1. Regional Tectonic History of Northern Virginia

By Richard Diecchio[1] and Richard Gottfried[2]

Introduction

The objective of this one-day field trip is to examine the field relations that allow us to characterize the major physiographic provinces of northern Virginia and to interpret the tectonic history of this area. We will visit outcrops in the Coastal Plain, Piedmont (including a Mesozoic basin), and Blue Ridge provinces (fig. 1), for the purpose of comparing and contrasting their geology.

We will discuss tectonic events in terms of the Wilson Cycle of ocean-basin opening (rifting) and closing (mountain building), the final product being the mountain belt. The Appalachian Mountains are an excellent example of the repetitive nature of the Wilson Cycle (fig. 2). The tectonic events we will discuss include (oldest to youngest) Middle Proterozoic (Grenville) mountain building, Late Proterozoic (Proto-Atlantic or Iapetus) rifting, Paleozoic Appalachian (Taconic, Acadian, Alleghanian) mountain building, and Mesozoic (Atlantic) rifting.

The dynamic nature of the Earth is a consequence of plate tectonics. These plates are made of rigid continental and oceanic lithosphere. This lithosphere overlies an asthenosphere that is in constant motion. The lithospheric plates experience tensional, compressional, and shearing forces that lead to processes such as rifting, collisional tectonics, and transform faulting. In the process, new ocean floor may be created as well as chains of volcanic islands, areas of earthquake activity, and new mountain ranges. The continents themselves may shift their position as plates move. All of this affects the shape of the land and the distribution of rocks, minerals, fossils, climate, and natural resources. Northern Virginia has experienced several major tectonic episodes that are now recorded in the local rock record and may be visited at many places. The sites to be visited on this trip are selected on the basis of their significance relative to the tectonic history. These sites also illustrate the field relations that allow the recognition of the relative timing of these events.

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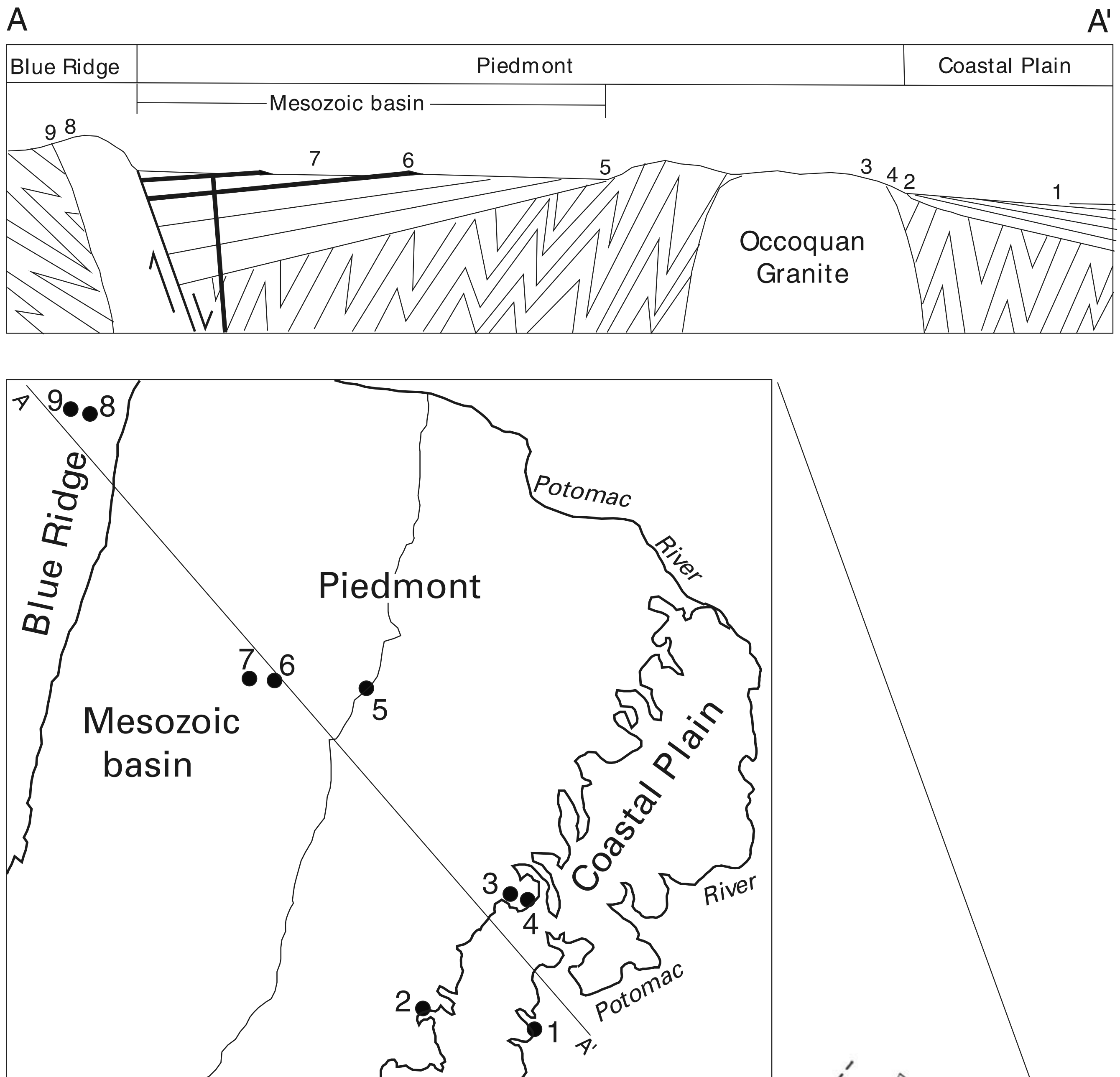
Geologic History

