The National Association of Geoscience Teachers

Eastern Section Spring Conference
May 15-18, 2014

Hosted by James Madison University, Harrisonburg, VA

"A Billion Years Between Friends: A Record of Earth Systems in the Virginia Blue Ridge, Piedmont, and Valley & Ridge"

Eric J. Pyle, Department of Geology & Environmental Science, Conference Host

Contact Eric Pyle, conference coordinator at: pyleej@jmu.edu

Harrisonburg, VA, is situated in the middle of the Shenandoah Valley, in a broad section of the "Great Valley" of Virginia. Flanked on both sides by mountains reaching nearly 3500 feet high, the Valley is rich in history from the 1730's up through the Civil War and beyond. Originally settled by German Moravians and Ulster-Scots Presbyterians, the geology of the region has supported extensive agriculture as well as base-metal extraction. But these historical facts are just the tip of the iceberg, so to speak.

While the Valley itself is represented by early Paleozoic sedimentary rocks, the Blue Ridge Mountains to the east are built of billion-year old twice-metamorphosed rocks, capped by 600-million year old greenstones. Continuing to the east, one crosses the iron-rich soils upon which Thomas Jefferson and James Madison built their homesteads and into the Triassic basin rocks on the flanks of the Piedmont. And then things get really messy! But if one travels west across the Valley, one passes through a younger, structurally diverse suite of early and middle Paleozoic rocks that form the Valley & Ridge. But the story does not stop there – the Valley hosts a number of unmistakably volcanic features, which date to the Paleogene.

Our event this year will attempt to capture this range of ancient and more contemporary features with a range of activities. Thursday night will include a light reception followed by an exclusive show in the John C. Wells Planetarium, presented by Shanil Virani. Friday morning provides the opportunity for you to share your newest and best ideas for teaching Earth science during the concurrent sessions. At the same time, the JMU Mineral Museum will be open for your viewing enjoyment.

Friday afternoon offers you a choice of events – first, IRIS has offered to provide an educator workshop, which is significant considering the recent Louisa M5.8 earthquake. IRIS offers the following description of their workshop: *This workshop would introduce faculty to a collection of recently developed inquiry-based, data-rich classroom modules. These modules introduce undergraduates to core geoscience concepts, while also showcasing areas where modern seismological research actively contributes to our understanding of fundamental Earth processes. Modules, rooted in seismology, ultimately convey a variety of topics commonly included in introductory geoscience classes. How do faults slip? How does the near surface environment affect natural hazards and resources? How do magmas ascend and erupt? How do processes in the ocean and atmosphere interact with the solid*

Earth? What is the lithosphere-asthenosphere boundary? Where are water and hydrocarbons hidden beneath the surface? Also includes: Transcending nomograms and the S-P method: Modernizing the seismology you include in your 100 and 200 level geoscience courses. Presented by Melissa Driskell, U. North Alabama and Michael Hubenthal, IRIS Consortium.

If the field is more of a draw for you, then we have a local field trip as the other choice for Friday afternoon, which features two stops. Frazier Quarries will provide a local plant tour in the Edinburg Limestone quarry, from which the bulk of the original JMU campus is built. Frazier Quarries local plan shows not just a wonderful dark micrite that weathers light gray, but it also shows complex secondary calcite veins, some of which contain purple fluorite. The second stop will be a brief hike up Mole Hill, an Eocene volcanic neck composed of basalt last with mantle-sourced olivine and spinel. This trail is on private land and is unimproved, but collecting is allowed in each location.

Friday dinner will be on your own, but we will cap the day with the annual Geo-Auction.

Saturday offers a choice of day-long field trips. **Trip 1** takes us into the distant past, traversing the late-Proterozoic metavolcanic rocks, into the core of the Blue Ridge, and then on into the Piedmont, including some of the diverse terranes that were accreted onto the flanks of Laurentia. **Trip 2** will also start at the Blue Ridge, but travel west across the Page Valley and Massanutten Mountain, ending in the peaks of the Valley & Ridge. For each trip, we will filter the experience through the complexity of Earth systems. Collecting is allowed at some, but not all locations.

✯ ✯ ✯ **Significant new conference feature not listed in Winter 2014 Bulletin**: Attend the section meeting at JMU the weekend of May 15-18 and automatically be entered to win a collection of Rocks, Minerals and Fossils valued at over $500 ! Eastern section member Steve Lindberg will bring a collection of donated samples to be given away to a lucky attendee at this year's meeting. Steve will also have a large variety of geological samples available for sale at this year's meeting! Check the section website for details!

Other Nearby Attractions include:

The renowned *Green Valley Book Fair*, located just a few miles south of Harrisonburg, offers several buildings full of deeply discounted books, generally publisher's overruns, covering the near entire range of topics one would expect in a full-service bookstore. But at prices up to 90% off retail!

The *Frontier Culture Museum* is a living history experience near the town of that explores the history of the first non-native residents of the Valley, including the English, Germans, Irish and Africans, through reconstructions of representative households from the lands in which they originated.

For those of a subterranean bent, *Luray Caverns* is one of the many commercial caverns all along the Shenandoah Valley. But Luray Caverns is one of the oldest and least "glitzy" caverns in the area, offering unique cavern features with a dose of history.

And since the Blue Ridge Parkway ends nearby and Skyline Drive begins, hiking trails can be found in abundance, including those in the *Shenandoah National Park*. Or if you would like to try your kayak or canoe out in new waters, there are numerous boat landings along the North River and the South Fork of the Shenandoah River.

Conference Agenda

Unless otherwise specified, all events will be held in Memorial Hall. Transportation for field trips will be provided. Field trips depart from and return to Memorial Hall.

Thursday, May 15:

3:00 pm – 6:30 pm Check in at Hotels – Quality Inn and Courtyard Marriott. Dinner on your own this evening.

6:30 pm – 8:00 pm Presentation in the John C. Wells Planetarium, JMU, with light refreshments. Presentation will be *Ice Worlds*, followed by seasonal star talk. Program will be found at http://www.jmu.edu/videos/planetarium/ice-worlds.shtml.
Pick up registration materials at Planetarium.

Friday, May 16:

8:00 am – 9:00 am Conference check-in and registration Memorial Hall. Conference materials pick up. Enjoy the JMU Mineral Museum over coffee with friends.

9:00 am – 12:00 pm Concurrent sessions: Share your best activities, recent adventures, or critical issues. Please use the form included with this announcement.

12:00 pm – 1:00 pm Pizza lunch in Memorial Hall (provided as a part of registration).

1:00 pm – 5:00 pm IRIS Faculty Development Workshop (see description above).
OR
Local Field Trip: Frazier Quarry and Mole Hill. **(Trip is FULL)**

5:00pm – 6:30 pm Dinner local restaurants, on your own. Information is included in the program, but you may choose any other located in the area.

7:00 pm – 10:00 pm Overview on Saturday Field Trips and Geo-auction, with desserts and other sweets. **Location has moved to Courtyard Marriott meeting room.**

Saturday, May 17:

8:30 am – 5:00 pm Choice of Field Trips – Box Lunches are provided!

Field Trip 1: The Old Stuff: Blue Ridge and Piedmont – Late Proterozoic/Early Paleozoic (mostly) crystalline rocks that make up the Blue Ridge and western & central Piedmont of Virginia. Led by Eric Pyle (JMU) and Matt Heller (DMME). **(Trip is FULL)**

Field Trip 2: The (Less) Old Stuff – Mid-Paleozoic folded sedimentary rocks in the Valley & Ridge of Virginia. Led by Lynn Fichter (JMU).

7:00 pm – 9:00 pm Eastern Section Awards Dinner Banquet. Room 6110 Memorial Hall, JMU. Speaker: Callan Bentley, Northern VA Community College. Title of talk: *Metamorphic metaphors, digital detritus, and awful analogies: Visualizing and communicating the epic geologic history of the Mid-Atlantic region.*

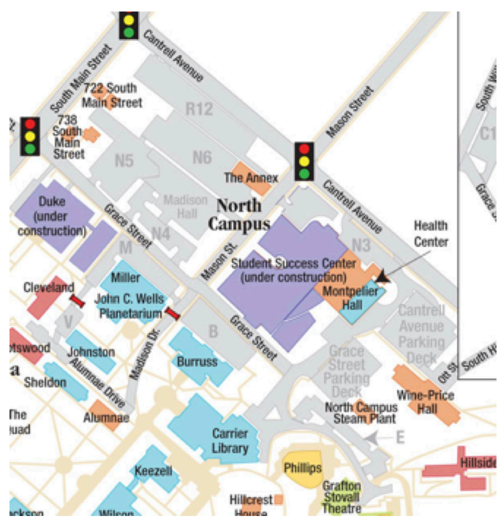
Sunday, May 18:

9:00 am – 11:00 am Eastern Section business meeting and breakfast buffet ($10/person, payable on site), Room 7370 Memorial Hall, JMU. All members welcome to attend, reservations required if you are partaking of the breakfast buffet, available from 8:00 AM.

Directions:

Harrisonburg is located in the Shenandoah Valley of Virginia, between Staunton and Winchester, at the intersection of Interstate I-81 and US Route 33. Generally speaking, the best exit to use is Exit 245, which deposits you on Port Republic Road. Travel to the west (turn left if you are arriving from the south, turn right if you are arriving from the north) and stay on this road until you meet South Main St., then turn right. At the third traffic light, turn left on to Martin Luther King Jr. Dr., which is also marked as “historic Cantrell Ave.” This road takes you right into the Memorial Hall parking lot. Park in lot C8 (see Map A below). The Planetarium show will be held in Miller Hall, which is a short walk from Memorial Hall, but parking can be found in lot N4 or N5, across Grace St. from Miller Hall (see Map B below).

Map 1



Map 2

(a complete campus map can be found at http://web.jmu.edu/parking/parkingmap.pdf)

Wireless access: Official events wireless: JMUFestival, ThmsYRwy.

Program Details, Day-by-Day

Thursday, 5/15/14

Opening reception and planetarium show, John C. Wells Planetarium. Refreshments and **hors d'oeuvre** starting at 6:30 PM in the planetarium lobby. Shanil Varani, director of the planetarium, will share with us two programs, starting promptly at 7 PM. The first one is *Ice Worlds*, which is described as, "*The delicate balance between ice, water and the existence of life has been a topic of exploration and discovery in science for generations. In travels to the Arctic and Antarctic regions of our planet, we'll examine the ecosystems that live and thrive there and see how their survival is connected with our own. Beyond Earth, we'll see how the existence of ice shapes the landscape and the natural systems on other planets and moons in our solar system. (30 minutes).*" This will be followed by a seasonal start talk and a Q&A session until about 8:30 PM. Parking is best found across Grace St., in the N4 or N5 lots. The walk to the planetarium is brief, just to the far side of Miller Hall.

Friday, 5/16/14

9:00 AM - Two main events will be going on Friday, starting with coffee and juice outside of Rooms 7110 and 7115 in Memorial Hall. This will start at 8:00 AM and remain set up through the morning. Promptly at 9:00 AM, we will begin our concurrent sessions. In Room 7110, Steve Lindberg will have set up for display and/or sale a collection of rock, mineral, and fossil specimens. Steve describes this as "Steve's Geoscience Stuff," with these details:

> *"I will have a large assortment of rocks, minerals, and fossils to set up on display for sale. I will be set up all morning Friday. A portion of the sales will be donated to the NAGT Eastern Section."*

In Room 7115, right next door, three sessions will be offered:

9:00-9:55 AM – Lynn Fichter (JMU) will discuss the changes that he and Steve Whitmeyer have made to the JMU BS and BA curricula, with their innovative *Stratigraphy, Structure, and Tectonics (SST)/Advanced Structure, Stratigraphy, and Tectonics (ASST) course sequence.* Beginning in 2008 the James Madison University Department of Geology and Environmental Science revised the BA program, and we introduced a course titled Stratigraphy, Structure, and Tectonics (SST) that was designed to combine stratigraphy, structure, and tectonics topics into one integrated course. The first organizing motif for the course is "no rock is accidental"; geoscientists must be prepared to gather all the information available from an outcrop, without discipline blinders. The second organizing motif is "follow the energy" connoting that every observable feature is the result of energy dissipation, and our intent must be to deduce energy transfer from the many signatures in the rock. The pedagogic strategy is an interplay between classroom-developed, top-down deductive theoretical models, and bottom-up inductive field experiences. These two threads are woven together in a semester long project whose goal is an examination of how stratigraphic, structural and tectonic principles have produced the regional geology of western Virginia and eastern West Virginia.

10:00-10:55 AM – Jon Tso (Radford) will discuss the *Geology of Virginia CD-ROM* series that was created at Radford University during 2000-2003. It is being updated as a new web-based version. Like the original CDs, the web version contains comprehensive coverage of the geology part of the Earth Science Standards of Learning as well as its outstanding photos and videos, and adds a modern web interface. The web version can be easily accessed outside the classroom, creating new ways for students and teachers to integrate this activity into their lessons. The presentation will demonstrate the functionality of the website and suggest ways that it can be used for instruction.

11:00-11:55 AM – Jason Petula (Millersville University of Pennsylvania, will host a round-table discussion of the *challenges faced by science education in public schools as a result of high-stakes testing*. The amount of time devoted to science at the elementary level has decreased to levels prior to 1983. Earth & Space Science has been removed from high schools in response to an emphasis on Biology. Collaborations between education and science faculty can have an unexpected impact. This session highlights a multi-year effort to increase the status of all sciences in public schools through a unique professional development program for instructional leaders (e.g., principals).
The professional development program has influenced over 10,000 instructional leaders in over 25 states; resulting in improved science programming for millions of students. The lessons learned from this collaboration may inform other organizations interested in providing students access to world-class science programming (e.g., NSF, NIH, etc.).

From 12:00 PM-1:00 PM, a pizza lunch will be available in the hallway near Rooms 7110 and 7125. The pizza will be provided by Little Italy Pizza, a local favorite.

At 1:00 PM, we will split into two groups based on your prior selections. One group will remain in Memorial Hall, using Room 7105, which is a computer lab classroom. The IRIS consortium will be presenting a short course entitled, *Transcending nomograms and the S-P method: Modernizing the seismology you include in your 100 and 200 level geoscience courses*. This short course, lead by both seismologists and science education specialists, will introduce and prepare participants to implement six inquiry-based, data-rich classroom modules that showcase modern seismological research, while covering topics commonly included in 100 and 200 level undergraduate courses. This collection of modules has been developed based on the "Seismological Grand Challenges in Understanding Earth's Dynamic Systems", a community-written long-range science plan for the next decade.

The second group will begin a local field trip to two locations. Departing from the Grace St. entrance of Memorial Hall, we will travel first travel north to the Frazier Quarries North Plant, which produces primarily aggregate from the Middle Ordovician Edinburg Limestone. We will have a plant tour and the opportunity to collect samples as needed. The second part of the trip is to Mole Hill, which is an Eocene volcanic neck that has punched upwards through the Cambrian and Ordovician sedimentary rocks of the Shenandoah Valley. The main rock type is basalt, which contains xenocrysts of olivine and spinel. In some locations, small columnar joints can be found (and collected!) Detailed geology of each site is found at the back of this program booklet.

Both the IRIS short course and the local field trip will conclude at approximately 5 PM. Dinner on your own follows. A selection of local restaurants is provided at the end of this program. And while reservations are difficult to make without exact numbers, the range of options should make the choice rather difficult!.

7:00-10:00 PM – Meet at the Courtyard Marriott on Evelyn Byrd Dr. (around the corner from the Quality Inn).in their meeting room space. It is a little on the small side, but should accommodate us all. We will have a desert and beverage reception while the Annual Geo-Auction takes place. Please bring your offerings to this room in time to start in a timely manner.

Saturday, 5/17/14

8:30- ~5:00 PM – Leaving from the Grace St. entrance of Memorial Hall, we will mount the vans to travel on our two separate trips. The first trip, led by Eric Pyle and Matt Heller (Virginia DMME) will have its first stop at the crest of the Blue Ridge, examining primarily the crystalline rocks of the Proterozoic basement of the Blue Ridge and the Ordovician metasediments that make up the western Virginia Piedmont.

Trip #2, led by Lynn Fichter (JMU), is an excursion based on the SST/ASST course described on Friday morning. Starting at the Blue Ridge, this trip will travel west across the Page Valley, over Massanutten Mountain, and across the Shenandoah Valley to the eastern Valley and Ridge. Along the way, you will learn about the stratigraphy, structure, and range of explanatory models that account for what was called in the past, the "Great Valley." Historically, this trip follows a similar path to the one followed by Peter Jefferson and Thomas Lewis and they surveyed the Fairfax line in 1746.

7:00-9:00 PM - Annual Section Awards Banquet and Guest Speaker. Returning to Memorial Hall at 7:00 PM, the Awards Banquet will be held in Room 6110 of Memorial Hall. While a large lecture hall, it lends itself well to the presentation that follows. Awardees for the Outstanding Earth Science Teacher award for each state in the section will be recognized, as will the section awardee.

Following dinner, we will have a guest speaker, Dr. Callan Bentley of Northern Virginia Community College. Dr. Bentley is a dynamic speaker and a leader in contemporary Geoscience pedagogy. He will speak on *"Metamorphic Metaphors, Digital Detritus, and Awful Analogies: Visualizing and Communicating the Epic Geologic History of the Mid-Atlantic Region,"* which promises to be an engaging presentation.

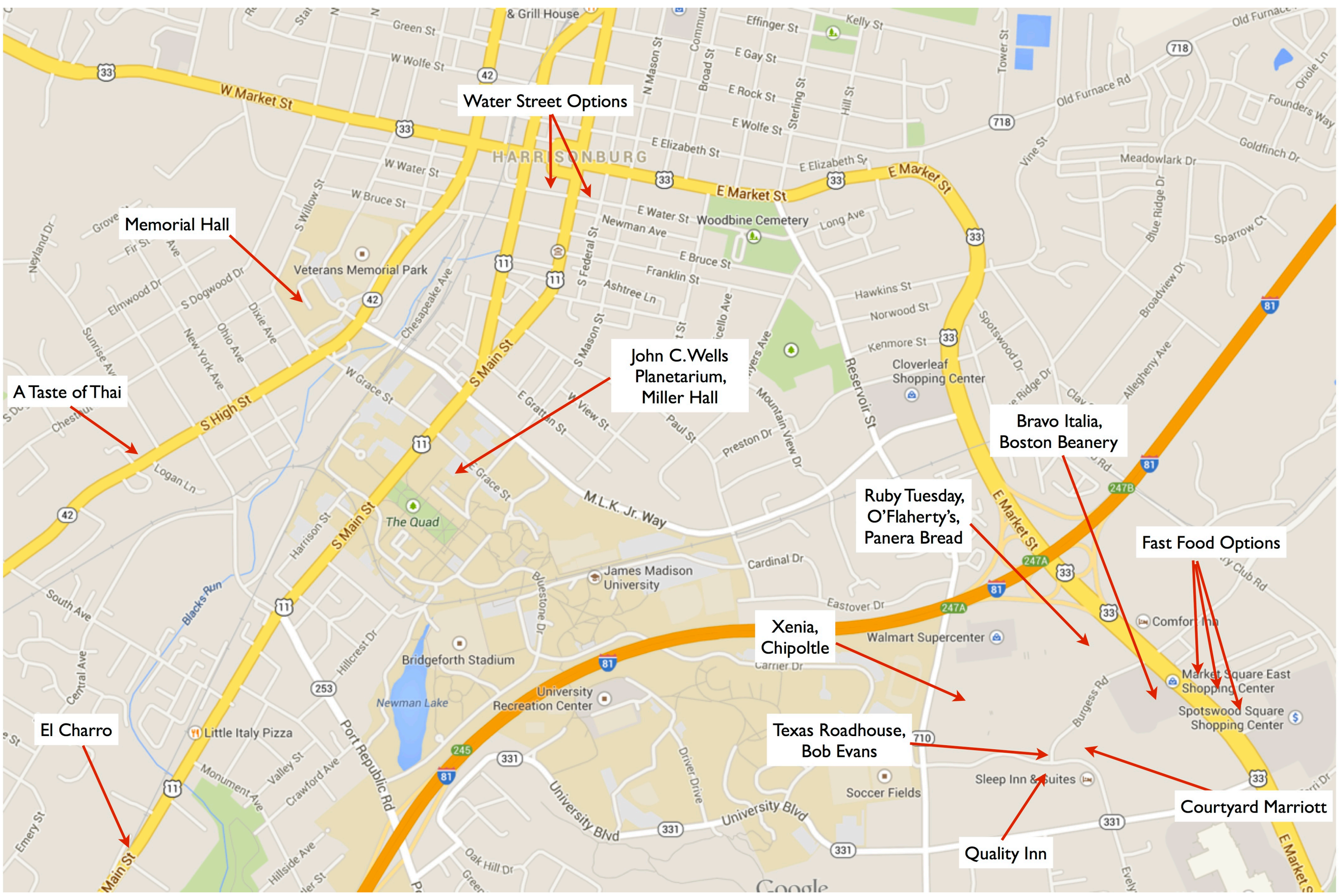
Sunday, 5/18/14:

9:00-11:00 AM – Annual Section Business Meeting. This event will be held in Room 7370 of Memorial Hall, which is a medium sized flexible classroom space in the Geology Department. A buffet breakfast will be available to those that pre-registered for the meeting, starting at 8:00 AM. If you are not having breakfast, you are still welcome to attend. The conference will officially conclude at the end of this event.

Friday Night Restaurant Suggestions:

Nearby to the conference hotels, there is a range of fast food as well as upscale eateries. Along US 33, you will find a Chick-Fil-A, a Jimmy Johns, Taco Bell, and a Wendy's. Across the street from the Quality in you will find a Texas Roadhouse and a Bob Evans. Just down the hill in the shopping mall, there is Panera Bread, an O'Flahertey's, a Ruby Tuesday, the Aroma Buffet, a Chipoltle, and Xenia Mediterranean Café. Moving further up the scale, you will find a Boston Beanery in the mall behind the Chick-Fil-A, as well as Bravo Italia.

