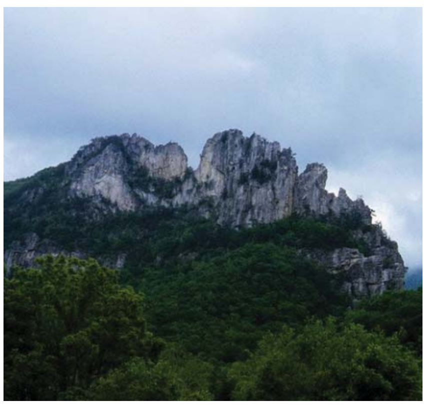
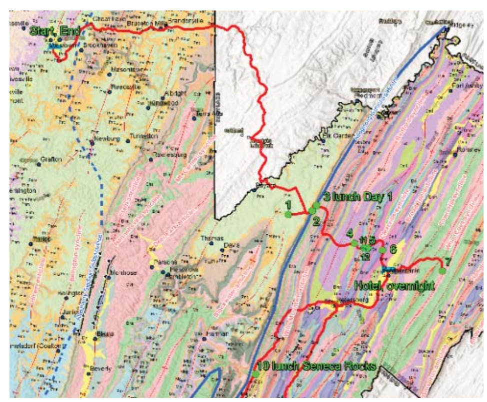
What the H!?

Paleozoic Stratigraphy *Exposed*

Regional Stratigraphy and Structure in the Central Appalachians from the Ordovician to the Pennsylvanian as seen in new outcrops along US 48 (“Corridor H”) and other locations





Pre-Meeting Field Trip Guide for the 46th Annual Meeting
Eastern Section of the American Association of Petroleum Geologists (ESAAPG)
Morgantown, West Virginia

September 24 and 25, 2017

Field Trip Leaders and Authors

Paula J. Hunt[1], Ronald R. McDowell[1], B. Mitch Blake, Jr.[1], Jaime Toro[2], Philip A Dinterman[1]

[1] West Virginia Geological and Economic Survey, 1 Mont Chateau Rd., Morgantown, WV 26508
[2] Department of Geology and Geography, West Virginia University, PO Box 6300, Morgantown, WV 26506

Cover Images

Top: Tonoloway road cut foreground, quarry background along US 48

Middle (left to right): Seneca Rocks, "Dragon's Tongue," Paleoseismites in Spechty Kopf Formation (Dinterman for scale)

Bottom (left to right): US 48 ("Corridor H"), Old Reedsville/Martinsburg quarry on US 33, Field-Trip Route on Geologic Map

Photos in this report were taken by WVGES personnel unless noted otherwise.

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GEOLOGY UNDERLIES IT ALL

West Virginia Geological and Economic Survey
Mont Chateau Research Center
1 Mont Chateau Road • Morgantown, WV 26508-8079
304.594.2331 • fax: 304.594.2575
www.wvges.org • info@geosrv.wvnet.edu
39°39'30" N, 79°50'57" W

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INTRODUCTION

This two-day field trip leaves from Morgantown, West Virginia and has stops in the spectacular rock exposures along recently constructed portions of US Route 48 ("Corridor H"). The trip includes an overnight in Moorefield, West Virginia and ends at Seneca Rocks on the second day (Table 1 and Figure 1), returning to Morgantown via Elkins. For logistical reasons, the field trip begins in the youngest rock units (Pennsylvanian) and ends in the oldest units (Middle Ordovician). A stratigraphic column with the field-trip stops is shown in Figure 2, and brief descriptions of rocks we will see are listed in Table 2.

Many of these outcrops are relatively new to researchers at the West Virginia Geological and Economic Survey (WVGES) and West Virginia University. The purpose of this trip is to give participants a look at these fresh road cuts and allow them to form their own interpretations of what they see. More research and study are planned along this new section of highway.

Physiographic Provinces and Geologic Structure Overview

The trip begins in the Appalachian (Allegheny) Plateau Physiographic Province, characterized by relatively flat-lying to gently folded rocks containing extractable coal and natural gas. It ends in the Valley and Ridge Physiographic Province, with folded and faulted rocks containing relatively little coal or natural gas, compared to the Plateau. The Allegheny Structural Front marks the boundary between the two provinces. The Appalachian Plateau Physiographic Province is further divided into the Allegheny Mountain Section or subprovince, and the Valley and Ridge Physiographic Province is further divided into the Great Valley subprovince, as shown in Figure 3.

In the Plateau, the strata are almost horizontal at the surface, being disturbed only by widely spaced, low amplitude folds. Occasional small-displacement thrust faults are present at depth, but overall strain in the Appalachian Plateau region is small. Before crossing the Allegheny Front at Stop 2, the dip of the beds becomes steeper as the trip enters into the Valley and Ridge. Here the landscape has a strong structural control with the ridges being defined by steeply dipping resistant strata on the flanks of long linear folds with NE-SW axial traces and the valleys usually formed where shaley units crop out. Much of the Valley and Ridge is beautiful farm country. The rocks exposed are sedimentary strata ranging in age from Ordovician to Pennsylvanian. They record the long subsidence history of the Appalachian Basin in response to a series of terrane accretions and collisions along the margin of Laurentia culminating with the late Paleozoic Alleghany Orogeny which created most of the structures seen during the field trip.

Traditionally, three major deformation episodes are recognized in the Appalachians: Taconic – Ordovician/Silurian, Acadian-Devonian, Alleghany-Carboniferous, which were caused by a sequence of collisions that eventually led to the amalgamation of Laurentia with Gondwana. The direction of tectonic transport was consistently to the northwest. Strike-slip processes were important near the margin, but most of the major structures in West Virginia are compressional in nature. Although the three orogenic episodes are manifested by rapid subsidence events in the stratigraphy of the Appalachian foreland basin, most of the structures observed on this trip formed during the late Paleozoic Alleghany Orogeny, when deformation propagated west into the foreland.

A regional cross section by Kulander and Dean (1986) from the Plateau in the west through the Valley and Ridge into Virginia to the east is shown in Figure 4. The cross-section location is shown on Figure 1. Sea-level changes and common stages are shown on Figure 5, and orogenic and depositional environment interpretations for each formation are shown in Figure 6 and Figure 7, respectively.

The stratigraphic column above the igneous and metamorphic Precambrian basement starts with a thick succession of Cambrian through Ordovician limestones and dolomites deposited along the Laurentian passive margin and in several early Paleozoic failed rifts. These units are only exposed in southernmost West Virginia and to the east in Virginia. They amount to more than 5000 feet (1500 m) of strata which exert a strong influence on the large-scale structure of the central Appalachians. The Cambro-Ordovician carbonates behave as a coherent structural unit with a major decollement at its base. They are cut by widely spaced large-displacement thrust faults which are blind in West Virginia, but breach the surface further east (Kulander and Dean, 1986; Mitra, 1986; Wilson and Shumaker, 1988). Although there is general agreement about the overall style of the structures, the details differ among authors because high-quality deep seismic data are sparse. Above the Cambro-Ordovician, several cycles of alternating clastic and carbonate units were deposited in response to tectonic loading events along the Appalachian active margin coupled with sea-level changes (Figure 5, Figure 6, and Figure 7). These units form a separate structural package with tight folds and multiple internal detachments. This package is referred to as the Martinsburg Sheet (Kulander and Dean, 1986) or the Allegheny Roof Sequence (Dunne, 1996). All the structures observed during the field trip are within this roof sequence.

General Bedrock Geology

Rock units exposed at the surface becomes progressively younger from east to west across West Virginia (Figure 3). The oldest rocks in the state are the very late Precambrian Catoctin Formation in the eastern tip of West Virginia's eastern panhandle. The youngest sedimentary rocks are located in the northwestern portion of the state and are assigned to the Dunkard Group, which spans the Upper Pennsylvanian-Lower Permian boundary. A nearly complete section of Paleozoic strata is exposed in the state, but not in a single outcrop. No significant Mesozoic or Cenozoic rocks are present in West Virginia except for relatively small exposures of Jurassic (Mesozoic) and Middle Eocene (Cenozoic) igneous intrusives in Pendleton and Pocahontas counties, in the east-central portion of the state near Virginia. Quaternary (Cenozoic) alluvium is found in larger stream valleys.

Table 1. Field Trip Stop Information

AAPG17 Eastern Section Pre-Meeting Field Trip Stops, September 24 and 25, 2017

Day	Stop	Name	Road Log from Water-front Place	US 48 High-way Mile Marker	Time Arrive	Time Leave	Time at Stop (minutes)	NAD83 Lat, Lon
Day One								
	Start	Leave Hotel, Waterfront Place, Morgantown			7:15	**7:30**		
1	1	Dragon's Tongue, US 48	87	77.8	10:00	10:40	45	39.2127, -79.2642
1	1.5 roll by	Mississippian -Pennsylvanian boundary						39.2162, -79.2042
1	2	Mauch Chunk from overlook, US 48	92	~81	11:00	11:15	15	39.2204, -79.1925
1	3	Lunch: Price/Spechty Kopf/Hampshire	93.6	83.25	11:15	12:45	90	39.2335, -79.1787
1	3.5 roll by	Tonoloway folds and quarry, US 48	97.3	87.0	12:50			39.2092, -79.1479
1	4	Marcellus/Mahantango, US 48	105.7	95+	1 pm	1:45	45	39.1416, -79.0665
1	4.5 roll by	Helderberg Folds	107	97.1&97.5	1:55			39.1297, -79.0293
1	5	Helderberg at Truck Stop, US 48	108.4	97.8+	2 pm	2:45	45	39.1299, -79.0262
1	6	Helderberg/Oriskany/Needmore, US 48	112.8	102.0	3 pm	3:45	45	39.1240, -78.9819
1	6.5 roll by	Hampshire thrust and drag fold, US 48	123	112+	3:50 pm			39.0995, -78.8663
1	7	Whip Cove Anticline Foreknobs, US 48	127.9	116.8	4 pm	4:45	45	39.0717, -78.8033
	Dinner				**6 pm**			

Day	Stop	Name	Road Log from South Branch Inn, Moore-field		Time Arrive	Time Leave	Time at Stop (minutes)	NAD83 Lat, Lon
Day Two								
	Start	Leave Hotel, Summit Inn, Moorefield			7:15	**7:30**		
2	8	Tuscarora, Oswego, Juniata along US 33	50		9:00	9:20	20	38.7099, - -79.4074
2	9a	Reedsville/Martinsburg, Germany Valley Overlook, US 33	52		9:30	9:50	20	38.7081, - -79.4132
2	9b	Old quarry: Martinsburg off 33	52.5		10:00	11:00	60	38.7023, - -79.4562
2	10	Lunch: Seneca Rocks	67		11:30	**2 pm**	90	38.8357, - -79.3728
	End	Arrive Morgantown for Ice Breaker			by 5 pm			

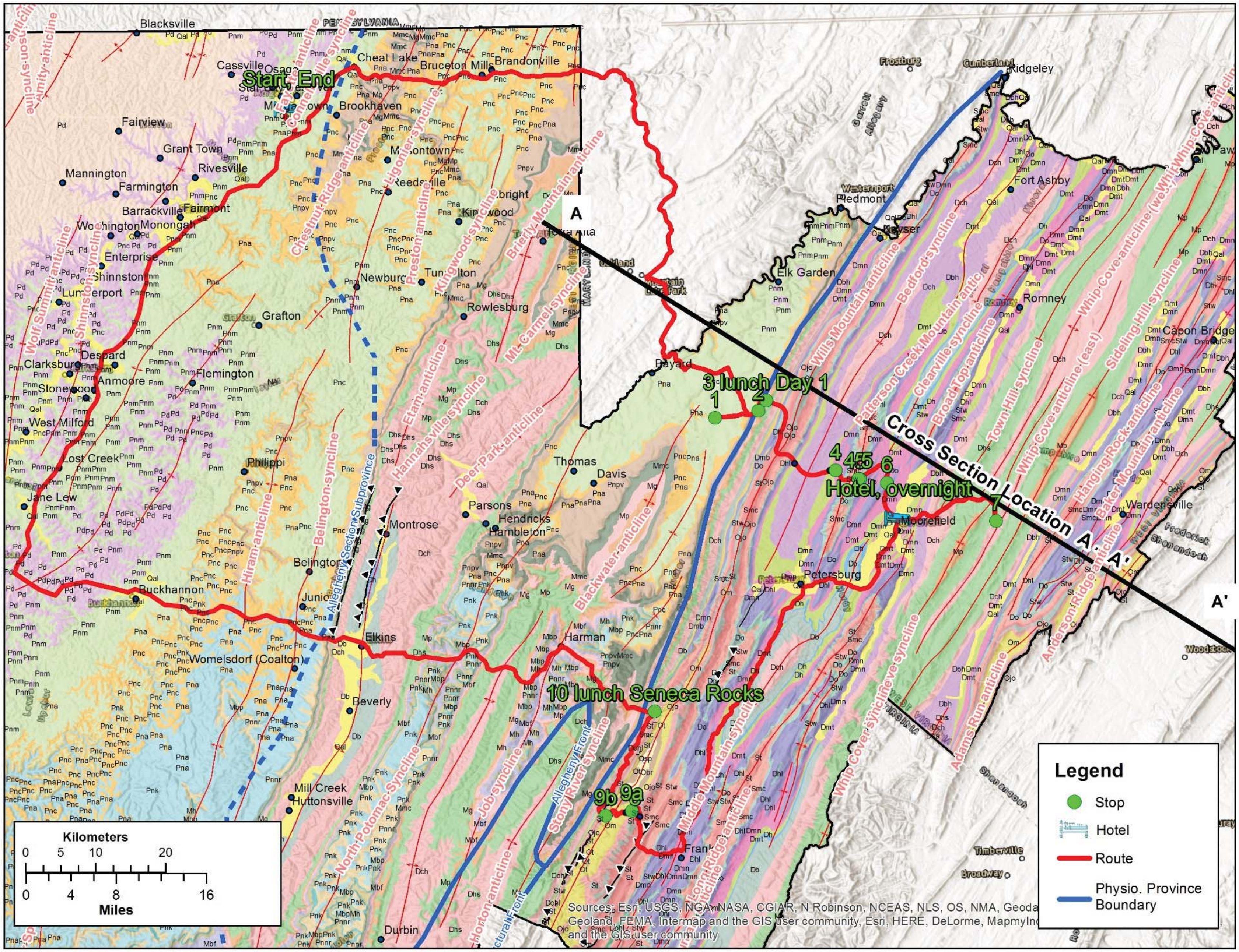

Figure 1. Location Map (start, end, and all stops) (geology from Cardwell et al., 1968)

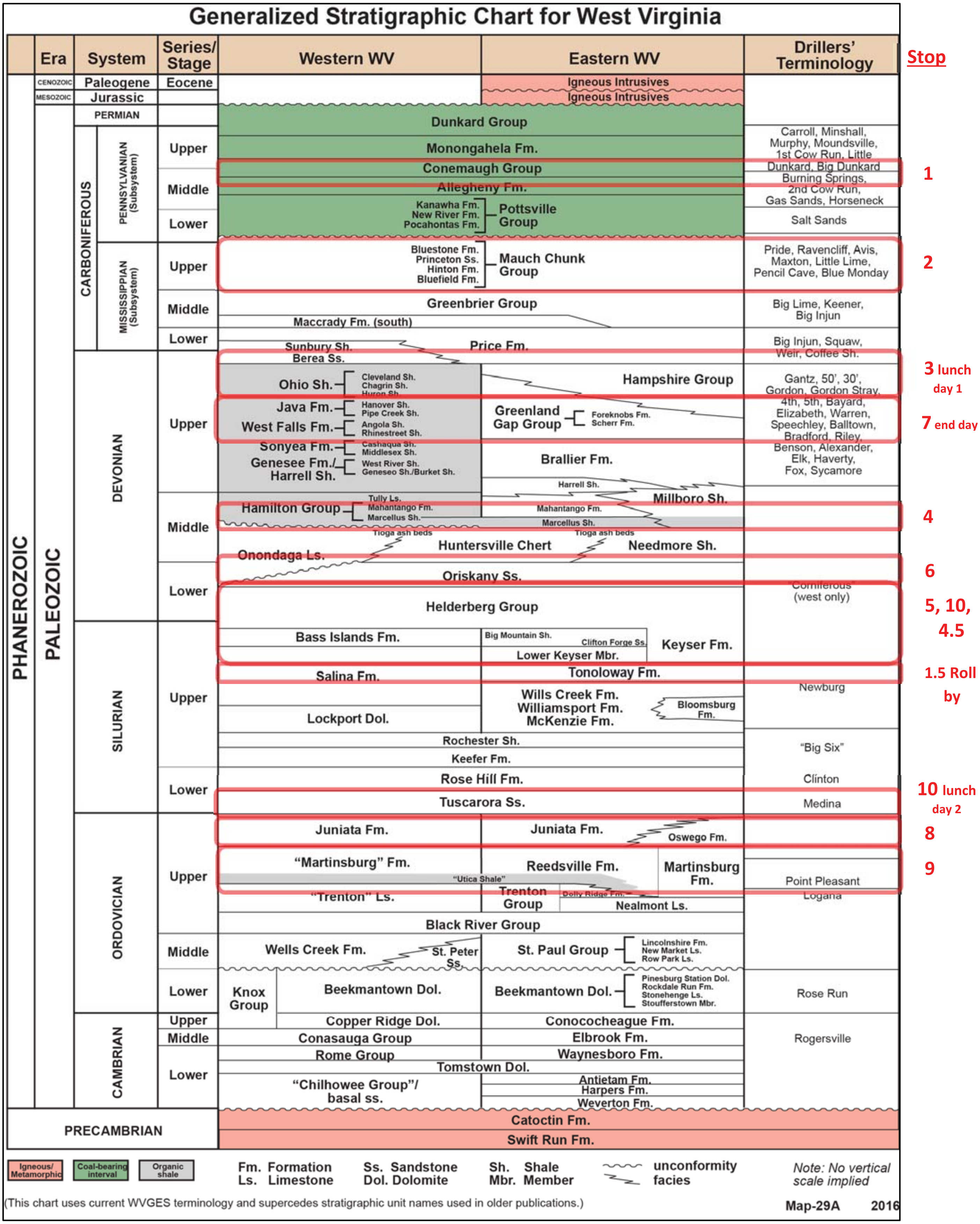

Figure 2. West Virginia Generalized Stratigraphic Chart

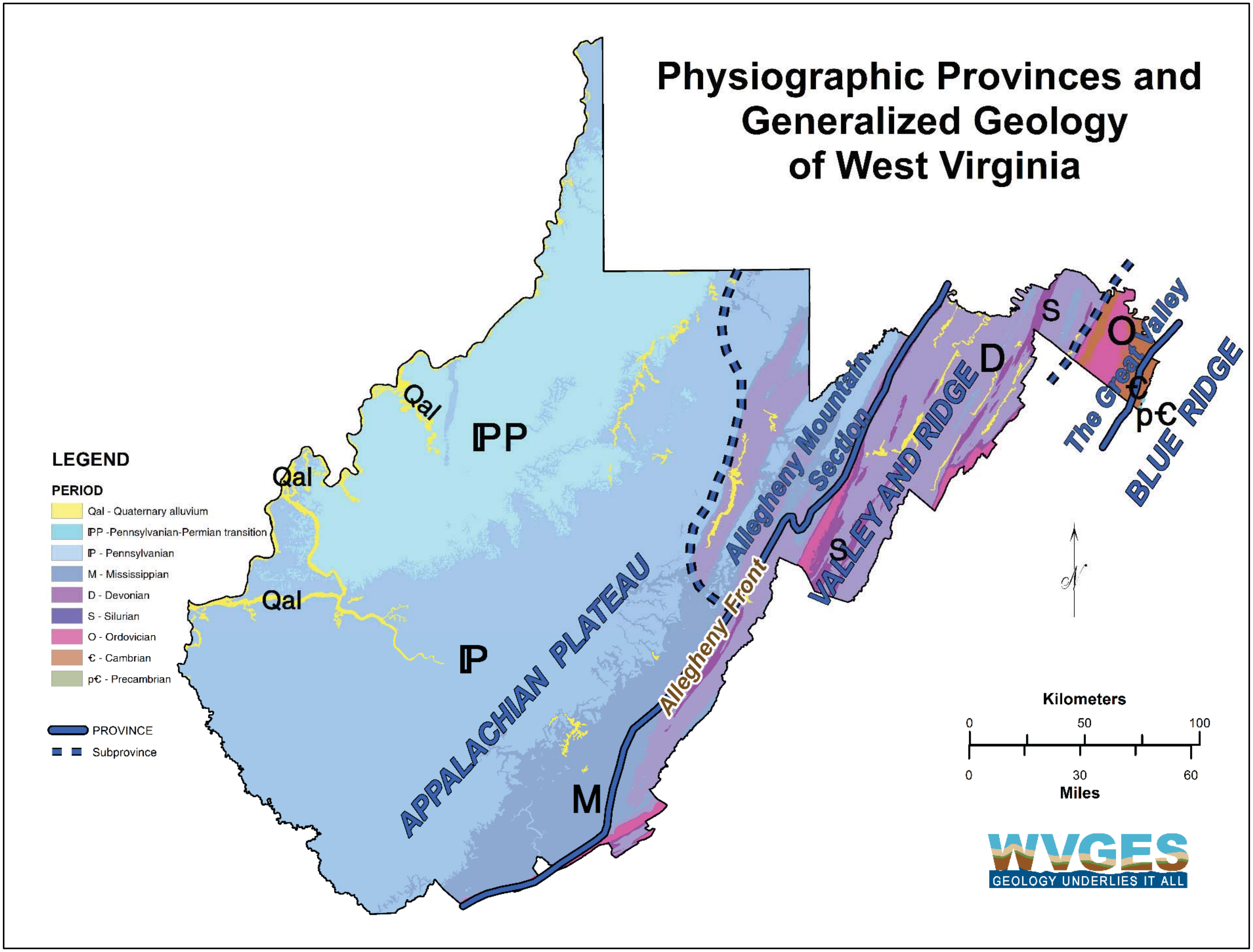

Figure 3. West Virginia Physiographic Provinces with General Geology

A **A’**

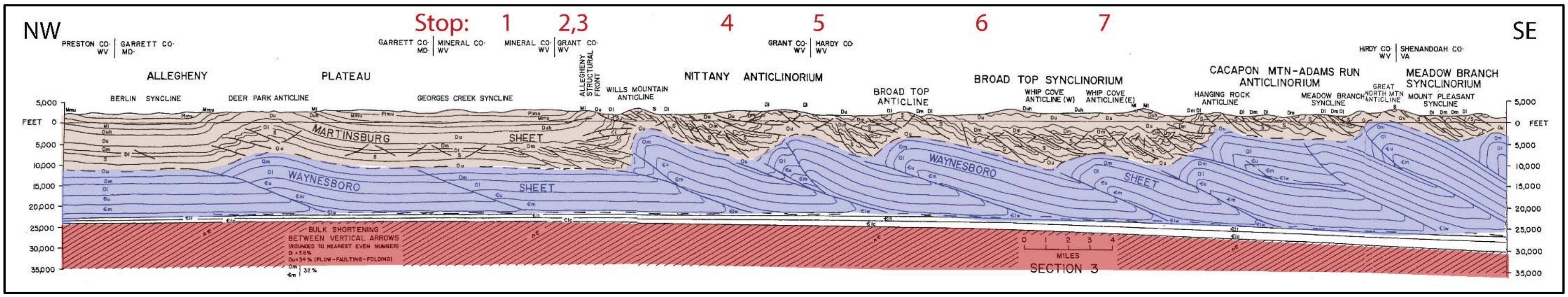

Figure 4. Regional cross section through the Appalachians near US 48 Along A – A’ (from Kulander and Dean, 1986).

Red = Basement
Blue = Cambro-Ordovician Waynesboro Sheet
Gray = Deformed Roof Sequence (Martinsburg Sheet).

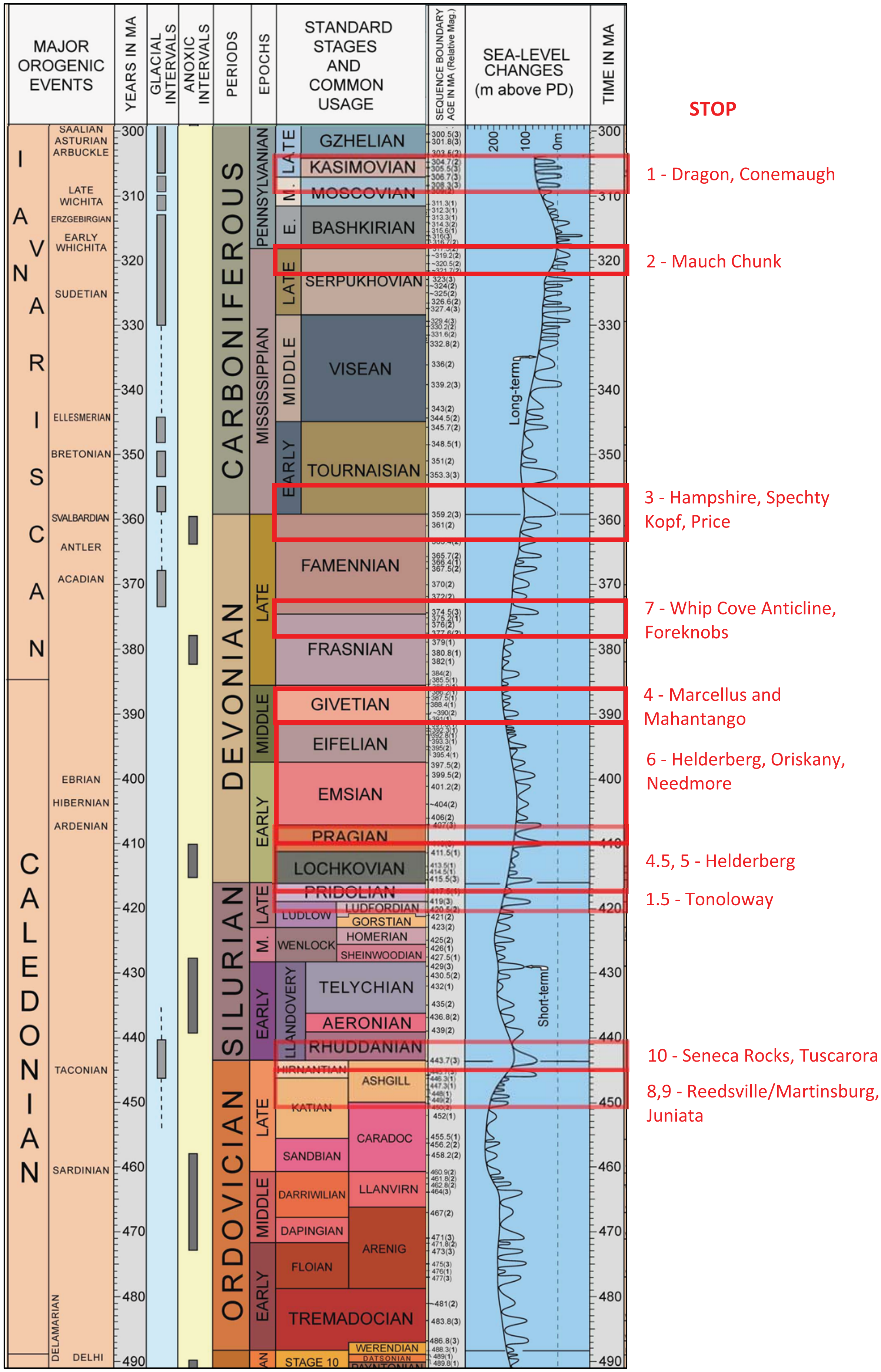
MAJOR OROGENIC EVENTS
YEARS IN MA
GLACIAL INTERVALS
ANOXIC INTERVALS
PERIODS
EPOCHS
STANDARD STAGES AND COMMON USAGE
SEQUENCE BOUNDARY AGE IN MA (Relative Mag.)
SEA-LEVEL CHANGES (m above PD)
TIME IN MA
VARISCAN
CALEDONIAN
SAALIAN ASTURIAN ARBUCKLE
LATE WICHITA
ERZGEBIRGIAN
EARLY WHICHITA
SUDETIAN
ELLESMERIAN
BRETONIAN
SVALBARDIAN
ANTLER
ACADIAN
EBRIAN
HIBERNIAN
ARDENIAN
TACONIAN
SARDINIAN
DELAMARIAN
DELHI
CARBONIFEROUS
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
GZHELIAN
KASIMOVIAN
MOSCOVIAN
BASHKIRIAN
SERPUKHOVIAN
VISEAN
TOURNAISIAN
FAMENNIAN
FRASNIAN
GIVETIAN
EIFELIAN
EMSIAN
PRAGIAN
LOCHKOVIAN
PRIDOLIAN
LUDLOW
LUDFORDIAN
GORSTIAN
WENLOCK
HOMERIAN
SHEINWOODIAN
LLANDOVERY
TELYCHIAN
AERONIAN
RHUDDANIAN
HIRNANTIAN
ASHGILL
KATIAN
CARADOC
SANDBIAN
DARRIWILIAN
LLANVIRN
DAPINGIAN
ARENIG
FLOIAN
TREMADOCIAN
WERENDIAN
STAGE 10
Long-term
Short-term
STOP
1 - Dragon, Conemaugh
2 - Mauch Chunk
3 - Hampshire, Spechty Kopf, Price
7 - Whip Cove Anticline, Foreknobs
4 - Marcellus and Mahantango
6 - Helderberg, Oriskany, Needmore
4.5, 5 - Helderberg
1.5 - Tonoloway
10 - Seneca Rocks, Tuscarora
8,9 - Reedsville/Martinsburg, Juniata

Figure 5. Stages and sea-level changes from Haq and Shutter (2008)

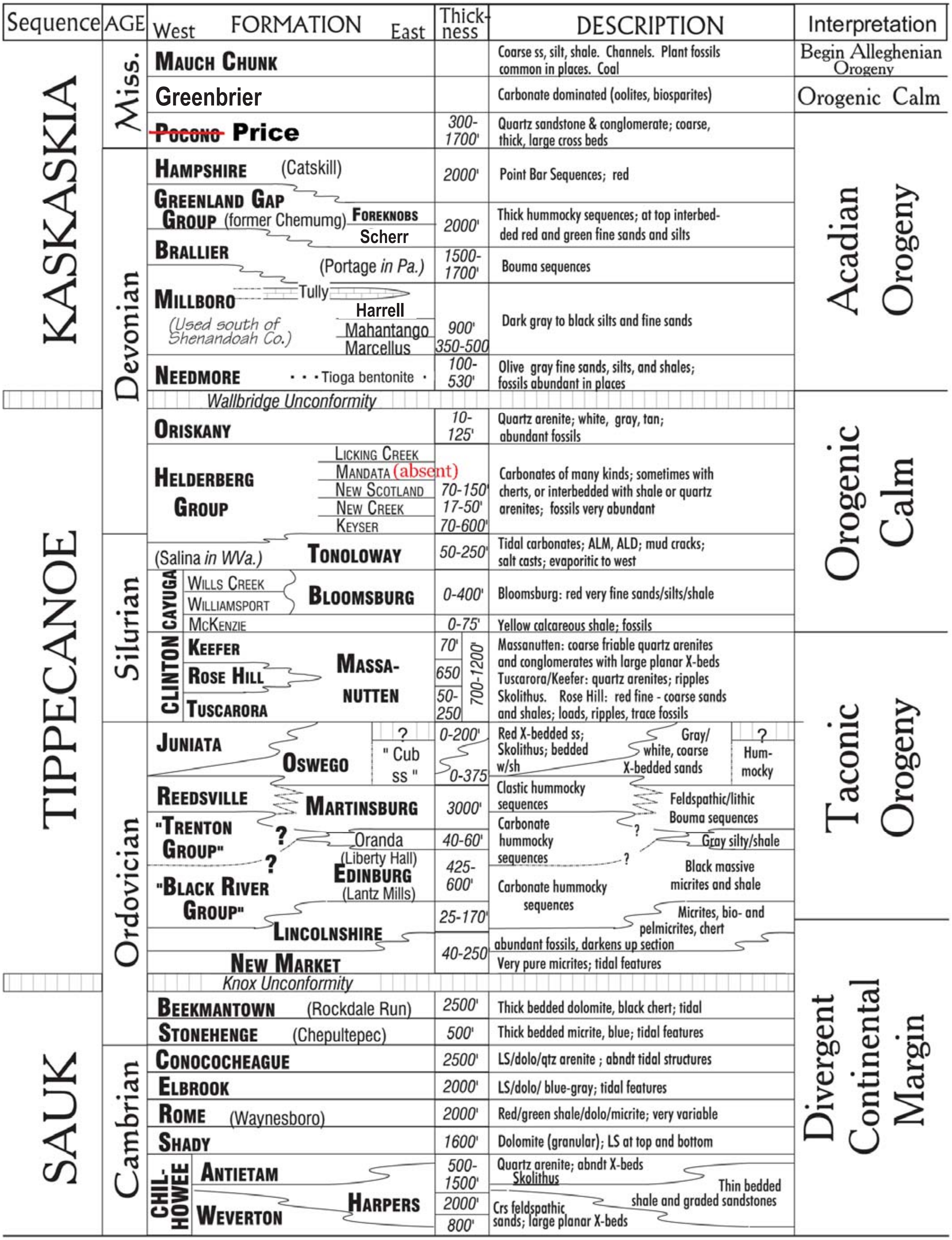

Figure 6. Orogenic interpretations for eastern West Virginia and Shenandoah Valley, Virginia (modified from Fichter et al., 2010 after Fichter and Diecchio, 1993)