Over one billion years ago in the Mesoproterozoic, narrow strips of land (microcontinents, volcanic arcs, and suspect terranes) collided with and compressed the eastern edge of the then developing North American continent. The rocks from these events are part of the Grenville province of the Precambrian Canadian Shield of North America. This collision between proto-North America and other continents led to the formation of a supercontinent called Rodinia. The formation of Rodinia also resulted in the formation of a mountain range: the Grenville Mountains, now the Grenville province of the Canadian Shield. This mountain-building event is called the Grenville orogeny. Locally, these rocks are found in the Blue Ridge province and are considered to be the oldest rocks in northern Virginia. They are exposed at the surface only after much weathering and erosion of overlying younger rock. Magmatic processes that accompanied this orogeny produced molten rock that was injected into the crust. These igneous rocks, along with the sediments that were eroded from the eastern margin of the Precambrian shield before this collision, were deformed and metamorphosed. We will see metaigneous rocks of Grenville age below the unconformity at Stop 9.

Following the Grenville orogeny, tensional forces associated with changes in mantle convection and (or) other processes led to a breakup of the Rodinian supercontinent. This latest Precambrian (Neoproterozoic) and Early Cambrian rifting led to the opening of the Proto-Atlantic or Iapetus Ocean that predates the Atlantic Ocean. Basaltic rocks that formed during this rifting (and were subsequently metamorphosed during the Paleozoic) are now part of the Catoctin Formation and will be visited at Stop 8. During rifting, fragments of the Grenville continental crust were broken off and became islands, later to be reunited with North America by subsequent closure of the ocean. The Goochland terrane of the Piedmont province may be one of these Grenville fragments (Spears and others, this volume).

As the Iapetus Ocean continued to widen, the rift margin became passive. Sediment continued to be deposited on the eastern edge of the continent, and a broad clastic shelf developed (Chilhowee Group). As the Grenville Mountains were eroded during the Cambrian, the source of clastics diminished and deposition of limestones predominated into the Early



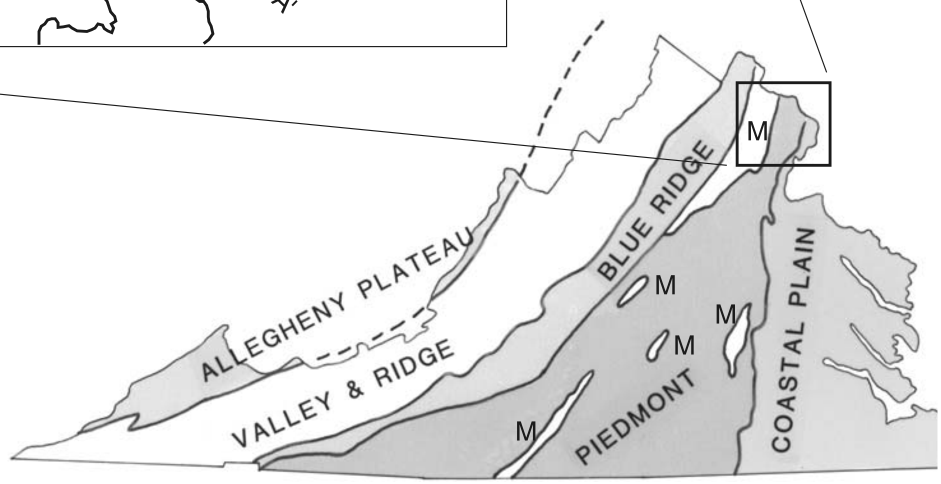


Figure 1. Physiographic provinces of Virginia and in field trip area, and generalized cross section A–A′ of field trip. Numbers refer to field trip stops. Heavy lines in Mesozoic basin on cross section are dikes and sills. M, Mesozoic basins.

