AN ABSTRACT OF THE THESIS OF

Wendy Sonya Kelly for the degree of Master of Science in Geology presented on June 16, 2011.

Title: Cycles of Life and Landscape: Interpreting the Geological Foundation of Shenandoah National Park

Abstract approved:

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Robert J. Lillie

The significance of geology is commonly overlooked by the general public and underrepresented in free-choice learning environments including national parks that exhibit spectacular examples of geological features and processes. Parks are a major contributor to public learning, and a key way to teach how geology influences many aspects of our lives. Shenandoah National Park represents a snapshot of over a billion years of Earth's history. Phases of continental rifting and collision that formed the Appalachian Mountains reflect multiple "Wilson Cycles" of opening and closing ocean basins. Shenandoah's spectacular landscape is a product of past and ongoing geological processes that strongly influence the park's flora, fauna, and cultural history. Interpreting this landscape presents opportunities to increase public science literacy and draw attention to national parks as natural geological classrooms. By developing a geology-based training manual for Shenandoah National Park rangers, this thesis aims to increase ranger knowledge of the geological history of the Appalachian Mountains and thereby increase their ability to educate visitors about stories of the past, present, and future that these mountains have to tell.

This thesis is the precursor to a condensed geology training manual for the interpretive staff at Shenandoah National Park. The thesis is intended as a more in-depth reference for park rangers to help them better understand the significance of Shenandoah's geology. Its format and content have been guided by the results of an informal survey of the park's interpretive staff and two seasons of employment with the National Park Service (NPS) as a Shenandoah interpretive ranger. The thesis is broken into five primary sections. The first two discuss the big-picture geological story of the Appalachian Mountains, putting the geology of Shenandoah National Park into a broader context. The third and fourth sections zoom in on Shenandoah, revealing specific links between the park's geologic features and other aspects of it's natural and cultural history. A final section reviews basic principles of NPS interpretation and discusses how park rangers can incorporate geology into their educational programs.

As interpreters, national park rangers have the ability to bridge the gap between scientists and the general public. So often, important concepts that are explained by scientists do not reach the public because the public and the scientific community use two very different languages. Interpreters are the go-between. By speaking the language of both the scientist and the common public, interpreters can breach the language barrier and by doing so, greatly improve public science literacy, influence public policy, and increase environmental awareness. It is my hope that this thesis and the associated training manual will be used as an interpretive tool. By incorporating aspects of Shenandoah's fascinating geological story into their programs, park rangers can inspire the public to make intellectual and emotional connections to our country's natural history and its meanings. Ultimately, this will lead to greater appreciation and protection of our national park resources.

Cycles of Life and Landscape:

Interpreting the Geological Foundation of Shenandoah National Park

by

Wendy Sonya Kelly

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APPROVED:

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Major Professor, representing Geology

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Chair of the Department of Geosciences

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Wendy Sonya Kelly, Author

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Cycles of Life and Landscape:

Interpreting the Geological Foundation of Shenandoah National Park

PART I
Introduction

It is second nature to appreciate the view from the top of a mountain. But there is more to the landscape than aesthetic beauty. There is a story, bursting at the seams to be told. The Appalachian Mountains of the eastern United States provide a playground of physical outdoor adventures all the while presenting a virtual reading book of intellectual adventures through time and space. As scientists, we have the ability to be interpreters of the landscape. Interpreters can crack open the pages of this book of adventure, so that the public may explore the amazing story of the land, and by doing so, help understand the significance of our mountains, our planet, even ourselves.

This thesis has been developed specifically for the purpose of improving public science literacy. Its goal is to inspire Shenandoah National Park rangers to be creative interpreters of the land by revealing the connections between geology and cultural history, botany, and biology. In order to do so, the thesis has been divided into two major components: a story telling format and a technical format. Story telling is the primary language of Park Rangers. It is a technique they commonly utilize to communicate concepts to the public. As such, it is a familiar and useful tool. Part II and IV of the thesis solely use story telling to reveal the geological story of the Appalachian Mountains and Shenandoah National Park. Complementing the storytelling are Parts III and V, which are written in a more technical format. These technical sections synthesize relevant aspects of scientific research in order to provide a more in-depth understanding of the local and regional geology. Incorporated into Part III is also an in-depth review of the structural geology of the central Appalachian Mountains. This portion is provided for rangers who may want to significantly increase their understanding of why Shenandoah National Park looks the way it does. The format and content of the thesis were guided by a survey of Shenandoah National Park staff (Appendix A). The survey reveals strengths and weaknesses of Shenandoah employees in terms of their scientific background and knowledge of Appalachian geology. The survey also reveals how frequently park staff incorporate geology into park programs, and which geological concepts they struggle to understand and explain to the public.

What is geology and why should we care?

Geology is the study of the physical landscape and the processes that form and continue to modify it. The landscape tells a story of the past, present, and future that structures our very existence. It connects to, and to a large degree determines, the cultural, historical, and biological processes that occur in any location. It is our responsibility as interpreters to be the conveyors of this story to the public, and by doing so, increase Earth science literacy.

The National Science Foundation has funded a project called the EarthScience Literacy Initiative (www.earthscienceliteracy.org), which is dedicated to outlining big, relevant scientific ideas that connect the public to their planet. These foundational scientific concepts can greatly contribute to the development of geology-related national park ranger programs, and improve the significance of national park interpretation. The nine "Big Ideas" about the Earth and its processes are:

1. Earth scientists use repeatable observations and testable ideas to understand and explain our planet.
2. **Earth is 4.6 billion years old**.
3. **Earth is a complex system of interacting rock, water, air, and life**.
4. **Earth is continuously changing**.
5. Earth is the water planet.
6. Life evolves on a dynamic Earth and continuously modifies Earth.
7. **Humans depend on Earth for resources**.
8. Natural hazards pose risks to humans.
9. **Humans significantly alter the Earth**.

Each of these Big Ideas is close to being what interpreters might consider a "theme statement" that would help structure content about a particular aspect of geology and its deeper meanings within a park. Big Ideas number 2, 3, 4, 7, and 9 (in bold) might be particularly applicable to interpretive programs in Shenandoah National Park and are addressed throughout this thesis.

Why Interpretation?

Interpretation is a method to convey the meanings of our environment to a variety of audiences. It helps improve science literacy and public understanding of critical topics such as landscape development, natural resources and hazards, and climate change. Examples of famous interpreters include Carl Sagan, John Muir, and Stephen Hawking. With their help, complex scientific concepts have been translated into understandable language that has helped educate and inspire the public. These efforts have enabled citizens to apply science to bigger-picture issues, such as climate change, public policy, and even daily life.

The role of National parks.

National parks are free-choice learning (FCL) environments that reach a large portion of the general population. Parks provide critical opportunities to educate visitors about how the physical landscape connects to a region's flora, fauna, and human history. For many visitors, national parks are iconic landscapes that represent memorable and special experiences. The National Park Service strives not only to protect and preserve these special places, but also to provide the public with an experience that inspires them to become better stewards of the land.

Development of a geology training manual.

Successful scientific interpretation within national parks helps the public understand and value natural resources. The purpose of this thesis is to develop a training manual for the park rangers of Shenandoah National Park that improves understanding and communication of the geological history and deeper meanings of the Appalachian and Shenandoah landscapes.

Surveys distributed to 26 Shenandoah National Park rangers during the summer of 2009 and 2010 provide a formative assessment of park needs (Appendix A). The survey reveals that, although 36% of employed Shenandoah Park Rangers had attained college degrees, only one ranger had a degree related to Earth Science. It further suggests that rangers need more in-depth training in some concepts, including:

- an explanation of techniques geologists use to determine the age of rocks;
- a better understanding of geologic time;
- better appreciation of large-scale geological process such as plate tectonics and the metamorphism of rocks;
- working knowledge of how geologic events, including plate tectonics, have shaped Shenandoah's Blue Ridge Mountains;
- understanding of how geology relates to local flora, fauna, and cultural history

Such concepts are fundamental to understanding the landscape and are incorporated into the thesis and subsequent training manual. The thesis is divided into sections addressing both the regional (Appalachian) and local (Shenandoah) components of Blue Ridge Mountain geology. Geological concepts are revealed through engaging stories as well as technical review of each component, helping to establish a sense of time and place for Shenandoah National Park.

Commonly asked questions

Below is a short list of twelve common geology-related questions that visitors or park rangers have had about Shenandoah. They were compiled from 2009 – 2011 through informal conversations with park rangers, and formal interactions with park visitors. This list of questions is provided to help rangers better understand and interpret geological concepts while delivering programs or during informal communication with park visitors. These questions and the brief answers serve as a quick reference and each supplies a link to a portion of the thesis.

<u>1. What mountain range do I see?</u>

> Visitors may become confused about the names of portions of the Appalachian Mountains - there are many. Shenandoah National Park sits on the Blue Ridge Mountains. From the park, we can look far to the north and west and see layers of blue mountains in the distance that are the Alleghany Mountains of Pennsylvania and West Virginia. Directly west of the Park is Massanutten Mountain, a needle-shaped ridge, and further, the Shenandoah Mountains that border West Virginia. All of these mountains are small portions of the enormous Appalachian Mountain chain that extends from Alabama to Maine and up into the maritime provinces of Canada (for a map of these mountains, refer to Figure 11 on page 24 and Figure 12 on page 25).

<u>2. Were there ever glaciers here?</u>

> During the last ice age, polar ice sheets from the north expanded southwards across North America. The position of Shenandoah National Park was just south of the ice sheet, which terminated in central Pennsylvania. Even though the ice sheet did not reach the Blue Ridge Mountains, it had a great impact on the area that is now Shenandoah National Park (refer to the section: **Past Climate Change - an Age of Glaciers** on page 139 for more information about the last Ice Age).

3. Are there any caves in the park?

Caves and caverns typically form in water-soluble limestones, a type of rock made up of bits and pieces of calcium carbonate shells from ocean-dwelling organisms. The Shenandoah Valley is mostly underlain by various types of limestone, which is why so many commercial caves exist below the western boundary of the Park. Limestone is only seen in the very northern tip of Shenandoah National Park, where the Park boundary dips down into the lower elevations of the surrounding valley. Caves in the park are not commercial and are dangerous, so they are inaccessible to the public.

4. What kind of fossils are in the park?

Fossils are rare in Shenandoah National Park because these mountains formed due to the intense squeezing that occurred as Africa and other landmasses slammed against our coast 300 million years ago, forming the supercontinent called Pangea. This squeezing resulted in high temperatures and pressures in the rocks, erasing most of the fossils of shallow marine organisms that were preserved in the rocks prior to mountain building.

Only one type of fossil can be seen within Shenandoah today that survived metamorphism - a trace fossil called *Skolithos linearis*. These fossils look like very long pencil shapes within the metamorphosed sandstones (quartzites) of the Antietam and Harpers formations. A trace fossil is simply an impression, rather than the actual organism, that was left behind and preserved, like a footprint. *Skolithos linearis* tells us a lot about the environment where this organism once lived, and is an important hint about the ancient life of the Blue Ridge Mountain region (refer to the section **A new ocean is born** on page 69 for more details about the environment in which this organism lived).

5. Do you get earthquakes here?

Think of the Blue Ridge Mountains as an old house - occasionally, it creaks. Even though we think of earthquakes occurring on the west coast they have, do, and will probably continue to occur here in the east. This is because our mountains are riddled with faults. Sometimes, the land shifts or settles a little bit along one of these faults, resulting in what usually is a minor earthquake. The last one at the time of this writing occurred on July 16, 2010, a magnitude 3.4 that gently shook buildings and awakened some people at 5:05 am. It's epicenter, or point on the surface above where the faulting occurred, was near the town of Rockville, Maryland. Earthquakes have occurred in the past causing severe damage to local caverns by breaking beautiful cave formations (if you would like further information about Virginia Earthquakes, check this United States Geological Survey website: http://earthquake.usgs.gov/earthquakes/states/index.php?region=Virginia).

6. Were there ever volcanoes here?

Long before the Appalachian Mountains formed, there were volcanoes, fissures, and lava flows in the area that is today Shenandoah National Park. We see evidence of these features in park formations. The Catoctin Formation is a series of metamorphosed lava flows that spewed from fissures, or cracks, in the ground long before the Appalachian Mountains formed. This rock formation formed as ancient supercontinent Rodinia rifted apart. This rifting event caused many volcanoes, fissures, and lava flows to form all along the area that today is the Appalachian Mountains (for more information about this rifting event refer to the section ***Breaking Away*** on page 52).

7. Why does the greenstone of the Catoctin Formation not look like the basalt lava in Hawaii?

Lava flowed over this landscape hundreds of millions of years ago when the ancient supercontinent, Rodinia, rifted apart. At that time, the cooled lava, called basalt, would have looked similar to the dark lava flows seen in places like Hawaii. Since the lava flows erupted, the East Coast has been squished multiple times by several landmasses and island chains that collided with ancient North America. The collisions caused the rocks under our feet to become metamorphosed, or altered, by heat and pressure. The black basalt that once existed here became the grey-blue greenstone of the Catoctin Formation that we see today (refer to sections concerning collisional events and the **What is Metamorphism?** textbox on page 88 for more information).

8. Which type of rock in the park provides the richest soil?

The diversity of rock types within Shenandoah National Park contributes to a diverse range of soil types. Specifically, the Catoctin Formation greenstones break down to form the richest soils within the park. Refer to **Soils and Plants** on page 168 for more information about how bedrock contributes to Shenandoah National Park soils.

9. I heard that this area was under water once, is that true?

The Shenandoah National Park region was once on the very edge of the continent and occasionally was underwater. An ocean once covered much of ancient North America hundreds of millions of years ago. Many rocks throughout the United States capture this period of geologic history, including the Grand Canyon, which would have been at the other edge of the ancient continent. The Shenandoah Valley is underlain by thick sedimentary layers – mostly limestones that were deposited during this time. Although a shallow ocean covered much of this area in the distant past, the Appalachian Mountains themselves were never under water (refer to the section **A new ocean is born** on page 69 and Figures 37, 38, 40, 41, 42, and 45).

10. Are these Mountains still growing?

The Appalachians are a mature mountain range. They are no longer growing, unlike the Himalayas, which are in a tectonically active setting where continents are still colliding. Today, the East Coast of the North American continent sits on a passive continental margin, meaning that the primary processes occurring in this region are erosional – or the flattening of the landscape by wind and water. Millions of years in the future, Shenandoah National Park may sit on a flat plain when the Appalachian Mountains erode away. See **Weathering and Erosion – the fate of the Blue Ridge** on page 199.

11. How tall were the Appalachian Mountains in the past?

The Appalachian Mountains, in places, may have been as high as the Himalayas of today, towering to elevations of over 20,000 feet. When they first formed, the Appalachians may have been the largest mountain range on Earth at that time. In the vicinity of Shenandoah National Park, the mountains were probably at least twice as high as they are today. See The final collision on page 97, the textbox: **The Appalachians were how tall?** on page 105, and the textbox: **We've only scratched the surface** on page 116.

12. Are the Appalachian Mountains the oldest mountains on earth?

No! We need to clarify that there is a difference between when a mountain range formed, and when the rocks that are incorporated into the mountain range formed. For example, the basement complex in Shenandoah National Park is over a billion years old, however, the Appalachian Mountains did not form a billion years ago, they formed much more recently (approximately 300 million years ago). There are many locations across the Earth where rocks that are much older than Shenandoah's basement complex are exposed. Many of these rocks are the roots of ancient mountains. The Guiana Highlands of South America and the Barberton Mountains of East Africa are both at least twice as old as Shenandoah's basement complex. Compared to the Alps, Andes, Himalayas, or Rockies, the Appalachians are quite old, however, they are geologically a young mountain range.

PART II
The Appalachian Story – Our Foundations

Experiencing the life of the Appalachian Mountains takes us on an epic journey through space and time.

This section is written as a compelling story that summarizes the development of the Appalachian Mountain chain. It is designed for park rangers to use as a foundation for understanding and conveying the geological events that have shaped Shenandoah National Park. Versions of this story might be told to Shenandoah visitors during ranger programs, accompanied by a paleogeographic flipbook or other visual props. For this story, we'll be traveling through time from the distant past to the present, visiting global locations that illustrate the changes the East Coast of the United States underwent throughout its development. Our travels will establish a sense of time and a sense of place for the Appalachian Mountains.

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Early Appalachian geologists envisioned the story of these majestic mountains through the lens of their classic education. As a result, aspects of Greek mythology were used as a metaphor that contributed much to naming the natural features and geological processes that have shaped our world for millennia.

[1]*From the empty chaos of the void at the beginning of time, the primordial mother Gaia sprung forth. She created from herself the majestic Ourea, the mountains, that grew tall and jagged across the land and upwards towards the sky. Taken by Gaia's beauty, the sky, Ouranos, threw himself upon her, and together they conceived the powerful Titan gods and goddesses of the swirling sea: beautiful Tethys and Rhea, and handsome Iapetus. Gaia's children, having seen the callus nature of their sire, fought to free Gaia from the grips of the sky. Forever after, Iapetus's stout-hearted son, Atlas, would hold the defeated Ouranos upon his shoulders, separating the Earth and sky for eternity.*

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[1] This narrative is my own synthesis of information primarily derived from Hesiod's *Theogony*.

Imagine yourself standing in a rugged, mountainous landscape that is barren of all plants, inhabited by no animals. The story of the Appalachian Mountains takes us back in time, to an unknown and alien terrain. In many senses, it is one that is as foreign to us as an entirely different planet. Can you imagine a world without trees? A world without grass? This is the first stop of our journey - we've arrived on Mars (Figure 1). The rugged landscape of Mars, although foreign, is comparable to what was once the East Coast of North America one billion years ago. Unlike Mars, there was primitive life, but only the most basic forms; bacteria, fungi, algae, plankton, and viruses. This is where our journey begins, because at this time Shenandoah's rocky foundations were just being set, and Earth was a very different place than what we know today. In Mars, we find an unusual parallel to the early Appalachian Mountains. The barren land of our ancient North America was, then, in the southern hemisphere, squished up against other ancient lands that would become modern South America and Africa. Imagine one giant supercontinent, surrounded by a single, massive sea (Figure 2a).

Although Earth's continents were barren and lifeless, there were grumblings of movement deep within Earth's stomach. Tremendous heat and pressure had been building beneath this mass of rocky, barren land. The heat and pressure tore the land apart like gooey saltwater taffy (Figure 2b). Now imagine you are in modern eastern Africa. Look around you and you'll see that hot lava is spewing out of the ground from volcanoes and along long tears (Figures 3 and 4), depositing thick layers of lava across the land. Eastern Africa is a special place today because it is giving birth to new oceans. 700 million years ago, this is exactly what was occurring right here, as the giant continent ripped apart.

As the land continued to tear, it gave way to a new, sub-tropical ocean. Let's travel now to the modern coast of Florida. Warm waters lap against the shore, swirling ripples of tan-colored sand this way and that (Figure 5). The region that is today Appalachia was, in fact, the edge of a vast ocean 500 million years ago. And as Earth's stomach grumbled and the land's surface changed, so too did life. Multi-celled creatures were evolving and populating the Earth. Worms spent their days burrowing into the warm beach sands looking for food, leaving behind long, pencil-shaped burrows that we can see today - remnants of ancient life in Shenandoah National Park (Figure 6).

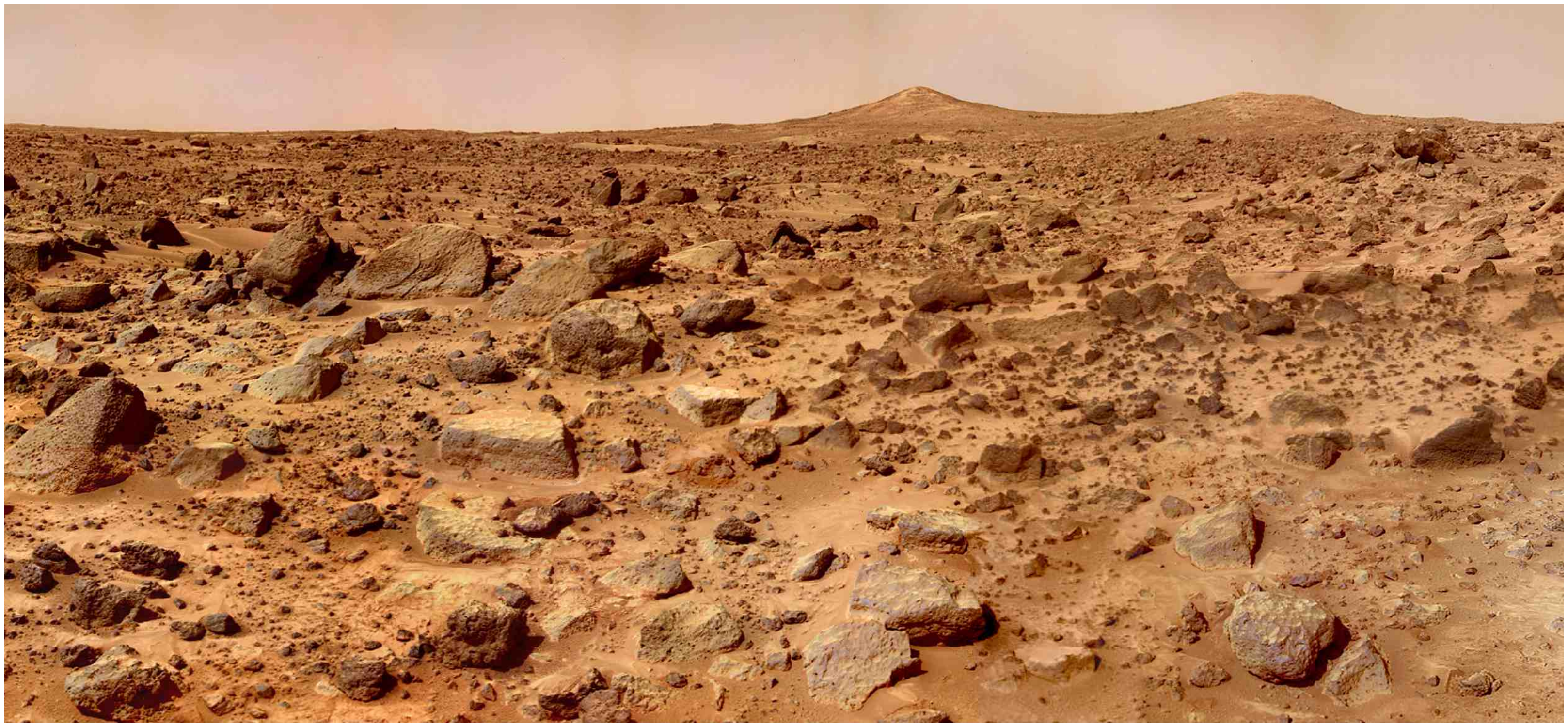

Figure 1: The rocky terrain of Mars may be what Earth looked like over a billion years ago. Earth was void of any plant life, making the landscape appear much more harsh and quite foreign to eyes that now gaze across the densely vegetated Appalachian Mountains. Mars may give us a unique analogy to what Earth looked like during the union of supercontinent Rodinia, over a billion years ago. (Photograph taken by the 1997 Pathfinder expedition, courtesy of the National Aeronautics and Space Administration, NASA)

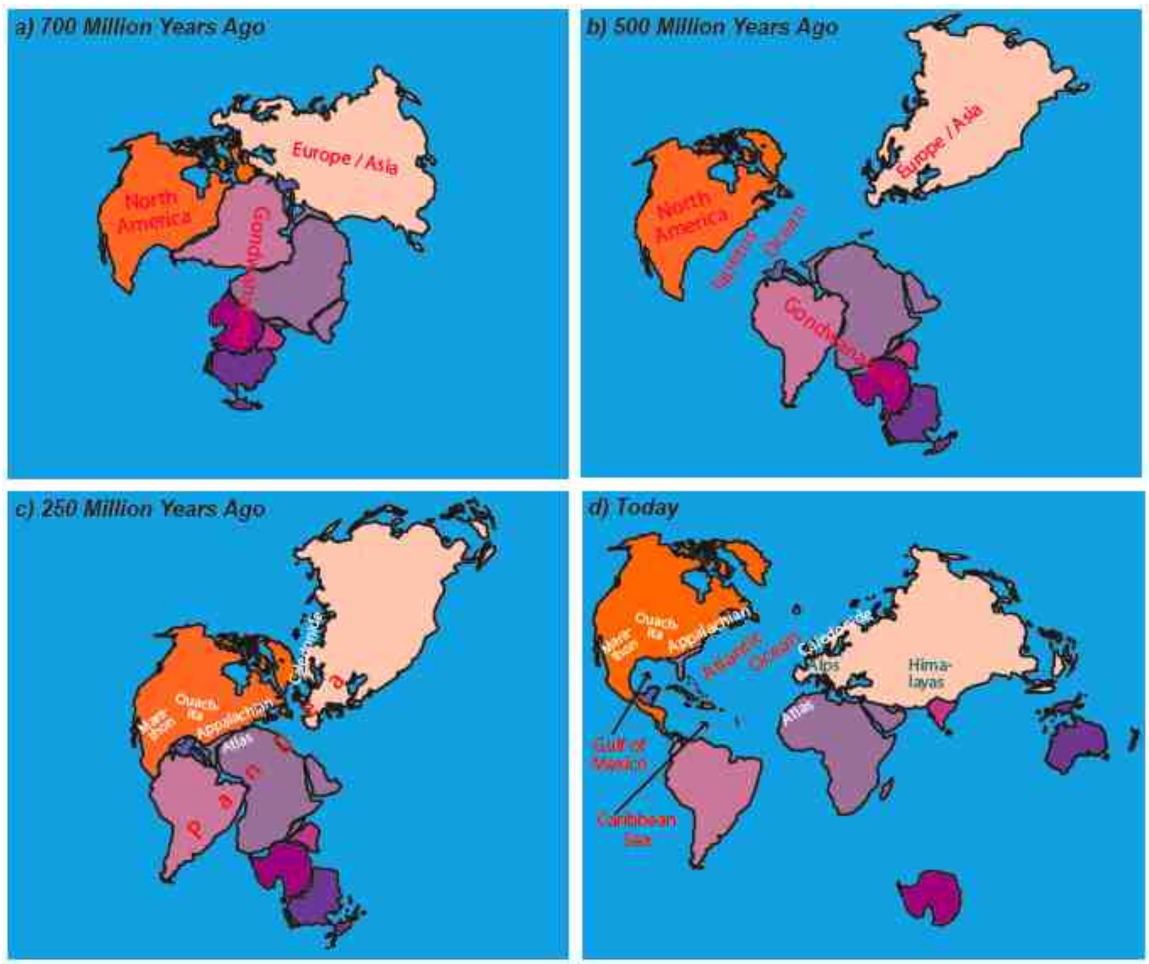

Figure 2: The story of the Appalachian Mountains is one of opening and closing oceans. A billion years ago, there was a massive continent called Rodinia (a). Rodinia broke apart (b), only to come crashing back together millions of years later to form Pangea (c). Pangea ripped itself apart to form the geography we are familiar with today (d). Note: This is a cartooned illustration of paleogeographic maps that has the outline of continents as they appear today. More technical and accurate maps can be viewed within Part III. (Modified from Lillie, 2005)

Figure 3: Africa is ripping apart, like North America did 700 million years ago. This massive crack in the ground in eastern Africa marks the location of a huge tear, along which a new ocean may eventually grow. The landscape of eastern North America may have looked like this 700 million years ago as the supercontinent of Rodinia began to rip apart. (Courtesy of the Afar Consortium: www.see.leeds.ac.uk/afar).

Figure 4: Along these massive fissures, magma breaches Earth's surface forming volcanoes. The lava erupts into lakes and eventually flows along the landscape. (Courtesy of The Afar Rift Consortium: www.see.leeds.ac.uk/afar).

Figure 5: The Shenandoah region sat on the shore 500 million years ago. This view from a Florida beach is perhaps similar to what we would have seen in the past (minus the birds!), peering from the shoreline of ancient North America across the Iapetus Ocean as the sun set in an ancient sky. (Photograph by Wendy Kelly)

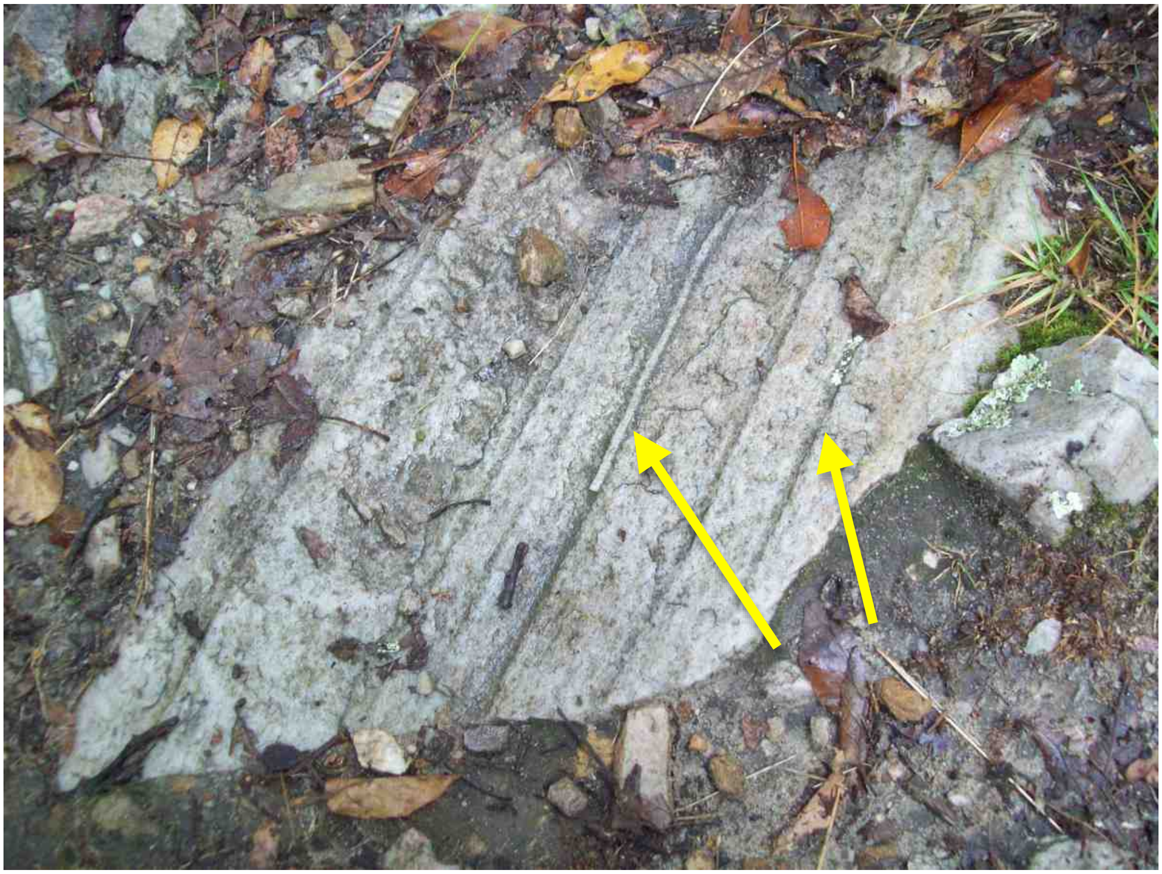

Figure 6: Trace fossils preserve ancient life in Shenandoah. Fossilized burrows of ancient worms that lived during the Cambrian Period (about 500 million years ago), are now preserved in metamorphosed beach sand (quartzite) of the Antietam Formation. The worms lived on the beach that once spanned the region that is now the Appalachian Mountains. (Photograph taken by Wendy Kelly on Cavalry Rocks, Shenandoah National Park)

Here, change is the only constant. As time passes, the interior mountainous landscape is attacked by the strong forces of nature. The sun, wind, and rain crumble the land to pieces as gravity slowly carries it away in landslides and along rivers to the ancient ocean, building onto those beautiful, sandy beaches. But the Greek's Gaia – Mother Earth - would give birth to many new mountains and oceans soon enough. Think of the Earth as a massive recycling machine. When oceans form, it is because the land is ripped apart. When mountains grow it is because the land is crunched together. And when volcanoes spew hot lava it is sometimes because land is pulled underground into Earth's hot stomach, resulting in melted rock that flows back to the surface.

If we had ventured to sea from North America 500 million years ago, we might have seen steaming volcanic islands, like Hawaii. As recycling occurred, the islands, along with other small pieces of continents, moved closer to ancient North America. Rock layers that were thick mud and sand were scraped off the sea floor and squished like toothpaste onto the coast (Figure 7).

In a final blow, 300 million years ago, a massive continent collided with our shore (Figure 2c). The coast buckled, cracked, and folded like rumples in a squished carpet. Massive slices of land broke free and slid past one another, traveling upwards and inland (Figure 8), forming a new, jagged mountain range. These were Gaia's new children, the Appalachians, and at that time, they were the fiercest mountains on Earth, perhaps rivaling the modern Alps in Europe or even the majesty of the mighty Himalayas of Asia (Figure 9), where, today, India is crashing into Asia.

When the Appalachians crashed into being, every continent had united once again (Figure 2c). You could have walked across the rugged mountains from North America directly onto Africa. It wasn't until just after the dinosaurs began stomping around the Earth that our familiar Atlantic shore formed as we were torn apart from Africa (Figure 2d) - Earth's stomach grumbled once again as the giant plate tectonic recycling machine continued running its course.

Over the next couple of hundred million years, the mountains of Appalachia were slowly battered and broken, crumbling into pieces from wind and rain, just as their ancestors had been hundreds of millions of years before. The eroded mountain pieces traveled in rivers down the mountains and towards the sea, forming the calm and flat coastal plain and leaving the once rough and jagged Appalachians more smooth and rolling, as we see them today (Figure 10).

