Systems: Tectonic & Hydrologic – Field Study Observations & Interpretations – Part 2

by

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I. Introduction

The Cumberland Valley dike was created as a result of the continental collision of North America and North Africa due to the intense volcanic activity that is typical of that type of geological event. This will be supported as described by the following observations and subsequent interpretations.

dike (definition): "A tabular intrusive rock that cuts across strata or other structural features of the surrounding rock." [WC1]

The Cumberland Valley is just one of the fourteen Great Appalachian Valleys that extend from Vermont to Alabama as shown in the following map figure, with its dike (shown as redline) located about 14 miles west of Harrisburg, PA.

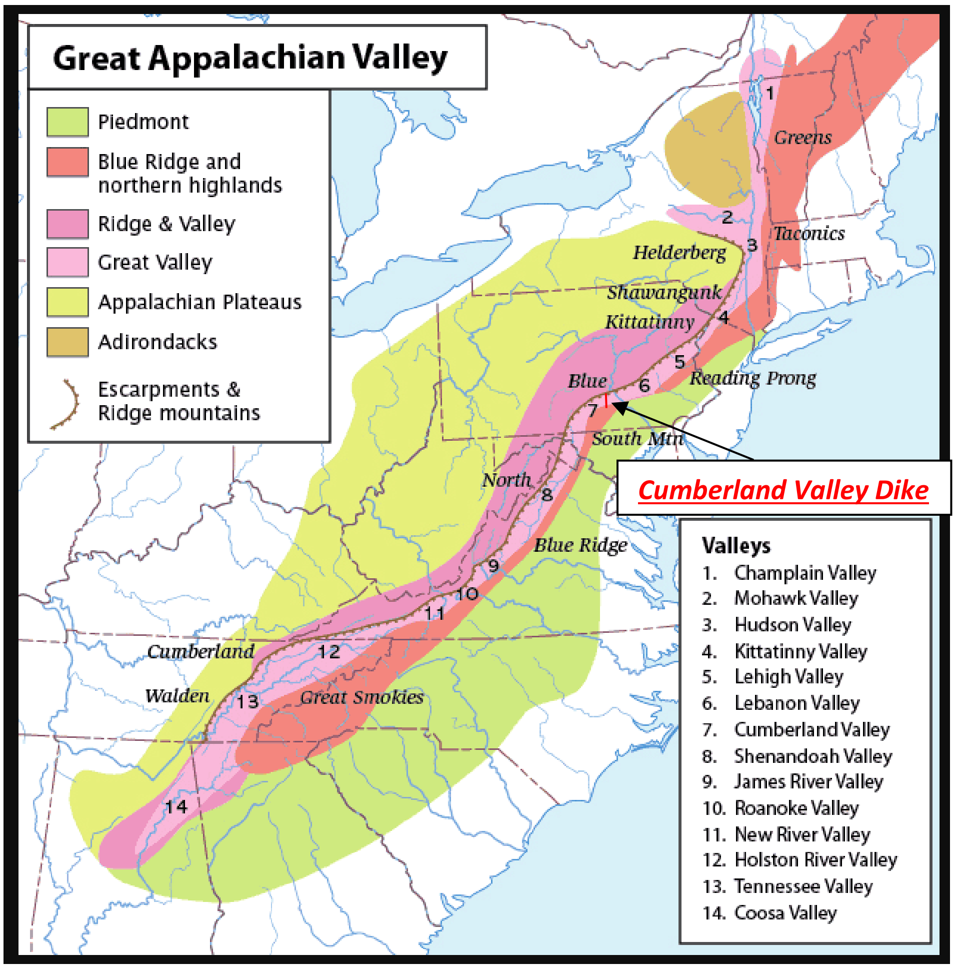

Figure 1.1: Great Appalachian Valley
Reprint source: https://upload.wikimedia.org/wikipedia/commons/5/5f/Greatvalley-map.png

II. Observations

In order to observe the length of the dike in the field, I had to find it! I had to map it relative to the highways, roads, and the Appalachian Trail (AT). The following table lists my field observations, with dates of visit, locations, and descriptions.

Most field observations listed in the following table were initial visits. However, some were revisits needed to gather or confirm initial information and are annotated with Observation Field Notes (OFN). These notes are alongside the dike map for easier correlation (side-by-side) in Figure 2.6: Dike Mapped with Observation Field Notes.

Table 2.1: Field Observations

Date	Location	Description
5/13/22	AT (N) - AT parking West Trindle Road (Rt 641) West of Mechanicsburg	Hiked to 2nd outcrop
9/18/22	AT (S) - AT parking Scott Farm Bernheisel Bridge Road Carlisle	Hiked to I-81 Parking area (S) Trail Head
9/24/22	AT (S) - Bernheisel Bridge Road I-81 parking area near Stony Ridge Park on Bernheisel Bridge Rd	Hiked to Turnpike (I-76)
10/22/22	AT (N) - AT parking West Trindle Road (Rt 641) West of Mechanicsburg	Hiked past 2nd outcrop to Turnpike (I-76)
11/5/22	AT (S) - AT parking West Trindle Road (Rt 641) West of Mechanicsburg	Hiked S. to Rt 74 parking N. of Boiling Springs; about 45min (past 1st AT Parking, Lisburn Rd)
11/12/22	Road Trip - Scott Farm to Trindle	Field Observations by car and foot
11/13/22	Road Trip - Lisburn Rd to Rt 174	Field Observations by car and foot; hiked from Rt 74 to Rt 174
11/20/22	AT (S) - AT parking I-81	Mapped dike to Turnpike; collected rock sample near location OFN #1 (between creek and dike/road)

Date	Location	Description
11/25/22	AT (N) - AT parking West Trindle Road (Rt 641) West of Mechanicsburg	Confirmed/refined OFN segments #7 and #8.
12/4/22	AT (S) - AT parking West Trindle Road (Rt 641) West of Mechanicsburg	Hiked to Lisburn Rd; OFN #9 confirmed dike exposure not natural, most likely cleared from field for farming and used as property boundary.
12/10/22	AT (S) - AT parking Scott Farm Bernheisel Bridge Road Carlisle	Hiked to Ordovician outcrop near I-81 to get GPS location of the outcrop for mapping.