Ordovician. Locally, these limestones can be seen in the Frederick Valley and the Shenandoah Valley but will not be seen on this trip. Information about this part of the tectonic history of Virginia can be found in Fichter and Diecchio (1993) and in the additional resources listed at the end of this field guide. During the early Paleozoic the east coast of North America was aligned parallel to the equator that passed through the central part of the United States, roughly coincident with the present-day longitude of Kansas.

During the Middle Ordovician, the plate movements reversed, Iapetus began to close, and once again, continental plates began to converge. As Gondwana approached North America, a subduction zone formed and a volcanic arc complex developed off the east coast of North America. Continental fragments like the Goochland terrane (Spears and others, this volume), that had previously detached from North America, were now caught along with the volcanic arc between North America and Gondwana. Over time, the volcanic islands and continental fragments were thrust back onto North America, eventually to become today's Piedmont terrane. The carbonate and clastic rocks that were deposited on the eastern edge of North America during the Cambrian and Ordovician were now caught between the Piedmont and the eastern edge of North America, and subsequently were compressed. This entire compressional episode, like the earlier Grenville orogeny, resulted in thrust faults, folds, felsic intrusions (like the Occoquan Granite of Stop 3), volcanics (like the Chopawamsic Formation of Stop 2), and metamorphism (evident at Stops 2–5). All of this activity was part of a mountain-building episode known as the Taconic orogeny. This was the first phase in the building of the Appalachian Mountains.

We will not visit the Valley and Ridge province on this trip; however we will briefly discuss its geology to complete the story. Further information can be found in Fichter and Diecchio (1993) and in the additional resources listed at the end of this field guide. The results of these events can be seen in sediments deposited west of the Blue Ridge, in the Valley and Ridge province, and in igneous and metamorphic rocks and deformation in the Piedmont. Of note, two additional mountain-building periods, the Acadian orogeny and the Alleghanian orogeny, occurred during the Paleozoic Era. These orogenies are associated with continued collision and the resulting folds, faults, intrusions, and metamorphism as occurred during the earlier Taconic orogeny. While all this mountain-building activity was taking place, sediments were accumulating west of the Blue Ridge, in the Appalachian basin, which developed on the eastern edge of North America in part as a result of loading by thrust sheets and sediment. These sediments were themselves folded and faulted during the orogenies. At the end of the Paleozoic Era, the final result of the full collision of North America and Gondwana was the formation of the Appalachian Mountains on the supercontinent of Pangea.

Pangea existed during most of the Permian and Triassic. During the Triassic, the plates once again began to pull apart. Rifting began to break up Pangea. One system of rifts opened up along the extent of today's east coast, to become the Atlantic Ocean. This rift system included intracontinental rift basins known as the Mesozoic basins. Here in northern Virginia, one such basin is known as the Culpeper basin (Stops 5–7).

As rifting progressed, erosion of the higher land on either side of the Mesozoic basins produced a variety of sediments that accumulated in fluvial, deltaic, and lacustrine environments (Stops 5–7). The rifting also produced mafic igneous intrusions and volcanism (mafic dikes of Stop 3 and diabase sill of Stop 6) in the basins. Locally the igneous rocks are more resistant to erosion; thus as the sedimentary rocks have been eroded many of these igneous rocks, even intrusions formed at depth, are expressed today as topographic highs.

The Mesozoic basins eventually became inactive as the continental margin became passive. However, the Atlantic continued to open along the Mid-Atlantic Ridge and continues even today. During the Mesozoic, sediments also began to be deposited on the new continental margin, continued to be deposited through the Tertiary, and are still being deposited today. These sediments are now part of the Coastal Plain province and the continental shelf. We will see Coastal Plain deposits at Stops 1 and 2.

Acknowledgments

This field guide has been reviewed and improved by Stephen W. Kline of Arkansas Tech University.

