of failure along this slope.

Stop 3 (90 minutes): Sugar Grove Sill-Dike – Igneous activity and its effect on country rocks

The hillside in front of you is formed by the silty shales of the Devonian Millboro Shale (section described in Woodward, 1943). As you exit the vans, examine the exposed



Figure 13. Rock ballast covers an earlier landslide surface in the Millboro Shale, US 250, east of Monterey, VA.

strata of the Millboro. If you are lucky (and the sunlight is just right), you may find the remains of small cephalopods, gastropods, and cone-shaped conularids (Figure 14), an extinct animal group of problematic nature, as well as the valves of tiny brachiopods. If you examine the brachiopods, you will see that they appear to have between three and four annual growth ridges parallel to the margin of their shell. This indicates that they are not the valves of immature individuals. Instead, these are probably the shells of adults. The same curious condition is exhibited by the tiny cephalopods – there may be at least five or more chambers (probably annual) present. This collection of depauperate, dwarf invertebrates is indicative of poor environmental conditions, probably low oxygen content in the waters in which the animals lived.

The Millboro Shale also contains spheroidal concretions of sandy carbonate. Concretions appear to form around buried dead and decaying organic matter as bacteria consume all the oxygen present within the sediment's pore waters. This change in chemical conditions can result in the precipitation of pyrite, calcite, or siderite (here) depending on the composition of the associated pore fluids. In some instances, fossils are found in the centers of concretions, but you will find that the concretions here are disappointing. At this locality, we have never found any fossils in the interiors of broken concretions. NOTE: similar concretions are typical of dark, organic-rich Devonian shales worldwide.

Originally flat-lying strata of the Millboro have been squeezed and tilted by forces from the east associated with the Appalachian Orogeny. The Millboro lies on the steep

east limb of a broad syncline whose axis is centered along the crest of Shenandoah Mountain visible to the east. Here, the Millboro is dipping approximately 60° to the

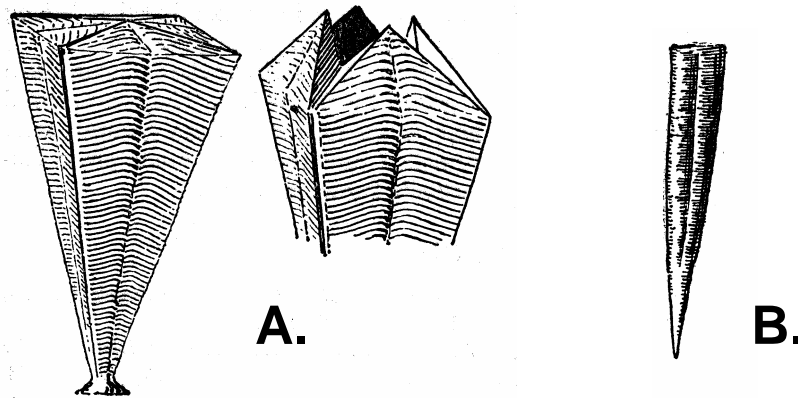


Figure 14. Sketches of - A) a reconstruction of *Conularia* sp. in growth position and B) a flattened specimen of *Styliolina* sp. Both organisms are classed as conularids. Since all representatives of this group are extinct and living relatives are unknown, the biological value of this group is dubious. However, these animals do make good index fossils for Lower Paleozoic rocks. Drawings to scale.

(Modified from Moore and others, 1952, Figure 11-3, p. 461)

southeast. The steep dip, associated with folding of the syncline, occurred while the Millboro was buried thousands of feet below the land surface. We believe this to be true because when rocks are subjected to compression, they are more likely to bend if they are confined or surrounded by an equally strong pressure. This confining pressure corresponds to the weight of overlying rocks (approximately 1 pound per square inch for each foot of overlying rock).

The Millboro also exhibits another kind of deformation. A number of nearly vertical joints cut across the rock and intersect to form two distinct sets at a 30° angle. This brittle deformation is seen when rocks are subjected to extensional forces tending to pull them apart *or* to compression with greatly reduced confining pressure. Without confining pressure, rocks will break and move relative to each other (faulting); when minimal confining pressure is present, rocks will fracture without movement (jointing). This suggests that the joint sets were formed by the compression of Millboro strata overlain by a greatly reduced thickness of rock – decidedly after folding had occurred.

Today, the Millboro has been exposed by an extensive period of erosion that has removed several thousand feet of Devonian through Mississippian sedimentary rock overburden. As at Stop 2, the exposed Millboro here is a geological hazard because the steeply dipping and fractured rock spalls off and slides down the dipping surface into the roadbed at the foot of the slope. You can see that the highway at this point and other spots along

our travel route has been built up on artificial fill and shows evidence of recent landslides and rock fall.

An additional geologic event has effected the rocks at this outcrop. Long after the Millboro was tilted, jointed, and much of the overlying strata removed, magma with a basaltic composition migrated upwards towards the surface and intruded these rocks. The dark reddish brown rock unit (Figure 15) exposed before you is not part of the Millboro Shale. It is a *sill-dike* of middle Eocene basalt dated at 43.1 ± 2.1 ma (Southworth and others, 1993).

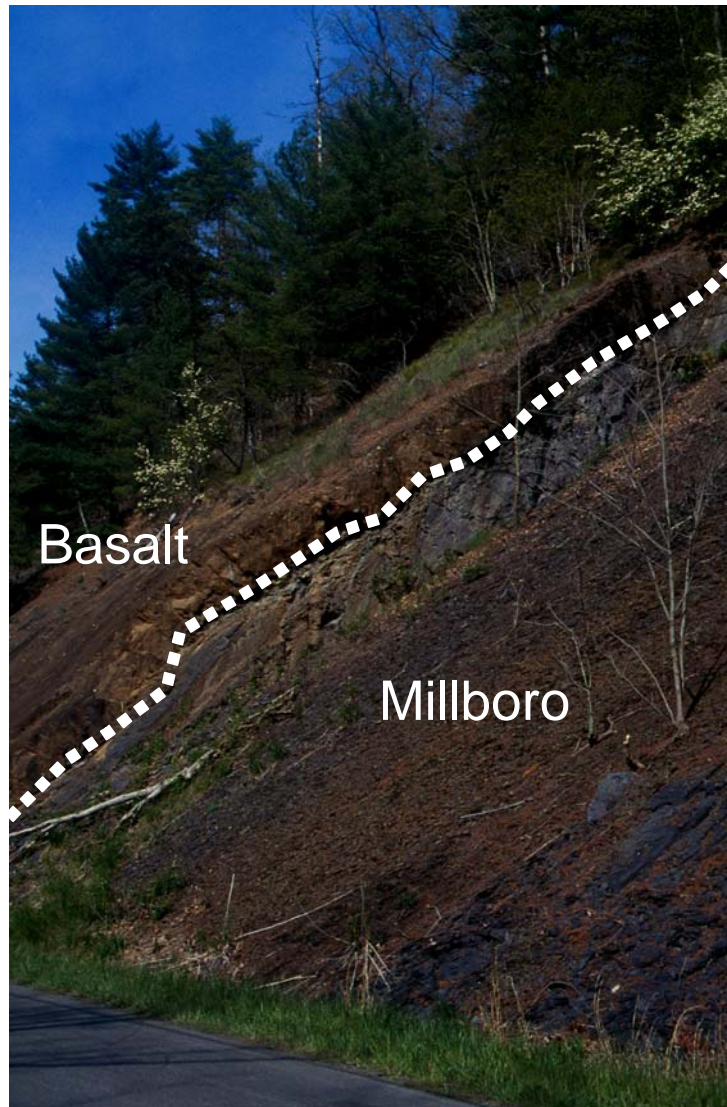


Figure 15. *Sill-dike* of porphyritic-amygdaloidal basalt overlying steeply dipping (60°) beds of the Millboro Shale. A thin ($< 1'$) zone of alteration separates the two rock units.