A. Mapping The Dike

Not safe to get a closer look than the photographs in the following figure, the geologic map reference [WC6] clearly corroborates the dike running along Bernheisel Bridge Rd. Also, I confirmed this dike location by collecting and identifying rock sample d3 at this location.

Dike Heading North

Dike Heading South

Figure 2.1: Dike Structural Views - Bernheisel Bridge Rd (OFN #1)

As shown by dashed box below in a side view, photo taken on the AT, the Cumberland Valley dike heading north to south (left to right) at Chambers farm cemetery.

Figure 2.2: Dike - Chambers Farm Cemetery

Dikes are discordant geologic structures, meaning that they cut across preexisting structures such as layers in metamorphic or sedimentary rocks. [WC1] The Cumberland Valley dike passes through the following sedimentary rock in no particular order: shale, siltstone, sandstone, limestone, chert, dolomite, and conglomerate. [WC6]

As can be seen in the following figure (photograph), westbound view from the Appalachian Dr. bridge over PA turnpike. At first glance, I thought that this was all dike. However, upon closer observation, I realized that the dike is only part of this exposure, Lighter sedimentary bedrock adjacent to the darker igneous diabase dike rock can be clearly seen in this photograph.

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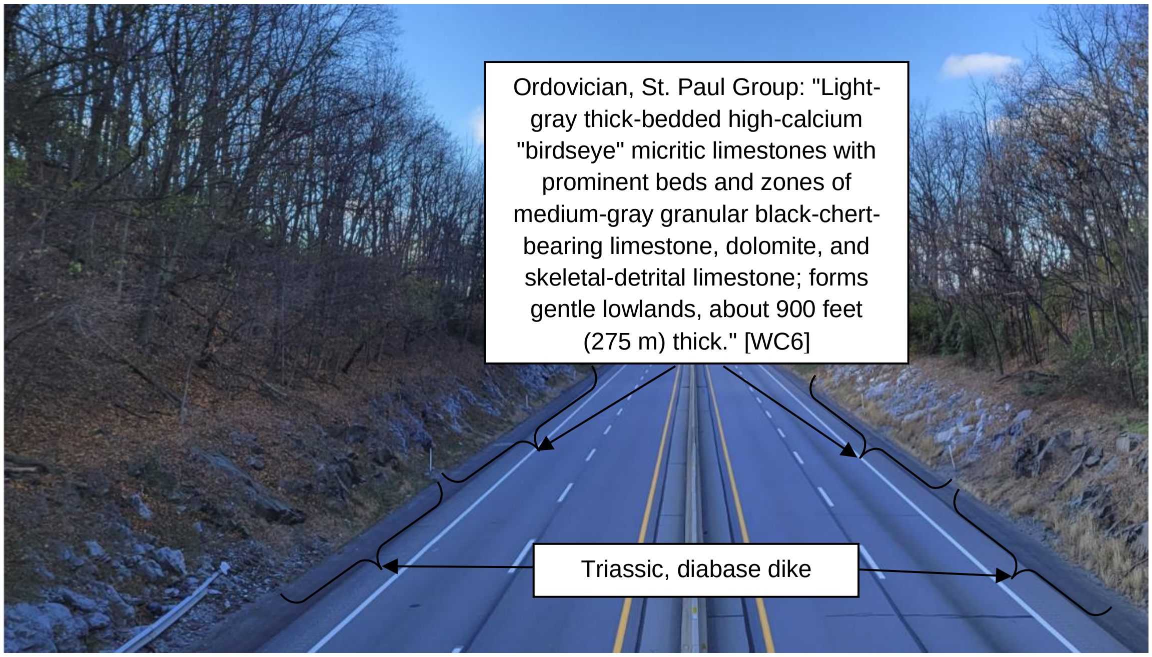

Figure 2.3: Dike Crossing Turnpike (OFN #6)

The photograph in the previous figure clearly shows the dike split by the highway, the PA Turnpike, since the dike can be seen on both sides. This is the key that I realized, how to map the difficult to see dike, was to locate where the dike intersects highways and roads. With this newly realized dike mapping technique, my investigative journey of observations began!

The key tools, techniques, and information that I used to map the dike were as follows:

- Field Observations
    - Dike and Highway/Road junction
    - AT (on foot)
    - Roads (driving)
- Android Smartphone, Google Map Global Positioning System (GPS) Pins
- Google Maps
- Geologic Map [WC6]
    - Dike is diabase rock, shown as red line
    - Forms Stony Ridge
    - PA Turnpike crossing exposure, ≈75ft (25m)
    - PA Route 74 crossing exposure, ≈150ft (45m)
- AT trailhead sign (see Appendix A)
- AT map without my added overlays (see Appendix B)

See figure 2.6 for my mapped dike with observation field notes.

After erosion, the surface expression of a dike is usually a long narrow ridge [WC1]. During my later field observations in November, after the leaves had fallen, I was able to clearly see where a road or the AT was on top of or crossing a ridge (i.e. the dike). Therefore, I was able to more confidently map the dike.

The following photo was taken on the AT near Trindle Rd (view to the south) standing on top of the dike. As shown by dashed lines, its crest representing the highest points of the ridge sloping down to lowest points on either side called ridgelines.

Figure 2.4: Diabase Dike W. Trindle Rd (Rt 641) - AT South [OFN #9]...Ridge View

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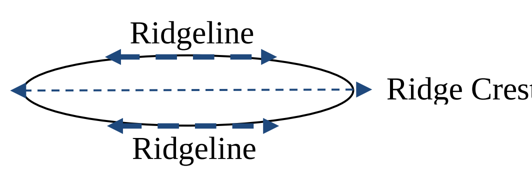
Diabase dike rock in the following figure photograph, near ridgeline (left in previous photo) that appears to have been cleared from nearby farm fields and used to mark land boundary. A wire fence continues the boundary south to the left (out of view) and the diabase rock continues the boundary north to the right (out of view).