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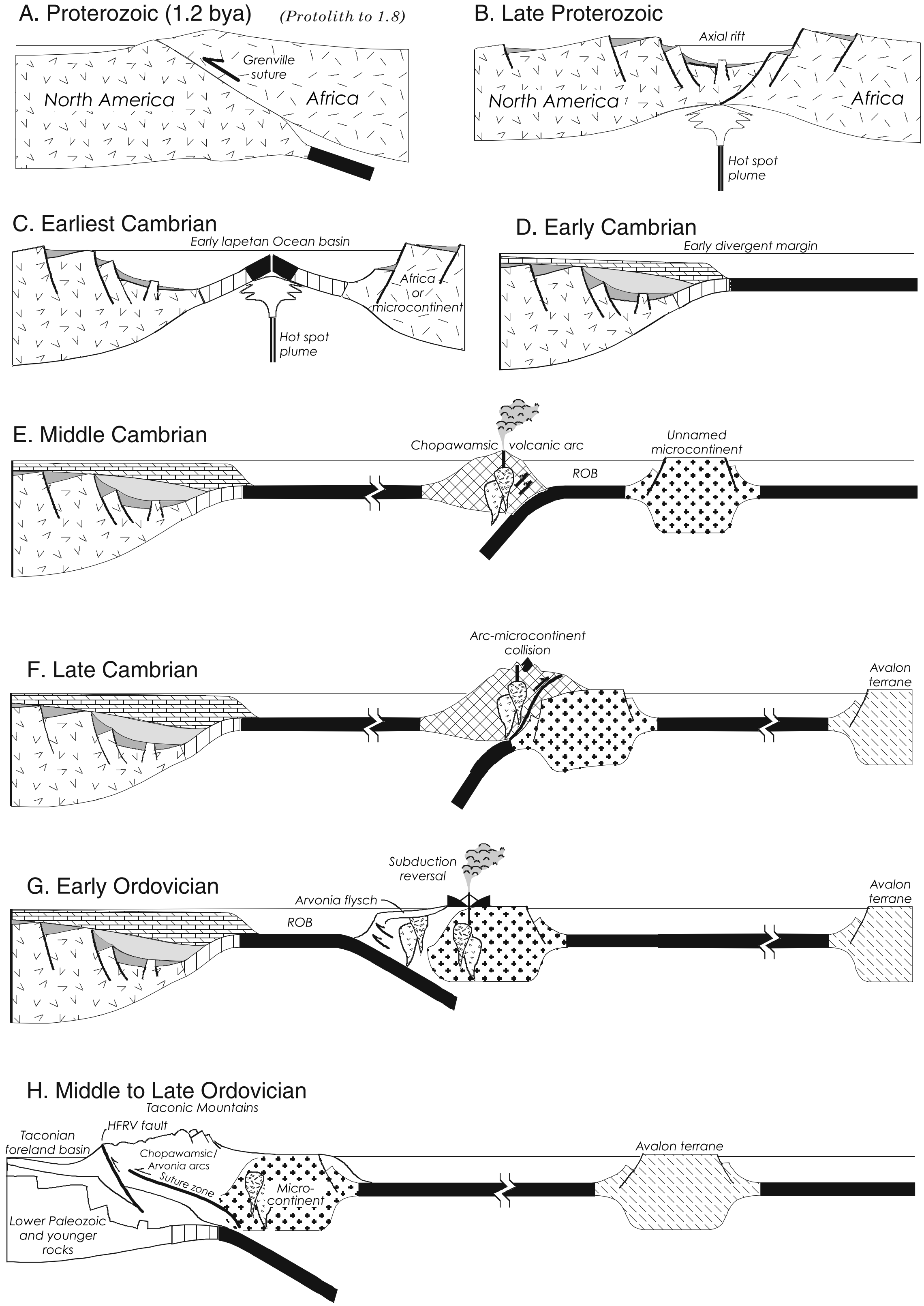
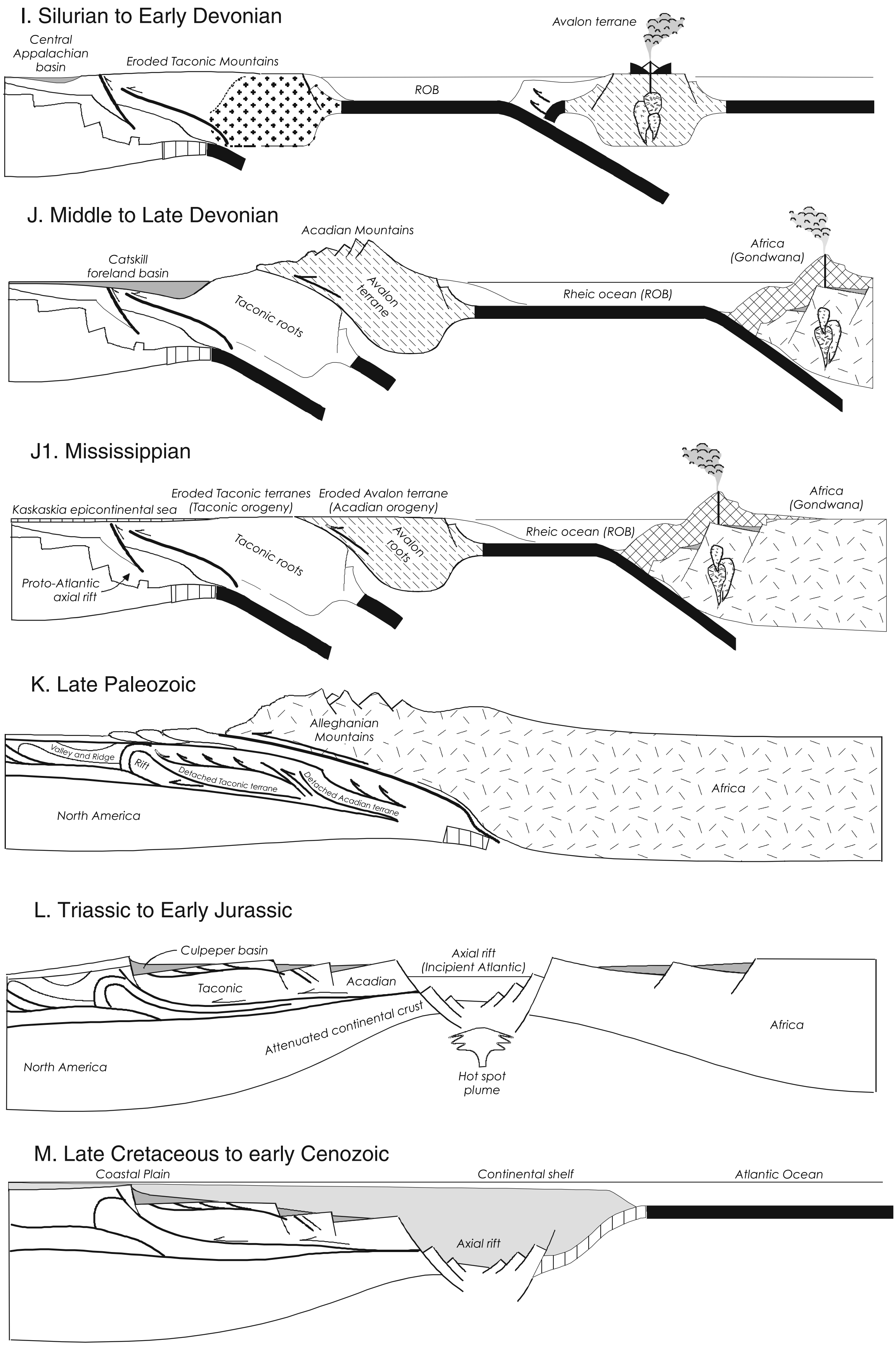
Figure 2 (following two pages). Wilson Cycle as it applies to the northern Virginia area (after Fichter, 1993).