The shales of the Millboro immediately adjacent to the basalt take on a phyllitic sheen due to contact metamorphism. In addition, you will find small and large (up to 3 feet) diameter, irregularly shaped pieces of Millboro Shale that have been caught up in the basalt. These xenoliths clearly post-date structural deformation of the Millboro.

The igneous rock body observed here is unusual in that it changes *character* over the width of the outcrop. Igneous material first reached the near surface by moving upward along one of the large joints within the Millboro (Figure 16). At this point, the igneous body is a dike that cuts across the bedding of the Millboro at approximately right angles. As the igneous material got closer to the surface, it intruded between the bedding of the Millboro by simply pushing the layers of strata apart. This portion of the igneous body is a sill because it parallels the bedding of the country rock. During the latter stages of intrusion, broken pieces of Millboro Shale were picked up and included in the molten material as xenoliths. The igneous material cooled and the remainder of overlying sedimentary rock eroded away leaving the exposed sill-dike we see today.

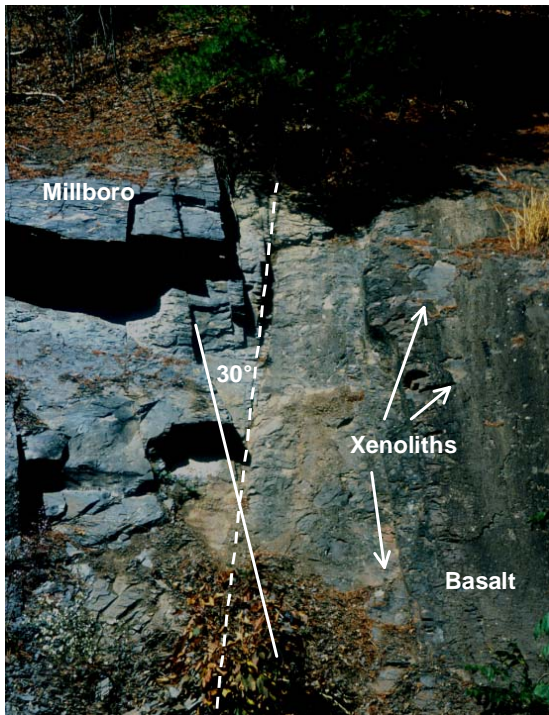


Figure 16. Contact between the Millboro Shale and the dike portion of the Sugar Grove basaltic sill-dike. The basalt has been intruded along a joint (dashed line). Notice that a second joint set intersects the first at a 30° angle. Also notice the xenoliths of Millboro caught up in the basalt.

There is another apparent paradox here. The igneous rock making up the sill-dike is a porphyritic, amygdaloidal basalt. It has the aphanitic groundmass of an extrusive volcanic rock as might be associated with a lava flow, yet we believe that it is intrusive. When igneous intrusions occurs within a few tens to a few hundreds of feet of the surface, cooling occurs rapidly at rates similar to those experienced by lava. This is

especially true when groundwater is present in the near-surface rock. The end result is a very fine-grained igneous rock texture such as we see here.

Basaltic magmas typically melt at 1000° to 1300° C (1800° to 2300° F) depending on depth of burial and water and gas content (Hyndman, 1972). The slightly phyllitic nature of the Millboro near the intrusive indicates contact metamorphism. It should be noted, however, that metamorphic alteration does not appear extensive here and it is possible that the temperature of the molten material was significantly cooler than those listed above. The north end of the sill is in direct contact with the underlying Millboro. A zone of alteration six to ten inches wide is present and is marked by a slight yellow coloration of the rock material. The underlying Millboro shows little alteration other than the phyllitic sheen observed elsewhere in the outcrop. More importantly, geochemical analyses of samples from the basalt of the sill-dike, the contact zone, and the adjacent Millboro Shale do not indicate any whole-scale transfer of trace or other metals from the basalt into the country rock which would be the case if a large volume of liquid was present in the magma or a large volume of groundwater was present in the country rock. Here, we see the effects of a *dry* emplacement. The resulting contact metamorphic features are related primarily to heating rather than hydrothermal alteration of the country rock.

If you examine the basalt, you will see that there are a number of vesicles and amygdules present. Many of the amygdules have been filled with crystals of calcite, quartz (Figure 17), and zeolites after the basalt was emplaced and was cooled or cooling. The number and size of vesicles and amygdules appear to increase upwards towards the exposed upper surface of the sill. The basalt itself consists of an equigranular, aphanitic groundmass of calcium plagioclase crystals with phenocrysts of euhedral biotite and euhedral to corroded pyroxenes, probably augite (Figure 18). The phenocrysts indicate that the magma stopped its ascent to the surface long enough for the larger crystals to begin to precipitate. The corrosion of the pyroxene crystals indicates that they were in disequilibrium with the rest of the magma as it rose closer to the earth's surface; they are partially resorbed. The aphanitic, *felted* groundmass of calcium plagioclase is the result of a final, relatively rapid stage of cooling near the surface.

Lastly, before we leave this site, notice the cylindrical holes drilled into the surface of the sill-dike. Small cores were taken from the basalt (Ressatar and Martin, 1980) using a diamond coring drill. These samples, carefully marked with their compass orientation with respect to the earth's magnetic north pole, were subjected to paleomagnetic analysis which yielded a middle Eocene date and confirmed the results of radiometric dating.

Stop 4 (45 minutes): Wilfong Church Gabbro Dike – Coarser-grained, mafic igneous rocks

The igneous rock exposed here is coarser-grained than at Stop 3 and probably should be classified as a gabbro based on its texture. Garnar (1951; 1956) referred to it as a diabase because of the predominance of calcium plagioclase over pyroxene (Figure 19). Both