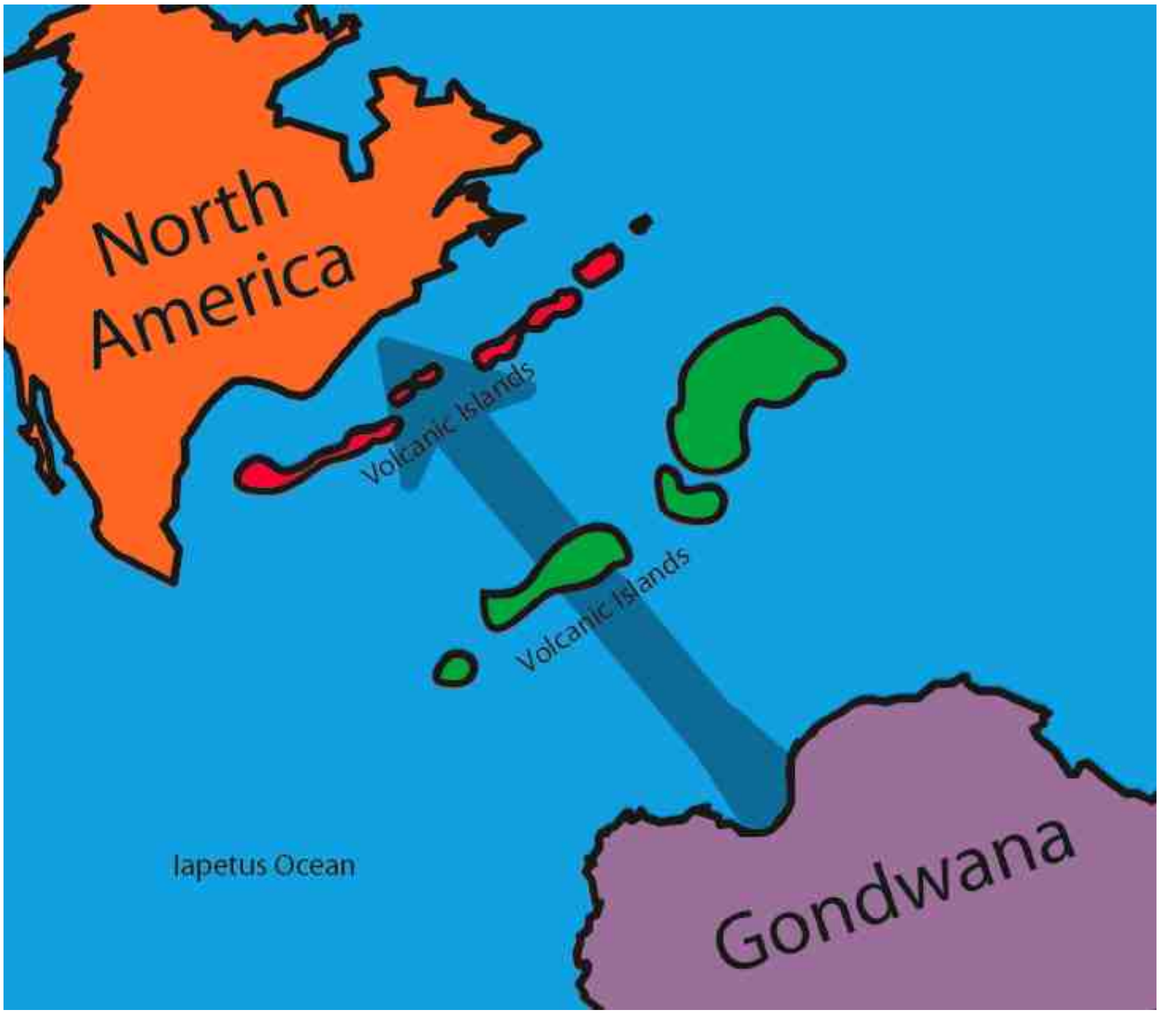

Figure 7: Three landmasses collided with ancient North America to form the Appalachian Mountains. Volcanic islands, small pieces of a continent, and a massive continent collided with the coast of North America hundreds of millions of years ago. (Modified from Lillie, 2005)

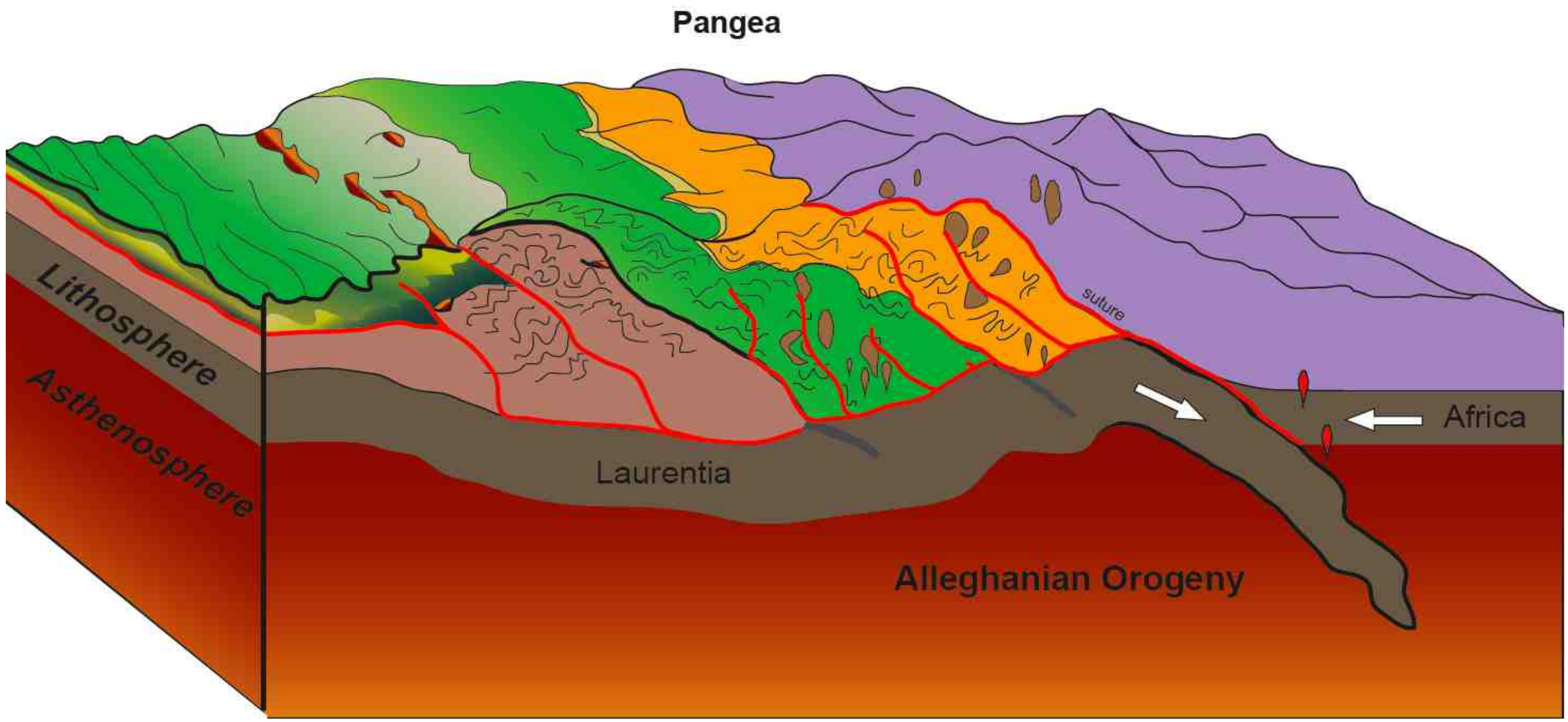

Figure 8: The final collision formed the towering Appalachian Mountains. As Africa collided with Northern America about 300 million years ago, the land was crumpled, folded, and faulted, forming a rising, dramatic mountain range. (Modified from Lillie, 2005)

Figure 9: The young, jagged mountains of the Himalayas in Asia. The Appalachians perhaps looked similar when the collision of continents formed the supercontinent known as Pangea. (Photograph from Lillie, 2005)

Figure 10: The Appalachian Mountains of central Virginia during a fall day. Today, these mountains are smooth and sinuous, as opposed to the sharp and jagged mountains they were sculpted from. (Photo courtesy of the National Park Service)

PART III
The Appalachian Story - Technical review

Entire oceans open and close as continents rip apart and crash together, leaving traces that tell the story of the Appalachian Mountains.

Part III of the thesis is an in-depth geological history of the Appalachian Mountains. Its content is more technical than Part II, providing detailed information about the geological processes that have shaped the Appalachian Mountain chain and its geological features. This will help Shenandoah National Park rangers add depth to a variety of interpretive programs. Geologic concepts or features will be tied to specific locations within Shenandoah National Park and are written in **bold and underlined**.

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A. A Brief Background

The Appalachian Mountains formed from a series of geological events that occurred over a vast expanse of time and space. The resulting mountain chain covers over 2,000 miles (3,000 kilometers) of eastern North America, stretching all the way from Alabama to Newfoundland (Figure 11). But the mountain chain is far more extensive. In addition to the Appalachian Mountains in North America, other parts include the Caledonide Mountains in Greenland, the British Isles, and Scandinavia, as well as the Atlas Mountains in western Africa (Figure 12). This enormous mountain chain formed as oceans closed and continents collided from 450 to 280 million years ago. It has since been fragmented because the continents ripped apart as the Atlantic Ocean opened in the past 200 million years. As one of the oldest mountain ranges on Earth, the Appalachians capture a long and unique geologic history – a vivid autobiography of the landscape that, upon reading, takes us on an epic journey through much of Earth's history (Figure 13).

In the Shenandoah region, the events that formed the Appalachian Mountains have resulted in distinct physiographic provinces (Figure 14). From west to east, the provinces are described as follows:

- The **Appalachian Plateau** represents the relatively undeformed interior of ancient North America. Other than mild deformation and the deposition of sediments, this area was not severely impacted by events that formed the Appalachian Mountains.
- The **Valley and Ridge Province** is a deformed, sinuously-crumpled carpet of folded and faulted sedimentary rock layers that rippled like an accordion and slid westward in front of the Blue Ridge.
- The **Blue Ridge Province** contains highly deformed, ancient igneous and metamorphic rocks that represent the exposed roots of the Appalachian Mountains and the remains of the ancient edge of North America. These rocks were cracked, crunched, uplifted, and shoved westward as a broad upfolded mass of rock (an anticlinorium).
- The **Piedmont Province** literally means the 'foothills.' This province includes highly-deformed igneous and metamorphic rocks, as well as younger sedimentary deposits. They include the remains of an ancient ocean, fragments of other landmasses that collided with ancient North America, and rift basins from opening the Atlantic Ocean.
- The **Coastal Plain** is largely a chunk of land that broke off of Africa and has been covered by sediment that eroded off the Blue Ridge and Piedmont Provinces.

The following pages recount this journey, not only taking us back through time over a billion years, but also across the modern-day globe and down through the depths of the interior of our planet. We begin at a moment in time when most of the continental masses of Earth were one huge continent, and the landscape was barren like the surface of Mars. We then travel through time to experience the drama and confusion of a land torn apart by continental rifting. The constant lateral bombardment of this new land by other continents and smaller landmasses illustrates the long-term development of the Appalachian mountain range. We conclude with the current landscape – the slow and eventual erosion of a mighty mountain range down to more subtle topography following modern North America's birth and independence from the rest of Earth's continents.

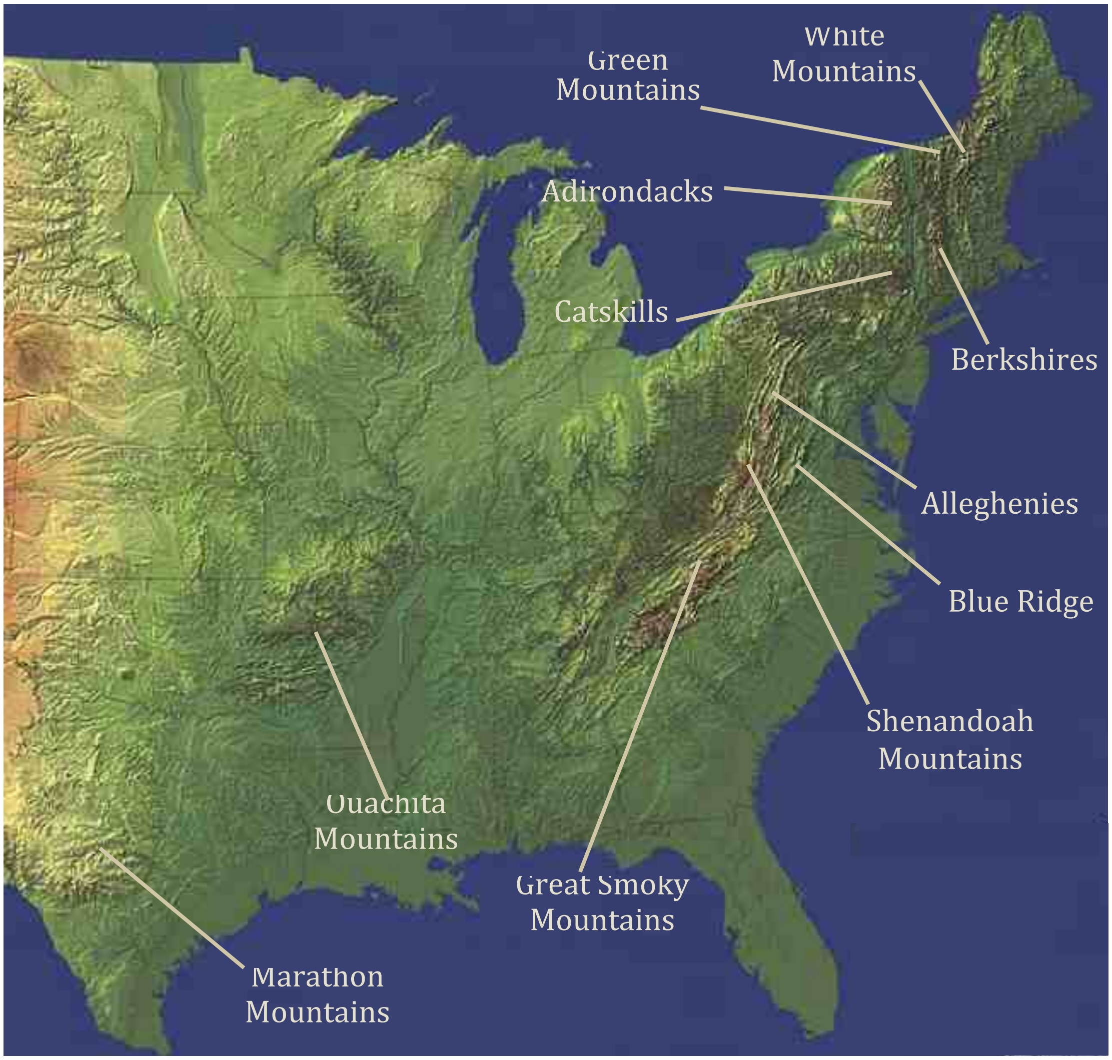


Figure 11: The Appalachian Mountains extend from Newfoundland to Alabama. Because they are so extensive, the Appalachians have been broken into familiar 'sub-mountains'. Like wrinkles across the landscape, the Mountains are the ancient roots of a mountain chain that once appeared more like the Rocky Mountains of the western United States. (Courtesy of the U.S. Geological Survey)

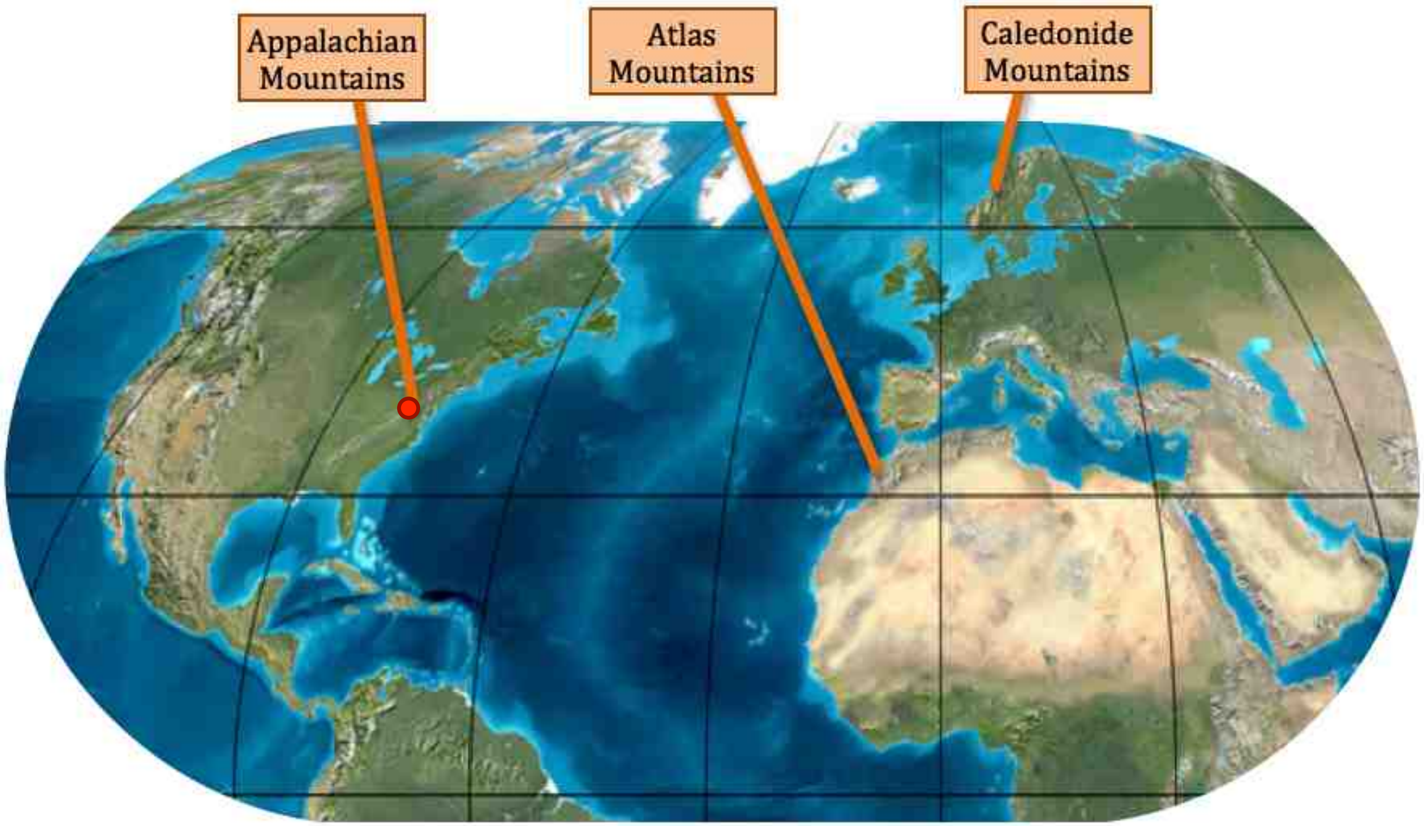


Figure 12: The Appalachian Mountains of North America are only a piece of the whole. These mountains were torn away from their siblings – the Atlas Mountains and Caledonides of Europe and Africa about 200 million years ago, when the massive supercontinent Pangea ripped apart opening the modern Atlantic Ocean. The red dot indicates the approximate location of Shenandoah National Park. (Map modified from Dr. Ron Blakey, Northern Arizona University)

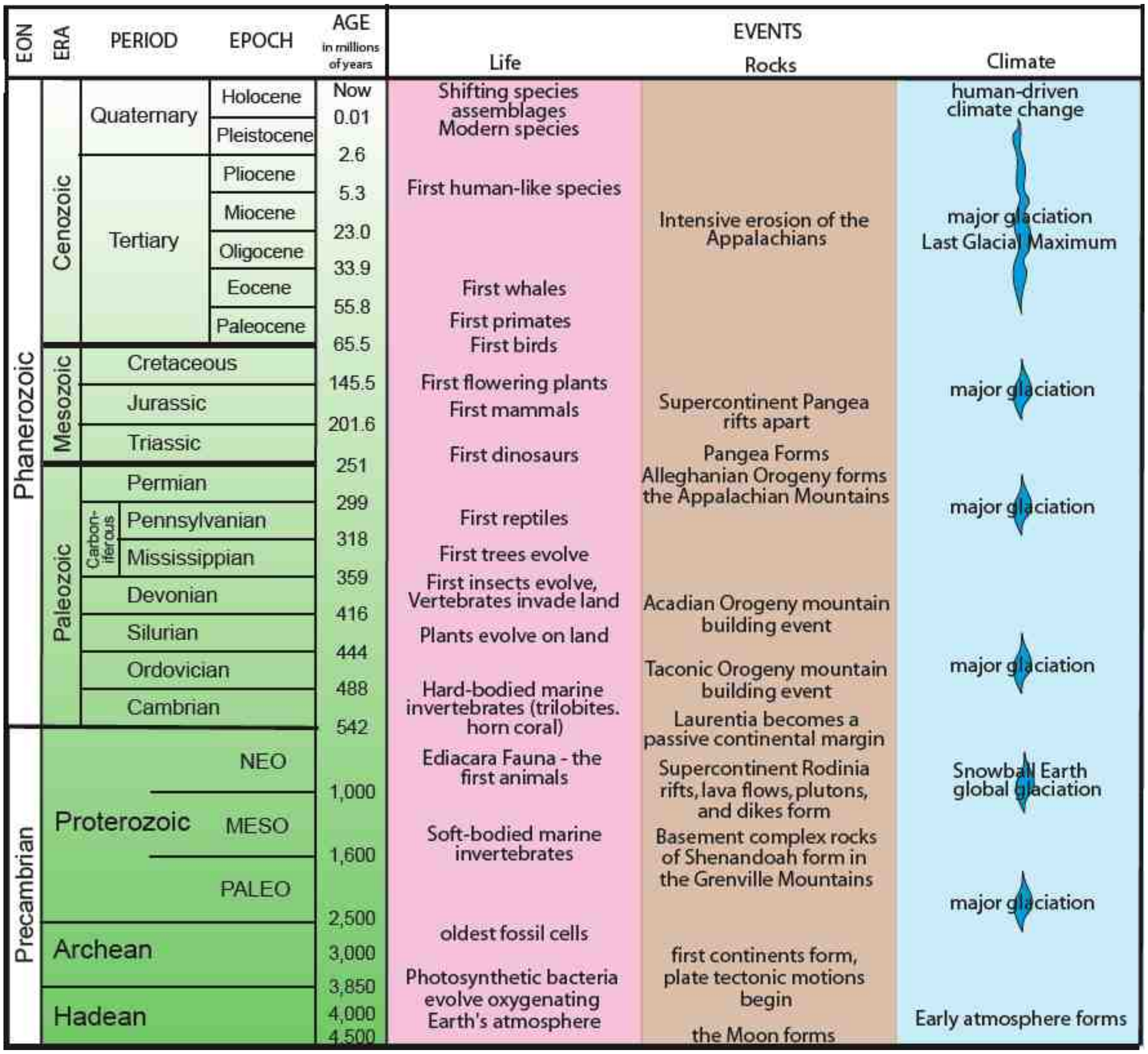


Figure 13: A timeline of events that shaped the modern landscape of the Appalachians. Note that the scale changes as the table approaches modern time.

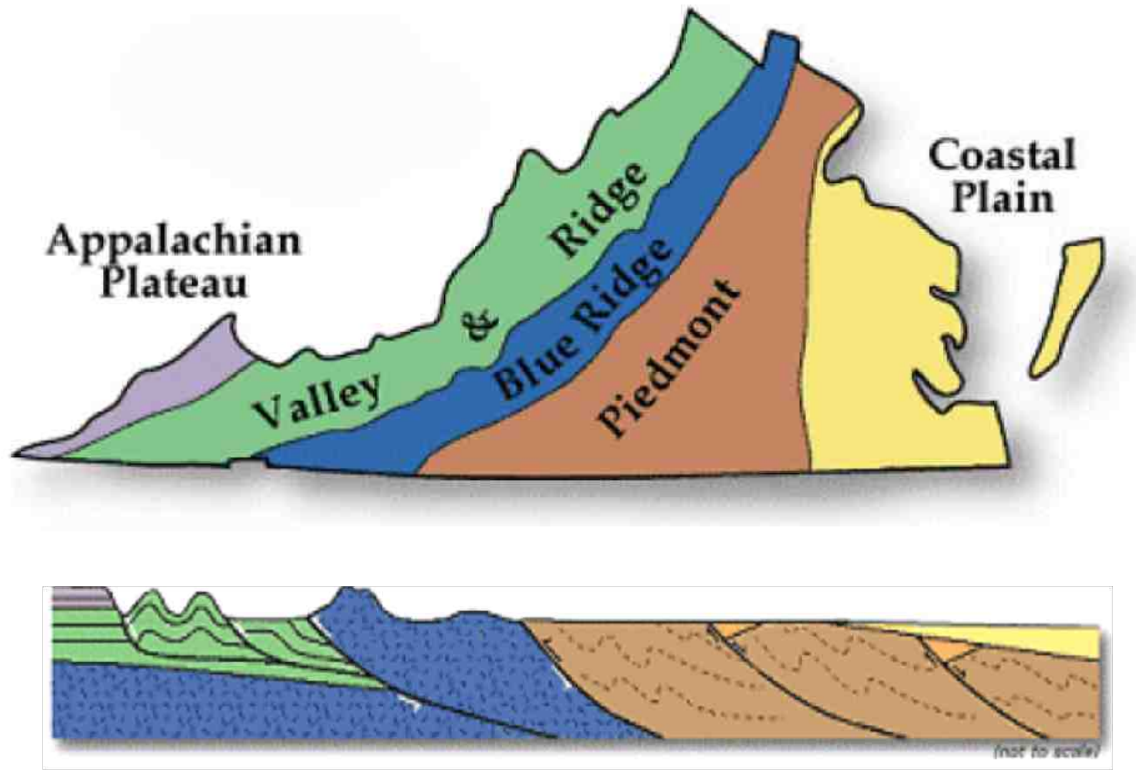


Figure 14: The physiographic provinces of Virginia tell the story of the Appalachian Mountain chain. A bird's eye view of the state from above paired with a simple geological cross section below help us see each distinct province. From the west, the Appalachian Plateau is the relatively undeformed land that was in front of the uplifting Appalachian Mountains. The Valley and Ridge Province folded like an accordion, riding the waves of deformation in front of the incoming Blue Ridge Province. The Blue Ridge is essentially a massive fold of hard rock on the edge of ancient North America that was crushed and transported from the east. The Piedmont Province is also highly deformed rocks of the closed ocean, including metamorphosed ocean crust and overlying sediments, as well as fragments of volcanic islands and other landmasses. The coastal plain is formed of many layers of sediments that eroded off the mountains onto a fragment of land that broke off of Africa. (Modified from the College of William and Mary Geology Department website, Available: http://web.wm.edu/geology/virginia)

B. An Ancient landscape

Going further and further back in time becomes more and more of a geologic challenge. Like uncovering a Sherlock Holmes mystery, we start with bits of known information and then piece together scenarios that seem most plausible. The more factual information we uncover, the more evidence we have to support or disprove possible scenarios.

Through much of Earth's history, masses of land have collided and ripped apart, forming new land, new mountains, and new oceans. This process of opening and closing oceans is called a Wilson cycle (Wilson, 1966). Two complete Wilson cycles have shaped the eastern North American continent (Thomas, 2006). North America, as we know it today, is the amalgamation of multiple slices of land that have been zipped together over the course of a few billion years (Hatcher, 2002; Williams and Hatcher, 1983). These so-called accreted terranes (also referred to as suspect terranes or exotic terranes) are unique from each other and add to the mass of continents over time, allowing gradual, but dramatic changes in the appearance, and even climate, of our Earth (Williams and Hatcher, 1983).

The current landscape of Shenandoah National Park relates to events that began over a billion years ago, when North America looked very different than it does today. We begin our story of the Appalachian Mountains over 1.2 billion years back in time. The hard-rock foundation (referred to by geologists as the crystalline basement or basement complex) of the Appalachian Mountains formed at that time, as ancient North America (Laurentia) collided with another ancient landmass, becoming a massive continent known as Rodinia (McMenamin and McMenamin, 1990; Figure 15). This collisional event is called the Grenville orogeny and brought change to the land that would eventually become the eastern United States. Paleogeographic reconstructions over the past thirty years have focused on accurately depicting the positions of Earth's continental landmasses back through the earliest geologic time (for example, Stewart, 2009). The problem is four-dimensional. Continents move in three dimensions: laterally across the surface of the Earth, as well as vertically up and down. But there is also the fourth dimension of time, which is why a series of illustrations is needed to reveal the evolution of the Appalachian region.

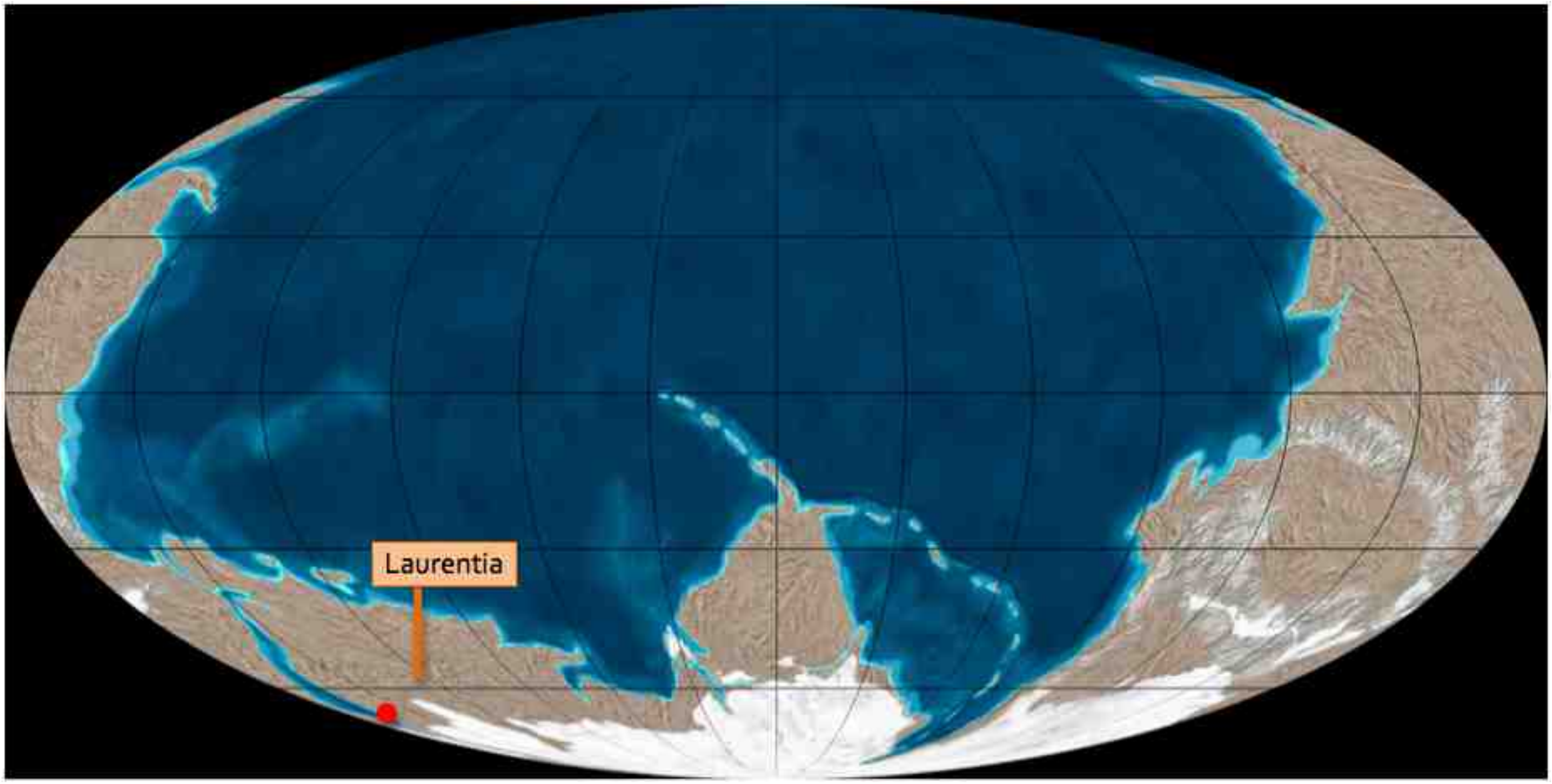


Figure 15: A supercontinent called Rodinia existed 600 million years ago. During this time, most landmasses on Earth had drifted together, squeezing into one. The small red dot represents an approximate location of what would become Shenandoah National Park. Modern North America will take form from the ancient continent called Laurentia. (Courtesy of Dr. Ron Blakey, Northern Arizona University)

As Rodinia formed between 1.3 and 1.0 billion (1,300 to 1,000 million) years ago, most of the continental masses on Earth squished together, deforming rocks throughout what would become the eastern United States, eastern Canada, southern Greenland, the British Isles, and Scandinavia (Wicanter and Monroe, 2000). The sequence of geological events that results in the formation of a mountain range is called an orogeny. The Grenville Orogeny refers to the collision of the continent Laurentia with other landmasses, forming the supercontinent called Rodinia. When this occurred, large volumes of magma intruded into the base of the crust, leaving subterranean blobs of magma (plutons) all along the border of the continental collision zone. This igneous intrusive magma cooled very slowly over time, insulated beneath the heart of the ancient Grenville Mountains.

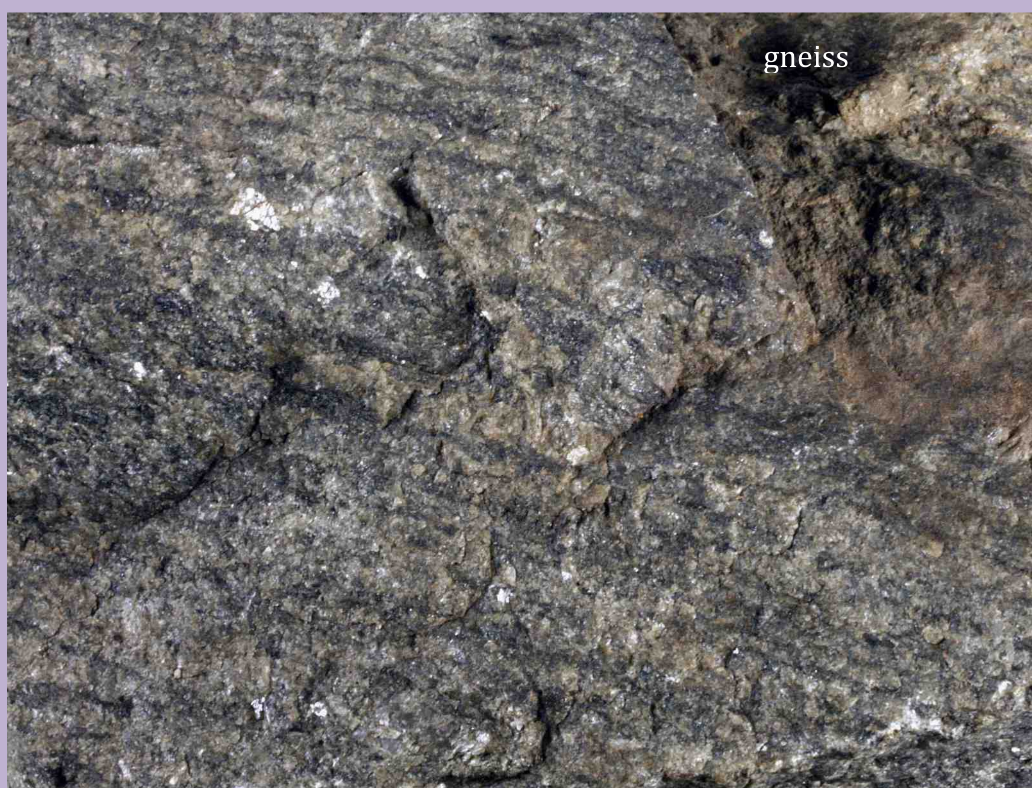
The slow cooling of magma allows time for large crystals to grow, leaving behind rock such as the granite with which we frequently top our kitchen counters. Such intrusive plutons now form the basement complex exposed in Shenandoah National Park (including **Old Rag Mountain**) and elsewhere along the modern-day Appalachian Mountains, including the Adirondack Mountains of New York (Fichter and others, 2010; McLelland and others, 1996; Rankin, 1994; Figures 16 and 17). These basement rocks are literally 'the basement' – underlying much of the landscape underneath younger sedimentary rocks. The strip of ancient basement rock that runs along Shenandoah in the Blue Ridge Mountains is referred to as the Shenandoah massif (Figure 17).