GEOLOGIC ERAS, PERIODS AND EPOCHS			ROCK TERMINOLOGY	HISTORY	
CENOZOIC ERA				Lake deposits and drainage changes due to glaciation to north	
MESOZOIC ERA	CRETACEOUS JURASSIC TRIASSIC			Igneous activity in Pendleton and surrounding counties	
PALEOZOIC ERA	PERMIAN		DUNKARD GROUP	Appalachian Orogeny. West Virginia was uplifted and became an erosion surface. For more than 200 million years it has never been invaded by the sea and no extensive sediments have been deposited.	
	PENNSYLVANIAN	LATE	MONONGAHELA GROUP CONEMAUGH GROUP		
		MIDDLE	ALLEGHENY FORMATION	Swamp conditions throughout most of the State resulted in the preservation of plant remains which were altered to peat and in turn altered to the many coal seams.	
		EARLY	POTTSVILLE GROUP: KANAWHA FM.; NEW RIVER FM.; POCAHONTAS FM.		
	MISSISSIPPIAN	LATE	MAUCH CHUNK GROUP	Nonmarine environment. Shale and sandstone predominate, red beds very predominant near top. Occasional marine incursions.	
		MIDDLE	GREENBRIER GROUP	Shallow sea once again covered most of West Virginia. Carbonate deposition predominates. Last important marine deposition in West Virginia.	
		EARLY	MACCRADY FORMATION PRICE FORMATION	Uplift continued and a nonmarine environment existed. Sandy shales predominate.	
	DEVONIAN	LATE	HAMPSHIRE FORMATION GREENLAND GAP GROUP BRALLIER FORMATION	Shoreline gradually shifted westward, causing abundant continental beds which were deposited farther and farther westward throughout the epoch.	Acadian Orogeny with main uplift to northeast
		MIDDLE	HARRELL SHALE MAHANTANGO FORMATION MARCELLUS FORMATION	Uplift to east provides clastic sediments for marine dark shale with sandstone layers.	
			ONESQUETHAW STAGE: TIOGA BENTONITE	Volcanic activity to east results in thin bentonite zone.	
			ONESQUETHAW STAGE: ONONDAGA LIMESTONE / HUNTERSVILLE CHERT / NEEDMORE SHALE	Slight subsidence. Shale deposition predominant in northeast, chert in southeast, passing to cherty limestone in west.	
		EARLY	ORISKANY SANDSTONE	Sea somewhat shallower. Blanket sandstone deposition.	
			HELDERBERG GROUP	Slight submergence creates a predominantly carbonate-producing environment, but with invasions of sand and clay.	
	SILURIAN	CAYUGAN — LATE	TONOLOWAY FORMATION (BLOOMSBURG FACIES)	Sea covered most of the State. Carbonates predominate in southwest. Evaporite deposition in restricted sea of northern West Virginia.	
			WILLS CREEK FORMATION (BLOOMSBURG FACIES)	Red delta deposits in northeastern West Virginia; marine shale and limestone to southwest.	
			WILLIAMSPORT FORMATION (BLOOMSBURG FACIES)	Red bed deposition continues in northeast; shallow sea sandstone deposition in rest of State.	
		NIAGARAN — MIDDLE	MCKENZIE FORMATION (BLOOMSBURG FACIES)	Tidal flat in northeast marks beginning of red bed deposition. Shallow marine carbonates in southwest.	
			ROCHESTER SHALE KEEFER SANDSTONE ROSE HILL FORMATION	Predominantly a shallow marine environment with clastic deposition.	
		EARLY	TUSCARORA SANDSTONE	Shallow sea covered the State. Sandstone deposition.	
	ORDOVICIAN	LATE	JUNIATA FORMATION	Delta-type environment throughout State.	Taconic Orogeny formed an area of high mountains to the east, the source of most of the sediments of the Late Ordovician and Silurian.
			OSWEGO FORMATION	Delta-type environment in eastern West Virginia.	
			REEDSVILLE SHALE	Clastic deposition in marine environment.	
		MIDDLE	TRENTON GROUP: MARTINSBURG FM.; NEALMONT LS. BLACK RIVER GROUP	Carbonate deposition continues to predominate.	Volcanic activity caused deposition of bentonite beds.
			ST. PAUL GROUP	Knox unconformity; predominant in Ohio and western West Virginia.	
		EARLY	KNOX: BEEKMANTOWN GROUP	Carbonate deposition.	
	CAMBRIAN	UPPER	KNOX: CONOCOCHEAGUE FM. (EAST) / COPPER RIDGE DOL. (WEST)		
		MIDDLE	ELBROOK FORMATION		
		LOWER	WAYNESBORO FORMATION	Clastic deposition.	
			TOMSTOWN DOLOMITE	Shallow sea carbonate deposition.	
	Ante-Camb.		CHILHOWEE GROUP: ANTIETAM FM.	First fossils in West Virginia rocks.	
			CHILHOWEE GROUP: HARPERS FM.; WEVERTON-LOUDOUN FORMATION	Clastic deposition in narrow trough in eastern West Virginia; beginning of Appalachian Geosyncline.	
			CATOCTIN FORMATION	Volcanic activity in eastern West Virginia.	
PRECAMBRIAN			CRYSTALLINE ROCKS	History complex and obscured.	

Figure 7. Stratigraphic column with depositional environments (modified from Cardwell, 1975)

Major Stratigraphic Sequences in the Paleozoic of West Virginia

Six major stratigraphic sequences are found in the Paleozoic units of the Appalachian Basin. Sediments deposited during orogenic activity and periods of inter-orogenic calm are marked, for the most part, by regional unconformities which form the boundaries of each sequence (de Witt and Milici, 1989, 1991). Interpretations of tectonic and depositional environments are shown in Figure 6 and Figure 7, respectively. From oldest to youngest the six sequences are

- Deposition along the passive continental margin during Iapetan rifting (not observed on this trip);
- Deposition during the Taconic Orogeny (Stops 8 and 9);
- Deposition after the Taconic Orogeny during orogenic calm (Stops 3.5, 4.5, 5, 10);
- Deposition during the Acadian Orogeny (Stops 3, 4, 6, 7);
- Deposition during the Lower Carboniferous during orogenic calm (Stops 2 and 3); and
- Deposition during the Alleghanian Orogeny (Stop 1).

Stratigraphic Nomenclature

This field guidebook uses stratigraphic nomenclature and physiographic province boundaries recognized and used by the West Virginia Geological and Economic Survey (WVGES). Some nomenclature used by the United States Geological Survey (USGS) and geological surveys from surrounding states may vary slightly from that used in this document. Subsurface terminology, gas plays, drillers' terms, and outcrop terminology differ. Figure 2 is a rough correlation of the various terms as they are used by the WVGES.

US Route 48 ("Corridor H")

The term Corridor H was applied to this road prior to its final designation with US Route numbers, and many West Virginians still refer to it by that name. West of the field trip area, the corridor from Interstate 79 in Weston east to Harman is now US 33. In the field trip area, the corridor from WV 32 at Davis east to Wardensville is now called US 48. A portion of the corridor had been called WV 55 in the past, and older literature may reference WV 55 instead of US 48. WV 55 still exists, and the portion of WV 55 running parallel to US 48 east of Moorefield has interesting outcrops (for a future field trip?). To further add to the confusion, this is the second time a route has been designated US 48 in West Virginia. Prior to the completion of Interstate 68 from Morgantown to the Maryland state line, the pre-I-68 corridor was known as US 48 (see Eastern Section AAPG 1979 field trip guidebook and WVGES Map WV-14). "Corridor H" has been built in segments over many years, and is still under construction between Harman and Davis, West Virginia.

Stop 1 is on the newest portion of US 48. Generally, the road cuts are older and more overgrown as one proceeds east on US 48 from Stop 1. As the trip proceeds east from the relatively flatlying Allegheny (Appalachian) Plateau, particants will observe faulting and folding characteristic of the Valley and Ridge. During the first few stops, participants have good views of the The NedPower Mount Storm wind farm, a line of 132, two-megawatt wind turbines built along the Allegheny Front that can generate up to a total of 264 megawatts of electricity. This joint venture between Shell and Dominion Resources extends twelve miles along the Allegheny Front (Wikipedia *Mount_Storm_Wind_Farm 2017*). The wind turbines' juxtaposition with Dominion Energy's Mount Storm Power Station, a coal-fired power plant generating up to 1,600 megawatts (dominionenergy.com), is interesting.

Oil and Gas Field in the Field-Trip Area

This area of West Virginia contains few gas fields (Figure 8). Discussion of fields and significant wells near the route will take place at the various stops.

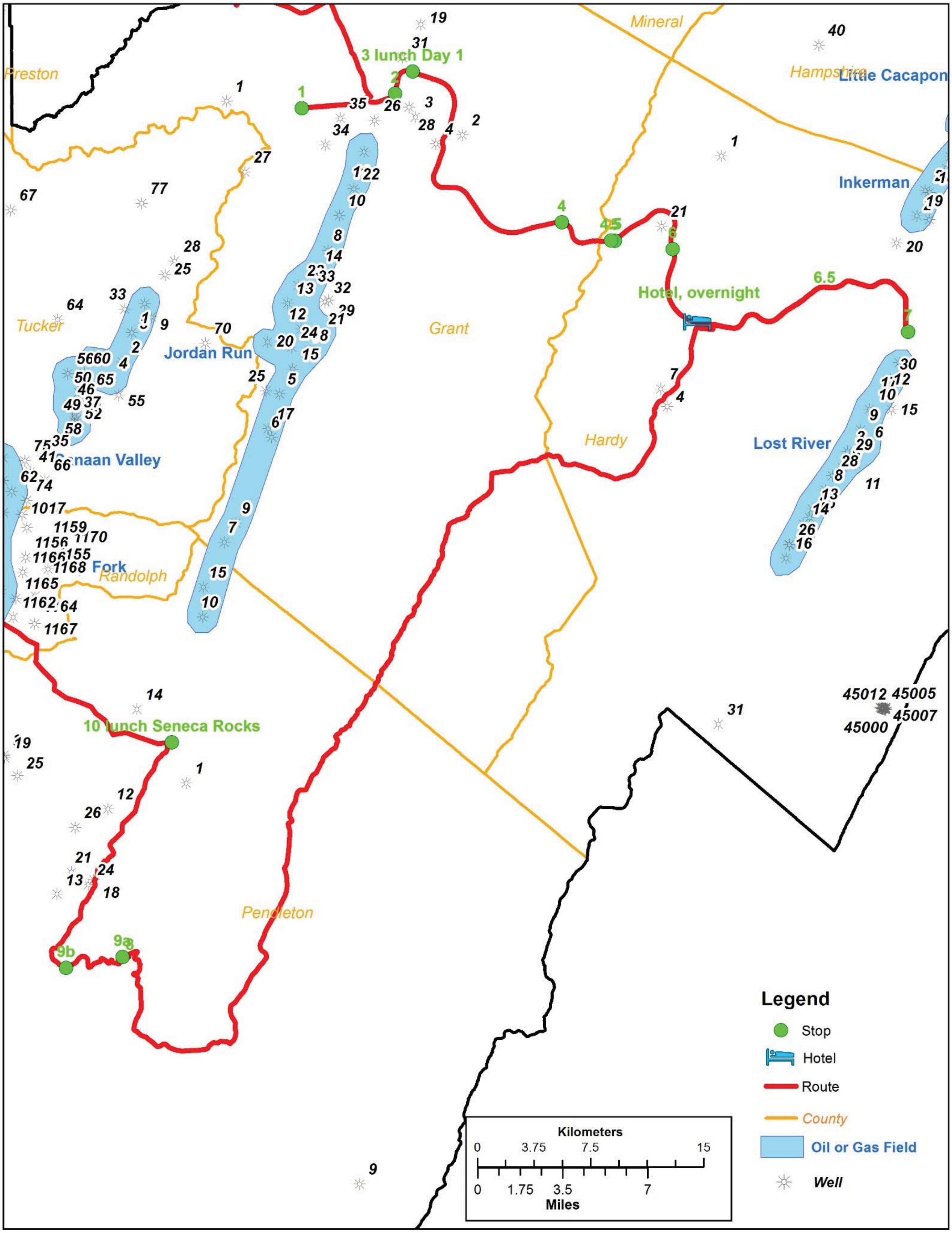

Figure 8. Oil and Gas Fields in the Field-Trip Area

Table 2. Unit Descriptions and Characteristics

Unit	Approximate Thickness	Description
Glenshaw Formation, Conemaugh Group	300 to 365 ft (91 to 111 m)	Red, light to dark gray or gray-green sandstone, mudstone, claystone, shale, siltstone, limestone, and coal. Sandstones are fine-to coarse-grained, occasionally pebbly to conglomeratic. Mudstones frequently contain carbonate nodules that locally coalesce into rubbly, discontinuous beds. Claystones commonly occur beneath coal beds, and occasionally contain fossil root traces. Shales are commonly micaceous and occasionally silty or sandy. Siltstones are commonly micaceous, locally sandy, and grade vertically to sandstones, shales, and mudstones. Limestones are lenticular, nonmarine, hard, and micritic. The **Bakerstown coal bed** is the most commercially important coal in the Glenshaw Formation. Two marine zones occur in the area. Contact with the overlying Casselman Formation is gradational and is usually placed at the highest occurrence of fossils in the Glenshaw. Contact with the underlying Allegheny Fm. is sharp (Matchen et al., 2008).
Mauch Chunk Group / Formation	1,000 ft (330 m)	Dark red, light to dark gray, or gray-green interbedded sandstone, shale, mudstone, siltstone, and limestone beds. Dark red mudstones and shales are the most obvious characteristic of this group. Sandstones, where present, are very fine- to coarse-grained with framework grains comprised of quartz with lesser amounts of mica, feldspar, and rock grains. Shales may be clayey, silty, or sandy, and occur in thick sequences or interbedded with mudstone, siltstone, or sandstone. Mudstones are commonly silty or sandy. Siltstones are commonly micaceous, frequently sandy, and generally grade to sandstones, shales, and mudstones. Where present, limestone units occurring near the base of the unit serve as marker beds. Contact with the overlying New River Formation is unconformable and represents the Mississippian - Pennsylvanian boundary. Contact with the underlying Greenbrier Limestone is sharp (Matchen et al., 2008), where observed.
Price Formation (formerly Pocono)	330 ft (100 m)	Interbedded brown, light to medium gray, and gray-green sandstone, shale, and siltstone. Sandstone framework grains are comprised of quartz with lesser amounts of mica, feldspar, and rock grains. Sandstone beds are often cross-stratified with sharp, erosional basal contacts and intra-unit scour surfaces; commonly fill scours cut into subjacent units. Some lower sandstone units have sharp erosive lower contacts with scattered quartz pebbles or thin zones of quartz-pebble conglomerate. Other thin sandstone beds are highly bioturbated and burrowed. A thin, red, hematitic sandstone at the top of this unit serves as a good marker bed throughout the nearby Canaan Valley map area. The basal contact of this sandstone is sharp and erosive. The contact between the Price Formation and the overlying Greenbrier Limestone is not exposed in the field-trip area and marks a regional unconformity. The contact between the Price and the underlying Spechty Kopf Formation, where present, is sharp. Note: Kammer and Bjerstedt (1986) use marine fossils to place the Devonian-Mississippian boundary within the basal Price Formation (Matchen et al., 2008).
Spechty Kopf Formation	up to 700 ft (212 m) regionally	Red, gray, tan, and green interbedded sandstones, siltstones, mudstones and shales. Locally distinctive units include a thick-bedded layer of dark brown pebbly mudstone (diamictite) with rounded clasts of local and exotic (igneous and metamorphic) origin up to 10 inches in diameter. Overlying the diamictite is a chaotically bedded layer of dark greenish gray micaceous siltstone in elongated pillow-shaped “lumps” with a satin-like sheen (from micas). This soft-sediment deformation is interpreted as a debris flow with load structures or a paleoseismite. Contact with the overlying Price Formation is sharp.

Table 2. Unit Descriptions and Characteristics (continued)

Unit	Approximate Thickness	Description
Hampshire Formation (formerly Catskill)	2,000 to 2,500 ft (600 to 760 m)	Interbedded dark red to maroon, dark green, brown, and gray siltstone, mudstone, and fine-grained quartz sandstone. The dark red to maroon color is one of the characteristics of this formation. Sandstones have framework grains comprised mainly of quartz with lesser amounts of mica, feldspar, and rock grains and are commonly cross-stratified with sharp, erosional basal contacts and intra-unit scour surfaces. Fill scours commonly cut into subjacent units. Mudstones are commonly variegated or mottled. Siltstones are thin-bedded, laminated, or nonbedded and grade to silty mudstone. Plant fossils occur in some beds. Contact with the overlying Spechty Kopf Formation (or Price Formation where the Spechty Kopf is absent) is sharp. Contact with the underlying Greenland Gap Group is gradational and is placed at the first occurrence of red mudstone or the last occurrence of marine fossils, whichever is stratigraphically higher (Matchen et al., 2008).
Foreknobs Formation, Greenland Gap Group (formerly Chemung Group)	2,000 ft (600 m)	A coarsening-upward assemblage of interbedded sandstones, siltstones, shales, and mudstones. Sandstones are predominantly quartz with silica cement, well-sorted, subangular, very fine to fine-grained, micaceous, greenish-brown to brown to gray, hard, weather tan to orange-brown, are commonly iron-and-manganese-stained, and often exhibit Liesegang banding and boxworks. Sandstones vary in thickness from several centimeters to a few meters. Shales and mudstones are olive green to tan, sometimes gray, and sometimes weather into chips. Some sandstone beds contain conglomeratic lag zones, foreset and tabular crossbedding, and ripple marks. Some members of the Foreknobs are reddish-brown siltstones that may be thinly bedded (2 cm thick) totaling 3 meters in thickness or more. These red beds may sometimes be mistaken for the overlying Hampshire Formation due to their color. The base of the unit typically contains more shales, and the top of the unit typically contains more sandstones. Marine body fossils, mostly articulate brachiopods and crinoid columnals, are abundant in some beds. Wood imprints are also observed, especially near the top of the formation (Matchen et al., 2008). Other beds are relatively unfossiliferous. Trace fossils include *Arenicolites*, other feeding traces, and tool marks. *Pteridichnites biseriatus* is rarely observed; much less so than in the underlying Brallier Formation. Contact with the overlying Hampshire Formation is interfingering and is placed at the last occurrence of tan mudstone and shale or the last occurrence of marine fossils, whichever is stratigraphically higher. Contact with the underlying Brallier Formation is gradational and for mapping purposes is placed at the base of coarser siltstones or sandstones beds containing marine body fossils (Hunt et al., 2016).
Mahantango Formation	1,200 to 1,400 ft (360-420 m)	Dark gray siltstone and shale, often heavily limonitized with numerous brachiopods in some beds. Other marine fossils, sometimes including corals may be present. Contacts with the overlying Harrell Shale and the underlying Marcellus Shale are interfingering.
Marcellus Formation	300 ft (100 m)	Black, limonitic and pyrtititic finely laminated shale interbedded with dark brownish gray silty shale weathering reddish brown. Light gray to tan weathering observed around the edges of dark shale chips. Calcareous nodules common in the field-trip area. Elsewhere the Marcellus contains limestone stringers and beds. Some beds may contain miniature (underdeveloped) adult brachiopods, styliolinids, and cephalopods. Where present, trace fossils are most commonly clay-filled feeding tubes. The unit may contain Tioga Ash bed(s). The Marcellus interfingers laterally and vertically with the Mahantango Formation. Contact with the underlying Needmore shale is seldom observed except where the Tioga Ash separates them (sharp contact). Contact with the overlying Brallier Formation, where the Mahantango is absent, is interfingering.
Needmore Formation (Onondaga equivalent)	300 ft (100 m)	Dark gray, fissile, and locally calcareous shale weathering to lighter gray, especially around edges of shale chips. Some beds contain articulate brachiopods and the characteristic trace fossil *Chondrites*. Contact with the overlying Marcellus Shale is seldom observed except where the Tioga Ash separates them (sharp contact). Contact with the underlying Oriskany Sandstone may be interfingering in the field-trip area.

Table 2. Unit Descriptions and Characteristics (continued)

Unit	Approximate Thickness	Description
Oriskany Formation	150 to 200 ft (45 to 60 m)	Locally gray, well-sorted, fine- to medium-grained calcite-cemented sandstone. Elsewhere buff-colored fine- to coarse-grained silica-cemented sandstone, often limonite stained. Some beds contain abundant brachiopods, often as voids in lags; large spirifer brachiopods are characteristic. Crossbedding is common. Contact with the overlying Needmore Formation is interfingering in the field-trip area. Contact with the underlying Helderberg in the field-trip area is placed at the top of the flint nodules in the Licking Creek Formation of the Helderberg Group.
Helderberg Group	500 ft (150 m)	A package of marine units comprised of crystalline limestones, micritic limestones, sandstones, cherty limestones, chert, and occasionally shale, typically dark gray to dark bluish gray, massive, and fossiliferous. Stromatoporoid and coral bioherms common in the basal Keyser Formation. Fossils abundant in some layers, and include brachiopods, crinoid stems, tabulate corals, stromatoporoids, bryozoans, ostracodes, and pelecypods. Contact with the overlying Oriskany in the field-trip area is placed at the top of the flint nodules in the Licking Creek Formation of the Helderberg Group. Contact with the underlying Tonoloway Formation is placed where the more crystalline massive limestone beds of the Keyser Formation in the Helderberg Group are distinguished from the thinly laminated micrites of the Tonoloway Formation (Hunt et al., 2016). Note: The basal unit of the Helderberg Group, the Keyser Formation, straddles the Silurian-Devonian boundary.
Tonoloway Formation	300 to 400 ft (90 to 120 m)	Medium to dark gray marine limestone: thinly laminated micrites, calcareous shales, and argillaceous limestones. Thinly laminated micrite is characteristic; however, massive beds, sometimes sandy, occur in the middle of the formation. Other characteristics include mudcracks, ripple marks, and anhydrite casts. Ostracodes, especially leperditiids, are the most common fossils. Algal laminae and stromatolite domes may also be present. Contact with the underlying Wills Creek Formation, where observed, appears to be gradational because of the similar appearance of the two units. Woodward (1941) described the Wills Creek limestones as being more argillaceous than the overlying Tonoloway limestones and used this distinction as the contact between the two formations. Contact with the overlying Helderberg is placed where the more crystalline massive limestone beds of the Helderberg Group's Keyser Formation are distinguished from the thinly laminated micrites of the Tonoloway Formation (Hunt et al., 2016).
Tuscarora Formation	200 ft (61 m)	Light pink to white, extremely resistant, medium- to coarse-grained quartz sandstone. Locally conglomeratic with rounded, white quartz pebbles up to 2 cm in diameter. Very well indurated due to quartz overgrowths on grains. Trough and ripple-scale crossbedding observed. Horizontal trace fossils common on the undersurfaces of beds, particularly *Arthrophycus* and *Phycodes*. Vertical trace fossil *Arenicolites* also common. Contact with overlying Rose Hill Formation is sharp; contact with the underlying Juniata appears gradational (McDowell et al., 2002).
Juniata Formation	400 ft (122 m)	Pinkish grey to dark maroon, interbedded fine-grained, argillaceous, quartz sandstone and mudstone. Bedding in sandstones consists primarily of ripple-scale and minor trough crossbedding. Contact with the overlying Tuscarora appears gradational; exposure of the upper Juniata is typically poor and marked by red soil developed on the unit that becomes increasingly covered with Tuscarora talus as one approaches the contact. Contact with the underlying Oswego is poorly exposed and may be transitional (McDowell et al., 2002).
Oswego Sandstone	150 ft (45 m)	Lenticular, thin-bedded, grey-green, fine-grained quartz sandstone. Interfingering contacts are observed with red mudstones of the overlying Juniata Formation. The contact with the shales of the underlying Reedsville Formation are sharp at Stop 8.

Table 2. Unit Descriptions and Characteristics (continued)

Unit	Approximate Thickness	Description
Reedsville Formation (west of Little North Mountain, including Stops 8 and 9); Martinsburg Formation (east of Little North Mountain)	1,000 ft (300 m)	**Martinsburg**: gray to greenish gray, shale, siltstone and sandstone. **Reedsville**: lower portion is interbedded calcareous shale and sandstone with interbeds of dark grey, crinoid-brachiopod packstone and tan, fossiliferous siltstone (McDowell et al., 2003). The middle portion has less limestone, some siltstones, and normal marine fauna. The upper portion is terrestrial bioturbated mudstone along with shale, siltstone, and sandstone interbeds. The shallow-water *Orthorhynchula* biozone is present in this upper portion of the Reedsville and is one of the characteristics of this unit west of Little North Mountain (Diecchio 1980, 1985). East of Little North Mountain, equivalent strata are turbiditic, and the upper sandy beds do not contain *Orthorhynchula* fauna. Thus they are named Martinsburg (Diecchio, 1980, 1985). The outcrops in Germany Valley (Stops 8 and 9) are considered Reedsville, as they are located west of Little North Mountain and mudstones here contain well-preserved inarticulate and articulate brachiopods of the *Orthorhynchula* biozone (McDowell et al., 2003). Contact with the overlying Oswego sandstone is sharp at Stop 8. Contact with the underlying Dolly Ridge is poorly exposed and appears to be gradational.

Additional Resources

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FIELD-TRIP STOPS DAY 1

Stop 1 (Day 1): Dragon's Tongue
Leaders: Mitch Blake, Jaime Toro, Phil Dinterman (NAD83 Lat 39.21, Lon -79.26)

Figure 9. The Dragon's Tongue
Coalified Bakerstown peat stringers entombed in clastic sediments possibly mark the location of an incised paleovalley wall. Fibrous peat resisted erosion and tattered coalified peat stringers commonly mark the erosional margin of peat bodies in the Appalachian basin.

Brief Description

This stop, named for the interesting structure resembling a dragon's tongue that formed when the floating tattered remnants of the eroded margin of the Bakerstown peat were entombed in sediment (Figure 9), displays a superb example of paleoslumps with rotated blocks. Field trip leaders will discuss the formation of these blocks and invite comments from trip participants.

Setting

Paleogeography and Stratigraphy

During the Upper Mississippian and Pennsylvanian, the Late Paleozoic Ice Age affected global sedimentation, including the Appalachian basin. Dominantly terrestrial sediments were deposited in swamps of a varying subsiding, generally overfilled foreland basin punctuated periodically with glacioeustatic marine transgressions (Blake et al., 2009). Sea-level curves are shown in Figure 5. Paleogeographic reconstructions place the central Appalachian basin 10 degrees south of the paleoequator (Scotese and McKerrow, 1990), as shown in Figure 10 and Figure 11 with a tropical to subtropical climate.