Figure 2.5: Diabase Dike W. Trindle Rd (Rt 641) - AT South [OFN #9]...Diabase

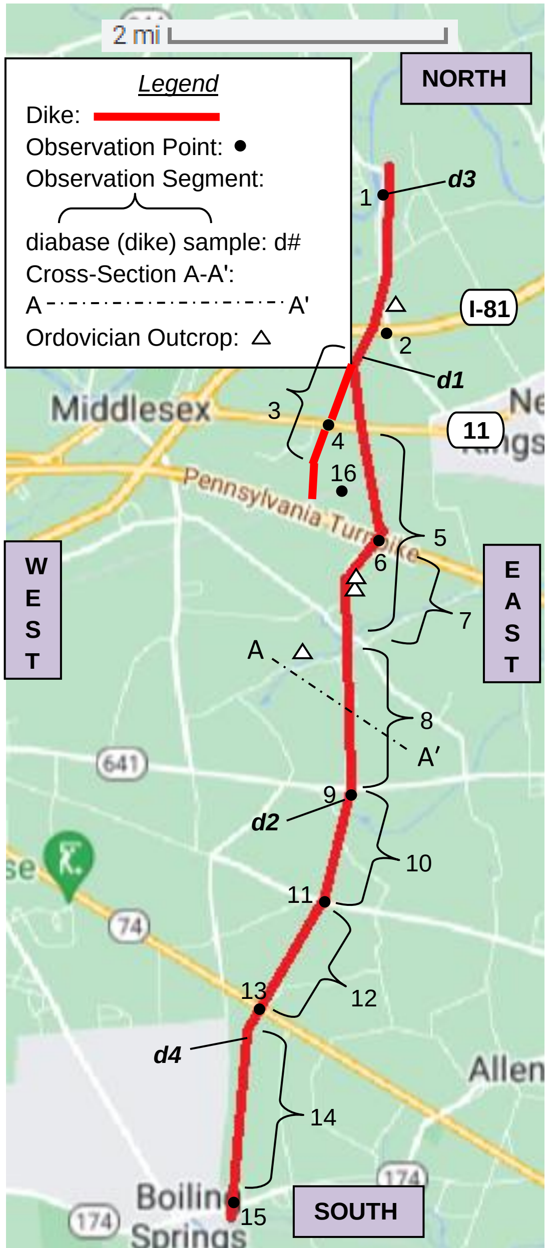
Since the geological structure of a dike is most similar in shape to an ellipse, the position of any point on a dike segment can be modeled and represented in the elliptical coordinate system; where provided a point P(ε, η) in elliptical coordinates, the Cartesian coordinates (x, y) can be found using the following tranformation equations: [WC9]

$$x = f \cosh \varepsilon \cos \eta, \qquad y = f \sinh \varepsilon \sin \eta$$

Dike Segment



Dike width can range from a fraction of a centimeter to hundreds of meters; where length is always much greater than the width [WC1]. The width of the Cumberland Valley dike has been measured to be ≈ 25-45 meters (75-150ft)[WC6]; where its length is ≈ 13 kilometers (8 miles).



△Ordovician outcrop samples collected at each of the four mapped locations tested positive to an acid test; i.e. reacted to a 10% Hydrochloric Acid solution; therefore, rock outcropping is likely either limestone or dolomite as indicated present in the formations/group of the Cumberland Valley Sequence per the geologic map [WC6].

Observation Field Notes (OFN)

1. [AT along Conodoguinet Creek] Exposed dike along road where Bernheisel Bridge Rd parallels the creek; rock sample d3 collected for further observation.
2. [Bernheisel Bridge Rd bridge over I-81] Recorded GPS location and observations using geologic map [WC6]; used binoculars to locate dike crossing I-81 (from the north) and estimated GPS location to be about 1000ft west of bridge over I-81 where I was standing.
3. [AT] Exposed dike rocks in woods on trail with a dike stone boundary at south end of this segment; trail clearly following the dike ridge; rock sample d1 collected for further observation just inside woods after meadow near trailhead.
4. [AT & Rt 11] Dike west branch segment crossing Rt 11.
5. [Appalachian Dr] Main dike segment appears to start (not visible north) at Rt 11 and follow Appalachian Dr south to Chambers farm cemetery; dike walls along road.
6. [AT on Appalachian Dr over PA Turnpike] Dike exposed both sides of highway.
7. [AT] Dike follows Appalachian Dr from PA Turnpike to Chambers farm cemetery.
8. [Hickory Rd/Oak Ridge Rd] Dike on or near roads from Old Stonehouse Road to W. Trindle Rd (Rt 641).
9. [AT] Dike on ridge near W. Trindle Rd (Rt 641); diabase rock appears to have been used as boundary border from clearing farm land; rock sample d2 collected for further observation, near trailhead where fence connects with dike rock.
10. [AT] Exposed dike rock and as border/fence observed all along trail.
11. [AT/Lisburn Rd] Dike crossing at junction of Lisburn Rd and Ridge Rd.
12. [Ridge Rd] Dike follows Ridge Rd to Rt 74 junction; diabase dike walls along road.
13. [Rt 74] Dike crossing Rt 74.
14. [AT] Dike ridge peak on trail at northern and southern parts of this segment; central part moves off dike peak; three dike rock exposed structures: one appeared to be used as a wall and the other two as borders; rock sample d4 collected for further observation, part of rock exposure (appears to be a man-made boundary used as border) near trailhead.
15. [AT & Rt 174] Dike crossing Rt 174.
16. [AT] Dike rock appeared to be used as boundaries splitting two farm fields in half; both dike segments: main and west branch visible across farm fields clearly seen as ridges.

    Note: Dike west branch (south segment) not shown on this map or observed; west branch continues south to just north of W. Trindle Rd (Rt 641). [WC6]

General Note: The stone walls and boundaries were commonly used by farmers in the 1800s to mark property borders and clear their land.

Figure 2.6: Dike Mapped with Observation Field Notes

B. Rock Samples

The suspected diabase dike rock samples collected were subsequently observed using a Carson MicroBrite Plus 60x-120x LED Lighted Pocket Microscope. Rock identification was confirmed, with the samples matching characteristic correlations using a chart similar to the one below; with contrast, texture, and diabase rock added. These rock samples were part of the diabase dike as described in the geologic map reference [WC6].