While all these processes were occurring underground, the world above ground was just as interesting. Changes in climate caused four major episodes of glaciation between 900 and 600 million years ago. These included Earth's most extensive global glaciation, referred to as Snowball Earth (Hoffman, 1998; Kennedy and others, 1998; Hoffman, 2001; Fairchild, 2001), and impacted eastern Laurentia by playing a major role in breaking down the ancient Grenvillian Mountains (Wicanter and Monroe, 2000). The weathered and then eroded fragments of these ancient mountains were carried down through valleys by streams and rivers to the coast and deposited as conglomerates and sandstones that are now observed within the modern Appalachian landscape. Such sedimentary layers made from the broken fragments of the silica-rich basement rocks are referred to as siliciclastic rocks. They comprise the Swift Run Formation (approximately 700 – 575 million years old) in Shenandoah National Park found along the **Bearfence Mountain** Trail.

The Secret Life of Rocks

Wandering through the Appalachian Mountains we are likely to see a homogenized view of moss and lichen covering the landscape. But beneath the lichen lies a cornucopia of rocks, each appearing strikingly different from the other. In order to read the Appalachian's autobiography, we must learn the language of these rocks.

Metamorphic Rocks:
The most common type of rock occurring throughout the Appalachians and many other mountain ranges on Earth, metamorphic rocks are named for the changes they have undergone. These rocks have experienced high pressures and/or high temperatures that altered the very fabric of the rock. The change reveals itself through the alignment of flat or rod-like minerals, as pressure squeezed the rock. This alignment of dark and light-colored minerals makes the rock look striped, or banded. A good example is gneiss, which can be found in the basement complex rocks of Shenandoah National Park. Look for these rocks along the Appalachian Trail near the **Little Stony Man Cliffs**.



Igneous Rocks:
Igneous rocks come in two flavors; intrusive and extrusive. Igneous intrusive rocks formed from magma that did not reach Earth's surface. Instead, the magma remained underground, insulated by the surrounding rock and cooled very slowly. As the magma crystallized, its chemistry allowed a variety of minerals to form. Over time, the mineral crystals grew larger and larger. The rate of cooling determines how large the crystals grow – slow cooling over a long period of time results in very large crystals, whereas a blob of magma that cools rapidly 'freezes' growth before large mineral crystals form. A slow-cooling intrusive rock, such as granite, which comprises **Old Rag Mountain** in Shenandoah National Park, is a mass of large interlocking crystals.

The extrusive variety of igneous rocks were once magma that flowed out onto Earth's surface as lava. Because the extruded lava is not insulated within the Earth, the lava cooled so quickly that crystals did not have time to grow very large. A metamorphosed version of the fine-grained igneous extrusive rock called basalt can be found on **Stony Man Mountain** in Shenandoah National Park.

Sedimentary:
When small bits and pieces of rocks (sediments) settle together and become cemented like glue, a sedimentary rock forms. Sediments may collect from landslides (including those occurring underwater known as turbidites), rock falls, and deposits in lakes, oceans, and rivers. They harden to form sedimentary rocks such as sandstone, limestone, and conglomerate. An example is the Swift Run Formation up to **Bear Fence Mountain**.

There are many ancient sedimentary rock layers in Shenandoah National Park, but sedimentary deposits are still forming - recent storms have triggered thousands of landslides all along the mountains. Those loose deposits may eventually become cemented into hard sedimentary rock. Farther beneath our feet, the Blue Ridge Mountains hold many quartzites. Once sandstone, these rocks were altered under heat and pressure to become metamorphic rocks.

Other interesting components of Earth during the late Proterozoic Eon included the atmosphere and evolution of life. Early in Earth's history (over 4 billion years ago), our atmosphere was completely devoid of oxygen. Over time, the chemistry changed in ways that allowed the development of life. By a billion years ago, the air was still thinner than it is today, containing less oxygen (Wicanter and Monroe, 2000 p.226-228). As the atmosphere was making it's transition, so too was life. An extremely important event had just occurred in Earth's evolutionary history - the dawn of multicellular organisms. Early life on Earth consisted of microscopic, single-celled algae and bacteria. Mutations and evolution formed multicellular life, allowing organisms to become larger, longer living, complex life forms. Multicellular green algae and other organisms quickly evolved, but these new creatures were confined to the sea. We would have to hike across the lifeless, barren landscape of Laurentia in order to find life at the shore (Wicanter and Monroe, 2000). Large mats of algae called stromatolites layered over the sandy sea floor, forming what would become some of the earliest signs of life in the fossil record.

If we were to land on the Martian surface today, we would cast our eyes on a barren landscape. Rocks, dust, and our footprints would comprise the view - a view that may give us clues about how Earth appeared over a billion years ago. Without the presence of life as we know it today, the Martian surface is rough, with rocky highlands like mountains, and smooth but dusty lowlands (Figure 18). The only thing that moves past our vision would be particles of dust carried along by the winds. On Earth a billion years ago, we would have seen and felt perhaps a similar landscape. In this way, some of the other planets may present interesting parallels to Earth, as snapshots of 'what it would have been like' hundreds of millions of years in the past, or perhaps even, in the future.

Figure 16: The foundation of the Appalachian Mountains is ancient rock. Referred to as the basement complex, these crystalline gneisses and granites are over a billion years old, capturing a rich history of dynamic geological processes. Photograph courtesy of the National Park Service.

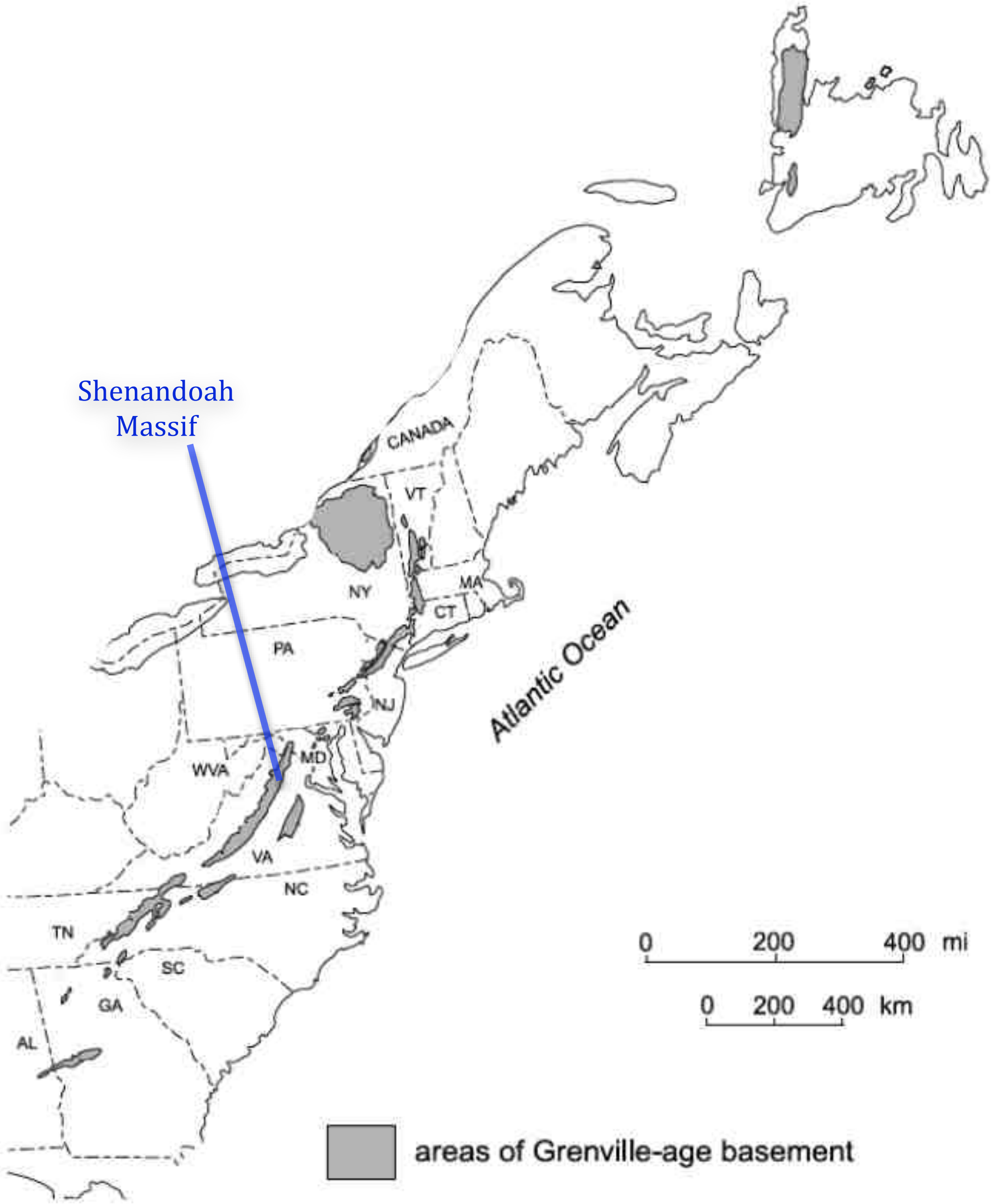


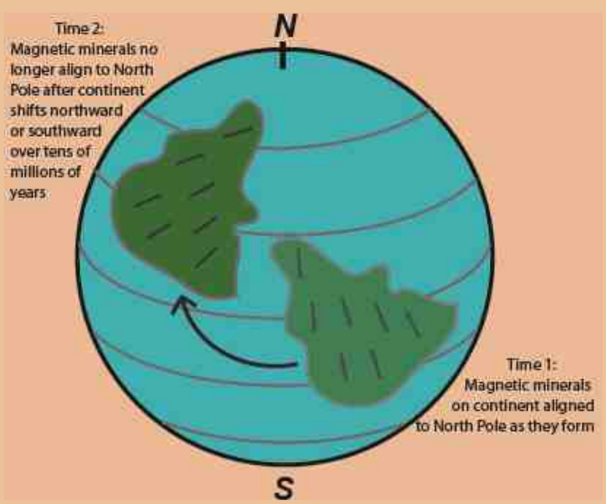
Figure 17: Ancient Grenville basement rocks can be found all along the Appalachian Mountains. Today, chunks and slivers of billion year-old granites and gneisses tell a story of ancient mountains that existed long before the Appalachians formed. Crystalline basement rocks are exposed today in parts of Canada, the Adirondacks of New York, Green Mountains of Vermont, the Berkshires of Massachusetts, the Great Smoky Mountains of North Carolina and Tennessee, Pine Mountain in Georgia, and our Blue Ridge Mountains (called the Shenandoah massif) in Virginia. (Modified from Tollo and others, 2004)

Paleogeography

How do we know that the positions of the continents in the past were so different than they are today? Today, we use two measurements of position to locate ourselves on Earth: Latitude and Longitude. But how do we know the latitude and longitude of the continents in the geologic past? Like fitting together a puzzle, we can use patterns to help us piece together the landscape. There are two very important pieces of the puzzle we need to know in order to determine where a continent was in the past:

1) Paleolatitude: the position of a continent relative to Earth's paleomagnetic poles. The position of a continent related to Earth's magnetic field, or its paleolatitude, can be used to determine its latitude. In order to know the latitude of a continent in the past, we use Paleomagnetics. This is how it works:

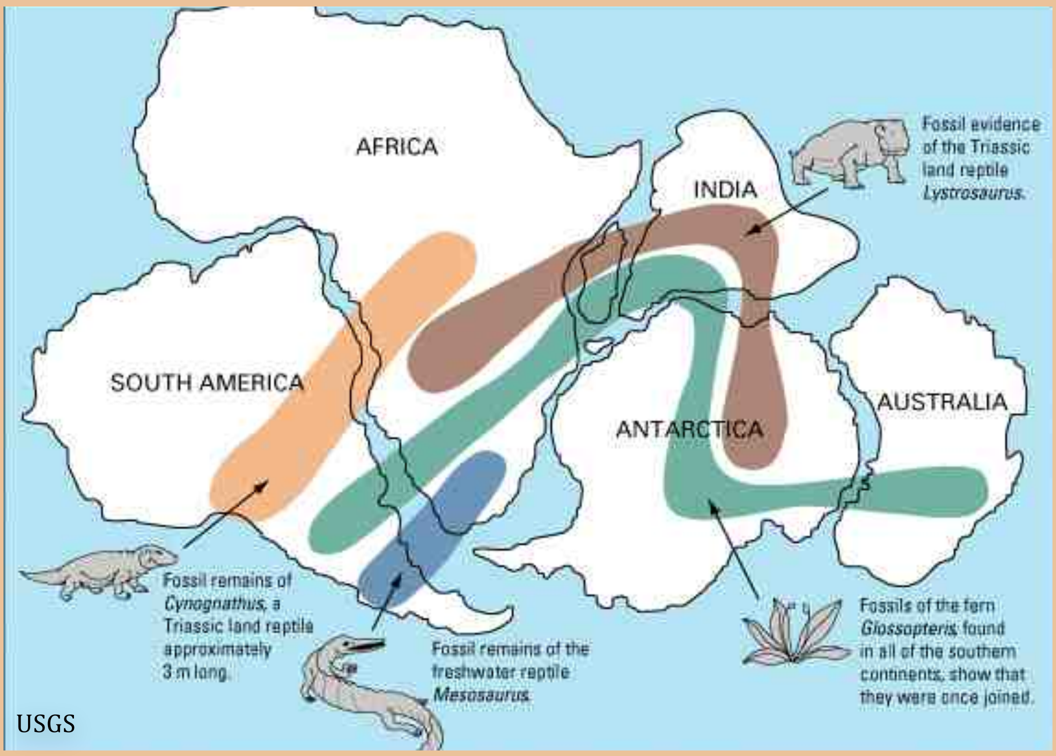
Earth's outer core is liquid and made of metal, primarily iron. As it circulates, the metallic core causes a magnetic field to form around the Earth (right). There are magnetic minerals in lava flows (especially basalt, which is rich in iron). Similar to a compass needle, the magnetic minerals in lava are aligned to the magnetic North Pole that existed at the time the lava was still hot. When the lava cooled, those minerals became 'frozen' into place, preserving the orientation of the magnetic minerals and thus a record of where that rock was in relation to Earth's magnetic North Pole at the time.



Today, the Atlantic Ocean floor is preserving a record of latitude because magma is continually erupting from the mantle onto the sea floor and cooling into hard basalt, allowing the magnetic minerals to align to the magnetic North Pole. The angle at which the minerals align must match up to the magnetic field of the Earth. If the lava cooled near Earth's equator, the magnetic minerals would be nearly horizontal, however, if the lava cooled closer to the poles, the magnetic minerals would point steeply into the Earth (see above right). Therefore, we can determine the original latitude of a rock when it formed by seeing how the current alignment of magnetic minerals in a lava flow compares to the magnetic field.

2) Paleolongitude: the longitudinal position of a continent in the past, or the relative position of one continent to other continents.

Determining the positions of continents relative to one another requires a different set of tools. Multiple methods help us figure out where continents used to be in the past. Mountains present a clue by providing folded layers of rocks that, when unraveled, help explain the old location and travel path of continents that have collided and ripped apart again (Stewart, 2009).



Scientists also look at the global distribution of igneous and sedimentary rocks that indicate how continents were once connected. For instance, fossils of specific land-dwelling species of animals and plants have been uncovered on totally different continents. For example, various *Lystrosaurus* genus land reptile fossils have turned up in Antarctica, India, and Africa – continents that are today separated by oceans. We can use the current distribution of these fossils as a clue to how the continents were once positioned in Earth's past.

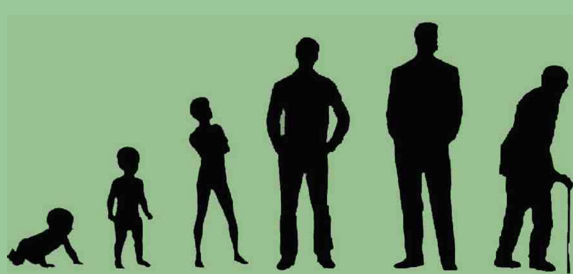
Geologic Time

The concept of time is one we are very familiar with, yet one that may also confuse us. Although we can grasp the length of our own lifetime – a hundred years or so, it is much more difficult to understand "deep" time (thousands, millions, or even billions of years). When communicating with park visitors about time, it is important to understand this dilemma, and provide some kind of tool, such as comparison, that makes deep time more understandable. For example, we can compare Earth's age with a calendar year, the length of a football field, or a human lifespan. Let's compare Earth's age to a human lifespan.

Our own birth, when we are zero years old, serves as our starting point, when Earth first began to take form 4.54 billion (4,540 million) years ago. Just as we were disorientated and clumsy in our body, the Earth was also in a state of disorganization – its layers had not yet formed, and it's surface was void of oxygen and oceans. As a new baby is overwhelmed by new sights and sounds, the infant Earth was overwhelmed by thousands of meteor impacts.

Perhaps as early as our twenties (about a billion years into Earth's history), a hard outer shell (lithosphere) had formed and plate tectonic motions began. The giant slabs of lithosphere were cranked across Earth's surface as mantle convection encouraged landmasses to crunch together and rip apart. These early Wilson cycles helped form the ancient nucleus of North America.

As we develop careers in our middle-aged years (30s and 40s – about two billion years through Earth's history), Earth would have slowly been developing an oxygen atmosphere.



By our 59th birthday (a billion years ago), the crystalline basement complex of the Blue Ridge Mountains (Old Rag Mountain) would just be forming as Rodinia crushed together. There would still be no life on Earth as we know it in sight.

When we became 70 years old (half a billion years ago), the hot lava flows of the Catoctin formation would just be pouring over the ancient Laurentian landscape as Rodinia tore apart.

The Taconic and Acadian mountain building events that spliced continental fragments onto the eastern United States and metamorphosed rocks of the Appalachians occurred throughout our early seventies. By the time we were 74 (300 million years ago), the super-continent of Pangea had crushed together, forcing up the Appalachian Mountains.

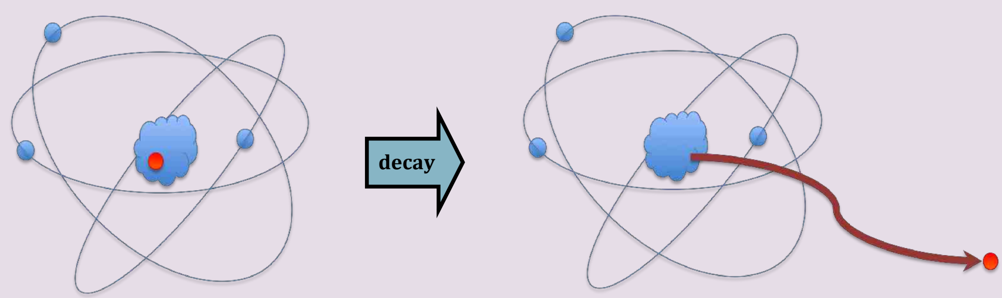
As humans like to travel during retirement, so too do the Appalachians. Throughout our late 70s the majestic Appalachian Mountains would be weathering, their fragments traveling far across the landscape, covering the Piedmont and Coastal Plain and continental shelf.

By our 80th birthday party (today!), the graceful Appalachians are celebrating by welcoming millions of visitors into their hills and valleys, hiking, biking, and learning about the complexity and beauty of the landscape.

Geologic Age – How do we know the rocks are so old?

Geologists and other scientists use radiometric age dating to calculate the age of a rock by determining when a specific mineral inside the rock formed. Age-dating works because of basic principles of chemistry and physics.

Any rock is made up of a variety of minerals. Each mineral is a solid compound of one or more elements. Each element in the periodic table contains atoms (below) that combine a certain number of particles: electrons, protons, and neutrons. It is the differences in these atoms that allows for the amazing variety of substances we have on Earth. An atom has a nucleus of positively charged protons, and neutrons of no charge. Circulating around this nucleus is a cloud of negatively charged electrons. The number of protons in the nucleus determines the type of element. Sometimes two atoms of the same element can have a different number of neutrons. When this occurs, the atom with the extra neutron is called an isotope. Sometimes isotopes may have an unstable arrangement of extra particles. The key to age dating lay here.

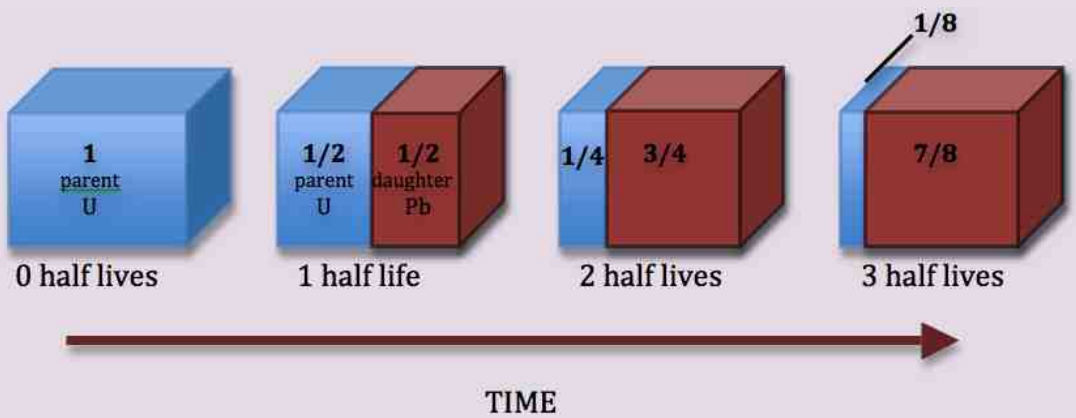


unstable atom with extra neutron particle

stable atom that has lost its extra neutron particle (decay)

Over time, unstable (radioactive) elements decay into stable elements. Such radioactive decay helps us understand rock age because each radioactive element decays at a specific rate. The amount of time it takes for half of the radioactive element to decay to its stable form is called a half-life. Geologists choose rocks with specific minerals that are known to contain unstable elements. Scientists can measure what percentage of that element has decayed to its stable counterpart, and thus determine how much time has passed since the unstable element first formed.

For example, a common element used to date the rocks of the Appalachian Mountains is uranium (U) that, over time, decays to lead (Pb). The isotope *U-235* decays to *Pb-207*, with a half-life of around 700 million years (following Lillie, 2005). Therefore, after 700 million years 1/2 of the U has decayed to Pb, after 1400 million years 3/4 of the U has decayed to Pb, and after 2100 million years 7/8 of the U has decayed to Pb.



Scientists can examine a rock and identify how much uranium (U) has already decayed into lead (Pb), therefore giving us an amount of time that must have past since the rock formed.

The half-life of each unstable isotope means that there is a limit to the usefulness of each isotope in dating various objects. For example, carbon has a very short half-life of only 5,700 years (it decays quite quickly). Therefore, carbon can only be used to date objects that are relatively young – formed less than 40,000 years ago or so. Uranium, on the other hand, decays very slowly (having a much longer half-life of 700 million years), and may be used to date really old rocks, such as the billion-year-old rocks that comprise the basement complex of the Appalachian Mountains.

Technique	**Half Life (years)**	**Material Dated**	**Dates material formed this many years ago**
Uranium to Lead	700 million	Minerals	1 Million to 4.6 Billion
Rubidium to Strontium	490 million	Minerals	60 Million to 4.6 Billion
Potassium to Argon	130 million	Minerals	10,000 to 3 Billion
Uranium to Thorium	80,000	Minerals, Shell, Bone, Teeth, Coral	0 to 400,000
Carbon 14 to Carbon 12	5,700	Minerals, Shell, Wood, Bone, Teeth, Water	0 to 40,000

Figure 18: A photograph of the surface of Mars. Taken in 2004 by the Spirit Rover, this image is a mosaic of photographs showing the rocky and barren topography of this planet. The view may have been similar if we were standing on Earth over a billion years ago, on what would become the state of Virginia. Courtesy of NASA, the Jet Propulsion Laboratory and Cornell University.

Complexities of the Basement Complex

The oldest rock type in the Park is the Basement Complex. It is a series of igneous rocks that intruded into other rocks of the ancient mountains of supercontinent Rodinia over a billion years ago. Although within this thesis we have simplified these rocks into one complex, understand that there are actually many different types (19) of granites and gneisses that comprise the basement complex. The classification of rocks can get complicated, but here is a quick review of the oldest rocks in Shenandoah National Park.

All the basement rocks are considered granitoids, meaning that they are igneous intrusive rocks that have cooled slowly, forming large interlocking crystals of minerals such as feldspar and quartz, giving them a light-colored appearance. Granitoids are commonly associated with mountain building.

The granitoids of Shenandoah are further divided into three categories by Scott Southworth and others in the U.S. Geological Survey map based on their age. These groups are:

Group 1
(1,183 - 1,144 million years old) Orthogneisses with strong foliation and Metagranitoids
The oldest rocks in the park are pieces of granite from an ancient mountain building event called the Shawinigan Orogeny. These rocks were metamorphosed into gneisses as they fell as xenoliths into plutons of melting continental crust as the ancient supercontinent Rodinia was being squeezed together. Many of these rocks have larger-grained interlocking crystals and layers of alternating light and darker-colored minerals, called gneissic banding.

Group 2
(1,143 to 1,111 million years old) Strong to weakly foliated Metagranitoids
This group consists of igneous intrusive rocks that contain both dark and light colored minerals, perhaps indicating a mixing of continental crust with the mantle underneath the ancient Grenville Mountains of Rodinia. More recent metamorphism has caused the darker rod-shaped minerals to begin to align into discontinuous bands throughout the rock.

Group 3
(1,078 to 1,028 million years old) massive metagranitoids
Mostly metamorphosed granites with large interlocking crystals that formed as xenoliths of the ancient Grenville Mountains that had fallen into cooling plutons. Some of these rocks are darker, containing more mafic minerals that may indicate that the continental crust was mixing with the mantle. Rocks of this group have intruded into younger granitoids, as plutons or dikes. The Old Rag Granite is in this group.

For more details about each of the Basement Complex rock units and where to find them, refer to the Geologic Map of the Shenandoah National Park Region, Virginia and accompanying open file report 2009-1153 composed by Scott Southworth and others.

C. The Rifting of Rodinia

A view into Earth

Earth is dynamic. In order to better understand the processes of continents rifting apart and colliding together, we need to address the mechanisms by which Earth moves.

Jules Verne, the 19th Century writer, had a vivid imagination when he wrote his novel *Journey to the Center of the Earth*. Taking his journey in real life, although not physically possible, would prove quite different than the one he imagined; let's take that journey!

Many scientists, including seismologists and other geophysicists, study the interior of the Earth in order to better understand what we see on the surface. The Earth is similar to an onion – it has many layers. These layers exist because of both chemical composition and physical conditions. When the Earth formed 4.54 (4,540 million) billion years ago, it was almost completely molten, so that gravity caused materials of differing densities to settle at different depths (similar to the oil separating to the top of a container of peanut butter). Lighter compounds of silicon and oxygen, known as silicates, remained close to Earth's surface, forming a crust, while more dense compounds, such as iron and magnesium silicates, sank below the crust to form Earth's mantle. The densest compounds and elements were pulled deeper, settling in the very heart of the planet to form the iron-nickel core.

Today, Earth has had billions of years to cool and is mostly solid. The three chemical layers of the Earth – crust, mantle, and core - that formed so long ago are also governed by differences in their physical state, because temperature and pressure increase from the surface to the center of the Earth. Earth's outermost shell, the lithosphere, is a hard solid because it is cold. The lithosphere includes the crust and the uppermost portion of the mantle and is broken into thirteen major tectonic plates (Figure 19). This is the rigid outer shell that includes the surface of the Earth on which we walk. The crust is part of this lithosphere and is composed of two types of material. High topographic areas, such as mountains and continents, are composed of thick and buoyant continental crust, whereas much of the crust we cannot see because it lies under the ocean is made up of thinner and more dense oceanic crust. As we descend deeper into Earth's mantle, it becomes hotter, resulting in a softer but still solid layer, the asthenosphere (Figure 20).

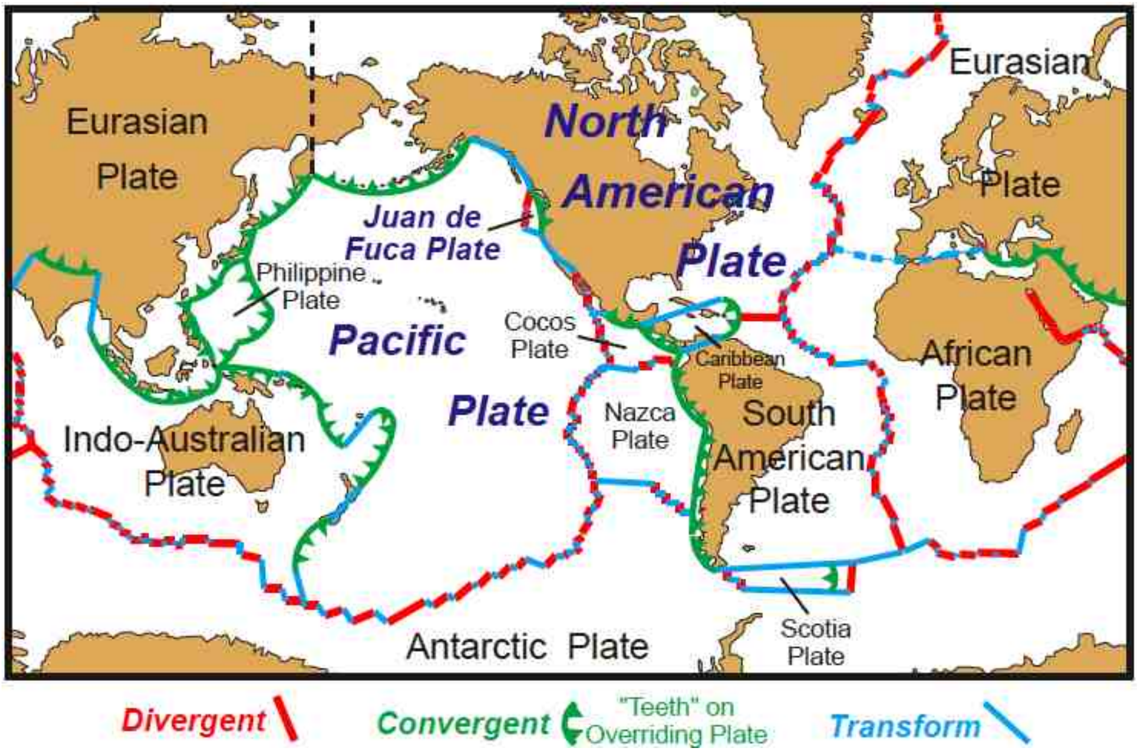


Figure 19: A map of Earth outlining 13 major tectonic plates. Think of tectonic plates like puzzle pieces of Earth's dynamic outer hard shell that shift throughout time. Three major boundaries between these plates exist: divergent (pulling apart), convergent (squishing together), and transform (sliding past each other). (Modified from Lillie, 2005)

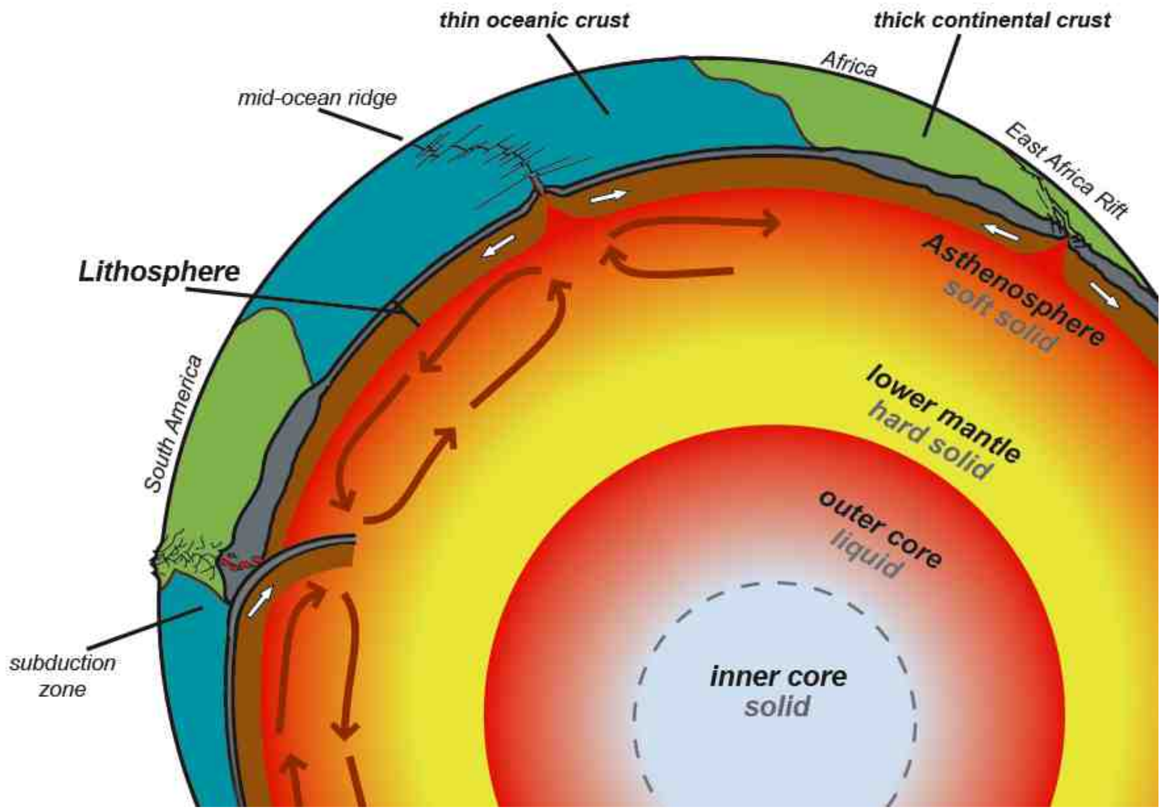


Figure 20: A view into the interior of planet Earth. Earth is composed of different layers, like an onion. Each layer has different physical properties based on changes in temperature, pressure, and composition. Variations in composition and density are important because they drive convection of the mantle, especially at subduction zones, where plates of dense cold oceanic lithosphere sink into the deeper mantle, and at mid-ocean ridges, where hot asthenosphere rises and pulls plates apart.