Closer to Memorial Hall is A Taste of Thai (one of my favorites!) on South High St., and El Charro on South Main St. There are several relatively new restaurants in the downtown area along Water St., including Bella Luna Wood-Fired Pizza, Beyond (Asian Fusion), and Rick's Cantina.



Stop #1: Frazier Quarries North Plant

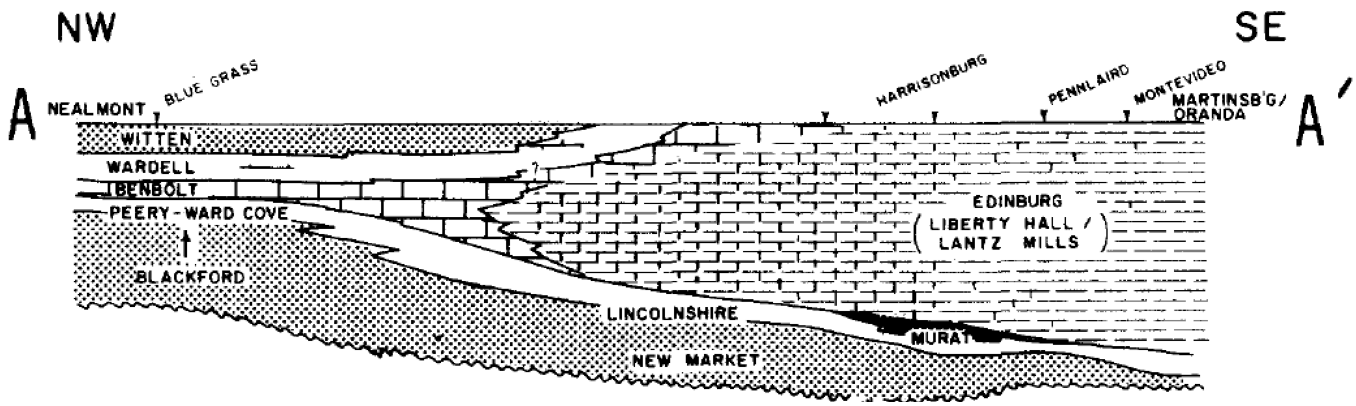
Frazier Quarries, Inc., is a 4th generation family business that will be celebrating100 years of operation in 2015. Currently, three of the four generations are engaged in the business. The North Plant is situated in the Edinburg Limestone, providing primarily aggregates to the local community. Aggregates are the most basic building block of all construction, with the largest single cost being transportation. Therefore the North Quarry is in located in the heart of Harrisonburg-Rockingham County market. Over past 40 years, Frazier has developed this quarry, with 600 acres in remote valley, makes it perfect for a NIMBY industry. One needs to remember that, given current development rates, any location needs to be within 25 miles of an aggregates quarry. About 75% of concrete is stone, with the remainder consisting of cement, water, and additives; Asphalt is 95% stone, 5% petroleum, smallest adequate home will consume ~150 tons of stone. If one multiplies the local population by 10 tons, one learns the annual consumption figure of aggregates for a community.

Basically, Frazier makes little rocks out of big rocks sorting them along the way. After drilling & blasting, the first crusher takes bucket sized to 12" or smaller (primary), which is moved to a 5" screen to make secondary material. From here, the material is sorted to make -1" base (crusher run) grade material and 5"x1" raw material for the sorted tertiary product. This becomes the most common aggregate product, 1"x.5"x.2". All specialized products originate from this size. The finest material, dust, is used for pipe bedding and asphalt. Upgraded in 2010, the plant produces up to 1000 tons per hour of "primary" material, and up to 500 tons per hour of tertiary material. The process is highly automated, with a data center connected by fiber-optic cables. The plant itself is "up-armored" with stronger wear-plates on crushing and sorting material, with equipment designed for much more abrasive rocks. Silica content wears metal parts, but since the Edinburg limestone has a low silica content, Frazier quarries will never have to replace these parts and can remain in continuous operation for at least the next 75 years. Such a high-tech approach allows for a flexible response to demand and allowing the plant to build up surge demand quantities, then switching to different products as needed. It also allows Frazier Quarries to be a vertically integrated operation– clearing property, extracting and processing materials, marketing and delivering the material, and ultimately reclamation.
(Thanks to Bib, Rob, and Cy Frazier for facilitating this trip and supplying the information above.)

Edinburg Limestone

The *bluestone* on the James Madison University campus is from the Middle Ordovician (approximately 455 million years old) Liberty Hall Member of the Edinburg Formation. It is fine-grained limestone that is composed of calcium carbonate, clay minerals, and contains carbon. The carbon is present because the calcium carbonate and clay that compose the rock were deposited in a deep-water, oxygen poor (anoxic) environment. The carbon gives the rock its distinct dark appearance when a fresh surface is exposed. The dark color of a fresh exposure of the rock lightens to a blue-grey patina as the carbon slowly oxidizes due to exposure to the atmosphere. The upper part of the Liberty Hall Member is evenly bedded consisting of bedding layers that are typically between 1 to 6 inches thick, with some beds being more clay-rich and darker than others. This gives the rock a banded appearance, and provides relatively flat surfaces upon which the rock preferentially breaks. The Liberty Hall Member also contains distinctive white calcite veins that resulted from fracturing during later (about 250 million years ago) mountain building events (Leslie, 2014, personal communication)

Interpreted as a slope and basin facies, the Liberty Hall member is thin or nearly absent in Northern Virginia, increasing to basinal sequences that are 200-450 m thick. The thin-bedded black limestones and shales of the Liberty Hall grade to the southeast and southwest into the Paperville Shale (Read, 1980). A facies representation is seen below.

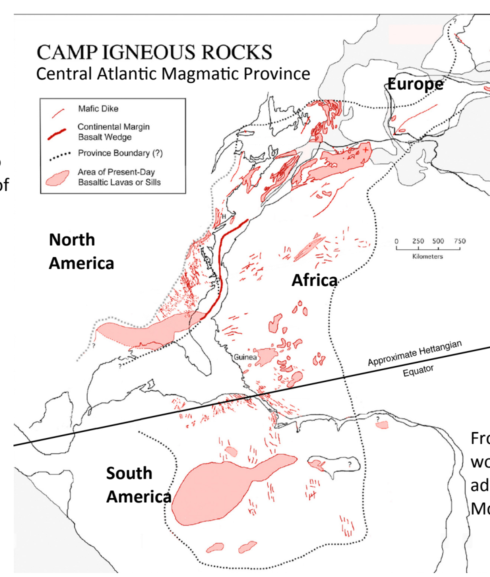


(Thanks to Steve Leslie and John Haynes for supplying the information above. Figure derived from Read, J.F, 1980. Carbonate Ramp-to-Basin Transitions and Foreland Basin Evolution, Middle Ordovician, Virginia Appalachians. *AAPG Bulletin, 64*(10), 1575-1612.*)*

Stop #2: Mole Hill

Departing Frazier Quarries, we next travel to Mole Hill, a prominent local landmark just west of Harrisonburg. Mole Hill is supported by a central column of tholeitic basalt, which has punched through the early Paleozoic sedimentary rocks of the Shenandoah Valley. This is not a unique feature to the region, which is dotted with igneous features of the Central Atlantic Magmatic Province (CAMP). These features are shown in the map below.

Volcanic Rocks erupted ~200 million years ago during breakup of Pangaea



From Olsen (ENAM workshop 2011); adapted from McHone (2002)

Focusing in on the Shenandoah Valley and adjacent Valley and Ridge, Eocene age volcanic rocks are present in Rockingham, Highland, and Pendleton (WV) Counties. See figure below.

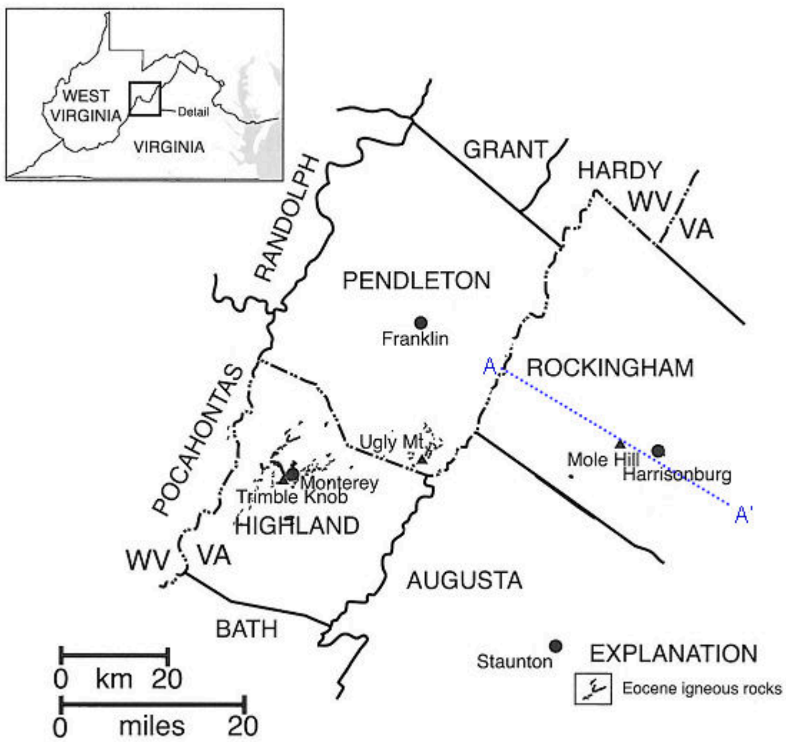
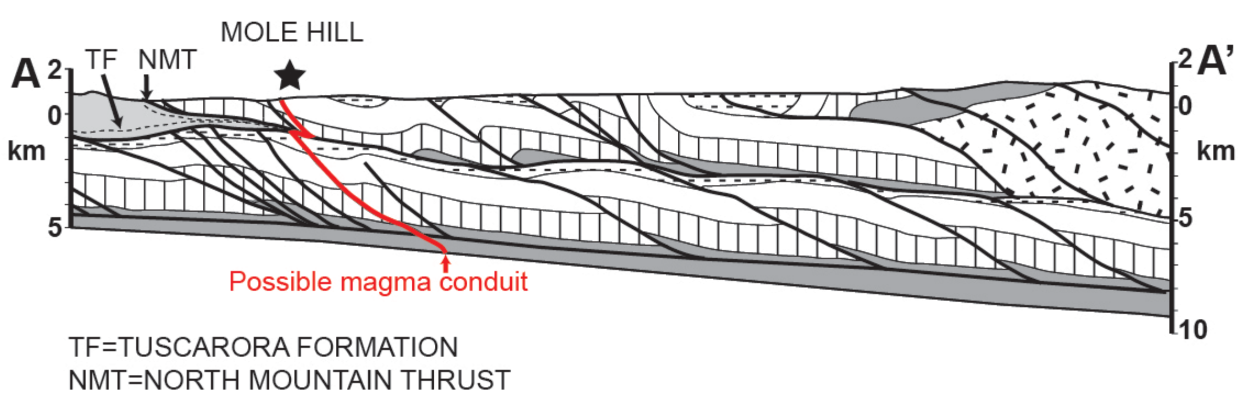


Figure 1. Locations of Eocene (53.5-37.5 million-year-old) igneous rocks in Highland and Rockingham Counties, VA, and Pendleton County, WV. Figure modified from Tso et al. (2004). A-A' refers to the cross-section.

So in the midst of a tectonically relatively quiet region, what would promote the expression of volcanic features? The subsurface structure of the region offers a clue. The extensive and complex set of Alleghenian thrust faults could have provided a conduit for mantle-sourced magmas. But what evidence is there that the material was from the mantle?



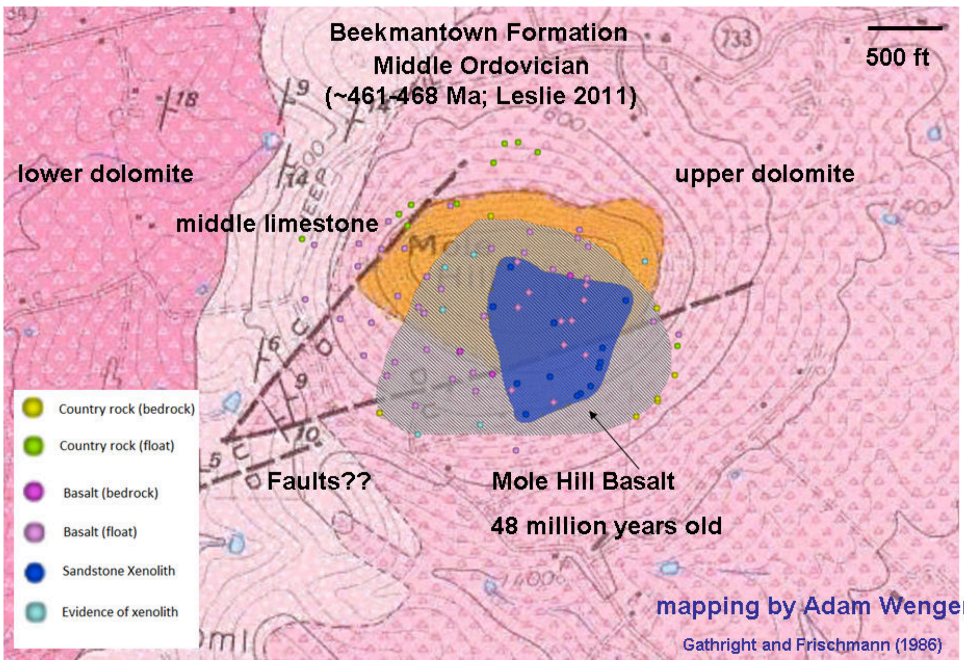
Observing hand specimens of the basalt, one is struck by the prominent xenoliths and xenocrysts. Xenocrysts of sandstone have been identified as Tuscarora Sandstone, which is at depth under parts of the western Shenandoah Valley, cropping out at the surface further to the west and southwest of Harrisonburg. The abundant xenocrysts of olivine, clinopyroxene and spinel (Hercynite) also suggest a deep source where these crystals could have formed and been entrained in the magma. Close examination of the inclusions within the xenocrysts show a diffusion of hydroxyl (OH) that is consistent with a low water content (18-40 ppm) in the mantle, with about 1% water content in the basalt. Finally, thermobarymetric analysis of the spinel xenocrysts, comparing the rims to the cores, suggest a source depth of up to 13 km, well within the basement material shown in the figure above.

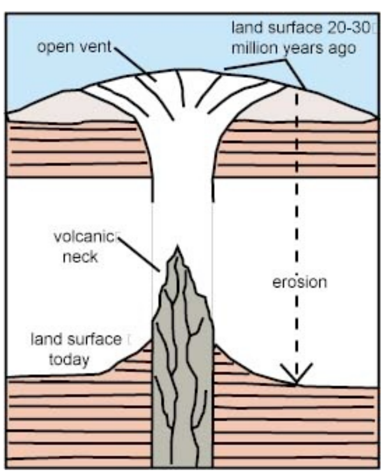
(above) Tuscarora Ss xenolith
(below) Clinopyroxene xenocryst

(above) Spinel (Hercynite) xenocryst
(below) Olivine xenocryst

Parking on the north side of Mole Hill, we will hike upwards along one of the old tractor trails. A few years ago, the owner of the property was beginning to develop the site for groups such as ours, working to set the property aside under a conservation easement. Tragedy struck one morning when the side of the road gave way beneath his wheels, causing the tractor to slide and roll over, pinning him underneath and killing him. He was not found for three days. In accordance with his wishes, the executors of his estate have made access available to educational groups under specific conditions, as outlined in the release form that you signed.

Mole Hill has been the site of extensive research, including student mapping projects. Walking up the hill itself, one sees fragments of Beekmantown dolomites, some of which contain fossil brachiopods and gastropods. Hydrothermal silicification of the country rock is noted as the rock appears cherty and resists hammer blows the closer one gets to the basalt. There are a few "dog holes" in the woods where galena and sphalerite were sought during the Civil War by Confederate forces. The slope steepens as one reaches the basalt, and columnar jointing is observed, up to 6-8", in the rocks along the west side of the trail. Reaching the top, one finds large chunks of basalt all across the surface. Cracking them open reveals the xenocrysts pictured above. A generalized geologic map is seen below.



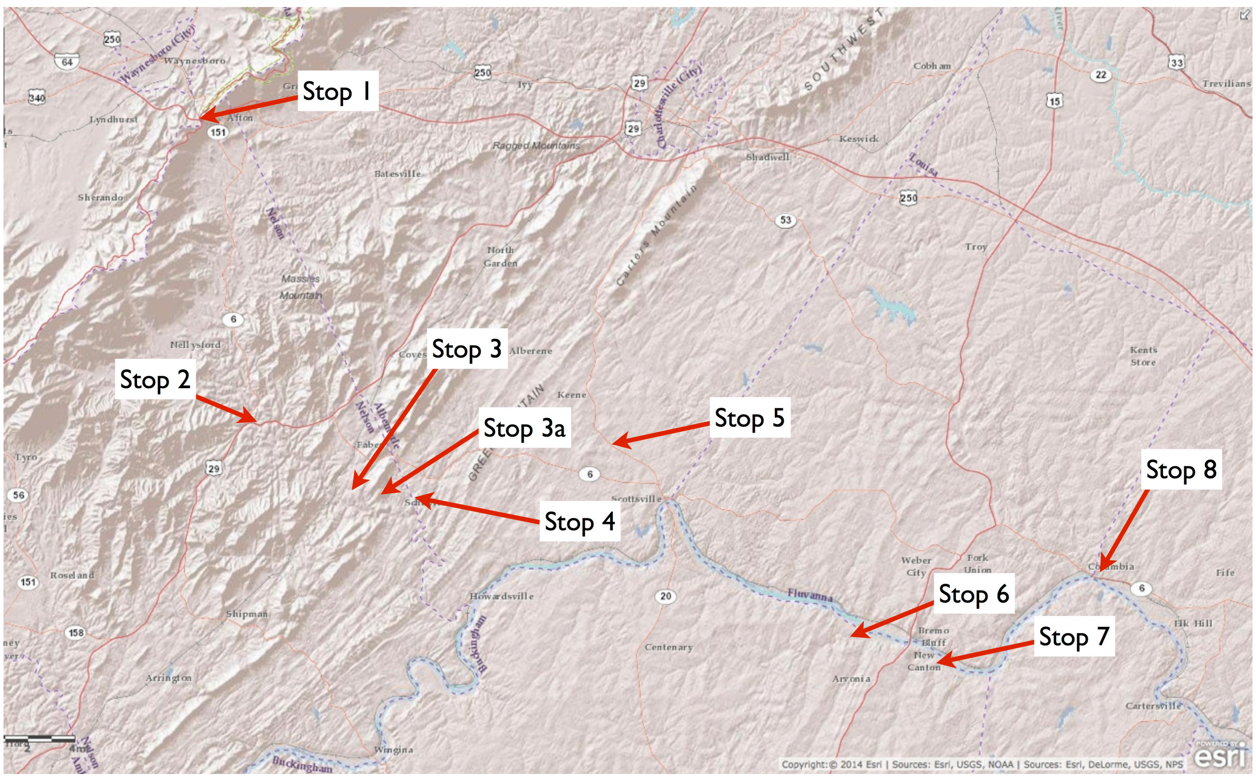


http://written-in-stone-seen-through-my-lens.blogspot.com/2011_01_01_archive.html

(Thanks to Mole Hill Acres, LLC, for access to the property. Many thanks to Elizabeth Johnson for figures and geologic information on Mole Hill.)

Field Trip 1: The "Old" Stuff: Complexity in the Blue Ridge and Piedmont Region of Virginia

Field Trip Leaders: Eric J. Pyle, JMU, and Matt Heller, Virginia DMME



NAGT Eastern Section Meeting
Harrisonburg, VA

May 15-18, 2014

With the increased understanding of plate tectonics in the late 1970s, a major change in the way geologists thought about the Virginia Blue Ridge and Piedmont occurred. Until then, geology was largely a descriptive science, focused on mapping rock types and delineating structures. Geologists could describe what they saw – in fact, the details that can be gleaned from early geological reports remains quite valuable – but no existing model could adequately explain the observed variety and distribution of features. This was especially true in the very complex poly-deformed and intensely weathered rocks of these two provinces. Plate tectonics allowed accumulated knowledge to be interpreted in terms of global-scale events that occurred over many millions of years. Mountain belts and supercontinents were formed by colliding crustal plates; the continents split apart, forming rift basins and flood basalts; post-rift continental margins cooled and subsided, accommodating thousands of feet of marine sediment. And sometimes, a piece of foreign or "exotic" crust would be plastered to the edge of a continent. Examples of and evidence for, all these events can be found in Virginia.

This field trip starts in the Blue Ridge \ west of Charlottesville and goes southeast as far as Buckingham County, about 45 miles from Charlottesville. Along the way, we will see representative rocks of the Lynchburg Group, the Catoctin Greenstone, a Triassic basin, the Western Piedmont, and the Arvonia Formation adjacent to the Chopawamsic Metavolcanic Belt. We will cross several major faults (none of which we will actually see) and consider the boundary relations between major geologic terranes of the Piedmont.

Starting at JMU Memorial Hall, head east on Grace St., turning right on South High St. At the first light, Maryland Ave., turn left. Cross two sets of railroad tracks, passing through the intersection with South Main St. Go up and over the hill, taking a right turn onto I-81S. Travel south to I-64E, approximately 25 miles. Bear right onto I-64E. Travel east to Exit 99, turning right at the bottom of the ramp onto US250 east. Nearly immediately after passing under I-64, turn right towards "The Inn at Afton" and the Tourist Information site. Drive past this building, turning around.