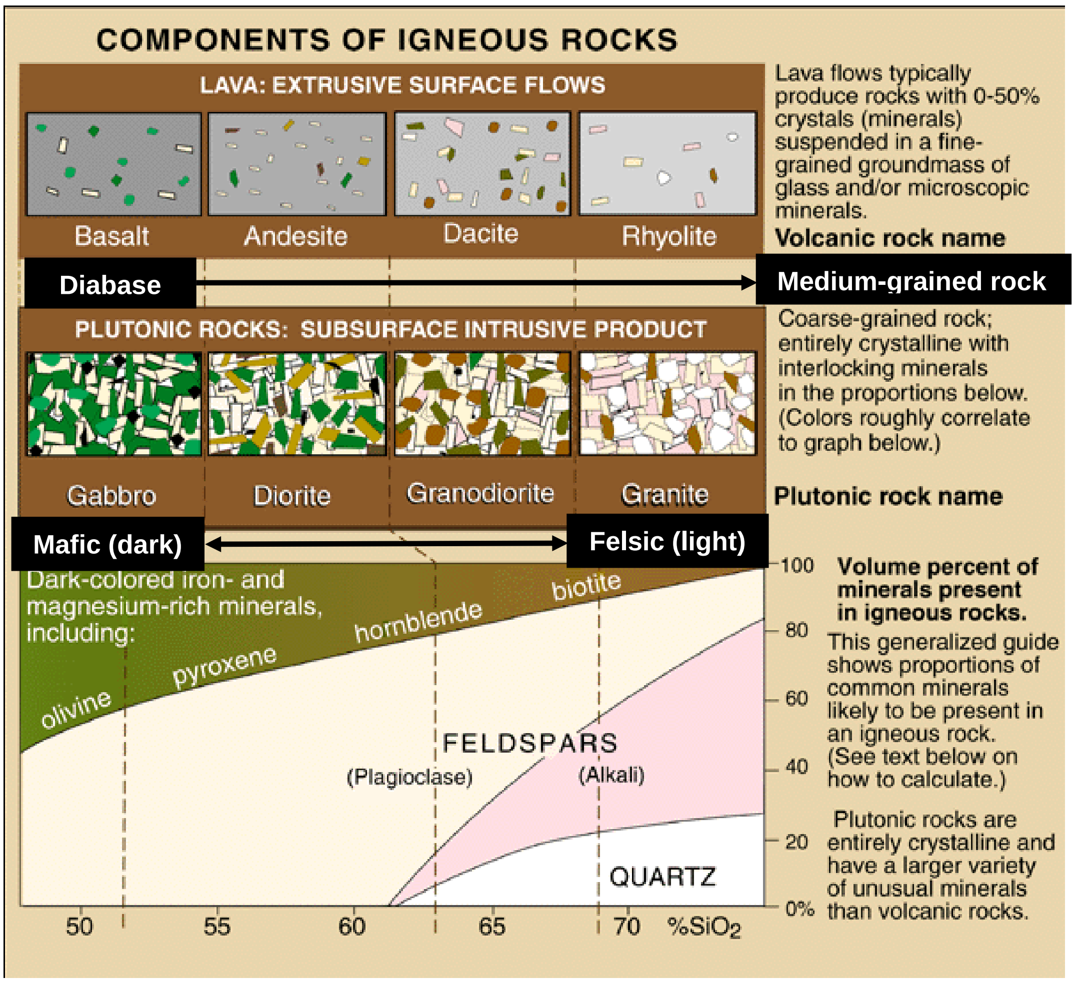
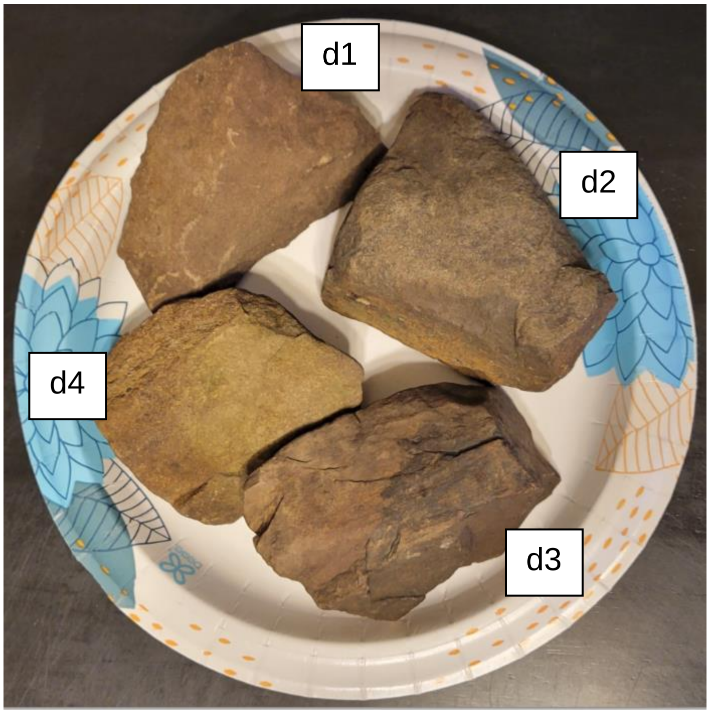


Figure 2.7: Igneous Rock Composition Chart
Reprint Source [WC5]

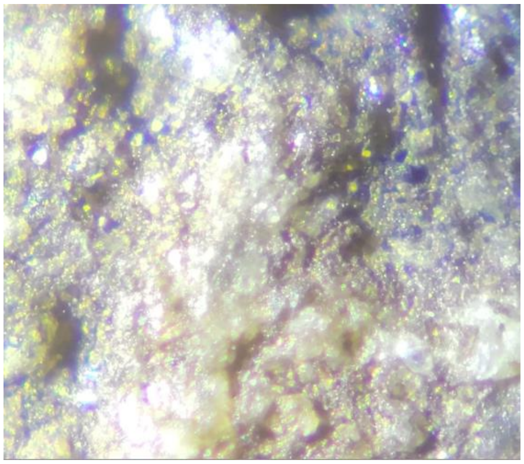
Key Characteristics of diabase as reflected in previous chart:

- Same mineral composition as basalt and gabbro
- Grain size = Medium-grained rock: 0.1-2mm, due to magma cooling rate between basalt (faster) and gabbro (slower)
- Mafic rock: consisting of dark-colored iron and magnesium rich minerals like olivine and pyroxene.