Variations in temperature, pressure, and possibly chemical composition (Anderson, 2001) drive massive convection currents within the mantle. Like conveyor belts, the currents transfer heat from Earth's core and mantle outwards, to the bottom of the lithosphere (Figure 20). This process concentrates areas of extreme temperatures and drives change on Earth's surface. As we descend still deeper into the mantle, it becomes a hard solid again because of increasing pressure. This lithosphere-asthenosphere-lower mantle relationship (hard-soft-hard) can be compared to the structure of an Oreo® cookie (Figure 21). Temperature continues to rise as we descend, such that the iron of the outer core is in a liquid state. It is believed that this liquid iron shifts, causing the formation of a magnetic field around the Earth (this is why we can use a compass to tell us direction). The skyrocketing pressure near the center of the Earth results in a solid inner core.

Think of Earth as a massive recycling machine. The motions of Earth's tectonic plates result in three primary types of tectonic plate boundaries (Figure 22). Plate boundaries are where much of the action on Earth occurs. If you can imagine hard rock being forced to slide past hard rock, or the dough-like asthenosphere being squeezed, you may see how plate motions cause dramatic events such as earthquakes, volcanic eruptions, and the formation of mountains to occur at the boundaries of the interacting plates.

Where continents or oceans pull apart, a divergent plate boundary exists (Figure 19, 22). Here, plates tend to thin and weaken. As a plate slowly pulls away, it makes room for the asthenosphere, which rises to fill the newly-formed gap. Decompression melting occurs, changing some of the hot asthenosphere into liquid magma as it enters a region of much lower pressure.

Liquid magma is also produced at a convergent plate boundary, where tectonic plates crash together. When a plate capped by thin, dense oceanic crust collides with a plate that has thick, buoyant continental crust, the thinner oceanic crust dives down below the continent, forming one type of subduction zone. Here, the subducting plate dives deeper and deeper into the mantle, experiencing higher temperatures. As a result it begins to loose water (dehydrate), like a person cranking the temperature in a sauna. Similar to a human, the oceanic plate sweats water, which rises, starting a chain reaction of melting called hydration melting. Some of the hot magma rises through the overlying continental crust, forming a chain of volcanoes (Figure 19, 22). Examples of modern subduction zones are the Andes Mountains of South America (Figure 23) and the

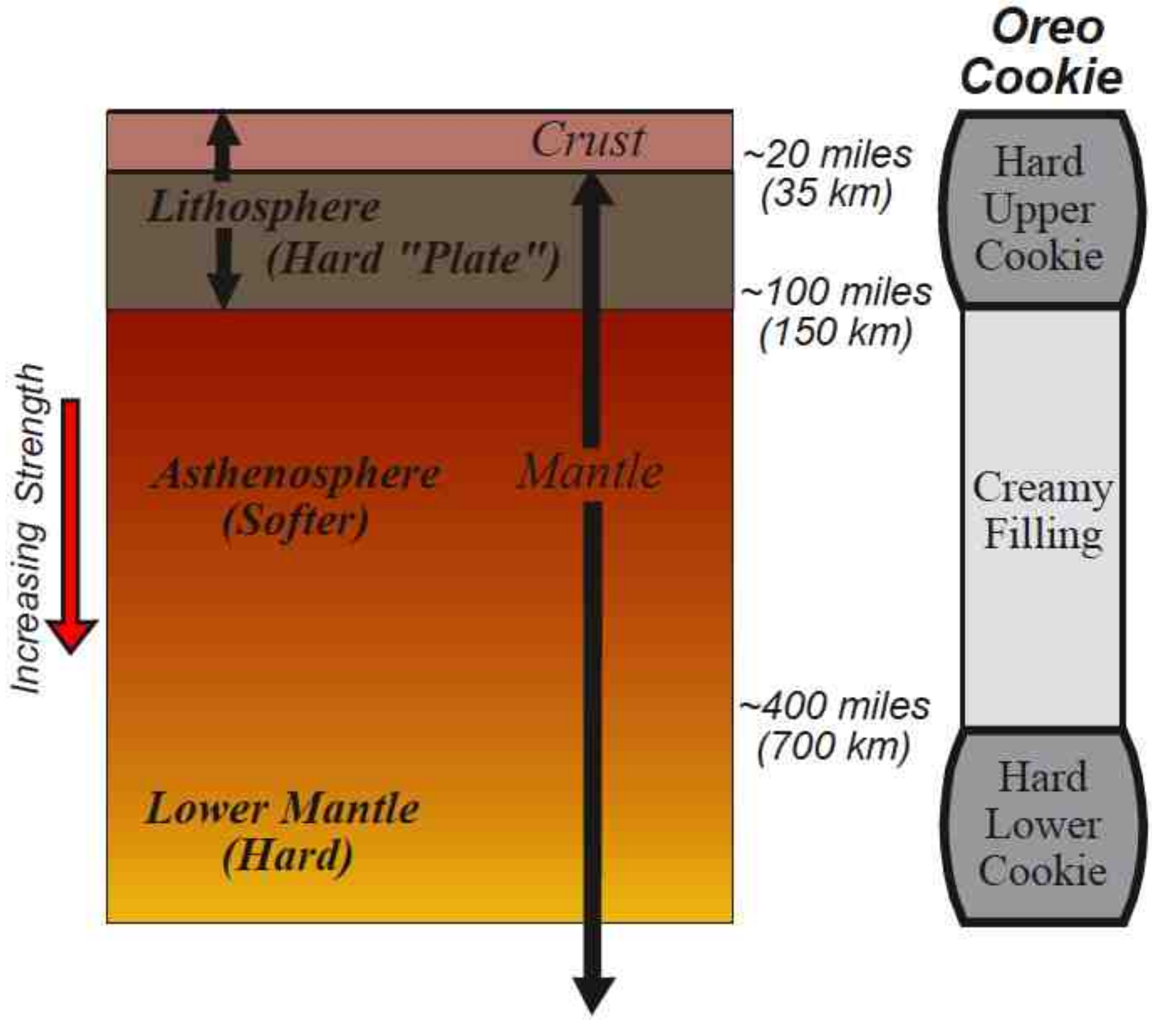


Figure 21: A cross section of Earth's outer layers. We can think of these layers like the layers of an Oreo cookie. The rigid lithosphere includes the crust of the Earth – the ground on which we walk, and is like the brittle upper cookie layer of an Oreo. Beneath the lithosphere is the softer asthenosphere, or the creamy filling of an Oreo. Finally, the rigid lower portion of the mantle can be compared to the bottom rigid cookie piece.

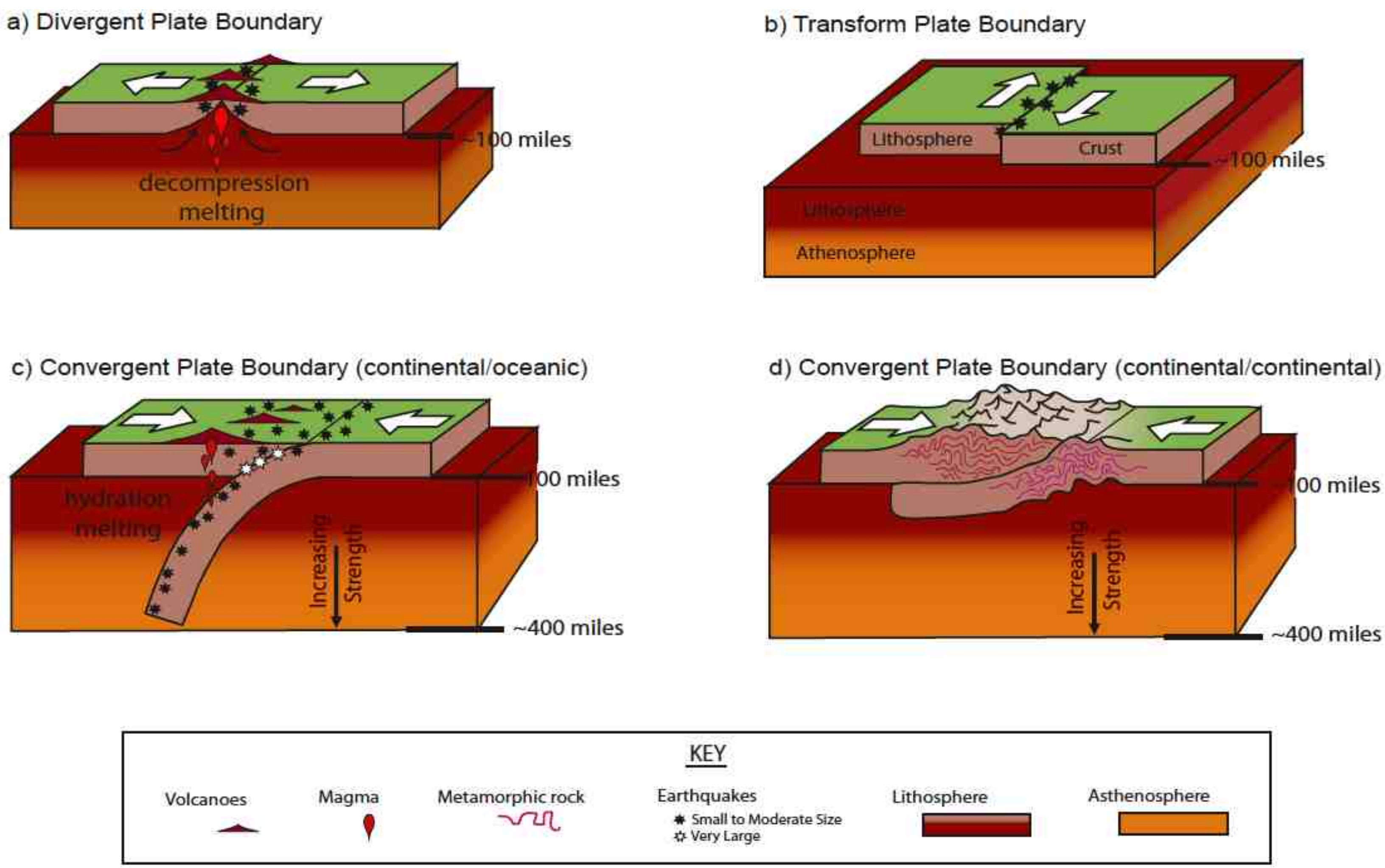


Figure 22: Three types of boundaries form where tectonic plates meet. Tectonic plates rip apart at divergent boundaries (a), a transform boundary exists where plates slide past one another (b), and colliding convergent boundaries can involve either an oceanic and continental plates (c) or two continental plates (d). (Modified from Lillie, 2005)

Figure 23: The young, jagged Andes Mountains of South America. The mountains are volcanic, forming as the Nazca Plate (see Figure 19), capped by thin oceanic crust, dives beneath the thicker continental crust of the South American Plate. (Photograph courtesy of Roman Bonnefoy)

Decompression Melting

Have you ever dived deep to the bottom of a swimming pool and felt squeezed by the weight of the water? Or felt your ears pop as you quickly drive up a mountainside? If so, you have experienced how it feels to undergo a significant change in pressure. Changes in pressure constantly occur on Earth as rock material moves up from Earth's interior to the surface (at a divergent plate boundary), or down from Earth's surface into the interior (at a convergent plate boundary).

Think of a kitchen pressure cooker. Imagine you are about to cook a delicious pot roast. First, you place the vegetables, meat and some broth into the pot. Securely closing the cooker, you crank the temperature and an hour later you return to serve the meal. Inside the cooker, the broth has reached a very high temperature; it is also under great pressure. Removing the lid of the cooker, the high pressure is released, and the fluid quickly turns into steam under the lower pressure and rises up from the pot.

This is a good analogy to decompression melting that occurs at a divergent plate boundary. When solid material from the mantle works its way up to Earth's surface, it moves from an area of high pressure to one of much lower pressure. When this occurs, some of the solid mantle material turns into liquid magma – what geologists refer to as "decompression melting."

Cascade volcanoes (like Mount St. Helens) in the Pacific Northwest. The Himalayan Mountains in Asia are an example of where two plates capped by thick continental crust collide. In this case, both plates are relatively similar in density, and both have a thick, buoyant crust, so neither one subducts; rather, the two crumple like a car wreck and one commonly slips at a low angle beneath the other. The great compression of landmasses results in folding, faulting, and the formation of non-volcanic mountains (Figure 22). Tectonic plates also move by sliding past each other at a transform plate boundary (Figure 22). A famous example is the San Andreas Fault, where the Pacific plate slides northward past western California. Earthquakes are common here as the two plates grind against each other.

It is important to understand that the motion of tectonic plates across Earth's surface is not only driven by subduction of old and dense lithosphere, but also by the force of ridge push and slab pull (Stern, 2004; Cloos, 1993). As thin, cold oceanic crust dives into the hot mantle at a subduction zone, it pulls behind it the rest of the attached plate (Figure 19, 22). This is because the oceanic crust is relatively cold and as it is pushed further down into Earth's mantle, the material (basalt), metamorphoses under the increasing heat and pressure into eclogite, a more dense substance compared to the hot surrounding mantle. The densified oceanic plate thus acts like an anchor, sinking and pulling the plate down. At oceanic divergent boundaries (also called spreading centers), heat is focused directly at the spreading center, causing a mid-ocean ridge to bow upwards. The elevated oceanic plate at the spreading center slides down under its own weight, pushing the plate farther from the spreading center as new plate material takes its place (Figure 19, 22).

Breaking Away

Plate tectonic processes driven by mantle convection and slab pull/ridge push have greatly shaped the Appalachian Mountains (Kline, 1994; etc). The Appalachian story involves two dominant processes – the opening of oceans, and the collision of continents. The formation of new oceans results from continents tearing themselves apart as plates diverge. Such occurred when Rodinia tore apart, forming what would eventually become North America and the other continents of Earth. The rifting processes and features that led to the formation of a new ocean occurred between 765 and 555 million years ago, during the Late Proterozoic Era (See the **Geologic Time** textbox on page 40 and Figure 13).

Phase I – The Robertson River Igneous Suite

Like all good things, the existence of the Rodinian supercontinent would not last forever. Supercontinents have formed on Earth cyclically, crashing together every 500 million years or so (Sutton, 1963; Gurnis, 1988), only to tear apart into scattered, individual continents that slowly glided across the globe and once again re-joined other landmasses. What drove Rodinia to break apart? Why do continents rift and make way for new oceans?

Rodinia broke apart in two phases (Tollo and others, 2004; Fetter and Goldberg, 1995; Badger and Sinha, 1988; Walsh and Aleinikoff, 1999; Li and Tull, 1998). The initial breakup began about 765 million years ago, when a large mantle plume was coalescing beneath the supercontinent. A mantle plume is a large volume of hot material from deep within Earth's mantle that slowly rises, due to its buoyancy, towards Earth's surface. As the hot plume rises, a drop in pressure causes it to partially melt, forming a large disc of magma at the base of the lithosphere (Campbell and others, 1992; Parfitt and Wilson, 2008) (Figure 24). Mantle plumes are common instigators of continental rifting. They seem to form due to the buildup of high temperatures deep beneath a large cap of continental crust, like the supercontinent Rodinia (Burke and Dewey, 1973; Courtillot and others, 1999). The hot plume causes the overlying plate to weaken and thin (Kline, 1994; Parfitt and Wilson, 2008), straining the rock and forming a series of cracks called faults. Three primary types of faults exist that relate to the way rocks break and shift when pushed (Figure 25). In this case normal faults formed under the tension of land ripping apart. Imperfections or weak zones in the Rodinian continent probably determined the location of the developing faults, but generally they seemed to have formed in the north and migrated southwards, as transform faults unevenly connected normal faults (Burton and Southworth, 2010; Fetter and Goldberg, 1995). Once established, the continental rift zone was able to grow as the faults unevenly joined (Courtillot, 1982; Lahitte and others, 2003).

Simultaneously, the continental crust was heated by the rising mantle plume and began to melt (Figure 26). The granite-rich continental crust contaminated the basalt-rich mantle plume, enriching the magma with silica (Francis and Oppenheimer, 2004; Parfitt and Wilson, 2008). Just as broth changes to gravy when you add flour, the consistency and composition of magma changes as you add silica. Early magmatism is commonly bimodal, meaning it consisted of both

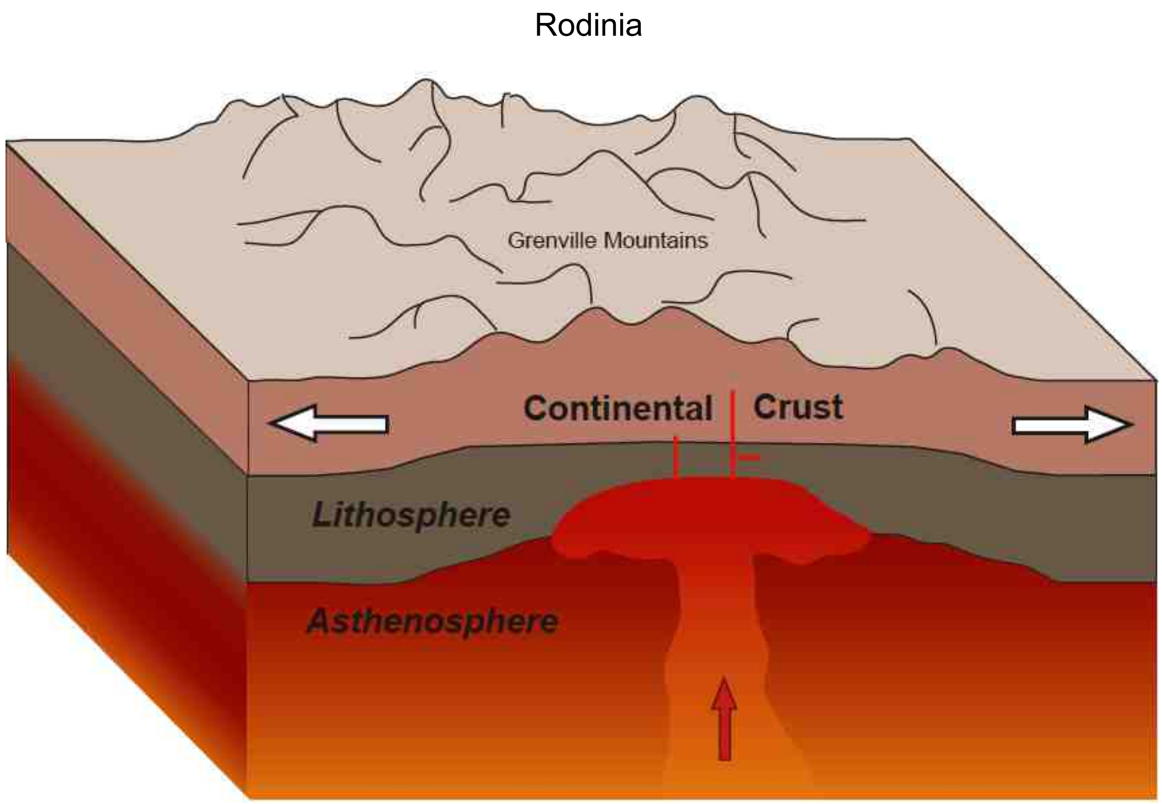


Figure 24: Over one billion years ago the supercontinent Rodinia formed. All continents on Earth crashed into one, forming the Grenville Mountains. However, such a large area of thick continental crust led to a blanket effect – insulating the underlying lithosphere until a large plume of hot magma rose through the mantle and collected directly beneath the massive continent. The concentration of heat began to warp and weaken the overlying continental crust. Eventually, the magma reached Earth's surface through feeder dikes and faults, and the supercontinent began to rip apart.

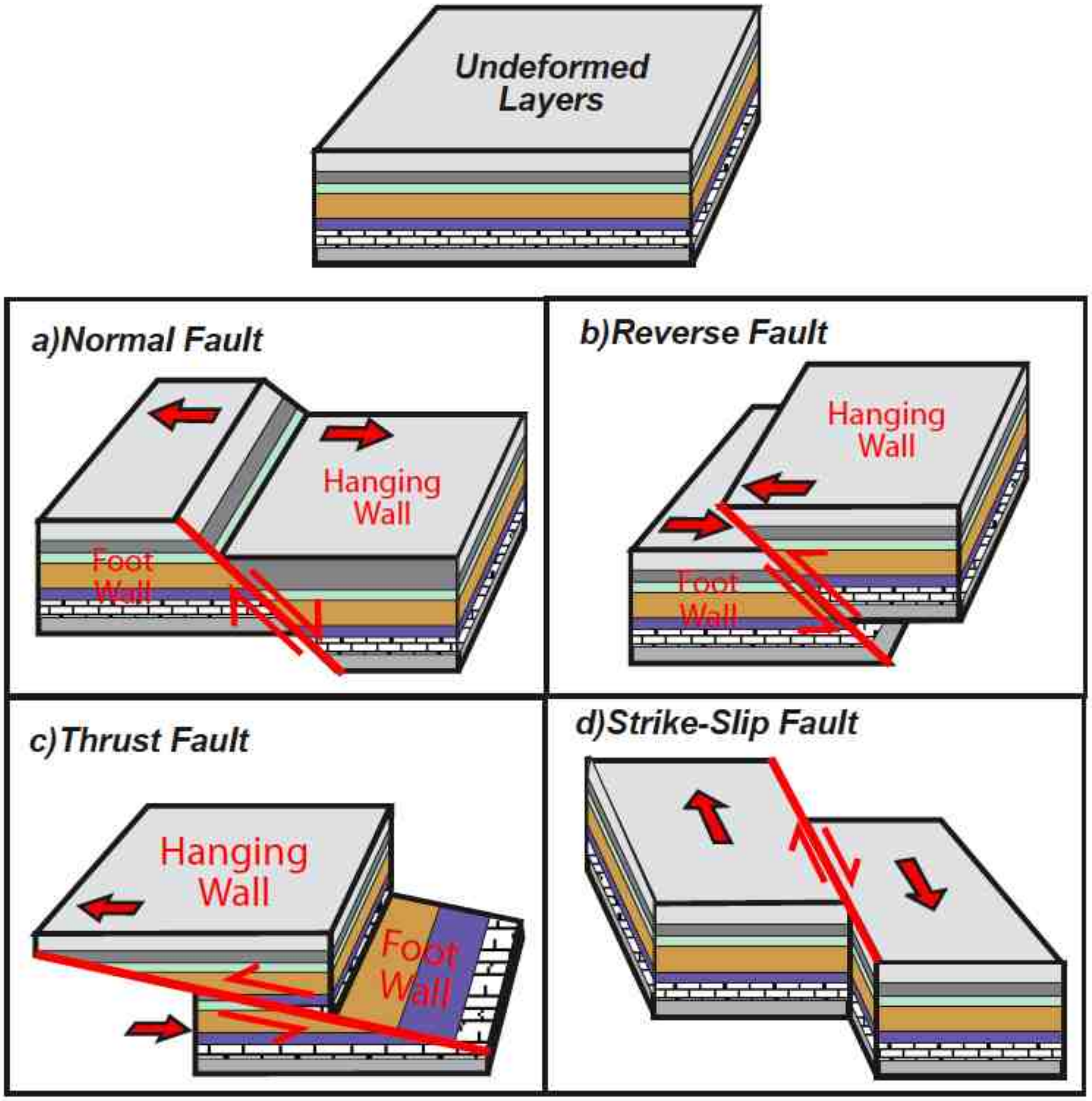


Figure 25: When brittle rocks are subjected to stress, they break in four primary ways. When tension pulls the rock apart, a normal fault forms (a). Compression squeezing rocks together causes a reverse fault to form (b). When reverse faults occur at very shallow angles and transport slices of rock far distances, they are called thrust faults (c). Strike-slip faults occur where rock breaks and is forced to slip laterally past itself (d). (Modified from Lillie, 2005)

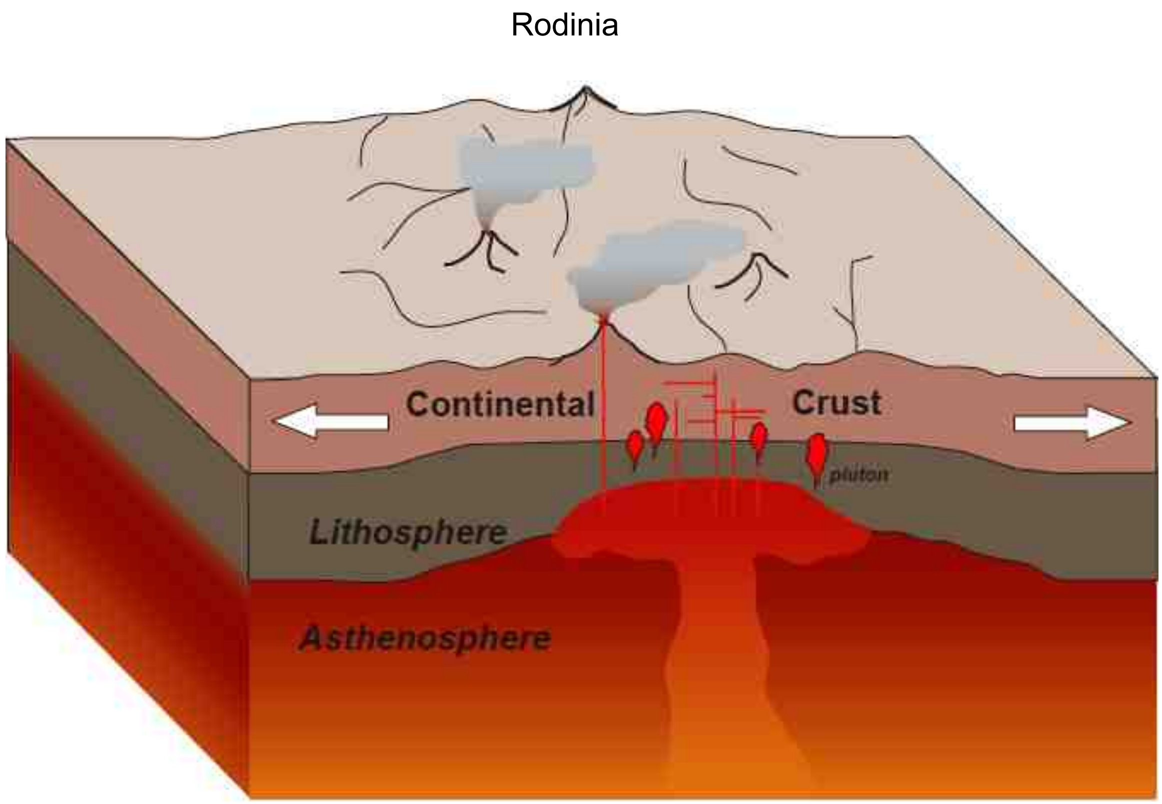


Figure 26: By 765 million years ago, magma reached Earth's surface across the modern Carolinas. As the Grenville Mountains eroded away, dikes and sills transported magma from the trapped mantle plume into volcanoes that popped up across the landscape. Bimodal magmatism produced both viscous (rhyolite) and fluid (basalt) lava flows. Bulbous plutons of magma separated from the plume like tears flowing upwards until they became locked within the crust.

low silica (basaltic) magma, as well as blobs of high silica (rhyolitic) magma. A series of igneous intrusive, silica-rich magma bodies, called plutons, became lodged in the crust up and down the entire East Coast along the continental rift zone (Figure 26). Some of these early intrusive plutons, called the Robertson River Igneous Suite (730-700 million years old), are exposed today just east of Shenandoah National Park (Southworth and others, 2009) (Figure 53). The magma also made it to Earth's surface through a series of new volcanoes, spewing thick, viscous, silica-rich lava (Tollo and others, 2004). Some of the oldest, or first formed lava flows to reach the surface did so in what is today North Carolina. If you have ever hiked on Mount Rogers or Grandfather Mountain, you may have trodden on top of volcanic rocks associated with the earliest rifting that occurred at the Laurentian-Rodinian margin, dated between 750 and 800 million years ago or so (Rankin, 1993; Tollo and others, 2004). By 680 million years ago, most of this action stopped as the rift zone was aborted (Walsh and Aleinikoff, 1999; Fetter and Goldberg, 1995).

Phase II – The Catoctin Formation

There was a period of calm, like the eye of a hurricane that passed over Rodinia. For 110 million years this calm persisted, until by 570 million years ago, it all began again. This second phase of rift activity eventually led to the final tearing of Rodinia and formation of the new ocean called Iapetus. The landscape broke into multiple, mile-scale slivers of rock, surrounded by ductile fault zones (Mylonite zones) (Kline, 1994) (Figure 27). These faults peppered the landscape as the zone of weakened crust broadened. Because normal faults can crack the crust to significant depths, they present a conduit along which magma can travel. These conduits are the primary veins connecting the mantle directly to the surface through the magma plume. When magma hardens within them they form feeder dikes. Connected feeder dikes are essentially a plumbing system through which large volumes of magma can travel to the surface and fill newly-formed rift valleys (Figure 27). A great example of a feeder dike can be found in Shenandoah National Park near **Mary's Bridge** and the overlook at **Little Devils Stairs**. While magma rose through feeder dikes, and across the ground, the interaction of these different rocks with heat and water resulted in a type of contact metamorphism called hydrothermal alteration. The surrounding basement complex was bleached and altered into Unakite, a rock composed of both the minerals pink potassium feldspar and green epidote (Southworth and others, 2009). This geologic feature can be seen particularly well at the outcrop directly below **Timber Hollow Overlook**.

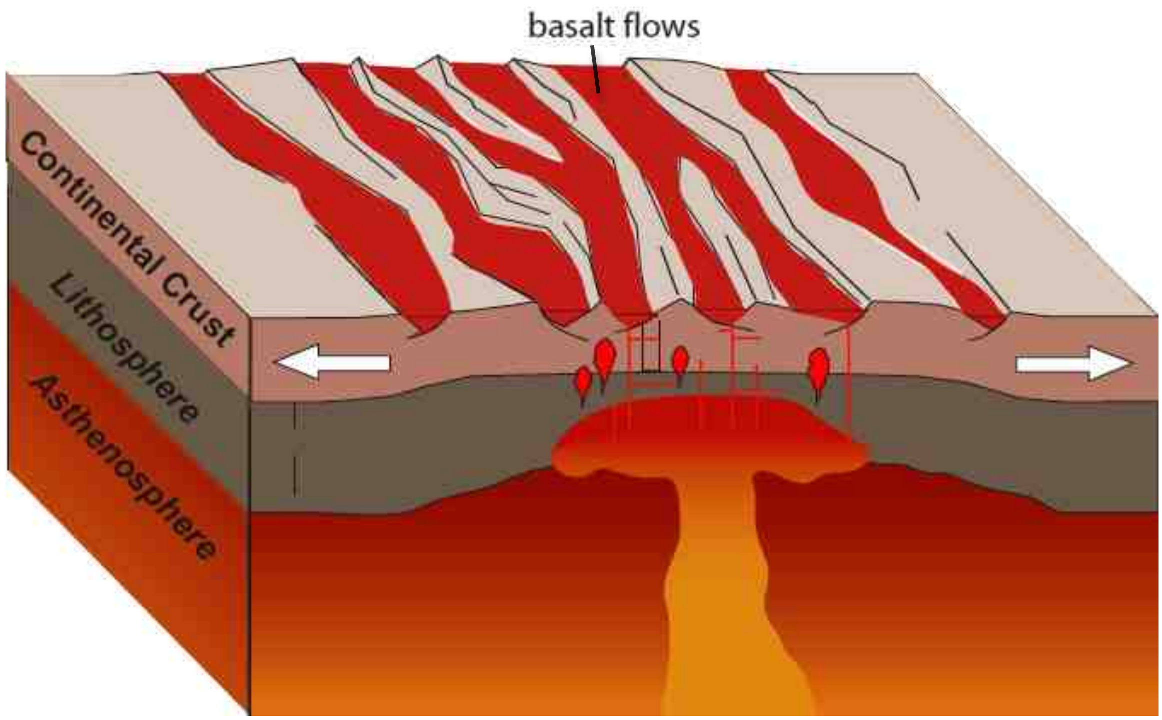


Figure 27: The super continent Rodinia ripped apart 570 million years ago. As heat built up beneath the crust it thinned, forming a continental rift zone with multiple valleys. As magma from the lithosphere reached Earth's surface through feeder dikes, the valleys filled with lava flows. Some of these will become the Catoctin Formation of Shenandoah National Park.

Hydrothermal Alteration and Unakite


Courtesy of Sally Hurlbert

In certain locations within Shenandoah National Park, you may see reddish swirls (below) or red and green veins (left) cutting through a completely different looking rock. First of all, consider yourself lucky. These spots are not rare, but they can be difficult to spot.

When dikes of hot magma broke through the landscape as the supercontinent called Rodinia tore apart, the contact of extremely hot magma against the surrounding rock (typically the basement complex) caused the minerals within the rock to change. We already know that minerals are sensitive to temperature, pressure, and chemistry. If any of these factors change, the minerals are likely to react by changing.

Imagine taking something extremely hot and quickly putting it in contact with something cold and wet - steam would form. But what if that steam could not escape? What if the steam was trapped within the rocks? The rapid changes in temperature with the presence of water would cause the rocks to become hydrothermally altered, meaning the minerals would change in response to the changing temperature and water.

In Shenandoah National Park, hydrothermal alteration rears its head as bleached ("steamed") or minerally altered semiprecious stone called Unakite (top). The reddish color is the mineral potassium feldspar, called Orthoclase (common in granite and also known as the gemstone moonstone). Typically paired with the pink orthoclase is a pretty green mineral called epidote.