Stop 1: Catoctin Greenstone
In the parking lot of the Inn at Afton: Fine-grained, dark greenish-gray chlorite-epidote-albite schist and actinolite-chlorite-albite schist, amygdaloidal and vesicular metabasalt, and light-green, medium- to coarse-grained metamorphosed sandstone (mostly as loose boulders: unit is plainly visible on the north side of I-64 roadcut). The ***Catoctin Formation*** is predominately greenstone, but includes meta-arkose, purple meta-tuffs, and fine-grained phyllitic meta-sedimentary rocks. The formation was originally a series of basaltic lavas separated by beds of pyroclastic and volcanoclastic material. Pillow lavas have been found in some areas, but are not common. There are no recognized vents or cones recognized, which suggests the lavas resulted from fissure-style eruptions. The Catoctin is exposed on the Blue Ridge as well as the line of mountains (including Southwestern, Carter, and Green mountains) to the east of Charlottesville across Rockfish Valley. See Figure 1.

From: Scott Southworth, John N. Aleinikoff, Christopher M. Bailey, William C. Burton, E.A. Crider, Paul C. Hackley, Joseph P. Smoot, and Richard P. Tollo Geologic Map of the Shenandoah National Park Region, Virginia. USGS Open-File Report 2009–1153.
Petrology: The Catoctin Formation consists mostly of green, gray, and purple, aphanitic, massive to schistose basalt that was metamorphosed during the Paleozoic to metabasalt. The

metabasalt (Zcm) consists of albite laths in a fine-grained matrix of chlorite, actinolite, epidote, and pyroxene. The unit contains flow autobreccias, interbeds of pebble conglomerate, sandstone, metarhyolite (Zcr), laminated phyllite, and dark, variegated phyllite and slate. Laminated phyllite and sandstone beds (Zcs) are interpreted as alluvial deposits laid down on the volcanic landscape. Phyllite and slate beds (Zcp) containing spots and blebs of smeared chlorite have been interpreted as vesicular flows, volcanic tuffs, pumice, and volcanic ash.
Stratigraphic Position: The Catoctin Formation locally unconformably overlies Mesoproterozoic gneiss and may be disconformable or transitional above the Neoproterozoic metasedimentary rocks of the Swift Run Formation. Where the molten lava altered the surface of the basement rocks, the granitic gneisses are bleached and altered to unakite, which consists of pink potassium feldspar, quartz, and yellowish-green epidote. Named after rocks in the Unaka Range in the Blue Ridge of eastern Tennessee and North Carolina, unakite (Bradley, 1874) is the unofficial state stone of Virginia.

Leaving the parking lot, turn right onto US250 east, proceeding down the mountain. You will see on your right outcrops of Catoctin Greenstone, laced with bands of yellowish-green epidote. Proceed down the mountain ~3.2 miles, taking a right turn on SR151, heading south. Travel ~8.6 miles south, turning left on SR6 (River Road). Travel ~5.7 miles, turning right at the junction of US 29 and SH 6 (Woods Mill) to an outcrop on the right (W) side of the southbound lanes of US 29, just before the store and gas station. Park on right, well off the pavement, or at east end of park and ride lot at US29 and SH6 intersection. Watch for traffic as you exit the van.

Stop 2: Middle Proterozoic Lovingston Gneiss/Quartz monzonite?

The Lovingston "Gneiss" is one of the crystalline basement rocks of the Blue Ridge anticlinorium. It is generally a coarse-grained rock with plagioclase, orthoclase, biotite, hornblende, quartz, and accessory apatite, zircon, and various opaque oxide minerals. In this region, why might the Lovingston be mapped as a gneiss (a metamorphic rock) in one area, and as a quartz monzonite (an igneous rock of the granitic family of plutonic rocks) in another? What do you think it is here at this exposure at Woods Mill?

From: Scott Southworth, John N. Aleinikoff, Christopher M. Bailey, William C. Burton, E.A. Crider, Paul C. Hackley, Joseph P. Smoot, and Richard P. Tollo Geologic Map of the Shenandoah National Park Region, Virginia. USGS Open-File Report 2009–1153.
Petrology: The compound unit, biotite monzogranite-quartz monzodiorite (Ybg; 1,040±9, 1,032±10, and 1,028±9 Ma), is the youngest known rock in the Blue Ridge of Virginia. The reference locality is the 1,028±9 Ma rock (table 1, sample 12) on the west side of the driveway of a parsonage on the north side of Virginia Route 670 in Criglersville (Madison 7.5-minute quadrangle; Bailey and others, 2003) (fig. 5*D*). This rock is very dark due to as much as 25 percent biotite and blue quartz. The dominant mineral assemblage is alkali feldspar, plagioclase, quartz, and biotite (Tollo, Aleinikoff, Borduas, and Hackley, 2004; Tollo, Bailey, Borduas, and Aleinikoff, 2004; Bailey and others, 2006). The rock does not have a conspicuous Mesoproterozoic foliation, but greenschist-facies mineral assemblages define a pervasive foliation of Paleozoic age.

Return to the vans. Turn left on US29 north, traveling ~1.5 miles to SR 617, turning right. This is Rockfish River Rd. Travel approximately 3 miles, to a series of outcrops on the left. Park on the left, watching for oncoming traffic.

Stop 3: Late Precambrian amphibolite and metagabbro

Here you see black, crystalline (see the numerous crystal faces) rock, with some lighter minerals as well. This is an amphibolite, which is almost always formed from metamorphism of mafic rocks, either basalt or gabbro. (Interestingly, *pyroxenite* is an igneous rock, and *amphibolite* is a metamorphic rock). This exposure has been mapped as part of an extensive dike that is up to 1 km wide and can be traced for over 20 km laterally. Hornblende is the primary mineral, with some plagioclase, epidote, and magnetite, and their mineralogy is appreciably different from the metabasalts of the Catoctin greenstone. Are these foliated or non-foliated metamorphic rocks? See Figure 2.

Returning to the vans, continue along SR 617 for ~1.25 miles, to SR 714, Drumheller Ln. Park on the right side of SR 617. Walk across the bridge, then walk down the gravel lane on the right to the outcrop beneath the Drumheller Lane bridge.

Stop 3a: Neoproterozoic Rockfish Conglomerate member of the Lynchburg Group.

This is the type locality (what does that mean?) of the Rockfish Conglomerate, first discovered and described in 1932 by Professor W.A. Nelson from U.Va. Look at the large pebbles and cobbles, and maybe boulders as well; what is their lithology? What is the lithology of the matrix that surrounds them? This conglomerate, which is really a metaconglomerate, has been variously interpreted in the past 80 years as a submarine fan deposit, a river gravel, or subaqueously deposited glacial outwash. See Figure 3.

Return to the vans, and continue west along SR 617 for 5.2 miles to Schuyler. Turn left onrSR 800.. Drive ~.3 miles, passing the Alberene Soapstone Co. . Traveling another ~.35 miles,turn left on SR808, Gold Mine Ln, and park carefully the side of the road immediately west of the intersection. Cross back over SR 617 on foot and proceed to the quarry.
Schuyler was the setting for "The Waltons", a long-running TV show in the 1970s, as it was the boyhood home of Earl Hammer, who wrote and produced the show.

Stop 4: Late Proterozoic metapyroxenite ("soapstone") dike

This abandoned quarry is one of numerous such quarries in the Schuyler ("Sky-ler") area that have produced soapstone for many uses for over 100 years; four quarries in the area are still active and comprise the largest (by volume) source of soapstone in the United States, which is cut and prepared at the Alberene Soapstone Company facility that is on Schuyler Road about ½ mile south of here. The soapstone, a hydrothermally altered pyroxenite dike, may include variable amounts of talc, chlorite, termolite, serpentine, and even some calcite and magnetite. Also at this old quarry right along the road are exposures of the surrounding Lynchburg Group into which the dike was intruded. Geologic relations show that these dikes cut, and are thus younger than, the Swift Run Formation, but are older than the Catoctin, restricting their age to the late Precambrian, perhaps about 700 Ma. Convince yourself that this rock does indeed feel "soapy", and that talc is a major mineral in this particular exposure. Return to Figure 2.

Travel ~Return to SR800 and head north for approximately 1.8 miles to to Irish Road SR 6/715. Turn right and travel 8.2 miles, continuing along SR 6 to the intersection with SR 626. Turn left (north) towards SR 20 (Scottsville Rd.), which will be found in 1.4 miles. Turn left and travel ~.9 miles to SR 713, Glendower Rd. Turn right and turn around, parking along SR 713.

Stop 5: Triassic fanglomerate

This is the youngest exposure along the trip, a small but informative exposure of some of the sedimentary rocks that fill the Scottsville Basin, one of Virginia's several Mesozoic rift basins that are inliers in the Piedmont, and mostly exposed but in the case of the Taylorsville Basin now mostly buried by the younger Cenozoic sediments of the Coastal Plain. The exposures here are of pebble to boulder conglomerate (fanglomerate, from gravels deposited on alluvial *fans*) that accumulated near the western border fault of the Scottsville basin. The red sandstone matrix encloses angular to subangular pebbles, cobbles, and boulders of greenstone, gray quartzite, white vein quartz, and red shale. Do you see other lithologies? The basin is typical of half grabens, fault-bounded in the west and marked by pebble and boulder conglomerates and breccias in the west and by red siltstones and shales to the east. The basin is completely surrounded by metamorphic rocks of the Western Piedmont. See Figure 4.

Turn left (SE) on SR 20 for 3.3 miles to Scottsville and the junction with SR 726; turn right (S), cross SH 6, and in about 100 yards, turn right on SR 737. Drive west for ~0.5 miles to a low exposure on the right (N), and park on the left.

Stop 6: Phyllite of the Western Piedmont (CZpm)

These outcrops are representative of a rock type that underlies large portions of the western Piedmont: chloritic phyllite. These are strongly deformed, low-grade meta-sediments or meta-volcanics, interpreted to have formed in an elongate basin between North America to the west and a volcanic island arc to the east. These rocks are strongly foliated, and the foliation has been warped and kinked by a second (or third??) compressional event. This exposure is just a few miles east of the Mountain Run Fault, which thrust these rocks over the stratified rocks of the eastern Blue Ridge. See Figure 5

Return to SR. 726 and turn right (south). Go 1.2 miles and proceed STRAIGHT on Rt. 1302; go 0.3 miles to stop sign and turn right (south) on Main St./SR 20. Cross the James River (note the impressive levee constructed to protect Scottsville from floods!) and go 5.9 miles to SOLO gas station (Ali's Place) on the left. Pit stop.

Continue south on US 20 for 0.2 miles to Rt. 652 and turn left. Go east on Rt. 652 for 12 miles to US Rt. 15. (At 10.5 miles, we will cross a creek that marks the boundary of the Shores Melange and enter the Arvonia Slate mining district. The creek is occupying a zone of weakness caused by the boundary fault of these two terranes.) There is a railroad cut, and with permission, large slates and be seen in outcrop along the tracks to the left.

At the intersection of US 15, turn left (north) and drive 0.6 miles to Rt. 670 and turn right. Go 0.8 miles and turn left on Rt. 687('public boat ramp), go to the end of the road and park in the parking lot. Outcrops are along the railroad track to the west. (NOTE: if there is a problem with access to these exposures, continue north on US 15 across the James River and turn left on Rt. 656 (Bremo Road) and circle back to the east beneath the bridge. Exposures on the left just east of the bridge. BEWARE POTENTIAL FALLING ROCK!!)

Stop 7: Bremo Quartzite member (Obq) of the Arvonia Formation (Oa)

We are in the historic Arvonia Slate District, from which the world famous Arvonia Slate is quarried (no doubt all of you have noticed the beautiful slate roofs on UVA buildings). The Arvonia is geologically significant in that it contains recognizable fossils, quite rare in the metamorphic rocks of the Piedmont. From these fossils, a Late Ordovician age has been established for this unit. The formation sits unconformably on the metavolcanic rocks of the Chopawamsic volcanic formation and the meta-plutonic rocks of the Columbia Granite. The rocks here are cross-bedded quartzites which underlie the finer-grained slates. Note that sedimentary bedding is easily distinguished, and it is nearly vertical. You should be able to determine which way is stratigraphically up… These rocks are part of the Chopawamsic Terrane, an extensive fault-bounded block interpreted to have originated as a volcanic island arc off the eastern edge of Laurentia in the Cambrian and accreted to Laurentia during the Taconic Orogeny. Return to Figure 5.

From USGS, http://mrdata.usgs.gov/geology/state/sgmc-unit.php?unit=VAOa%3B0
Petrology: Slate and porphyroblastic schist. Dominantly dark gray to grayish-black, lustrous, very-fine-grained, graphitic slate (northeastern sector); and, medium-grained, porphyroblastic garnetiferous biotite schist (southwestern sector). Discontinuous beds of quartzose muscovite schist, coarse grained to pebbly micaceous quartzite, and conglomeratic schist occur along the margins of the outcrop belt, stratigraphically at the base of the section. Interbeds of dacite metatuff occur in the western portion of the slate outcrop belt. Graded laminated metasiltstone and metasandstone are interbedded with slate in the central and eastern portions of the outcrop belt at the latitude of the James River (Evans and Marr, 1988); these rocks pass into porphyroblastic schists at higher metamorphic grades to the southwest. Bremo Quartizite Member: Light-gray, fine- to medium-grained, thick-bedded and locally crossbedded quartzite; includes quartz-muscovite schist, and quartz-pebble conglomerate. Mineralogy: quartz + muscovite + chlorite +/- plagioclase +/- potassium feldspar +/- calcite +/- magnetite-hematite +/- zircon.
Structure and Tectonics: The Stoses (1948) considered the Arvonia a sequence deposited on a post-Taconic-orogeny regional unconformity, and folded and metamorphosed during subsequent orogenies; that interpretation is consistent with geologic constraints as we know them today. The Arvonia Formation occurs in a major synclinal structure (Fig. 4), now overturned to the northwest, and the commercial slates are in the more northwesterly, lower-grade limb of this fold. Conley and Marr (1980), following Stose and Stose (1948), showed an intervening anticline (Fig. 4), such that the structure is more complicated than a simple syncline.

Return to US 15 by the way you came in. Turn right and cross the James River. Proceed ~7.8 miles to the intersection of US 15 and SR 6. If time permits, proceed straight along SR 6 for 4.8 *miles through the town of Columbia. Just past the town, pull off to the right into the open gravel lot. Park and walk north across SR 6, carefully watching the traffic.*

If time does not permit, turn left at the intersection of US 15 and SR 6, proceeding north for ~15.5 miles, at the intersection of US 15 and I-64, exit 136. Cross the bridge and take I-64 west towards Charlottesville. At Exit 89, bear right towards I-81 north. Exit at Port Republic Road/Maryland Ave., Exit 245. Turn left and retrace the steps from the beginning.

Stop 8: Columbia Meta-Granite *(state highway 6 at Columbia)*

The Columbia metagranite forms a large pluton that intrudes the metavolcanics of the Chopawamsic terrane. The Columbia granite has been radiometrically dated at 457 Ma. Here it has been metamorphosed to a level that has imposed a strong lineation, creating agranodioritic gneiss containing plagioclase, quartz, biotite, K-feldspar, and epidote with minor garnet, muscovite and opaque minerals. Although the exact facies has not been determined, one possible inference is that the mineralogy and lineation suggest an amphibolite grade. At the pluton scale, the foliation is folded into a series of asymmetric northeast plunging folds that require two deformation events. Less than a mile east on Rt. 6 is a large diabase dike (Tr-J age).

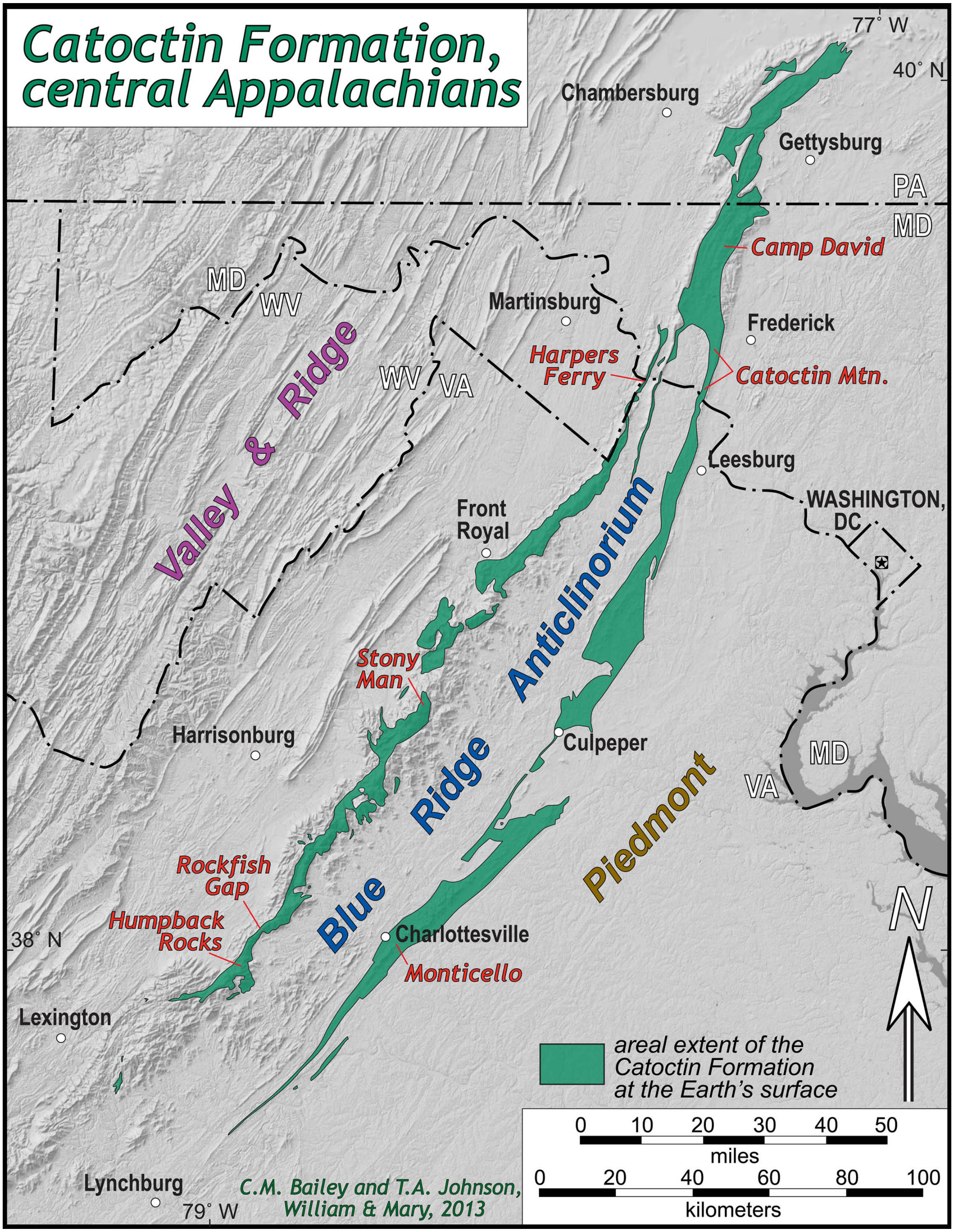


Figure 1. Extent of the Catoctin Greenstone in the Mid-Atlantic region.

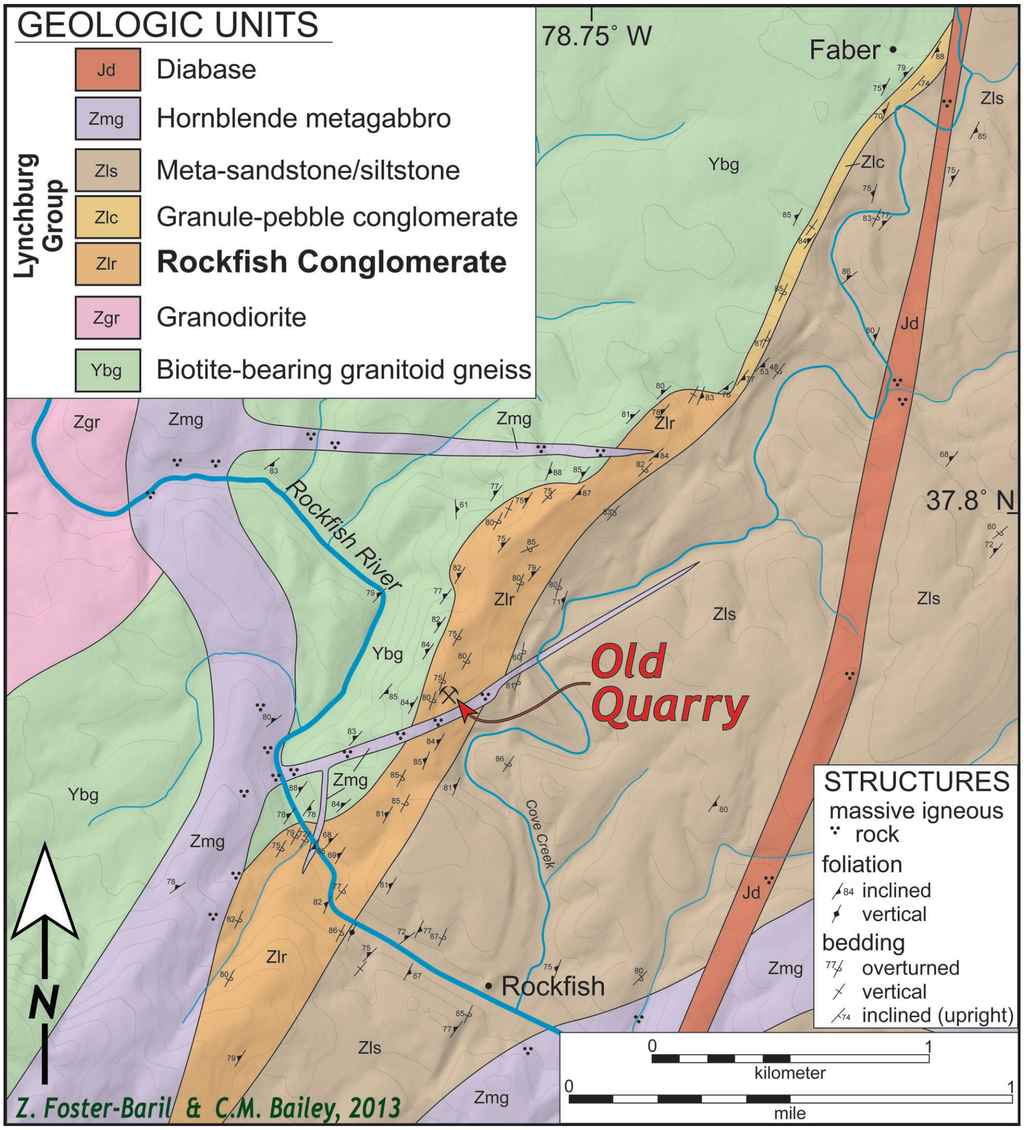


Figure 2. Geologic Map of the Rockfish, Virginia area.