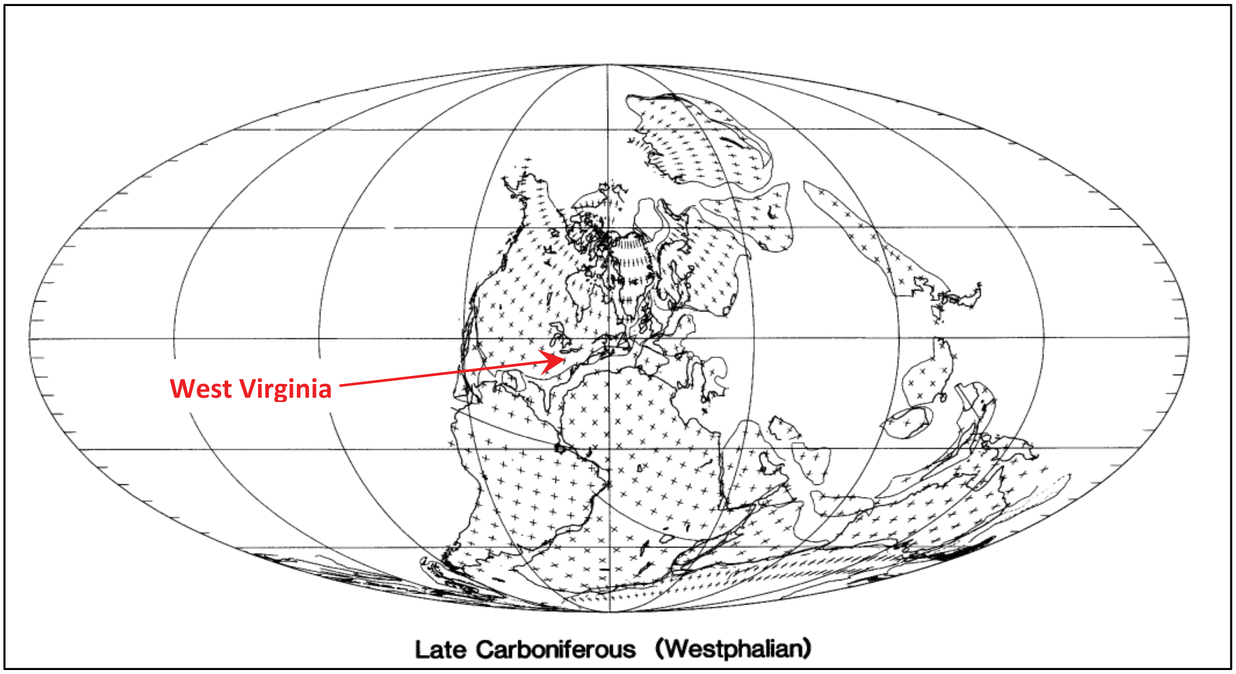

Figure 10. Location of West Virginia during the Pennsylvanian (Late Carboniferous) (after Scotese and McKerrow, 1990)

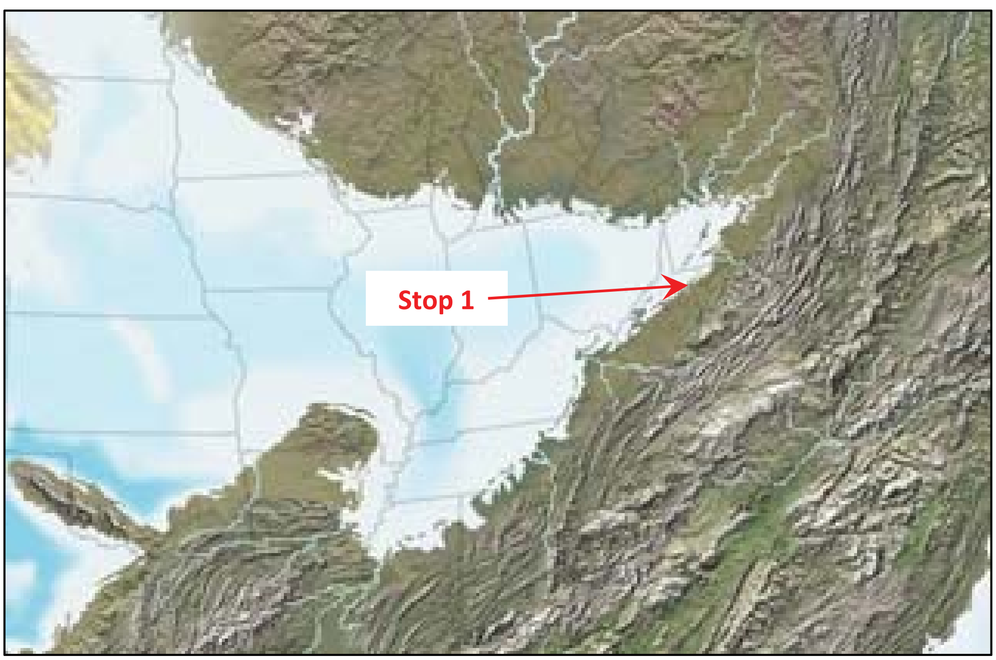

Figure 11. Paleogeography, Late Pennsylvanian, 300 MA (Blakey, 2007)

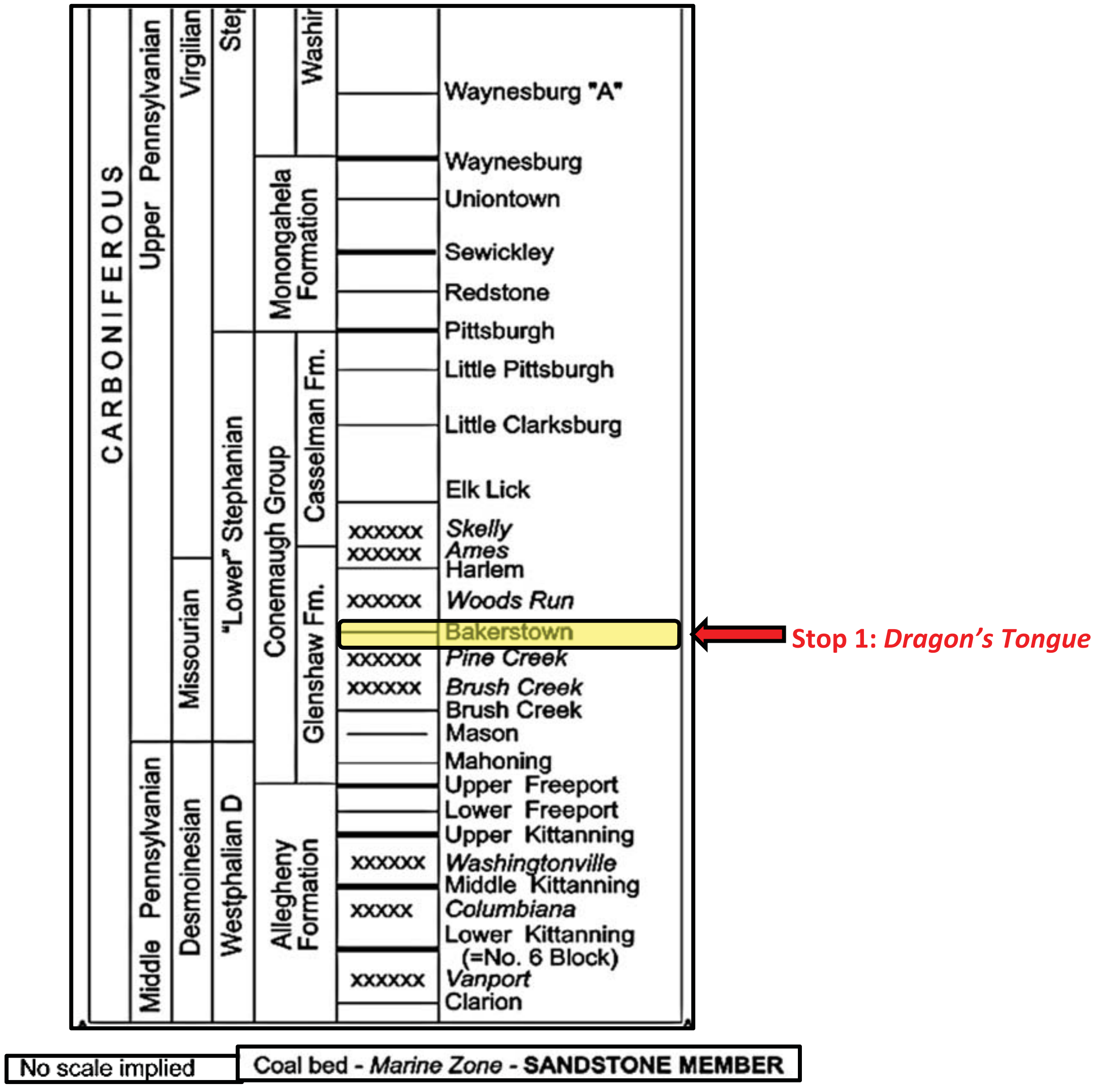

Figure 12. Chronostratigraphic chart showing Pennsylvanian stratigraphy at Stop 1 (Blake et al., 2002).

Stratigraphy and Tectonics

The strata observed at this stop are assigned to the Upper Pennsylvanian Conemaugh Group (Figure 2, Figure 12; ***Pcc*** and ***Pcg*** in Figure 13). The multi-bedded coal is the Bakerstown coal bed (Figure 9). The Conemaugh Group extends from the top of the Upper Freeport coal bed to the base of the Pittsburgh coal bed, and while formally subdivided into the Glenshaw and Casselman formations, "Conemaugh" is generally better recognized and has wider overall usage. A stratigraphic column showing divisions and major coal beds in the Pennsylvanian is shown in Figure 12. These contacts follow long-established tradition in North America of placing formation contacts at geographically-widespread, economically-important coal beds. Unfortunately, these contacts are difficult, at best, to locate in the absence of the designated formation contact coal bed. Across the Appalachian region numerous marine zones of continent-wide, if not global extent, are recognized and mapped (Heckel, 1990, 1994) and can be identified as classic cyclothems, as originally described in Upper Carboniferous successions around the world in many basins where coal-bearing strata alternate with other sedimentary strata in repetitive vertical sequence (Heckel, 1994). The marine zones are assigned to the lower Glenshaw Formation; the overlying Casselman is comprised solely of terrestrial sediments.

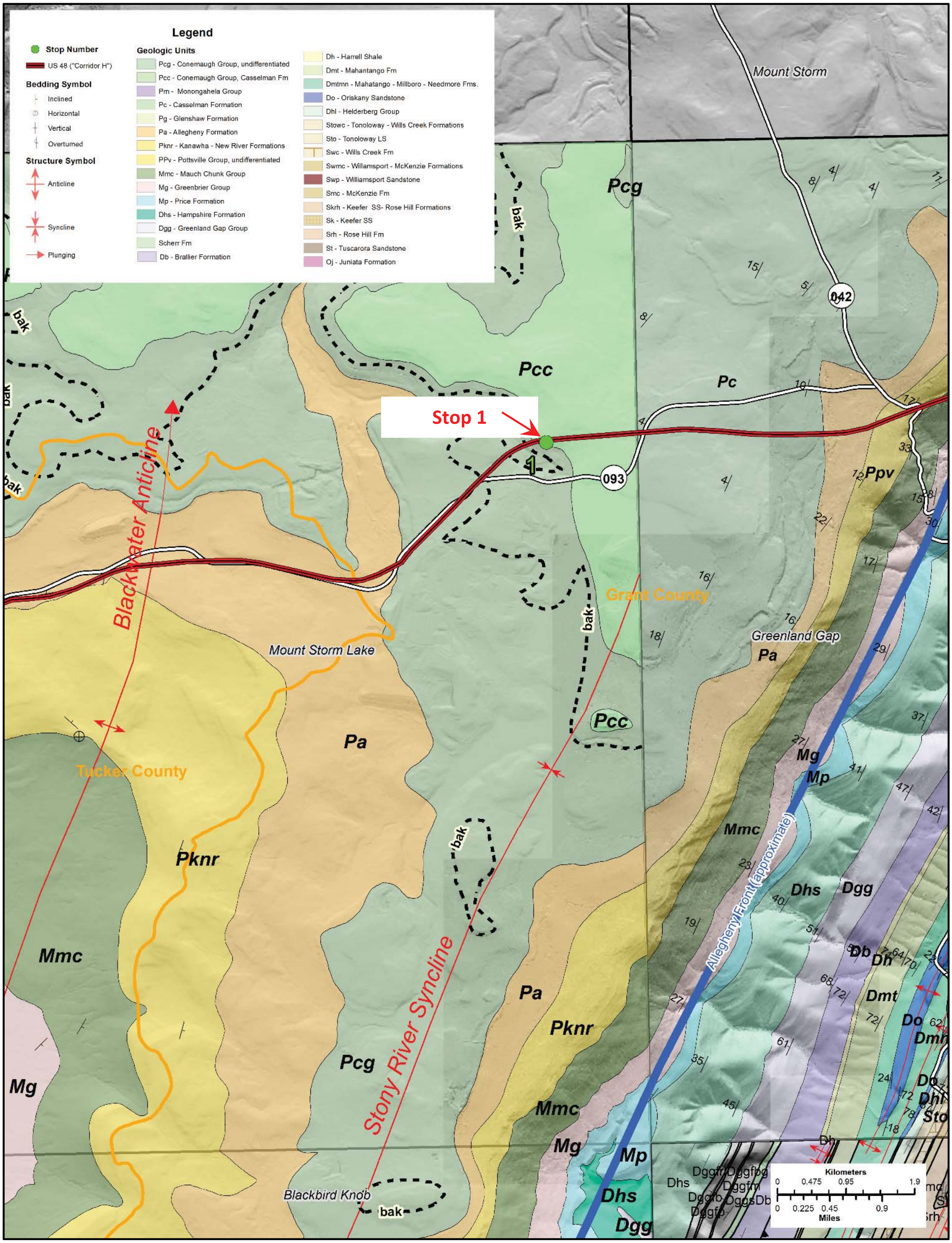

Figure 13. Geologic Setting for Stop 1 (Dragon's Tongue) (geology from Matchen et al., 2008; Dean et al, 2011)

The non-marine parts of the Conemaugh Group are dominated by abundant, well-developed red paleovertisols and paleocalcisols with features indicating development under seasonally-dry (monsoonal) climatic conditions such as calcareous glaebules that locally coalesce into calcretes (caliche), common mud cracks, calcite and possible gypsum films coating vertic structures (Joeckel 1995; Blake et al., 2002): gypsum has been found in subsurface drill tests (unpublished data). Coal beds in the Conemaugh Group are thin, impure, and aerially restricted, suggesting that water table position was the primary factor controlling peat formation and accumulation in contrast to the importance of an everwet climate in controlling peat formation in the lower series (Cecil et al., 1985, Cecil 2003; Cecil and Dulong, 2003). Intercalated marine zones are stratigraphically important for correlation, demonstrating biotic connection with the more-marine North American Interior basins (Busch and Rollins, 1984; Heckel 1990, 1994) and represent Heckel's (1994) Appalachian cyclothems, where clastics shed from the rising Appalachian orogeny overwhelm the classic cyclothemic pattern of the midcontinent. The younger Casselman Formation, while lithologically similar to the Glenshaw, does not contain intercalated marine zones. This stop is located on the east limb of the Blackwater Anticline and west limb of the Stoney River Syncline (Figure 13), structures formed during the Alleghany Orogeny.

Depositional Environment: Possible Incised Paleovalley

This stop is a series of rotated slump blocks involving the Bakerstown coal and immediately overlying strata. The entombed terminal stringers of the Bakerstown at the western end of the exposure are common features in the Appalachian Basin and formed where paleochannels eroded through peat bodies and the tattered peat mat stringers floated in the stream. If completely detached from the peat body, these peat mats can float downstream and eventually be deposited with other stream deposits, generally sand. The allochthonous nature of these floated peat mats is demonstrated by the lack of an underlying "seat earth," or stratum derived from the soil beneath the coal-forming vegetation. At this stop, a series of rotated slump blocks occurs east of the entombed peat margin (Figure 14). Evidence suggests these are repetitious blocks of the same sediment, including the Bakerstown coal. The leading edges of the slumps show evidence of compression formed during slumping and rotation. The Bakerstown "peat" clearly shows evidence of cataclysmic movement such as differential rotation within coherent peat masses, rapid variation in bed thickness within individual slump blocks, and rapid termination of peat into stringers disconformably entombed in sediment as discussed above.

On the upper bench of the cut, the Bakerstown peat and overlying shales are deformed into a "U" shape over a few meters. Beware while examining the outcrop: the relationships between the various coal stringers in the vicinity of the Dragon's Tongue are much more complex than they first appear. Excavation on the upper bench demonstrates that the stringers exposed on the lower bench do not physically connect with any stringers on the upper bench, greatly complicating interpretation.

The top of the 5- to 7-meter thick slump block is unconformably overlain by a variable, thin sandstone with an erosive contact. At one place this sand fills a channel incised several meters into the slump block complex and is filled with a quartz pebble conglomerate lag. This sand is present along the entire exposure. Locally towards the eastern end of the exposure, laminated sands and silts clearly drape a several meter thick rotated block that is not clearly related to the underlying slump block complex (Figure 15). The entire interval is capped by a thin coal bed and associated seat earth. A heavily weathered dark gray shale overlies the coal bed and contains poorly preserved plant fossils. Here at the top of the exposure the material is too badly weathered to adequately collect and identify.

Figure 14. Part of a series of slump blocks
Interpreted as rotated paleovalley wall slumps formed after incised valley formation, stratal relationships between the slump blocks are complicated and slumping may have been initiated by seismic activity in the nearby growing Appalachian Orogen.

Figure 15. Sediments above the continuous erosive surface overlying the slump block complex. Notice the shale beds draping what appears to be a rotated slump block.

Economic Importance

The Bakerstown coal bed is the most important coal in the Glenshaw Formation. While not of great significance, it was commercially mined in the past in West Virginia, Pennsylvania, and Maryland.

Questions for this Stop

One interpretation of how these slump blocks formed is shown below in Figure 16. Field-trip participants are challenged to come up with their own interpretations (faulting? compaction? paleoseismic activity? slumping along the wall of a paleovalley?).

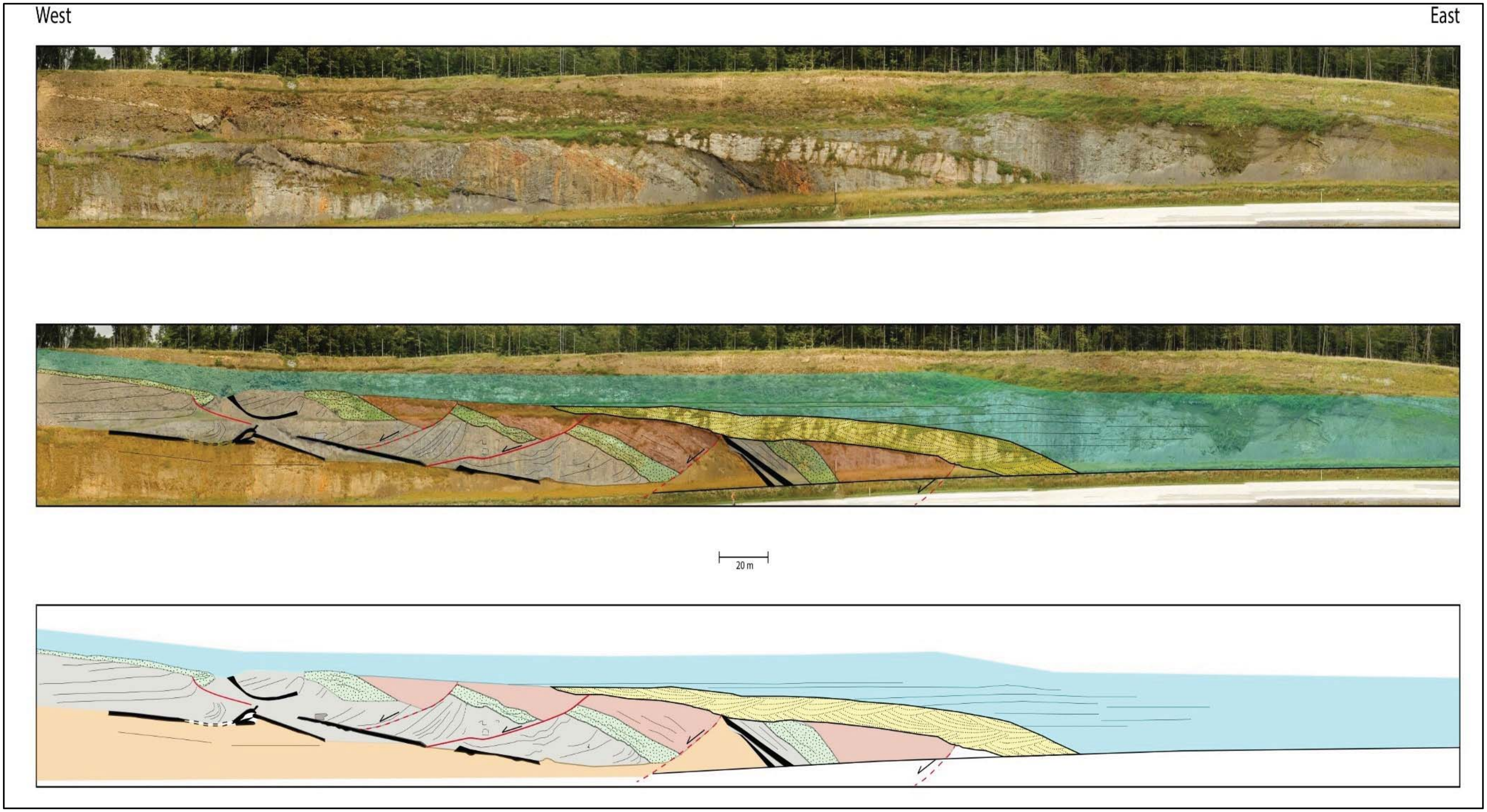

Figure 16. Slump-block and rotation-surface interpretation at Dragon's Tongue from Pitts (2015)

Additional Resources

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Stop 1.5 (Roll Over) (Day 1): Miss-Penn Boundary (under bridge)
Leaders: Mitch Blake, Jaime Toro (NAD83 Lat 39.2162, Lon -79.2042)

Description

As the field trip proceeds from Stop 1 to Stop 2 it crosses over the Mississippian-Pennsylvanian boundary (exposed along Route 42 just under the US 48 overpass). This boundary is a major unconformity present throughout most of the Appalachian basin, thought to be the result of a major glacioeustatic sea-level fall known as the mid-Carboniferous eustatic event (Blake and Beuthin, 2008). Stop 2 is near the Allegheny Front (Figure 17).

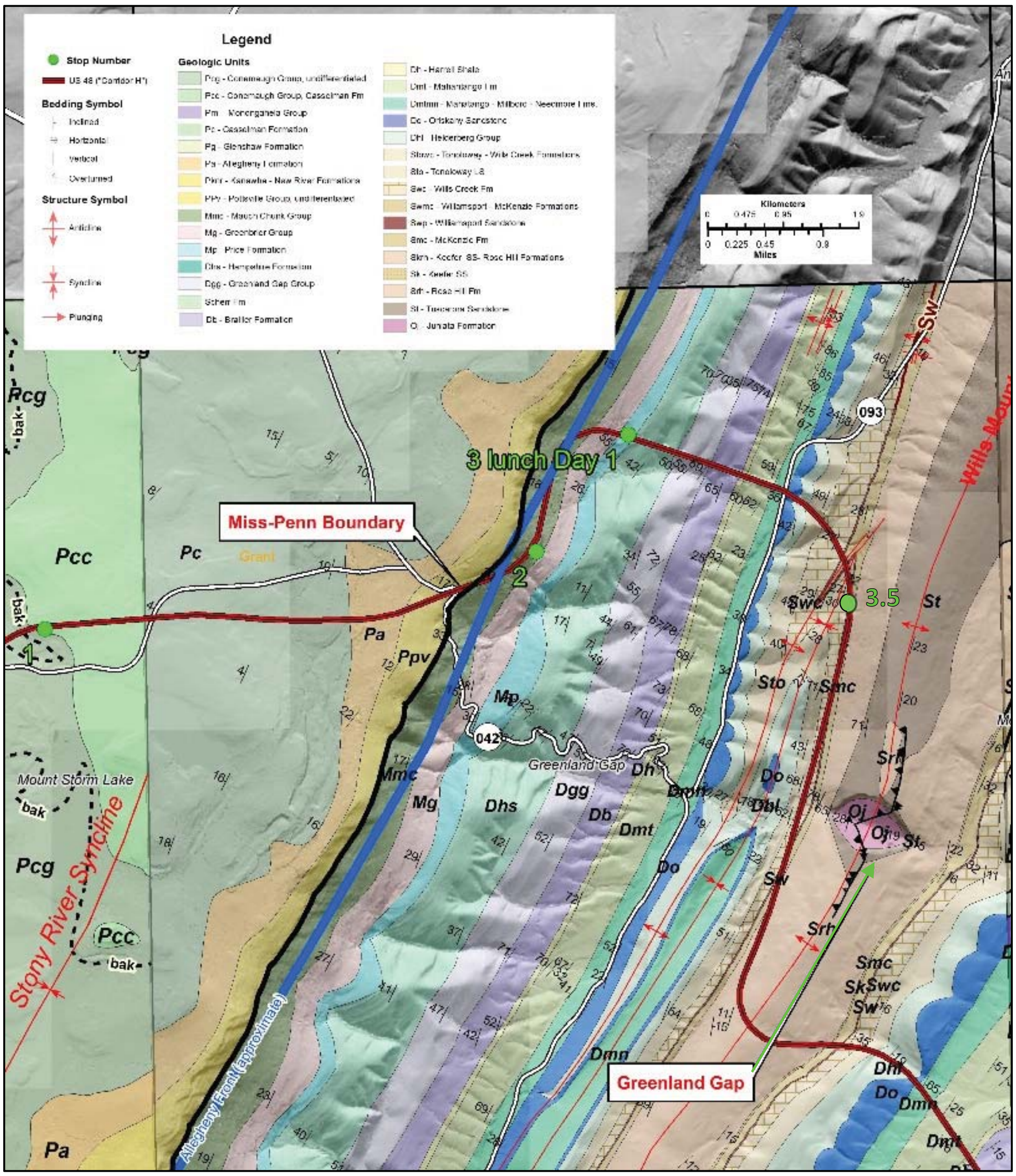


Figure 17. Geologic Setting for Rollover and Stop 2
(Miss-Penn Boundary: the contact between *Mmc* and *Ppv*; blue line is approximate location of Allegheny Front)
Geology from Dean et al. (2011)

Stop 2 (Day 1): Allegheny Front, Mauch Chunk Quick Look
Leaders: Ron McDowell, Mitch Blake, Jaime Toro, Phil Dinterman, Paula Hunt
(NAD83 Lat 39.2204, Lon -79.1925)

Figure 18. Mauch Chunk outcrop across from scenic overlook

Brief Description

Stop 2 is a scenic overlook on the Allegheny Front, the boundary between the Appalachian Plateau and the Valley and Ridge physiographic provinces. This stop provides a scenic vista of the Wills Mountain Anticline (Figure 17) to the southeast, and a good view of the Mississippian Mauch Chunk (Figure 18) to the northwest.

The Wills Mountain Anticline is on the western flank of the Nittany Anticlinorium and is the westernmost structure in the Valley and Ridge of West Virginia. The view is toward the anticlinal axis, so rock units become progressively older with increasing distance from the overlook. Another view and a more detailed discussion of the Wills Mountain Anticline is included with Stop 9a on this field trip.

The Mauch Chunk thickens from north to south, exceeding 3,500 feet (2,000 m) at its maximum thickness. In southern West Virginia it is subdivided into the Bluefield, Hinton, Princeton, and Bluestone formations. Here in northern West Virginia where marine zones and other marker horizons are absent or difficult to correlate, individual formations cannot be distinguished. Where the absence of marker beds necessitates stratigraphic "lumping," as it does here along US 48/Corridor H, the Mauch Chunk is afforded formational rather than group rank. A 7-meter thick limestone can be seen near the base of the Mauch Chunk on the way to Stop 3. This limestone is the only marine unit in the otherwise terrestrial Mauch Chunk at this location.

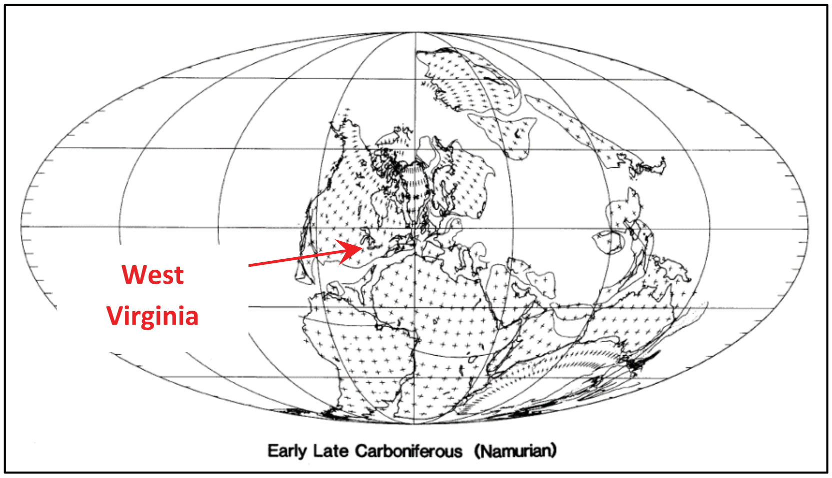
Later in the day the trip will pass another thick series of redbeds: the Devonian Hampshire Formation (formerly Catskill). Both of these units (the Mauch Chunk and the Hampshire) are predominantly terrestrial in this part of West Virginia with some marine evidence.

This stop will be brief, and an additional exposure of the Mauch Chunk, including the Reynolds Limestone(?) equivalent, will be viewed from the vehicle *en route* to Stop 3.

Setting

Paleogeography

Paleogeographic reconstructions place West Virginia slightly farther south of the paleoequator during the Mississippian than during the Pennsylvanian with increasing sedimentation coming from sources located to the east (Figure 19).



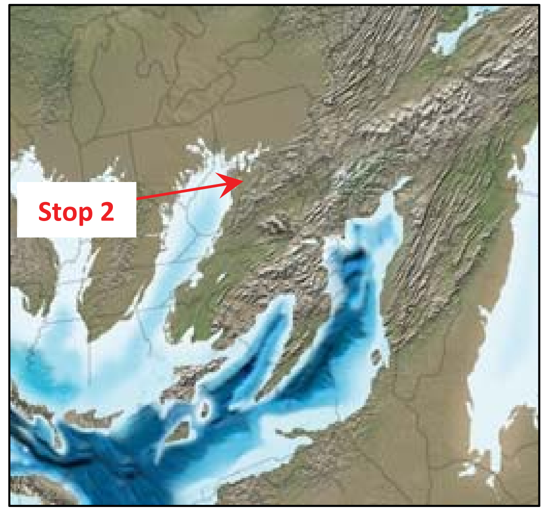
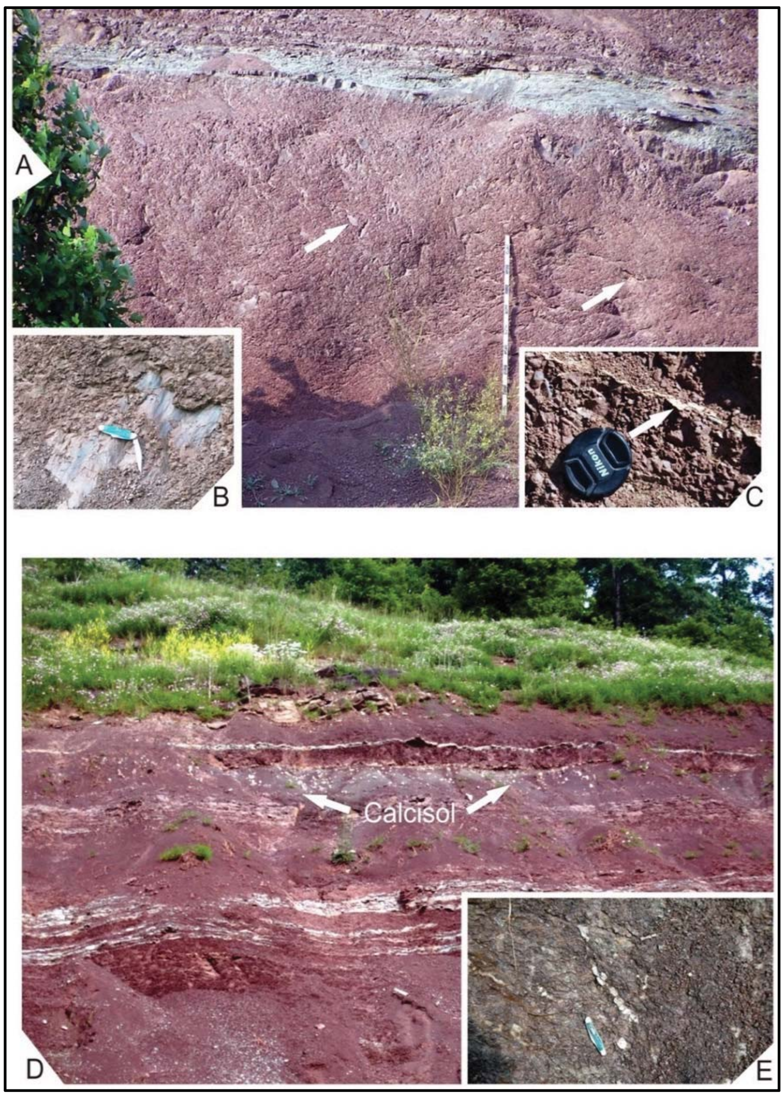


Figure 19. Paleogeography of Stop 2
Left: Location of West Virginia during the late Mississippian (Early Late Carboniferous) (from Scotese and McKerrow, 1990). Right: Paleogeography, Late Mississippian, 325 Ma (Blakey, 2007)



Photos taken approximately 200 miles (300 km) southwest of Stop 2, where the Mauch Chunk is thicker and can be subdivided into formations. A) Paleovertisol from the Hinton Formation located near Princeton, West Virginia. B) Close up of slickenside surface from paleovertisol seen in A) above (knife handle is 7.5 cm long). C) Calcite films coating slickenside surfaces in paleovertisol from the Hinton Formation near Athens, West Virginia; lens cover is 63 mm in diameter. D) Calcisol from the red member of the Bluestone Formation near Green Valley, West Virginia. E) Close-up of calcisol showing calcareous nodules and possible rhizoconcretions.

Figure 20. Paleosols from the Mississippian Hinton Formation of the Mauch Chunk Group

Stratigraphy and Depositional Environment

The Mauch Chunk is named from the town formerly known as Mauch Chunk (Lesley et al., 1895), now named Jim Thorpe, Pennsylvania. Much of the Mauch Chunk is conspicuously red and dominated by terrestrial sediments. These sediments were deposited at the top of the delta, derived from a low-lying coastal plain distal from the sea to the south, deposited in upper delta/alluvial flood plains under a semiarid climate subject to periodic monsoons. The non-marine beds are dominated by abundant, well-developed red paleovertisols and paleocalcisols (Figure 20), calcareous glaebules that locally coalesce into calcretes (caliche), common mud cracks, calcite and possible gypsum films coating vertic structures (Joeckel 1995; Beuthin and Blake, 2002). Gypsum has been found in subsurface samples (unpublished data), gypsiferous nodules within at least one calcic vertisol (Blake et al., 2009) and rare salt crystal casts have been observed. These features indicate development under seasonally dry (monsoonal) climatic conditions. Lungfish burrows (Figure 21, left) are another indication that sediments periodically dried out, forcing precursors to modern-day lungfish to burrow into sediment and hibernate until wetter conditions prevailed (Royer, undated publication).