Unakite is the unofficial state rock of Virginia and is named after a portion of the Appalachian Mountains called the Unaka Mountain range of North Carolina and Tennessee.

Volcanic eruptions littered the landscape, but unlike the earlier eruptions, most of the later eruptions were thin, watery flows that spread far across the land. These flows may not have been as contaminated by melted continental crust compared to the earlier rhyolitic flows; they were relatively 'pure' mantle melt (basalt). Even so, these lava flows tell the story of the mixing of ancient ductile rocks far beneath Earth's surface (Badger and others, 2010). Along the **Appalachian Trail** near **Timber Hollow Overlook** you might spot a huge boulder of the Catoctin Formation that displays what may be the accumulation of blobs of lava ejected from a spatter cone (Badger and Sinha, 1988). However, the occasional spatter cone was far outnumbered by the hundreds of feeder dikes, called dike swarms that broke across the landscape from Newfoundland to South Carolina (Rankin and others, 1988; Bartholomew, 1989; Southworth and others, 2009; Walsh and Aleinikoff, 1999). As these lava flows cooled, they contracted like mud contracts as it dries in a puddle. The contracting lava cracked across the surface into interesting five (pentagonal), six (hexagonal), or eight (octagonal) sided shapes that elongated into columns down into the heart of the lava flows as time passed and cooling continued. Look for this columnar jointing everywhere in Shenandoah National Park, especially along the **Limberlost trail**, the Appalachian Trail south from **Timber Hollow Overlook**, along the **Bearfence** **Mountain** trail, and on the way up to the **Little Stony Man Cliffs**. When you see this geologic feature, it is likely that you are positioned at or near the top of one of the many lava flows that make up the Catoctin Formation.

The large-volume lava flows that covered areas around the maturing rift zone are called flood basalts, poured over an area of over 1,500 square miles (4,000 square kilometers) over the coarse of 15 to 20 million years (Southworth and others, 2009; Badger and Sinha, 2004). Such large-volume outpourings (sometimes up to 2.4 million cubic miles or approximately 860 Lake Superiors!) of basaltic lava are commonly associated with continental rifting (Parfitt and Wilson, 2008). Flood basalts may erupt over either short durations of time (days) in large volumes, or in multiple episodes of slow eruptions over decades (Parfitt and Wilson, 2008). They occur in several places around the world, each one telling a story of a continental rifting event. Flood basalts associated with the rifting of Laurentia from Rodinia erupted on and off for about 15 million years (from 570 to 555 million years ago) are seen today, along with igneous plutons, in various locations along the Appalachian Mountains (including Shenandoah's Catoctin Formation which is 570 million years old) (Southworth and others, 2009) (Figure 28, 53). Multiple lava flows formed the Catoctin Formation of Shenandoah National Park. Travel to the base of the **Little Stony Man Cliffs** to see volcanic breccia, or the broken fragments of older lava flows that were tumbled into a new flow as it spread across the ground.

In many of the outcrops of the Catoctin Formation, you may notice small holes or dark polka-dots like chocolate chips. These spots are a unique testament to the origin of the Catoctin Formation. Open holes, called vesicles, formed when the hot magma extruded onto Earth's surface. Gases within the magma formed bubbles that expanded as the magma traveled from an area of high pressure (underground in a feeder dike) to an area of low pressure (Earth's surface). The expanded bubbles of gas were then frozen into the lava as it cooled into basalt. A great place to find open vesicles in the Catoctin Formation is in the middle of **Big Meadows**. You may also find small polka-dots within the Catoctin Formation. These may be amygdules (pronounced 'ah-mig-jewels') or fiammé (pronounced 'fee-ah-may' with the emphasis on the 'ah'). Fiammé are small pieces of pumice or ash that fell to the ground and were mixed in with the surrounding rock during a volcanic eruption. When the rock later became squeezed, or metamorphosed, the pieces of pumice turned into little dark greenish spots of the mineral chlorite. Amygdules are open vesicles in the lava that filled with quartz, calcite, epidote, and/or chlorite crystals as water circulated throughout the metamorphosed basalt as it became greenstone. Look for fiammé and amygdules on the way down to **Dark Hollow Falls**, the top of **Bear Fence Mountain**, and along the Appalachian Trail towards **Little Stony Man Cliffs.**

While flood basalts poured across the land, the underlying lithosphere continued to thin. Within the rift valley, the central faults joined to form a rift graben that sunk below sea level (Fichter and others, 2010). Once significantly thinned and faulted, the rift valley completely pulled apart as pure basaltic magma from the mantle reached Earth's surface. The surrounding continental crust pushed apart as this magma began to form a thin layer of oceanic crust (Figure 29). As magma continued to rise through the continental rift zone, the ribbon of oceanic crust widened. Eventually, a new ocean began to fill in the lower topography (Figure 30) forming a successful but jagged continental rift zone (Figure 31). Laurentia thus gained its independence as ancient North America slowly drifted away from the rest of Rodinia (now called Gondwana), comprising what would later become South America and the other southern continents.

Columnar jointing

In many locations throughout Shenandoah National Park, you will stumble upon bizarre rock outcrops that look like a bunch of pointy spires (right). Typically in five-sided (pentagonal), six-sided (hexagonal), or eight-sided (octagonal) forms, this geological feature is called columnar jointing. Joints are simple cracks in rock along which motion does *not* occur (a fault is a crack along which there was movement).

If you see this columnar jointing, it is a great indicator that you are in the Greenstone rock of the Catoctin Formation because this feature only forms in cooling lava.

Help park visitors understand columnar jointing by comparing it to mud in a mud puddle. As mud dries up in the sun, it usually cracks because the mud shrinks as the water evaporates away (below). Similarly, as lava cools, it shrinks, breaking into cracks that elongate down into the lava flow as the lava cools from the outside-in. Columnar jointing can be seen elsewhere in the world and you may help visitors make intellectual connections by mentioning Devil's Postpile National Monument in California, Devil's Tower National Monument in Wyoming, The Giant's Causeway in Northern Ireland (featured on the cover of the musical band Led Zeppelin's album *Houses of the Holy*).

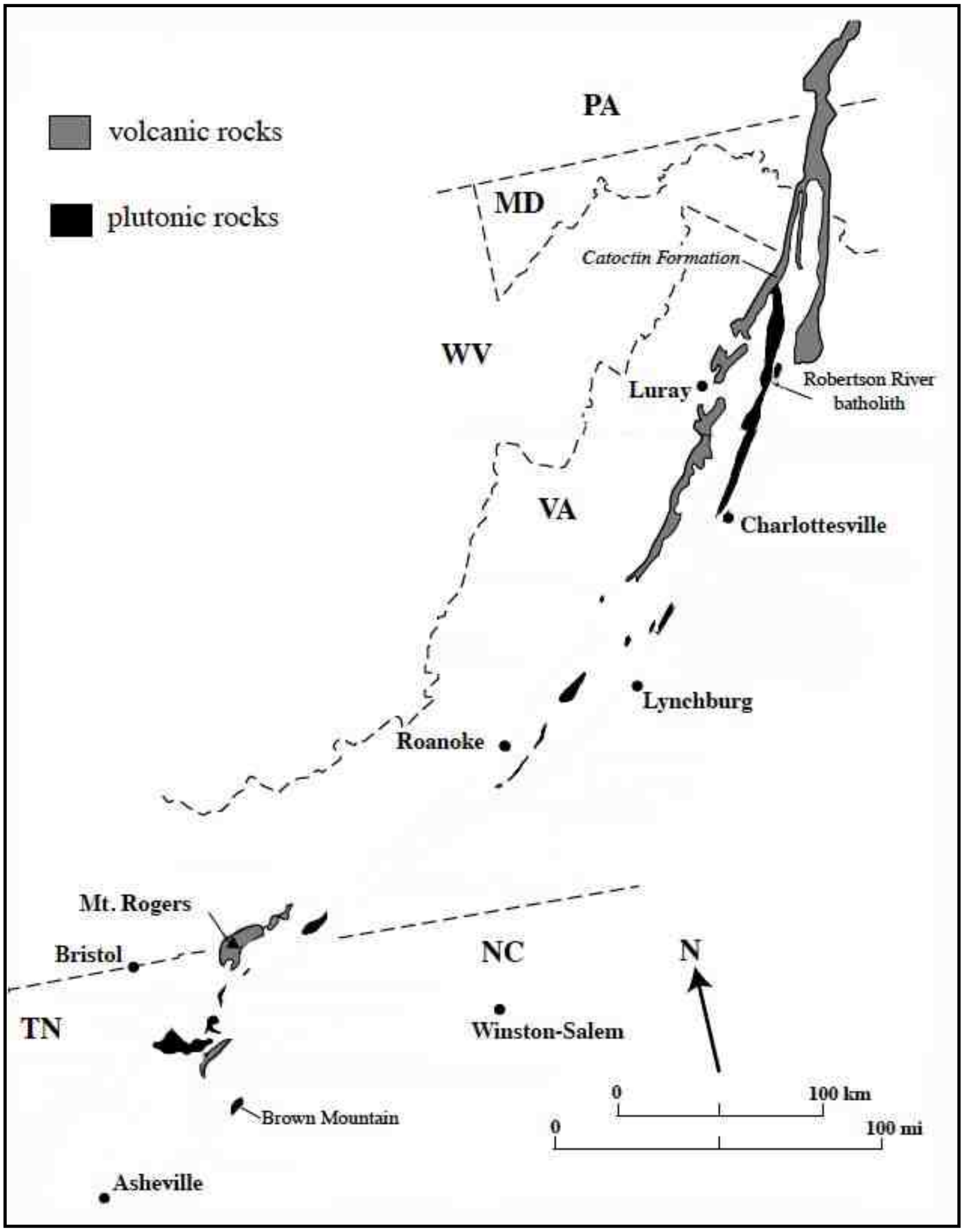


Figure 28: Ancient igneous rocks are a remnant of continental rifting. Both lava flows (flood basalts) and plutons pepper the eastern states and can be studied to reveal the story of how and when supercontinent Rodinia tore itself apart. (Modified from Tollo and others, 2004)

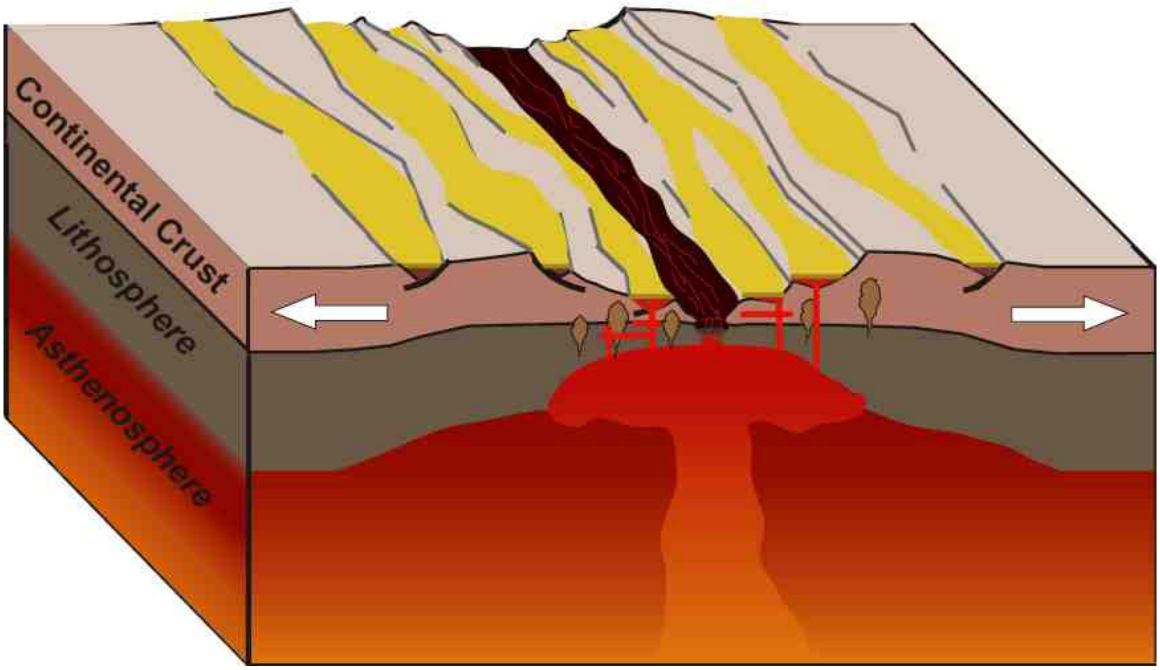
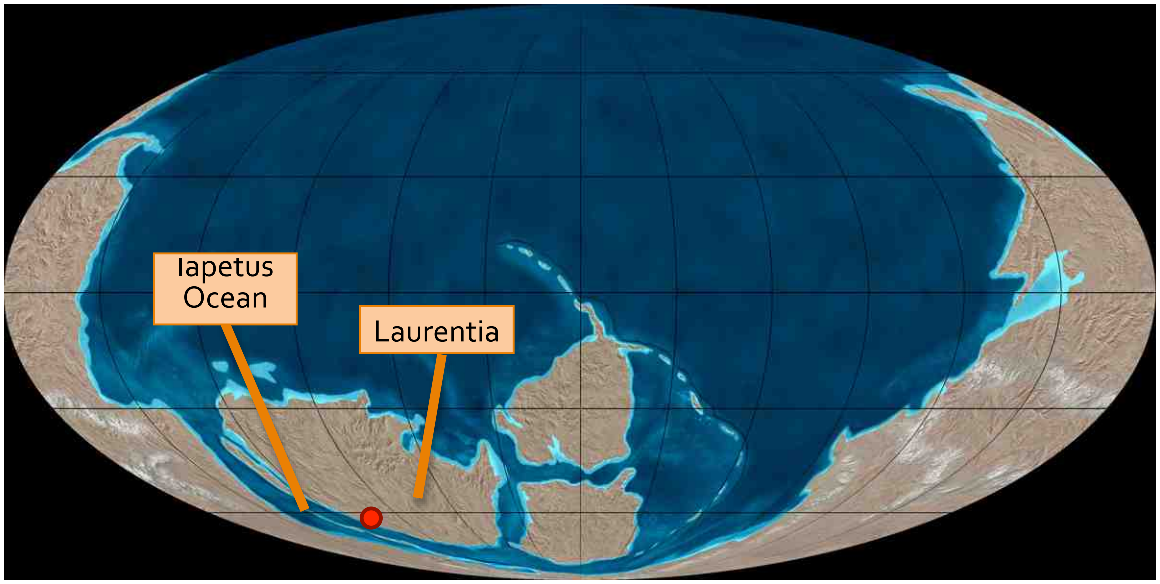


Figure 29: By 560 million years ago, the rift zone matured into oceanic crust. Fresh magma from the asthenosphere rose to the surface, forming a thin ribbon of dense oceanic crust that would continue to widen, pushing apart the two halves of ancient continent Rodinia. Meanwhile, the low valleys filled with sediment from the higher topography, forming rocks layers that would become the Swift Run Formation of Shenandoah National Park.



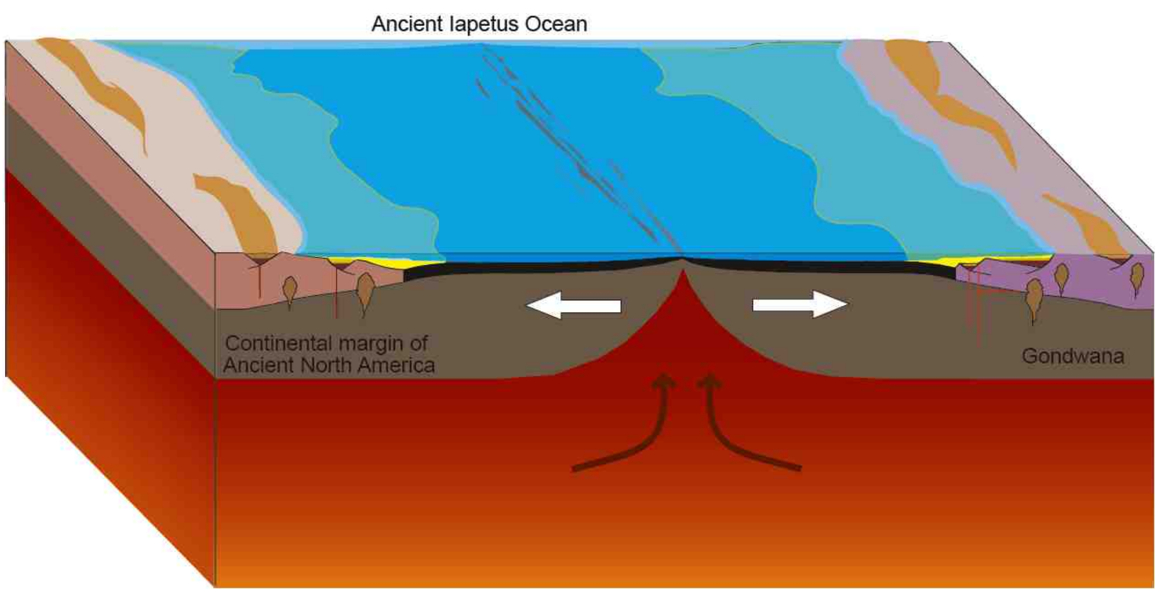


Figure 30: The ribbon of oceanic crust widened, forming an ocean basin. Fresh magma continued to rise from the asthenosphere, continually adding to the ribbon of dense oceanic crust. This process allowed an ancient ocean (called Iapetus) to divide Ancient North America (referred to as Laurentia) from the rest of Rodinia (now called Gondwanaland). This illustration provides a bird's eye view (map, top) and a cross sectional view (block diagram, bottom) of this 'rift to drift' process. Many of the other figures in this thesis will pair a block diagram with a global map view to help put regional geologic changes into a global perspective. The red dot on the paleogeographic map (top) always signifies the approximate location of what will become Shenandoah National Park. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

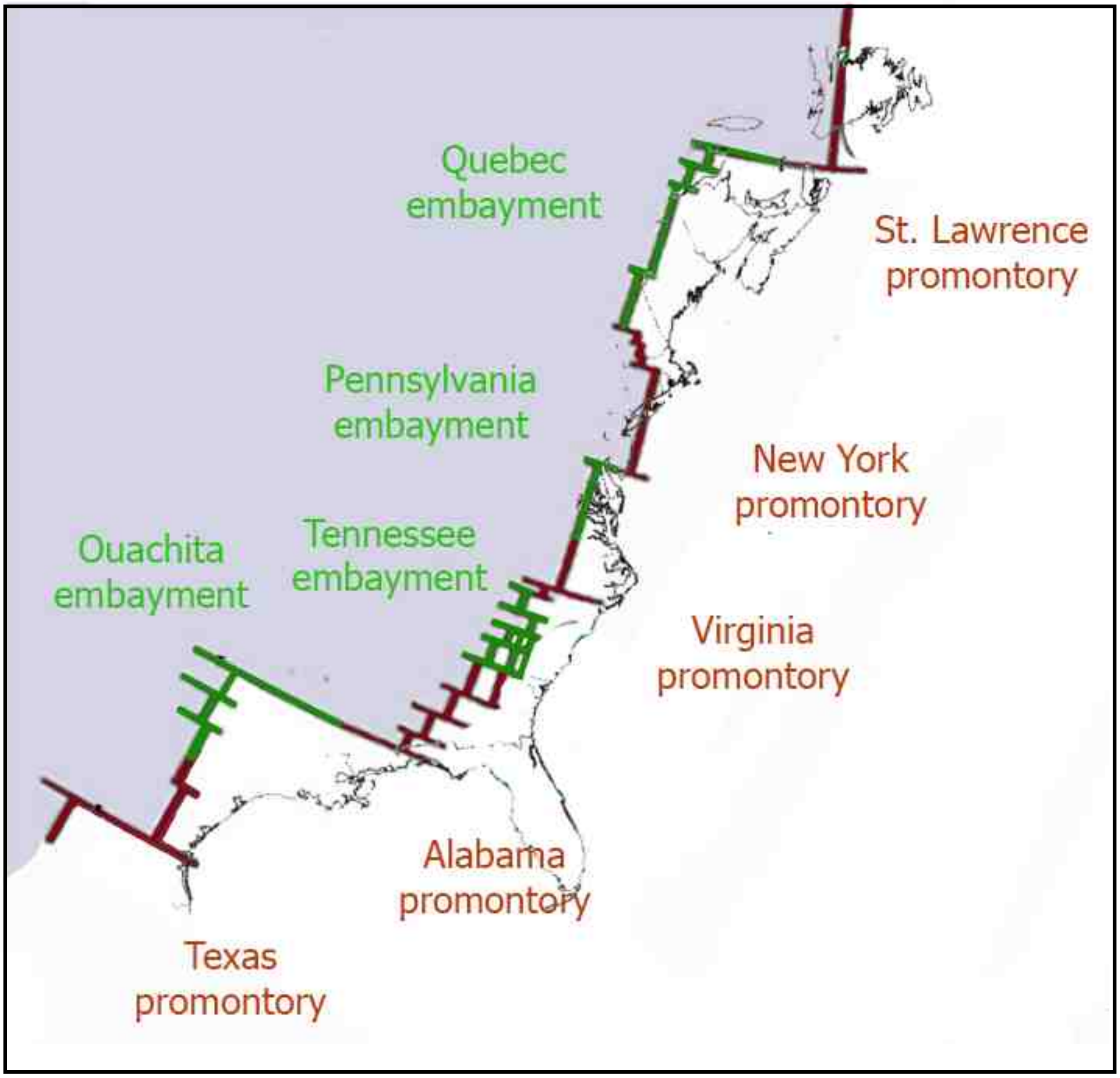
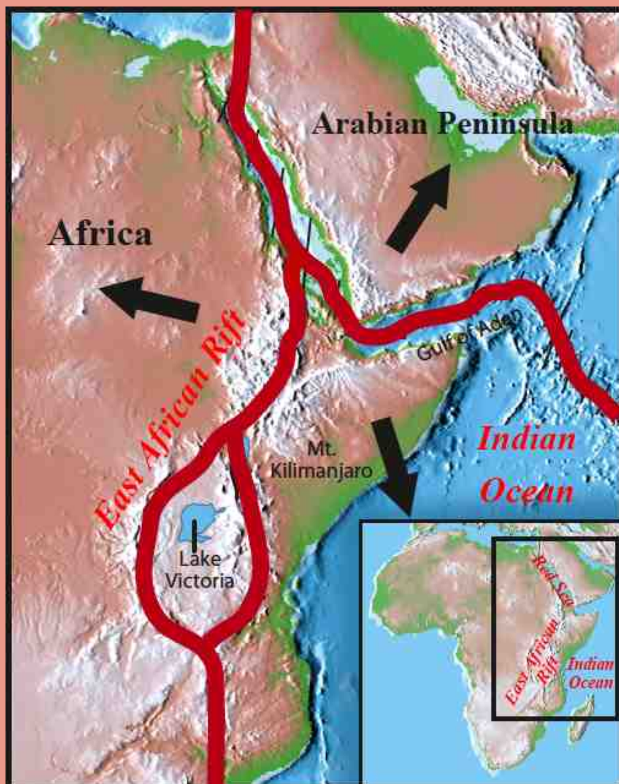


Figure 31: The rifting of Rodinia left a jagged coastline on ancient North America. Promontories jutted out into the Iapetus Ocean, while embayments formed recesses, like bowls, in which sediment accumulated. (Modified from Thomas, 2006)

The Afar Triple Junction: A modern analog for Rodinian rifting



Flood basalts have been identified across the globe, tracking various continental rifting events that have occurred throughout Earth's history. Geologists understand that the present is the key to the past. Studying a continental rift zone that is active today provides valuable information about how continental rift zones form and evolve into ocean basins.

An active continental rift zone is currently ripping eastern Africa apart. This rift is a triple junction where three plates are diverging from one other. The Red Sea, the Gulf of Aden, and the lakes and mountains of southeastern Africa (East African Rift) result from this tearing action. Together, the three limbs combine to form the Afar depression.

Studying the East African Triple Junction reveals that the opening of continental rift zones (below) occurs in fits and spurts, unevenly, as normal faults crack and spread across the land until they join. The Gulf of Aden and Red Sea are two limbs of the triple junction that are more advanced than the more southerly East African Rift - they have already made way for new oceans over their newly-produced oceanic crust.

Courtesy of Elizabeth Baker

Over millions of years, fissures and volcanoes popped up along these linear zones, spewing thick silicic lava (rhyolite) and thinner, less viscous flows of basalt. The two overlap each other over time, leaving a geologic record of massive flood basalts seen at the surface at this continental rift zone.

Photos courtesy of Marco Fulle from stromboli.net

The Afar triple junction region is dominated by volcanism. Flow upon lava flow have formed a thick cap of basalt spanning an area of over 500,000 square kilometers (200,000 square miles) - close to the size of the state of Texas! Eventually, the three rift arms may join and open completely. Perhaps, if we could have been standing on Laurentia 760 million years ago, this is exactly what we would have seen!

D. A new ocean is born

All along the eastern side of North America, a record of sedimentary rocks preserves an ancient passive continental margin – the edge of an old ocean similar to our modern Atlantic Coast (Hatcher, 2010; Southworth and others, 2009; Thomas and Whiting, 1995). In Shenandoah National Park, the following events are preserved within the Chilhowee Group of rocks that contain the Antietam, Harpers, and Weverton Formations. Once the Rodinian rifting was complete in the late Proterozoic Era (about 560 million years ago) (see geologic timescale - Figure 13) and a new divergent plate boundary was established, the continental crust was completely pushed aside by the formation of new, thinner and more-dense oceanic crust (Figure 29, 30). A new sea, the Iapetus Ocean, filled the gap between the continental fragments as they drifted apart. With any ocean comes the deposition of sediment. As the surrounding high topography continued to weather and erode, streams and rivers carried the broken fragments far from their origin. These sediments - rich in high-silica minerals like quartz and feldspar - accumulated on top of the crystalline basement rocks along river channels, in low topographic basins. It accumulated within river deltas, down along the newly forming beach, and out into deeper waters of the continental shelf and continental slope, forming a thick wedge of siliciclastic sediments (Faill, 1997, Figure 32). The sediments formed a variety of rocks, including coarse conglomerates, gritty sandstones (such as the Antietam Formation in Shenandoah National Park), and fine-grained mudstones. Some of these sedimentary layers overlapped lava flows, and were themselves overlapped by younger lava, while the continental rift took its final, firey breaths (Tollo and Hutson, 1996; Bailey and others, 2007; Southworth and others, 2009).

As thin oceanic crust developed within the new ocean basin, the older crust was pushed farther and farther away, carrying Laurentia with it. As the divergent plate boundary (new mid-ocean ridge) moved away from the shore, the continental edge subsided, sinking lower as the plate cooled and contracted, and was covered by thick layers of sediments. During the latest Proterozoic time (550 million years ago), Laurentia gradually drifted farther north, entering more equatorial waters (Figure 33). Carbonate rocks (for example, limestone) formed by the chemical precipitation of calcium carbonate from seashells. The more silica-rich sands and silts that were eroding off the land were overlain by these new carbonate deposits, including recently-evolved coral reefs. The carbonate rocks would later form the cavern-ridden limestones and dolomites of the Shenandoah Valley (such as Luray Caverns). A carbonate shelf formed as reefs and mud

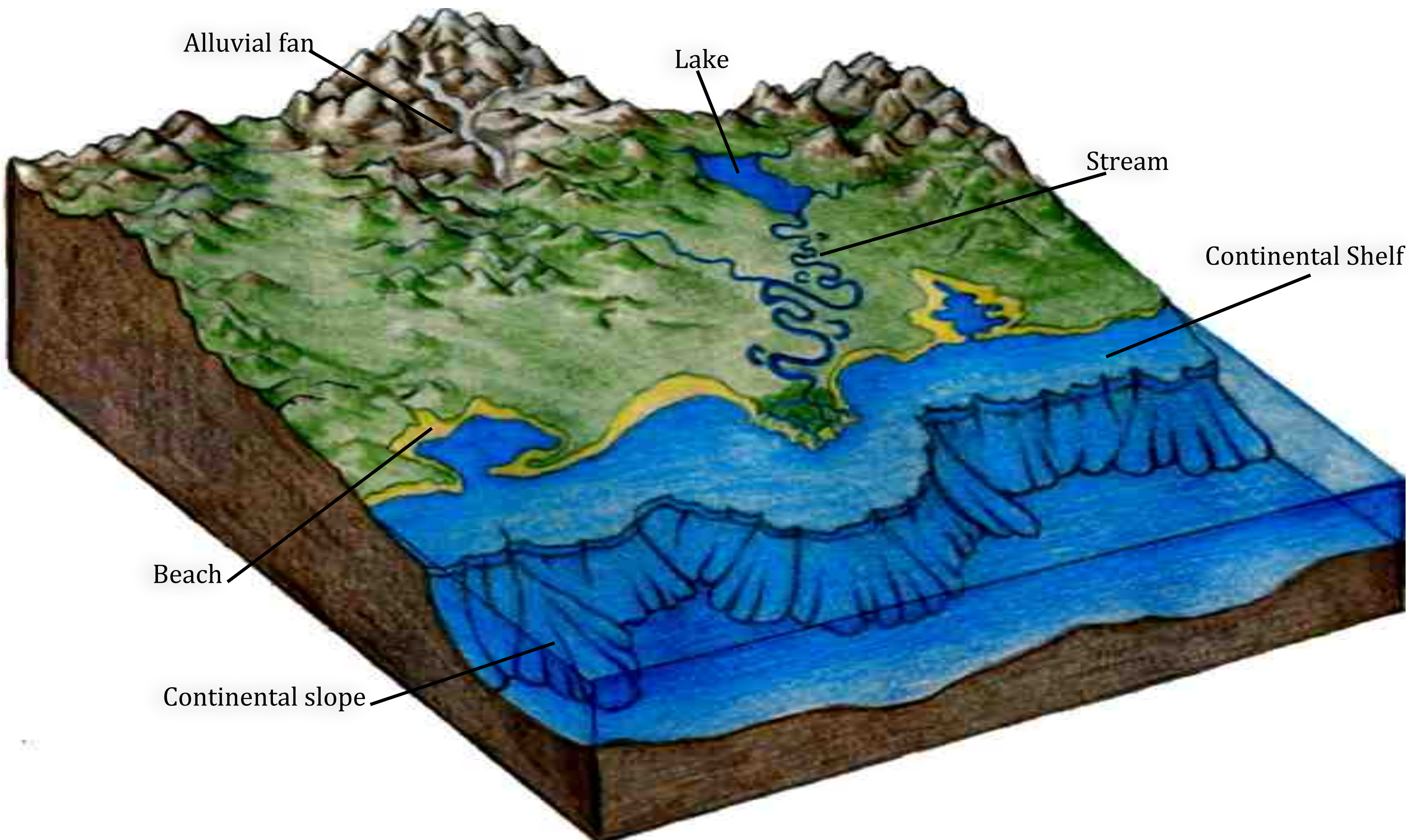


Figure 32: A map of depositional environments. When the elements weather and erode a landscape, the loose pieces of rock are transported as sediment and deposited into different depositional environments. High topography, such as the ancient Grenville Mountains, slowly broke down and were transported downhill by streams, rivers, and landslides until they came to rest in river channels as cobbley conglomerates, along beaches as sands, and in lakes as fine mud and silts. Note that the green plants in this illustration had not yet evolved on Earth when Rodinia rifted apart! (Inspired by Jones, 2000: Laboratory Manual for Physical Geology, 3rd Ed.)

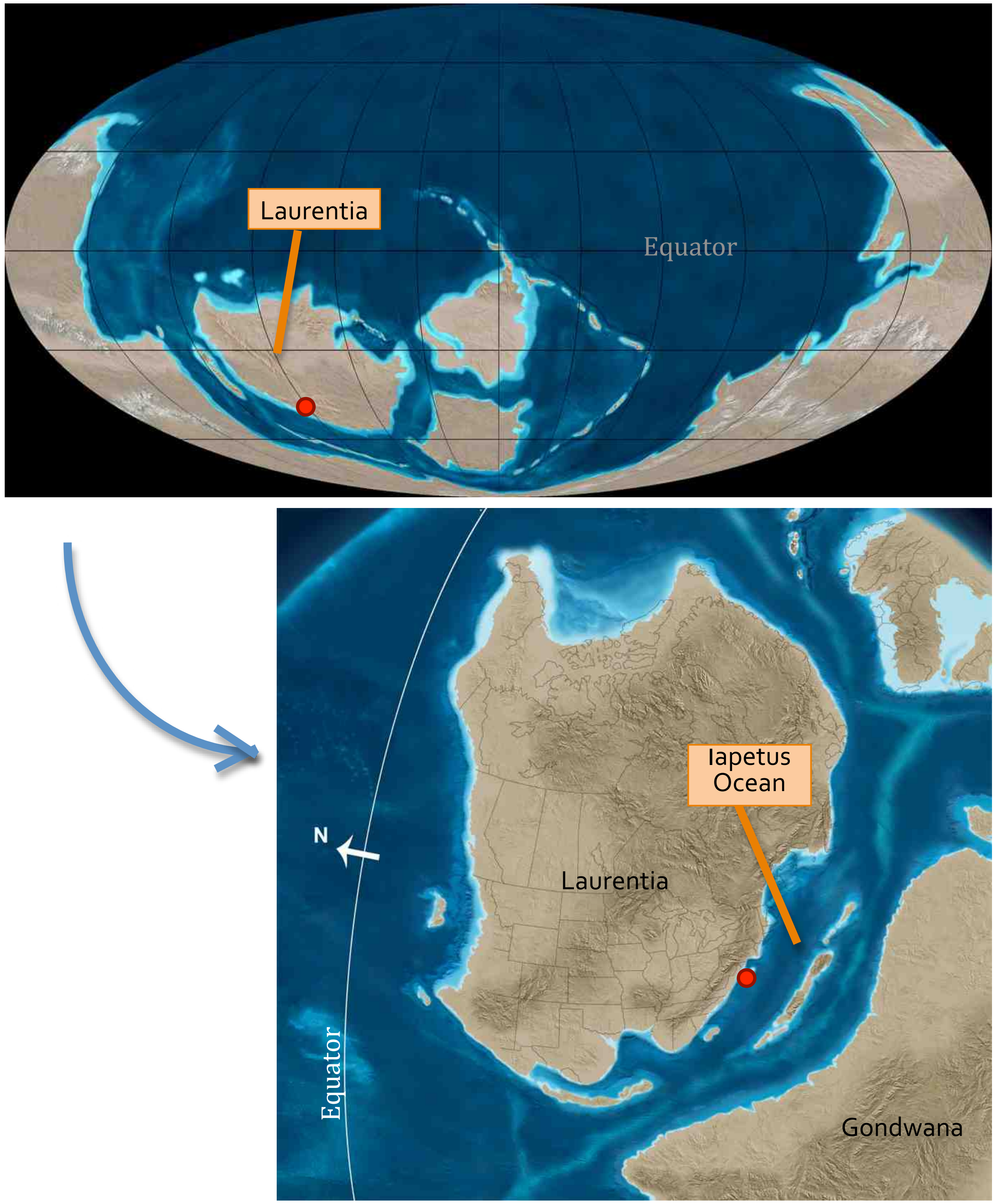


Figure 33: Our coast was in a very different location 550 million years ago. As the broken fragments of Rodinia separated, Laurentia began to drift towards a more northerly location, entering warmer waters. The close up view of Laurentia illustrates that at that time, the coast ran through what would later become Vermont, the cities of Philadelphia and Washington, DC, southward through western Virginia into central Georgia**.** The red dot signifies the approximate location of Shenandoah NP. **(**Maps courtesy of Dr. Ron Blakey, Northern Arizona University)

accumulated offshore on the continental margin. At the same time siliciclastic rocks (sandstone, shale, and conglomerates) formed in the rivers and on the beaches. The deposition of such sediments is called a transgressive marine sequence, which is well-preserved in sedimentary rock layers in the central Appalachians (Faill, 1997). This sequence of rocks suggests a completion of continental rifting during the Cambrian Period that progressed from north to south (Thomas, 1991; Bartholomew, 1989). This sequence also hints at a global rise in sea level, which eventually flooded much of the Laurentian continent under the shallow Sauk Sea. These sedimentary deposits can be seen today throughout the Appalachian Mountains interlayered with metamorphosed rift lava flows, especially within the valleys east and west of the Blue Ridge Mountains (Bailey and others, 2007).