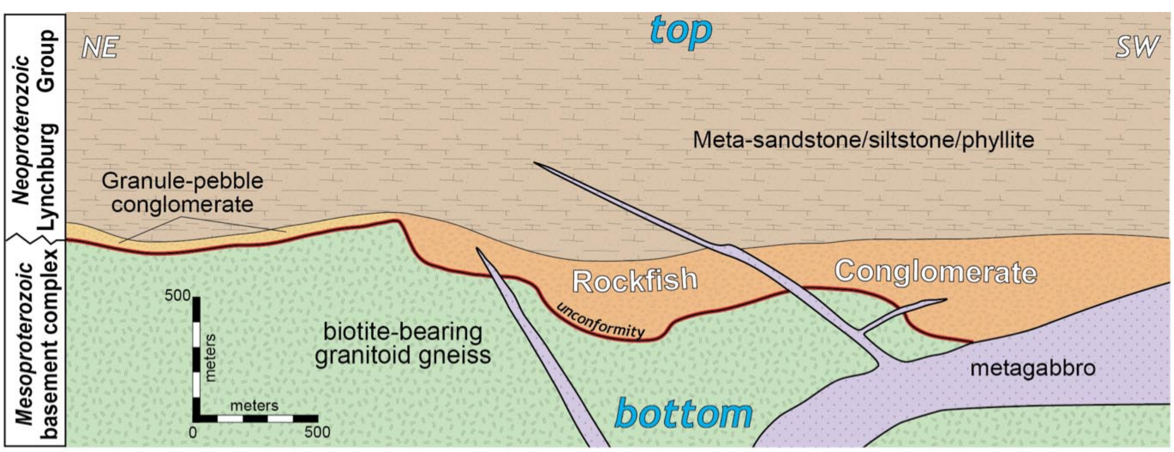


Figure 3. Cross section showing Rockfish Conglomerate. Reprinted with permission of C.M. Bailey.

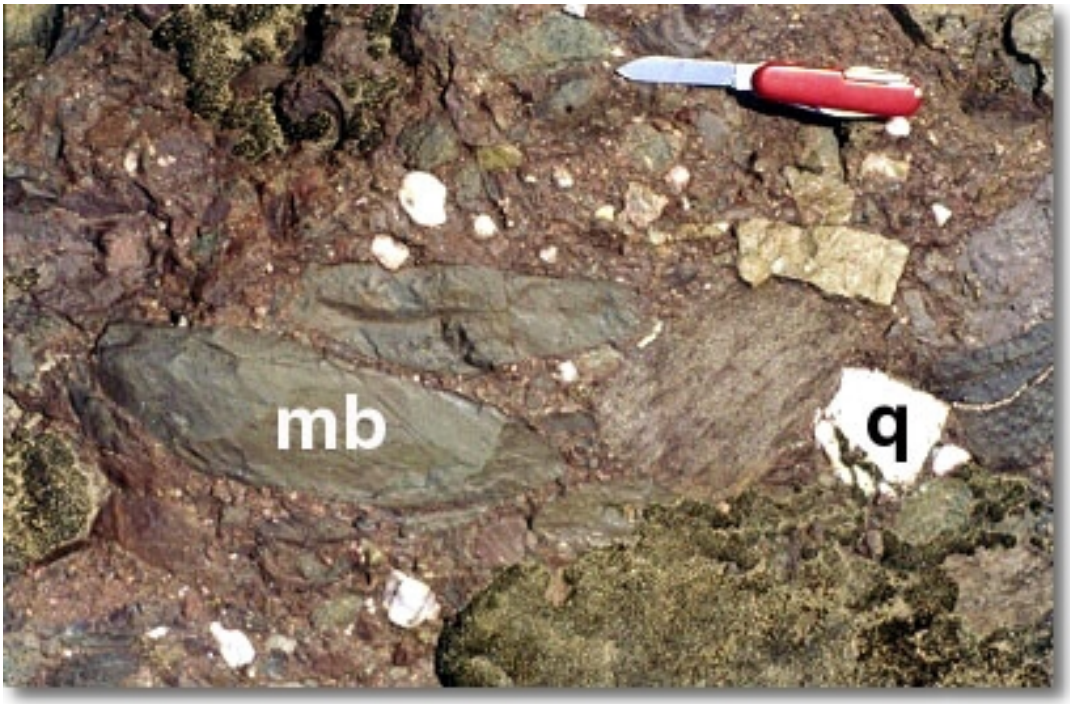
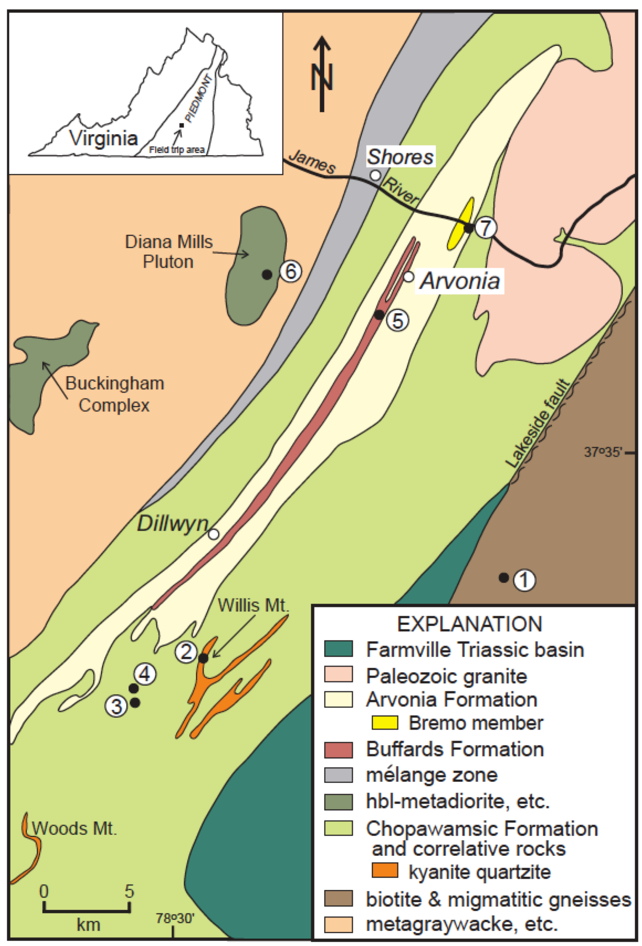
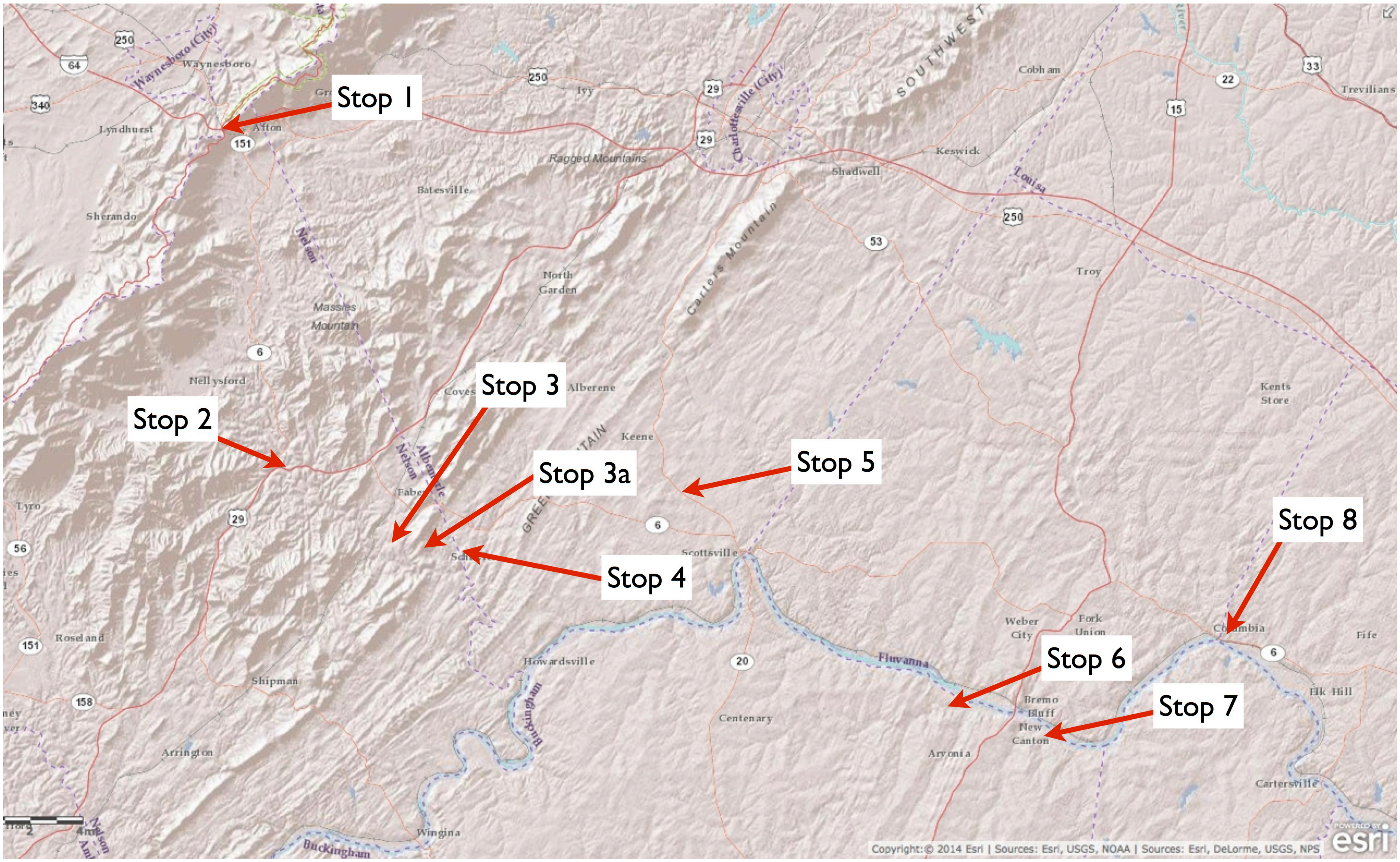


Figure 4. Triassic fanglomerate from the western margin of the Scottsville Basin. From http://web.wm.edu/geology/virginia/provinces/piedmont/mesozoic_breccia.html

Figure 5. Geologic map of the Arvonia and Dillwyn region, central Virginia. From **Geology in the Heart of Virginia: the Central Piedmont,** 40th Annual Virginia Geological Field Conference, October 8th - 9th 2010, Brent Owens, College of William & Mary




Stop 1
Stop 2
Stop 3
Stop 3a
Stop 4
Stop 5
Stop 6
Stop 7
Stop 8
Waynesboro
Afton
Lyndhurst
Sherando
Ivy
Ragged Mountains
Charlottesville (City)
Shadwell
Keswick
Cobham
Trevilians
Batesville
North Garden
Massies Mountain
Nellysford
Coves
Alberene
Keene
Carters Mountain
Troy
Kents Store
Scottsville
Howardsville
Shipman
Roseland
Arrington
Wingina
Centenary
Fluvanna
Buckingham
Weber City
Fork Union
Columbia
Fife
Elk Hill
Bremo Bluff
New Canton
Arvonia
Cartersville
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Integrating Stratigraphy, Structure and Tectonics on the Outcrop

A Geologic Transect from the Blue Ridge, Across Page and Shenandoah Valleys, and into the Eastern Valley and Ridge

Lynn S. Fichter, Eric Pyle, Steve Whitmeyer
Department of Geology and Environmental Science
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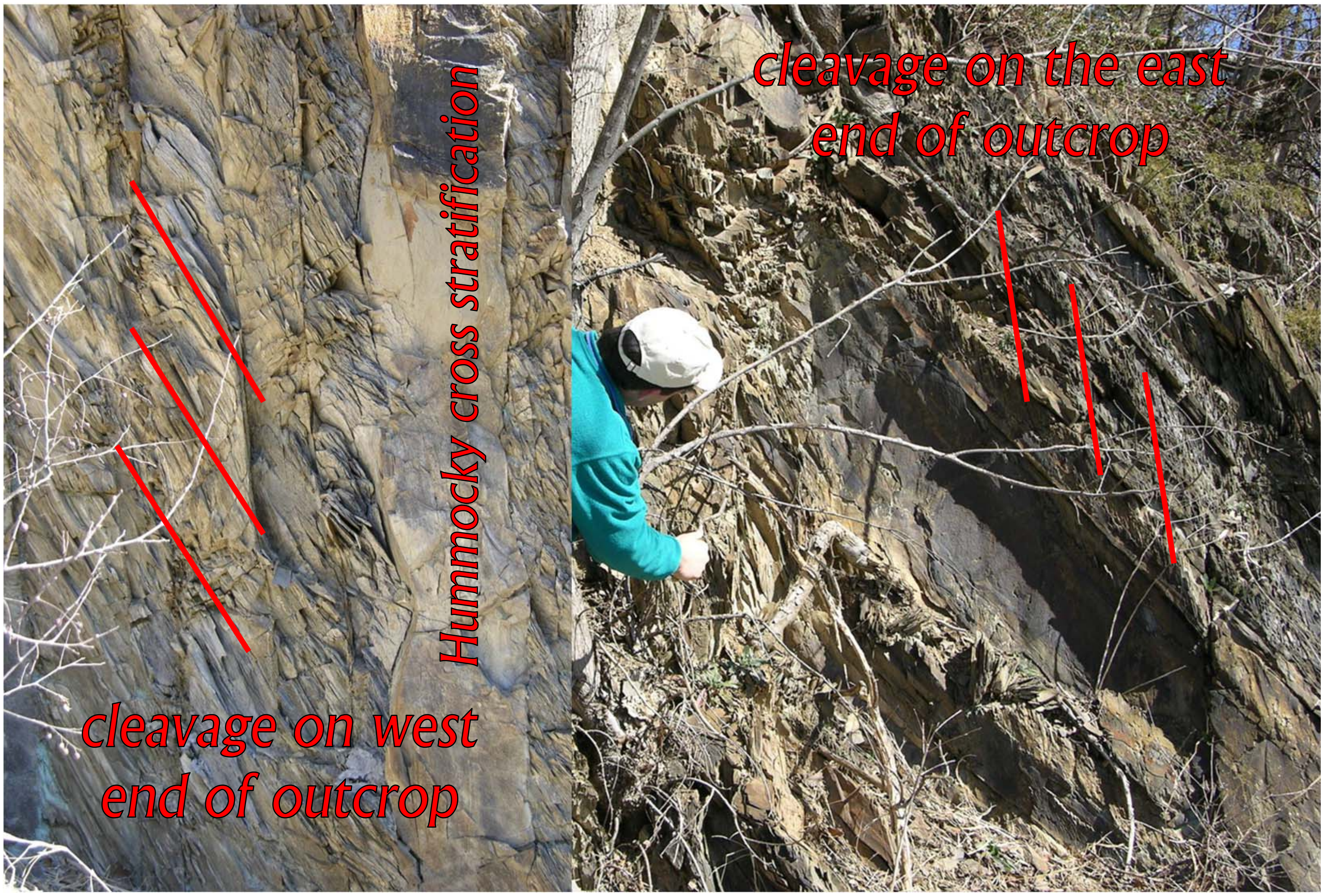
May, 2014



NAGT Field Trip #2
Spring, 2014 Meeting
James Madison University

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Field Trip for the NAGT Spring, 2014 Meeting

Introduction:

Stratigraphy, structure, and tectonics are not naturally compatible topics. Just sit in on the courses; there is virtually no overlap of subject, evidence, techniques, or tools, and structural geologists and stratigraphers have little common terminology—they can barely talk with each other. Yet, structure and stratigraphy are clearly related because both result from the dissipation of tectonic energy, and the evidence for each commonly exists in the same outcrop at the same time.

This field trip is based on a new course instituted 6 years ago in the revised JMU BA program by Lynn Fichter–stratigrapher–and Steve Whitmeyer–structural geologist–deliberately designed to use tectonics as an organizing and integrating principle for combining stratigraphy and structure in one course. It is titled “Stratigraphy, Structure, and Tectonics (SST). SST uses 5 field trips that together make an across-strike transect from the Allegheny Front in Pendleton Co., West Virginia to the eastern side of the Blue Ridge province, and provides evidence for virtually a complete history of the region—structurally, stratigraphically, and tectonically.

This field guide is based on one of those trips, the Rt 211-Rt 259 transect from the western flank of the Blue Ridge province northwest through Brocks Gap in Little North Mountain (Figure 1 - all the figures are in order at the back of the guide). We include most, but not all the stops the SST class makes on that trip, and mimic the strategy we take on the outcrop.

The deliverables for the SST course include 3 structural cross sections (including the Rt 211-Rt 259 transect for this trip), and a stratigraphic/tectonic history based on the sum total of all evidence seen on all the outcrops, interpreted through theoretical models developed in lecture. The 3 cross sections constitute a complete cross section from the Allegheny Front in Pendleton Co., West Virginia to the eastern side of the Blue Ridge province, with a nod to the Triassic basins and Atlantic rifting.

Exploring the S, S and T of an outcrop requires a deliberate and systematic strategy. It is important to keep evidence straight; what does each rock tell us, about what, at what scale of observation, and how does it do it. This requires looking at a rock through more than one lens: a stratigraphic lens, a structural lens, and several tectonic lenses. We begin with empirical data: what do we immediately see in the outcrop, and what is its immediate interpretation. Only when that is clear do we start looking at regional contexts and constructing tectonic histories from all the outcrops. Each stop on the field trip is organized this way.

On the 5 field trips that are part of the course it is common for some formations to be seen more than once, including stops that are germane to constructing a complete stratigraphic/tectonic history but which we will not see on this trip. Stratigraphic data gathering and interpretation is done only at the best locations, but a formation may be visited multiple times in other locations to gather structural data. When we first began the course we visited every available outcrop on the transect; since then we have trimmed them back to only those that efficiently provide the optimal information to make the necessary interpretations.

The Different Expressions of Tectonic Energy:

Tectonic energy drives everything in the geosphere, but the effects are not equally conspicuous. On the one hand, structural features (joints, folds, faults, etc.) in all their myriad forms, resulting from tectonic deformation, allow rich interpretations; rheological analysis is typically direct from data measurable on the outcrop.

Conversely, although the stratigraphic record also responds to tectonics, the evidence is much less direct, does not feed back directly to the responsible stresses, and usually requires interpretations within interpretations. For example, relative water depth can be interpreted with color, texture, flow regime, etc. but each of these lies within a theoretical framework of its own (geochemistry for color; and hydraulics for texture and flow regime).

Complicating the issue, water depth—accommodation space—is controlled by more than one variable—including subsidence, eustasy, sediment influx rates, compaction, loading, and climate—each of which may be operating largely independent of the others, and in different fractal time scales. Yet, the results look the same regardless of the mechanism—water responds to depth, not how the depth is created.

Also, large tectonic processes—such as foreland basin development—that control the evolution of the stratigraphic record cannot be seen in outcrop. We deduce they exist, that they represent subsidence from shallow into deep water, and that they influence the stratigraphic record, but we do not have direct outcrop evidence of the subsidence, or its rates, or the size and shape of the basin. Indeed, as trying to teach this stuff to undergraduates demonstrates, while observing any particular outcrop it is very difficult to imagine what is happening in the larger vertical, horizontal, and temporal contexts. We cannot 'see' foreland basins but have to imagine them fragment by fragment.

The result is, sedimentary-tectonic interpretations from stratigraphic outcrops are almost always inferences based on deductive arguments from a diversity of indirect data that must be synthesized from evidence gathered from accumulated specific outcrops. Sedimentary-tectonic interpretations require a predictive model that coordinates (plate) tectonic energies with sedimentary energies so that we can use stratigraphic observations to deduce the tectonic conditions that produced them. For SST our primary model is the Tectonic/Accommodation model.

The Tectonic/Accommodation Model:

Figure 2 is a theoretical Tectonic/Accommodation model (accommodation is the space available for sediment to fill). It is based on the plate tectonic concept that during a continent-continent collision or an arc-continent collision the over thrusting hinterland places a load on the foreland resulting in relatively rapid foreland basin subsidence and accommodation increase. Figure 2 models the tectonic subsidence portion of the model. Note: this is a time series diagram (not a cross section) showing the evolution of basin subsidence at a single geographic location. The geographic location is proximal to a hinterland where subsidence is greatest. (If it were a location distal from the hinterland, closer to the basin-to-craton transition, it would be a different diagram). The time series begins with cratonic or mature DCM conditions—slow subsidence, small accommodation space—interrupted by the sudden onset of tectonic activity and rapid subsidence into deep water conditions, followed by an exponential decay in subsidence rate. In the absence of deposition the result is a deep water basin.

The accommodation curve in Figure 2 says that initially accommodation space increases largely in concert with the increase in subsidence. Or, depth increases more rapidly than sedimentation can keep up. In time, however, subsidence rates slow while sedimentation rates increase (it takes time for sediments to prograde across the basin from the eroding mountain) resulting in rapidly decreasing accommodation—filling of basin and shallowing water.