The 7-meter thick limestone observed near the base of the unit (Figure 21, right) en route between Stops 2 and 3 is tentatively correlated with the Reynolds Limestone Member of the Bluefield Formation of the Mauch Chunk Group to the south, but possibly may be correlated with the Glenray limestone of the Bluefield Formation, also farther south, or it may not be possible at all to correlate this limestone with a named member in the south.

Where present, coal beds are aerially discontinuous, low quality and thin, suggesting ground water control on peat accumulation (Beuthin and Blake, 2002, 2004). Collectively these climatic proxies suggest the central Appalachian basin Late Mississippian paleoclimate varied between semi-arid and subhumid in response to Milankovitch-forced changes in southern hemisphere ice volumes (Cecil et al., 1985; Cecil, 2003; Cecil and Dulong, 2003; especially see discussion in Blake et al., 2009). Late Mississippian and Pennsylvanian sediments thicken southward into the rapidly subsiding portion of the Appalachian foreland and the Upper Mississippian (lower Namurian; Serpukhovian) Mauch Chunk Group exceeds 2,000 m (3,500 feet) in thickness. Intercalated marine-influenced intervals were deposited during periodic glacioeustatic transgressions and these limestones are used to subdivide the monotonous stacked red beds into the Bluefield, Hinton, Princeton, and Bluestone formations (Blake and Beuthin, 2008). At Stop 2 and farther north in the Appalachian basin, marine zones and other marker beds are absent or uncertain, and as a result, individual formations cannot be distinguished and the Mauch Chunk is afforded formational rather than group rank.

The basal contact is conformable with the underlying Greenbrier Limestone, which is not exposed along the route of the field trip and may be especially thin or not be present. (More investigation is needed.) The upper contact with the overlying Lower Pennsylvanian Pottsville Group marks a basin-wide unconformity (Blake and Beuthin, 2008).

Figure 21. Features of the Mauch Chunk.
Left: Lungfish burrow in mudstone of the Mauch Chunk (AA battery is 3.75 cm long).
Right: Dinterman and McDowell examine possible the Reynolds Limestone equivalent.

Economic Importance

The Mauch Chunk does not have significant economic importance in West Virginia. Its limestones are sometimes quarried farther south, its coals are thin, and while it is a gas play in West Virginia, Pennsylvania, Kentucky, and southwest Virginia, it does not contain rich gas reserves. Barlow (1996) estimated that gas production from the Mauch Chunk in the Appalachian Basin came from an estimated 1,200 wells in 170 fields in the early to mid 1990s. Driller's terms for units in the Mauch Chunk include Pride, Ravencliff, Avis, Maxton, Little Lime, Pencil Cave, and Blue Monday (Figure 2). Much of the drilling in these shallow sands occurred prior to required submittal of detailed production data.

Because of its high clay content, the Mauch Chunk can be problematic ("slippery") for construction and drilling. The exposed Mauch Chunk west of Elkins along US 33 has been reworked and restabilized several times since that part of Corridor H opened to traffic. Slides also developed in the Mauch Chunk along WV Route 42 (Avary, 1984) near the field trip route.

Significance of This Stop

The Mauch Chunk as a whole has a varied depositional environment and overall is marginal marine, containing mostly terrestrial with some marine deposits. This stop is an extensive terrestrial deposit with soil development and the single marine incursion. Glacioeustatic sea level changes resulted in periodic marine transgressions in the Mauch Chunk, although most did not get this far north. Farther south where the Mauch Chunk is much thicker, it has group status and contains named formations with the limestones marking marine incursions.

A number of redbed sequences exist in West Virginia. Another sequence of redbeds seen on this trip is the Devonian Hampshire Formation. Some of these redbed sequences appear to be quite similar, and so a detailed look at each is necessary to tell them apart.

Additional Resources

Bentley, C., Mid-Atlantic Geo-Image Collection (M.A.G.I.C.), GigaPan Systems, URLs: http://gigapan.com/gigapans/173089, http://gigapan.com/gigapans/181674, and http://gigapan.com/gigapans/173210

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Stop 3 (Day 1): Hampshire, Spechty Kopf, and Price formations (Lunch)
(Lat 39.23, Lon -79.17)
Leaders: Mitch Blake, Ron McDowell, Jaime Toro, Phil Dinterman, Paula Hunt

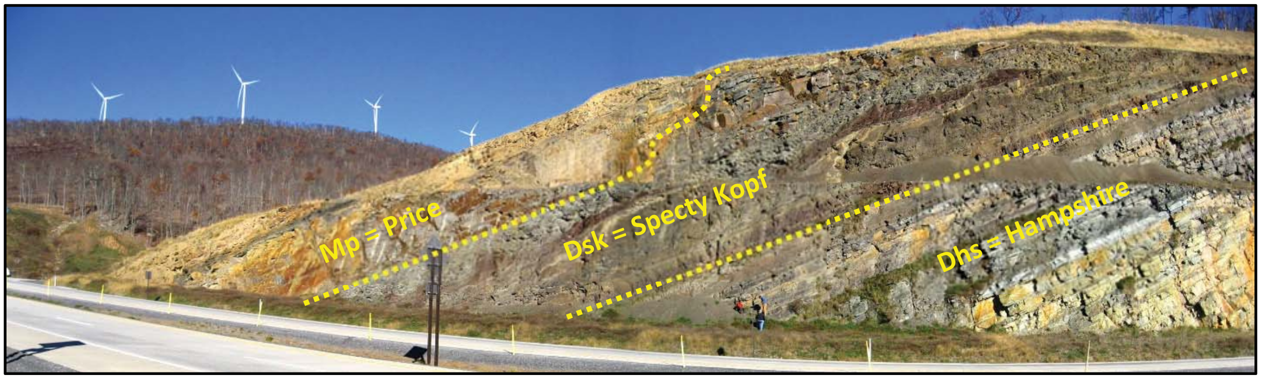

Figure 22. Hampshire, Spechty Kopf, and Price formations (right to left) at Stop 3.

Brief Description

Stop 3 is a road cut exposing three stratigraphic units: the Upper Devonian Hampshire Formation, Upper Devonian Spechty Kopf Formation, and the Upper Devonian-Lower Mississippian Price Formation (Figure 22). The contacts between these units are well exposed at this stop. Participants will observe the contact of the Hampshire Formation with the Spechty Kopf Formation, will discuss the origin of the very interesting and unusual Spechty Kopf, and will decide where to place the contact between the Spechty Kopf and the overlying Price Formation.

Setting

Paleogeography

Paleogeographic reconstructions place West Virginia south of the paleoequator in the mid latitudes during the Late Devonian, with sedimentation coming from sources located to the east (Figure 23 and Figure 24).

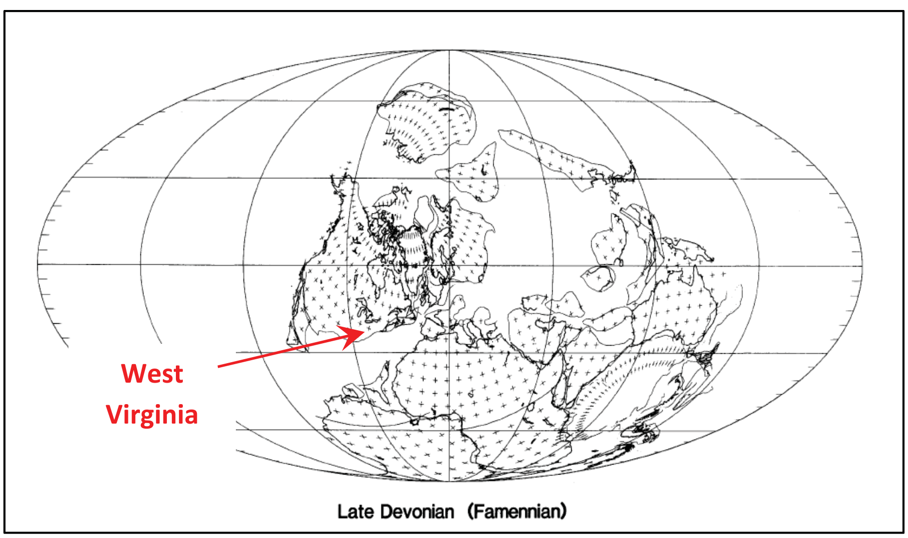

Figure 23. Location of West Virginia during the late Devonian (from Scotese and McKerrow, 1990)

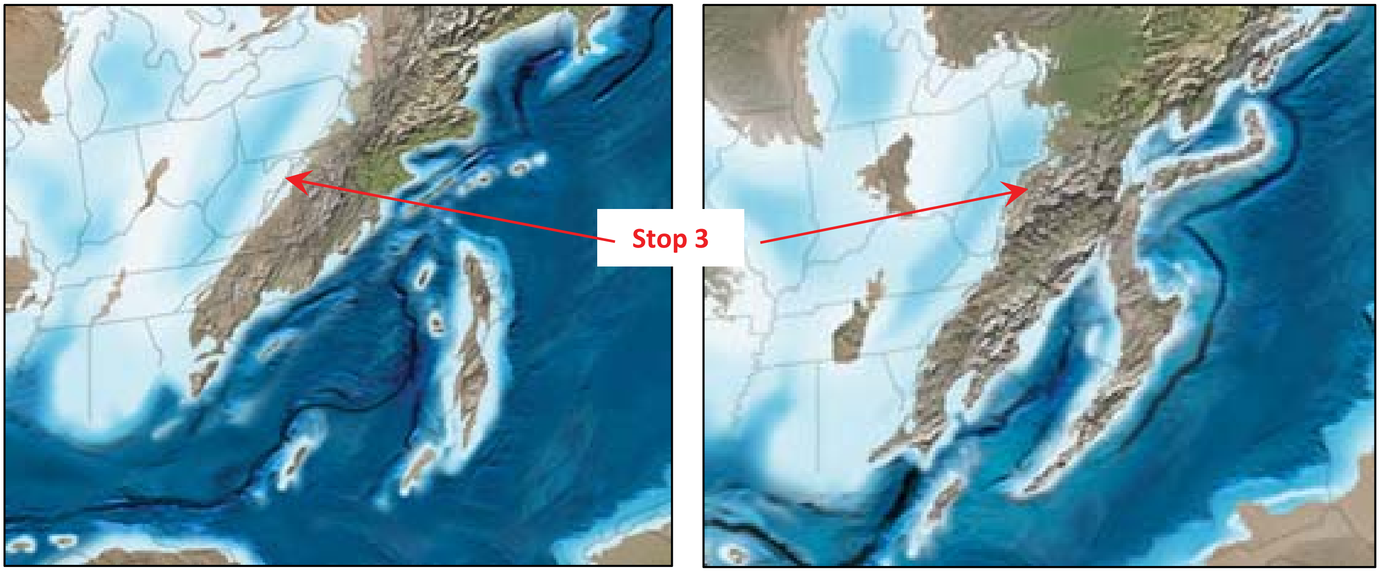

Figure 24. Left: Late Devonian (360 Ma) Right: Early Mississippian (345 Ma) (from Blakey, 2007)

Depositional Environment and Tectonic Setting

Hampshire Formation

The Hampshire is one of the redbed sequences shed from erosion of the pre-Appalachian Mountains formed during the Acadian Orogeny, and is part of the late Devonian Catskill complex, or Catskill Clastic Wedge. As with other siliciclastic redbeds in this region, the Hampshire represents deposition in a variety of environments including alluvial fans, river channels, and floodplains, all with superimposed soil development and all proximal to a marine basin that lay to the west. Indications of marine influences are rare in the Hampshire outcrops of eastern and southern West Virginia. However, here at Stop 3, the uppermost Hampshire contains glauconite and the trace fossil *Arenicolites* sp. which is indicative of shallow marine conditions. Approximately 60 miles (37 km) west of this location the Hampshire is approximately 90% marine, and farther west where the unit is a gas and oil play, it becomes fully marine. The trip will stop by a fold in the Hampshire at Stop 6.5.

Spechty Kopf Formation

Several authors have speculated on the origin of the diamictite in the Spechty Kopf (Figure 25A and B). Interpretations range from debris flow into lakes, to tsunami, to glaciation. Brezinski et al. (2008, 2010, and 2015) have examined the unit in detail in Maryland and Pennsylvania, and have determined the unit, because of its geographic extent (400 km by 40 km), is too large to be a localized debris flow. In addition, Brezinski et al. (2008) also showed the diamictite is not a subaqueous deposit and the unit's age coincides with a drop in global sea level (Bjerstedt and Kammer, 1988; Brezinski et al., 2008), leading to a glacial origin for the formation.

This begs the question of how ice could be present in the equatorial to mid latitudes (Figure 23). McDowell et al. (2005), hypothesize this may be the beginning of the Carboniferous Ice Age in the latest Devonian.

A bed exhibiting unusual soft sediment deformation is present above the diamictite at this stop (Figure 25C and D). This chaotic layer exhibits flattened, spheroidal clasts, and the red mudstone “pillars” intruded from the underlying unit suggest post-depositional loading or some other type of stress has deformed this unit. Mills, (1983) and Roep and Everts (1992) interpreted similar deposits to be seismic or turbidity flows. The authors believe these “slurpy” deposits (Figure 25D and E) to be paleoseismites.

Price Formation

This unit was deposited during the Pocono Clastic Wedge, a smaller, later, series of clastic deposits coming after the Catskill Clastic Wedge. The unit was known as the Pocono Formation until Kammer and Bjerstedt (1986) suggested the name Price after Campbell (1894). Originally thought to be entirely Mississippian, Carter and Kammer (1990) cited paleontological evidence showing the lower Price Formation is Devonian. The Oswayo sandstone at the base of the Price Formation contains Latest Devonian brachiopods, and so the Oswayo sandstone, where present, straddles the Devonian-Mississippian boundary. Here at Stop 3 the Oswayo is not present and the Price contact with the Spechty Kopf may be erosional (Figure 25E).

Unit Descriptions

Hampshire Formation (Late Devonian)

This unit is mostly dull-red, dark gray, and brown. Thickness ranges from 1,000 ft to 1,400 ft. (300 to 400 m). Previously called the Catskill Formation in early publications, Woodward (1943) revived the name Hampshire from Darton (1892, p. 17) who used the term for the “uppermost series of dark sandstones” in Hampshire County, West Virginia. The name Catskill remains as a facies of the late Devonian rather than a distinct stratigraphic unit.

The formation is comprised of alternating nonmarine sandstone, shale, and mudstone, most of which are characteristically a maroon to dark brownish-red color, although some beds are greenish, gray, tan, or brown. Sandstones are fine-grained, micaceous, and often crossbedded in tabular sets typically 5 cm to 0.5 m thick. Some beds contain ripple marks. Rounded quartz pebbles may be present. Plant fossils, especially wood imprints, are relatively common, especially in the shales. The unit thins to the southeast based on regional mapping.

Contact with the underlying Greenland Gap Group is gradational, and for mapping purposes is placed at the top of coarser siltstones or sandstones beds containing marine body fossils of the Foreknobs or at the last occurrence of tan mudstone and shale, whichever is higher in the section. Finding the contact between the two may be difficult where members of the Foreknobs exhibit a reddish color and tabular crossbedding similar to the Hampshire Formation. Fossil content is a useful mapping guide, as the Hampshire does not usually contain marine fossils in this part of West Virginia. The unit becomes more marine toward the west. Both the Hampshire and the Foreknobs contain wood imprints. Contact with the overlying Spechty Kopf, where present, is sharp.

Spechty Kopf Formation (Late Devonian)

Overlying the Hampshire is an unusual unit first described by Trexler and others (1962) in eastern Pennsylvania. Originally named the Spechty Kopf Member of the Catskill Formation for Spechty Kopf Hill in the Lykens quadrangle, Dauphin County, Pennsylvania (Trexler, 1962), this Late Devonian unit is comprised of gray to gray-green sandstone shale and conglomerate in the lower portion with a few interbedded red beds. The upper portion contains a diamictite overlain by a bed characterized by soft-sediment deformation. The diamictite was later interpreted by Brezinski and others (2008) as glaciogenic based on the presence of a pebbly mudstone (diamictite) containing "exotic," non-sedimentary rock fragments bearing striations interpreted to be glacial in origin. In addition to the diamictite present at Stop 3, another unit is present in the Spechty Kopf. This chaotically bedded unit is characterized by nearly 10 feet of light greenish grey, very micaceous silty shale occurring in bulbous, rounded, seemingly randomly oriented, "clasts" that range in longest dimension from 0.5 ft to 2ft. Thoughts on the origin of this layer range from simple load casts/fluid escape, to loading associated with an overriding glacial ice mass, to a paleoseismite. One of the trip leaders (McDowell) believes that this "slurpy" soft-sediment deformation, slump-roll, ball-and-pillow-like unit is similar to an interpreted paleoseismite observed along the Niagara River Valley in the Silurian Decew Dolomite (Figure 25).

Price Formation (Late Devonian to Early Mississippian)

The basal portion of the Price is Late Devonian and the remainder is Early Mississippian. This unit was known as the Pocono Formation until Kammer and Bjerstedt (1986) suggested changing the name to Price after Campbell (1894), who first named and described exposures at Price Mountain located between Christiansburg and Radford in Montgomery County, Virginia. As discussed previously, Carter and Kammer (1990) cited paleontological evidence showing the lower Price Formation is Devonian because the Oswayo sandstone at the base of the Price Formation contains Latest Devonian brachiopod. The base of the Price Formation at Stop 3 is marked by a massive quartz sandstone – not the Oswayo sandstone -- (Figure 25E) that overlies the Spechty Kopf and the contact is sharp and possibly erosional. The top of the Price is concealed at this location.

Economic Importance

West of this location, deeper in the basin, strata correlative with the Hampshire Formation lose their characteristic red color and become fully marine. The subsurface unit contains the oil- and gas-bearing sandstones of the Venango Play. According to Boswell et al. (1996) the Hampshire corresponds to "cycles" V-2 through V-5 of the Venango Play, which includes from oldest to youngest, the Elizabeth, Bayard, Fifth, Fourth, Gordon/Gordon Stray, Thirty-Foot, Fifty Foot and Gantz sands in the subsurface.

The Price Formation is part of the Berea/Murrysville oil and gas play farther west. Driller's terms for units in the Price Formation are, from oldest to youngest, Berea, Sunbury, Coffee, Weir, Squaw, and Pocono Big Injun. In the past Keener was used, but it is now attributed to the Greenbrier Formation (Matchen and Vargo, 1996). There have been some recent horizontal wells drilled in the Berea and Big Injun sandstones and some renewed interest in others, most notably the Weir, for potential oil production.

Figure 25. Features of the Spechty Kopf Formation

A) Diamictite in the Spechty Kopf (arrows point to pebbles deposited along with the mudstone matrix material). B) Diamictite in the Spechty Kopf (circled is large, exotic clast deposited along with the mudstone matrix material). C) Chaotic "slurpy" layer in the Spechty Kopf interpreted as paleoseismite (Phil Dinterman for scale). D) Paleoseismite in the Silurian Decew Dolomite from the Niagara River Valley in New York (coin is 3 cm in diameter). E) Contact between the Spechty Kopf Formation and the overlying Price Formation.

Points of Interest and Discussion Topics

The Hampshire is mostly terrestrial in the east and mostly marine about 60 miles (37 km) southwest of this location. Here at Stop 3 the Hampshire shows evidence of just beginning to become more marine.

What is the origin of the Spechty Kopf diamictite? Glacial? Mass wasting? Debris flow? Turbidite? Olistostrome? Is it glaciomarine sediment melting out of ice but not sorted or transported by flowing water?

Discuss load structure: if they are from ice, they would need more directionality to them, but they appear to be loaded from the top with little to no horizontal structure. ***Is it ice or something else?***

What is the origin of the "slurpy" soft-sediment deformation, slump-roll, ball-and-pillow-like deposits above the diamictite? The authors believe these structures may be from local tectonic activity and therefore consider them to be paleoseismites.

Where is the Price-Hampshire contact here? One author places it in one location and another author places it in another location. *Ask the participants: where would YOU place it?* Is it the base of the thick sandstone immediately above the "slurpy" paleoseismites? The original, formal definition of the Spechty Kopf (Trexler, 1962) places that formation between the basal Pocono (Price) and the uppermost Catskill (Hampshire), making the Spechty Kopf latest Devonian in age. Therefore it cannot have additional Hampshire above it and the Price-looking, sandstone with marine trace fossils located below the Spechty Kopf at this stop is really part of the Hampshire. However, the location of redbeds at this outcrop has another author thinking the contact is farther down, below the paleoseismites.

Where is the Devonian-Mississippian boundary? Is the Spechty-Kopf/Price contact an unconformity here? Assuming the top of the paleoseismites it the top of the Spechty Kopf Formation, then the boundary would be in the thick sandstone above the paleoseismites. The Oswayo sand is not present at this stop.

Where is the Greenbrier Limestone?
McDowell, Blake, and others have walked the area around this outcrop and can find no sign of the Greenbrier Formation, the unit immediately overlying the Price Formation. Is it faulted out? Thinned because of the influence of the "West Virginia Dome," or simply covered up.

Additional Resources

Bentley, C., Mid-Atlantic Geo-Image Collection (M.A.G.I.C.), GigaPan Systems, URLs: http://gigapan.com/gigapans/162341, http://gigapan.com/gigapans/162340, http://gigapan.com/gigapans/162342, http://gigapan.com/gigapans/181670, http://gigapan.com/gigapans/162339, http://gigapan.com/gigapans/162343

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Stop 3.5 (Roll By) (Day 1): Tonoloway Quarry and Folds
Leaders: Ron McDowell, Jaime Toro (NAD83 Lat 39.2092, Lon -79.1479)

Figure 26. Road cut along US 48 exposing the Tonoloway Formation (foreground) along strike with a Tonoloway quarry (background)

Brief Description

Between Stops 3 and 4 trip participants have an interesting view of the thinly bedded limestones of the Late Silurian Tonoloway Formation along strike with a quarry in the same unit (Figure 26). Here the Tonoloway Limestone exhibits characteristic, paper-thin layers of silty, micritic carbonate. The Tonoloway, as the authors usually see it, appears to be a shallow marine deposit that has undergone periods of subaerial exposure as evidenced by polygonal mudcracks that are often encountered. At other locations, the Tonoloway contains algal stromatolites and fauna that is, at least, marginally "normal" marine (Bell, 1997) and consists of large leperditiid ostracodes and gastropods. Fresh outcrops of the Tonoloway may appear as thick, flat-bedded units, which on close inspection, appear to be composed of thinly laminated micrite that is probably of algal origin. The Tonoloway is stratigraphically equivalent to a portion of the evaporitic strata of the Salina (Smosna et al., 1977). Indications of this regional trend towards shallowing and subaerial exposure in the late Silurian are seen in the desiccation cracks and the occasional salt and gypsum crystal casts found in the Tonoloway.

This "Roll By" is also near Greenland Gap (Figure 16 and large map accompanying trip), seen from the overlook at Stop 2

Setting

Paleogeography

Paleogeographic reconstructions place West Virginia south of the paleoequator in the mid latitudes during the Late Silurian when shallow seas covered most of West Virginia (Figure 27).

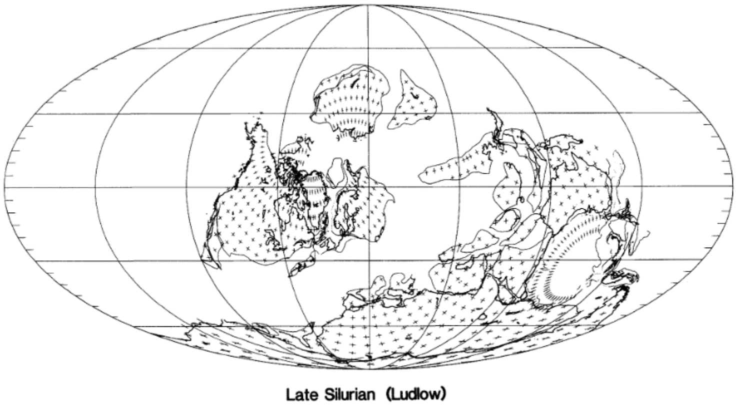

Figure 27. Late Silurian 420 Ma
from Scotese and McKerrow (1990), left and Blakey (2007), right

Depositional Environment and Tectonic Setting

The predominantly carbonate Tonoloway Formation was deposited during the calm between the Taconic and Acadian orogenies, when much of West Virginia was covered by a shallow sea. The Tonoloway exhibits several facies as sediments were deposited in the various environments found in a carbonate ramp complex, from carbonate lagoon-sabkha to deeper ramp (from northeast to southwest) (Bell and Smosna, 1999).

Unit Description

Ulrich (1911) named the Tonoloway Formation for exposures on Tonoloway Ridge along the Cacapon River near Rock Ford in Morgan County, West Virginia. Woodward (1941) used the name Tonoloway Limestone to replace the name Bossardville Limestone or Bossardville Group of the earlier county geologic reports. Dark gray, thinly laminated micrites, calcareous shales, and argillaceous limestone comprise this marine unit. More massive limestone beds, sometimes sandy, may be found in the middle portion of the formation. Algal laminae and stromatolite domes are present in some beds. Mudcracks, bioturbation, and evaporate casts are observed on some bedding surfaces. Freshly broken micrites may produce a petroleum-like odor. Ostracodes, especially *Leperditia* sp., are the most common fossils found in this unit. Contact with the underlying Wills Creek Formation appears to be gradational because the two units are both thinly bedded limestones. Woodward (1941) described the Wills Creek limestones as being more argillaceous than the overlying Tonoloway limestones and used this distinction to separate the two units. Contact with limestones of the overlying Helderberg Group is reported as sharp by Woodward (1941), as the Keyser Formation of the Helderberg Group is more crystalline and has thicker, more massive beds. But to most it appears gradational, as both units are mostly limestone and the contact is seldom exposed.

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Stop 4 (Day 1): Marcellus and Mahantango formations
(NAD83 Lat 39.14, Lon -79.07)
Leaders: Ron McDowell, Jaime Toro, Phil Dinterman, Mitch Blake, and Paula Hunt

Figure 28. The Marcellus Formation at Stop 4

Brief Description

Stop 4 is an exposure of the Middle Devonian Marcellus (Figure 28) Formation and overlying Middle Devonian Mahantango Formation, showing how the Marcellus weathers and the nature of the contact between the two formations. Participants will examine Marcellus core brought along for comparison, and may use the provided Geiger counter to measure radioactivity at the outcrop.

Setting

Paleogeography

Paleogeographic reconstructions place West Virginia south of the paleoequator in the mid latitudes during the Middle Devonian with increasing clastic sedimentation coming from sources located to the east (Figure 29).

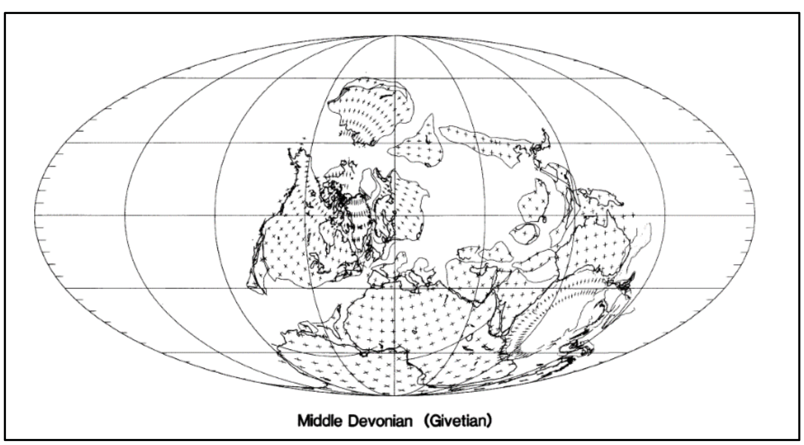

Figure 29. Stop 4 paleogeography
A) Location of West Virginia during the late Devonian (from Scotese and McKerrow, 1990).
B) Middle Devonian (385 Ma) (from Blakey, 2007)

Depositional Environment and Tectonic Setting

A new major pulse of clastics filled the Appalachian foreland basin during the Middle Devonian in response to the Acadian Orogeny. This sedimentary sequence started with the black shales of the Marcellus Formation and become progressively swamped by clastic input sourced from the east, which entered the basin as part of the Catskill clastic wedge, as seen in the siltier Mahantango Formation overlying the Marcellus at the stop. Figure 30 shows the nomenclature used by WVGES for the Middle to Upper Devonian Shales and their stratigraphic relationships with units in the west.