Although lava was no longer spewing forth over the landscape, the new coastal environment was not necessarily more relaxing. There were wide-spread ice ages during the late Proterozoic, peaking 700, 635, and 580 million years ago (Stanley, 2009). Such events would have aided weathering and erosion of the landscape, helping to expose the deep roots of the ancient Grenville Mountains. The intensive glaciation may also have spurred a flamboyant diversification of life on Earth (Stanley, 2009; Narbonne and Gehling, 2003). The appearance of a new ocean provided a perfect setting for some of the first complex life. The Ediacara Fauna capture some of the oldest animal fossils known in the fossil record. During the end of the Proterozoic, around 560 million years ago, animal life diversified into a variety of soft-bodied organisms. Early ancestors to mollusks (*Kimberella* - similar to modern-day snails) and arthropods (*Spriggina* – similar to soft-bodied trilobites) moved slowly across the sea floor, while simple suspension feeders (*Charnia* – fronds with a kelp-like appearance) were secured by holdfasts to the substrate (Stanley, 2009; Narbonne and Gehling, 2003; Glaessner, 1971; Figure 34). Algal or cyanobacterial mats covered patches of the shallow ocean floor, sticking to and wrinkling the underlying sand and mud. Early sponges and calcium carbonate-secreting tubeworms (*Cloudina*) also made an appearance, leaving behind some of the first tiny, hard-body parts. Closer to land, the beach also held a kind of life. Early segmented annelids (*Skolithos* – similar to earth worms) made very simple burrows in the sand. Today, these trace fossils (*Skolithos linearis*) are preserved in Shenandoah and can be found in abundance within the Antietam Formation of **Calvary Rocks**.

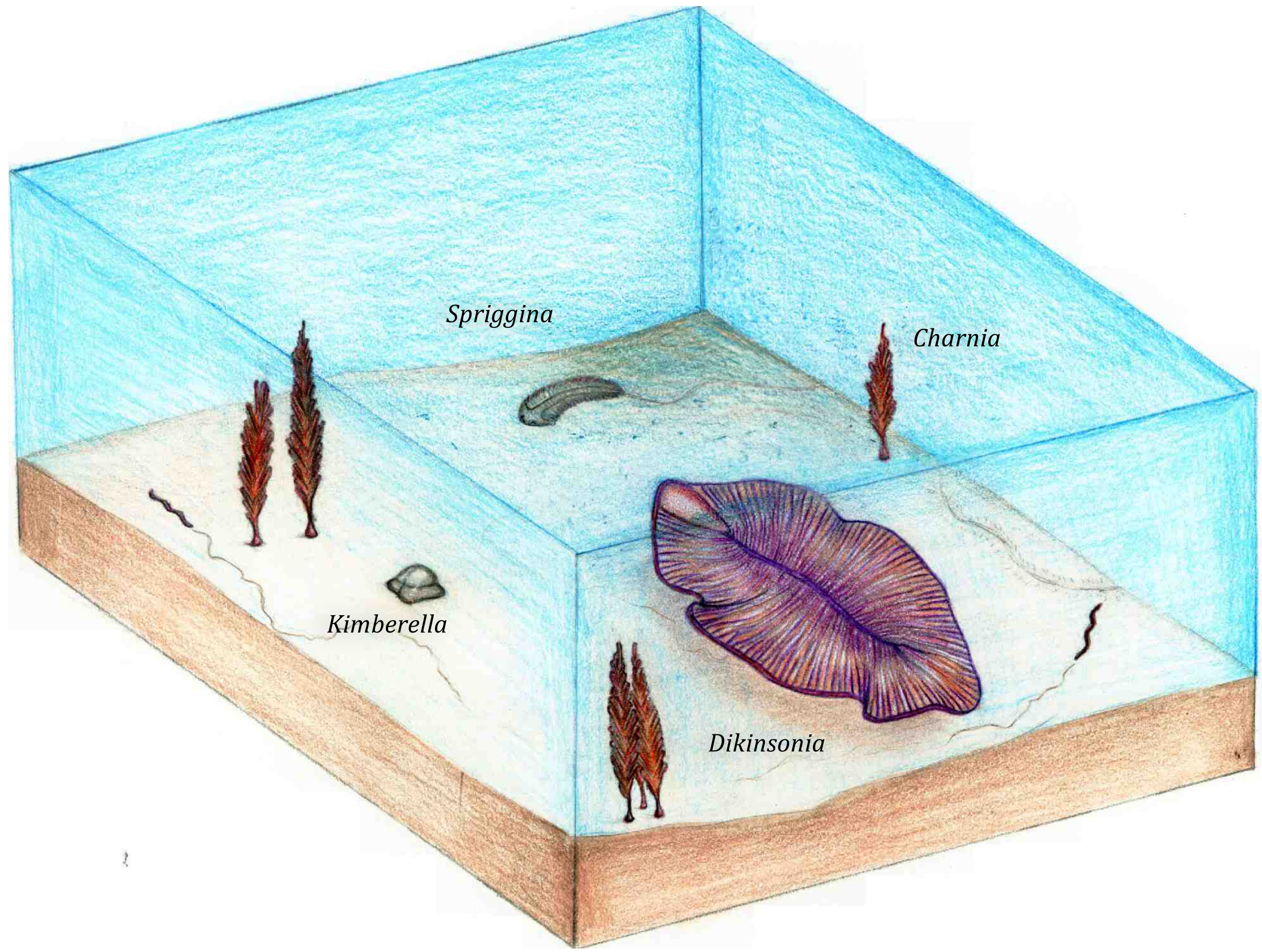


Figure 34: Life on Earth during the Late Proterozoic (560 million years ago). At this time in Earth's history life would have been confined to the oceans, comprising a variety of soft-bodied organisms. Known as the Ediacara fauna, these animals were largely sedentary, attached to the sea floor like the plant-like *Charnia*, or able to move independent of the sea floor, such as the snail-like *Kimberella*, or the disk-like *Dikinsonia* that could reach up to 5 feet in length! Early annelid worms made their first appearance scurrying across the sea floor and making shallow burrows near the beach.

E. Crashing Continents

So far we have learned about the late Proterozoic rifting of Rodinia, represented by a series of volcanic and igneous rocks, and the deposition of sedimentary rocks that once formed off the calm Laurentian shore. When we find these rocks in the landscape today, we can see that all of them have been squeezed and transported far distances (up to 150 miles westwards) from where they originally formed (Hatcher, 2010; Evans, 1989; Badger and Sinha, 1988; Cook and others, 1980). Such catastrophic deformation could only be caused by a major geological event.

This section focuses on the tectonic-scale events that shaped the Appalachians as we see them today – the process of mountain building referred to as orogenesis. Three major events involving the collision of relatively thick blocks of crust (continents, continental fragments, and volcanic islands) formed the Appalachian Mountains over a 200 million year interval (Rast, 1984; Hatcher, 1981). The first two events involved comparatively small masses of land, while the final collisional event compressed what would become the continents of Africa, South America, and Europe against the coast of ancient North America (Figure 35). Each collisional event resulted in three primary geological processes: metamorphism of rock, intrusion of magma, and deformation of the crust (Williams and Hatcher, 1983; Williams and Hatcher, 1982). As each event dramatically changed the landscape, it contributed to the growth of the Appalachian Mountains.

The Arrival of Minor Landmasses

Taconic Orogeny

After the supercontinent Rodinia rifted apart, the calm coastline of Laurentia traced a jagged line along what is now Vermont, south through Washington, DC, western Virginia, and into Georgia (Corrie and Kohn, 2007; Thomas, 2006; Figure 31). But this coastline would soon undergo a major change. The first of three collisional events that formed the Appalachian Mountains occurred about 450 million years ago, called the Taconic Orogeny. The orogeny is named after the Taconic mountain range in eastern New York State, a northern portion of the Appalachians and the center of much research about mountain building processes and plate tectonic theory. The Taconic Orogeny was not a single collisional event, but rather, a sequence of events like dominoes that led to the first mountain building phase of the eastern seaboard (Rodgers, 1971).

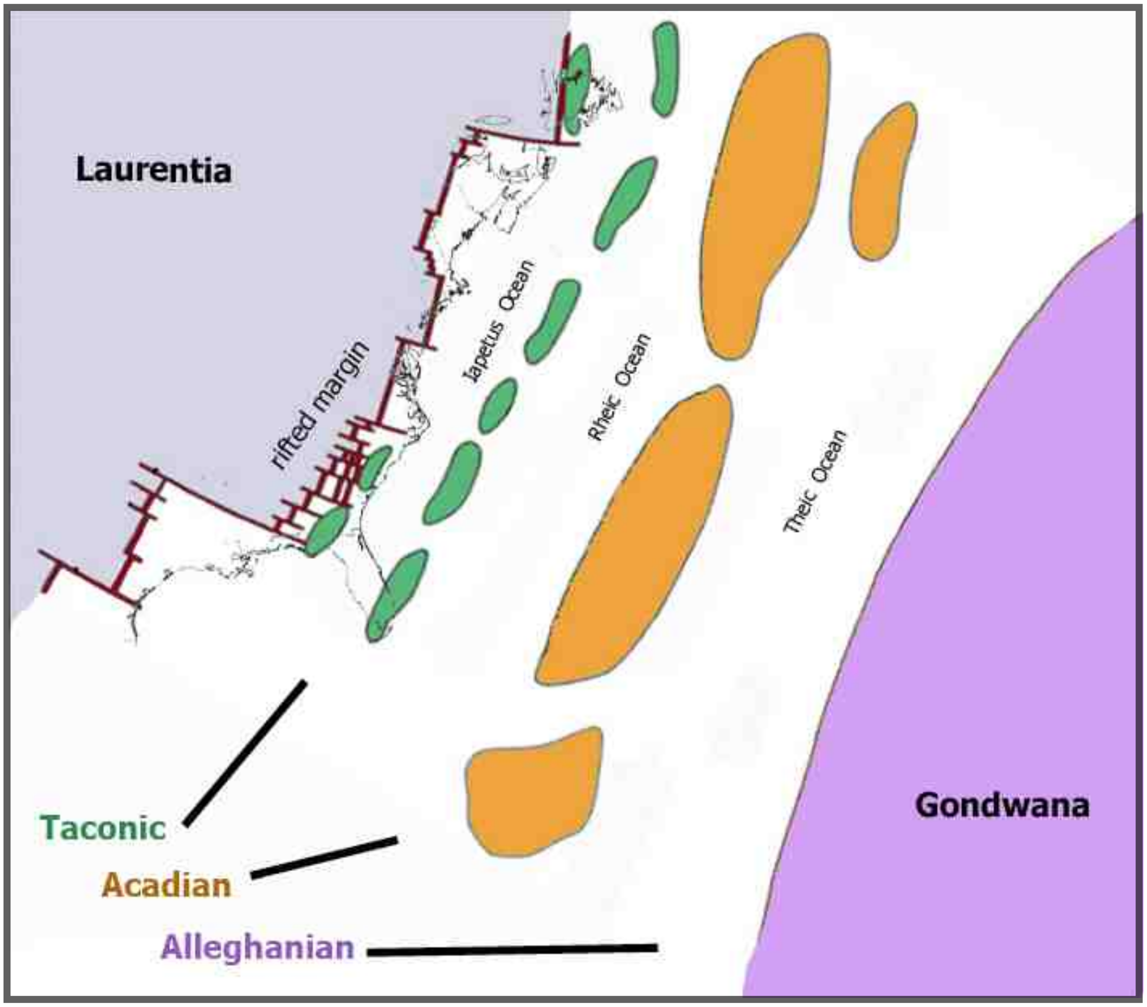


Figure 35: Three landmasses collided with the uneven coast of Laurentia. The Taconic (green), Acadian (orange), and Alleghanian (purple) landmasses collided with the pointy promontories and recessed embayments, adding to the complexity of our present-day landscape. The green islands represent the incoming volcanic island arc that collided with Laurentia to produce the Taconic Orogeny. The orange landmasses represent the incoming continental fragments that produced the Acadian Orogeny. Gondwana, in purple, is a huge continent that formed our Appalachian Mountains when it collided with Laurentia during the Alleghanian Orogeny as supercontinent Pangea developed. Note that the shoreline of Gondwana would also have been unevenly rifted and is greatly simplified in this map. Three distinct ocean basins existed between each collisional landmass – the Iapetus Ocean formed when supercontinent Rodinia first rifted apart. The Iapetus Ocean basin closed as the Taconic islands collided with the coast. A new ocean basin, called the Rheic, then existed off the shore of Laurentia until the Acadian landmass collided, closing this ocean basin. Before Gondwana collided with Laurentia, the Theic Ocean existed. Following the rifting of Pangea (as Gondwana tore from North America) the newest ocean basin, the Atlantic, formed. (Modified from Hatcher, 2010 and Thomas, 2006)

From divergence to convergence

Plate divergence that rifted ancient North America (Laurentia) from the rest of Rodinia continued to spread the landmasses apart. But by the end of Precambrian time (around 550 million years ago) the opening Iapetus Ocean underwent a transition. Over time, the new oceanic plate that was forming between the rifting Laurentian and Rodinian landmasses was cooling and contracting - becoming more and more dense (Cloos, 1993). Eventually, the heavy oceanic plate became too heavy, and gravity pulled it down into the underlying asthenosphere, forming a subduction zone (Stern, 2004). With the formation of this new subduction zone, the Iapetus Ocean, which had been opening for a few hundred million years, began to close.

The Chopawamsic volcanic arc

If we were to remove all the water from Earth's oceans, we would see a complex sea-floor landscape of topographic highs and lows. It is believed that high bathymetry (topography under the oceans) is more likely to encounter resistance at a subduction zone, catching on the colliding plate and becoming glued on as a new accreted terrane (Ben-Avraham and others, 1981). Much of the North American continent was added in this fashion, as pieces of high ocean bathymetry and landmasses such as volcanic islands collided with ancient North America and became zippered on (Cloos, 1993; Ben-Avraham and others, 1981). Thus much of the land beneath our feet originally came from far away, making eastern North America a patchwork quilt of allochthonous landscapes.

The new subduction zone engulfed these bathymetric features, pulling in the surrounding lithosphere like the conveyor belt that pulls in groceries at the check out line. This swallowing of oceanic crust started a chain of events that would forever alter the landscape. As the subduction zone consumed the dense oceanic plate, the plate sunk deeper and was subjected to higher temperatures and pressures. The basaltic oceanic crust metamorphosed into eclogite, an even more dense rock that enhanced the downward decent. The sinking plate began to dehydrate (sweat off water), which caused the surrounding rock to melt and rise. The hot magma climbed up through the lithosphere and melted more rock, forming an underwater chain of volcanoes. Flow upon flow of lava piled up on the sea floor, until volcanoes grew so tall that they breached the ocean surface, forming an island chain known as a volcanic island arc – in this case, one called the Chopawamsic Island Arc (Figure 36).

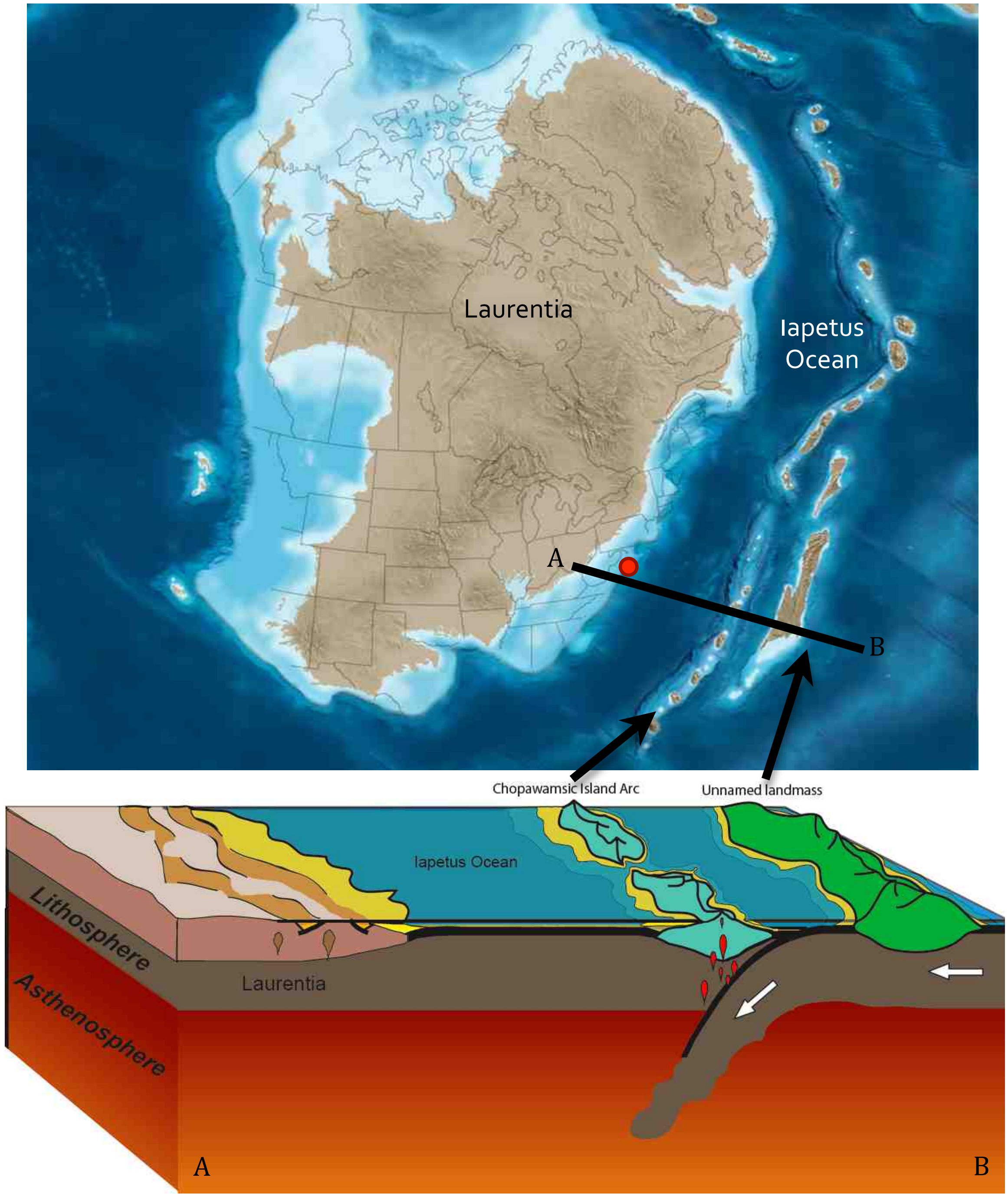
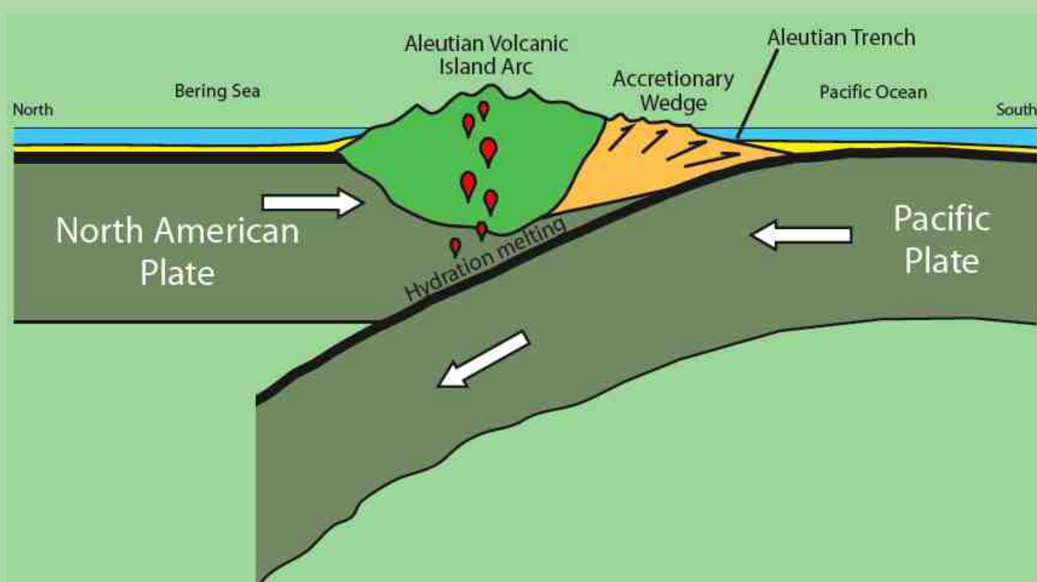


Figure 36: The Chopawamsic islands sit off the coast of Laurentia 510 million years ago. The thin chain of islands is the beginning of what would become the Taconic volcanic island arc, a linear chain of volcanic islands (Chopawamsic Island Arc) and a sliver of land that eventually will collide together and squish onto the eastern shore of Laurentia, adding land to North America known today as western New England, portions of Pennsylvania, and Virginia. The cross section (line A-B on the map) illustrates what the subduction zone and landmasses would have looked like if we could have sliced them open – a view downwards, into the Earth. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

Alaskan Aleutian Islands - a modern analog to the Taconic Island Arc

The state of Alaska has a unique comparison to Virginian geologic history in that today, the Aleutian Island chain is very similar to what the Chopawamsic volcanic arc might have been like before it collided with Laurentia during the Taconic Orogeny. In southwestern Alaska, a modern subduction zone pulls the Pacific Plate underneath the North American plate, forming an elegant chain of islands as hydration causes magma to rise to Earth's surface forming the Aleutian volcanic island arc.



In most cases, looking at the world today is the best way to learn about how the Earth would have been in the past. In this way, we can find connections between our own homeland and places far across the globe. Highlighting a parallel such as this can be a useful teaching tool and source of inspiration for park visitors.

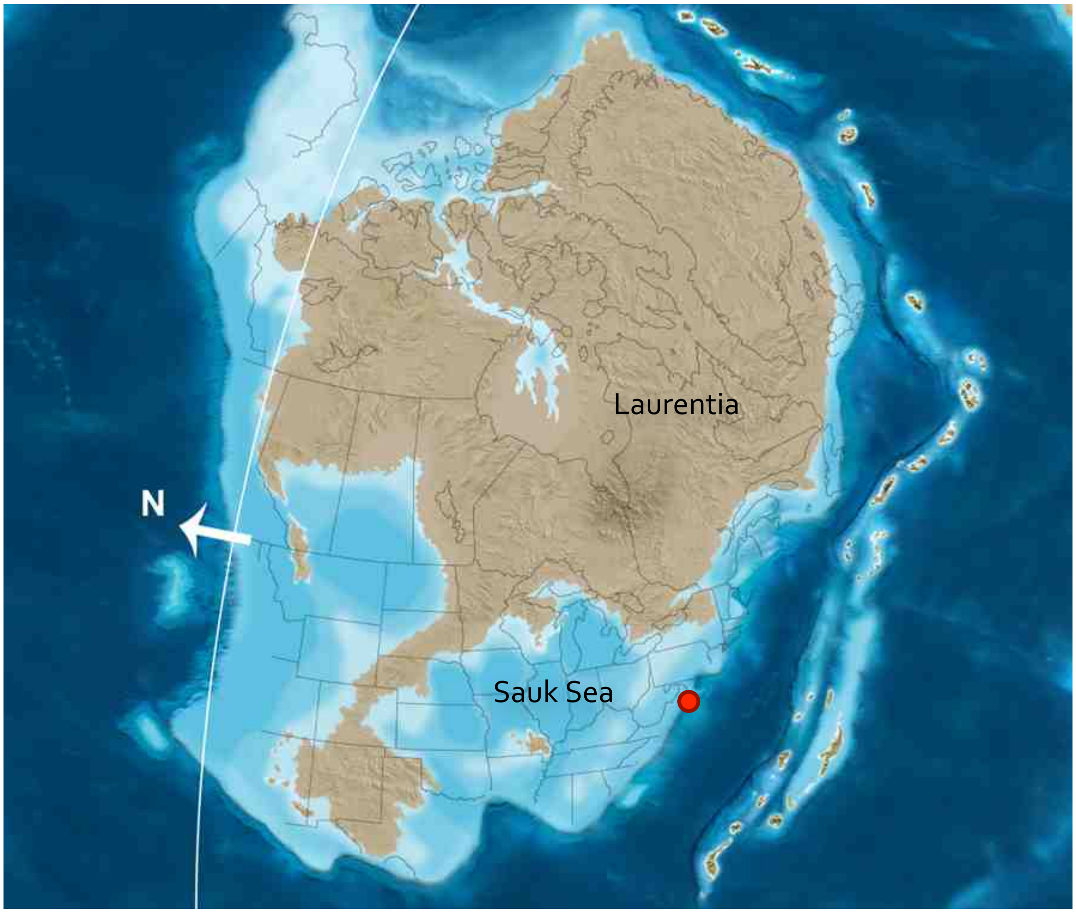
The Arvonia Island Arc

The Chopawamsic Island Arc volcanoes grew as subduction continued – ever adding lava flows, ash, and other materials to the volcanic islands. Pieces of the volcanoes themselves began to pile up on the mountain flanks as the elements weathered and eroded the volcano peaks into sediment. This dual process continued until an approaching landmass, a small fragment of Gondwana carried by the subduction zone conveyor belt (Hibbard and others, 2007), slammed into the eastern side of the Chopawamsic volcanic island chain (Figure 37). When this occurred the incoming landmass was too buoyant to subduct under the Chopawansic islands; instead it became glued on (accreted) along a suture zone, forcing the subduction zone to stall. As the subduction zone stalled, so too did the growth of the Chopawamsic volcanoes. The volcanoes became extinct and over time, began to erode more intensely, exposing the deeply buried plutons that once fed the volcanoes themselves. This pieced-together mass of land and volcanoes is now called Arvonia.

For perhaps 50 million years, Arvonia slowly eroded. As this change occurred above ground, so too did changes commence below. Like a line of dominoes, once the first piece is tipped, a chain reaction follows. In this case, when the Chopawamsic island arc collided with the other landmass, the result was that the subduction zone stalled. However, the two plates continued to converge, forcing a new subduction zone to form, but flipped in the opposite direction. This polarity reversal occurs as the two converging plates switch roles; the plate that was once above the subduction zone is now the plate that is being subducted (Stern, 2004; Figure 38). Now the new subduction zone began to swallow oceanic crust in a westward direction, slowly pulling in the Laurentian mainland. Volcanoes formed on Arvonia, just as they had on the old Chopawamsic arc and began spewing their hot lava once again across the land.

In the shadow of the Taconic Orogeny

While the Laurentian landmass approached the coast of ancient North America, the calm life of the continental margin began to change. By the middle Ordovician (around 460 million years ago) the warm, shallow Sauk Sea that flooded most of Laurentia was slowly draining away, as massive polar ice caps, acting like sponges, held much of the water that otherwise would have been in the ocean. As this occurred, previously submerged areas of southeastern Virginia, eastern Pennsylvania, and elsewhere became exposed. Whenever rocks and sediment are exposed above



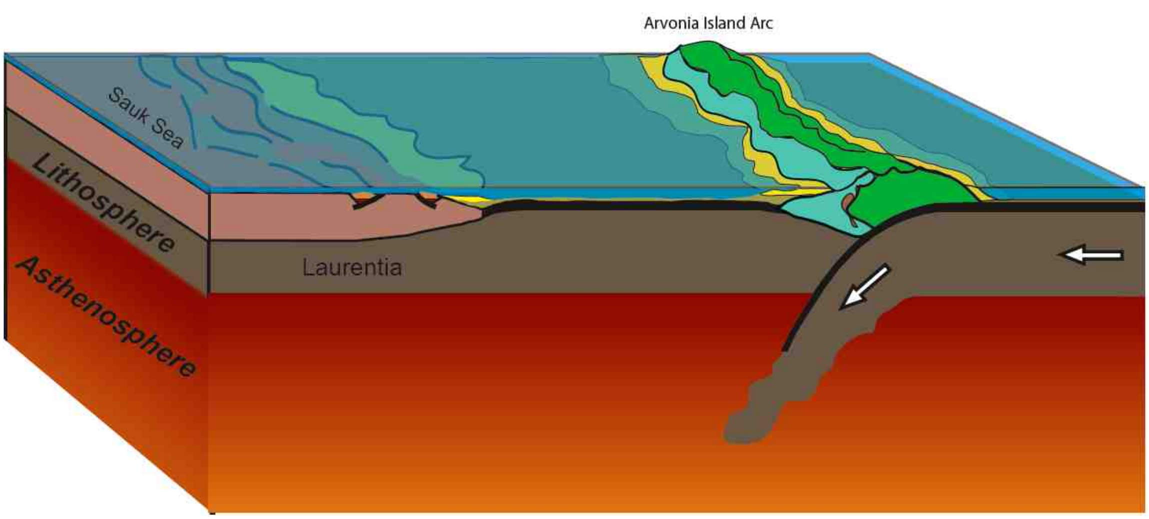
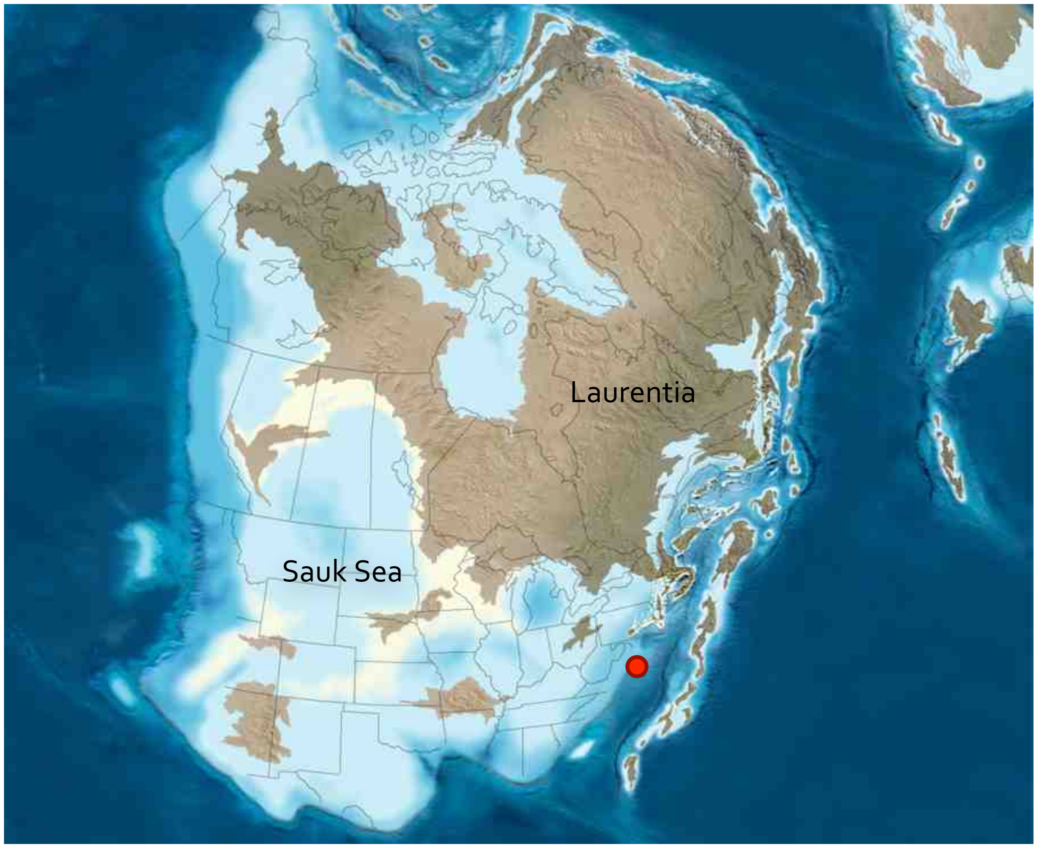


Figure 37: The Chopawamsic Island Arc collided with another landmass to form Arvonia. This collision occurred 500 million years ago and clogged the subduction zone, forcing it to switch direction. Meanwhile, the Sauk Sea began to flood mainland Laurentia. The red dot signifies the approximate location of SNP. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)



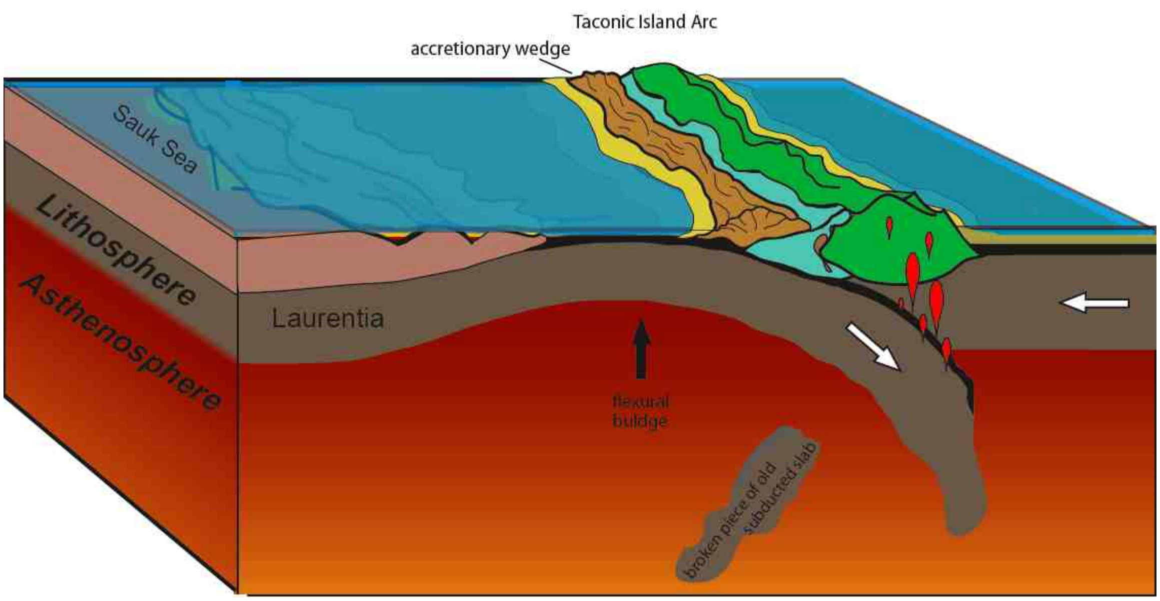


Figure 38: The subduction zone switched polarity around 485 million years ago. During the Ordovician Period, this switch activates the new Taconic Island arc. Volcanoes form and erupt as the islands draw closer to the Laurentian coast. The islands acted like a bulldozer, scrapping sediments off the subducting sea floor to form an accretionary wedge. The red dot signifies the approximate location of SNP. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

sea level, they are victim to the processes of weathering and erosion, and thus may become erased from the land. The erasing of rock layers by this process leaves what is called an unconformity. Unconformities exist everywhere across the world, and record erosional events throughout Earth's history. In Virginia, the Knox unconformity records the drop in sea level during the Ordovician Period (Fichter and Baedke, 1999).