The Geological Evolution of Virginia
Divided into Fourteen Stages A–M




I. Silurian to Early Devonian
Avalon terrane
Central
Appalachian
basin
Eroded Taconic Mountains
ROB
J. Middle to Late Devonian
Acadian Mountains
Catskill
foreland basin
Africa
(Gondwana)
Avalon
terrane
Taconic roots
Rheic ocean (ROB)
J1. Mississippian
Eroded Taconic terranes
(Taconic orogeny)
Eroded Avalon terrane
(Acadian orogeny)
Africa
(Gondwana)
Kaskaskia epicontinental sea
Rheic ocean (ROB)
Taconic roots
Avalon
roots
Proto-Atlantic
axial rift
K. Late Paleozoic
Alleghanian
Mountains
Valley and Ridge
Rift
Detached Taconic terrane
Detached Acadian terrane
Africa
North America
L. Triassic to Early Jurassic
Culpeper basin
Axial rift
(Incipient Atlantic)
Taconic
Acadian
Attenuated continental crust
Africa
North America
Hot spot
plume
M. Late Cretaceous to early Cenozoic
Coastal Plain
Continental shelf
Atlantic Ocean
Axial rift

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ROAD LOG AND STOP DESCRIPTIONS FOLLOW

Road Log and Stop Descriptions

Road log begins at entrance station to Leesylvania State Park, Va.

Mileage

Incremental	Cumulative	
0.0	0.0	Entrance station to Leesylvania State Park. Proceed straight ahead into park toward Freestone Point. *Entrance fee may be waived for educational groups if application is filed in advance.*
1.7	1.7	Turn right into parking area and park vehicles. Proceed on foot to Freestone Point.

Stop 1. Freestone Point, Leesylvania State Park.