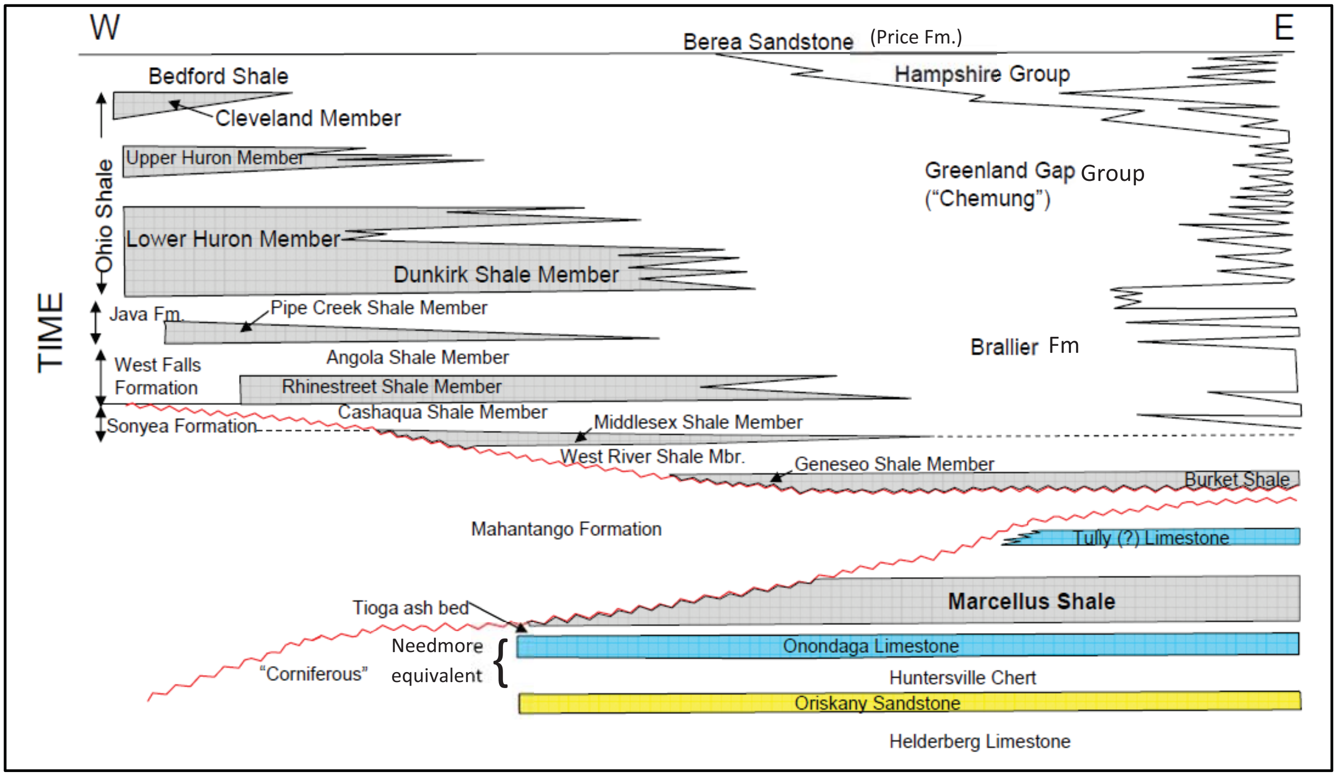

Figure 30. West Virginia nomenclature used for Devonian units (modified from WVGES, 2017 and Avary and Patchen, 2008; after Patchen and Hohn, 1993)

Unit Descriptions

Marcellus Shale (Middle Devonian)

This unit was named by James Hall (1839) for the town of Marcellus, New York. Fresh exposures of the Marcellus Shale are typically jet black, platy (Figure 28), and weather rapidly to dark gray, often with a reddish brown "rusty" coating resulting from pyrite oxidation. This pyrite is likely the result of bacterial degradation of original organic matter – the same material that makes the Marcellus a petroleum source rock. Here the Marcellus carbonate concretions ranging in size from a few inches (Figure 33 Left) to several feet in diameter. Elsewhere, the Marcellus contains limestone as lenses or beds. Fossils in Marcellus are few and unusually small. Typically fauna, where recovered, consist of miniature inarticulate and articulate brachiopods, clams, cephalopods, and the unusual, conical, phosphatic mollusk *Styliolina* sp. Because many of the brachiopods, clams, and cephalopods appear (based on the

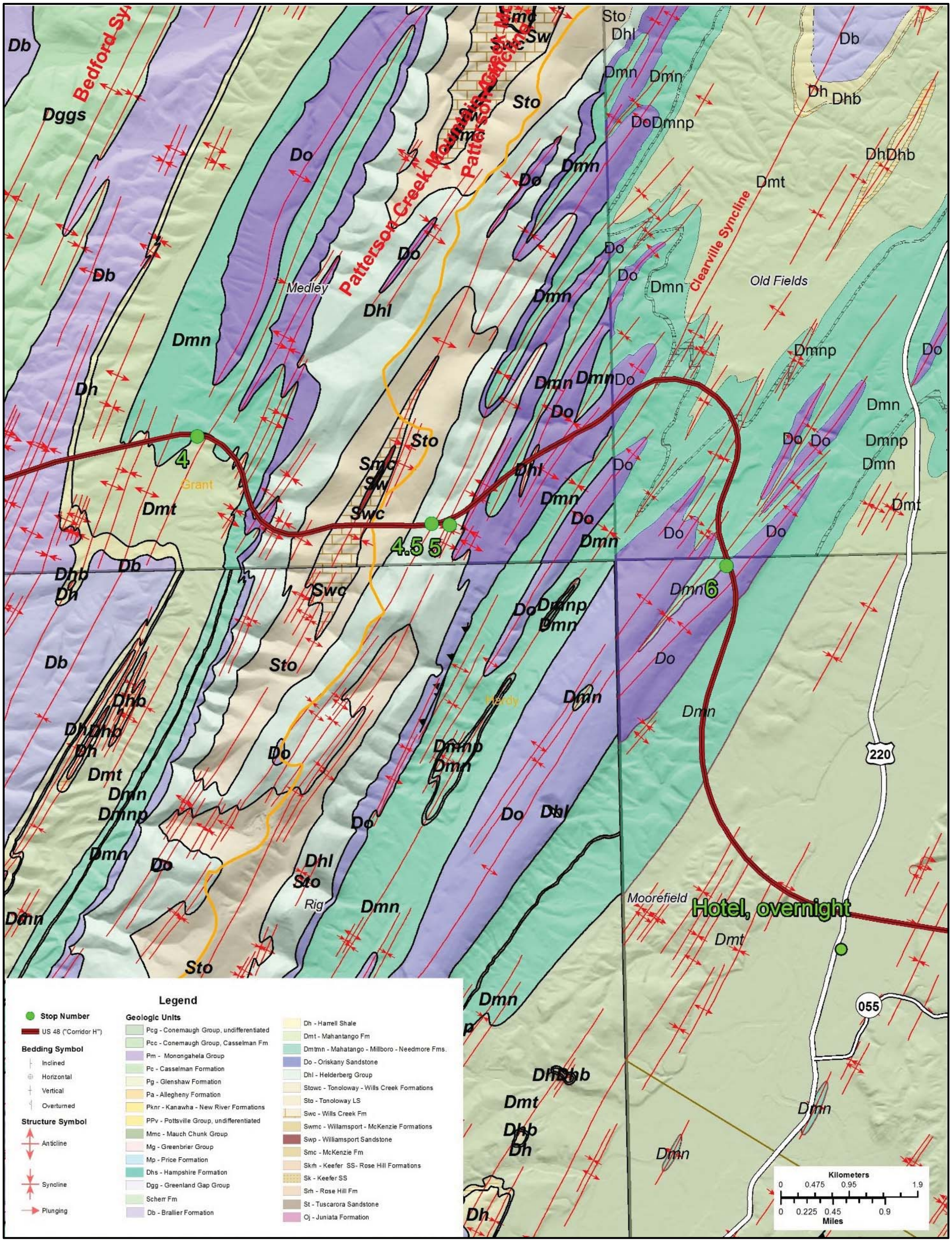

Figure 31. Geologic Map for Stops 4 through 6 (geology from Dean and Kulander, 2003, Dean et al., 2004, and Dean et al., 2009)

number of annual growth lines) to be adults, the authors believe this to be a "depauperate" fauna that lived in marine conditions associated with low oxygen content, high salinity, high temperature or some combination of factors. The lack of oxygen was potentially caused by organic overproduction, water depth, or restricted circulation (McDowell et al., 2010). These conditions may have helped preserve the Marcellus' high organic content (Chen et al., 2015). Another characteristic of the Marcellus is the presence of high-radioactivity zones that serve as markers on geophysical logs acquired during petroleum well drilling activities (Figure 35). As a rule of thumb, black shales are more radioactive than other lithologies due to the affinity of uranium for reducing conditions associated with the degradation of organic matter by bacteria. In the case of the Marcellus, however, radioactivity spikes noted on geophysical logs have been found to be associated with radium (Soeder et al., 2014). Visual examination of drill core from the Marcellus (see example core material accompanying the field trip) shows nothing unusual but the radioactivity spikes can be detected using a hand-held Geiger counter (Figure 32Right). The authors conducted a reconnaissance Geiger counter traverse parallel to the highway across the Marcellus exposure at Stop 4 and the results are shown in Figure 35A. It appears that the traverse intersected one of the radioactivity spikes in the Marcellus based on comparison of the Geiger counter reading to the initial "free air" value. As with the Marcellus cores, the lithology at this spike does not appear any different visually from that on either side of the measurement point.

The contact between the Marcellus and the overlying Mahantango Formation is exposed at Stop 4 and farther east. The contact itself appears to be interfingering because black platy shales of the Marcellus are interbedded with dark gray, silty shales of the Mahantango and repeat again farther east.

Compared to the poorly represented fauna of the Marcellus, the Mahantango represents a change to "normal" marine conditions as indicated by the presence of full-size adult fossils including inarticulate brachiopods, articulate brachiopods, and trilobites.

Figure 32. Characteristics of the Marcellus Formation at Stop 4.
Left: calcareous nodule. Right: Some portions are more radioactive than others

Figure 33. Additional Characteristics of the Marcellus Formation at Stop 4

Left: Small septarian concretions developed in one of the carbonate nodules common in the Marcellus. Coin is 3 cm in diameter. Right: Pyrite is common in the Marcellus and is probably associated with bacterial degradation of original organic material in the unit.

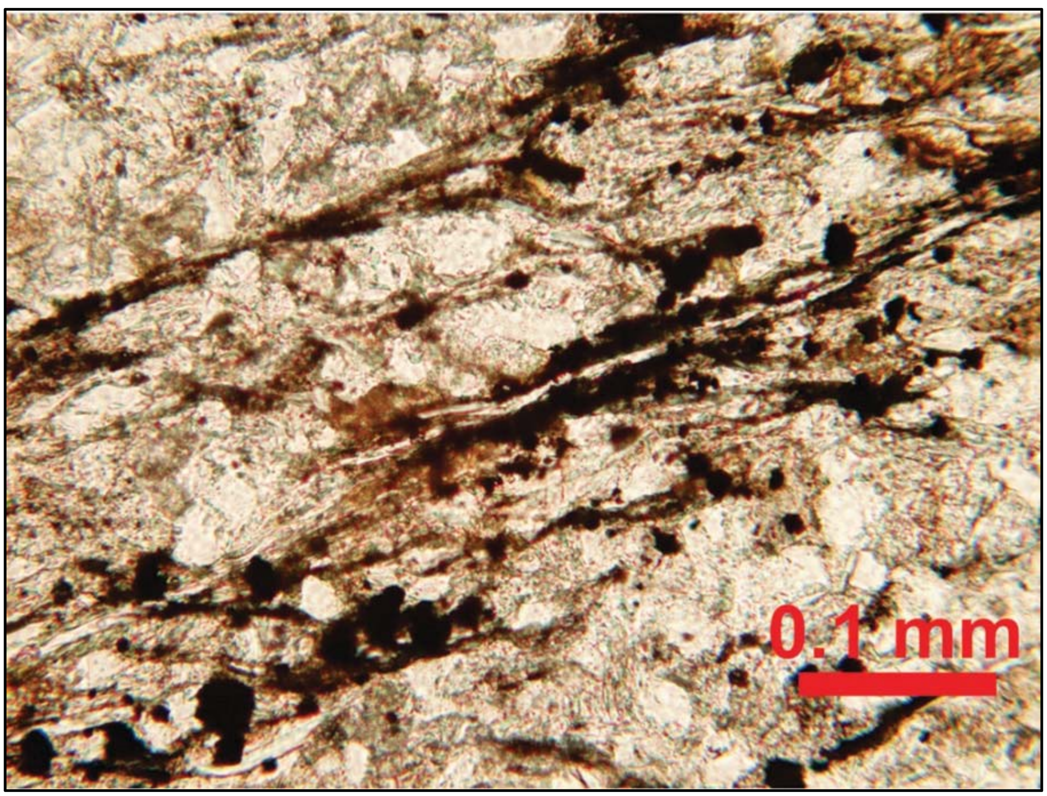

Figure 34. Thin-section photomicrograph from a carbonate concretion

from the Millboro Formation (Marcellus-equivalent) from Pendleton Co., WV. Opaque, spherical objects are pyrite framboids associated with bacterial degradation of organic matter and chemical reduction of sulfur.

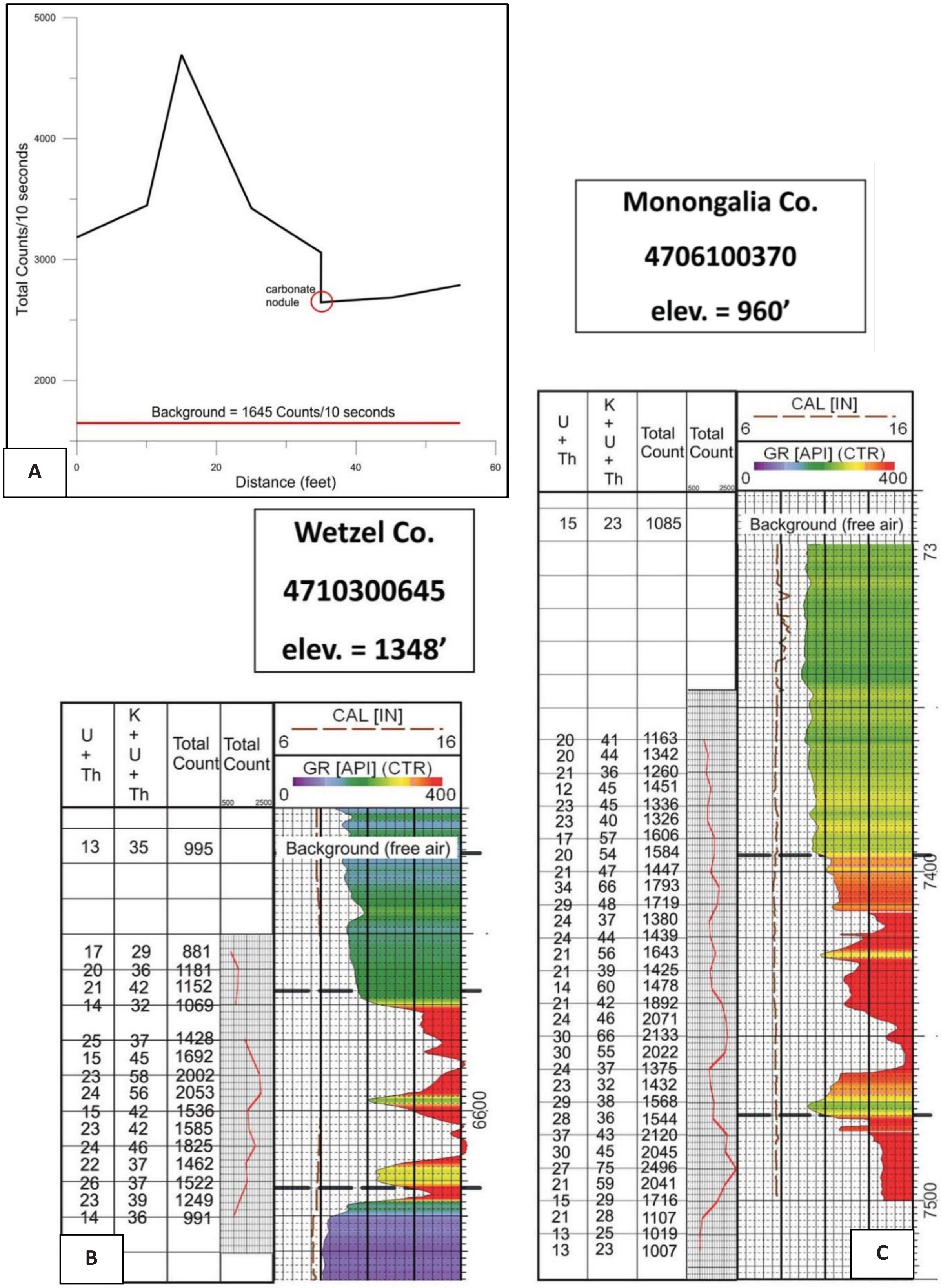

Figure 35. Radioactivity in the Marcellus
A) Ground traverse with handheld Geiger counter at Stop 4. One high-radioactivity "spike" was detected but not directly correlable to those shown on the geophysical logs in B) and C). Geophysical and Geiger counter log for B) Wetzel County well 645 and C) Monongalia County Well 370

Mahantango Formation (Middle Devonian)

Named for the North Branch of Mahantango Creek in Snyder County., Pennsylvania by Bradford (1935), the Mahantango Formation is dark gray siltstone and shale, often heavily limonitized with numerous brachiopods in some beds. Other marine fossils, sometimes including corals may be present. Contacts with the overlying Harrell Shale and the underlying Marcellus Shale are interfingering. The West Virginia Department of Highways sometimes uses the Mahantango for road material, and has several small quarries in the unit, including one along US 48 between Stops 3 and 4.

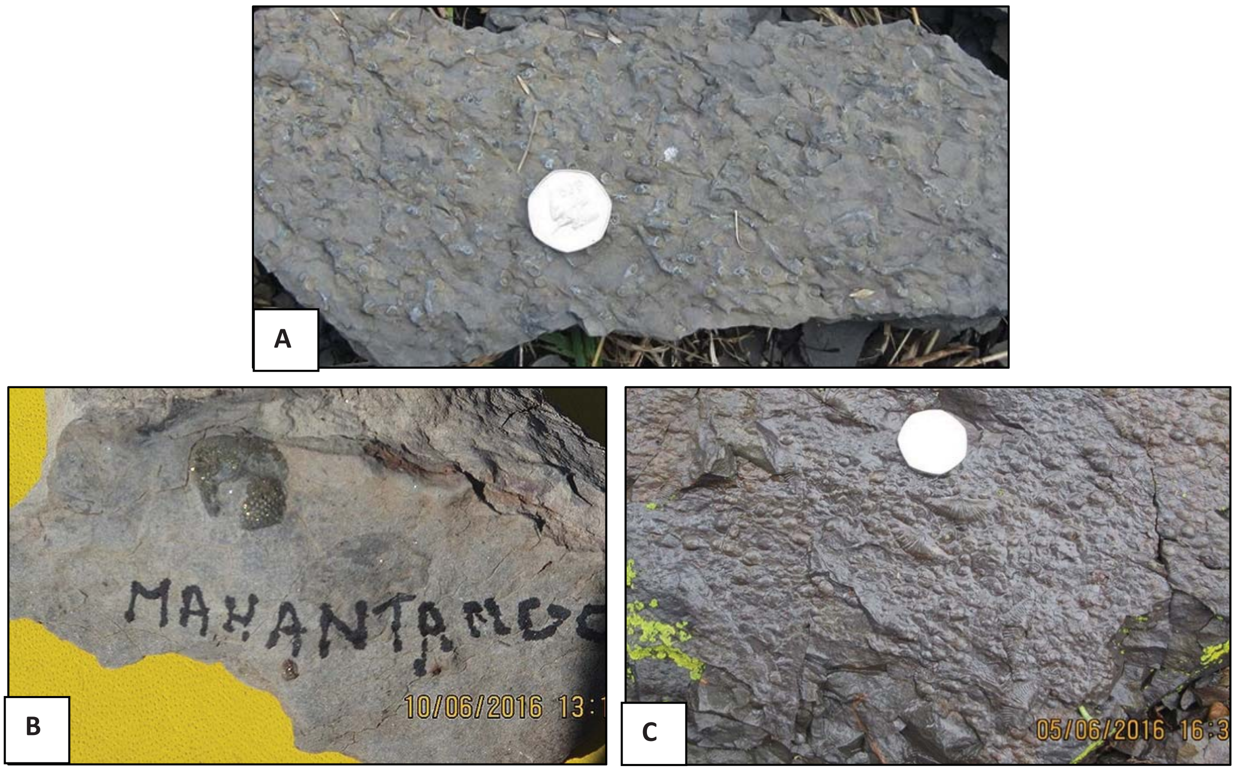

Figure 36. Fossils in the Mahantango Formation

A) Unidentified tabulate coral in the Mahantango and other full-size fossils signal a return to normal marine conditions with this unit. Coin is 3 cm in diameter.

B) Pyritized eye structure of an unidentified phacopsid trilobite from the Mahantango.

C) Spiriferid brachiopods typical of the Mahantango Formation and indicative of "normal" marine conditions. Outcrop near Petersburg, WV. Coin is 3 cm in diameter.

Economic Importance

The Marcellus gas play extends from New York to Kentucky and includes West Virginia, Pennsylvania, and Ohio. At the end of 2015, the Energy Information Agency (EIA) (2017) estimated the productive Marcellus footprint to be about 72,000 square miles, with estimated gas reserves of 77.2 trillion cubic feet (Tcf), and estimated oil reserves of 143 million barrels (MMbbls), making it one of the largest natural gas plays in the country. As of September 10, 2017, over 3,000 wells had been completed in the Marcellus in the state of West Virginia alone (WVGES, 2017), and approximately 2,000 of those wells are horizontal. To say the Marcellus has been a game changer for the natural gas industry in West Virginia is an understatement.

Discussion Topics

Contact with Mahantango is interfingering here. Marcellus goes away (into Mahantango) and then shows up again farther east. Is it the nature of the contact? Or is this is a repeated section/fault here??

Weathered versus fresh Marcellus (need to dig out fresh) appear very different.

Marcellus has calcareous concretions here, other places actual limestone layers.

Marcellus as a gas play

Tiny fauna in Marcellus and normal fauna in Mahantango.

At this stop we see no fossils in the Marcellus. That is unusual, as we usually see a few.

Discuss Harrell and when to use "Millboro" using Dennison's definition.

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Stop 4.5 (Day 1): Tonoloway and Helderberg Folds, Roll By
Leaders: Jaime Toro and Ron McDowell (NAD83 Lat 39.14, Lon -79.03)

Figure 37. Folds in the Tonoloway and Helderberg along US 48

Description

Please see Stop 3.5 for a discussion of the Tonoloway Formation and Stop 5 for detailed stratigraphy and depositional environments for the Helderberg Group. The latitude and longitude location for Stop 4.5 is in the Helderberg (Figure 37), but these folds begin in the Tonoloway Formation and extend almost to the Helderberg at the truck stop at Stop 5.

This stop is a series of well-exposed anticlines and synclines with wavelengths of a few hundred meters at this stop. Notice that the folds are slightly asymmetrical with steep eastern limbs and more gently-dipping western limbs. Also, the folds can be approximated by a series of straight limbs separated by narrow curved hinge zones. These features indicate that these folds are good examples of the classic “fold bend” and “fault propagation” models of fold development in stratified rocks. These folds are minor structures superimposed on the regional Broadtop Anticline. A nice, interactive 3D model of a similar set of folds in the Tonoloway Limestone, made by Dr. Ryan Shackleton, is available at: https://sketchfab.com/models/29f4574b2afe43bea86edbb2f44c8886.

Additional Resources

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Shackleton, Ryan, 3D model of carbonate folds along US 48: https://sketchfab.com/models/29f4574b2afe43bea86edbb2f44c8886.

Stop 5 (Day 1): Helderberg Group (complete) and Oriskany Contact at Truck Stop (NAD83 Lat 39.13, Lon -79.03)

Leaders: Ron McDowell, Jaime Toro, Phil Dinterman, Mitch Blake, and Paula Hunt

Figure 38. The Helderberg Group outcrop at Stop 5

Brief Description

This stop is an almost-complete section of the calcareous Helderberg Group (Figure 38). From the fault, karst features (tufa filling cavities), and tension gashes observed in the Keyser Formation near the unit's base at the west end (beginning) of the truck stop to the Helderberg's upper contact with the Oriskany Sandstone in the east, past the end of the truck stop. The predominantly calcareous Helderberg is divided into four formations at Stop 5 (Figure 39). These units contain a variety of marine fauna, chert and flint nodules, indications of stress, and many other interesting features. The arenaceous Oriskany Formation, with its characteristic large spirifer brachiopods, overlies the Helderberg Group. Contact with the underlying Tonoloway Formation is concealed.

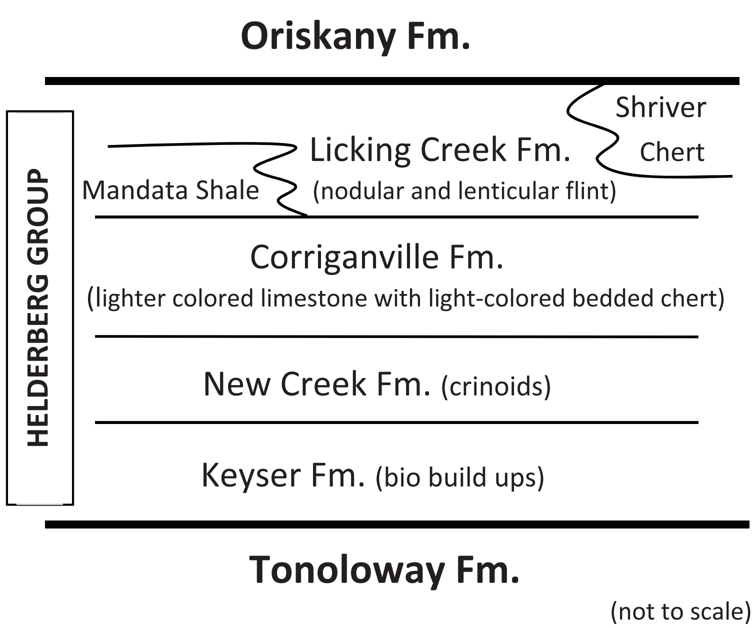


Figure 39. Formations in the Helderberg Group at Stop 5 (with major characteristics)

Setting

Paleogeography

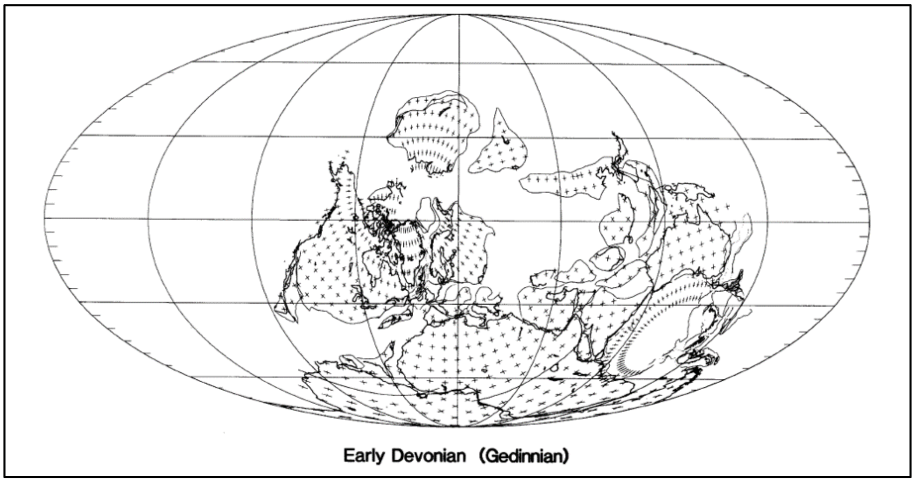


Figure 40. Paleogeography of the Early Devonian

Figure 41. Location of West Virginia in the Late Silurian (420 Ma) (left) and Early Devonian (400 Ma) (right)

Depositional Environment and Tectonic Setting

Rocks of the Helderberg Group are carbonate shelf deposits formed during the calm between the Taconic Orogeny and the Acadian Orogeny (Figure 6). The bioherms and algal buildups of the basal Keyser Formation appear to have been smothered by the crinoidal grainstones of the overlying New Creek Formation.

Unit Descriptions

In this region the lowest portion of the Helderberg Group is Silurian: the Keyser Formation straddles the Silurian-Devonian boundary (Denkler and Harris, 1988a,b; Harris et al., 1994). Named for deposits forming the basal portion of the Helderberg Mountains in Albany County, New York by Conrad (1839), the mostly Devonian Helderberg Group has been subdivided many times over the years by many authors working in various locations within the Appalachian Basin. The formations seen at this stop, from oldest to youngest are the Keyser, New Creek, Corriganville, and Licking Creek (Figure 39).

The Keyser Formation is the basal formation in the Helderberg Group. It is a coarse-grained limestone comprised of grainstone and packstone containing normal marine fauna including rugose corals (Figure 42) and brachiopods, in addition to algal mounds and stromatoporoids. The New Creek Formation (formerly Coeymans Limestone) overlies the Keyser and is a gray, relatively thick-bedded coarse-grained, crinoidal grainstone. The Corriganville Limestone (formerly New Scotland Limestone) overlies the New Creek. It is a brachiopod packstone and wackestone with light gray to gray bedded chert that weathers very light gray to white. The Mandata Shale (where present), overlies the Corriganville Formation. It is a fossiliferous black shale, relatively limited in areal extent and the authors have not observed it at this location (maybe the participants can prove the authors wrong!). Here at Stop 5, where the Mandata Shale is not observed, the Licking Creek Formation (formerly Becraft Limestone) overlies the Corriganville Formation and is the uppermost formation in the Helderberg Group. This gray, medium-grained limestone contains nodules and lenses of dark gray to black chert (flint), and where more flint than limestone is present, the unit is called Shriver Chert (Figure 39).

The contact of the Licking Creek Formation (top of the Helderberg Group) with the overlying Oriskany Formation is exposed just past (east of) the Truck Stop on the main highway (Figure 45 Right). Because the outcrop at Stop 5 is so long, participants will view the contact from the bus and see it up close at Stop 6.

The Oriskany is about 75 feet (23 m) thick at this location. To find the contact, look for chert/flint nodules in limestone (Licking Creek of the Helderberg) below the gray, calcite-cemented fine-grained sandstone of the Oriskany. The contact between the Helderberg and overlying Oriskany appears to be conformable, perhaps even gradational; however, unconformities are known to exist above and below the Oriskany in this region (Meglen and Noger, 1996). Participants and trip leaders will discuss this in more detail at Stop 6.

Structure

This outcrop exposes the gently-dipping eastern limb of the Wills Mountain anticline. At the western end of the outcrop there is a sharp syncline in the footwall of a minor east-vergent, bedding-parallel thrust. The core of the syncline is cut by numerous sub-horizontal veins. On the outcrop, one can observe inclined pressure solution cleavages above the fault plane that demonstrate top-to-the-east simple shear. Cleavage is also found in shaley beds between thin limestone layers. The cleavage fabric dips east more steeply than the bedding, also demonstrating top-to-the east sense of shear. Steep veins are confined to specific, more brittle, beds and bedding-plane veins of two types. Some of the bedding-parallel veins accommodated the differential motion caused by the steep veins, while others are along through-going bedding-parallel slip planes, or small shear zones. Locally, there are examples of hydrothermal breccias up to 20 cm thick also along bedding planes. These are filled with calcite and siderite cements. The veins accommodate extensional deformation of the limestone during folding. Notice the slikenlines on vein faces which suggest that a significant portion of the motion is out of the plane of the outcrop.

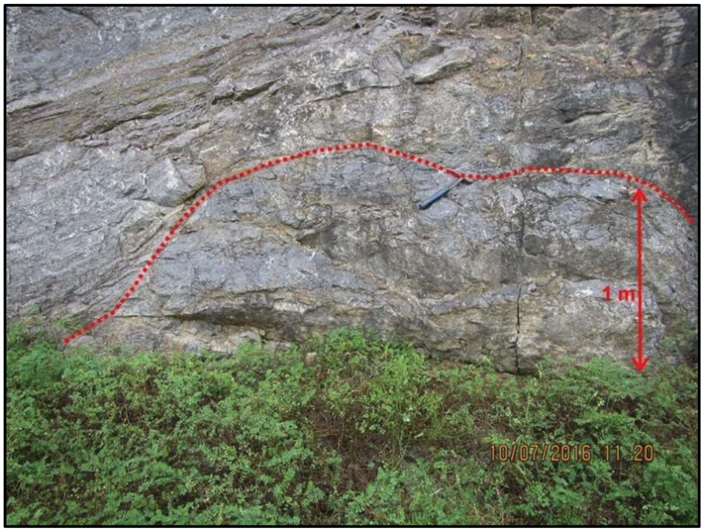
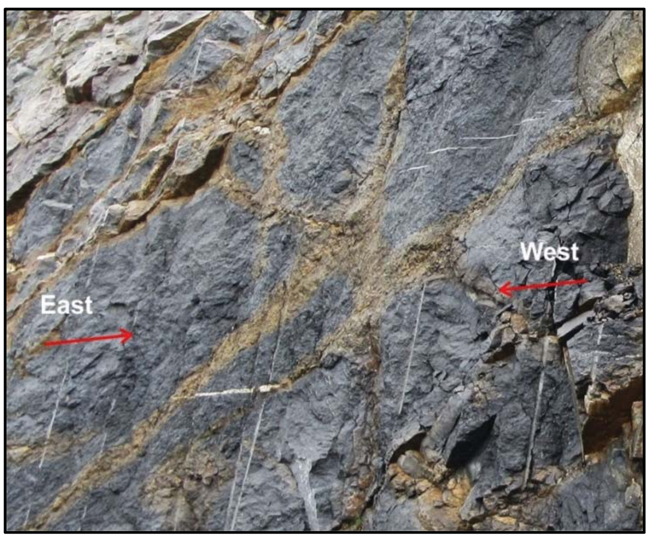


Figure 42. Features of the Keyser Formation
A) Small mud mound in the basal portion of the Helderberg Group (Keyser Formation) overlain by "encrinites" (echinoderm packstone-grainstone). B) "Encrinites" (echinoderm packstone-grainstone) at the contact between the Keyser and New Creek formations and well-defined stylolites are present, marked by dark layer of clay and organic material caught by the pressure-solution process.