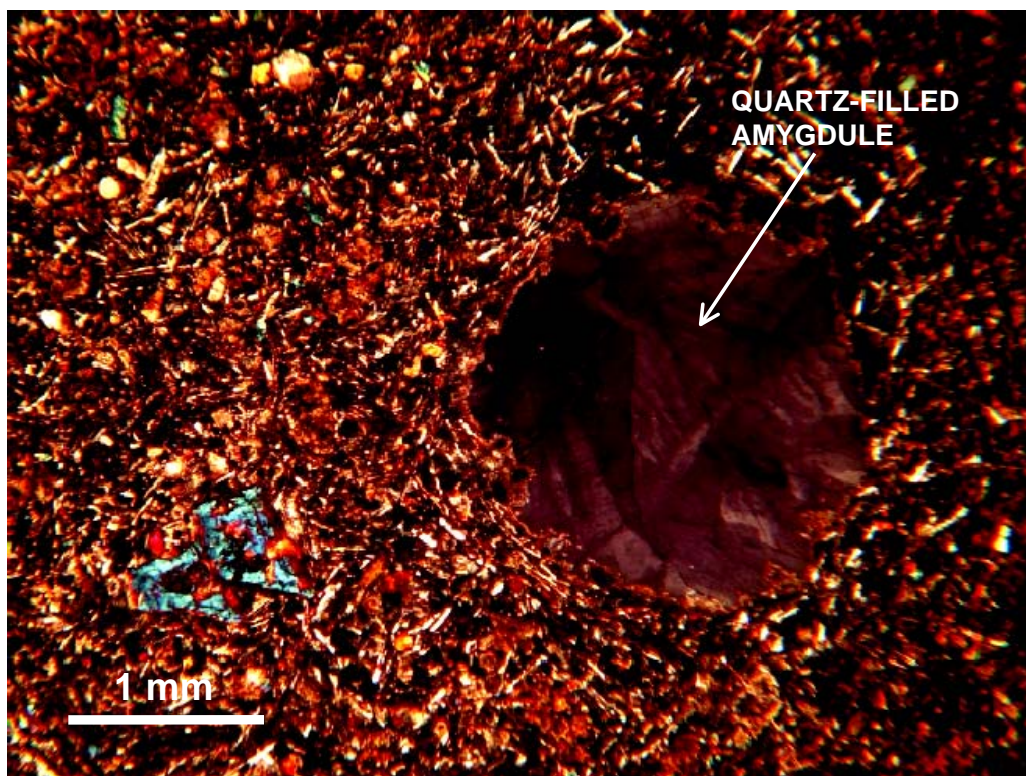


Figure 17. Color photomicrograph of amygdaloidal basalt from Sugar Grove. Quartz-filled amygdule is visible. Opaque minerals are probably magnetite. Crossed polars.

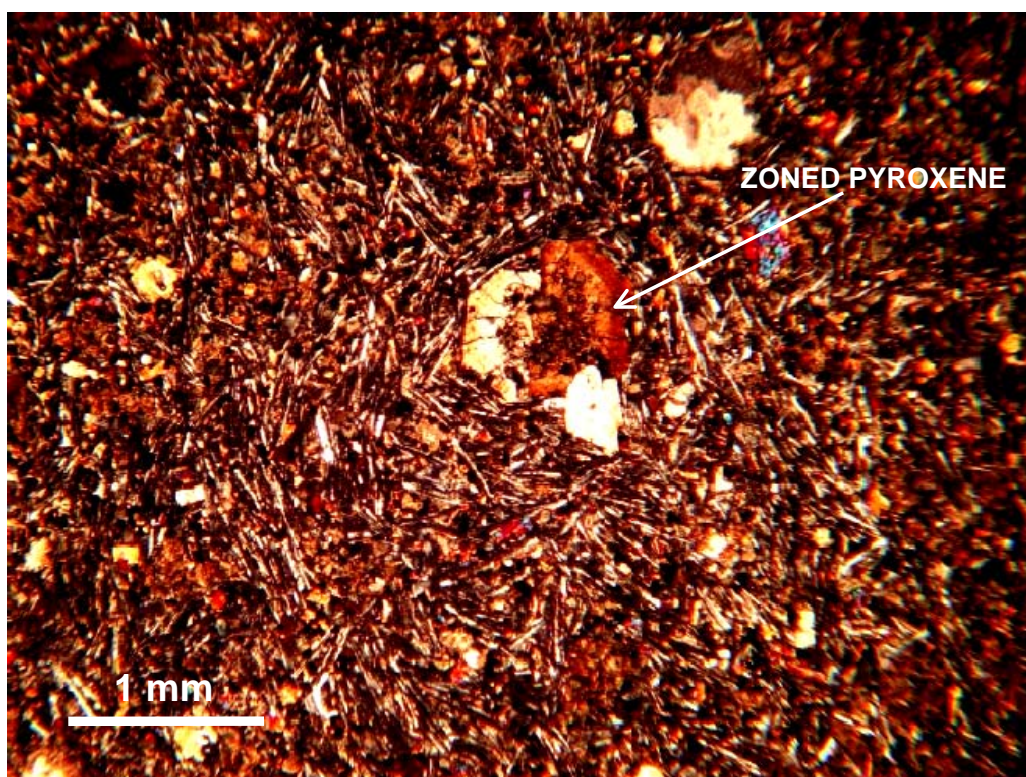


Figure 18. Color photomicrograph of amygdaloidal basalt from Sugar Grove. Euhedral pyroxene with compositional zonation is visible as is the groundmass of plagioclase with felted texture. Crossed polars.

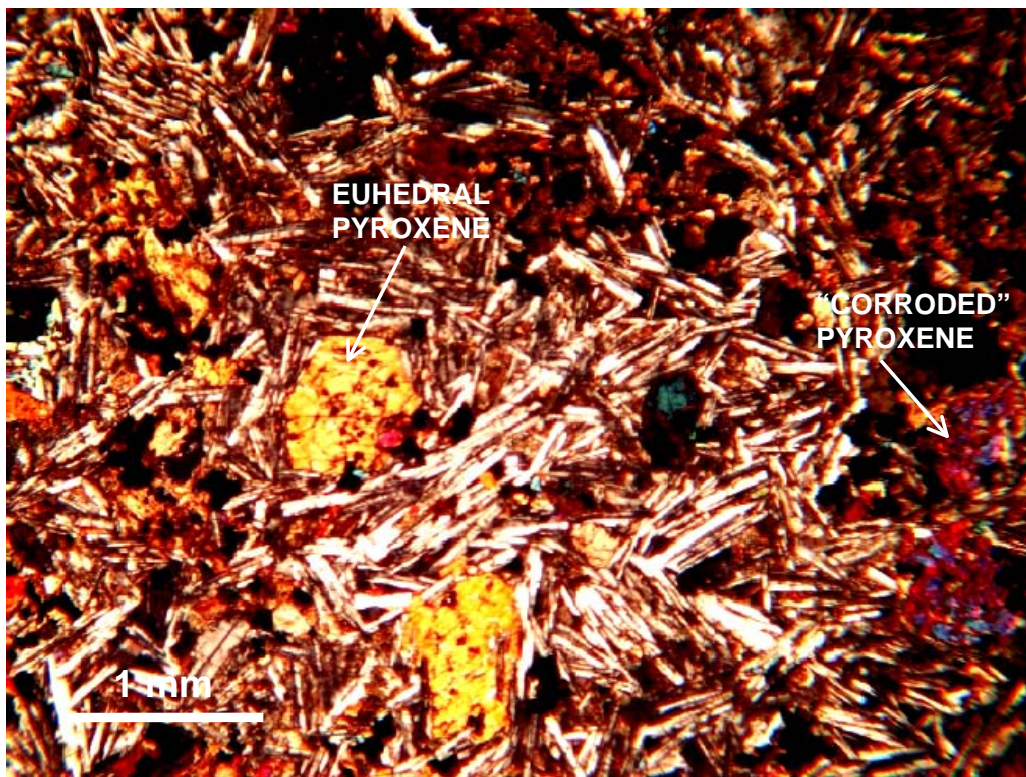


Figure 19. Color photomicrograph of gabbro from Wilfong Church. Pyroxenes suggest different times of precipitation. Euhedral crystals are late; corroded crystals are early. Crossed polars.

euhedral and corroded pyroxenes are present in this rock suggesting two stages of precipitation of these minerals with the euhedral crystals representing the later stage. This igneous material has not been dated but is assumed to belong to the middle Eocene group. NOTE: a mica pyroxenite dike dated at 143.8 ± 1.8 ma (Southworth and others, 1993) is present 1 mile to the east.