Sea level soon rose again, submerging Laurentia in another shallow sea (called the Tippecanoe Sea) that quickly became full of a variety of organisms. Many hard-bodied animals, called the Paleozoic fauna, evolved during a major biodiversification event of the Ordovician Period. These new creatures included bryozoans, brachiopods, crinoids, graptolites, cephalopods, starfish and even early fish (Turner and others, 2004; Figure 39). Because many of these new species had hard body parts, they were preserved and fossilized much more easily than earlier soft-bodied animals, leaving a wonderful record of life on Earth. Many fossil-hunting locations in the United States take advantage of this event, digging into Ordovician aged rocks (500 to 450 million years old) that once lined the ancient ocean floor, entombing thousands of sea organisms. The city of Harrisonburg, Virginia sits on top of the shales and limestones that formed during the Ordovician Period (Fichter and others, 2010).

Meanwhile, the large Arvonian chain of islands was being pulled by the new subduction zone towards the Laurentian shore. An inevitable collision was on the horizon. Ash from volcanic eruptions fell like thick blankets of snow across the land and sea. Today, this ancient ash is preserved within layers of limestone throughout much of the eastern United States, along the Shenandoah river within the Shenandoah Valley, and even across portions of northern Europe (Southworth and others, 2009; Fichter and Baedke, 1999; Kolata and others, 1996). The sea floor (the carbonate shelf) began to bow upwards under the pressure and weight of the incoming island chain, forming what is known as a flexural bulge (Figure 38), bowing upwards out of the shallow ocean as the heavy volcanic islands approached. Layers of the shelf were eroded away, as they were exposed to shallow ocean waves, wind, and rain. As the islands approached, they also bulldozed up piles of sea floor sediments, scraping them up onto the front of the Arvonian volcanic islands, forming an accretionary wedge (Figure 38). Given enough time and sediment, an accretionary wedge can grow quite large, forming a coastal mountain range. This is the case

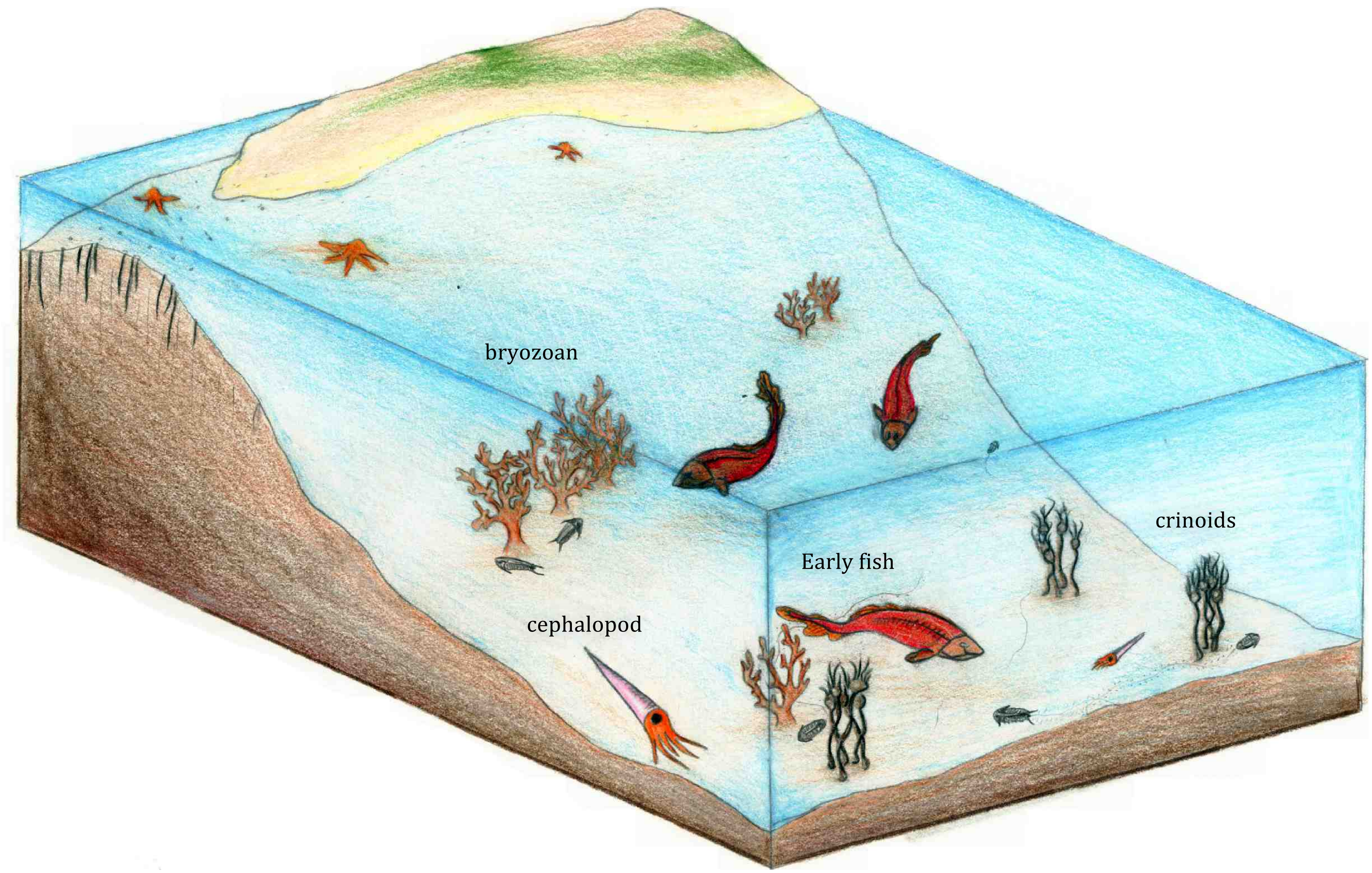


Figure 39: Life during the Ordovician Period. Known as the Paleozoic fauna, life forms evolved during that were hard-bodied, unlike the soft-bodies of most earlier life on Earth. Brachiopods, bryozoans, cephalopods, crinoids, starfish, graptolites and fish filled the shallow Tippecanoe Sea that covered Laurentia 450 million years ago.

on our modern day west coast – the Olympic Mountains and other coastal ranges in the Pacific Northwest are a huge accretionary wedge scraped and piled onto the coast. Along with the sea-floor sediments, actual pieces of the hard-rock sea floor itself (ophiolites) were spliced up into the mash of material bulldozed in front of the incoming islands (Hatcher, 2010; Stanley, 2009; Southworth, 2008; Miller and others, 2006; Williams and Hatcher, 1983). If you have ever visited Belvidere Mountain in Vermont, or hiked the mountains of eastern North Carolina, you may have been standing directly on top of a fragment of the ancient sea floor. Many other examples of the seafloor are exposed today in northern New England and Canada.

The initial collision

The Arvonian Island Arc began to crash into the coast of Laurentia about 450 million years ago, kicking off the Taconic Orogeny (Hibbard and others, 2007). The two landmasses were shoved together unevenly at an angle (Van Staal and others, 1998), closing like a zipper from the south to the north, over the course of millions of years (Hibbard and others, 2007). The Laurentian continental margin was forced into a nosedive, while Arvonia rode up the ramp of the subduction zone, climbing ever upwards on top of the edge of Laurentia (Figure 40). Mountains formed up the coastline from what is now Georgia through eastern Canada (Hibbard and others, 2007; Rodgers, 1971). The mountain building, however, occurred in an uneven pattern, as the coast itself was a jaggedly-ripped continental margin (Corrie and Kohn, 2007). Think of an unmanned game of Tetris – the incoming game pieces (called tetrominoes) would collide haphazardly as they pile together, rather than fitting together like puzzle pieces. Now imagine the Laurentian coast and incoming island landmasses as a giant game of Tetris. The coastline consisted of pointy promontories that jutted out into the closing Iapetus Ocean, separated by recessed embayments, like the edge of a serrated steak knife (Figure 31). Thus, when the Taconic crunch occurred, it was an uneven collision where the promontories received the initial and hardest collisions (Hibbard and others, 2007; Corrie and Kohn, 2007; Thomas, 2006; Faure and others, 1996). Such locations included the south-central portion of Virginia (referred to as the Southwest Virginia High) and the southeastern corner of what is now Pennsylvania (Figure 35). The recessed embayments were thus protected from the brunt of the hard collisions and left instead as depressions that collected sediment from the surrounding higher land (Hatcher, 2010; Corrie and Kohn, 2007; Thomas, 2006). The incoming Taconic terrane first struck the Virginia promontory, squishing the land and causing the greatest metamorphism of rock to occur in the area of the

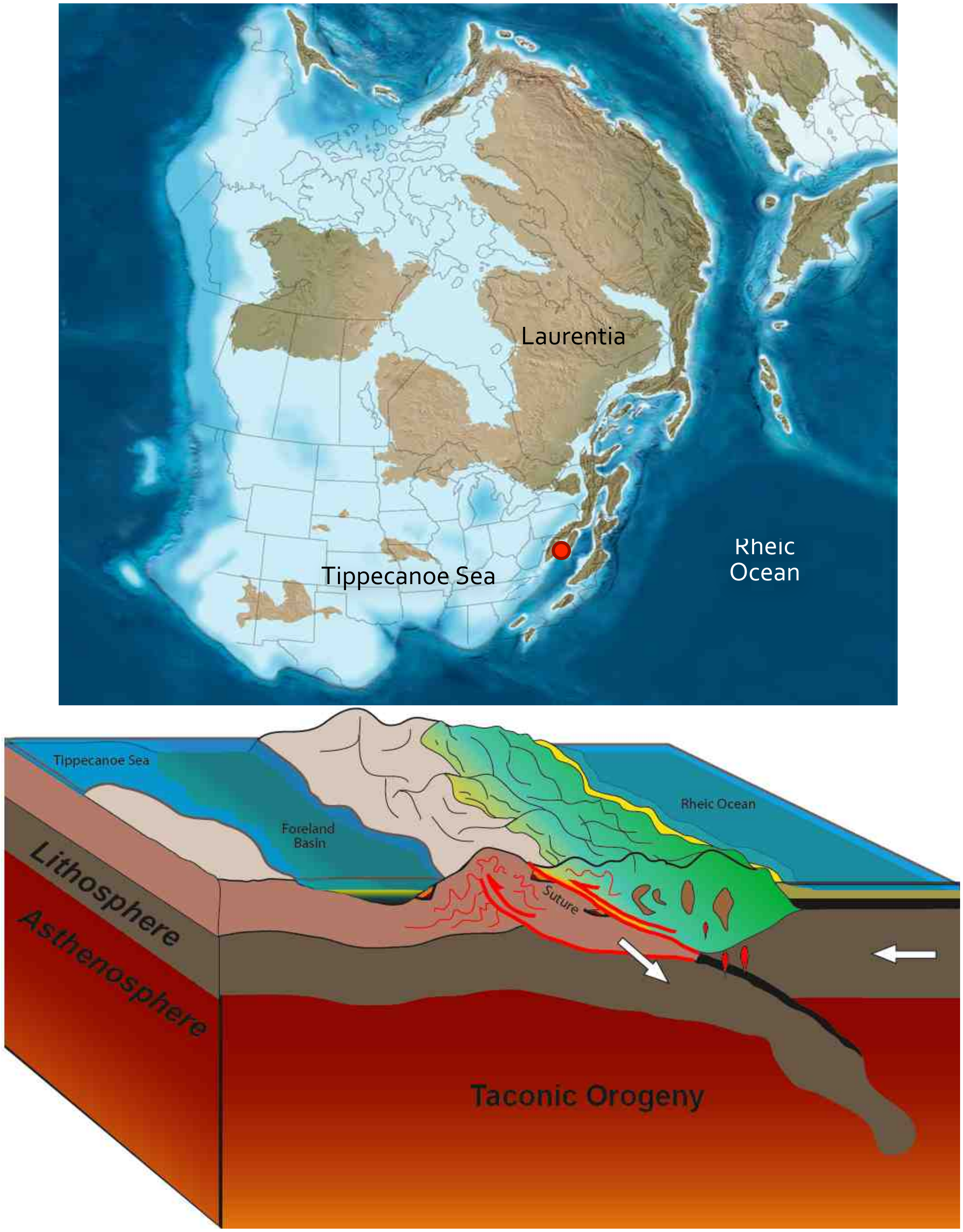


Figure 40: Arvonia collided with Laurentia 450 million years ago causing the Taconic Orogeny. The massive inland Tippecanoe sea flooded much of Laurentia during the late Proterozoic, Cambrian, and Ordovician. This paleogeographic map demonstrates the breadth of the sea at its fullest extent 450 million years ago, during the time of the Taconic Orogeny. The red dot is the approximate location of SNP. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

Great Smoky Mountains, even compared to the continental collisional events of the upcoming Acadian and Alleghanian orogenies (Corrie and Kohn, 2007).

The volcanic island arc that pushed against the eastern shore of Laurentia squeezed rocks from New Brunswick all the way south to what is today the Great Smoky Mountains of Tennessee and North Carolina. Ancient lava flows that were strewn across the landscape during the rifting of Rodinia were heated and metamorphosed into greenstone (metabasalt), forming the Catoctin Formation of Shenandoah National Park. The Taconic collision also metamorphosed the sands, silts, and muds that had eroded off the ancient Rodinian Mountains, changing the sandstone and shale layers into the quartzites and phyllites that make up the Chilhowee Group (the Weverton, Harpers, and Antietam Formations) (Thornton-Ehrlich, 2005).

As the two landmasses crashed together along the promontories, massive faults formed – giant fractures along which the rock slid towards the mainland. Some of these faults cut deeply down into the ancient bedrock - the basement complex that was eventually exposed in the Shenandoah region (Evans, 1989). As the collision continued, many old faults that formed during the rifting of Rodinia were reactivated, providing weak zones where the landscape gave way to the compressing terrain (for example, Clemons and Moecher, 2009). The compression reactivated old faults and also broke new ones, allowing the landscape to literally stack on top of itself, as the Taconic Island arc slipped on top of Laurentia, forming what is known as an allochthon. In New England, major Taconic faults are found in the west (such as the Champlain thrust), whereas in the central and southern Appalachians, Taconic faults are concentrated in a linear zone within the core of today's Appalachian Mountains (examples are the Rockfish Valley fault of the central Appalachians - see Figure 53, and the Hayesville fault and Brevard zone to the south) (Fichter and others, 2010; Bailey, 2000; Hatcher, 1981). Major faults like these split through and folded the soft sedimentary rocks and the hard crystalline basement, forming huge slivers of rock that slid up and westwards onto Laurentia, forming mountains (Hatcher, 1981).

The increasing weight of the developing mountains pushed down the surrounding land into low basins that filled with water. In the central Appalachians a major basin, called the Appalachian foreland basin, began forming early in the mountain building process and collected bits and pieces of sediments eroded off the Taconic Mountains (Southworth and others, 2001; Horton and others, 1989). These sediments were deposited in layers across modern-day West Virginia (Figure 40). Massive underwater landslides, called turbidites, deposited coarse fragments of mountain rocks covered by fine sediment. These flysch deposits eventually filled the foreland basins (Horton and others, 1989). The eroding mountains continued to pile sediment over the land, depositing what is called molasse. After the Taconic Orogeny ended about 445 million years ago, the mountains were slowly eroded flat, removed piece by piece and transferred far and wide into the western foreland basins under what is now called the shallow Tippecanoe Sea, and back into the deep eastern ocean, now called the Rheic Ocean (Figure 35). Some of the sediment reached as far as the western edge of North America; you can see the resulting sandstone and shale layers when you hike down the Grand Canyon in Arizona!

The evidence for the Taconic orogeny is seen strewn today across the eastern states. The rocks of the Laurentian promontories were metamorphosed as mountains rose from New Jersey southward through North Carolina. The Taconic Orogeny increased Laurentia's size, adding slivers of land that would become western New England and eastern Canada. Even the westernmost Piedmont province (Figure 14) of Virginia is largely composed of slivers of the Chopawamsic volcanic islands and ocean sediments. But the Taconic Orogeny was simply the first of a series of dynamic events that would increasingly impact the Shenandoah National Park region.

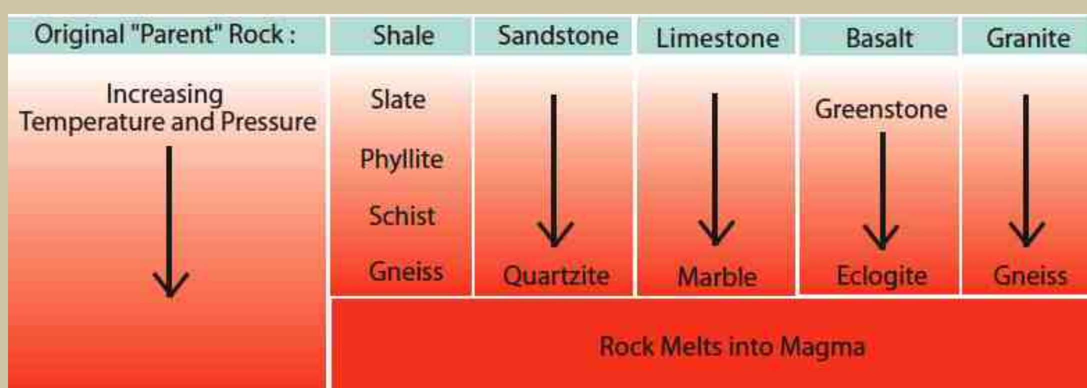
What is Metamorphism?

Everything changes. Just like the Monarch caterpillars of Shenandoah that undergo metamorphosis and transform into beautiful butterflies, rocks too experience life changes. In a sense, rocks live multiple lives, reincarnated over the course of hundreds of millions of years. Metamorphic rocks are merely a stop along the transformation process.

All rocks - igneous, sedimentary, and metamorphic - can metamorphose, like caterpillars, into something completely new and different. But metamorphism is a journey with many possible turns and stops. Rocks undergo metamorphism by being placed somewhere with high temperatures and / or pressures, typically, deep below Earth's surface. The deep Earth thus acts as a giant pressure cooker, both heating and compressing rock.

Humans develop accents based on where we live or grow up. In a way, our accents distinguish us from each other, making it easier for others to figure out who we are and where we are from. We can think of metamorphism, specifically, metamorphic grade, or metamorphic facies, as a rock 'accent' – it tells us all about the rock's past.

Metamorphic grade in a rock reveals aspects of a rock's past because minerals (the components of a rock) are very picky about when and where they like to grow. Certain minerals will only grow in high temperatures, whereas others prefer lower temperatures, but high pressures.



Common rocks of Shenandoah National Park are listed in the chart above. Note that the *parent* rock is what a rock was before it was heated and compressed (metamorphosed). Here are some examples. Walking through the mountains today, we commonly see the Catoctin greenstone. This rock once was hot lava that cooled into basalt and became squished by the Taconic, Acadian, and Alleghanian Orogenies. It was squished and heated, but not too much, because it did not turn into eclogite, a rock that requires very high pressures and temperature. Based on its mineralogy (especially the presence of the green-blue chlorite and epidote), we can determine that the Catoctin Formation experienced only medium-grade (called greenschist facies) metamorphism. On the other hand, we also see the gneisses of the Basement Complex. Here, igneous granites have been heated and squeezed considerably (to amphibolite facies or granulite facies – high grade metamorphism).

Acadian Orogeny

Nature loves patterns. In leaves, flowers, the ocean, folds in rocks - we see patterns everywhere forming our beautiful environment. Nature also repeats patterns over time. For example, the series of events that made the Taconic orogeny so spectacular repeated themselves millions of years later as the second mountain building event that greatly shaped the Appalachian region. This second event is called the Acadian Orogeny. It was named after the island of Acadia, which was settled by the French Acadian people in the 1600's, later to be called Nova Scotia.

In the shadow of the Acadian Orogeny

Following the Taconic Orogeny, the most dramatic changes that occurred in the Shenandoah region involved the sea. By about 430 million years ago, during the Silurian Period, the impressive Taconic Mountains had greatly eroded away, their final bits and pieces strewn as patches of sand and mud across the Sea floor. The Tippecanoe Sea still covered most of Laurentia, but a low and flat plain of land stood above the sea to the east and north, where the mountains once towered. Frequently the Tippecanoe Sea rose and fell, occasionally exposing pieces of the Laurentian mainland here and there. When sea level dropped, a regression occurred, and the elements ate away the exposed land. When sea level rose, it was called a transgression and sediment was deposited in bulk. The sediments that accumulated became lithified into hard rock, mostly sandstones (from sand) and shales (from mud, seen today in the Fort Valley Formation of **Massanutten Mountain**, east of Shenandoah National Park) (Fichter and others, 2010). The geographic position of the Laurentian continent impacted the type of sediment deposited. Hundreds of feet of salt beds accumulated as Laurentia drifted across the dry, hot latitudes (Fichter and Baedke, 1999).

The Armorica Terrane

Millions of years of relative calm ensued, as sediments piled underwater across what would become North America. But just as happened during the Taconic Orogeny, a landmass was slowly approaching the shore. The powerful subduction zone that pulled Arvonia into the Laurentian coast became choked during the Taconic collision (Murphy and others, 2006; Stern, 2004), but the motions of the tectonic plates continued. Like a relay race, the torch of subduction was simply passed on to another location: the front of a large landmass called Armorica (Figure 41). Armorica, like Arvonia before it, was a sliver of land that had broken free from Gondwana many millions of years earlier (Murphy and others, 2006). Armorica was larger than Arvonia had been, it included a large triangle of land (Baltica) with a tail of islands that ran southwards (Avalonia) (Figure 41). This was land that would eventually become portions of Europe, Newfoundland, and eastern Massachusetts (Hibbard and others, 2007).

The second collision

Because Armorica was so large, it impacted the Laurentian shore in many different locations over the course of millions of years. Three major collisions can be identified by deformation and the erosion and deposition of large quantities of sediments. By 430 million years ago (the Silurian Period), the first, and most intense collision occurred as the large northernmost portion of Armorica (also referred to as Baltica) squeezed against a hard Canadian promontory (along with what would become Greenland) (Williams and Hatcher, 1983). This collision would leave its trace today as far abroad as the Caledonide Mountains of Norway and Northern Scotland (Figure 2). This intense northern collision acted like a hinge, slowly hauling in the long chain of islands (Avalonia) that remained hundreds of miles offshore (Figure 41). Over the course of 60 million years or so, mountains formed southwards down the Laurentian coast, as hard promontories concentrated the impact (Hibbard and others, 2007). Such promontories included southeastern New York and southern Virginia, where collisions occurred around 360 million years ago (Southworth, 2008). The incoming Armorican islands would add more land to the East Coast, including eastern New England, and central and eastern Virginia.

Incoming Armorica rode up onto the eastward-dipping subduction zone as it crashed into Laurentia, grinding upwards along a huge suture zone of many faults (Figure 42). The collision led to squeezing, and shearing of the East Coast (Trupe and others, 2003). Old faults were reactivated and new faults cracked (Fichter and others, 2010; Hatcher, 1981). Rocks folded and shifted, and massive plutons collected in the heart of the Acadian Mountains. Some of this magma may have reached the surface, forming scattered volcanoes that deposited layers of lava and ash. Some of the plutons are exposed today in the Piedmont Province of Virginia (Fichter and Baedke, 1999; Figure 14). Foreland basins (called the Catskill and Pocono) bowed downwards as the second and third impacts crashed along eastern Pennsylvania, New York, and southern Virginia. These basins collected thousands of feet of clastic sediments that eroded westwards off the newly-forming Acadian Mountains. Turbidite flows slowly scattered

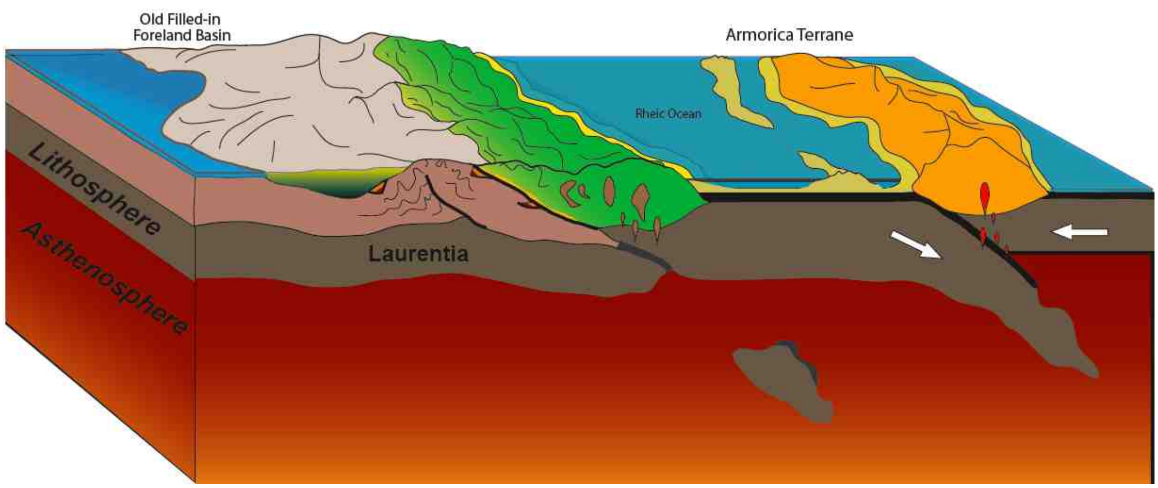
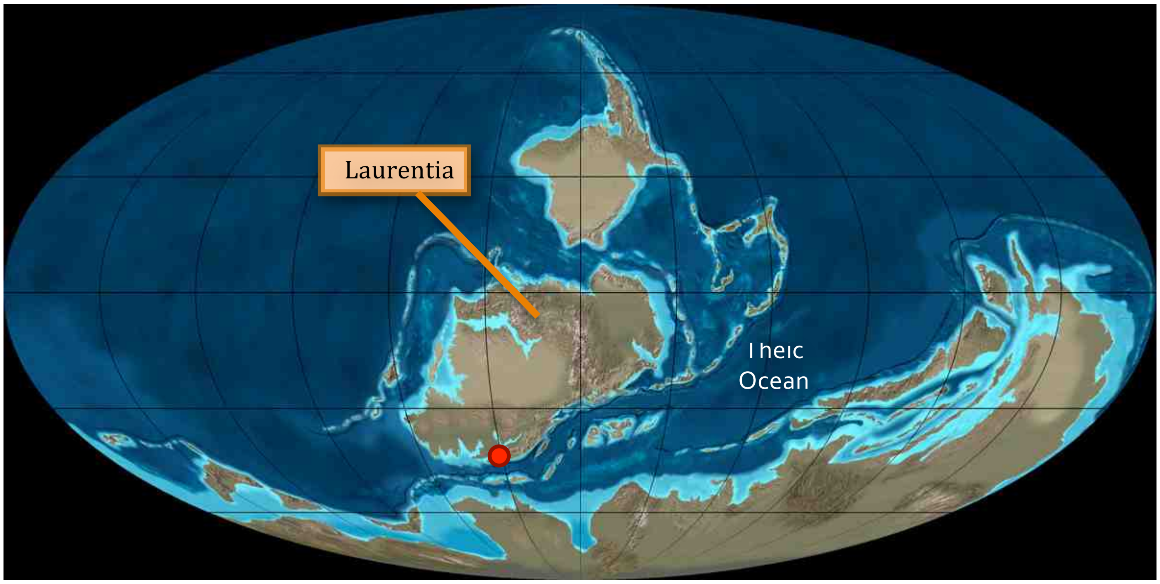


Figure 41: A new landmass approached the shore of Laurentia. By 430 million years ago, the Armorica terrane slowly drew closer to the coast. Although the old foreland basins of Laurentia were completely filled in with sediment from the eroded Taconic Mountains, new basins would soon develop as the Acadian Orogeny began. The red dot on the paleogeographic map (top) signifies the approximate location of Shenandoah National Park. (Map courtesy of Dr. Ron Blakely, Northern Arizona University)

sediments across what would become the Valley and Ridge Province and Alleghany Plateau (Fichter and others, 2010; Figure 14) as they piled on top of older sedimentary rocks from the Tippecanoe Sea and Taconic Mountains, and the ancient Rodinian crystalline basement.

The rising Acadian Mountains formed a significant feature in the east, running north and south through modern-day Richmond, Virginia. They towered above the surrounding seas – the shallow Tippecanoe Sea to the west, and the deeper eastern Theic Ocean (Figure 42). But now that the final Acadian collision was over, the mountains slowly eroded away, exposing their deep roots. If you would like to visit remnants of the ancient Acadian Mountains today, you need only travel to the border of Virginia and West Virginia, because their rocky pieces stacked to form the metasedimentary layers that are now Shenandoah Mountain (Fichter and others, 2010).

By the Devonian Period (around 400 million years ago) the weathering and erosion of the Acadian Mountains was slowed by the flourish of newly-evolving land plants. Life had continued to evolve into ever more complex organisms including jawed fish (Forey and Janvier, 1993). Some of these creatures took to the land as amphibians made their first appearance by the latest Devonian (Ahlberg and Milner, 1994; Figure 43). Small sharks swam with bizarre armor-plated fish, called placoderms, which can grow up to 40 feet long! On land, the first insects evolved, as spiders and centipedes scurried across the greening landscape. By the end of the Devonian (360 million years ago), another major glaciation occurred during the Acadian Orogeny, wiping out many species that had thrived during the early Ordovician and Cambrian Periods.