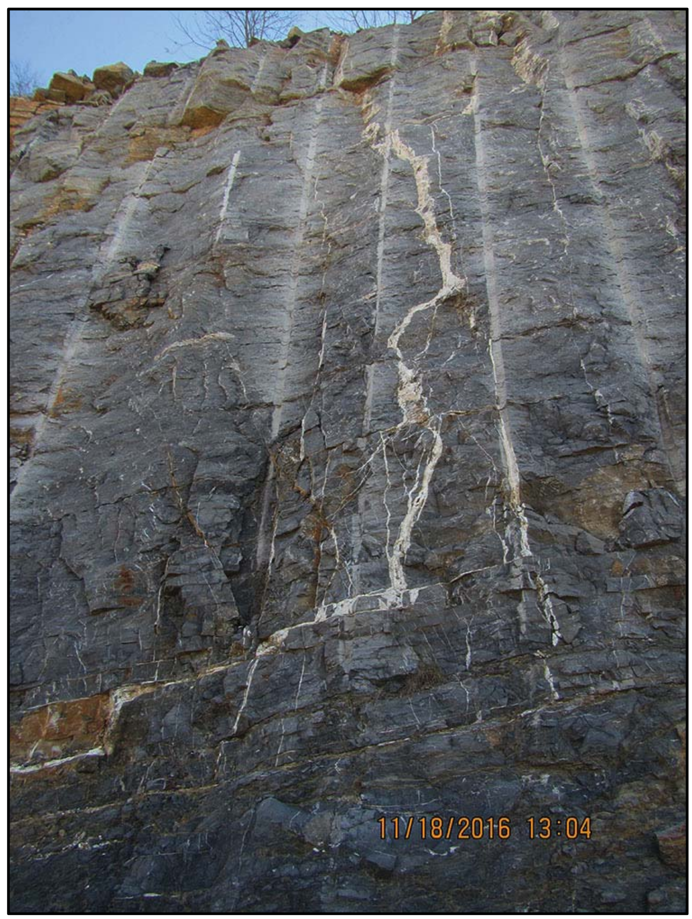


Figure 43. Fracturing in the Helderberg Group.
A) Calcite-filled, *en-echelon* fractures in the Helderberg produced by east-west compression.
B) Complex fracture system in the Helderberg healed with calcite.

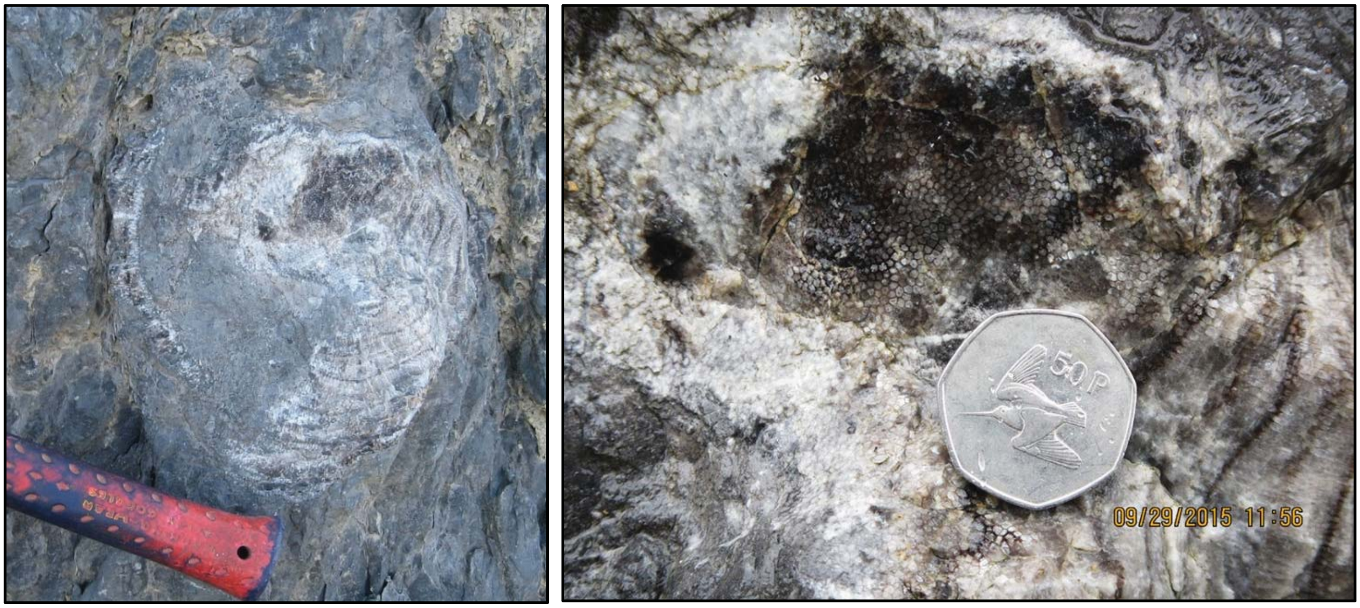


Figure 44. Fossils at Stop 5
A) Stromatoporoid in the Keyser Formation, Helderberg Group. B) Unidentified tabulate coral head in the Helderberg, partially silicified by black flint. Coin is 3 cm in diameter.

Figure 45. Contacts at Stop 5
Left: Crinoid-bearing New Creek Formation overlying Keyser Formation, Helderberg Group.
Right: Contact between the Helderberg Group and the overlying Oriskany Formation

Economic Importance

Baez et al. (2004) report the New Creek Formation contains small gas reserves. Overall, the Helderberg has little primary porosity. Secondary porosity exists but many fractures are filled with calcite. Some units give off a petroleum odor; other have H_2S. It is unlikely to be a source rock, but some of the chert/flint beds may form traps. The economic importance of the Oriskany Sandstone is discussed in the next stop, Stop 6.

Questions for this Stop

Is the Helderberg contact with the Oriskany gradational? Or not?? While we will only see the contact from the bus at stop 5, participants will be able to view the Helderberg-Oriskany contact up close at Stop 6. The contact between the Helderberg and the Oriskany appears to be gradational, or at least conformable, but an unconformity supposedly exists between the two units.

Are we looking at a conformable contact or a calcareous facies of the Oriskany? We will view the contact up close at Stop 6.

Additional Resources

http://gigapan.com/gigapans/173674

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Stop 6 (Day 1): Helderberg, Oriskany, and Needmore formations
(NAD83 Lat 39.12, Lon -78.98)
Leaders: Ron McDowell, Jaime Toro, Phil Dinterman, Mitch Blake, and Paula Hunt

Stop 6 features three exposed contacts within the units of the Early to Middle Devonian – the Needmore Shale, Oriskany Sandstone, and Helderberg Limestone; the last of these is located in the core of a small anticline. At this stop, the contact between the Needmore and the underlying Oriskany appears to be interfingering if one considers the shale below the highest sandstone to be part of the Needmore. In counties farther south in West Virginia the authors have noted that volcanic ashfalls associated with the Devonian Tioga eruptive event(s) occur between the Needmore and underlying Marcellus (Millboro) and within the Millboro (Marcellus) farther south. As one goes to the south, these ash beds appear to be the source of silica for the Huntersville Chert.

Setting

Paleogeography

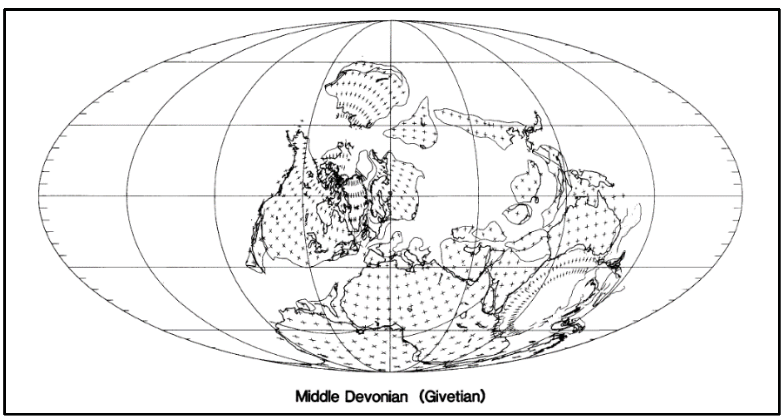

Figure 46. Stop 6 paleogeography and Middle Devonia reconstructions (385 Ma) from Scotese and McKerrow (1990), left and Blakey (2007), right

Depositional Environment and Tectonic Environment

The Helderberg Group (see Stop 5) overall is a thick carbonate shelf deposit overlain by the Oriskany Formation, a shallow marine sandstone. A regional unconformity supposedly exists above and below the Oriskany (Meglen and Noger, 1996) thought to be caused by global sea level change (Dennison and Head, 1975). Some authors attribute the Oriskany to the start of the Acadian Orogeny, and others place it just before the onset of clastics from the Acadian Orogeny. This would make the Needmore Formation the first pulse of clastics from the Acadian Orogeny to the east along with the deepening of the foreland basin, continuing into the Middle Devonian when the Marcellus was deposited in even deeper water.

Unit Descriptions

Helderberg Group (Late Silurian to Early Devonian)

See Stop 5 for an introduction to and discussion of the Helderberg.

Oriskany Formation (Early Devonian)

Named by Vanuxem (1839) for an exposure at Oriskany Falls, New York, Schuchert (1903) later refined the unit definition. The unit called the Oriskany Sandstone or Oriskany Formation in West Virginia is termed the Ridgeley Sandstone or Ridgeley Formation in Pennsylvania and Maryland. Named for an outcrop near Ridgeley in Mineral County, West Virginia by Swartz et al. (1913), the unit, along with the Shriver Chert, was considered part of the Oriskany Group. The current authors consider the Shriver to be part of the Helderberg Group and the Oriskany to be a separate formation. The Shriver is not observed at Stop 5, but is present southwest of this location. At this stop the Oriskany Sandstone is gray, weathering tan to brown, well-sorted, fine- to medium-grained quartz arenite. At stops 5 and 6 it is cemented with calcite, but may be silica cemented, or less commonly, limonite cemented. It is friable where poorly cemented, deeply weathered, or faulted. Some beds are highly fossiliferous, containing lags of marine fossils, mostly articulate brachiopods and crinoid columnals. Bed of large speriferids are characteristic of the Oriskany. Crossbedding is present in some beds, and some beds are conglomeratic.

Contact with the overlying Needmore Formation appears to be interfingering over a stratigraphic interval of approximately 1 foot (30 cm), but is supposed to be unconformable (Willard and Cleaves, 1939). Contact with the underlying Licking Creek Formation of the Helderberg Group could be considered gradational or sharp, depending on the criteria used to define the contact (see Discussion Topics near the end of Stop 5).

Needmore Shale (Early to Middle Devonian)

Named by Willard and Cleaves (1939) for exposures near Needmore, Pennsylvania, the Needmore Shale is comprised of a medium gray calcareous shale that weather in chips and often contains calcareous nodules and sometimes argillaceous limestone. The Needmore contains marine body fossils in some beds and the branching feeding trace fossil *Chondrites* (Figure 47). In early publications, geologists at WVGES considered this unit to be part of the Marcellus until Woodward (1943) defined the Onondaga Group as the Needmore Shale, Huntersville Chert, and Onondaga (Columbus) Limestone, the last only seen in the subsurface.

In some locations and in outcrop farther south in West Virginia, the Needmore has been chemically altered and replaced in part or completely by the Huntersville Chert, named by Price (1929) for exposure in nearby Huntersville, West Virginia, where the two units interfinger laterally. The Huntersville is exposed for approximately 120 miles (36 km) along the Browns Mountain Anticlinorium, extending from Green Bank to White Sulphur Springs, West Virginia (Rehn, 1942 a and 1942b). Described as “a rock unit for which it is difficult to find a precisely descriptive lithologic term, and to which the name, chert is only partly appropriate. Mostly it is a highly silicified black shale which contains many beds that have been brecciated and recemented with amorphous silica” (Woodward, 1943 p. 256-257). Because the Huntersville, where present, appears to be a chemostratigraphic unit that overprints or replaces

Devonian units including the upper Oriskany, Needmore, and lower Marcellus (Millboro), and whose development was dependent on diagenetic alteration of existing stratigraphic units, its formation may be younger than middle Devonian and locally and regionally diachronous.

The trace fossil *Chondrites* sp., observed in the Needmore at Stop 6 (Figure 47A), varies in size, number, and complexity, but generally resemble the branching roots of a plant. Because the tubular branches of this ichnofossil are typically backfilled with phosphatic organic matter and clay that are much lighter than the darker gray shales, they are easy to recognize and are a characteristic of the Needmore.

Contact with the underlying Marcellus appears to be sharp where the Tioga Ash is present between the formations, but is often concealed and difficult to determine where the Tioga Ash is not present, as the Needmore and the Marcellus are both dark shales. Contact with the overlying Oriskany is theoretically sharp due to an unconformity, but here at Stop 6, interbedded shale and sandstone are observed at the contact, indicating it is interfingering.

Tioga Ash beds

Ebright, Fettke, and Ingham (1949) named the Tioga Bentonite for the Tioga gas field in Pennsylvania. Roen and Hosterman (1982) renamed it Tioga Ash due to the unit's mineral content. The age of these beds and the potential locations of their volcanic source were discussed in detail by Parrish (2013). The Tioga Ash is a light gray to yellow to chocolate brown shale or clay and is possibly the source of silica for chert formation in the Huntersville (Dennison, 1961). However, Haught (1956), and Cecil (2004) believed the source of silica was from wind-blown sediments. One of the current authors (R.R. McDowell, personal communication) agrees with Dennison (1961) on the source of silica for the chert formation. The Tioga is a zone of multiple ash beds in some areas. Farther south in Pocahontas County, it is observed as multiple ash beds in the Millboro (Marcellus). North of Pocahontas County, in Pendleton County, West Virginia, (south of Stop 5 and north of Stops 8, 9, and 10) it is found between the Needmore and the overlying Marcellus.

Here at Stop 5 it may appear within the Needmore Formation as a yellowish layer (Figure 47C). However, one author says the layer cannot be an ash because it cuts across bedding, and so the linear yellow feature must be related to a fracture. Field trip participants can decide for themselves.

Economic Importance

Roen and Walker (1996) divided the Oriskany into four separate gas plays: the fractured Middle Devonian Huntersville Chert and Lower Devonian Oriskany Sandstone Play (Flaherty, 1996), Lower Devonian Oriskany Sandstone Structural Play (Harper and Patchen, 1996), the Lower Devonian Oriskany Sandstone Combination Traps Play (Patchen and Harper, 1996) and the Lower Devonian Oriskany Sandstone Updip Permeability Pinchout (Opritza, 1996). The Oriskany can serve as an oil and gas reservoir where it is not well cemented, where calcite cement has dissolved, or where fossils have been removed (biomoldic pores). Where the Oriskany is folded and faulted, structural traps and secondary porosity from jointing make the unit a good reservoir rock. In some parts of West Virginia, the Oriskany is used for gas storage.

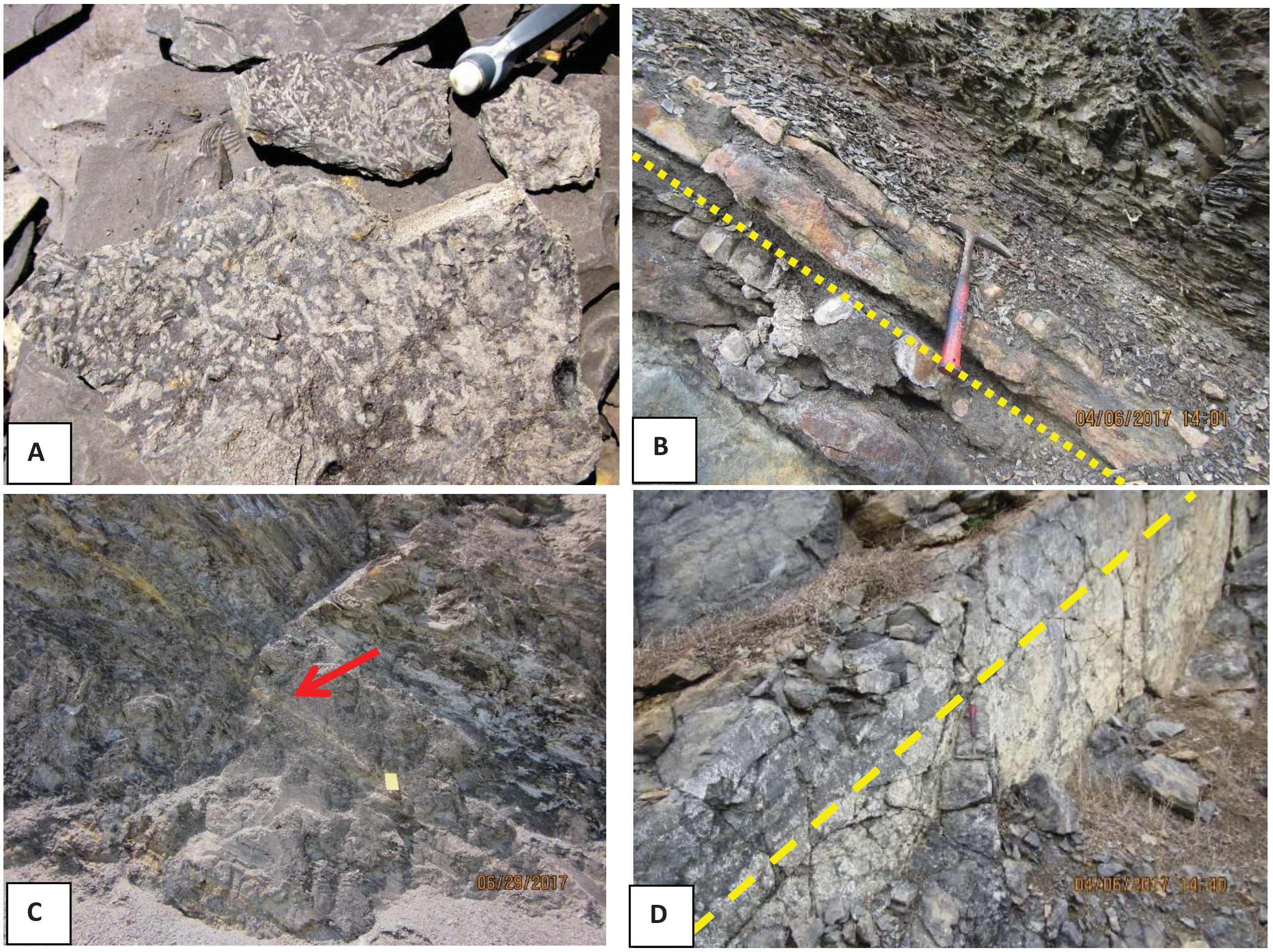

Figure 47. Features of interest at Stop 6
A) The trace fossil *Chondrites* sp. found in concentrated layers throughout the Needmore and is an easy-to-identify marker for the unit. B) Interfingering(?) contact between the Needmore and the underlying Oriskany. C) The pale orange layer visible in the center of the photo may be one of the volcanic ash falls associated with Devonian Tioga volcanism, although one author disagrees (yellow field notebook is 15 cm long). D) Contact between the Helderberg Group below and the Oriskany Formation above.

Features of Interest and Discussion Topics

Here we actually see two contacts when we usually see none in the field.

The Oriskany/Needmore contact, which the authors seldom see in the field, appears to be interbedded, or is it? (Note shale layer beneath sandstone at contact.)

Many *Chondrites* are here in the Needmore, but on the very eastern end of the outcrop on the south side of the highway.

Ash layer in Needmore? We often see ash layers in the Marcellus (but not along US 48/Corridor H – so far). Discuss the Tioga was not a single event.

Discuss the nature of the Helderberg/Oriskany contact, and follow up from the Truck Stop discussion. Is it sharp? Is it gradational? Below contact zone is cobble-sized, rubblized flint.

The other side of road may be better for some features. If you walk across the road, there are more-obvious flint nodules, so there is more Helderberg at this stop than originally thought.

Discuss the Onondaga; show it in core.

Discuss the Huntersville/Needmore/Onondaga? Not really a facies for the chert/flint, more of an overprint onto the Needmore.

Here we see vugs in the Oriskany. We are used to seeing brachiopod molds not vugs, and farther south we are used to seeing limonite-stained (buff to orange) silica-cemented Oriskany with little to no calcite, not the gray fine-grained calcite-cemented sandstone we see here. Discuss facies.

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Stop 6.5 (Roll by) (Day 1) Hampshire Structure

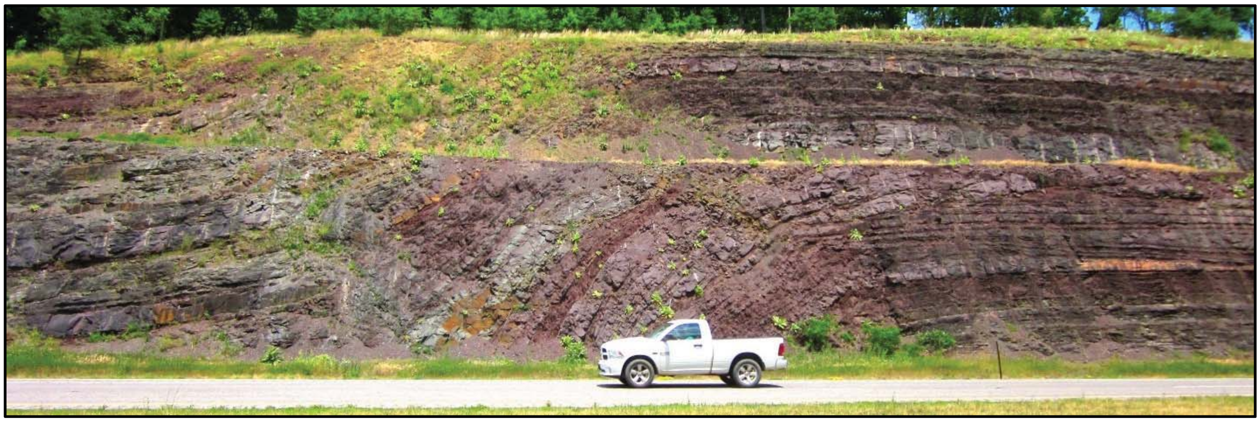

Figure 48. Structure in the Hampshire Formation at Stop 6.5

Brief Description

See Stop 3 for a detailed discussion of the Hampshire Formation. Stop 6.5 shows the Late Devonian Hampshire Formation as the authors are used to seeing it – a thick red-bed sequence with numerous interbedded sandstone and mudstones. Well-developed and well-preserved cross-bedding is probably the most recognizable feature of Hampshire sandstone (Figure 49A). The Hampshire was deposited as siliciclastic sediments eroded from the Acadian mountains to the east and shed westward in a complex of alluvial and fluvial depositional settings. Fossils in the Hampshire are few and generally restricted to plant fossils and trace fossils (Figure 49C). Unfortunately, neither of these have been found by the authors at this Stop. Nicely preserved desiccation cracks seen at this stop are the best evidence of shallow-water to exposed terrestrial conditions. Soils (paleosols) are another terrestrial feature frequently seen in the Hampshire.

This stop has nicely exposed west-vergent fold in the red beds of the Hampshire Formation in a sympathetic fold in the Whip Cove West Anticline (Figure 50). The fold has a short and steep forelimb and a broad and gentle back limb. This geometry is typical of thrust-cored folds, although the hypothetical fault is not exposed at this outcrop. There is a small, gently-dipping normal fault in the west limb. This type of secondary faults develop to accommodate stretching of the steep limb during folding. There are also small channels visible in the redbeds along the top of the fold.

Figure 49. Features of the Hampshire Formation.
A) Epsilon and tabular cross-bedding in the Hampshire Fm. south of Stop 6.5 in Pocahontas County, West Virginia. B) Desiccation cracks on the underside of a Hampshire sandstone bed at Stop 6.5. C) Insect larva trace fossil *Treptichnus* sp. at the top of the sample – Corridor H, near Baker, WV. Coin is 3 cm in diameter.

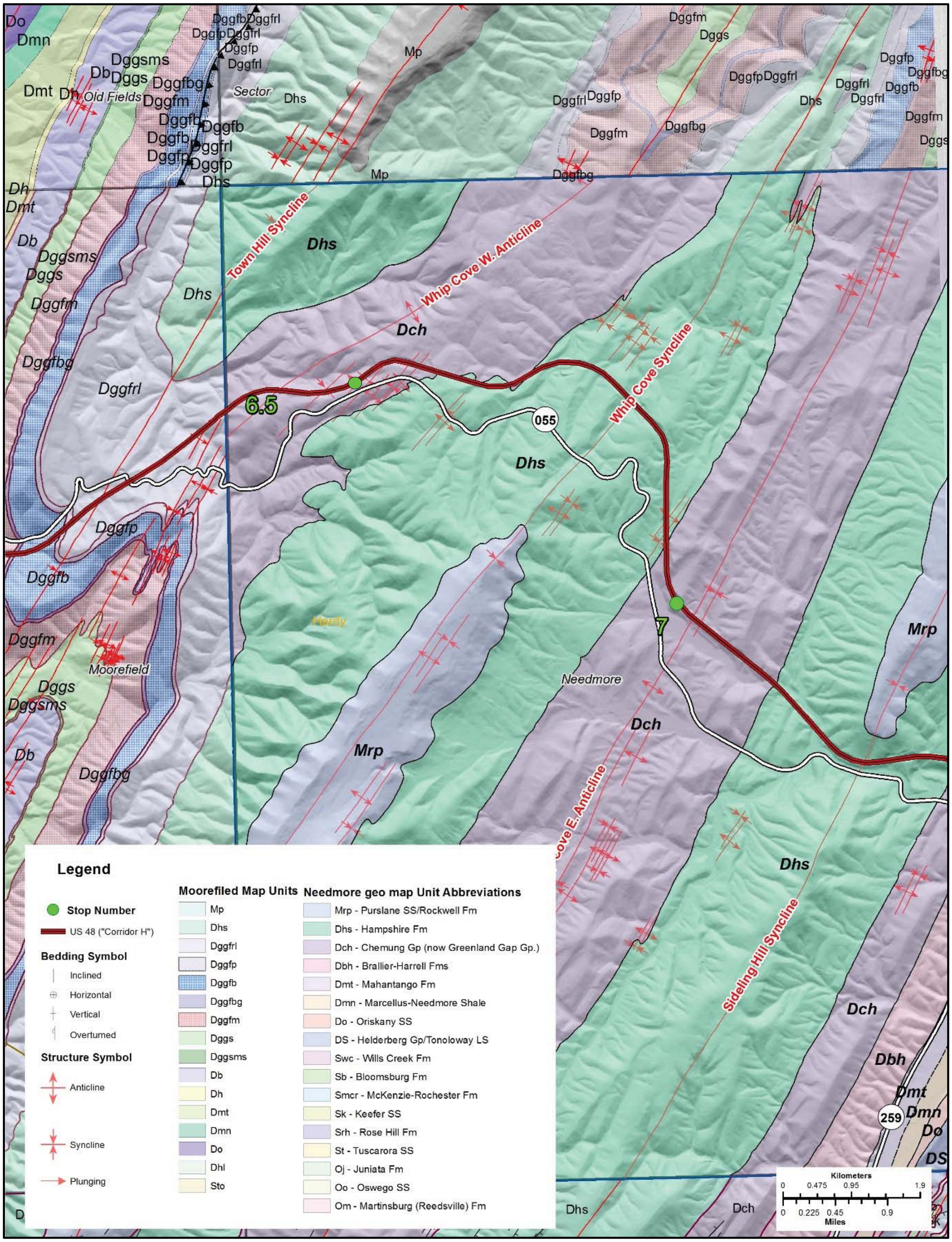

Figure 50. Geologic Map for Stops 6.5 and 7 (geology from Dean et al., 1992)

Stop 7 (Day 1): Whip Cove Anticline, Greenland Gap Group (Foreknobs Fm.)
(NAD83 Lat 39.07, Lon -78.80)
Leaders: Ron McDowell, Jaime Toro, Phil Dinterman, Mitch Blake, and Paula Hunt

Figure 51. The Foreknobs Formation in a sympathetic fold of the the Whip Cove East Anticline (west is to the left)

Brief Description

Stop 7 features a small fold in the Whip Cove East Anticline (Figure 51). This compressional structure is steep on the west side and gentler to the east. Its asymmetry may also indicate displacement of the entire structure to the west in association with a thrust fault. The Late Devonian Foreknobs Formation is exposed here. The diverse sedimentary features that typify the Foreknobs elsewhere are not observed here, potentially due to the limited stratigraphic thickness. In most general terms, the Foreknobs is divisible into an upper and lower sandy unit and a middle shaley unit. Dennison (1970), McGhee and Dennison (1976), and McGhee (1977) formally divided the Foreknobs into five members (Figure 53). At present, it is unclear to the authors the exact stratigraphic position of the exposed shale, siltstone, and sandstone beds at Stop 7 due to the absence of paleontological evidence. Additional investigation is needed at this stop.

Setting

Paleogeography

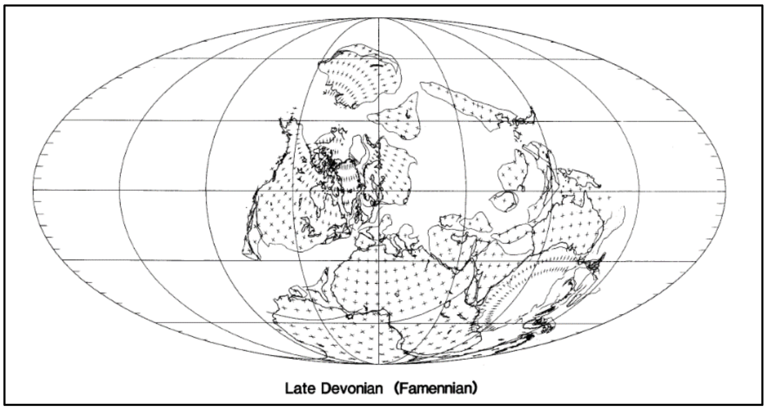

Figure 52. Paleogegraphy at Stop 7 and reconstruction from the Late Devonian (360 Ma) from Scotese and McKerrow (1990), left and Blakey (2007), right

Depositional Environment and Tectonic History

Transitions from "normal" marine to exposed terrestrial paleoenvironmental conditions complete with indications of sea ice are all recorded in the Foreknobs. The numerous sandstone intervals in the Foreknobs retained porosity and permeability as the unit prograded west into deeper marine waters.

These sediments are part of the Catskill Clastic Wedge, a sequence that began at the onset of the Acadian Orogeny during the Middle Devonian and continued through the end of the Devonian.

Unit Description

The Greenland Gap Group was formerly known as the Chemung Group until New York, the original type-section location, officially abandoned the name Chemung. Denison (1970) renamed this group and described a new type section near Greenland Gap in Grant County, West Virginia (near Stop 3). The Greenland Gap Group consists of the Scherr Formation overlain by the Foreknobs Formation. It should be noted that rocks of the Greenland Gap Group do not crop out in the geographic feature known as Greenland Gap (located near Stop 3 on this trip, Figure 17).

Dennison (1970) named the Foreknobs Formation after a series of peaks located along the Allegheny Front called the Fore Knobs. The formation is divided into five members. In depositional order they are the Mallow, Briery Gap, Blizzard, Pound Sandstone, and Red Lick (McGhee and Dennison, 1976). The

Foreknobs Formation is a coarsening-upward assemblage of interbedded sandstones, siltstones, shales, and mudstones. Sandstones are predominantly quartz, well-sorted, subangular, very fine to fine-grained, micaceous, greenish-brown to brown, and hard. They weather tan to orange-brown and commonly are iron-and-manganese-stained, sometimes exhibiting "boxworks." Some members of the Foreknobs are reddish-brown siltstones that may be thinly bedded (2 cm thick) totaling 3 meters in thickness. Shales and mudstones are olive green to tan, sometimes gray, and sometimes weather into chips. Sandstones vary in thickness from several centimeters to a few meters, and more massive beds may exhibit what appears to be spheroidal weathering, but is termed anastomosing cleavage by Powell (1979). Thinner sandstone beds may break into right angles with sharp edges. Some sandstone beds contain conglomeratic lag zones, foreset and tabular crossbedding, and ripple marks. As a unit, the Foreknobs Formation is relatively fossiliferous. Marine body fossils, mostly articulate brachiopods and crinoid stems, are abundant in some sandstone beds and are observed as individuals, in small groups, and in lags. Wood imprints are also observed. Other beds are relatively unfossiliferous, hindering exact stratigraphic placement of this exposure of Foreknobs. Trace fossils including *Arenicolites* sp., along with other feeding traces and tool marks are common. The trace fossil *Pteridichnites* sp. may be observed, but such occurrences are relatively rare, especially compared to the underlying Brallier Formation.