The very poorly exposed country rock here is Devonian Brallier Formation, an interbedded shale, siltstone, and sandstone unit that directly overlies the Millboro Shale. In fact, the contact between the two units is probably within 50 feet of the dike.

Stop 5 (60 minutes): Brushy Fork Creek Albitite dike – Felsic igneous rocks

The dike is exposed in the streambed and water may be high so *be prepared to get your feet wet.*

Ugly Mountain, the prominent feature to the west (Figure 20), is a middle Eocene plug or volcanic neck with a diatreme breccia near its top and on its west flank (Garnar, 1951; 1956). The rock that you are standing on is one of several dikes that radiate out in an easterly direction from Ugly Mountain. The dike (Figure 21) here is approximately 20 to

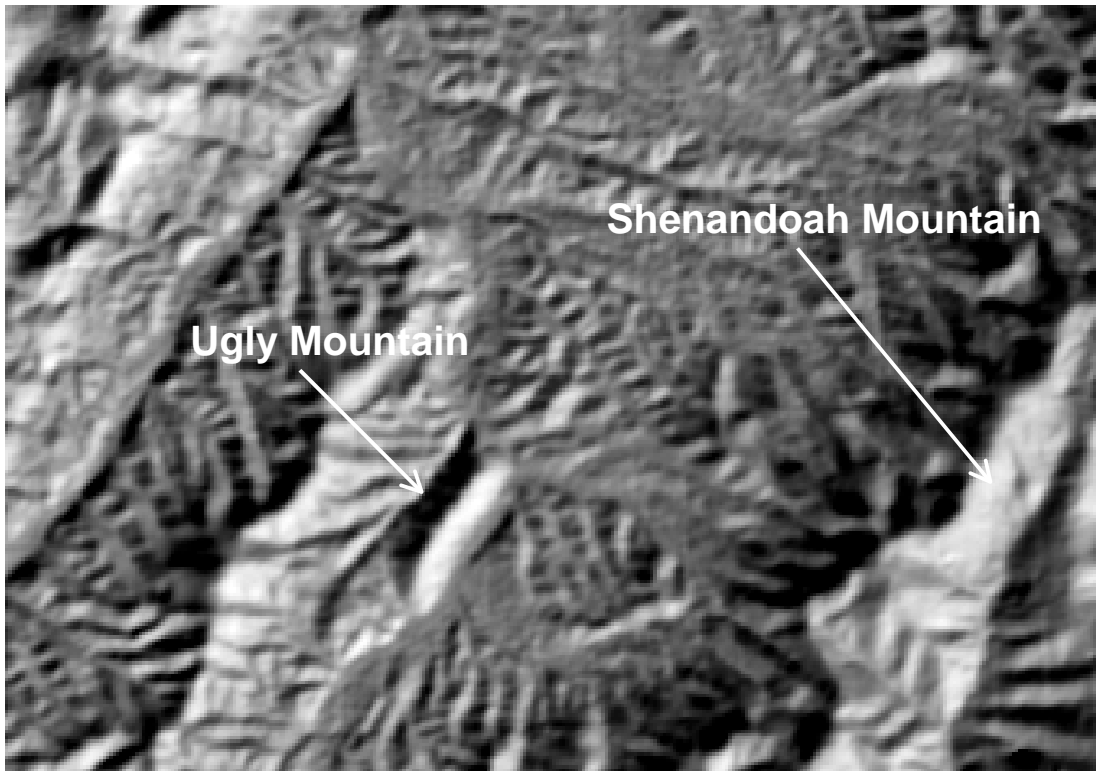


Figure 20. DEM image of Ugly Mountain and vicinity, southern Pendleton County, WV. Although not very impressive from the ground, Ugly Mountain has the highest relief of any topographic feature in the area except Shenandoah Mountain to the east.



Figure 21. Dike of albitite (>95% Na-plagioclase) exposed in Brushy Fork Creek. Unit is approximately 25' wide.

25 feet wide, trends N83°E, and has been dated at 42.8 ± 0.5 ma (Southworth and others, 1993). The light orange to pinkish color of the dike is a product of weathering. If you break off a piece of the rock, you will see that it has a thick, brown weathering rind with occasional dark blue or steel grey mineralized bands. The latter are probably pyrolusite, a common secondary mineral in this area; it precipitates out of near-surface groundwater. Fresh samples of this rock are nearly white or yellowish white in color. The texture is aphanitic and several people (including experienced geologists) have been fooled into thinking that this is a very fine-grained quartz sandstone. You will be hard pressed to see any visible crystalline minerals (except micas), even with a good hand lens. In thin section, this unusual rock consists almost entirely (> 95%) of a felted mat of equigranular, euhedral crystals of albite (sodium plagioclase) (Figure 22), a smattering of small mica crystals, and rare crystals of ilmenite. The absence of quartz, small number of mafic minerals, and the fine grain size suggests that this rock is properly named a rhyolite or dacite but because of the unusually high content of sodium plagioclase, the rock was termed an *albitite* by Garnar (1951; 1956).

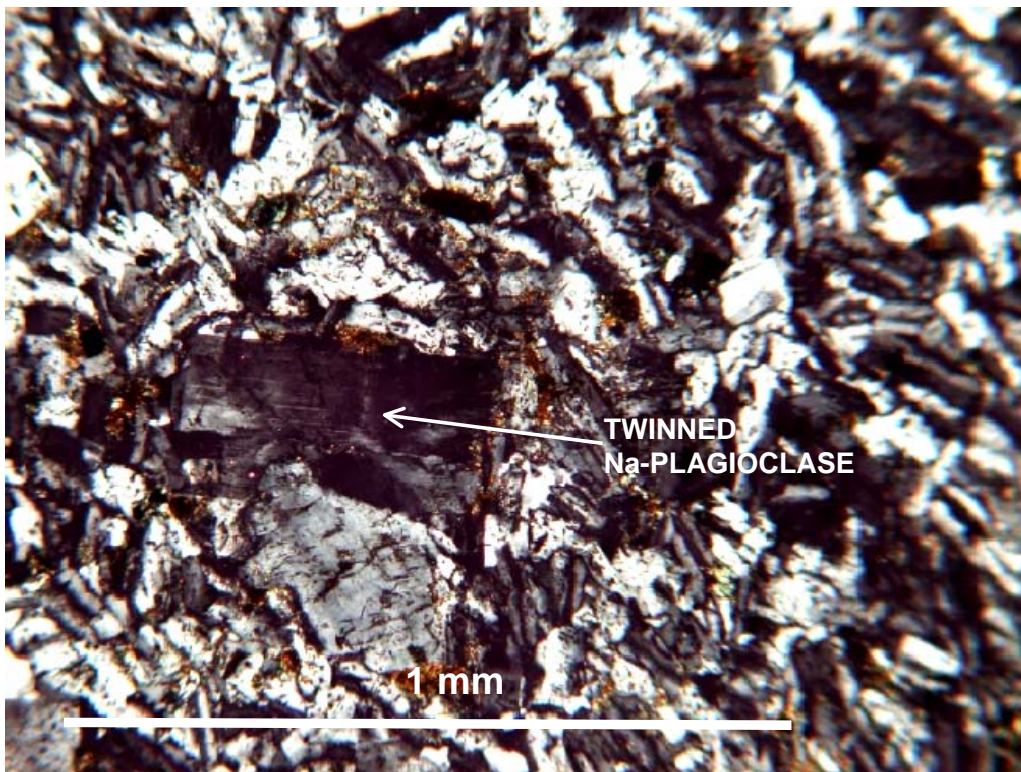


Figure 22. Color photomicrograph of sodium plagioclase-rich albitite from Brushy Fork Creek. The felted texture is due to the intergrowth of plagioclase crystals. Crossed polars.