For scale, the rock samples in the following figure are on an 8.5 inch paper plate. The microscope photograph covers an area of approximately one square millimeter and represents a typical view of all four samples. Dominated by the plagioclase feldspar known as labradorite (approximately 40% to 70% of the rock) [WC3], the iridescent colors of this mineral is present in all diabase samples.



Diabase Samples

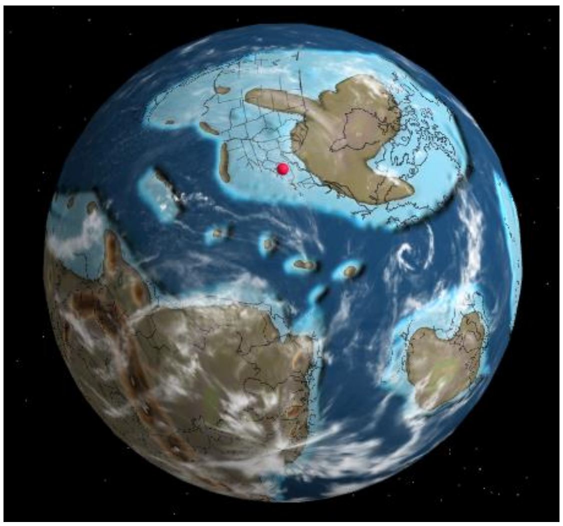


Diabase microscopic photo ≈ 1 mm^2

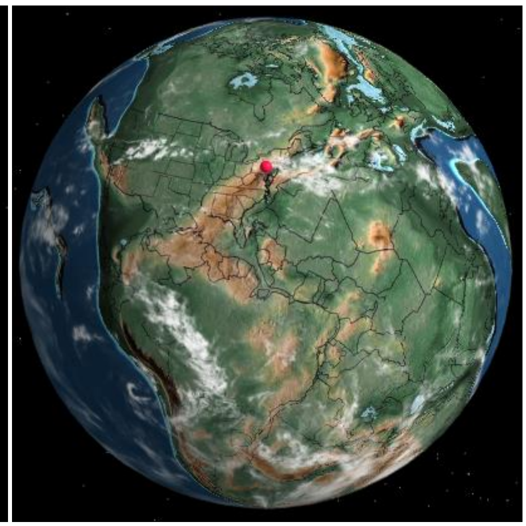
Figure 2.8: Dike (Diabase) Rock Samples

III. Interpretations

The format for my interpretations of the petrogenesis of the Cumberland Valley dike, marked by the red dot in the following images [WC2], will follow the geological timeline: A) pre-dike, limestone forming, B) dike (diabase) forming, C) continental drift and erosion. Interpretations are based on my observations and work cited.



A) <u>500mya (Shallow Sea-Cabrian, Middle)</u>



B) <u>240mya (post Continental Collision with Volcanism-Triassic, Middle)</u>

C) <u>0mya (Erosion-Quaternary, Holocene)</u>

key/format: mya (State-Period, Series)...where mya = millions years ago

Figure notes: "The locations are accurate to ~100 km. The coloring of the maps is based on elevation and bathymetry: dark blue = deep water, light blue = shallow water; dark green, green, tan, brown, white = ground in increasing order of elevation." [WC2]

Figure 3.1: Dike Geologic Timeline

A. Ancient Sedimentary Limestone Formation – Cambrian & Ordovician

540 - 450 million years ago (mya), the Cumberland Valley (not yet a valley), was under a warm, shallow epicontinental ocean. Epicontinental (epeiric) seas are shallow seas that covered the majority of a continent at particular times in earth history. For example, the seas of North America stretched almost unbroken by land across the entire continent during the Middle Ordovician (470-458.4 mya) [WC4].

Although the Cumberland Valley stratigraphic sequence consists of multiple types of sedimentary rock as previously mentioned; for interpretation purposes, we will focus our attention on the formation of the most common sedimentary rock in the sequence – limestone. Limestone is present in all of the Cumberland Valley Sequence rock units which the dike passes through from the north at the Conodoguinet Creek to the south at Boiling Springs [WC6].

Limestone is a sedimentary rock composed primarily of calcite, a calcium carbonate mineral with a chemical composition of $CaCO_3$. Usually a biological sedimentary rock, forming from the accumulation of shell, coral, algal, fecal, and other organic debris. Most limestones form in calm, clear, warm, shallow marine waters. That type of environment is where organisms capable of forming calcium carbonate shells and skeletons can thrive and easily extract the needed ingredients from ocean water. When these animals die, their shell and skeletal debris accumulate as a sediment that might be lithified into limestone. Their waste products also contribute to the sediment mass. Limestones formed from this type of sediment are biological sedimentary rocks. Their biological origin is often, but not always, revealed in the rock by the presence of fossils. Sometimes evidence of a biological origin is destroyed by the action of currents, organisms, dissolution, or recrystallization. [WC3]

Many limestone-forming environments are active on Earth today. Most of them are found in shallow parts of the ocean between 30 degrees north latitude and 30 degrees south latitude. [WC3]

Thus, the following supports my interpretation that the Cumberland Valley, in ancient times, was located near the equator in a shallow sea; and therefore in a limestone forming environment.

- Middle Ordovician example at beginning of this section
- Aforementioned latitudinal correlation to present day
- Orogenic events, first two orogenies, as described in next section
- Model represented in figure 3.1 A) 500mya (Shallow Sea-Cabrian, Middle)

Following this long limestone forming period after the Ordovician, ≈440 mya, the Cumberland Valley sedimentary rock strata was relatively unfractured and intact (i.e. pre-dike); and still in a shallow sea environment.

B. Tectonic Convergence and The Orogenies – Mississippian & Pennsylvanian

Between 450 to 260 mya, tectonic processes from a series of three mountain building events uplifted the Cumberland Valley, moved the area northward, and would transform this epicontinental sea into a great mountain range, the Appalachians, comparable to the Rocky Mountains of today. For the Cumberland Valley, this was largely due to the last orogeny during the Mississippian and Pennsylvanian.