Contact with the underlying Brallier Formation is gradational, and for mapping purposes is placed at the base of coarser siltstones or sandstones beds containing marine body fossils. Contact with the overlying Hampshire Formation is gradational, interfingering over tens of meters, and for mapping purposes is placed at the top of coarser siltstones or sandstones beds containing body fossils. Some members of the Foreknobs exhibit a reddish color and tabular crossbedding, and may be mistaken for the overlying Hampshire Formation. These reddish Foreknobs beds and the interfingering contact with the reddish, tabular-bedded Hampshire Formation sometimes make placing the contact difficult. The Hampshire does not typically contain marine fossils or body fossils in this part of West Virginia whereas the Foreknobs does.

The Foreknobs strata exposed at Stop 7 exhibit only a hint of the sedimentary features seen elsewhere in West Virginia.

Economic Importance

Stratigraphic equivalents to the Foreknobs in the subsurface of western West Virginia include (from youngest to oldest) the gas-bearing Warren, Speechley, Balltown, Bradford, Riley, Benson, and Alexander sands (Figure 2). These units have been drilled extensively in some areas and these vertical wells produce for relatively long periods of time.

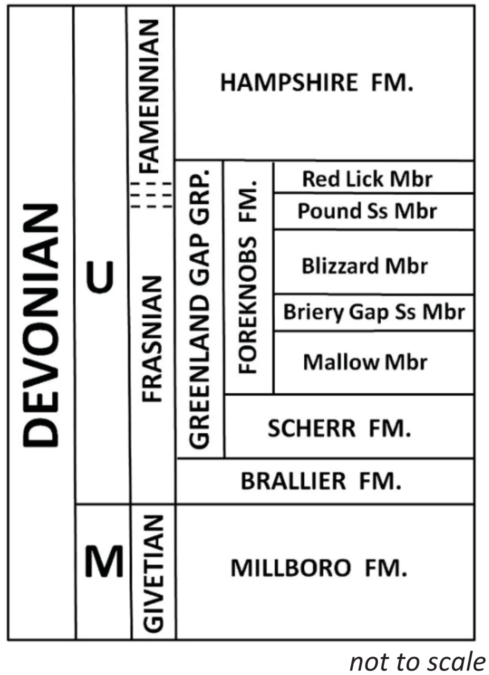

Figure 53. Divisions of the Greenland Gap Group and Foreknobs Formation within the stratigraphy of the Catskill Clastic Wedge, from McClung et al. (2013) based on Dennison (1970), McGhee and Dennison (1976), and McGhee (1977).

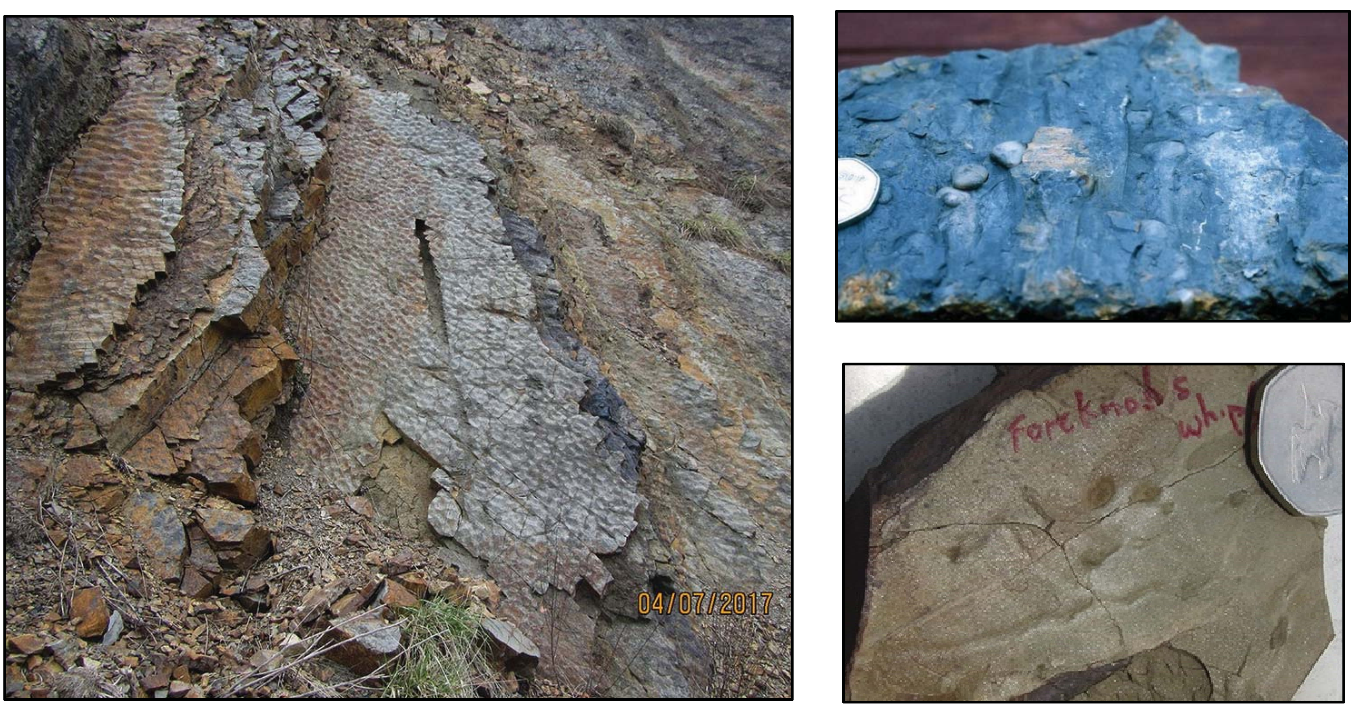

Figure 54. Features in the Foreknobs Formation
Left: Interference and sinuous-crested symmetrical ripples on exposed bedding surfaces in the Foreknobs east of Stop 7. Top right: Rounded and flattened quartz pebbles have been forcefully slid along the muddy seafloor leaving elongated tracks – possibly by floating ice in the Late Devonian sea. Bottom right: Solitary trace fossil *Cochlichnus* sp. found at Stop 7. Coin is 3 cm in diameter.

Figure 55. Fossils of the Foreknobs Formation
From left to right: large spiriferid brachiopod impression south of Stop 7 in Pocahontas County, limonitized wood impressions from Pocahontas County (coin is 3 cm in diameter), and rare crinoid columnals recovered from Stop 7.

Points of Interest and Discussion Topics

Point out ripples on the way to this stop.

Sequence stratigraphy (see McClung et al., 2013)

We only see a very few trace fossils here, when we usually see beds of trace and body fossils in other locations. We have not studied this outcrop enough to determine which part of the Foreknobs we are in here.

Facies: northern outcrops seem to have more sandstone and southern outcrops have more shale.

The sand packages are tight here at the outcrop, but in the subsurface they have porosity and permeability, so perhaps having gas in the pores precluded cementation (?).

Some of the shales at this stop are darker than we are used to seeing.
Farther west (subsurface?) where there are interbedded shales and sandstones, the shales can trap gas in the sandstones.

Is the Foreknobs turbidites? Water depth discussion; evidence of ice contact while deposited. Some places have mudcracks and some places have paleosols.

Some places have large amounts of wood debris that is almost "coalified."

Can pin down the times if brachiopods are found. Glass sponges found near Elkins.

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FIELD-TRIP STOPS DAY 2

Stop 8 (Day 2): **Oswego, Juniata, Tuscarora along US 33**
Leader: Ron McDowell (NAD83 Lat 38.71, Lon -79.41)

Brief Description

This road cut along US 33 exposes the Late Ordovician Oswego, Latest Ordovician Juniata, and Early Silurian Tuscarora sandstones. The pulloff across the road from the outcrop may be too small for the bus, so this "stop" may become a slow "roll by." The Tuscarora Formation is discussed in more detail in the section for Stop 10, Seneca Rocks.

Setting

Paleogeography

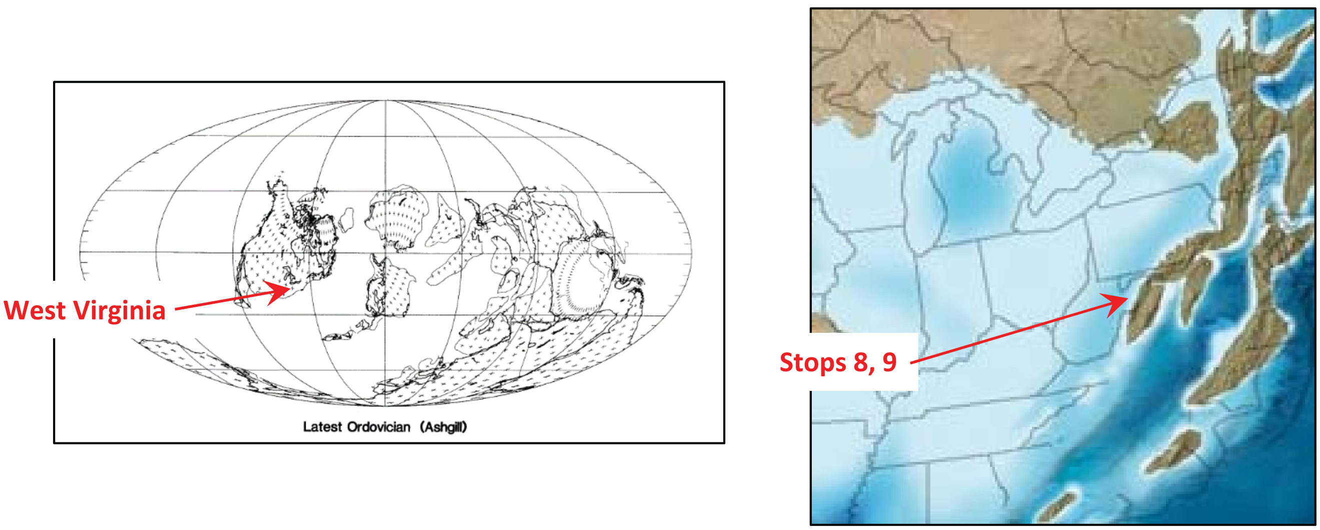

Figure 56. Paleogeography for Stop 8 and reconstruction for the Upper Ordovician (450 Ma) from Scotese and McKerrow (1990), left and Blakey (2007), right

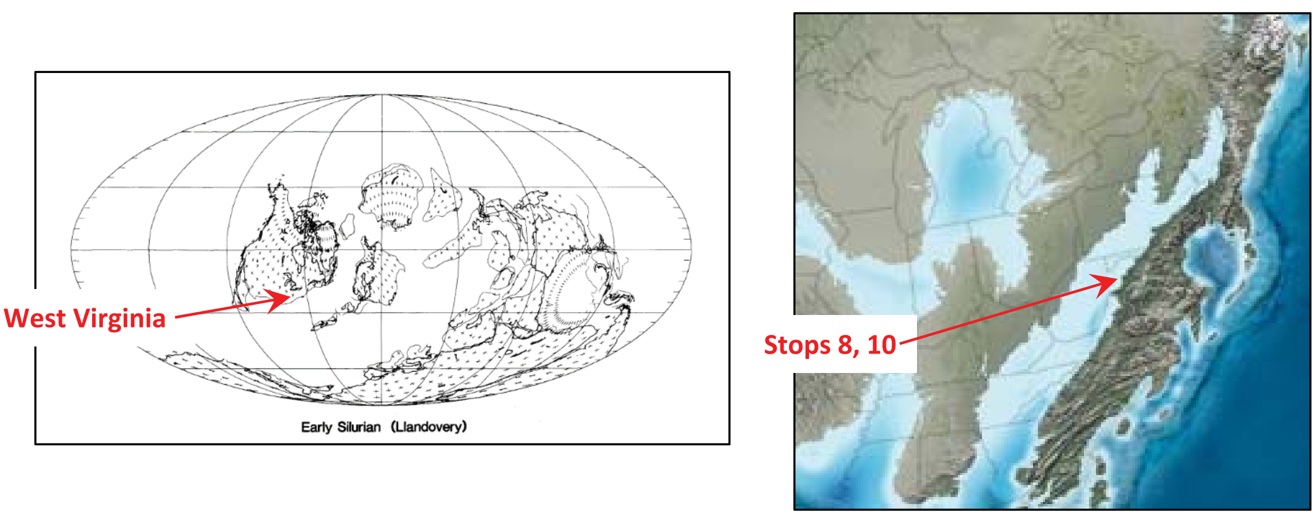

Figure 57. Paleogeography for Stop 8 and reconstruction for the Early Silurian 430 Ma from Scotese and McKerrow (1990), left and Blakely (2007), right

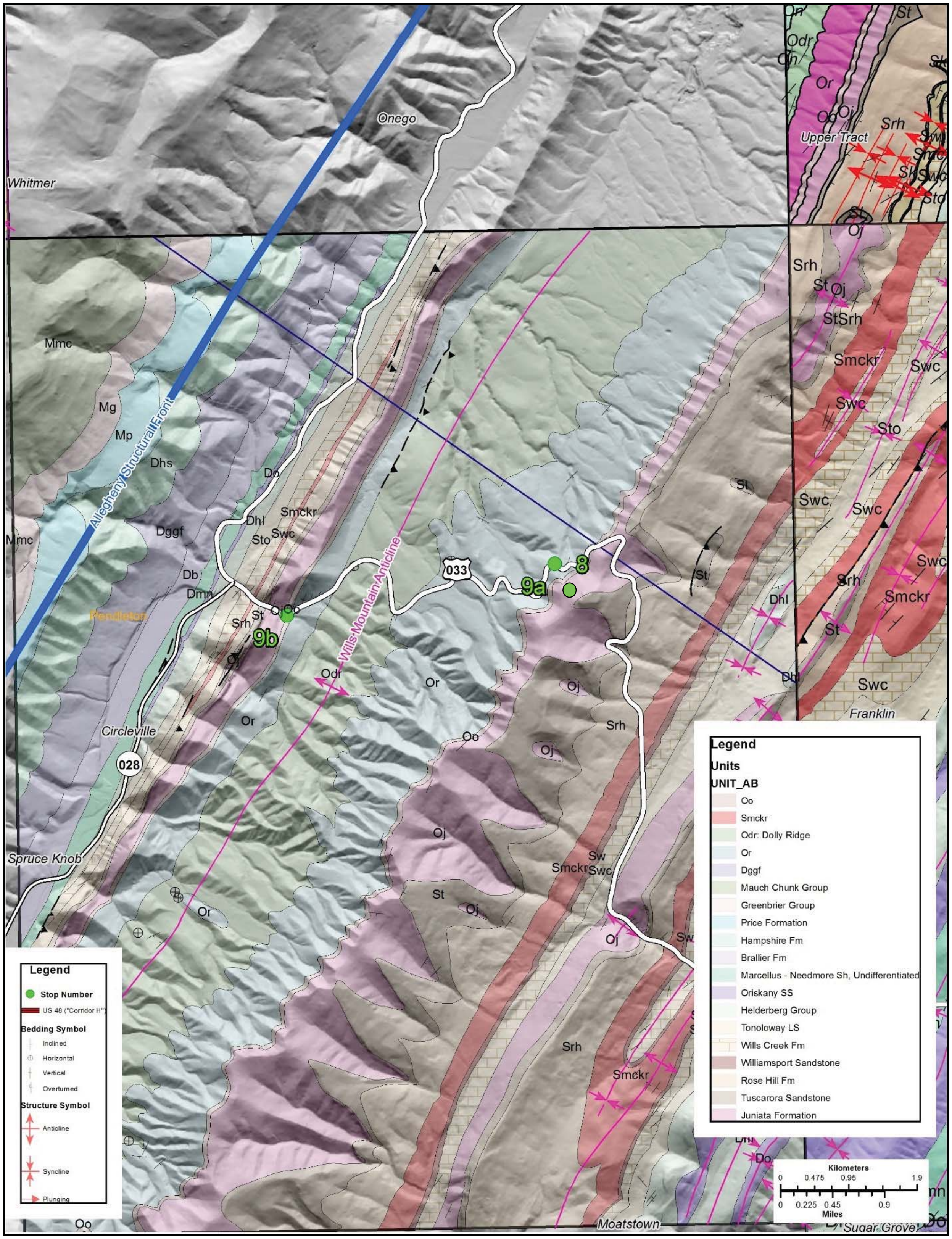

Figure 58. Geologic Map for Stops 8, 9a, and 9b (geology from McDowell et al., 2002)

Depositional and Tectonic Environment

The Taconic Orogeny continued into the Late Ordovician as uplift of the Taconic Highlands continued east of this location. The igneous and metamorphic rocks of the Taconic Highlands eroded and became the source of sediments for the Taconic clastic wedge, including the Oswego Sandstone and Juniata Formation. During the Early Silurian, mountain building to the east had ceased and erosion of the Taconic Highland continued, resulting in the very clean sands of the Tuscarora Formation.

Unit Descriptions

Oswego Sandstone

A lenticular, thin-bedded, gray-green, fine-grained quartz sandstone observed between the underlying Reedsville Formation and the overlying Juniata Formation, the Late Ordovician Oswego Sandstone was named by Prosser in 1890 for Oswego County in New York. It is correlative with the Bald Eagle Sandstone in Pennsylvania. Contact with the red mudstones of the overlying Juniata Formation appears to be interfingering. Contact with the shales of the underlying Reedsville Formation is sharp at this location.

Juniata Formation

Interbedded sandstones, shales, and mudstones comprise the latest Ordovician Juniata Formation. Formerly called the Red Medina and attributed to the Silurian System in the WVGES County Geologic Report (Tilton et al., 1927), Woodward (1941 and 1943) began using the name Juniata, after Darton and Taft (1896), and re-assigned the age of the formation to the Upper Ordovician. The formation had been classified as Ordovician in Virginia some years earlier by Bassler (1908). Originally thought to be nonmarine in origin and containing terrestrial trace fossils (Retallack, 2001), a more recent interpretation of a Juniata outcrop in Pennsylvania suggests that at least a portion of the formation is marginal marine (Davies and others, 2010). The Juniata is pink to grayish-red, hard, fine-grained quartz sandstone, sometimes interbedded with thinly bedded pinkish siltstone that appears shaley when weathered. Some exposures are brick red. Sandstones and siltstones of the Juniata have a reddish or pinkish streak. Beds may also be prominently jointed and sandstones are sometimes crossbedded. Trace fossils, including the vertical *Arenicolites* and the horizontal *Cruziana*, *Rusophycus*, and *Phycodes* are found in the Juniata. The formation lacks body fossils, except for *Lingula* reported in basal siltstone beds in some places (Diecchio, 1985). The upper contact with the overlying Tuscarora Formation appears to be gradational based on color and lithologic changes. The pinkish, flaggy sandstones of the Juniata become whiter near the top of this formation, and the typically white, massive sandstones of the Tuscarora become slightly pink at the base of that formation.

Tuscarora Formation

Please see Stop 10 for a detailed description of the Tuscarora Sandstone.

Economic Importance

Please see Stop 10 for a discussion of the Tuscarora play.

Features of Interest and Topics of Discussion

The contact between the Juniata and the overlying Tuscarora is exposed here.

The Oswego sandstone between the underlying Reedsville and the overlying Juniata is also exposed here.

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Stop 9a (Day 2): **Germany Valley Overlook, Wills Mountain Anticline and Reedsville Shale, US 33**
Leaders: Jaime Toro, Ron McDowell (NAD83 Lat 38.71, Lon -79.41)

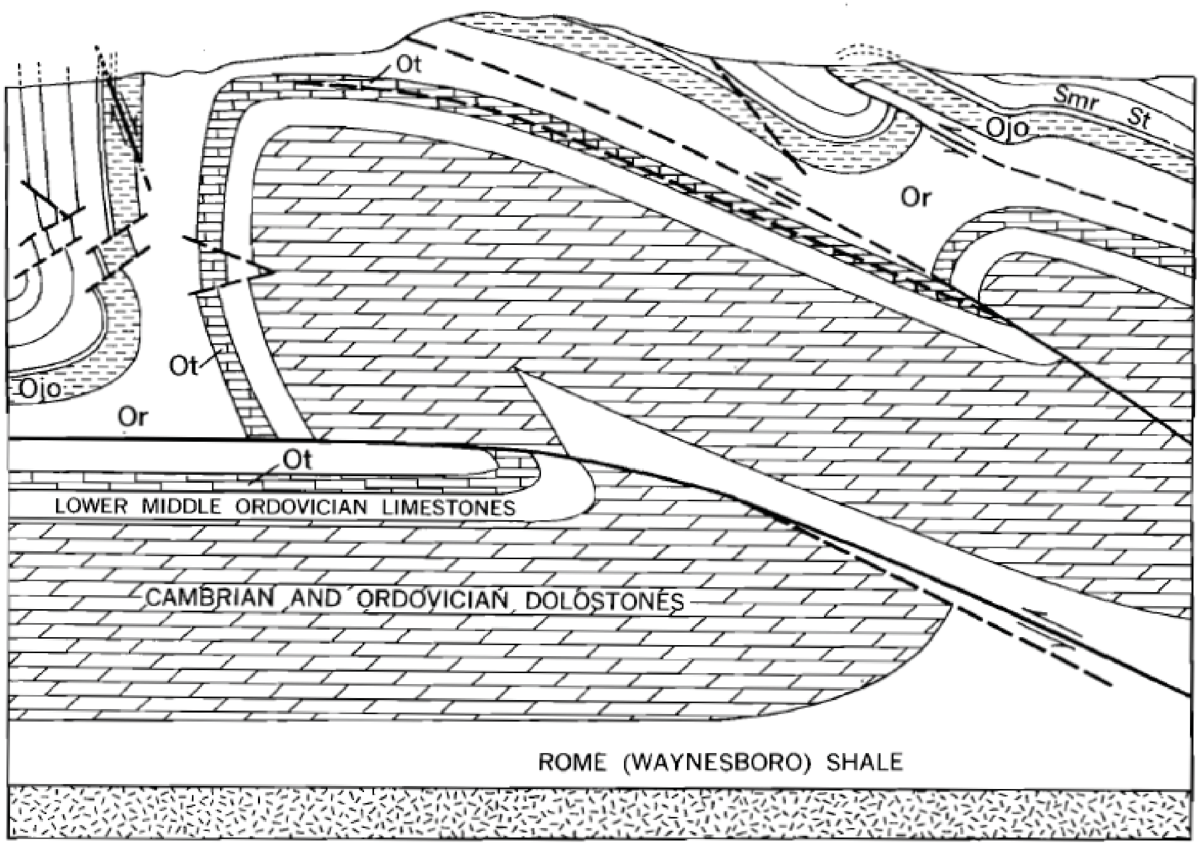

Figure 59. Schematic cross section of the Wills Mountain Anticline from Perry (1978)

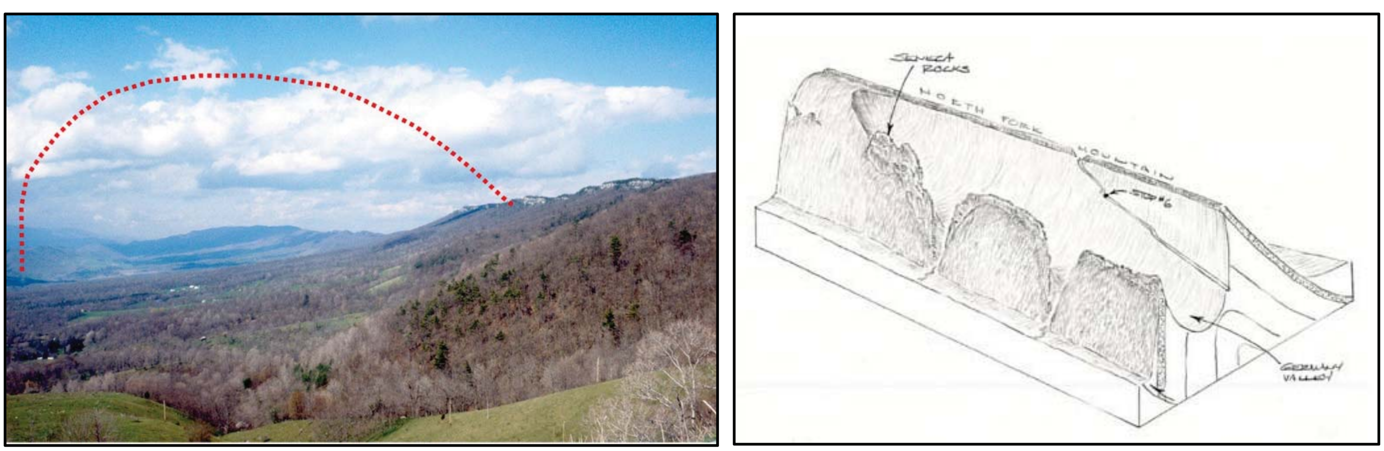

Figure 60. Germany Valley, and Wills Mountain Anticline, and Seneca Rocks
Left: View looking north into Germany Valley (Stop 9a) with dashed line by connecting Tuscarora outcrops across the Valley approximately reconstructing the Wills Mountain Anticline Right: Generalized perspective view of the Wills Mountain anticline, Germany Valley, and Seneca Rocks (Stop 10) (from Renton, undated).

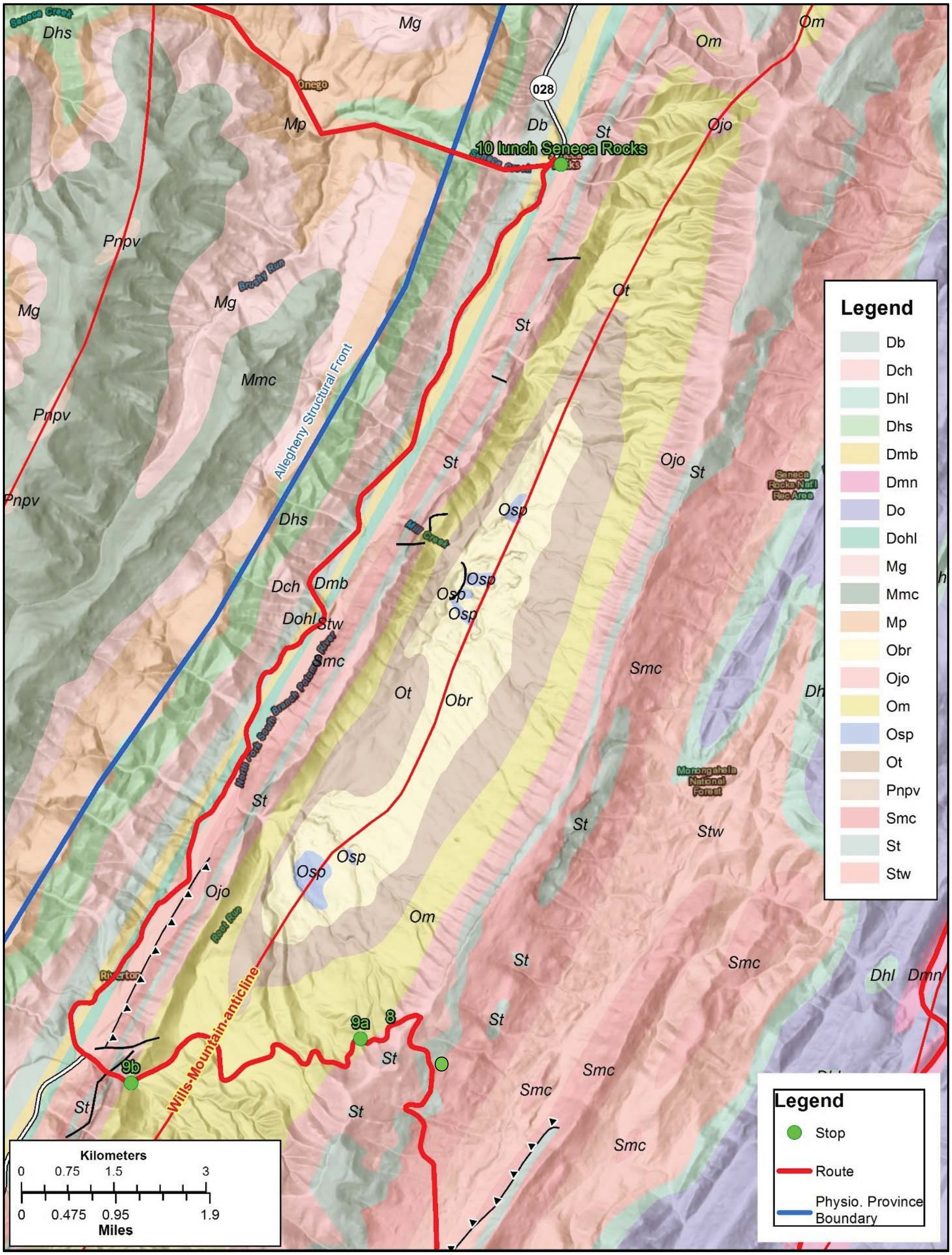

Figure 61. Geologic Map of Germany Valley (geology from Cardwell et al., 1968)

Brief Description

Stop 9a is at the Germany Valley scenic overlook. On one side is a picturesque valley formed by the complex Wills Mountain Anticline (Figure 59 and Figure 60), the westernmost major thrust-cored anticline of the Central Appalachians. On the other side, across US 33, a road cut exposes the upper Reedsville Formation, which participants will see in more detail at Stop 9b

Depositional and Tectonic Environment

The coarsening upward of the Reedsville Formation is characteristic of a clastic wedge, and the change from deeper marine fauna to shallower marine fauna (marked the *Orthorhynchula* zone in the upper Reedsville) may be the result in sea-level change, dropping in response to glaciation in the Late Ordovician (Diecchio, 1985).

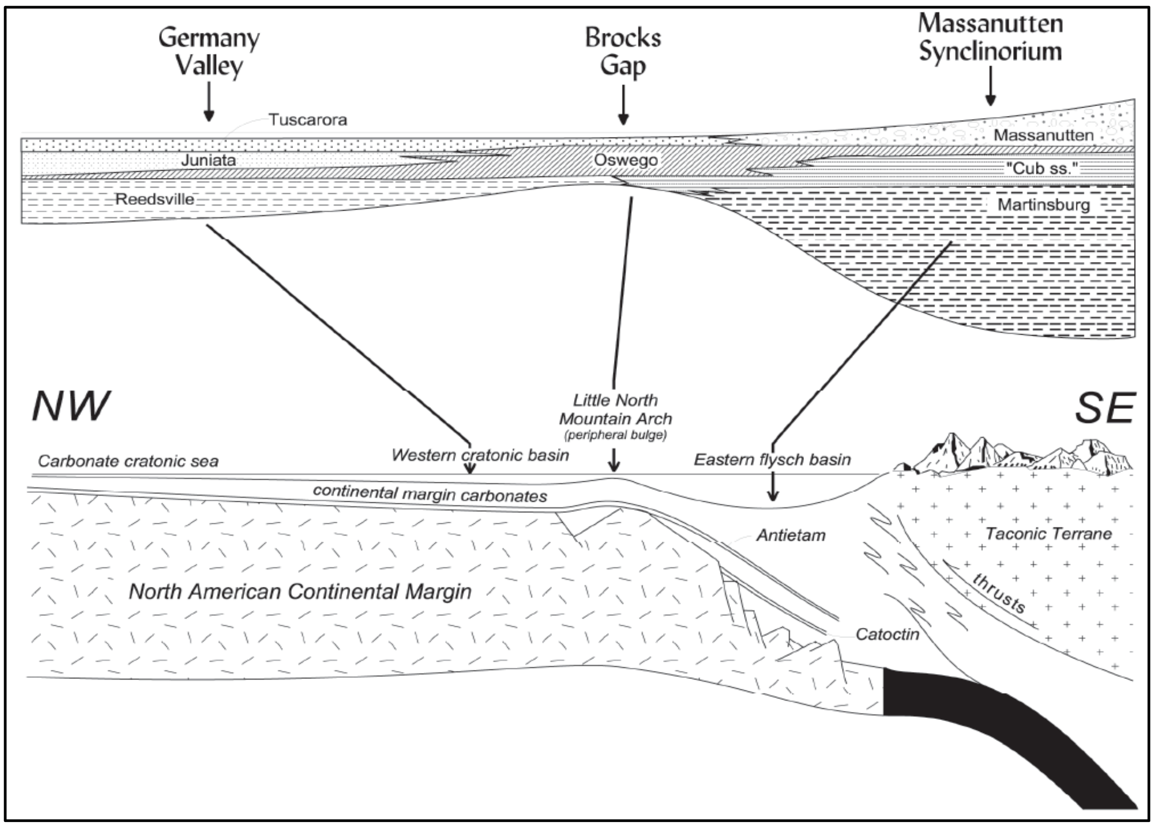

Figure 62. Stratigraphy and tectonics of Germany Valley
Top: stratigraphic cross section after Diecchio (1993) from Fichter et al. (2010). Bottom: tectonic cross sections for the Taconic sequences of Germany Valley, Little North Mountain (Brocks Gap), and the Massanutten Synclinorium from Fichter et al. (2010).