The Tectonic/Accommodation model presumes that an accumulating column of foreland basin sediments will reflect changing accommodation more than basin subsidence as the basin evolves. A predictive stratigraphic sequence would look like (bottom to top): 1) pre-tectonic shallow water deposits, 2) deep, quiet water, fine-grained, anoxic deposits, 3) mass transport deposits (e.g. debris flows, turbidity flows, etc.) down a steep underwater slope, resulting in a coarsening, shallowing upward sequence as the accommodation space fills, 4) distal to proximal shelf; coarsening, shallowing-upward facies, 5) shoreface deposits, 6) fluvial. Exactly what these deposits will look like depends on the specific basin, and variables such as, for example, the prevalence of tidal vs. storm energy on the shelf. This is where sedimentologic/stratigraphic knowledge and interpretation becomes requisite for making stratigraphic tectonic interpretations. These are extensively developed in the SST (and the following ASST—Advanced Structure, Stratigraphy, and Tectonics—course), but not here.

As an historical aside, during the 19th and 20th century development of geosynclinal theory—which took place with these very rocks—both Hall and Dana argued that subsidence and sedimentation kept up with each other and the miogeosyncline to exogeosyncline transformation (platform to foreland basin) filled completely with shallow water deposits. They would have categorically rejected this Tectonic/Accommodation model.

A Tectonic/Accommodation Model for the Ordovician Sequence of Page and Shenandoah Valleys

Figure 3 shows a new subsidence/accommodation model for the evolution of the Middle and Upper Ordovician strata of Page Valley developed by Lynn Fichter and Rick Diecchio. It is based on known stratigraphic thicknesses and ages, interpreted changes in relative sea-level and depths of sedimentation, and calculated isostatic response. It illustrates the total subsidence necessary over time to deposit the strata between the top of the Beekmantown and the base of the Massanutten, both of which are interpreted to have been deposited at sea-level. The "Cumulative thickness" curve on Figure 3 is equal to the subsidence necessary to accommodate the strata from the top of the Beekmantown to the base of the Massanutten Sandstone. The "Total subsidence at top of Beekmantown" curve is the cumulative thickness curve adjusted according to the interpreted water depth (below storm wave base) that existed during deposition of the Lincolnshire Limestone, Edinburg and Martinsburg Formations. The sediment filling the basin is illustrated by adding the thickness of each formation to the adjusted total subsidence curve.

This subsidence/accommodation model illustrates a possible isostatic effect of Taconic over-thrusting onto eastern North America. It is based on the tectonic concept that during a collisional event an over-thrusting hinterland places a load on the foreland resulting in relatively rapid foreland basin subsidence (e.g. Shumaker and Wilson, 1996). The tectonic subsidence appears as the steepest part of the total subsidence curve, given that total subsidence is due to both tectonic loading and sediment loading, among other factors.

The subsidence model starts with cratonic or mature passive continental margin conditions driven primarily by sediment load-induced isostatic subsidence (slow subsidence rate, small accommodation space, slow sediment accumulation), interrupted by the onset of rapid tectonic subsidence into deep water conditions, followed by an exponential decay in subsidence rate as sediment load-induced conditions return. The model depicts an evolving basin that fills with a predictable sequence of carbonate and clastic sediment. The sequence starts with shallow water deposits, followed by deep basin deposits, followed by shallow water deposits. These facies might look like (bottom to top): 1. pre-tectonic shallow water (carbonate) deposits, 2. deep, quiet water, fine-grained, anoxic (carbonate to clastic) deposits, 3. mass transport clastic deposits (e.g. debris flows, turbidity flows, etc.) down an underwater slope, resulting in a coarsening, shallowing upward sequence as the accommodation space fills, 4.

distal to proximal shelf, coarsening, shallowing upward facies, 5. shoreface deposits, 6. coastal facies, 7. meandering fluvial deposits, and 8. braided fluvial deposits.

Applying this model to Page Valley, during New Market deposition accommodation space increases largely in concert with the increase in subsidence due to sediment loading. Depth increases at about the same rate as sedimentation, and the depth of the depositional surface stays about the same. This would have been the case during the period in which most of the Cambrian-Ordovician carbonates were deposited. During Lincolnshire and Edinburg deposition, subsidence outpaces sedimentation rate and the basin gets deeper. During Martinsburg (immature submarine fan clastics) and Massanutten deposition (after the tectonic load has been emplaced) tectonic subsidence decreases exponentially.

Subsidence rates slow while sedimentation rates increase resulting in rapidly decreasing accommodation space, filling of the basin, and shallowing upward water depths and facies. The shift from deepening due to increasing accommodation from subsidence, to shallowing due to decreasing accommodation from deposition, probably happens during the transition from Edinburg deposition to Martinsburg deposition.

Field Trip Itinerary

Figure 1: the trip is an east-to-west transect across strike from the western edge of the Blue Ridge province, through Page Valley, over Massanutten Mountain, across the Shenandoah Valley, and through Great North Mountain (Brocks Gap) that marks the beginning the Valley and Ridge. It follows Routes 211 in the east, and Rt 259 in the west. Parts of this field guide were adapted from Whitmeyer, et.al. 2012

Figure 4 is the regional stratigraphic column showing the stratigraphy, location of field trip stops, and tectonic interpretations.

Stop One: Harpers Formation, Chilhowee Group.

Location: Location: lat 38.668839 long -78.379215. Route 211, west bound lane ~ ½ mile west of Park office

Exposure: 100 meter long, 20-30 meter high outcrop in median. Good shoulder, good parking.

	Outcrop Features
Stratigraphy	**Structure**
Storm shelf: interbedded sandstones and shales; sandstone with hummocky cross stratification (undulating bundles of laminations scouring into and intersection each other)	Strike/Dip: 012,60E. Overturned to the west. **Prediction:** it is not obvious these rocks are overturned; they appear quite normal (a stratigraphic analysis has not been done; sedimentary structures should have up indicators, however). If the rocks are right side up then traveling west we should go down section, into the Weverton or Grenville basement. A couple hundred yards west, however, on a side road is the Antietam fm., which is up section and also overturned. Stop 2 further west is the Beekmantown, also up section, but subhorizontal. Ergo, these are overturned (Figure 5).

Tectonics	
Sedimentary/Basin Tectonics	*Larger Tectonic Contexts*
Hummocky cross stratification is upper-lower flow regime combined-flow energy dissipated on a shelf with depths not usually exceeding 150 feet. These thicker sand units imply an environment much closer to shore and in shallower water. Aside from a shelf environment, hummocky cross stratification by itself gives no tectonic indicators since it can occur in many tectonic circumstances. Tectonic interpretations must be done in context of other formations/environments below and above - neither seen on this trip (but seen in the SST course). Harpers, however, is associated with rift and transition-to-drift formations elsewhere in the Blue Ridge, such as the Lynchburg, Swift Run, Mechum River, and Catoctin lava flows. The overlying Antietam formation is a quartzite with *Skolithus* and (were visible) abundant cross bedding indicating a prograding system, while at Swift Run gap to the south there are proximal Bouma sequences in the Weverton (?). Figure 6 are two reconstructions of the Blue Ridge.	**Rift Tectonics:** Harpers is part of the **Rift** of a Rift-to-Drift sequence (Figure 6). It is the middle of the Chilhowee Group (Weverton, Harpers, Antietam) and represents the stabilizing phase of the rifting of Rodinia in the late Proterozoic. **Alleghanian Orogeny:** Overturning of the rocks took place in the Alleghanian orogeny when the entire Blue Ridge was brought up from depth and thrust west to its present location as an overturned (break thrust) ramp anticline. East of the Blue Ridge mountain the Grenville basement is cut by a series of anastomosing shear zones (Ductile Deformation Zones) (e.g. Garth Run and White Oak shears) that indicate ductile deformation at great depth. These are dated as late Devonian and represent pre-Pennsylvanian initiation of Alleghanian deformation when the rocks of the Blue Ridge province were farther east, and deeper.
Metamorphism: These rocks, as well as the entire Blue Ridge, underwent low grade (greenschist) metamorphism during the Alleghanian orogeny. The fact that sedimentary rocks just to the west (e.g. Beekmantown fm.) are not metamorphosed is one of the pieces of evidence for these Blue Ridge rocks being in a different province from those to the west in Page Valley and the Blue Ridge and Page valley rocks being structurally juxtaposed.	

Stop Two: Beekmantown Formation; first exposure.

Location: Location: lat 38.677854 long -78.455312. Rt 340 ~ ½ mile north of 211 junction at Luray
Exposure: a long low outcrop right adjacent to the highway with little shoulder. Road is heavily traveled so use caution.

Outcrop Features	
Stratigraphy	**Structure**
Carbonate tidal flat: dolomites with algal laminates, black cherts, and karst breccias.	Strike/Dip: 078,08N

Tectonics	
Sedimentary/Basin Tectonics	*Larger Tectonic Contexts*
Passive margin carbonates: Beekmantown was deposited toward the end of a thick sequence of mostly shallow water carbonate formations (Shady through Lincolnshire) of dominantly tidal to shelf carbonate environments. The fact that 1000's of feet of shallow water carbonates could accumulate in succession tells us that sediment generation by the carbonate factory could easily keep up with subsidence.	This is the **Drift** of the *Rift-to-Drift* Sequence. Beekmantown and the other Cambro-Ordovician carbonates (Shady through Lincolnshire Fms.) are passive margin (Divergent Continental Margin) deposits laid down along a subsiding continental margin following the Rodinia rifting. Subsidence-to-stabilization is an exponential decay beginning with thermal decay (cooling and increasing density as continental margin drifts away from divergent plate boundary), followed by sediment loading (also an exponential decay).
Alleghanian deformation and Regional Structural Signatures: like all the rocks in this region these were caught up in the thrust stacking that accompanied construction of the Pangaea supercontinent and built the Appalachian mountains. This outcrop alone, however, tells us virtually nothing of those processes since, from this outcrop alone, we would assume the rocks are sub-horizontal and undeformed. The larger structural signature of this region consists of long areas of sub-horizontal, gently undulatory rocks, punctuated by periodic large scale—first order—break thrust ramp anticlines (like the Blue Ridge). We will see two more examples of this on our transect. Also present are smaller 2nd and 3rd order folds and faults—representing their fractal nature; a.k.a. Pumpelly's Rule—seen at some of the stops. Unless there is something special to comment on we will assume that all remaining stops fit into this Alleghanian thrust/fold belt signature.	

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Stop Three: Shenandoah River/Massanutten Mountain Overview

Location: Overlook of North Fork Shenandoah River valley and Massanutten Mountain in the distance from the crest of Rt. 211.

This stop is to gain perspective, and set up some predictive hypotheses of what should come next.

Massanutten Mountain Overview	
Stratigraphy	**Structure**
Exposures: Driving the long grade we just climbed traveling west from Luray are patchy outcrops of sub-horizontal Beekmantown Fm. From this high point looking west we see the North Fork Shenandoah River valley below, and Massanutten Mtn. in the distance. The next several stops take us to the top of New Market Gap, the low area seen along the crest of Massanutten Mtn. in the distance.	**Predictions:** Since we are at a high point, looking west, and sitting on the Beekmantown, it is reasonable to predict that as we continue west down to the river we will travel down section through the Conococheague, Elbrook, and what ever other formations might be exposed down section (Stonehenge, New Market and Lincolnshire are well preserved here). Taking the perspective that present evidence is the best predictor of what should come next, we would also predict that those formations will be sub-horizontal. The fact that these predictions turn out to be spectacularly wrong is insight into what the stratigraphy and structure can tell us about the geologic development of the region.

Stop Four: Edinburg Formation

Location: lat 38.38.34 long 78.31.34. Rt 658, off Rt 674, off Rt 211

Exposure: Quarry on the east bank of the Shenandoah River, South Fork; Hamburg

Outcrop Features

Stratigraphy	Structure
Deep water basin: black (weathering gray), amalgamated micrite, sometimes interbedded with thin black shale. Stratigraphic and sedimentary features are best observed not in the quarry but along the road just south of the quarry. Here the beds are sub-horizontal and overturned with minor folding and faulting. Beds are generally a few em thick, but some reach a thickness of half a meter or more.	Strike/Dip: 198,41W – S fold so much variability Large-scale (2nd order) recumbent fold; note that the left and right quarry walls are dipping opposite directions. The southeastern quarry wall contains the large-scale fold hinge. Also note large S fold at the left side of the northeast wall, down-dip slickenlines on bedding surfaces, and bent/warped cleavage in finer-grained beds. **Testing Our Prediction:** Note that at the previous overview stop we made a (simplistic) prediction that driving into the river valley we should go down section through sub-horizontal strata. Instead we have gone up section, into this Edinburg fold. The deduction is that the Beekmantown formation at the last two stops has been thrust up and over the Edinburg. That puts this stop as a drag fold in the foot wall of the thrust.

Tectonics

Sedimentary/Basin Tectonics	*Larger Tectonic Contexts*
Taconic foreland basin - initial filling stage: nominally, these rocks say low energy (micrite) and anoxic conditions (black). This does not automatically mean deep water or basin since similar facies could occur in a lagoon (an example is at the base of the Lincolnshire at Tumbling Run, Strasberg, Va.). Only in context of what is stratigraphically below and above can we understand the Edinburg as the initiation of foreland basin subsidence that corresponds with the beginning of the Tacoic orogeny. This is where the Tectonic/ Accommodation model becomes useful (Figures 2 and 3) since it establishes from a theoretical viewpoint predictions of what a foreland basin stratigraphic sequence filling should look like, and when we examine the sequence up section what these black micrites/shales of the Edinburg represents becomes clear. The Edinburg is interpreted to have been deposited in a deep-water anoxic environment by mass transport processes (turbidity or debris flows), during maximum subsidence of the Taconic foreland basin. The carbonates were most likely generated on a shallow western carbonate platform. It is not obvious from this stop alone that the Edinburg was deposited by mass flows down a slope into a deep-water anoxic basin. In other locations there are good examples of scours, slump, and soft sediment deformation features (e.g. Lowry and Cooper, 1970; Pritchard, 1980; Read, 1980) that suggest down-slope mass movement.	Folding in the quarry occurred during the Alleghanian orogeny, potentially in two episodes. Most folds observed in Page Valley are upright with sub-vertical axial planes. The folds in the quarry probably initially formed as upright, open folds similar to geometries seen elsewhere in Page Valley. The cryptic, west-directed thrust occurred later in the Alleghanian orogenic cycle and tightened and rotated the pre-existing footwall folds to horizontal. Ergo: there were multiple episodes of deformation in the Allgehanian. **It's a matter of scale:** Figure 7. Looking at this fold in the quarry it appears dramatic and important; few people are not impressed when first seeing it. But, human scales are not a good guide to the importance of a structure. Compared to structures in the surrounding area, for example the Massanutten Mtn. syncline, this fold is a small to medium sized and relatively unimportant structure. It does give us a clue to the presence of the thrust fault, but the surrounding area has considerable other evidence pointing to a large thrust fault. Figure 7 shows the scale of the Edinburg recumbent fold relative to the larger structural features in the region.

Stop Five: Upper Martinsburg (Cub Sandstone; first exposure).

Location: lat 38.38.32 long 78.33.15

Exposure: 50 meter long, ~ 8 meter high outcrop; badly weathered.

Outcrop Features	
Stratigraphy	**Structure**
Storm shelf: sub-vertical interbedded fine sandstones and shales of several cm thickness. Sandstones with megarippled tops and undulating bases, containing intersecting bundles of hummocky laminations. For as deeply weathered as this is it well shows hummocky signatures, but not the prograding parasequences that characterize the Cub Sandstone elsewhere (these are well developed on the road to Catherines Furnace a few miles south off Route 340.	Strike/Dip: 214,90E; foliation 020,48E; steeper than bedding; very high angle normal fault at east end of outcrop; Bedding is top to west. Beds are mostly subvertical with well developed cleavage in the shales. The structural complexity of the outcrop is hinted at by analyzing the cleavage at the eastern end of the outcrop (Figure 8).

Tectonics	
Sedimentary/Basin Tectonics	*Larger Tectonic Contexts*
Taconic foreland basin - final filling stages: The Cub SS represents the end of the Taconic foreland basin filling (Figure 3) when it has shallowed upward enough for storm wave to touch down and generate hummocky sequences.	At the outcrop scale this is a rich stop, both stratigrapically and structurally; there is a lot to be learned from close study. However, the fold and fault are 3rd order features and have little regional significance, with two caveats. First, there is not much outcrop along this stretch of highway, and anything that gives insight is useful. Second, because structure is fractal, we can anticipate that the nature of this small fold/fault reflects the nature of larger structures where we cannot see everything because of scale.

Stop Six: Middle Martinsburg Formation

Location: Location: lat 38.38.00 long -78.34.44 to 78.34.34. Long cut on north side of road at junction of Rt 340 and 211.

Exposure: 100 meter long, 40-50 meters tall; well exposed.

Outcrop Features	
Stratigraphy	**Structure**
Submarine fan: well developed Bouma sequences with mostly T_{ABD} units (graded bedding, high velocity laminations, laminated silts) of about dm thickness. Sands are very immature lithic, feldspathic, quartz wackes.	Strike/Dip: East 032,72E; Mid 210.78W; West 211,76W

Tectonics	
Sedimentary/Basin Tectonics	*Larger Tectonic Contexts*
Taconic foreland basin - middle filling stage: One of the frustrating things about the Martinsburg formation is that although there are decent or even excellent outcrops of the lower, middle, and upper portions, no where do we have outcrops that show how these transition. They differ from each other enough one might be tempted to think they are unrelated, except that mapping indicates they do stack in stratigraphic order. It is one of the enigmas of the Taconic foreland basin.	The consistent west dip of the middle Martinsburg at this location marks the eastern flank of the Massanutten synclinorium. This deformation is a response to Alleghanian thrust stacking during the Pennsylvanian. At this locality the Massanutten syncline seems simple and straight forward. We will see that is too simplistic.

Stop Seven: Upper Martinsburg (Cub Sandstone; second exposure); Massanutten Sandstone.

Location: lat 38.38.35.0400 long -78.36.48.70.
Exposure: Crest of Massanutten Mt., at New Market Gap, looking north. We view the outcrop from the south side of the highway. What is easily visible are thick sandstones in the roadcut. Above them in the woods is the Massanutten Sandstone, generally only visible in winter when the leaves have been shed.

Outcrop Features	
Stratigraphy	**Structure**
Cub SS: Proximal storm shelf: This does not look like the Cub Sandstone we saw at Stop 5 (interbedded sandstones and shales). The sandstones are thick and massive with little internal structure, at least from this distant vantage. But, these thick sandstones are consistent with proximal parasequences in a prograding shelf system. We see a similar coarsening, amalgamating upsection sequence at Catherines Furnace. **Massanutten SS:** we do not visit this formation on this trip. Consists of indurated, medium to coarse quartz arenite beds with planar and trough cross bedding. These have been interpreted as braided river deposits (Pratt, 1979).	Strike/Dip: 032,72E. Outcrop near the axis of the Massanutten synclinorium.

Tectonics	
Sedimentary/Basin Tectonics	*Larger Tectonic Contexts*
End of the Taconic orogeny: The enigma of the Massanutten SS is it contradictions. It is arguably a braided river system, but is quartz dominated and thereby very unlike most braided river systems which are lithic or feldspar rich. The enigma is yet to be resolved.	The end of the Taconic orogeny is believed to be an unconformity. A small angular unconformity is present in New York. The Cub SS-Massanuttten SS contact is not exposed in this region

Stop Eight: Upper Martinsburg (Cub Sandstone; third exposure).

Location: north side of Rt. 211 at the juncture of Rt 211 and Rt 620, on the west side of Massanutten Mtn.
Exposure: This stop is in a narrow, vertically sided drainage ditch that is easy to miss. We will not descend into the drainage ditch; the lesson can be made just looking at the surrounding topography. Nor are we particularly interested in the stratigraphy, which is very similar to Stop 5. It is the structure and tectonics we are after.

Outcrop Features
Structure and Tectonics
Strike/Dip: 0.38, 85E, overturned to the west. Cleavage: 0.28, 40E. Tight overturned anticlinal fold projecting out from the western flank of Massanutten Mtn (Figure 9). The lesson of this outcrop is that what seems pretty straight forward may hide revealing complications. If we presume the Massanutten Mtn. contains a syncline—based on the evidence that units on the east side dip west, and units at the top of the gap are sub-horizontal—then we anticipate that rocks on the west side of Massanutten must dip east—to complete the syncline. And it makes perfect sense topographically since traveling west from the Mountain toward New Market takes us into the Shenandoah Valley, not into another fold. So we reasoned too. But, the Upper Martinsburg (Cub sandstone) exposed in the drainage ditch is overturned to the west, indicative of an anticlinal fold between the Valley and Massanutten Mtn (Figure 9). Nothing topographically would give any hint this fold exists. Indeed rocks exposed in the Valley and out to Little North Mountain undulate sub-horizontally. On reflection, this tight overturned anticlinal fold is not inconsistent with the folding (we will not see) several miles south of New Market gap. There, at Catherine Furnace, in a narrow cross section only a few miles across, the Massanutten Sandstone is not a single syncline, but two tight synclines with a tight anticline in between. Reasonably, the overturned anticline in the Cub Sandstone might extend south to that part of Massanutten Mtn, making two synclines and two anticlines. But, wait, there's more. Small east directed thrust faults have recently been mapped on the eastern side of Massanutten Mtn. This indicates two sequential stress episodes; the main Alleghanian one resulting in the west-directed folding/thrusting, the second directed east to produce the small back thrusts (Heller, et.al., 2007).