Mountain ranges are generally classified as young or old, 0-100 or 100-500 million years of age respectively [WC1]. The Rocky Mountains are an example of a young mountain range. The Cumberland Valley is a part of an old mountain range – the Appalachain Mountains. The Appalachian Mountains, located in the eastern United States, deformed several times, creating tight folding and thrust faulting, with oceanic lithosphere subducting beneath a continental margin about 500 to 300 mya [WC1].

The Appalachian Mountains were formed from a series of three orogenies: Taconic, Acadian, and Alleghenian. Compression of the Appalachians was due to the subduction of oceanic lithosphere during the first two orogenies; followed by a continental collision which represents the third and last of the orogenies. These orogenies produced tight folding, thrust faulting, and volcanism. [WC8]

The first two orogenies were ocean-continent tectonic convergent type – Taconic and Acadian. The Taconic Orogeny started about 470 mya when the Taconic island arc converged with Laurentia. This first orogenic event continued for the next 25 million years. The second orogeny, the Acadian, started about 430 to 425 mya when Baltica and Avalonian arc converged with Laurentia. This second orogenic event continued for the next 40 million years. Consequently, these two mountain building processes represents the series of collisions that accreted land from eastern Canada to the Carolinas. During this time, much of the continental United States was located between latitude 0 to 30°S (compared to present day of 30°N to 60°N respectively) and covered by shallow seas. [WC8]

The Alleghenian Orogeny, the third and final of this series of mountain building events occurred during the Mississippian and Pennsylvanian. This oregeny was a continent-continent tectonic convergence which included the complete subduction of the oceanic crust. This was the convergence of two ancient continental landmasses, Laurasia and Gondwanaland, which started about 356 mya that subsequently joined present day Eastern United States with North Africa to form the supercontinent Pangaea. Laurasia consisted of: Europe, Asia, North America, and Greenland. Gondwanaland consisted of: South America, Africa, India, Australia, and Antarctica. [WC8]

As a consequence of this final orogeny, the sedimentary stratagraphic sequence of the Cumberland Valley was folded, faulted, and rotated on its side about 90 degrees; with the younger (Ordovician) bedrock positioned at the north and the older (Cambrian) bedrock at the south. [WC6]

Between 320 and 300 mya, this limestone valley now known as the Cumberland Valley emerged from the sea. Following the three orogenies (≈300 mya) towards the end of the Pennsylvanian, the final geologic environment was orogenic – high, much like today's Rocky Mountains.

C. Dike (Diabase) forming – Triassic (Early)

This section explains my interpretation of the formation of the Cumberland Valley dike and its associated diabase rock between 260 and 240 mya in the early to middle Triassic.

The following characterize the formation of a dike [WC1]:

- Sign of ancient igneous activity
- Position is determined by fracture systems within the surrounding rock
- Radiate from ancient volcanic necks and thus reflect the stresses associated with volcanic activity
- Forms when magma enters a fracture and cools

Magma, derived partially from the oceanic crust and partially from the overlying mantle, reacts with the overlying crust as it rises. Composition of this magma may contain components derived from the following: oceanic sediments, metamorphosed oceanic basalt, peridotite in the mantle wedge, and from the overlying crust. [WC1]

Slower cooling from a basaltic magma source in shallow intrusions, small subsurface structures such as sills, dikes, lopoliths or laccoliths allowed individual crystals to grow slightly larger, up to about two millimeters in size – characterize the formation of the igneous rock, diabase. [WC3]

Volcanic activities continued long after the aforementioned orogenic collision as the Cumberland Valley "hovered" over a basaltic a magma source, between 300 and 240 mya. As illustrated in the following figure, after fracturing of the sedimentary strata (Orr, Osp, Ops), the basaltic magma filled the fracture, consequently becoming a diabase dike (TRd). This dike forming event occurred between 260 and 240 mya.

Partial A-A′ Cross Section [WC6]

Cuts through the area near Chambers farm cemetery as approximated on the map in Figure 2.6