Another feature of this rock that has fooled several geologists into thinking that it is a sandstone is the presence of parallel foliations which resemble bedding. In reality, these layers are shrinkage cracks resulting from differential cooling. The final clue that this is not bedding is the orientation of the dike itself. Country rock here consists of shales and

siltstones of the Devonian Brallier Formation. The Brallier, visible approximately fifty feet downstream, is dipping steeply towards the southeast at 50°. The albitite dike has been intruded into a fracture and cuts across strike at a 52° angle. If the dike were really a sedimentary formation, it should lie parallel to strike.

Also of note here are a number of core holes drilled for paleomagnetic analysis (Ressatar and Martin, 1980). Results, again, confirmed the middle Eocene age of this igneous body.

Stop 6 (60 minutes): Hull Farm Basalt and Diatreme – Basalt, volcanoclastic rocks, and a reactive contact with the country rocks

Exposed in the creek bed to the north of the road is an unusual rock unit previously described as a diatreme breccia (Kettren, 1970) and as a volcanic breccia (Garnar, 1951; 1956). A volcanic breccia is a deposit of angular pieces of volcanic and country rock that can form in several ways. The more common of these include:

- 1) a gas or steam explosion forcibly ejects shattered bedrock fragments, volcanic rock, and ash into the air which subsequently fall back into the crater – the material is still hot and is typically welded together because the volcanic rock fragments and ash may be close to melting temperature - this is an explosion, fallback, or diatreme breccia (Figure 23) and is extrusive in nature;
- 2) a sudden withdrawal of magma from beneath a volcano can so stress the country rock and any volcanic deposits on top of it that the entire structure collapses into the magma chamber – again, the jumble of angular debris may be welded together - this is a collapse breccia and has no extrusive component to its formation.

The key feature of these types of volcanic deposits is the *angular* pieces of volcanic and country rock (making it a breccia rather than conglomerate), the presence of ash, and the lack of any evidence of flow – either flow layering or flow lineations.

The dark-colored rock unit in the streambed has several features that appear to be at odds with the interpretation of the unit as a diatreme breccia. The rock itself is a boulder mudstone or volcanoclastic conglomerate consisting of a dark matrix of very fine-grained material surrounding and supporting a large number of rock fragments. These rock fragments are polymict and most are rounded. The most obvious fragment that you see before you is a boulder of porphyritic basalt approximately four feet in length (Figure 24). Also present along with it are cobbles and pebbles (Figure 25) of the porphyritic basalt, clasts of the fine-grained matrix material, of light grey limestone (Devonian Helderberg), and of light grey quartz sandstone (Devonian Oriskany); in general, these are sub-rounded to rounded. There are weak indications of flow layering in the unit in



Figure 23. Eocene diatreme or fallback breccia in an active gold mine, Victor, CO. Notice the cone-shaped vent area and the large pieces of brecciated material that have fallen back into the vent after being ejected. The prospect shaft (circular hole) in the lower left corner of the photograph is approximately three feet in diameter.



Figure 24. Unit described previously (Kettren, 1970 and others) as a diatreme or volcanic breccia. The rounded clasts suggest that it may be a lithified lahar deposit - it is certainly not a breccia. The elongate clast in the center of the photograph is porphyritic basalt similar to dikes seen elsewhere on the Hull property.



Figure 25. Exposed surface in volcaniclastic deposit, stream bed just south of the Hull residence. Various clasts are identified as to their origin.



Figure 26. Exposed surface in volcaniclastic deposit, stream bed just south of the Hull residence. Flow is suggested by the concentration of pebbles (a lag deposit?) on this surface.

the form of rare, horizontal surfaces covered with small (less than ½ inch in diameter) pebbles (Figure 26). These may represent a lag deposit.

So what is this unit? The leaders of the field trip (McDowell, anyway) speculate that this unit is actually the lithified remains of a *lahar* deposit (Figures 27). A lahar is a debris or mudflow produced contemporaneously (usually) with extrusive volcanic activity. Volcanic events typically create a strongly localized weather anomaly associated with violent rainfall in the vicinity of the volcano. Heavy rainfall mixes with volcanic ash and any loose volcanic debris and soon produces a gravity flow with the consistency of wet concrete and as much momentum as the gradient of the volcano's slope will allow. Modern lahars sweep up trees, buildings, houses, and pieces of country rock as they move rapidly downhill. Because a lahar can contain a large amount of freshly erupted volcanic material, the temperature of the lahar deposit may be close to the boiling point of water. A solidified lahar should be a collection of fragments of various sizes and shapes (both rounded and angular), including boulders, caught up in a very fine-grained matrix, lithified into a material resembling concrete, and perhaps showing some flow structures. That description seems to fit the unit you see before you.

The general consensus is that no extrusive volcanic activity was associated with the middle Eocene igneous events in this area. The possible presence of a lahar deposit may suggest otherwise. We think that it may take drilling or geophysical survey work to finally answer this question.



Figure 27. Close-up of an Eocene lahar deposit from the 39-Mile Volcanic Complex in Colorado. Clasts include basalt, granite, and assorted small sedimentary rock fragments. Coin is 3 cm in diameter.

In the hillside just to the east of the Hull residence, we can observe the contact between volcanoclastic material (perhaps not the same as exposed in the stream bed to the south) and country rock (either Devonian Helderberg Formation or Oriskany Sandstone). Uncertainty as to the identity of the country rock is due to the fact that all carbonate has been removed from the rock leaving only a siliceous *skeleton*. In any event, the interaction between country rock and volcanoclastic material was a very reactive one and suggests that the volcanoclastic material may have been very hot, contained acidic fluids, or both.

A porphyritic basalt dike is exposed in the small valley to the north of the Hull residence. This igneous body protrudes from the ground to a height of approximately four feet and is roughly two feet wide (Figure 28). Large, euhedral pyroxene phenocrysts up to ½ inch in diameter are visible and abundant (Figure 29). In thin section (Figure 30), these phenocrysts may be euhedral or corroded.



Figure 28. Dike of porphyritic basalt exposed just north of the Hull residence near Doe Hill, Virginia. Dave Matchen (one of the coauthors) for scale.

Typical of most of the igneous bodies in the area, this dike is surrounded by volcanoclastic material. Clasts within this material may be rounded or angular and the *rubbly* weathering style is also typical. We have held several debates amongst ourselves as to whether the dike is exactly contemporaneous with the volcanoclastic material. Is the volcanoclastic material an emplacement breccia as suggested at Trimble Knob? Did the



Figure 29. Photograph of the dike in Figure 27 showing large, euhedral pyroxenes and a few vesicles. Coin is 3 cm in diameter.