One hypothesis for all this is that during the Alleghanian orogeny the rocks of Massanutten Mtn., moving westward, came up against an immovable barrier that caused them to accordion fold to take up the stress, and, when that was not enough, to finally back thrust eastward. It is hard otherwise to explain how the very tough Massanutten sandstone got so tightly folded. What was that immovable barrier to the west?" Speculatively, just to the west is another major break thrust that ramped Valley Cambro-Ordovician carbonates up and over the clastics in Little North Mountain. This would have built a large topographic high to the west of Massanutten Mtn. that could not be climbed by the Massanutten strata. Instead they would have been scrunched between irresistible stress to the east and an immovable barrier to the west resulting in tighter folding than is normal for the region.

Stop Nine: Beekmantown, New Market, Lincolnshire Formations

Location: Lat 38.37.23 Lon 78.49.08; outcrop extends east down Rt 259 couple of hundred yards

Exposure: Representative exposure of the Beekmantown, New Market (small, mostly covered and hard to find outcrops a hundred or so yards east) and Lincolnshire (at the crest of the road we have found samples only with much hunting; but several miles east is an outcrop showing distinctive Lincolnshire facies).

This stop is representative of the sub-horizontal to low angle dipping as these formations ripple across the Shenandoah Valley from New Market to here. Scattered and generally small outcrops of each formation are exposed along the transect and show similar gentle dips.

Outcrop Features	
Stratigraphy	**Structure**
Carbonate tidal flats and shelf: • Beekmantown: gray-white algal laminated tidal dolomites. • Knox Unconformity (not exposed) • New Market: tidal micrites with birds eyes; algal laminates. • Lincolnshire: shelf fossil rich limestones and black cherts.	Strike/Dip: 030,28E **Prediction:** the rocks at this stop are dipping gently east, so continuing our transect west should take us down section; next stop would be the Conococheague.

Tectonics	
Sedimentary/Basin Tectonics	*Larger Tectonic Contexts*
Carbonate passive margin: Although to a carbonate stratigrapher the changes in these lithologies holds fascination, from a sedimentary tectonic perspective they simply represent tectonic stability. The most dramatic shift is from tidal environments to shelf environments, which, could easily be explained as a transgression. If, however, we could see the next formation up section–Edinburg (seen at Stop 4)–we would be aware of the beginning of a much more dramatic transition; the beginning subsidence of the Taconic foreland basin, discussed at Stop 4.	Same as Stop One

Stop Ten: Conococheague Formation

Location: Lat 38.38.20 Lon 78.51.04

Exposure: low outcrop on north side of road about 40 meters long, 4 meters high. Well exposed, good parking on the opposite side of the road. Look west the stop give a good view of Brocks Gap a mile or so away.

Outcrop Features	
Stratigraphy	**Structure**
Carbonate tidal flat: Gray white dolomite, but aside from that the outcrop is too deformed to provide much sedimentologic evidence. At other localities Conococheague has algal laminates, stromatolites, pelletal sands, flat pebble conglomerates, ribbon rock, and herringbone cross bedding.	Severely deformed. It is difficult to see bedding in this outcrop, and it depends on the quality of the light. Toward the left (west) end of the outcrop some vertical bedding can be detected, but it quickly folds over toward the east. We have not been able to palinspastically restore this outcrop

Tectonics	
Sedimentary/Basin Tectonics	***Larger Tectonic Contexts***
Same as Stop 2: Beekmantown Formation	Same as Stop 2: Beekmantown Formation **Alleghanian deformation:** Large swaths of the carbonate rocks along this transect from New Market to here show little or no structural deformation. The severity of this deformation compared to the rocks just to the east imply a major dislocation. As we will see at the Brocks Gap stop (look just to the west about a mile) there is a major jump up-section from the Conococheague to the Reedsville and Oswego, both overturned to the west. The deduction is the Conococheague and other carbonate formations were thrust up and over the Brocks Gap section, putting them in the hanging wall of the North Mountain fault. This structural patterns repeats in many places.

Stop Eleven: Brocks Gap Section: Reedsville, Oswego, Tuscarora, Rose Hill, Keefer Formations

Location: Lat 38.38.38 Lon 78.51.45; outcrop extends west through most of gap ending at the Oriskanhy at Chimney Rock. We will travel no farther than the Keefer.

Exposure: large dramatic road cut several hundred feet high. Depending on time we will either cross the road, climb the guard rail and examine the rocks closely, or more quickly, walk the opposite side of the road with the leader narrating what is on the opposite side of the road.

Outcrop Features	
Stratigraphy	**Structure**
This section contains the Reedsville, Oswego, Tuscarora, Rose Hill, Keefer, and covered formations up to the Oriskany exposed at Chimney Rock. The section is largely unique in that it is a mixture of formations some found to the west but not the east, and vice versa. Figure 10 shows an interpretation of the facies relationships.	Strike/Dip: 034,84E overturned to the west **Prediction:** the Oriskany at Chimney Rock is the last exposed outcrop of the Brocks Gap sequence, but since we have been climbing section all the way through the gap it would make sense that rocks to the west should get even younger, as we will go see next.

Brocks Gap Formation Descriptions

Reedsville formation (storm shelf): East end of outcrop: interbedded fine grained sandstones and shales (~ dm thickness), with scattered mega-rippled biosparite beds. Sandstone beds shrink and swell in thickness, and are composed of bundles of thickening and thinning laminations (hummocky cross stratification). Upsection sandstones thicken and amalgamate and contain reactivation surfaces.

Oswego formation (braided river): coarse to very coarse gray to white quartz sands with small quantities of lithic fragments. Thick bedded (1 to several dm), amalgamated, rapidly changing thickness, with scours and reactivation surfaces, and large scale planar and trough cross bedding. Upsection scattered gray mud pebbles or zones appear. In the upper third, red zones several meters thick appear alternating with Oswego gray sands; basic lithology does not change, just the addition of red staining. Mud pebbles are red in these zones.

Tuscsarora (beach): white quartz sandstone. Along the road there is only a couple of dm exposures, but at the top of the gap it is well exposed; quartz pebble beds dm to m in thickness (a large boulder of the quartz pebble conglomerate in next to the guard rail). Superficially, this small outcrop look similar to Oswego, but is whiter.

Rose Hill (clastic tidal systems): not exposed along the road, but exposed at the top of the gap. Elsewhere red, interbedded shales and rippled sandstones forming coarsening upward parasequences.

Keefer (beach): quartz sandstone, with occasional pebble zones. Not much can be seen along the road due to weathering, but on the west side, 50 yards or so up into the woods are broad surfaces with oscillatory stokes and sinusoidal ripples (at 90 degree to each other). *Skolithus* traces are in the float, and occasional pieces with cross bedding.

Tectonics	
Sedimentary/Basin Tectonics	***Larger Tectonic Contexts***
Taconic foreland basin - final filling and post orogenic stages: The Oswego problem. The Oswego is at its thickest at Brocks Gap, and most simply has an eastern sourceland. The nearest Ordovician exposures east of Brocks Gap are in the Massanutten area, but historically no traces of Oswego have been found there (acknowledging that in the Ordovician these regions were widely separated). Recently two small outcrops of possible Oswego have been found in the southern end of Massanutten Mtn. by Matt Heller, but this requires more study).	The Taconic foreland basin has complex stratigraphic relationships, representing its complex history. To begin, the stratigraphic sections vary markedly from east to west (Figure 4). In the Massanutten region the sequence begins with Edinburg basinal black micrites that transition up section into Martinsburg submarine fan Bouma sequences, Cub shelf shales, and the Massanutten braided river. Just a few miles west at Brocks Gap (Little North Mountain) none of these formations are present; instead there is Reedsville storm shelf, Oswego braided river, and Tuscarora beach. Further west at Germany valley the section is Trenton shelf carbonates, Reedville shelf clastics, Oswego coastal sand bars, Juniata tidal flats, and Tuscarora beach. The interpretation is the Taconic foreland basin was divided into two basins separated by a peripheral bulge (preserved at Little North Mountain) Figure 10. The eastern (flysch) basin subsided the fastest and deepest, and is the one the Tectonic/ Accommodation model is based on (Figure 3). Most of its sediments derived from generally eastern sources—the Carolina volcanic terrane. The Germany Valley western basin subsided less and more slowly developing environments that were never more than deep shelf. These sediments flowed in mostly from Pennsylvania and southern Virginia. The Little North Mountain peripheral bulge sediments derive from both east and west in a complex history. The issue has always been the Oswego which has an apparent eastern source that cannot be identified. The problem is too complex to explore more here, but has better perspective when we look at a palinspastic restoration (Figure 11). Rocks that are nearly juxtaposed today by Alleghanian thrusting, were during the Ordovician widely separated, with none of the in between rocks exposed. Makes it challenging to reconstruct the basin.

Stop Twelve: Brallier Formation

Location: Lat 38.38.52 Lon 78.53.05

Exposure: series of low outcrops along the north side of the road; exposed at several places along a few miles of the highway.

Outcrop Features	
Stratigraphy	**Structure**
Bouma sequences and Submarine fan: interbedded very fine grained, indurated sandstones (1 to a few cm thick) interbedded with shales of similar thickness. Sandstones are Bouma sequences with mostly T_{CDE} units. Ripples sometime seen on sandstone tops, while bases have clear flutes and scours. Leisagang stain often masks the internal structures but sometimes the climbing ripples of the T_C unit are seen.	Strike/Dip: 330,16 NE These subhorizontal units just a few miles west of the Brocks Gap overturned anticline indicate again the structural signature of this region: long areas of subhorizontal rocks, punctuated by periodic large scale—first order—break thrust ramp anticlines. Smaller 2nd and 3rd order folds and faults are also present but none of our stops looks at them.

Tectonics	
Sedimentary/Basin Tectonics	***Larger Tectonic Contexts***
Acadian Foreland Basin: the Brallier (and Needmore and Millboro that come before it) are the first formations to show up after the carbonates and quartz sandstones of the late Silurian-early Devonian tectonic calm. The black shales of the Needmore and Millboro indicate deep water deposition, as does the Bouma sequences of the Brallier. Thus, these formations represent the initiation of rapid foreland basin subsidence.	The driver of the Acadian foreland basin subsidence in this region is enigmatic. No distinct terrane in the Mid-Atlantic piedmont is associated with the Acadian. On the other hand, older piedmont thrusts have evidence of right lateral strike-slip reactivation, as if a terrane had slid down the coast. The foreland basin has features of a typical foreland basin, but there is no evidence of the thrust-stacking that usually accompanies foreland basin subsidence.

Thus Endith the Field Trip

List of Figures

Figure 11. Interpretive cross sections across northern Virginia showing the progressive development of the Iapetan passive continental margin into the deep and shallow Taconic clastic basins (top two cross sections). Bottom cross section shows present-day geology after the Alleghenian orogeny foreshortened the orogenic belt. Rock units that are now geographically close were in the Ordovician widely separated (Diecchio,1993, fig 7).

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Field Trip Base Map

NAGT 2014 Meeting: James Madison University

A Geologic Transect from the Blue Ridge, Across Page and Shenandoah Valleys, and into the Eastern Valley and Ridge

KEY

#1 - Harpers
#2 - Beekmantown
#3 - Massanutten overview
#4 - Edinburg
#5 - Cub Sandstone
#6 - Martinsburg (middle)
#7 - Cub SS/Massanutten SS
#8 - Cub SS-structure
LUNCH: New Market

#9 - Beekmantown/New Market/ Lincolnshire
#10 - Conococheague
#11 - Brocks Gap: Reedsville, Oswego, Tuscarora, Rose Hill, Keefer
#12 - Brallier

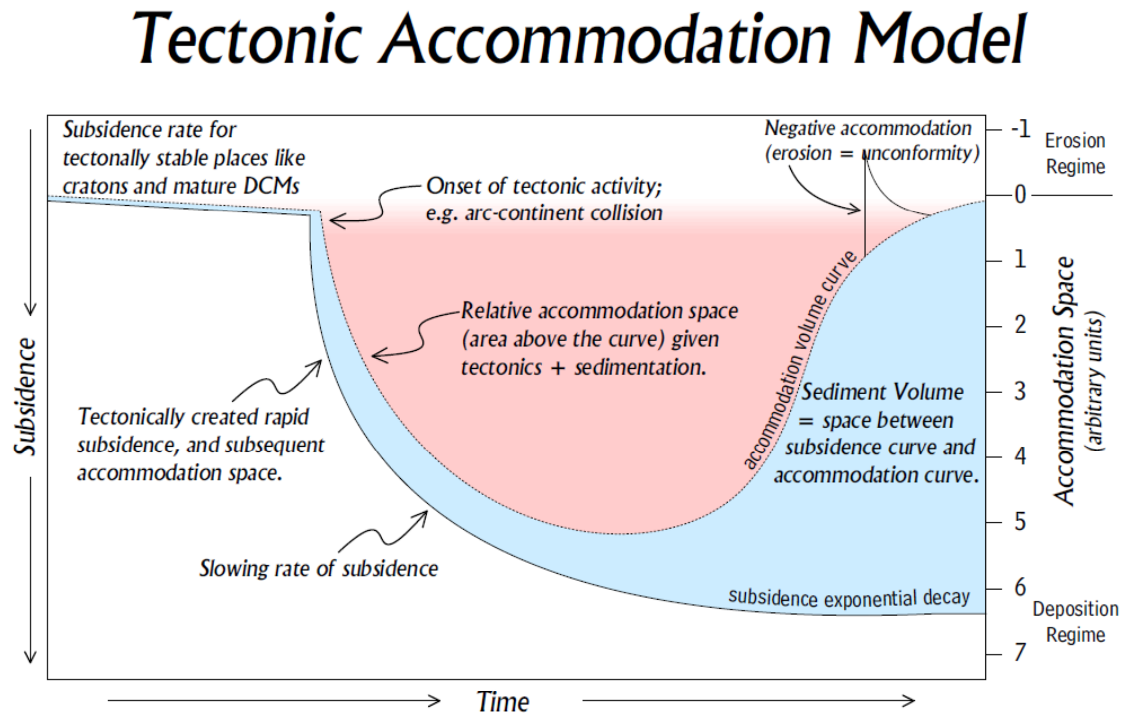


Figure 2. Theoretical Model For the Tectonic Creation of a Foreland Basin, and the Subsequent Filling of the Accomodation Space by Sedimentation.

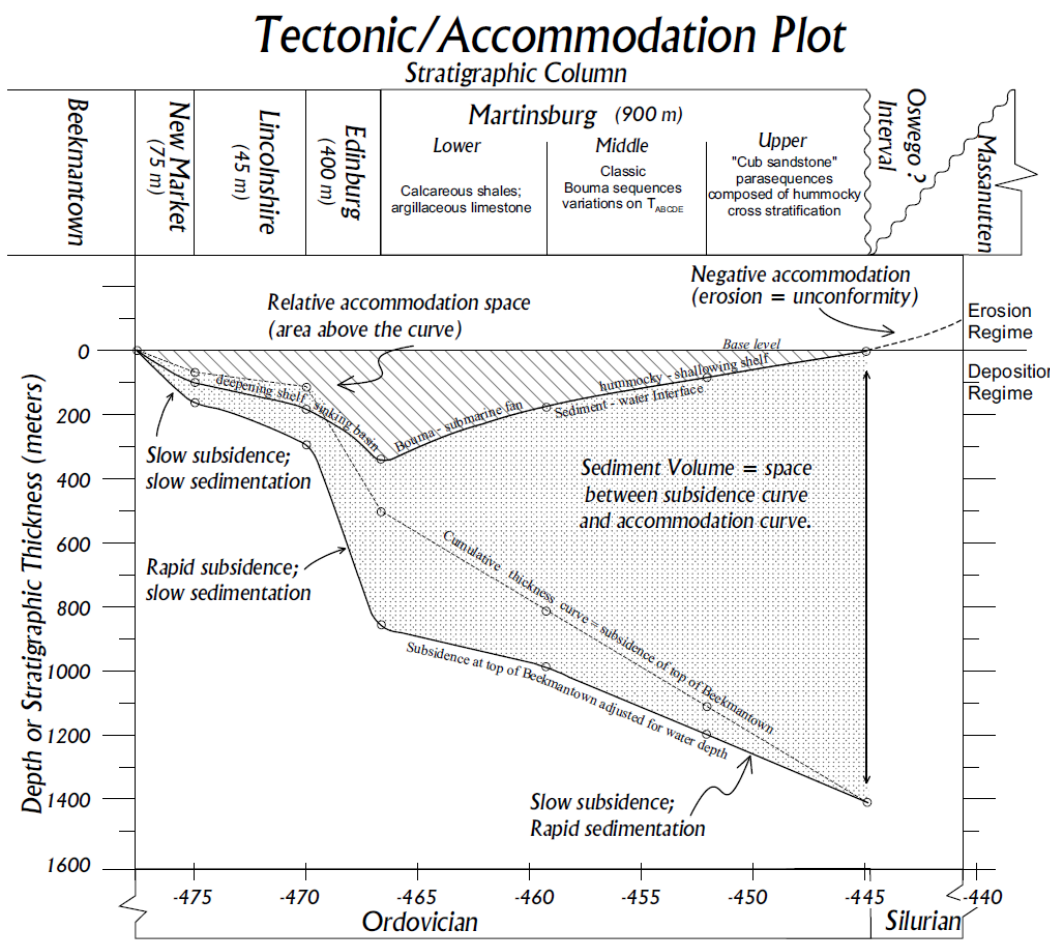


Figure 3. The theoretical Tectonic/Accomodation plot drafted using actual data from the Page Valley Taconic Section.

NAGT: Spring 2014 Field Trip: JMU

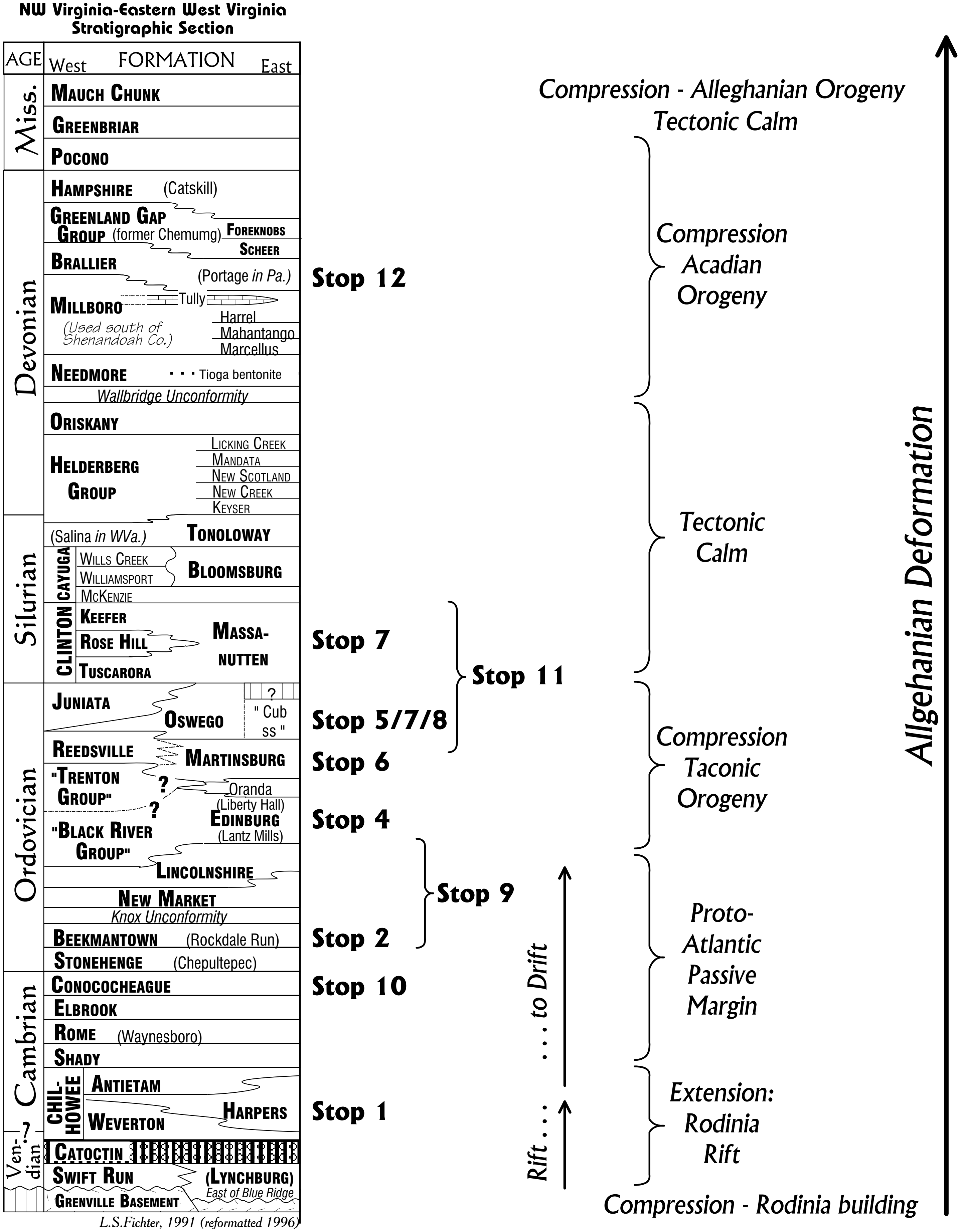


Figure 4. Regional stratigraphic column showing the stratigraphy, location of field trip stops, and tectonic interpretations.