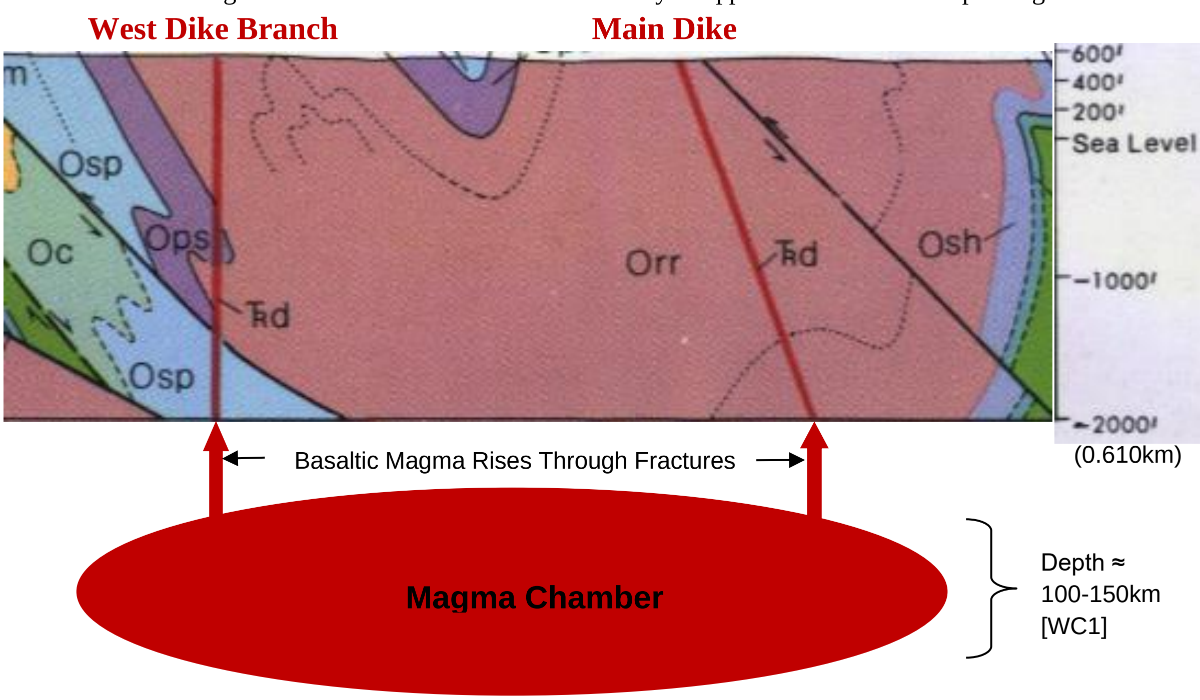


Figure 3.2: Dike (Diabase) Forming

D. Tectonic Divergence and Erosion – Triassic (Middle/Late) to Cenozoic

Continual erosion best describe the last 240 million years of the Cumberland Valley dike and the Appalachian Mountains in general. About 179 million years ago to present, the North American and African plates began to diverge as the mid-atlantic ridge formed and began moving the plates apart by sea-floor spreading. Consequently, this long period of erosion turned the young Appalachian Mountains into the old range of today.

Climate changes also impacted the area as the Cumberland Valley dike moved towards the northern latitudes from the equatorial region as previously described. Erosion by less rain and the introduction of a new erosive agent, ice, occurred over the last 100 million years.

As previously mentioned, after erosion, the surface expression of a dike is usually a long narrow ridge [WC1]. Thus, the following contributed to forming this diabase dike rock into a ridge:

- Softer surrounding sedimentary strata (e.g. limestone rock) eroded at a greater rate than the harder diabase dike rock
- Wind blown sediments from weathering of the surrounding mountains to the north and south of the Cumberland Valley covered the dike

Consequently, this great ridge was formed, today known as Stony Ridge.

Following ≈240 million years of erosion, this great dike now represents a prominent ridge cutting across the Cumberland Valley which can be seen and hiked at locations that overlap with the AT (see Appendix B). Its current geologic environment in today's Cenozoic, is orogenic – low, representative of an old mountain range that is part of The Appalachains.

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IV. Conclusion

As described by my observations and interpretations – The Cumberland Valley dike was created as a result of the continental collision of North America and North Africa due to the intense volcanic activity that is typical of that type of geological event.

The following table provides a summary of my interpretations. Beginning with limestone forming in an epicontinental sea during the Cambrian, to the oregenies which created the valley and volcanism during the Mississipian and Pennsylvanian, to the fracture of the sedimentary strata and subsequent diabase dike forming from volcanic activity during the Triassic (**bolded red**), and currently to the erosion from rain and ice forming the dike into a ridge while under tectonic divergence in the Cenozoic.

Table 4.1: The Cumberland Valley Petrogenesis Summary w/ Major States & Events

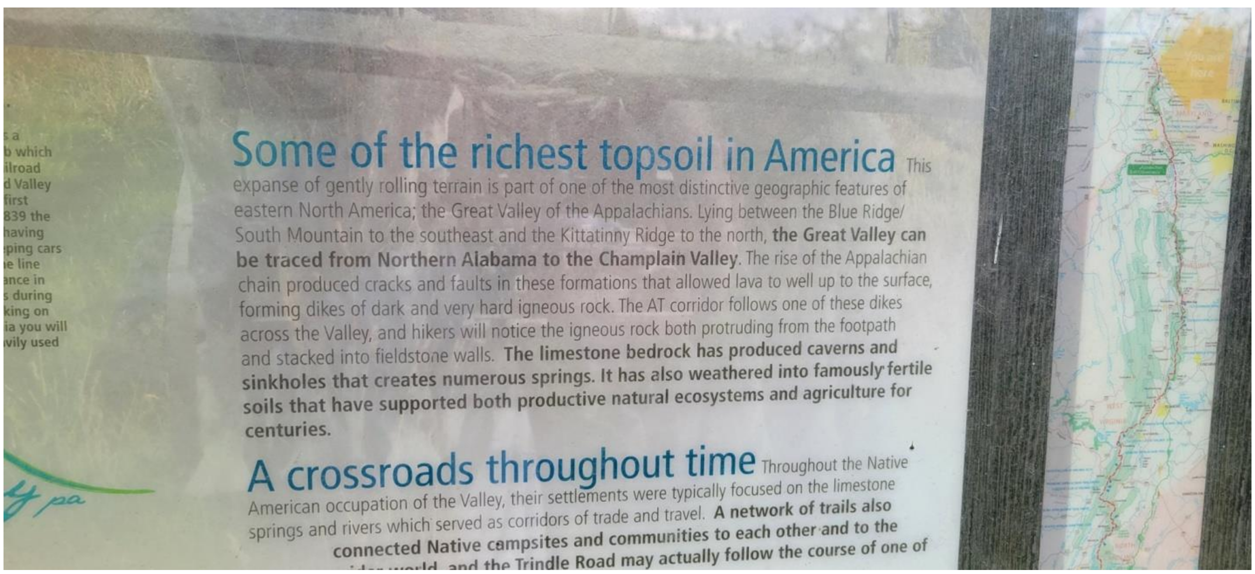
Geologic Time Period (Younger to Older)	State of the Cumberland Valley	Dominant Contributing Event(s) or Geologic Environment	Time Scale (mya)
CENOZOIC	Erosion forming dike ridge	Ice, Rain, Wind; Tectonic Divergence	--20
	Erosion forming dike ridge	Ice, Rain, Wind; Tectonic Divergence	--40
	Erosion forming dike ridge	Ice, Rain, Wind; Tectonic Divergence	--60
CRETACEOUS	Erosion forming dike ridge	Ice, Rain, Wind; Tectonic Divergence	--80
	Erosion forming dike ridge	Ice, Rain, Wind; Tectonic Divergence	--100
	Erosion forming dike ridge	Rain, Wind; Tectonic Divergence	--120
	Erosion forming dike ridge	Rain, Wind; Tectonic Divergence	--140
JURASSIC	Erosion forming dike ridge	Rain, Wind; Tectonic Divergence	--160
	Erosion forming dike ridge	Rain, Wind; Tectonic Divergence	--180
	Erosion forming dike ridge	Rain, Wind; Tropical Equitorial Climate	--200
TRIASSIC	Erosion forming dike ridge	Rain, Wind; Tropical Equitorial Climate	--220
	Erosion forming dike ridge	Rain, Wind; Tropical Equitorial Climate	--240
	1) Fracture, 2) Magma fill, 3) Diabase Dike	**Volcanic Activity**	--260
PERMIAN	Limestone valley above sea level	Volcanic Activity	--280
	Limestone valley above sea level	Volcanic Activity	--300
PENNSYLVANIAN	Limestone valley emerges from sea	Alleghenian Orogeny w/oceanic subduction	--320
MISSISSIPPIAN	Valley forming, Limestone folding & rotating	Alleghenian Orogeny w/oceanic subduction	--340
	Valley forming, Limestone folding & rotating	Alleghenian Orogeny w/oceanic subduction	--360
DEVONIAN	Sedimentation	Epicontinental sea	--380
	Sedimentation, Limestone folding	Epicontinental sea, Acadian Orogeny	--400
	Sedimentation, Limestone folding	Epicontinental sea, Acadian Orogeny	--420
SILURIAN	Sedimentation, Limestone folding	Epicontinental sea, Taconic Orogeny	--440
ORDOVICIAN	Limestone forming	Epicontinental sea	--460
	Limestone forming	Epicontinental sea	--480
CAMBRIAN	Limestone forming	Epicontinental sea	--500
	Limestone forming	Epicontinental sea	--520
	Limestone forming	Epicontinental sea	--540