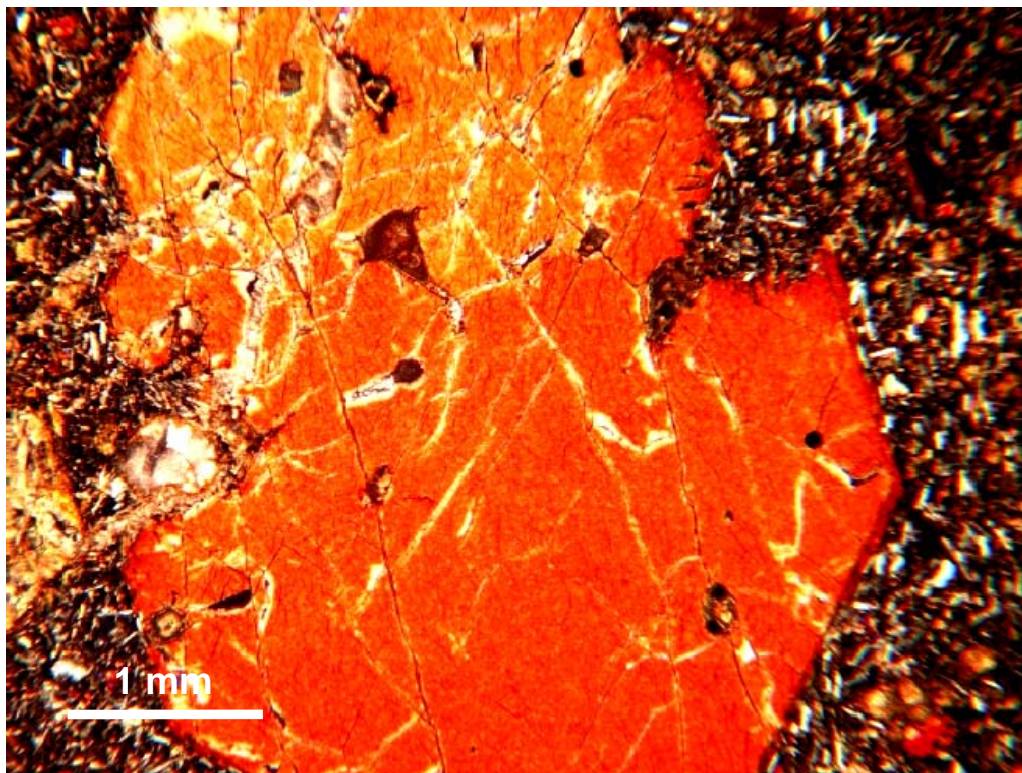


Figure 30. Color photomicrograph of the basaltic dike from the Hull property showing a large pyroxene phenocryst with corroded margins. Groundmass is predominantly calcium plagioclase.

dike intrude existing volcanoclastic debris? Is the volcanoclastic material part of a lahar deposit that flowed around the dike? What was the surface topography like in the Eocene? Could we be seeing the remnants of an extrusive igneous event here? Is it possible that the Eocene landscape looked similar to that seen in Figure 31 and that 35 to 50 million years of erosion have reduced it to the surface we see today?

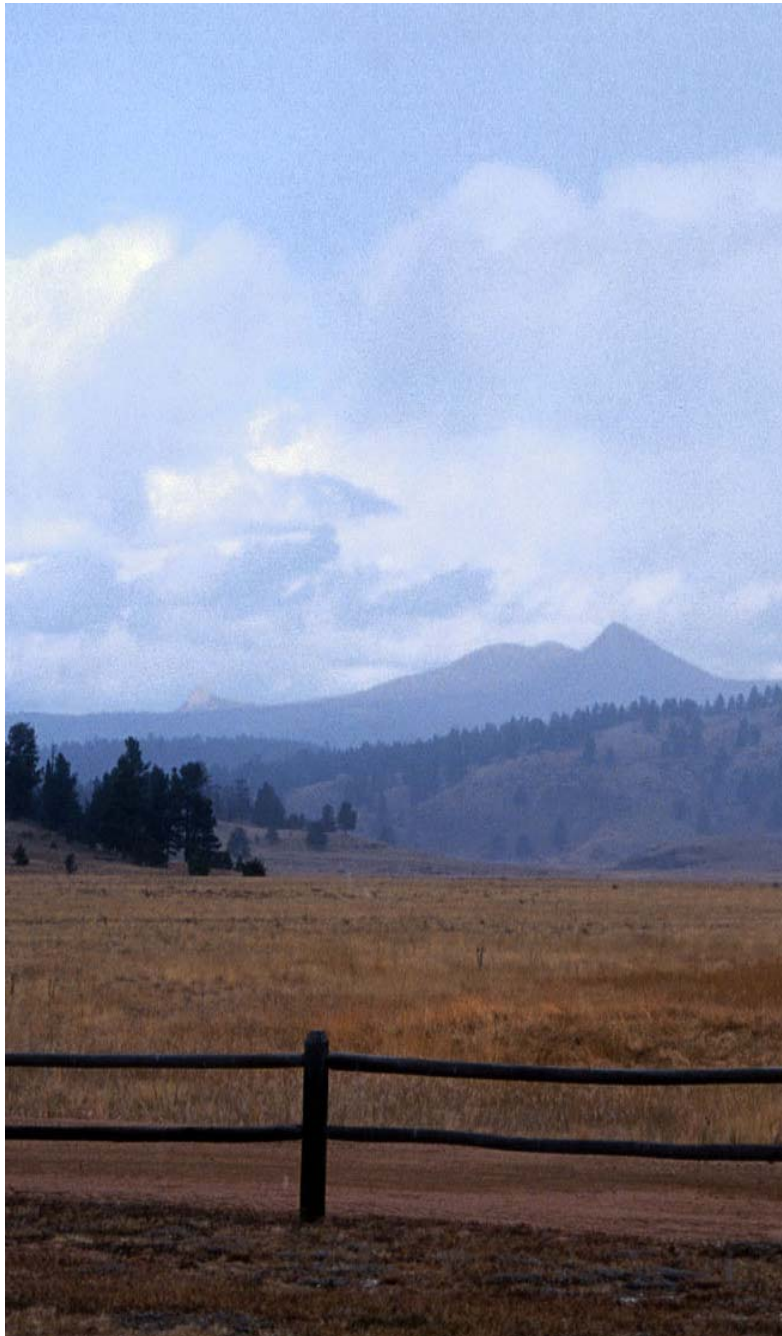


Figure 31. View of the middle Eocene, 39-Mile Volcanic Complex southwest of Denver, Colorado. The arid and sparsely vegetated climate has preserved extrusive igneous materials.