Mixon and others (1972) refer to the strata exposed at Freestone Point (and elsewhere on the Quantico quadrangle) as the Potomac Group. Seiders and Mixon (1981) refer to the same strata exposed on the adjacent Occoquan quadrangle (see Stop 2) as the Potomac Formation. For consistency, we will use the more recent terminology and will refer to these strata as the Potomac Formation.

Part of the Lower Cretaceous Potomac Formation is exposed at Leesylvania Park in the bluffs along the shore, beyond the end of the road at Freestone Point, in the northeast end of the park. This is a good exposure of one of the sandstone units in the Coastal Plain. These strata were probably deposited in a beach environment, as indicated by the sorting and the bimodal crossbeds. Note the presence of blue quartz. Blue quartz is common in the Mesoproterozoic Grenville rocks of the Blue Ridge province, indicating the source area of this sediment.

These Cretaceous beach sands occur above present-day sea level. During the Cretaceous, the Earth was probably free of glaciers, climates were warmer, and sea level was higher. In the current global warming controversy, it is significant to note that these conditions existed long before humans could influence the climate system. In the regional historical picture, the sandstone here represents a coastline developed along the eastern shore of North America during the Cretaceous.

Mileage

Incremental	Cumulative	
		Retrace route to leave park.
2.3	4.0	Turn left onto Neabsco Road.
1.5	5.5	Turn right at traffic light onto Jefferson Davis Highway, U.S. 1.
0.2	5.7	Turn left at traffic light onto Neabsco Mills Road.
1.1	6.8	Turn left onto Dale Boulevard.
0.4	7.2	Cross over I-95 and continue straight on Dale Boulevard.
0.6	7.8	Turn right at traffic light onto Gideon Drive.
0.8	8.6	Turn left at traffic light onto Opitz Boulevard.
0.6	9.2	Turn left at traffic light into parking lot for Gar-Field High School. Drive to gate in chain link fence directly behind the school.
0.2	9.4	Park at gate and proceed on foot down to Neabsco Creek. *Prior permission should be obtained to visit this outcrop, especially to arrange for gate to be unlocked.*

Stop 2. Neabsco Creek, Gar-Field High School.

This outcrop contains a nonconformity between the gneisses and schists of the Middle Ordovician Chopawamsic Formation (fig. 3) below and the sandstones of the Lower

Figure 3. Fold axis and axial-planar cleavage (parallel to hammer handle) in rocks of the Chopawamsic Formation at Stop 2.

Cretaceous Potomac Formation above (Mixon and others, 1972). The hiatus represents over 300 million years. The surface expression of this nonconformity defines the boundary between the metamorphosed rocks of the Piedmont province to the west and the unconsolidated strata of the Coastal Plain province to the east.

The regional metamorphic event that formed the schist here, along with the other foliated rocks of the Piedmont, can be used to determine the relative ages of other exposures we will see on this trip. This metamorphic event will be the basis for our discussion of the older rocks that predate metamorphism, and the younger rocks that postdate metamorphism.

The northeast strike of the foliation in the schists is consistent with the regional Appalachian trends of metamorphic foliation, as well as the trends of fold axes and thrust faults in the Blue Ridge and Valley and Ridge provinces. In other words, the metamorphism was part of Appalachian mountain building during the Paleozoic.

At this stop the nonconformity and the overlying strata of the Coastal Plain dip gently seaward and comprise the subsurface of the eastern shore. Permeable units, such as these, are aquifers and are usually confined between impermeable clay-rich aquitards. Regional ground-water flow is downdip to the east.

Mileage

Incremental	Cumulative	
		Retrace route to leave school parking lot.
0.2	9.6	Turn left at traffic light onto Opitz Boulevard.
0.9	10.5	Turn right at traffic light onto Minnieville Road.
2.4	12.9	Turn right at traffic light onto Old Bridge Road.

Figure 4. Mafic dike intruding the Occoquan Granite at Stop 3.

1.4	14.3	Turn left at traffic light onto Gordon Boulevard, Va. 123.
0.5	14.8	Cross Occoquan River and continue straight on Va. 123.
0.6	15.4	Turn left into Vulcan Graham Virginia Quarry.
0.4	15.8	Park at quarry office. *Prior permission is required to visit quarry.*

Stop 3. Vulcan Graham Virginia Quarry, Occoquan Granite.

The Occoquan Granite is exposed here and along the fall zone of the Occoquan River. The granite contains a foliation indicated by the orientation of biotite, and therefore the Occoquan is clearly premetamorphic. According to Seiders and Mixon (1981), the Occoquan Granite was emplaced during the Early Cambrian. A recent age determination (Aleinikoff and others, 2002) indicates the Occoquan was emplaced in the Ordovician during the Taconic orogeny. The Occoquan probably underwent metamorphism during a subsequent orogeny.