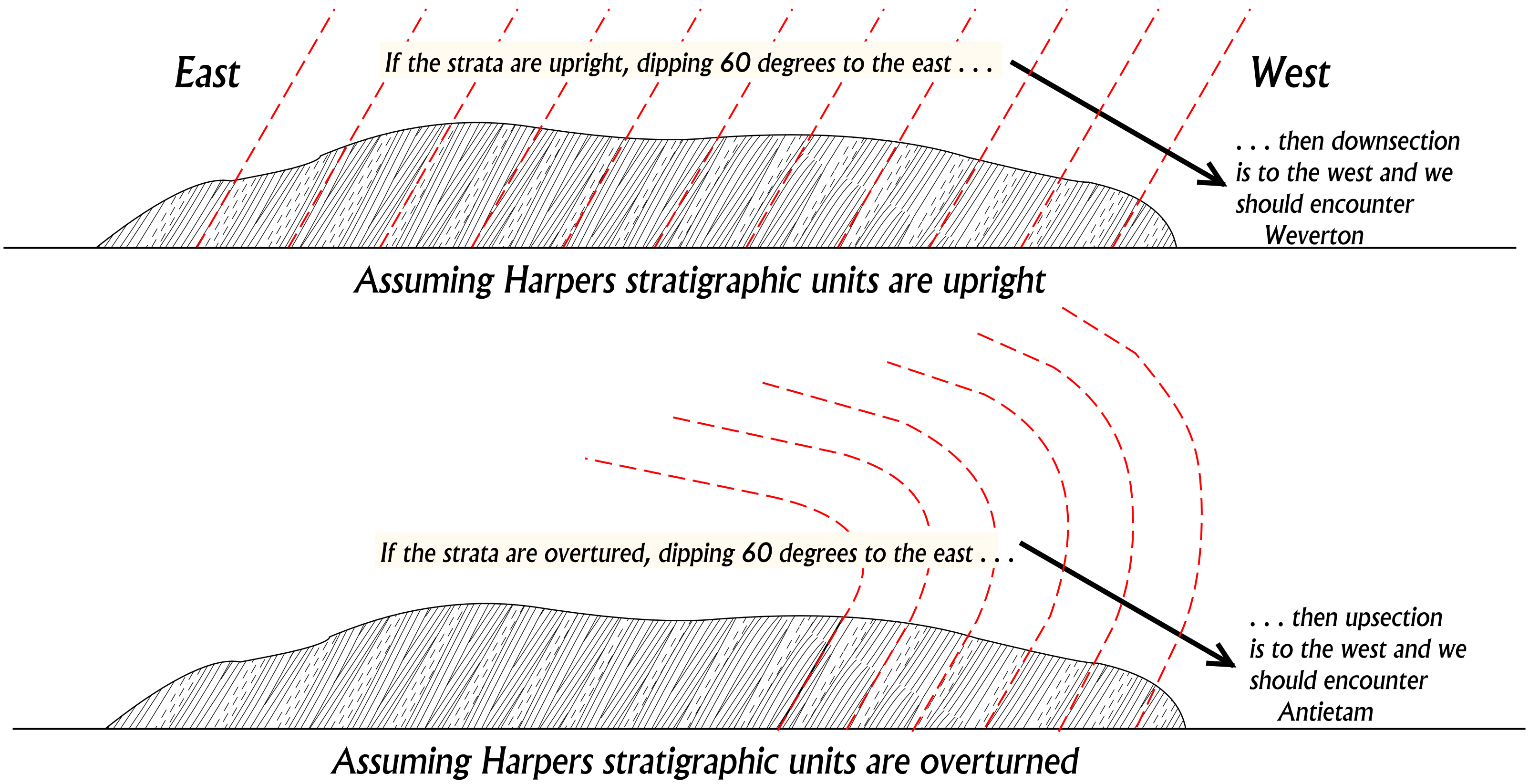
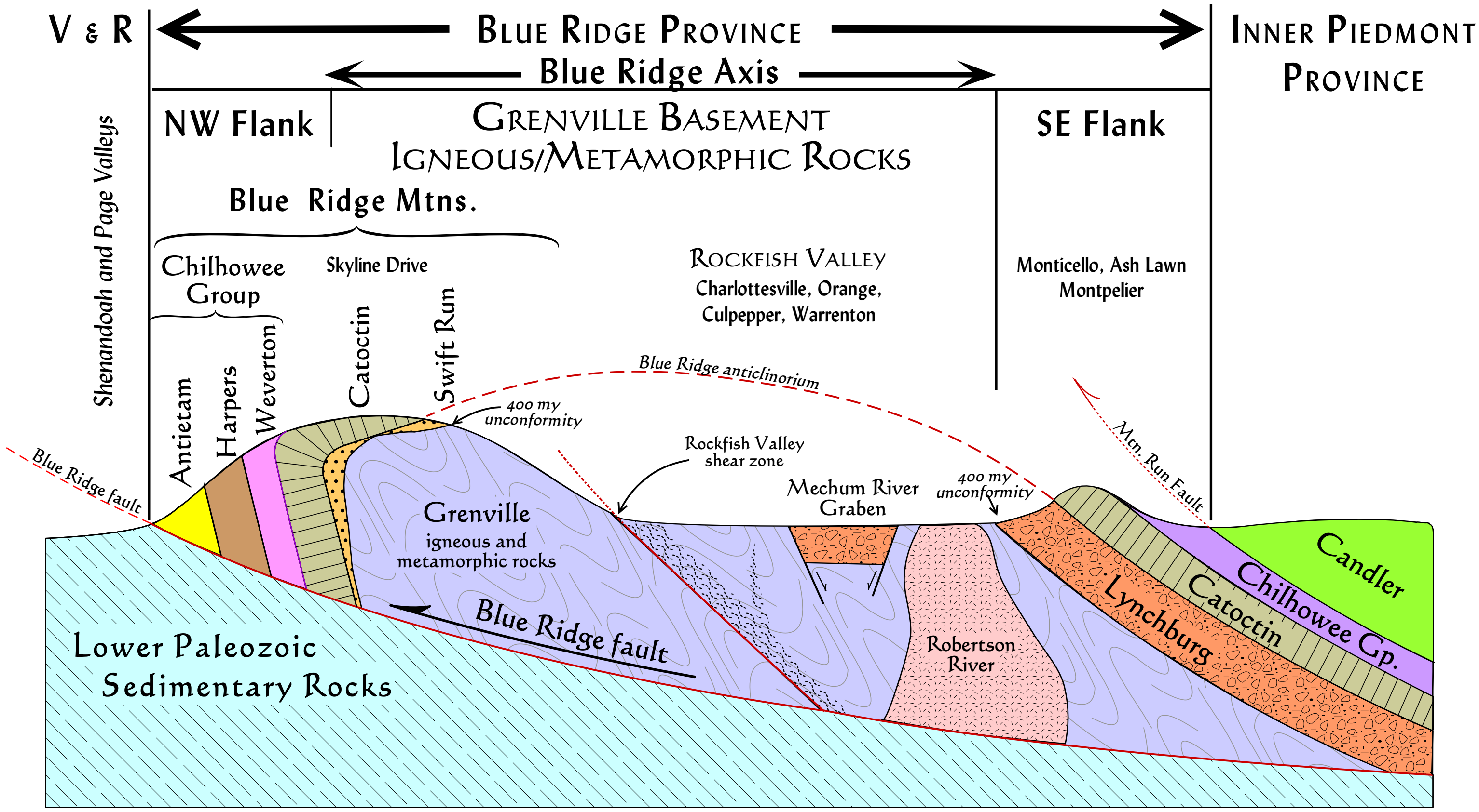


Figure 5. Predictive model of what should be found upsection if: 1) the Harpers at Stop 1 is right-side-up - Weverton to the west, or 2) overturned - Antietam to the west.



Conceptual Cross Section of the Blue Ridge Province of Central Virginia

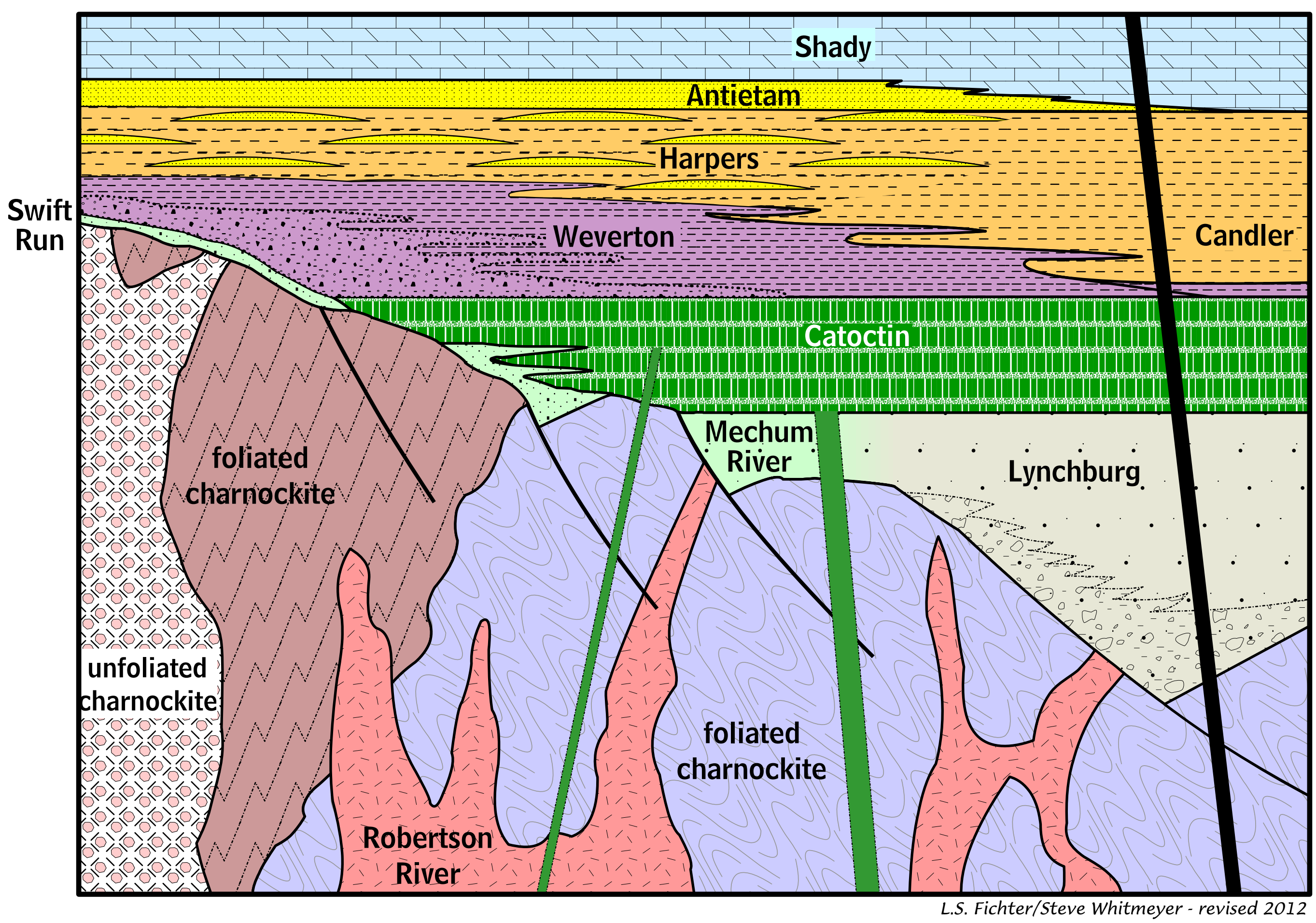


Figure 6. Interpretive Blue Ridge cross section (top drawing), and reconstructed Blue Ridge showing facies relationships.

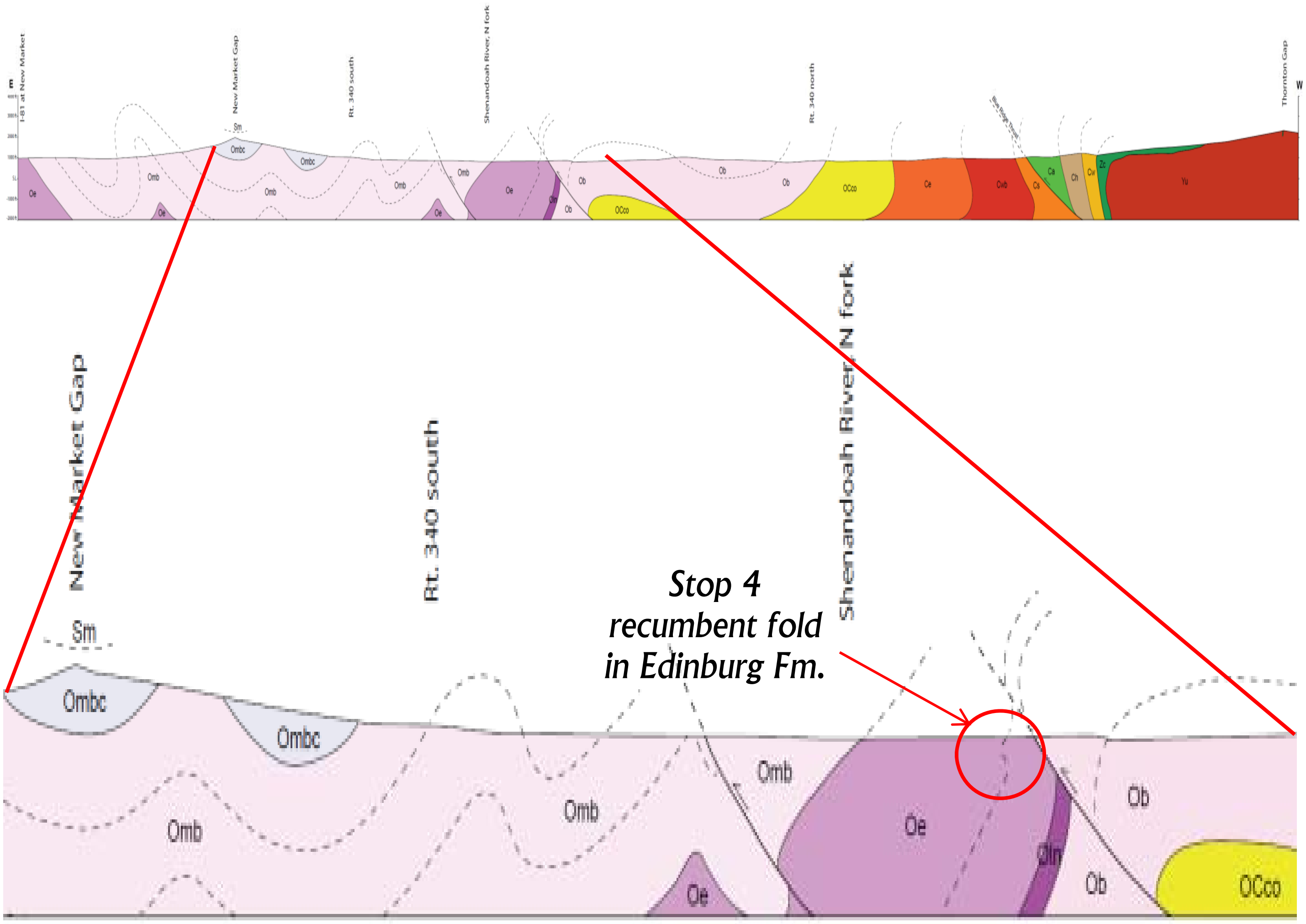


Figure 7. Detail of a structural cross section across Page valley showing the scale of the Edinburg recumbent fold at Stop 4 relative to the larger structural features. The Edinburg fold is a 2nd order feature..

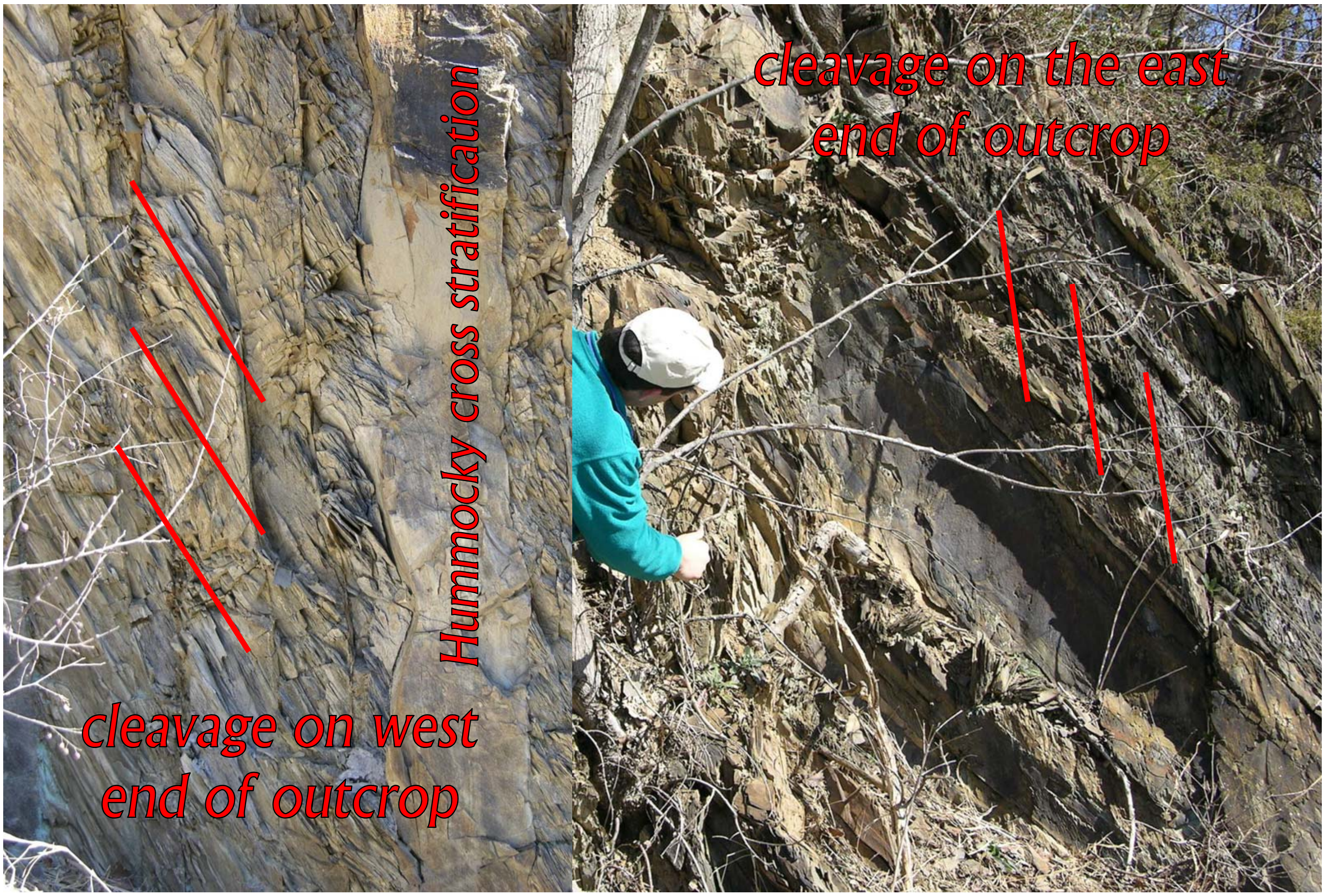


Figure 8. Stop Five Cub Sandstone (upper Martinsburg). Two section of the east end of the outcrop about 10 feet apart showing the different cleavage relationships. Analysis of these indicate a faulted anticlinal 3rd order fold. Structures this small have little regional significance, but the outcrop provides excellent opportunities for both stratigraphic and structural analysis.

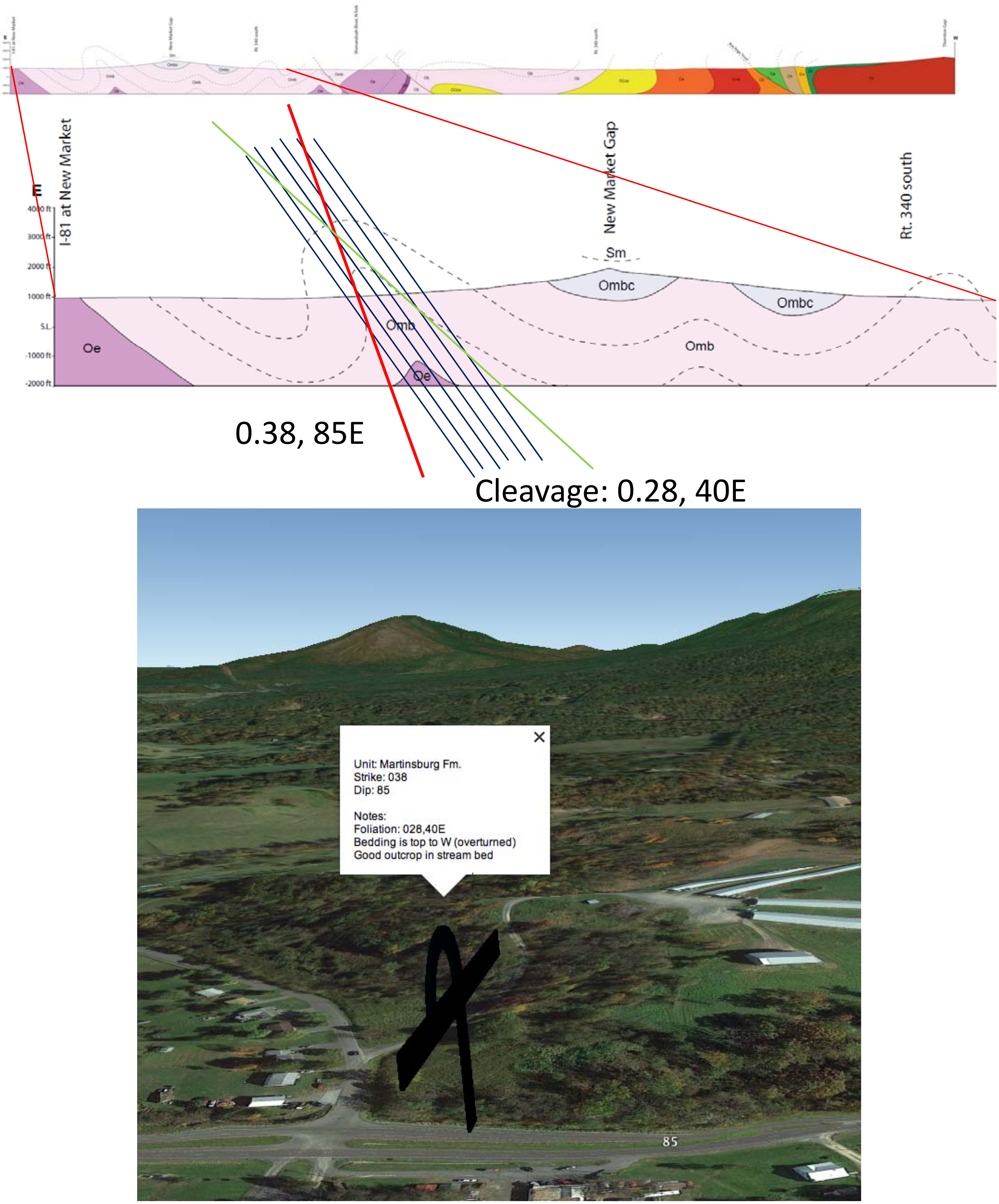


Figure 9. Stop Eight Cub Sandstone (upper Martinsburg). A tiny unremarkable outcrop in the drainage ditch, except that the beds are overturned to the west, and the cleavage patterns indicate an anticline. There is no topographic clue that this overturned anticline exists, and no trace of the Massanutten sandstone to the west. Thus, the necessity of detailed structural analysis to understand the region.