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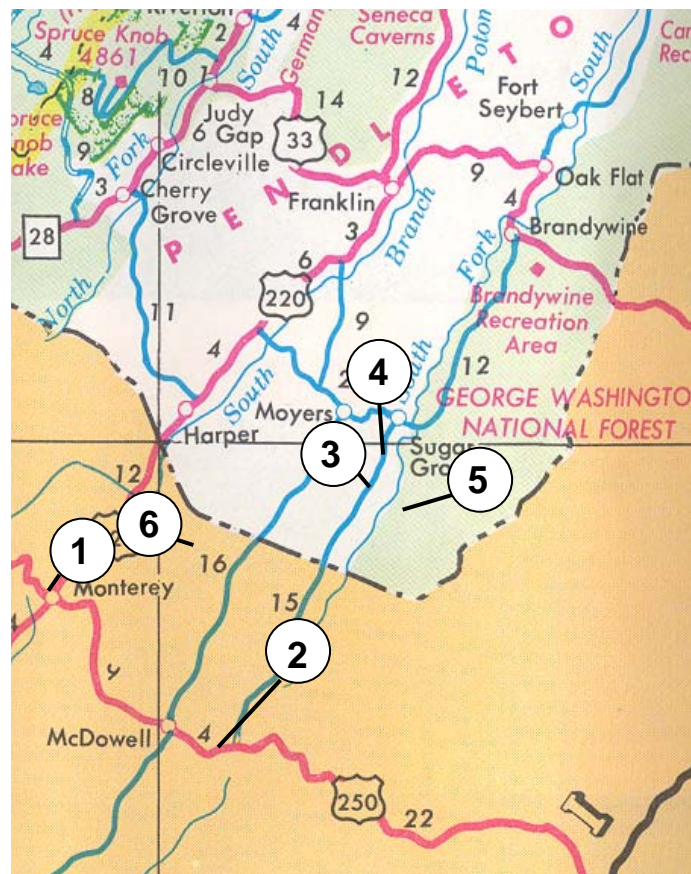
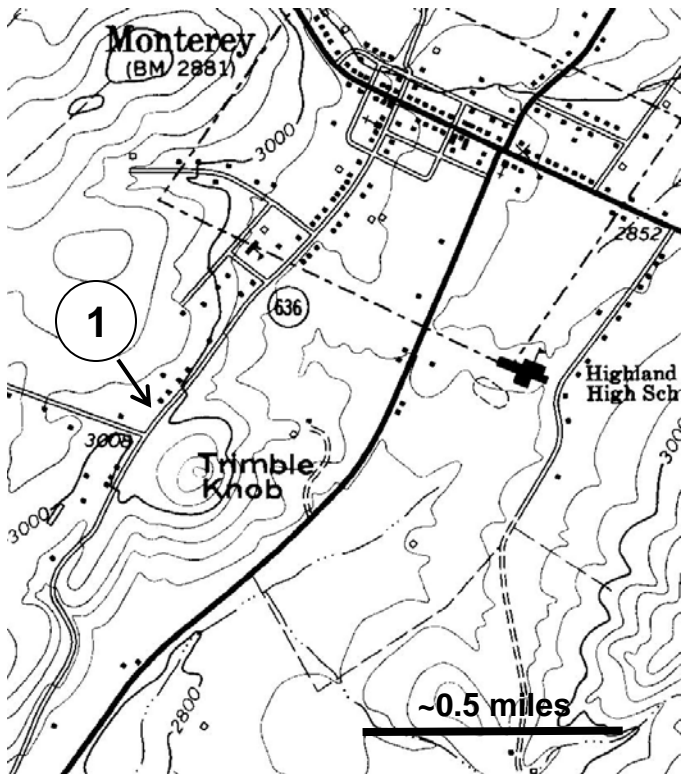


Figure 32. Portion of the West Virginia Highway Map showing the general locations of all stops on this field trip. Not to scale.

ROAD LOG (refer to Figure 32) PGS Spring Field Trip, April 26, 2003

Incremental Mileage	Total Mileage	
0.00	0.00	Depart Montvallee Motel via west entrance. Turn left (south) on U.S. 220. Make an immediate right onto Virginia Route 1002.
0.15	0.15	Stop sign. Turn left and follow the continuation of Route 1002. A felsic dike was exposed (John Dennison, personal communication) when the Word of Faith Church parking lot (on left) was excavated.
0.15	0.30	Turn left on Virginia Route 636 at stop sign.
0.25	0.55	Highland Center (former school). Vans will drop passengers off and return here to park.
0.30	0.80	Junction of Route 1002 and 621. Vans turn around here.

STOP 1 – Trimble Knob photo opportunity – **30 minutes**. Location map from Monterey 7 ½ minute topographic sheet.



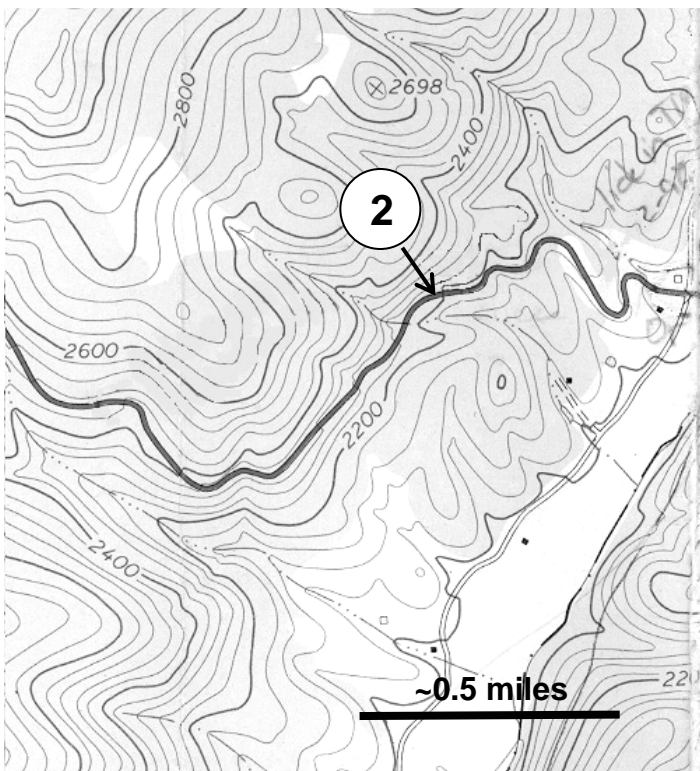
0.30	1.10	Reboard vans in front of Highland Center. Retrace route on Route 636 to junction with U.S. Route 250 beside Highland County courthouse.
0.40	1.50	Junction of Route 636 and U.S. Route 250. Turn right (east) on U.S. 250 and proceed through Monterey.
0.20	1.70	Junction of U.S. Route 250 and U.S. Route 220. Continue east on U.S. 250.
1.95	3.65	Summit of Jack Mountain.
0.35	4.00	Outcrop of Rose Hill on right (south) side of U.S. 250 contains many trace fossils.

1.80	5.80	Outcrop of Tuscarora Sandstone on right (south) side of U.S. 250.
1.60	7.40	Blocks of Tuscarora talus on right (south) side of U.S. 250.

0.70	8.10	Outcrop of Tuscarora on left (north) side of U.S. 250.
0.60	8.70	Outcrop of Tuscarora on left (north) side of U.S. 250.
1.30	10.00	Outcrop of Devonian shale on left (north) side of U.S. 250.
1.05	11.05	Village of McDowell.
0.20	11.25	Intersection of U.S. 250 and Virginia Route 654 (Doe Hill Road). Continue east on U.S. 250.
0.35	11.6	Cross Bullpasture River. Outcrop of Helderberg Limestone on left (north) side of U.S. 250 just east of river.
2.55	14.15	Summit of Bullpasture Mountain.
0.40	14.55	Outcrop of Helderberg on left (north) side of U.S. 250.
0.45	15.00	Outcrop of Helderberg on left (north) side of U.S. 250.
0.55	15.55	Outcrop of Needmore Shale on left (north) side of U.S. 250.

Park on right (south) side of U.S. 250.

STOP 2 – Bullpasture Mountain Landslide, U.S. 250 – **30 minutes**. Location map from McDowell 7 ½ minute topographic sheet.



Reboard vans and continue east on U.S. 250.

0.10 15.65 Junction with Virginia Route 614. Turn left (north) on Route 614 toward Sugar Grove. Drive more or less along strike in the Devonian shale-floored valley of the Cowpasture River.