We will observe one of several mafic dikes that intrude the granite (fig. 4). These dikes are nonfoliated and therefore postdate the metamorphism. Their ages are assumed to be Mesozoic and, if so, provide additional field evidence that basaltic volcanism occurred after emplacement and metamorphism of the granite.

Historically, the Occoquan Granite represents a volcanic arc that existed during the early Paleozoic. The mafic dikes are probably associated with the rifting that occurred during the Mesozoic.

Mileage

Incremental	Cumulative	
		Retrace route to leave the quarry.
0.5	16.3	Turn left onto Va. 123 North.
0.2	16.5	Turn right into Occoquan Regional Park.
1.0	17.5	Turn right into parking lot. Restrooms are available. Retrace route to leave park.
0.4	17.9	Park on right, off the pavement, and cross road to outcrop.

Stop 4. Occoquan Regional Park.

Metasedimentary rocks of the Piedmont are well exposed at this stop. We will look at the slates and metasandstones of the Upper Ordovician Quantico Formation, which are the primary rocks exposed in the park. Exposures of the Chopawamsic Formation and Occoquan Granite also are present in the park (Seiders and Mixon, 1981). All of these units are overlain nonconformably by the Lower Cretaceous Potomac Formation. We observed this nonconformity at Gar-Field High School and will not take the time to see it again here.

Mileage

Incremental	Cumulative	
		Continue straight ahead out of park.
0.7	18.6	Turn right onto Va. 123 North.
6.4	25.0	Turn left at traffic light onto Clifton Road.
1.7	26.7	Cross Wolf Run Shoals Road. Continue straight on Clifton Road.
3.2	29.9	Turn right onto Main Street in the town of Clifton.
0.3	30.2	Turn left and continue on Clifton Road.
3.5	33.7	Cross Braddock Road. Continue straight on Clifton Road.
0.6	34.3	Turn left onto Regal Crest Drive. Park on right.

Stop 5. Clifton Road, Centreville.

This locality is on the eastern edge of the Culpeper basin, a Mesozoic continental rift basin. Here is the nonconformable relation between the late Precambrian or Early Cambrian Piney Branch Complex and the Late Triassic Reston Member of the Manassas Sandstone (Drake and others, 1994).

Proceed on foot back to Clifton Road and turn right.
Walk to intersection of Moore Drive and observe small outcrop of the Piney Branch Complex on northeast corner of intersection.

The Piney Branch Complex clearly is pre-metamorphic, with a northeast-trending foliation.

Walk north on Clifton Road to a small outcrop on the east side of the road across from Regal Crest Drive.

The Reston Member here is a conglomerate (polymict diamictite, see figure 5). Various types of pebbles occur here and most contain a metamorphic foliation. The pebbles are contained in a nonfoliated hematitic mud matrix. The overall rock itself is therefore non-metamorphic or post-metamorphic. However, the foliated pebbles are clearly derived from an older, pre-metamorphic source. The contact between the Piney Branch Complex

Figure 5. Pebbles and cobbles of metamorphic rock in basal conglomeratic facies of the Reston Member of the Manassas Sandstone at Stop 5.

and the Manassas Sandstone is a nonconformity that is not exposed here and represents over 300 m.y. missing.

The historical significance of this stop is to illustrate the relative ages of the older pre-metamorphic Piedmont rocks and the younger post-metamorphic strata of the Culpeper basin.

Mileage

Incremental	Cumulative	
		Return to vehicles, turn around, and continue north on Clifton Road.
0.2	34.5	Turn left at traffic light onto Lee Highway, U.S. 29 South.
4.8	39.3	Turn left into Luck Stone Quarry.
		Stay to the right and park vehicles.
		Prior permission is required to visit quarry.

Stop 6. Luck Stone Quarry, Centreville.

The quarry is in a Lower Jurassic diabase sill (Drake and others, 1994) that was intruded into the sedimentary rocks of the Culpeper basin. The strata have a gentle westward dip due to the downdropping along the western border fault between the Culpeper basin and the Blue Ridge (fig. 2). Basalts are known to occur in the western part of the

Figure 6. West-dipping Mesozoic strata cut by east-dipping normal fault (arrows) at Stop 6. Strata on east (right) side of fault are overlain by diabase sill and have dropped down relative to the west (left) side. Photograph faces north.

basin; hence there was also extrusive volcanic activity. Because the igneous rocks of this area are more resistant to erosion than the sedimentary rocks, the intrusive and volcanic rocks form topographic highs within the basin. Elsewhere in the basin, contact-metamorphosed sedimentary rocks, such as hornfels, also form topographic highs.