Perry (1978) mapped this area and studied the structure in detail. His research found that the Wills Mountain Anticline formed during a complex sequence of events. Small-scale folding and faulting of the initial unfolded Silurian units was followed by additional folding as the Wills Mountain Anticline grew, creating uplimb thrust faults. During this phase, the overturning of the western limb resulted in reverse faulting. The more brittle units (such as the Tuscarora Sandstone) sheared and thinned out, while less brittle units folded. Perry determined that the entire structure detached between Middle and Upper Ordovician shales and carbonates and moved to the west, and intervening shales and mudstones were intensely fractured during the process. The geometry of the Wills Mountain Anticline, with a steep to overturned forelimb and a gently dipping back limb, suggests that is a fault-propagation fold (Toro, 2013).

Points of Interest

Participants are able to get an aerial view of another portion of the Wills Mountain Anticline, first seen at Stop 2. The Reedsville Shale across the road is discussed in more detail in the next stop, Stop 9b.

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Stop 9b (Day 2): Old Reedsville Quarry, US 33
(NAD83 Lat 38.70, Lon -79.46)
Leaders: Ron McDowell, Jaime Toro, Phil Dinterman, and Mitch Blake

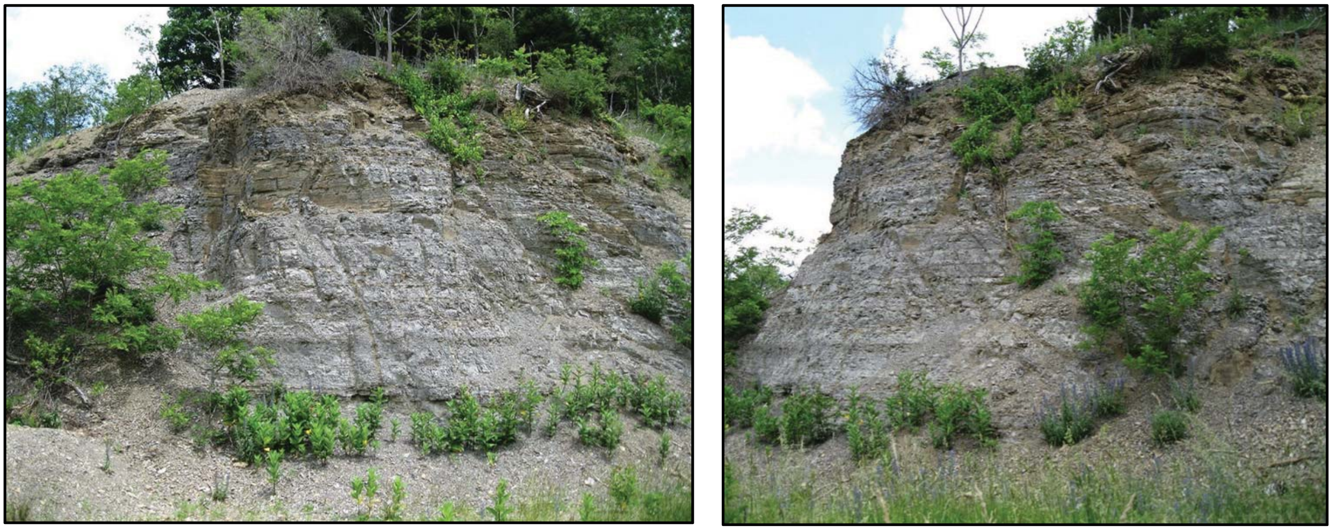

Figure 63. The shalier portion of the Reedsville as seen in an old quarry along US 33 near Judy Gap

Brief Description

This small quarry is in the upper middle portion of the Reedsville Formation. It has yielded (to a lucky few) bits and pieces of the Ordovician trilobite *Cryptolithus tesselatus*. Unfortunately, the fractured and splintered shale was quarried as fill material precisely because it breaks into small pieces.

Setting

Paleogeography

The location of West Virginia in the Latest Ordovician is shown in Figure 64 Left, and the location of the state with respect to the Taconic Mountains in the east is shown in (Figure 64).

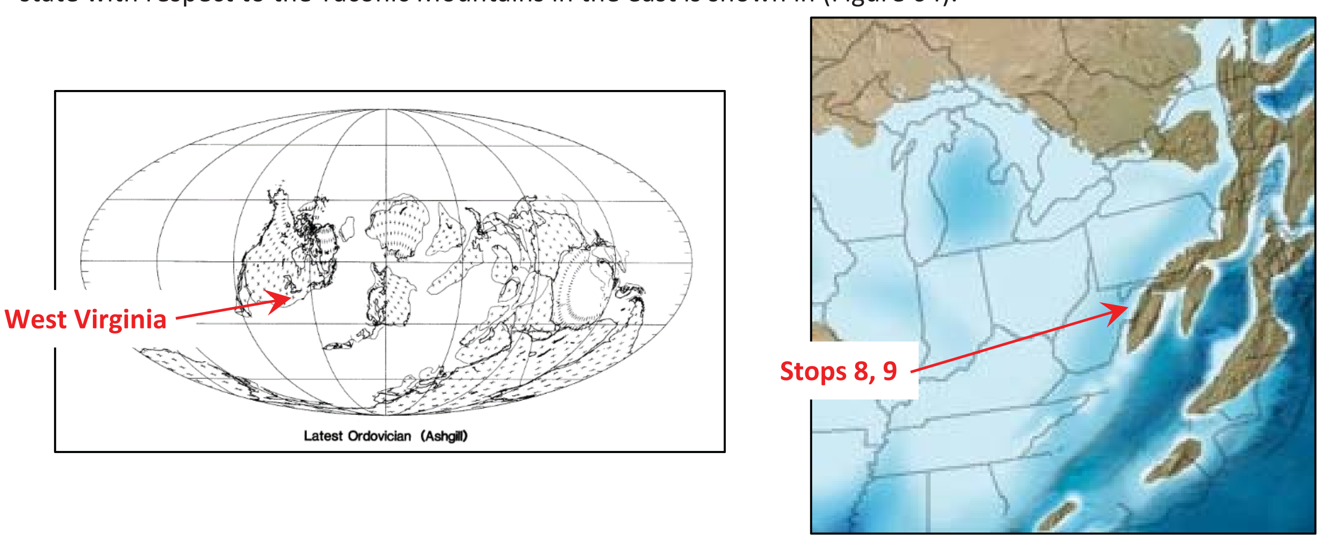

Figure 64. Latest Ordovician position of the continents and Upper Ordovician reconstruction (450 Ma) from Scotese and McKerrow (1990), left; Blakey (2007), right

Depositional and Tectonic Environment

During the Taconic Orogeny, clastic sediments eroded from highlands to the east (Figure 64 Right) were deposited over existing carbonates to the west, resulting in the turbidites of the Martinsburg Formation in the east and the mixed carbonates and clastics of the Reedsville Formation in the west (Figure 62 in Stop 9a and Figure 65 below).

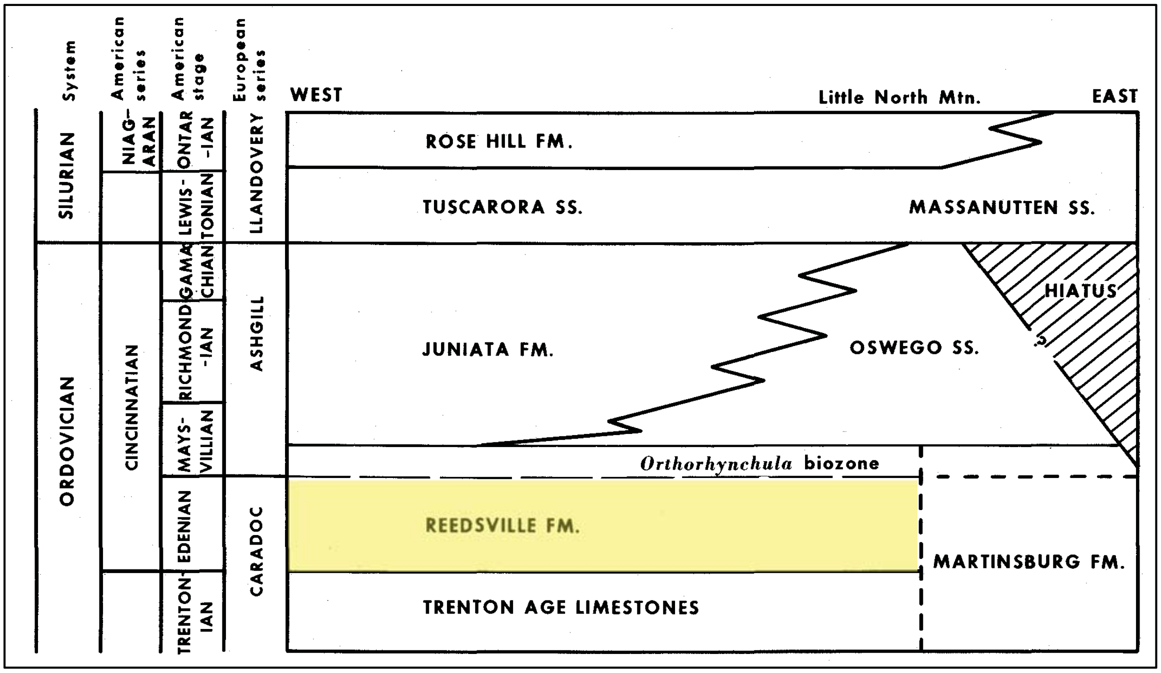

Figure 65. Correlation chart of upper Ordovician and lower Silurian strata near Stops 8, 9, and 10 from Diecchio (1985). Not to scale.

Unit Description

The Late Ordovician Reedsville Shale is named for the hamlet of Reedsville in Mifflin County, Pennsylvania (Ulrich, 1911). It overlies the Lower Trenton limestone and underlies the Oswego sandstone (Bald Eagle equivalent).

Geiger and Keith first named the Martinsburg Shale in 1891 while mapping in the Blue Ridge near Harper's Ferry, West Virginia. The Martinsburg Formation is comprised of gray to greenish gray, shale, siltstone and sandstone.

Because a recognizable Oswego Sandstone is present at Stop 9a and elsewhere in the Pendleton County, West Virginia area, and the *Orthorhynchula* fossil assemblage is also present, the name "Reedsville" is preferred by the authors for mapping and other stratigraphic purposes (Diecchio 1980, 1985).

Diecchio (1980, 1985) and McDowell et al. (2002) describe the lower Reedsville as medium gray to olive-gray interbedded calcareous shale and thinly bedded calcareous sandstone with interbeds of dark grey, crinoid-brachiopod packstone and tan, fossiliferous siltstone that weather to lighter gray. Fossils include a normal marine assemblage including brachiopods, graptolites, trilobites, cephalopods, gastropods, and crinoid columnals. The middle portion (Stop 9b, this trip) has less limestone and has some siltstones and thin to medium beds of fine-grained brown sandstone, still with normal marine fauna. The upper portion (Stop 9a, this trip) is bioturbated mudstone along with shale, siltstone, and sandstone interbeds. The *Orthorhynchula* biozone, an assemblage of shallow-water fauna described by Bretsky (1969, 1970), is present in this upper portion and is one of the characteristics of this unit west of Little North Mountain (Diecchio 1980, 1985). East of Little North Mountain, equivalent strata are more turbiditic, and the upper sandy beds do not contain *Orthorhynchula* fauna. Thus they are named Martinsburg (Diecchio, 1980, 1985). The outcrops in Germany Valley (Stops 8 and 9) are considered Reedsville, as they are located west of Little North Mountain and contain well-preserved inarticulate and articulate brachiopods of the *Orthorhynchula* biozone (McDowell et al., 2003). Contact with the overlying Oswego sandstone is sharp, with the contact considered to be the base of the lowest crossbedded sandstone above the *Orthorhynchula* zone (diecchio, 1985). Contact with the underlying Dolly Ridge is poorly exposed and appears to be gradational.

Economic Importance

It was once thought that the lower portion of the Reedsville Formation was equivalent to the upper Utica Shale, a significant gas play in in western Pennsylvania and eastern Ohio. However, in a major study on the Utica Shale Play, Patchen and Carter (2015) correlate the Reedsville Shale to the Kope Formation, stratigraphically located above the Utica Shale (Figure 66). Furthermore, Patchen and Carter (2015) found the Utica Shale "play is really neither 'Utica' nor 'shale,' … data all point to an interbedded limestone and organic-rich shale interval in the Point Pleasant Formation as the preferred drilling target…." Fifteen to 20 Utica-Point Pleasant wells have been completed in West Virginia and another 50 are permitted or in the permitting process. Though the majority of the play has been in Ohio, where the interval produces more liquids, dry gas volumes from wells in West Virginia have been extremely large.

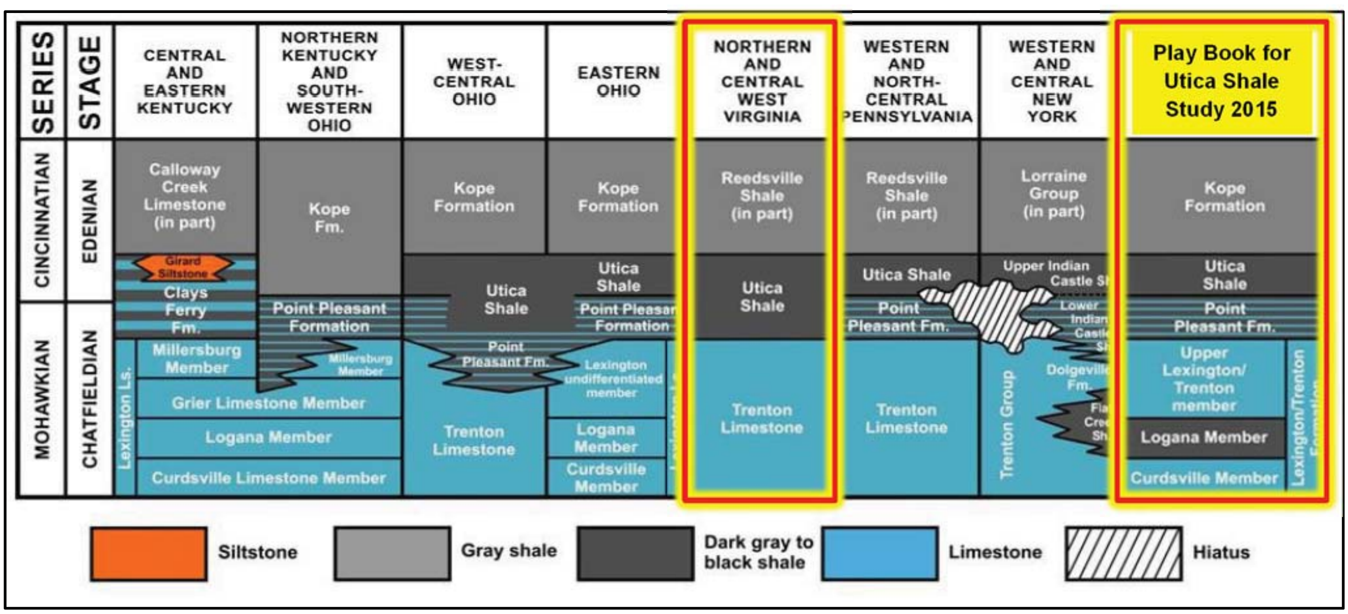

Figure 66. Correlation chart for early Late Ordovician units, modified from Utica Shale Play Book (Hickman et al, 2015)

Figure 67. ***Isotelus*** **sp. collected from the upper Reedsville at Stop 8 (Haynes et al. 2015), photo by R.C. Orndorf**

Items of Interest

The Reedsville contains numerous marine fossils, including crinoid columnals and brachiopods. Rarely, trilobite pieces are observed, and very rarely, entire trilobites may be found in this formation. The trilobite shown in Figure 67 was found in the Upper Reedsville between Stops 8 and 9a.

The authors believe the interbedded shale and carbonates appear to be turbidites because no indications of deep water, including no deep-water trace fossils, were observed at this stop.

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Stop 10 (Day 2): Seneca Rocks (Lunch)
(NAD83 Lat 38.84, Lon -79.37)
Leaders: Ron McDowell, Jaime Toro, Phil Dinterman, Mitch Blake, and Paula Hunt

Figure 68. Seneca Rocks as seen from the Visitors' Center

Brief Description

Stop 10 is a striking exposure of the Lower Silurian Tuscarora Sandstone at Seneca Rocks (Figure 68). Noted for its highly resistant nature, the Tuscarora is a prominent and recognizable ridge former in eastern West Virginia. The resistant nature of the Tuscarora is due to its composition of quartz sand overgrown with silica to the exclusion of almost all porosity and permeability. The quartz overgrowths so typical of the Tuscarora are, in turn, the result of extensive pressure solution of the sandstone. The macroscopic results of pressure solution are the presence of stylolites in many Tuscarora outcrop exposures. The microscopic results are the presence of extensive quartz overgrowths and interpenetrating quartz grain margins – grains have the appearance of being "welded" together.

Setting

Paleogeography

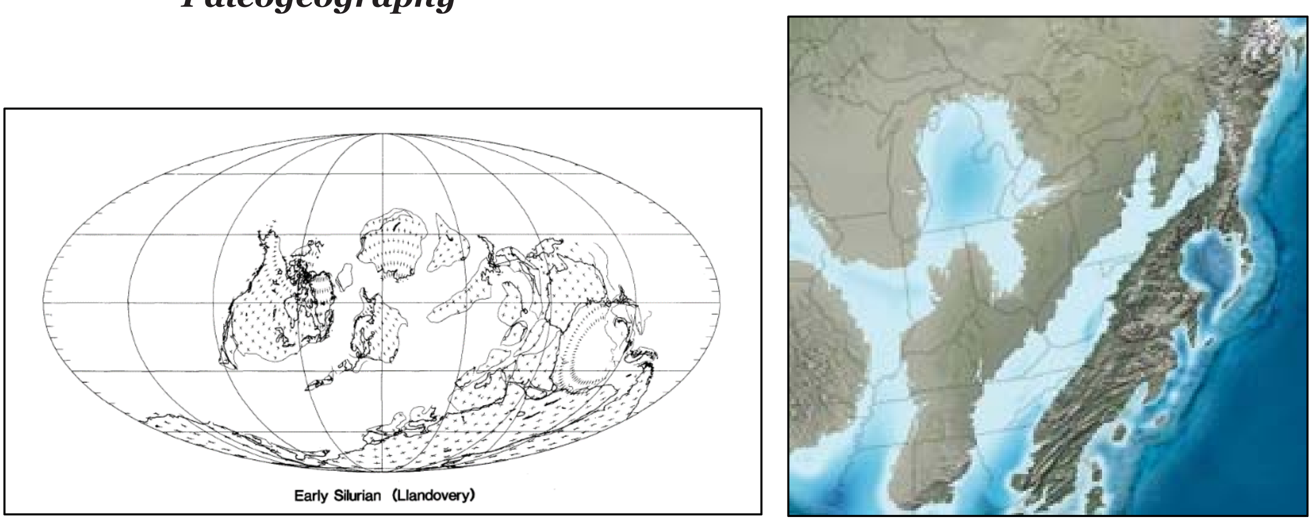
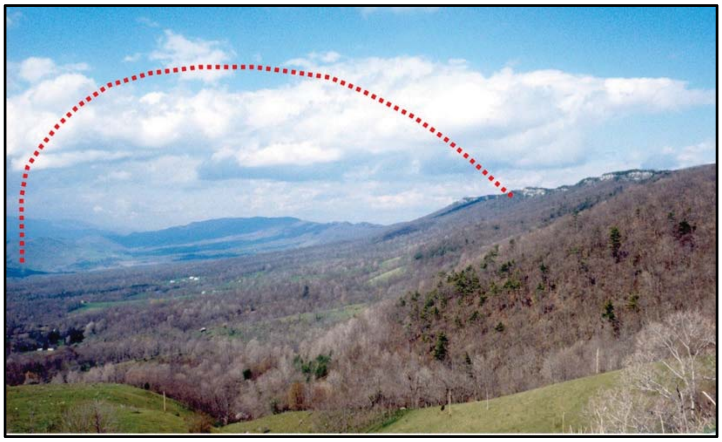


Figure 69. West Virginia during the Early Silurian (430 Ma)
from Scotese and McKerrow (1990), left and Blakey (2007), right

Depositional Environment and Tectonic Setting

The Wills Mountain Anticline was discussed in detail at Stop 9a. Seneca Rocks are part of the steep (vertical to overturned) west limb of the Wills Mountain Anticline (Figure 70 and Figure 71). A brittle rock like the Tuscarora will fold if deeply buried and compressed. But, if less deeply buried and subjected to either compressional or extensional stress, the brittle Tuscarora will fracture which yields usable secondary porosity and permeability with the possibility of a petroleum reservoir (Figure 72). Regionally, Folk (1960) interpreted the Tuscarora depositional environment as high-energy shallow marine with indications of minor fluvial influence.



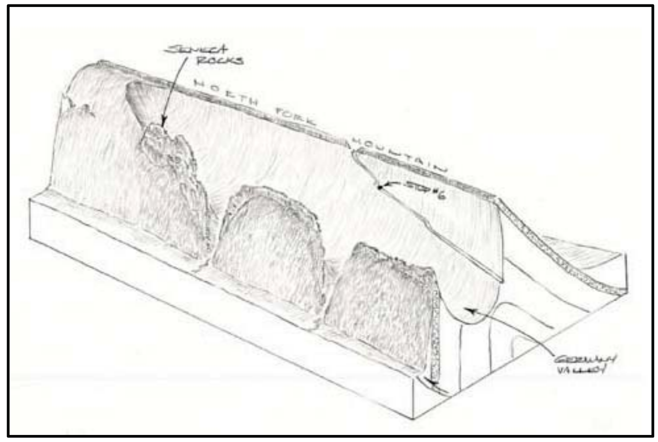


Figure 70. Germany Valley, and Wills Mountain Anticline, and Seneca Rocks
Left: View of Seneca Rocks from the Visitor's Center. The Tuscarora here is vertical and forms part of the western limb of the Wills Mountain Anticline. Right: View looking north into Germany Valley with dashed line by connecting Tuscarora outcrops across the Valley approximately reconstructing the Wills Mountain Anticline C) Generalized perspective view of the Wills Mountain anticline, Germany Valley, and Seneca Rocks (from Renton, undated).

Unit Description

Tuscarora Formation

Originally called White Medina in West Virginia (Tilton, 1927), Woodward (1941) began using the name Tuscarora after Darton and Taft (1896) and Clark (1897) for Tuscarora Mountain in Pennsylvania. The Tuscarora Sandstone is an extremely hard, light gray to white, fine- to medium-grained, well-sorted quartz arenite. Regionally the Early Silurian Tuscarora overlies the Late Ordovician Juniata Formation. The formation sometimes appears as two sandstone beds with a shaley layer between (Figure 73 left). The silica cement and extensive quartz overgrowths of an orthoquartzite characterize the unit, especially in the upper portion of the formation where the Tuscarora can break across, rather than around, individual sand grains. The Tuscarora often forms cliffs and produces prodigious quantities of resistant talus that armors hillsides and masks the stratigraphic units below it. Portions of the formation may be crossbedded and may contain quartz pebbles up to 1 cm in diameter. Thin, black shale interbeds show up as radioactivity spikes on geophysical logs. These shale beds contain the remains of Silurian plants growing in the intertidal zone. The Tuscarora is also known for the readily recognizable vertical trace fossil *Arthrophycus alleghaniensus* (Figure 73 middle and right), typically found on the bottoms of sandstone beds underlain by one of the shale intervals. The horizontal trace fossil *Arenicolites* sp. is also common, and both traces are useful for recognizing the Tuscarora. Otherwise, the formation is unfossiliferous.

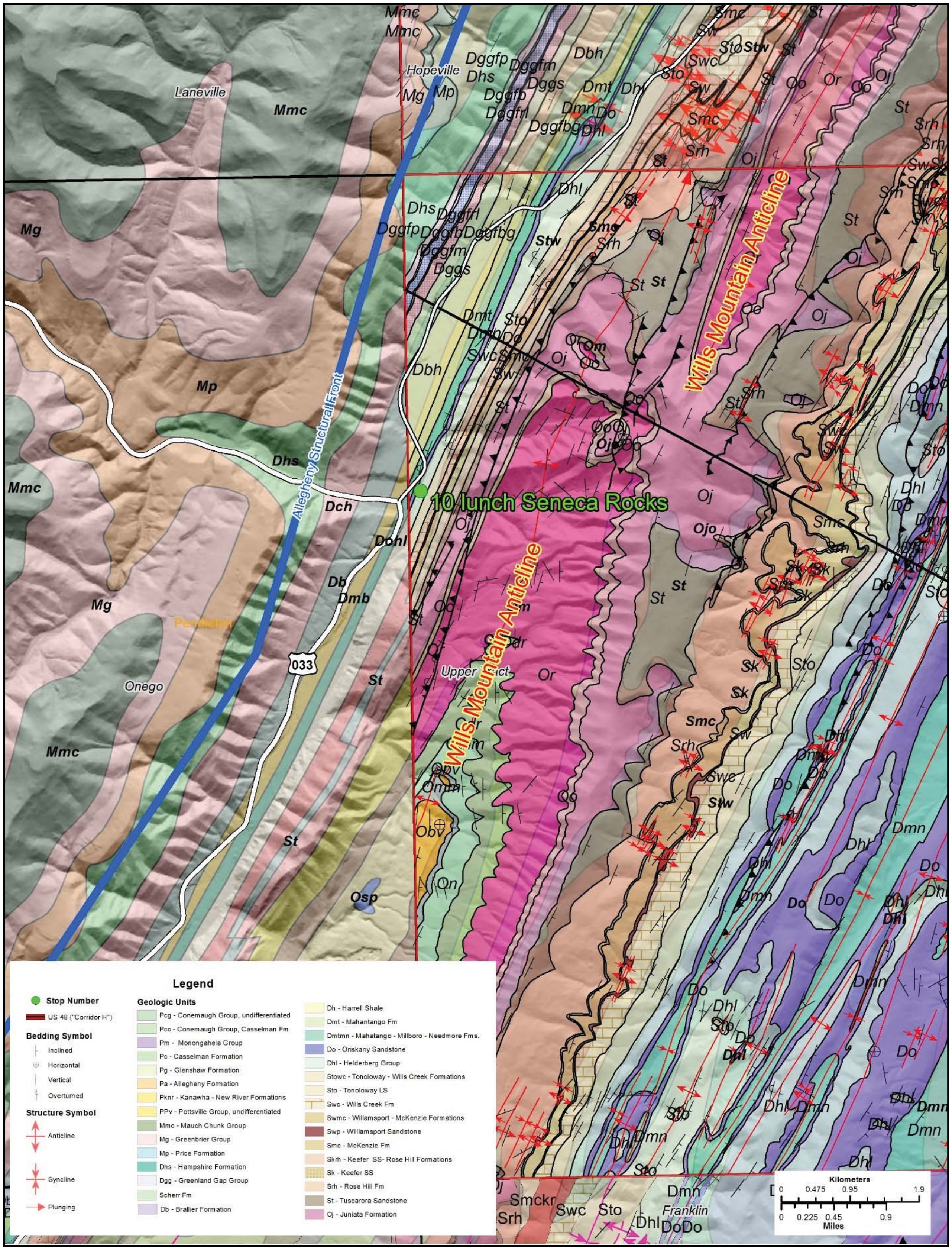


Figure 71. Geologic Map for Stop 10 (Dean et al., in progress, and Cardwell et al., 1968)

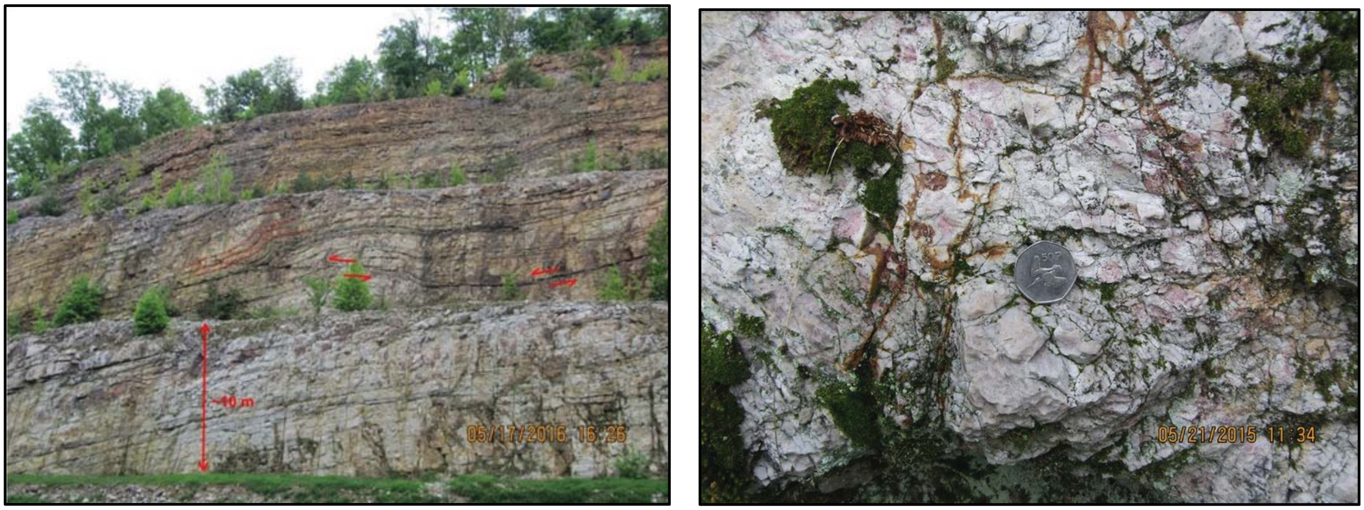


Figure 72. Fault with brecciated Tuscarora

Left: Termination of a thrust fault exposed in the Tuscarora near Baker, WV. East-west compression has moved the upper layers from the right of the photo. Right: Brecciated Tuscarora Sandstone in close proximity to a thrust fault in Pocahontas County, WV. Coin is 3 cm in diameter.

Figure 73. Characteristics of the Tuscarora

Left: Steeply dipping Tuscarora east of Moorefield, WV exposes a black shale interval

Middle: Branching variant of *Arthrophycus* on the undersurface of a block of Tuscarora. The "annulations" giving the appearance of an earthworm are diagnostic. Coin is 3 cm in diameter.

Right: Non-branching variant of *Arthrophycus* on the undersurface of a Tuscarora block. Again, the annulations are diagnostic. Coin is 3 cm in diameter.

Economic Importance

The prospects of petroleum production, storage, or migration in such a tightly cemented lithologic unit seem slim; however, fractures allow oil and gas migration, and anticlines and thrust faults in the detached structure form petroleum traps (Avary, 1996). The Tuscarora fractured anticlinal play is located in central Pennsylvanian and most of central West Virginia. Stop 10 is located on the eastern edge of the Play. Currently the Tuscarora is being examined as a potential geothermal source.

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