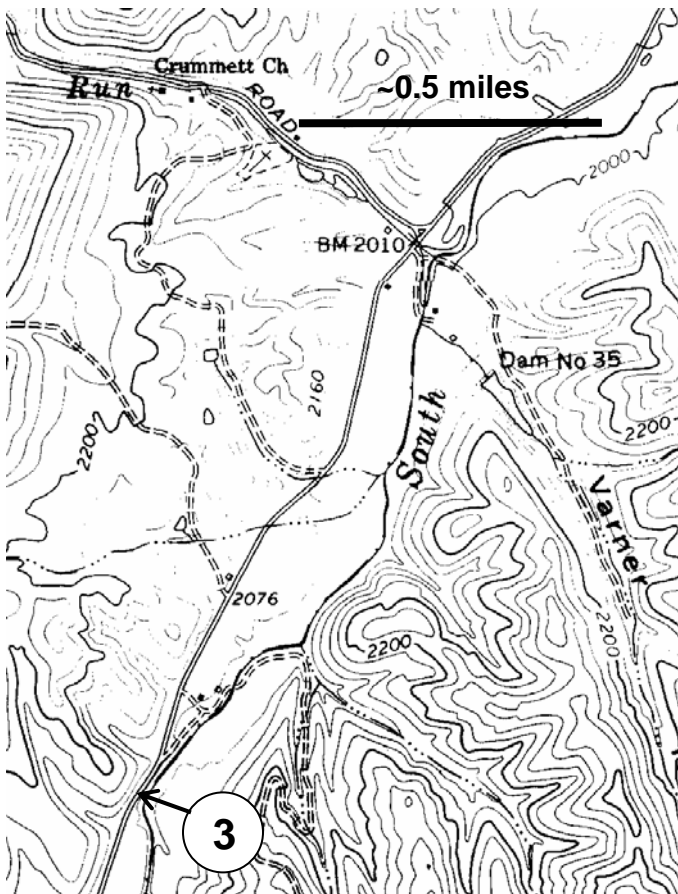
0.70 16.35 Devonian shale outcrop on left (west) side of Route 614.

7.80 24.15 Junction with Virginia Route 620 on right. Continue north on Route 614.

0.35 24.50 West Virginia State line. Now on Sugar Grove Road (Route 21).

1.70 26.20 Park vans on left (west) side of Route 21 for STOP 3.

STOP 3 – Sugar Grove sill-dike – **90 minutes**. Location map is from the Palo Alto 7 ½ minute topographic sheet.



Continue north on Route 21.

1.10 27.30 Junction with Crummetts Run Road to left (west). Continue straight ahead on Route 21.

1.40 28.70 Park vans on right side of road at Wilfong Church and cross road to examine outcrop on left (west) side of road.

Continue north on Route 21.

0.25 28.95 Junction with Brushy Fork Road (Route 30). Turn right (east) on Route 30.

0.90 29.85 Brushy Fork dam spillway. In the aftermath of Hurricane Fran in 1996, all of the material covering bedrock in the spillway was washed away, which for a brief time, left a nice bedrock exposure of part of the Foreknobs (Figure 33). Unfortunately, the Natural Resources Conservation Services

(formerly Soil Conservation Service) replaced the fill and re-seeded the spillway (Figure 34).

STOP 4 – Wilfong Church gabbro dike – **45 minutes**. Location map is from the Palo Alto 7 ½ minute topographic sheet.

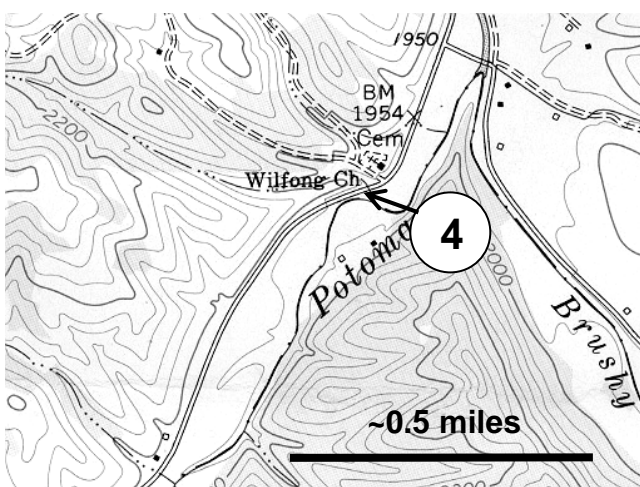




Figure 33. Eroded spillway following heavy rains from Hurricane Fran (Sept. 1996) and overtopping of Brushy Fork soil conservation dam just to the south. The exposed rock unit in the foreground is the Devonian Foreknobs Formation.

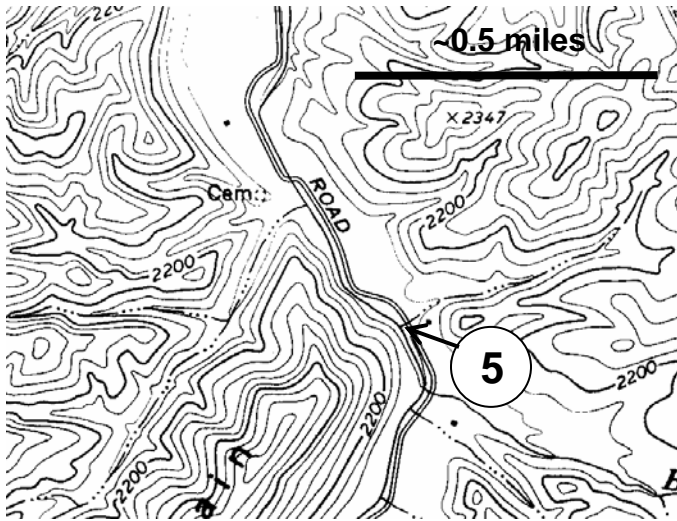


Figure 34. Spillway at Brushy Fork dam after repair, approximately one year later. Photograph was taken in the same direction as in Figure 33 but from about 50 feet east up the spillway. All Foreknobs strata have been covered by ballast.

Continue ahead on Route 30.

1.85 31.70 Albitite exposed in creek bed to right (east) of road. Park vans near driveway for Brushy Fork Church and walk back down road to creek bed.

STOP 5 – Brushy Fork Creek albitite dike – **60 minutes**. Location map is from the Palo Alto 7 ½ minute topographic sheet.



Reload vans, turn around and retrace route to Route 21.

2.95 34.65 Junction with Route 21. Turn right (north) on Route 21.

2.15 36.8 Outcrop of Oriskany Sandstone on left (west) side of road.

0.70 37.5 Junction with Moyer Gap Road (Route 25) at village of Sugar Grove. Bear right at stop sign to continue north on Route 21

1.25 38.75 Roadside park on left (west) side of road. Pull in and park for **LUNCH STOP**.

1.25 40.00 Retrace route to Junction with Moyer Gap Road (Route 25) at Sugar Grove. Turn right onto Moyer Gap Road.

3.45 43.45 Junction with Doe Hill Road (County Route 23). Bear left (south) on Route 23.

6.35 49.80 State line. Enter Virginia. Route 23 becomes Virginia Route 654.

6.00 55.80 Junction with Route 622 at village of Doe Hill. Continue on Route 654.

0.05 55.85 Junction with Route 624. Turn right on Route 624.

1.40 57.25 Park on right side of road.