Proceed through the tunnel under U.S. 29 to the north end of the quarry.

An east-dipping normal fault separates the Mesozoic strata from the diabase (fig. 6). The diabase does not have any metamorphic texture. It is therefore post-metamorphic and represents mafic plutonism-volcanism associated with extensional tectonics after Appalachian mountain building. The historical significance of this stop is Mesozoic continental rifting that accompanied the initial opening of the Atlantic Ocean.

Mileage

Incremental	**Cumulative**	
		Drive out of quarry and turn left onto U.S. 29 South.
0.7	40.0	Turn right into parking lot for Manassas Battlefield. Park vehicles. Walk west to the Stone Bridge.

Stop 7. Stone Bridge over Bull Run.

Upper Triassic red clastic sediments of the Balls Bluff Siltstone (Lee and Froelich, 1989; Southworth and others, 2000) are exposed here along Bull Run. These strata also display the regional westward dip seen at Stop 6. Note that this is a finer grained facies than the red conglomerates of Stop 5 even though both had a common source. The conglomerates near both the east and west margins of the basin are closer to the source. The much finer sediments (now rocks) in the center of the basin were transported a greater distance from the source.

Mileage

Incremental	Cumulative	
		Exit parking area and turn right onto U.S. 29 South.
1.5	41.5	Turn right at traffic light onto Sudley Road, Va. 234 North.
7.5	49.0	Turn right at traffic light onto James Madison Highway, U.S. 15 North.

Route 15 runs along the western side of the Culpeper basin. The western border fault lies to the west of U.S. 15, and just west of the fault is the Blue Ridge, which is visible on the horizon to the left. As we drive north, U.S. 15 gets closer to the western edge of the basin.

6.7	55.7	Cross U.S. 50, continue straight on U.S. 15 North.
4.1	59.8	Cross Goose Creek, continue straight on U.S. 15 North.
0.5	60.3	Turn left onto Lime Kiln Road, Va. 733.

Within a few hundred feet is the western border fault of the Culpeper basin.

3.7	64.0	Pass outcrop of metabasalt (greenstone) of the Catoctin Formation on right. Drive ahead 0.1 mile and carefully park vehicles on right across from house. Walk back to the outcrop.

Stop 8. Goose Creek near Steptoe Hill.

The Neoproterozoic Catoctin Formation is a foliated greenstone and greenschist interbedded with metasedimentary rocks. The Catoctin greenstone is metabasalt as indicated elsewhere by vesicles and amygdules, porphyritic texture, flow-top breccias, and pillows (Kline and others, 1991). The Catoctin is commonly referred to as greenstone (a field term) because of the abundance of green-colored chlorite and epidote.

The Catoctin Formation represents an episode of continental rifting. Its pre-metamorphic age (Southworth and others, 2000) indicates that it was emplaced before Appalachian mountain building in the Paleozoic, and certainly before the opening of the Atlantic Ocean in the Mesozoic. The Catoctin rifting occurred during the Neoproterozoic (latest Precambrian) and is good evidence of the opening of the Proto-Atlantic Ocean or Iapetus.

Mileage

Incremental	Cumulative	
		Continue west on Lime Kiln Road.
1.7	65.7	Turn left into Groveton Farm. *This stop is on private land, and permission is required.*

Stop 9. Goose Creek at Groveton Farm.

Here is the nonconformity between the gneiss (metagranite) of the Mesoproterozoic Marshall Metagranite and the arkosic metaconglomerate of the Neoproterozoic Fauquier Formation, as described by Kline and others (1991) and Southworth and others (2000). The Fauquier Formation is overlain by the Catoctin Formation.

Compare the relations here with the nonconformities observed earlier today at Gar-Field High School (Stop 2) and on Union Mill Road in Centreville (Stop 5). Similar to the earlier stops, this nonconformity represents younger sediments overlying older metamorphic rocks. However, one major difference exists here: the younger sediments (Fauquier Formation) are foliated (like the overlying Catoctin Formation) and therefore are pre-metamorphic. The older basement gneisses here are more severely metamorphosed than the overlying metasediments. This indicates that the older basement rocks had undergone metamorphism before deposition of the overlying sediments. Subsequently, these sediments and the underlying metamorphic basement rocks were metamorphosed. Two episodes of metamorphism are therefore evident, the older of which predates the metamorphism of the Appalachian events. This older metamorphism is associated with the Mesoproterozoic Grenville orogeny, which represents mountain building prior to the opening of the Proto-Atlantic Ocean.

Return to Leesylvania State Park.