Note: Scale for simplicity: each row represents about 20 million years.

Appendix A – Appalachian Trail (Trindle Rd (PA Rte 641) Parking Area)

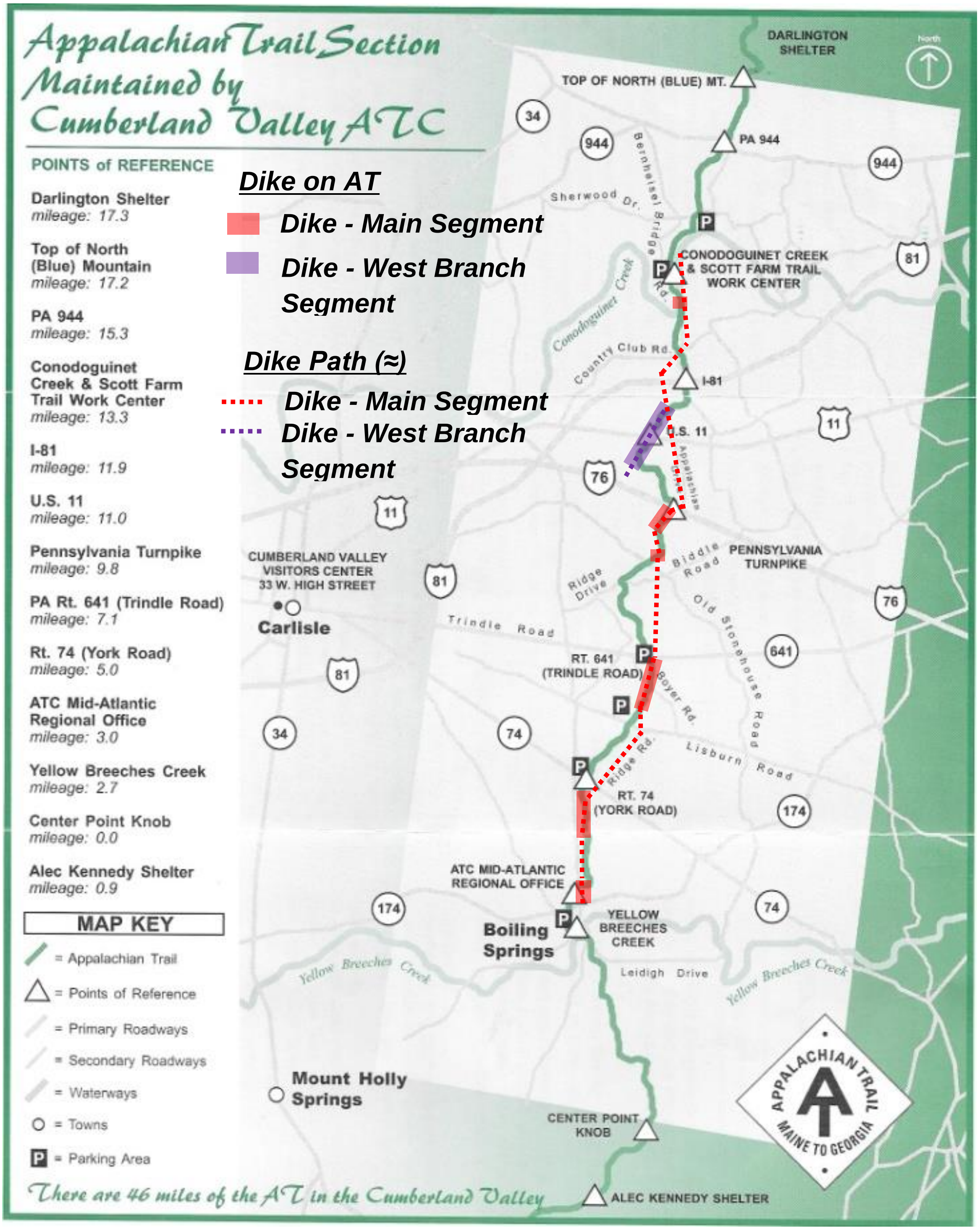
Trailhead sign below, located at Trindle Rd (PA Rte 641) Parking Area, sparked my interest in the topic to study this dike.

"...the Great Valley of the Appalachians. Lying between the Blue Ridge/South Mountain to the southeast and the Kittatinny Ridge to the north, the Great Valley can be traced from Northern Alabama to the Champlain Valley. The rise of the Appalachian chain produced cracks and faults in these formations that allowed lava to well up to the surface, forming dikes of dark and very hard igneous rock. The AT corridor follows one of these dikes across the Valley, and hikers will notice the igneous rock both protruding from the footpath and stacked into fieldstone walls."



Appendix B – Appendix Trail (Cumberland Valley)

AT Map [WC7] overlain with dike details that I added from my field observations.



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