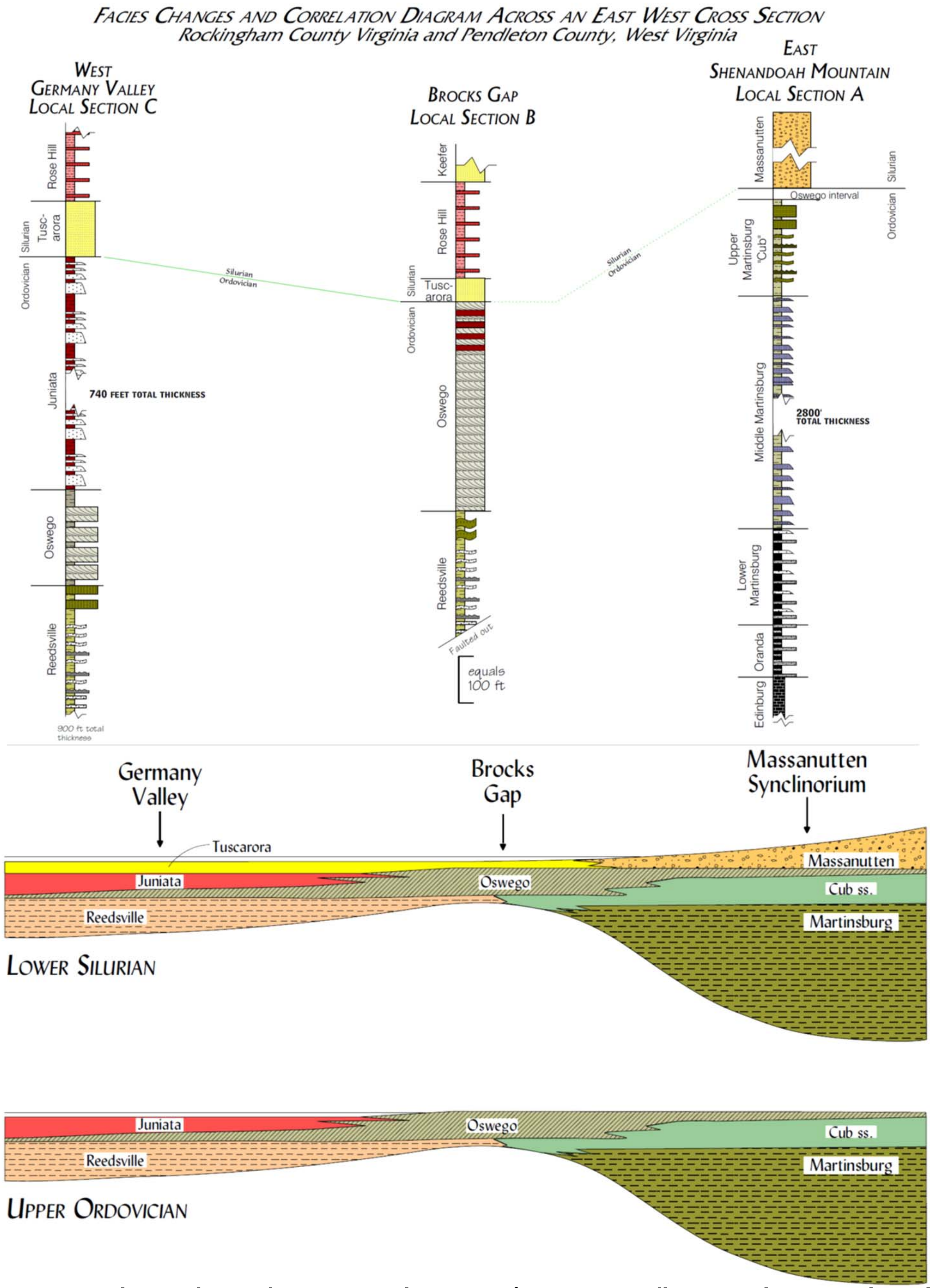


Figure 10. Top: Ordovician-lower Silurian stratigraphic sections from German Valley, to Brocks Gap, to Shenandoah Mtn. Although time equivalents these three sections differ markedly in their stratigraphic sequences and depositional environments. Bottom: two interpretive cross sections showing how the Taconic foreland basin was divided into two basins separated by a peripheral bulge (preserved at Little North Mountain).

Interpretive Cross Sections From Eastern West Virginia Across Northern Virginia Showing Deep and Shallow Taconic Facies Relative to Present Geology

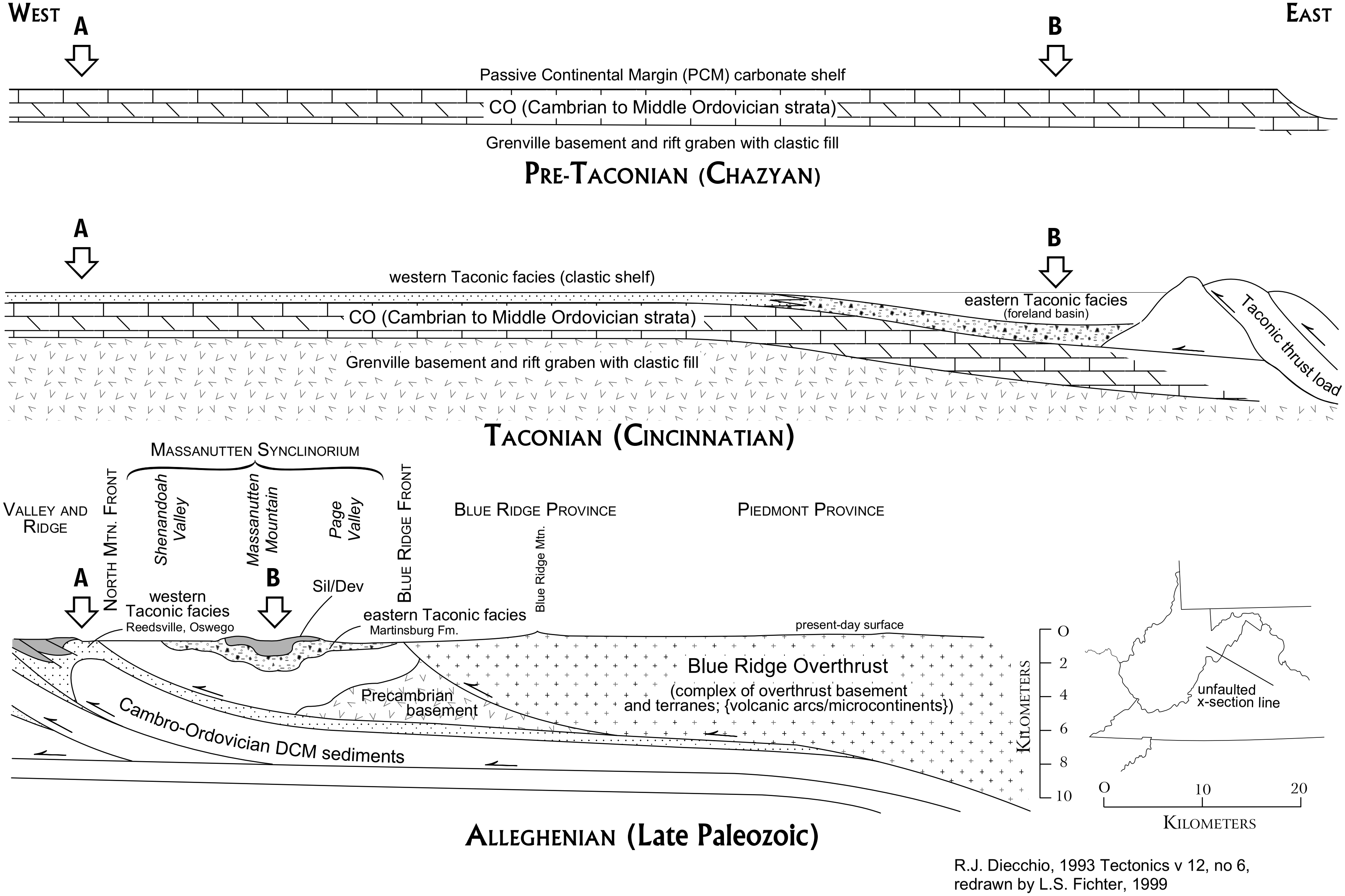
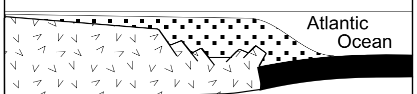
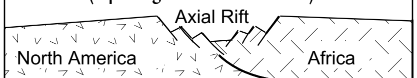
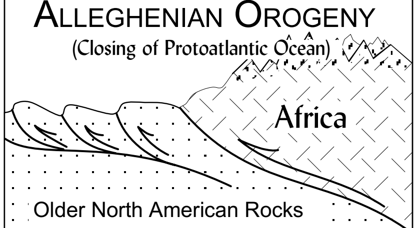
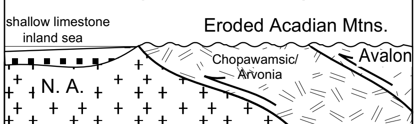
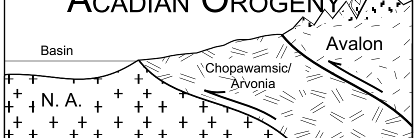
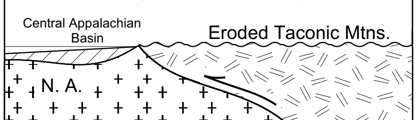
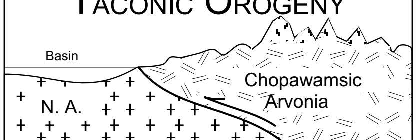
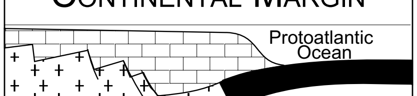
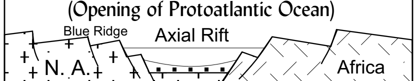
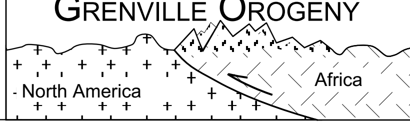


Figure 11 - Interpretive cross sections across northern Virginia showing the progressive development of the Iapetan passive continental margin into the deep and shallow Taconic clastic basins (top two cross sections). Bottom cross section shows present-day geology after the Alleghenian orogeny foreshortened the orogenic belt. Rock units that are now geographically close were in the Ordovician widely separated (Diecchio,1993, fig 7).

Short Geological History of Virginia

Age mya		Significant Rock Units	Sequence of Events	Description of Events
	Cenozoic	Alluvial and Coastal Plain Sediments	Rejuvenation	Gentle uplift of the eroded roots of the Alleghenian mountains starts erosion again leading to formation of the present mountains with their long ridges and water gaps.
70 140	Cenozoic K	Chesapeak Group Pamunky Group Potomac Group	Atlantic Divergent Continental Margin  	After the rifting the new continental margin sinks below sea level and accumulates an eastward thickening wedge of sediments, continuing until the present day. Virginia erodes completely down to sea level, and the sea may at times have covered most or all of Virginia. Present sea level is low.
230	TR/JR	Newark Group	Rifting (Opening of Atlantic Ocean)  	The supercontinent Pangaea rifts apart along a zone now located off the Virginia coast. Culpepper, Richmond, Farmville, etc. basins form. As Africa moves away the present Atlantic ocean begins to open and continues to the present.
310	Penn/Perm	Harlan Wise Gladeville Lee	Alleghenian Orogeny (Closing of Protoatlantic Ocean)  	Africa, which rifted away in the Cambrian, returns, closing shut the Protoatlantic ocean, and creating the supercontinent Pangaea. A Himalaya size mountain range exists throughout Virginia except the far southwest part of the state. At this orogeny most older rocks in Virginia are folded and thrust faulted toward the west. Coal swamps form in southwest Virginia and spread across most of the eastern United States.
345	Miss.	Princeton Hinton Bluefield Greenbriar McCrady	Inter-Orogenic Calm  	After the Acadian mountains are eroded a large inland sea spreads from eastern West Virginia across most of eastern North America and fills with limestone sediments containing abundant fossils.
395	Devonian	Price/Pocono Hampshire Greenland Gap Brallier Millboro Needmore	Acadian Orogeny  	A second terrane (*Avalon*) collides with eastern North America, building a mountain range in the piedmont area containing Richmond. A large basin sinks in western Virginia and W.Va. and fills with a thick sequence of gray, green and red sediments now exposed in Shenandoah mountain at the western state line.
435	Silurian	Oriskany Helderburg Tonolway Bloomsburg Keefer Rose Hill Tuscarora	Inter-Orogenic Calm  	After the Taconic mountains are eroded to a very low region the Central Appalachian Basin in western Virginia and W.Va. forms containing reefs and limestone deposition. Desert conditions across all eastern North America lead to salt deposition in the basin.
500	Ordovician	Massanutten Juniata Oswego Martinsburg Edinburg Lincolnshire	Taconic Orogeny  	A volcanic island arc terrane (*the Chopawamsic/Arvonia*) collides with southwest Virginia and southeast Pennsylvania creating a mountain range in the western Piedmont region. A deep basin forms in the Shenandoah valley area, and a second basin in W.Va., which fills with sediments from the mountain.
500	Cambrian	New Market Beekmantown Stonehenge Conocheague Elbrook Rome Shady	Protoatlantic Divergent Continental Margin  	As the Protoatlantic ocean basin opens the new continental margin sinks below sea level and an east thickening wedge of sediments is deposited. Climate was tropical and the sediments mostly tidal flat limestones /dolomites . Rocks now exposed throughout the Shenandoah valley.
570	Cambrian	Antietam Harpers Weverton Catoctin Robertson River (Lynchburg)	Rifting (Opening of Protoatlantic Ocean)  	The rifting of the Grenville supercontinent and the opening of the Protoatlantic ocean. The continental edge at this time ran down the axis of the present day Blue Ridge province, and Virginia lay south of the equator in a tropical climate.
1200	Pre-Cambrian	Old Rag Lovingston Pedlar	Grenville Orogeny  	The Grenville rocks may represent many geologic events, but the 1.2 billion year event closed an ocean basin and sutured North America and Africa together. Remains today in the Blue Ridge province as metamorphosed granite batholiths.

L.S. Fichter, 1991 (1997)

Acknowledgements

Considerable thanks are owed to a variety of individuals, without whom this meeting would not have been possible. Undoubtedly, I will miss a few names below, whom I hope will forgive me for their omission. But of those that I can name, my thanks, and the thanks of the NAGT Eastern Section, go out to you:

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C.M. "Chuck" Bailey, College of William & Mary
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Steve Leslie, James Madison University
John Haynes, James Madison University
Elizabeth Johnson, James Madison University
Lynn Fichter, James Madison University
Matt Heller, Virginia Division of Mines, Minerals, and Energy
Dustin Williams, James Madison University

Buckingham Branch Railroad Company

PERMIT AND INDEMNIFICATION AGREEMENT

I. Indemnity Agreement

KNOW ALL MEN BY THESE PRESENTS THAT I ______________________________(“Licensee”), have requested
Print individual’s name
and do request permission of BUCKINGHAM BRANCH RAILROAD COMPANY (called “Railroad”) to enter and be present upon equipment, rolling stock, premises, property and/or facilities owned, leased or controlled by Railroad (called “Railroad Property”), at and in the vicinity of
the Buckingham Division, Buckingham County, VA on the date of **Saturday, May 17, 2014**
Location

In consideration of the consent of Railroad to my entry and presence upon Railroad Property, I agree and undertake to:

(1) Give advance notice to Railroad’s office or agent of each entry upon Railroad Property.
(2) Accept direction from Railroad’s supervision while on Railroad Property.
(3) Assume all risk in injury to me (including death) and damage to my property or property in my custody or control arising directly or indirectly from my presence on Railroad Property, and
(4) Indemnify and forever save harmless Railroad and Other Parties described below from and against any and all loss, costs, claims, liability, damage and expense resulting from injury to or death of persons, including but not limited to myself and damage to or loss of property, including but not limited to property in my possession or ownership, caused by or arising or in any manner growing out of or resulting in whole or in part from directly or indirectly, my presence on Railroad Property, regardless of any negligence of Railroad or any Other Indemnified Party contributing thereto.

I know that railroad operation involves particular risks and dangers. If my being on Railroad Property exposes me to any railroad operations, I specifically assume all risk on injury (including death) and damage from railroad operations as part of the above assumption of risk.

The Other indemnified Parties mentioned above are all of Railroad’s corporate affiliates, subsidiaries and parent (if any) and all officers, agents, and employees of Railroad and such other subsidiaries, affiliates and parent.

I further agree that neither I nor my heirs, executors, administrators, assigns, or successors shall cause any claim or lawsuit to be brought for any injury (including death) I may sustain, directly or indirectly, as a result of my presence of Railroad Property.

I also agree that this agreement shall be binding upon my heirs, executors, administrators, successors and assigns and that if any term or provision of this agreement shall to any extent be held invalid or unenforceable, the remaining terms of this agreement shall not be affected thereby, but shall be valid and enforceable to the fullest extent permitted by law.

It is further understood and agreed that any material gathered or photographs taken incident to the purpose stated above will not be publicized or used for commercial purposes without the prior review and written consent of Buckingham Branch Railroad Company.

In witness of my understanding of the foregoing and to evidence my representation that I HAVE READ THIS ENTIRE PERMIT AND INDEMNIFICATION AGREEMENT AND UNDERSTAND AND ACCEPT AND AGREE TO ITS TERMS, I have executed this writing the _______day of

_________________, 2014.

(Signed) _______________________________________(Licensee)

(Print or Type Name) _____________________________

(Address) _______________________________________

____

(Phone) ____

RELEASE OF LIABILITY

1. NOTICE: Your execution of this Agreement will prevent you and/or the minor participant for whom you are signing from bringing certain claims for personal injury against Mole Hill Acres LLC, and its respective owners, managers, agents and representatives (collectively referred to hereinafter as the "Releasees") in any way connected with or arising from the minor child and/or you taking a hike or other excursion, or participating in any other activity, on the real property of Mole Hill Acres LLC, commonly known as Mole Hill.

2. VOLUNTARY PARTICIPATION: You acknowledge that the minor child and/or you have voluntarily requested to participate in the above referenced activity.

3. NO ADMISSION FEE: You acknowledge that Mole Hill Acres LLC is not charging an admission fee for participation in the activity on Mole Hill.

4. WAIVER: In consideration for Releasees granting the right to participate in the activity, you hereby expressly waive on behalf of yourself and/or the minor child any claims you and/or the minor child may have as a result of injuries sustained by the minor child and/or you while participating in the activity, except for claims arising from the willful or intentional negligence of Releasees. You further agree that neither you nor your heirs, guardians or legal representatives will pursue a claim against Releasees for personal injury (including the cost of any medical treatment for injuries) resulting from the negligence of Releasees. You further agree to forever hold harmless and indemnify Releasees from and against all liability for injuries resulting to you and/or the minor child in any way from the participation in the activity, except as otherwise expressly stated herein.

5. VOLUNTARY EXECUTION: You have carefully read this agreement and fully understand its content. You are aware this is a full release of liability and you sign it of your own free will.

6. SEVERABILITY: Any term or provision of this Agreement that is prohibited by law, unlawful, or unenforceable under applicable law, shall be ineffective only to the extent of such prohibition without invalidating the remaining terms and provisions of this Agreement. In the event that a court of competent jurisdiction determines that, notwithstanding the terms and conditions of this Agreement, you and/or your minor child has/have a right to pursue a negligence claim against any of the Releasees, you agree that, in the event a Releasee has insurance coverage available for such claim, the amount of recovery against that Releasee shall be limited to the amount of insurance coverage available to such Releasee. The waivers and limitations of liability set forth in this Agreement are intended to be enforced to the fullest extent allowed under the laws of all jurisdictions which may govern the interpretation of this Agreement.

7. REVOCATION MUST BE IN WRITING: This document may not be revoked, amended, or altered by me or any Releasee except by written agreement executed by the undersigned and said Releasee.

By signing this agreement, you acknowledge that you have read this agreement. If you are signing on behalf of a minor child participant, you consent to such minor child's participation in the activity on Mole Hill and your signature as the parent or guardian of the minor child shall be as effective to bind the minor child as if the minor child has full legal capacity to sign this document on the minor child's own behalf. If you are signing on behalf of a minor child, you warrant that you are either a parent or guardian of the minor child with authority to enter into this Agreement.

______________________	______________________	______________________
Print Name Participant	Print Name Mother	Print Name Father
Please Sign & Date Below	Please Sign & Date Below	Please Sign & Date Below
______________________	______________________	______________________
Participant/Date	Mother/Guardian Date	Father/Guardian Date

This form is good for the following date(s) only ____.

Additional permission must be granted for any other use not related to this class/or dates listed above.