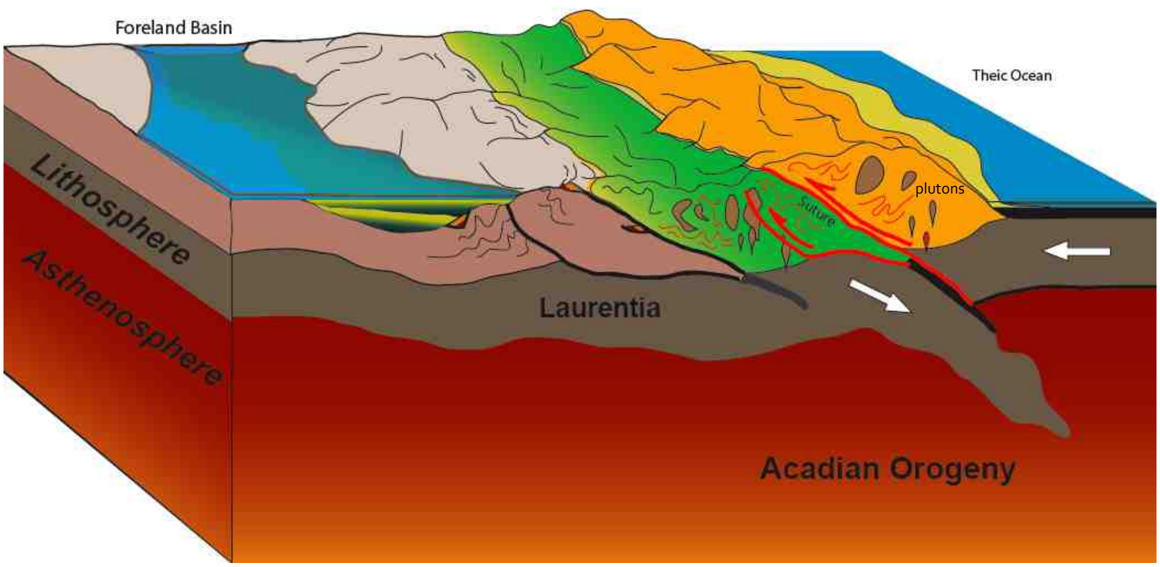


Figure 42: By 400 Million years ago the Acadian Orogeny was complete. The Armorica landmass had collided with Laurentia, forming deep foreland basins that collected thousands of feet of clastic sediments that eroded off the newly-formed Acadian Mountains. The red dot on the paleogeographic map (top) signifies the approximate location of Shenandoah National Park. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

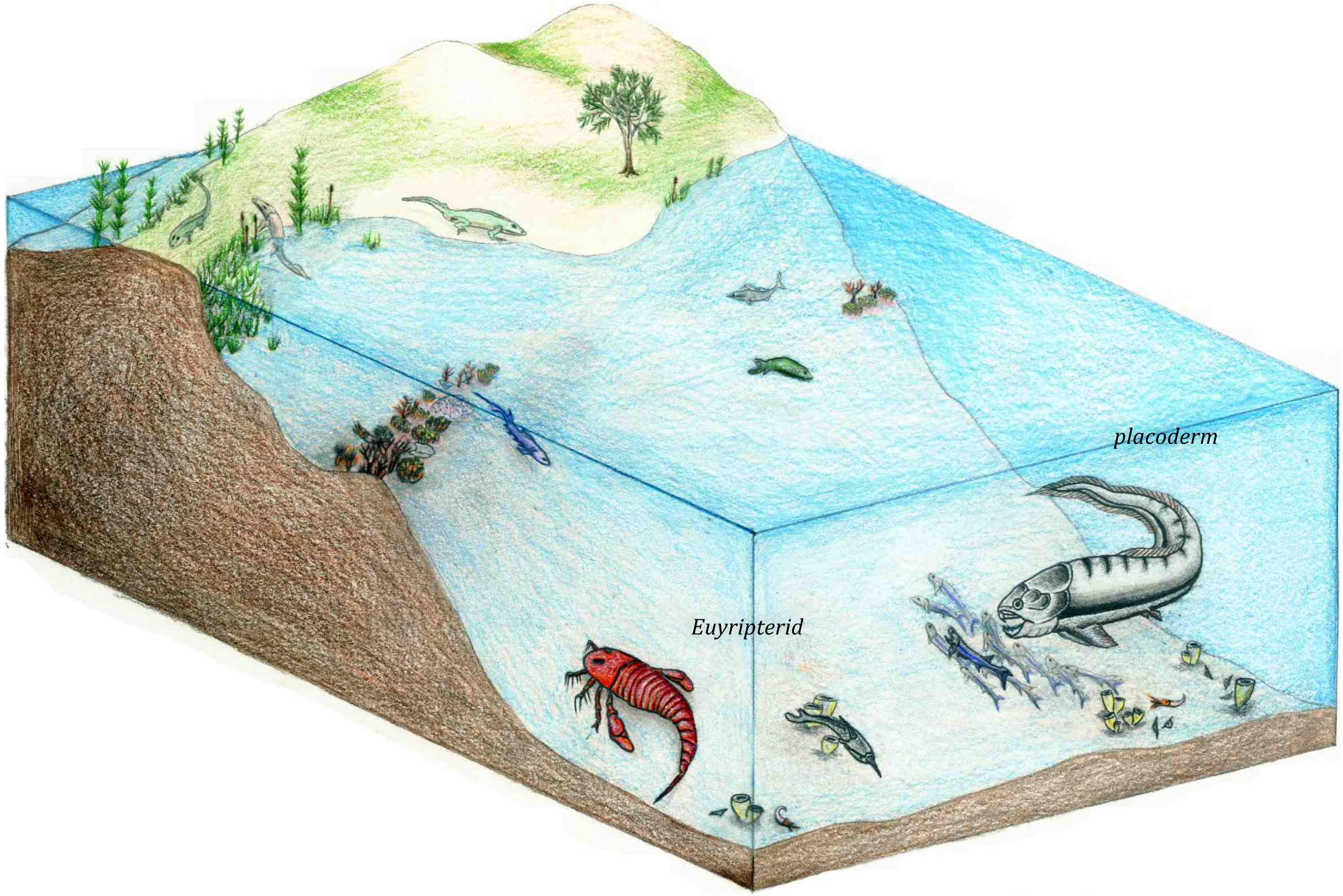


Figure 43: By the Devonian Period life had begun to invade the land. The first large trees evolved 350 to 500 million years ago, as the first amphibians walked on shore. Insects also began to evolve. The Devonian Period was considered the age of fish, as a huge variety, including sharks, populated the waters. Giant armor-plated *placoderms* and lobster-like *Euyripterids* became masterful predators

<u>The Arrival of Major Landmasses</u>

Two collisional episodes in our story have so far shaped our perception of the modern-day East Coast, but the most prolific is yet to come! A third, and most spectacular orogeny is on its way, bringing with it a giant that will shape this inspiring landscape into our home. For many millions of years following the Acadian Orogeny, a calm persisted. But the events that were to follow would soon wreak havoc on this seemingly stable land.

Alleghanian Orogeny

The final phase of mountain building that the Eastern Coast experienced is the one that formed the Appalachian Mountains we know today. The two prior events formed mountains that slowly eroded flat, leaving their trace only as eroded sediments and scattered metamorphism, but the products of the Alleghanian Orogeny remain for us to see today. For this reason, the Alleghanian Orogeny is closer to home and a vivid link to the past, helping us better understand the processes of mountain build-up and mountain break-down.

<u>A brief calm</u>

By the Carboniferous Period, about 359 million years ago, the erosion that erased the Acadian mountains ceased and the land appeared as only small hills, exposed here and there above the sea. Land plants flooded our view, coloring the brown land green with newly-evolving seed plants (Kenrick and Crane, 1997). Some of the first land reptiles and amphibians scurried by, while a 3-foot long Meganeura (the giant ancestors of the dragonfly) zoomed past. Looking around, we would see a blanket of pure, beautiful green, as Earth's first forests grew during this time. Ferns and large trees (Lepidodendron) formed massive forests –this was a very important event. As trees and plants of the forests died and fell to the forest floor, their pieces layered into piles of biomass. As more and more biomass piled onto the forest floor, peat formed. Over time, the peat became compressed, leading to the formation of coal beds (especially in Pennsylvania and West Virginia) that we rely on today for energy. (Figure 44)

For the preceding few hundred million years, most of North America had remained underwater, submerged beneath a warm, shallow sea. During the Carboniferous, this sea (called the Kaskaskia Sea) deposited layers of carbonate sediments that eventually formed limestones of the Appalachian Plateau and Valley and Ridge Province (Figure 14). Thriving in this shallow sea

Figure 44: Some of Earth's first thick, green forests grew during the Carboniferous Period. Reptiles, amphibians, and insects were abundant, including giant centipedes and the 3-foot long dragonfly, Meganeura. Trees crowded the landscape leading to the formation of coal beds we use today for fuel.

were bryozoans, brachiopods, crinoids, and corals. Beyond the shallow epicontinental sea and exposed roots of the Acadian Mountains lay the Theic Ocean, the ancestor to the Atlantic. And not too far offshore, a massive continent approached.

The final collision

Although each orogeny had deformed the landscape, it was this last Alleghanian Orogeny that built the Appalachian Mountains we know today. The Alleghanian was the master of all the orogenies, leaving the widest impression, one that inspired Spanish explorers to name the entire mountain range after the southeastern Apalachi Native Americans hundreds of millions of years after its formation (Rodgers, 1971).

In the finale of Appalachian collisions, Gondwana - the supercontinent that included the modern-day southern continents of Africa, South America, India, Australia, and Antarctica, was close on the heels of the Acadian collision. By 320 million years ago (during the Carboniferous Period) (Horton and others, 1989), Gondwana collided with Laurentia. Like the collisions before it, the Alleghanian Orogeny led to the metamorphism of rock, intrusion of magma, and structural deformation of the Laurentian coast (Hatcher, 2002; Williams and Hatcher, 1983; Williams and Hatcher, 1982). However, the massive continent of Gondwana was unlike the small islands and continental fragments that have rammed against Laurentia in the past. Gondwana was a giant (Figure 35). Its incoming edge was lined with volcanoes, as the subduction zone that drew it closer to Laurentia rested directly beneath Gondwana's shore (Figure 45). Because of this, it was the Alleghanian Orogeny that is primarily responsible for the extensive deformation that took place along the eastern coast. Two primary factors controlled the mountain building: the shape of the coast prior to the collision, and the type of faulting that occurred during the collision (Thomas, 2006; Fichter and Baedke, 1999).

Because the coastline of Laurentia was jaggedly rifted from Rodinia, and because the prior collisions of the Taconic and Acadian Orogenies were also uneven (Figure 35), Gondwana collided with an uneven shore. The Laurentian coast was a patchwork quilt of thick sediments, thin sediments, and exposed hard basement rock. This meant that when Gondwana collided, the style of collision was different depending on where you were. For example, over the preceding few hundred million years, the embayments acted like bowls, collected thick accumulations of

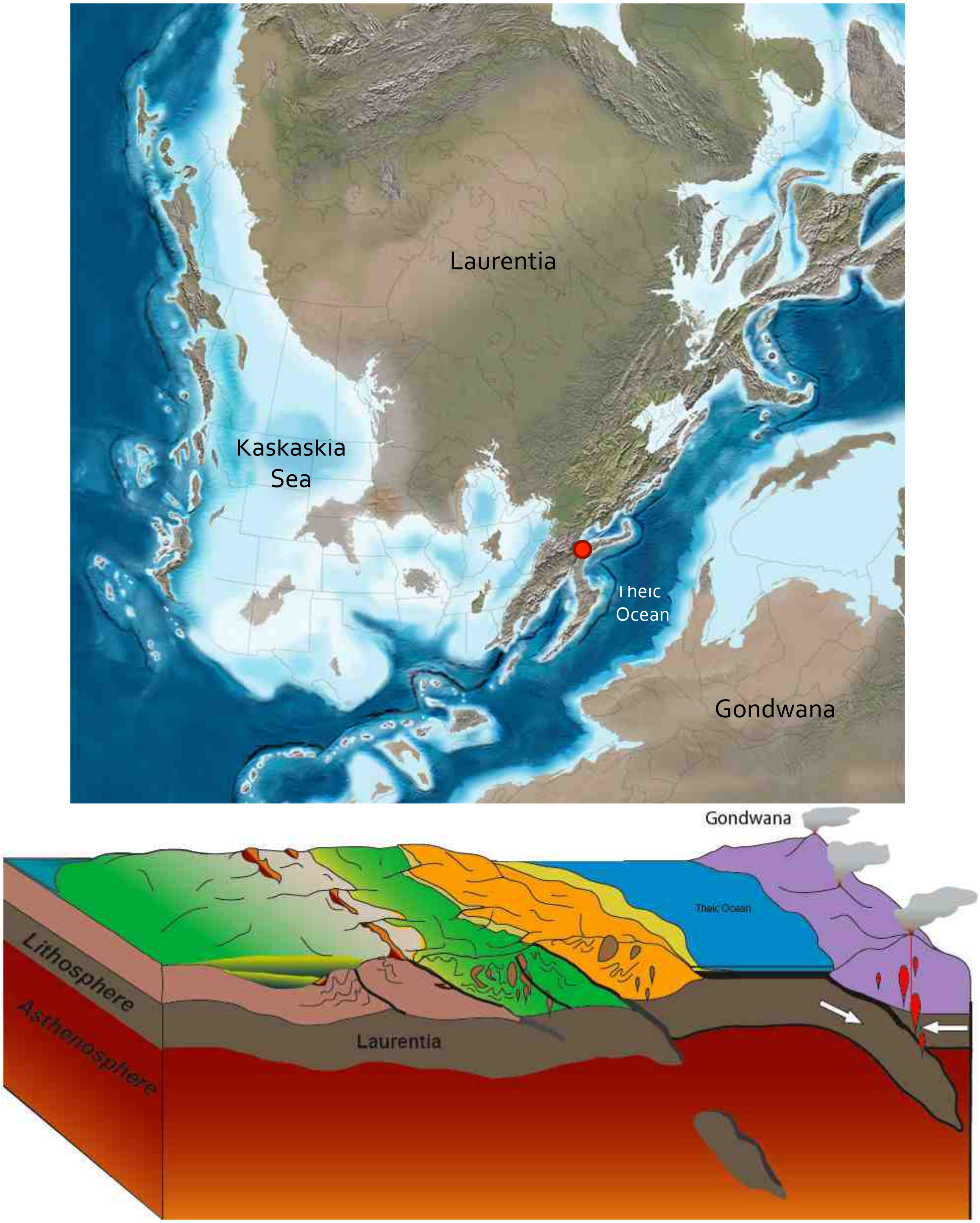


Figure 45: By 345 million years ago, a giant landmass, called Gondwana was approaching Laurentia. Gondwana included Africa and other southern continents that later broke apart following the rifting of Pangea. A subduction zone extended underneath the edge of Gondwana, forming a line of volcanoes near its shore. The red dot signifies the approximate location of Shenandoah National Park. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

sediment (up to 10 miles, or 15 kilometers thick!) that had eroded off the mountains (Hatcher, 2010). The weight of the thick layers pushed down the hard basement rock. In contrast, the pointy promontories that jutted out into the ocean had only a thin cover of sediments and therefore, the hard crystalline basement was pretty close to, or at, the ground surface. These variable areas of thick and thin sedimentary cover (think of a blanket on top of a bed) determined, in part, how our Appalachians would look today. During the Alleghanian orogeny, impacts along the promontories crunched hard against the shallow basement rock, breaking slices off and transporting them far to the west. In contrast, collisions along the embayments were soft against the thick sediments allowing faults to break through only the covering "blanket" of soft sedimentary rocks, and not reach down deep to the crystalline basement (Thomas, 2006). Faults that formed along embayments could easily push these soft sediments hundreds of miles to the west (Hatcher, 2002; Rankin, 1994). Imagine a car crashing into a furniture shop. The rigid wooden furniture would split and crack, pieces flying through the air. Now imagine a car crashing into a mattress store. The soft mattresses would buffer the collision, folding around the incoming car. These hard and soft collisions occurred throughout the Appalachians.

Another factor that controlled why the Appalachian Mountains look the way they do was the type of faulting that occurred. Not only did Gondwana collide with an uneven shore, but Gondwana unevenly collided with the shore. The Alleghanian collision began in the north, shearing (along strike-slip faults - Figure 25) landmasses that would become New England, Newfoundland and portions of eastern Canada (Hatcher, 2002). As Gondwana continued its collision southward, it rode up along the ramp of the subduction zone, sliding up on top of the older Acadian and Taconic terranes (Thomas, 2006; Cook and Oliver, 1981). South of New York, the strike-slip faults mostly became major thrust faults (Figure 25) (Hatcher, 2002). The sutures that had glued the Taconic and Acadian landmasses onto Laurentia so long ago, now failing, became major faults (Thomas, 2006; Fichter and Baedke, 1999). By the Permian Period (about 280 million years ago), the Alleghanian Orogeny was in its prime (Figure 46). Gondwana crushed into the shore, rotating as it collided so that by the time it reached Virginia, the collision was head-on (Hatcher, 2002; Rankin, 1994). In front of the incoming continent, Laurentia rippled like a squished carpet, folding layers of sediments and rock into a rolling blanket called the foreland fold and thrust belt (Valley and Ridge province of Virginia). Imagine Shenandoah National Park

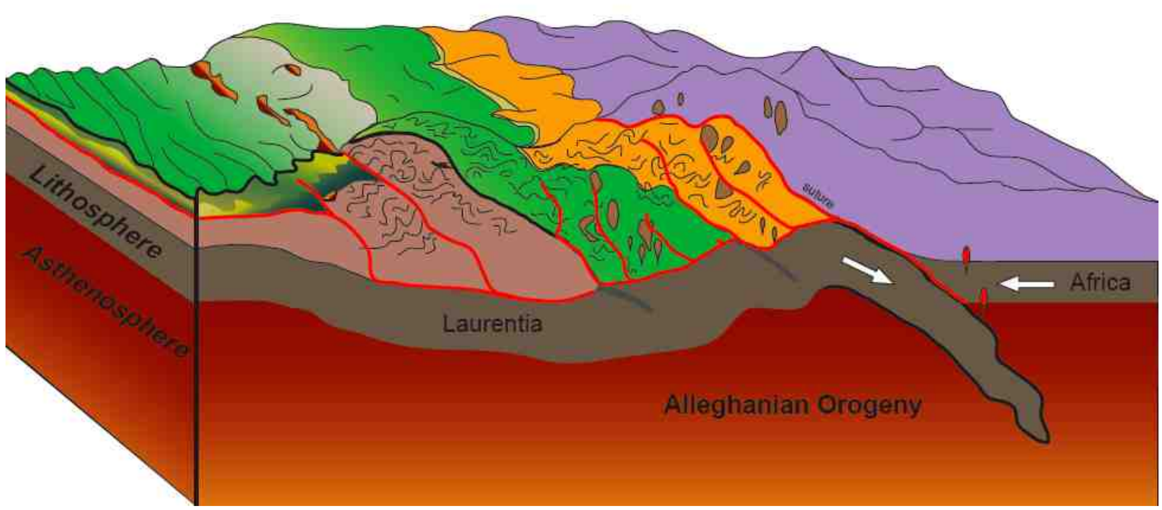


Figure 46: A close up view of Laurentia about 300 million years ago. The massive Gondwanan continent has collided with Laurentia, forming the Appalachian Mountains. Here, the Appalachians are in their prime, towering thousands of feet above sea level, similar to the modern day Himalayas. The red dot on the paleogeographic map (top) signifies the approximate location of Shenandoah National Park. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

riding the waves of folding rocks in front of the collision, like a surfer riding ocean waves. Below the ripples, old normal and thrust faults were forced to slip, awakening once again to carry rock on their backs miles across the land. Some of these old Taconic and Acadian faults were the Brevard, Rockfish, and Hayesville faults (Fichter and others, 2010; Clemons and Moecher, 2009; McBride and others, 2005; Hatcher, 2002; Hatcher, 1981). New major faults also formed, such as the North Mountain fault (Figure 53) and the Blue Ridge thrust (Figure 55, 56), which transported huge parcels of land tens of miles to the west across Earth's surface (Hatcher, 1981). The complex combination of folds and thrust faults that formed during the mountain building are what give this region its geological nickname - a fold-and-thrust belt. Because Alleghanian faults stacked slices of land like cards in a deck, the Appalachian Mountains grew as rock pushed high into the sky (Figure 47). Although certain areas along the Appalachian Mountains may have reached heights similar to that of the modern Himalayas, most locations, including that of Shenandoah more closely matched the Alps, Andes, or Rocky Mountains (Southworth and others, 2009) (Figure 46). The shear weight of Gondwana pushed the edge of Laurentia down into the underlying mantle. The crushing pressure and rising heat metamorphosed the older rocks of Laurentia, melting away millions of entombed fossils, fusing sedimentary rocks of the old foreland basins into quartzites and marble (see the **What is Metamorphism?** textbox, page 89), and peppering the new mountains with plutons of magma. Even so, many earlier features, such as vesicles, spatter cones and columnar jointing were not completely erased in areas where the intensity of metamorphism, or metamorphic grade, was relatively low (Badger and Sinha, 1988). These features are thankfully captured and preserved within Shenandoah National Park, helping to tell the story of it's own formation.

In a way, the Alleghanian Orogeny has given us a unique connection to the rest of the world (Figure 2, 12). Not only did the massive collision sandwich what would become Africa with Laurentia, but it also joined Central and South America with southeastern Laurentia, and Europe with northeastern Laurentia. Arkansas, Oklahoma, and Texas hold evidence of the southerly collision in the Ouachita and Marathon Mountains (Figure 11). Here, portions of what would become South America bulldozed rocks and sediment, including mud and chert from deep waters up onto southern Laurentia (Stanley, 2009). This formed a fold and thrust belt that connected to the Valley and Ridge Province of the southern Appalachians. In the north, what would become modern-day Europe squeezed against eastern Canada, New Brunswick, and Greenland continuing to build the Caledonide Mountains (Figure 2, 12) that had started to grow during the earlier Acadian Orogeny (Faure and others, 1996). In Africa, the Atlas Mountains were a continuation of the Appalachians across the disappearing Rheic Ocean (Figure 2, 12). Essentially, the Alleghanian Orogeny was a massive squeeze of every continent on Earth, leaving behind a long chain of Mountains that were connected as one.

The prior Taconic and Acadian Orogenies primarily are responsible for suturing on new land to eastern North America (Williams and Hatcher, 1983), however, it was largely the Alleghanian Orogeny that is responsible for majorly deforming the east. The Alleghanian Orogeny caused major transport of previously sutured and deformed terranes (slices of land) (Williams and Hatcher, 1983), especially in the southern Appalachians (Hatcher, 2002). The collision hit hard along the promontories, causing massive slices of basement rock to break free. These major cracks are called décollements and can carry parcels of rock like mail delivery across hundreds of miles of land (Hatcher, 2002; Cook and others, 1980). Faults like these broke all along the east, cutting through hard basement rock and the soft sedimentary cover rocks. Our Blue Ridge Mountains are a severed piece of hard crystalline basement of the edge of ancient North America (Laurentia) that was transported about 70 miles from the east (near the Virginia Promontory) along one of these décollements (Evans, 1989). Parcels of rock were pushed westward during the collision, burying rocks and sediment that had been left behind by Rodinian rifting, and the Taconic and Acadian Orogenies (Figure 47).

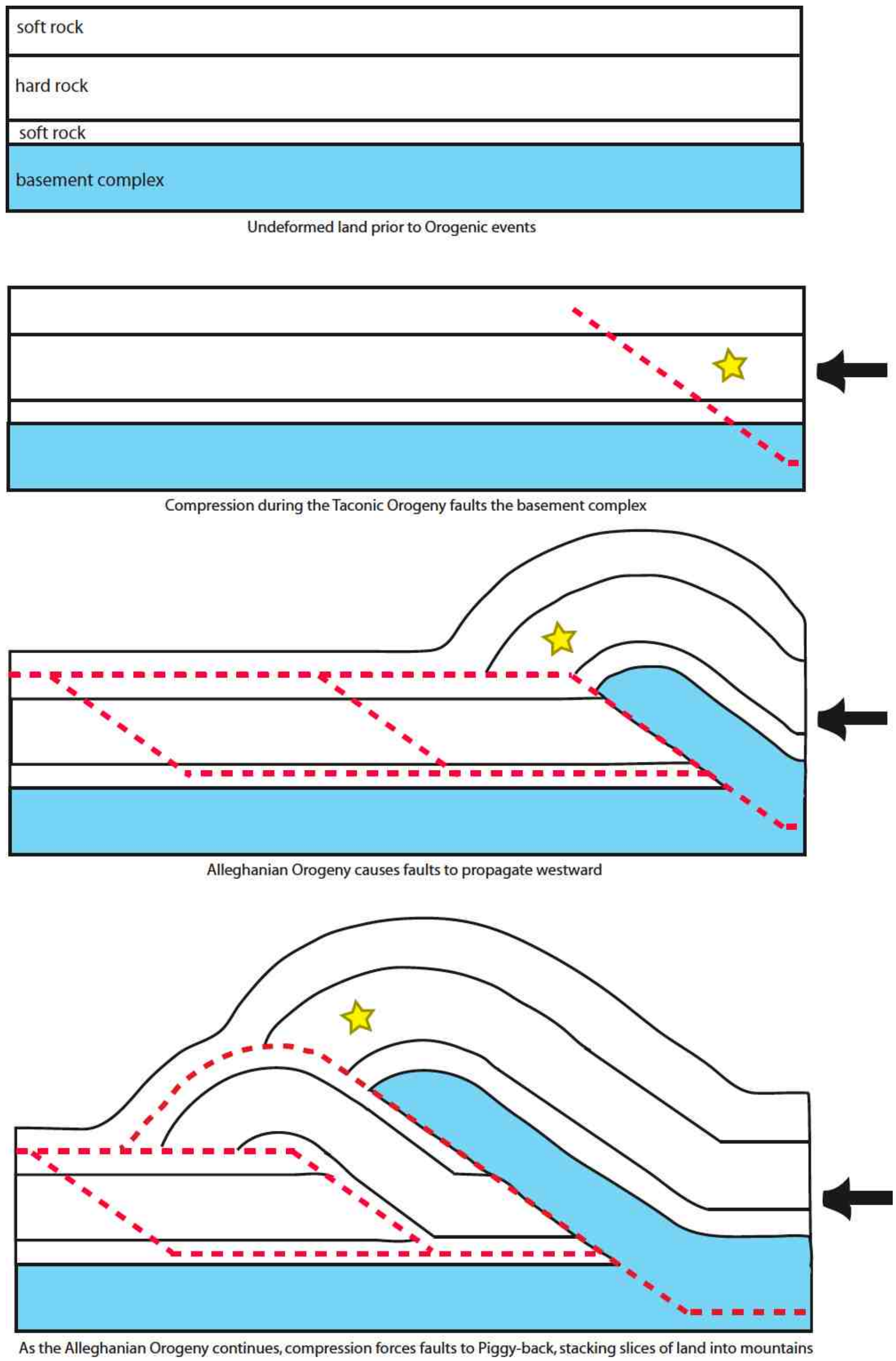


Figure 47: The Alleghanian Orogeny compressed the landscape. As Pangea crushed together, slices of land literally stacked on top of each other to form a pile of rock layers that make up the Appalachian Mountains. Red dotted lines are faults, or décollements along which rocks slid. These detachments tend to break within less resistant rock layers, like shale.

An International Appalachian Trail

The concept of a global mountain range may be difficult to picture. Our whole lives, we have peered at world maps that stubbornly place the continents in their modern-day positions. It is difficult for us to imagine how this world, so familiar to us, could have looked so entirely different in the past. The first step is to emphasize the idea of a dynamic Earth. Everything changes, only on different scales of time and size.

A fun way to explore the idea of supercontinent Pangea, is literally, to explore it! Encourage visitors to travel along the Appalachian Trail, not only the 2,000+ miles from Georgia to Maine, but also to continue their exploration beyond Mount Katahdin in Maine. Organizations of many different countries are pooling together to extend the original Appalachian Trail across the ocean following a path that pieces together bits of the ancient Appalachian Mountains that once would have been together before the Atlantic Ocean opened. Adventurers can follow the extended trail, called the International Appalachian Trail from Maine across eastern Canada through New Brunswick, Nova Scotia, and Newfoundland before jumping the Atlantic Ocean to southern Greenland, Ireland, Great Britain, Scandinavia, and northwestern Africa. Check the International Appalachian Trail website for updates on the extension of the hiking trail.

The International Appalachian Trail is a great interpretive opportunity. The path will reconnect the ancient Appalachians, taking us on a journey back through time and space to experience a landscape that once was connected as one. The trail will take explorers on a path across continents that would have butted directly next to each other a couple hundred million years ago. The Pangean Appalachian Trail is a great way for enthusiastic outdoorsmen and women to explore the Earth and appreciate its vast and colorful history!

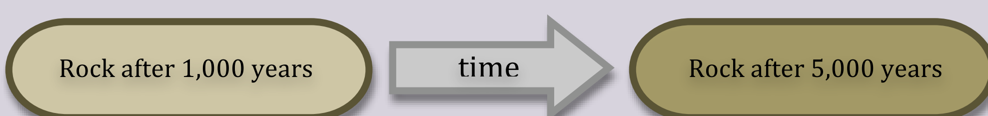
The Appalachians were <u>how</u> tall?

If no one was there to witness it, how do we know how high a mountain range used to be? A few good clues are the grades of metamorphic rocks and the study of cosmogenic nuclide dating.

Metamorphic grade can indicate at what depth a rock used to exist because rocks and minerals, like us, can be very picky about what sort of environment they prefer (see textbox **What is Metamorphism?** on page 89). Some minerals like higher temperatures or pressures. By identifying the metamorphic grade, it can reveal the depth at which the rock formed, thus giving us an idea of how much material must have been above it and was later removed by erosion. Therefore, if we see a high grade metamorphic rock sitting at the top of a mountain, we know that that rock must have formed originally at a <u>great depth</u> and therefore, must have come on an amazing journey of uplift to reach Earth's surface!

Cosmogenic nuclides are also an important key. Imagine peering towards the center of our Milky Way Galaxy. We are surrounded by the massive galaxy arms full of stars and planets, but we are also seeing a great nothingness – the giant black hole that lay in the heart of our galaxy. Wave upon wave of electromagnetic radiation, called cosmic rays fly by and through us. When these cosmic rays interact with material, such as rocks they start a reaction that leaves an imprint on the rock. Over time, this imprint becomes more and more distinct (like getting a darker and darker tan the longer you stay outside in the sun). Like forensics, geologists can detect how long a rock surface has been exposed to these cosmic rays by measuring the 'build-up' of certain isotopes (such as Beryllium-10) that form from the reaction of land surface with cosmic rays. (for example Zreda and Phillips, 1998)

Similar to a human getting a tan in the sun
Beryllium builds up within rocks exposed to cosmic rays



If we know how long the rocky outcrops at the mountain tops have been exposed to cosmic rays, we can reverse time and figure out a rate of erosion back through time until the exposed rock was underground. Combined with other geological data and techniques, this gives us a general idea of how tall the mountains were when they formed, and how quickly they are eroding away.

F. The View from Here

Following the three collisional events, a few important phases of life shaped the landscape into the Appalachian Mountains we know today. The supercontinent Pangea divided as the towering mountains slowly eroded across a new, calm continental margin.

A final rift

Like pressure building underneath the cork of a wine bottle, the thick cap of Pangean continental crust corked what was below. Tremendous heat from the mantle was caught underneath and trapped by Pangea. The building heat was the beginnings of another super plume. This massive plume of mantle material and magma, similar to the one that tore Rodinia apart, triggered another rifting event that ended the reign of Pangea.

The building heat beneath Pangea led to weakened continental crust that slowly began to thin and pull apart. As this occurred, massive faults cracked through the crust, cutting the landscape into blocks that slid laterally along transform faults and dropped down along normal faults as rift valleys formed (Fichter and others, 2010). The rifting began first in the east, opening a strip of ocean basin that we know as the Mediterranean Sea (Fichter and Baedke, 1999; Laubscher and Bernoulli, 1976). By about 210 million years ago, Africa began to separate from Laurentia (now modern North America). Large faults broke up and down the eastern shore forming a rift valley (Figure 48). Like scars across the landscape, faults broke and spread as basalt lava flows and diabase dikes popped up through the thinning continental crust between 200 to 150 million years ago, (Southworth and others, 2009; Figure 13). Traces of the Pangea rifting event are mostly east of Shenandoah National Park, and include the Culpepper rift basin (Fichter and Baedke, 1999; Bailey, 2000; Southworth and others, 2009; Sherwood and others, 2010). The Culpepper basin dropped down from the Blue Ridge highlands during the early Jurassic Period (about 200 million years ago) as the underlying block of rock sunk down. Similar basins can be traced from New England through South Carolina in the Piedmont Province. They formed on the western edge of the rift zone, filled with sediments eroded off the landscape, and provide evidence for the continental rifting event that eventually opened the Atlantic Ocean (Southworth and others, 2009; Rankin, 1975) (Figure 49). Similar features can be found across the Atlantic Ocean in Europe and Africa, which would have represented the eastern half of the continental rift zone (Rankin and others, 1988).

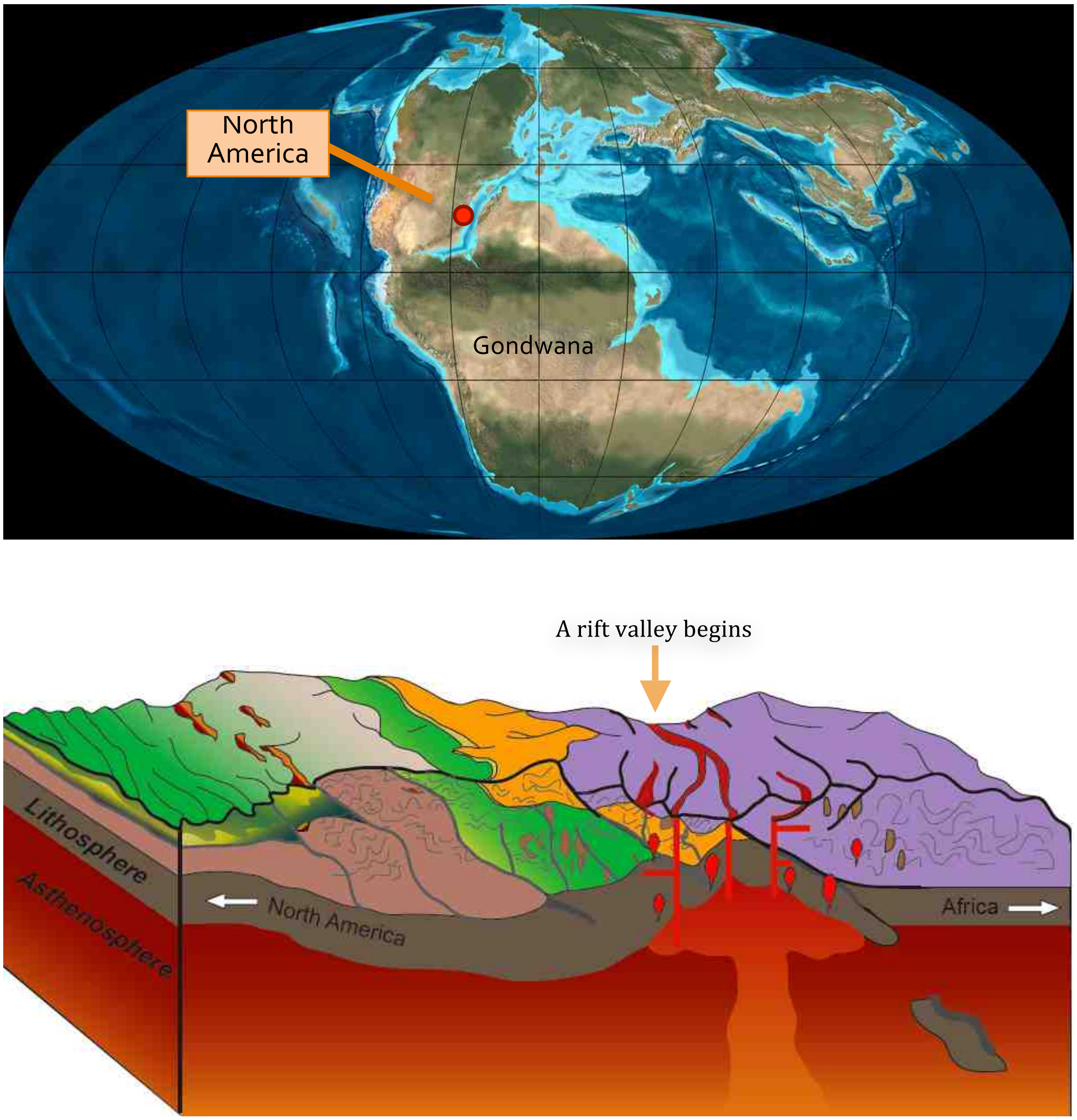


Figure 48: The birth of North America. Pangea rifted apart, forming the Atlantic Ocean. The rift tore open the Appalachian Mountains, sending fragments rifting apart in opposite directions – the Caledonides in Europe and the Atlas Mountains in Northern Africa. From now on, Laurentia is referred to as North America. The red dot on the paleogeographic map (top) represents the approximate location of Shenandoah National Park. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

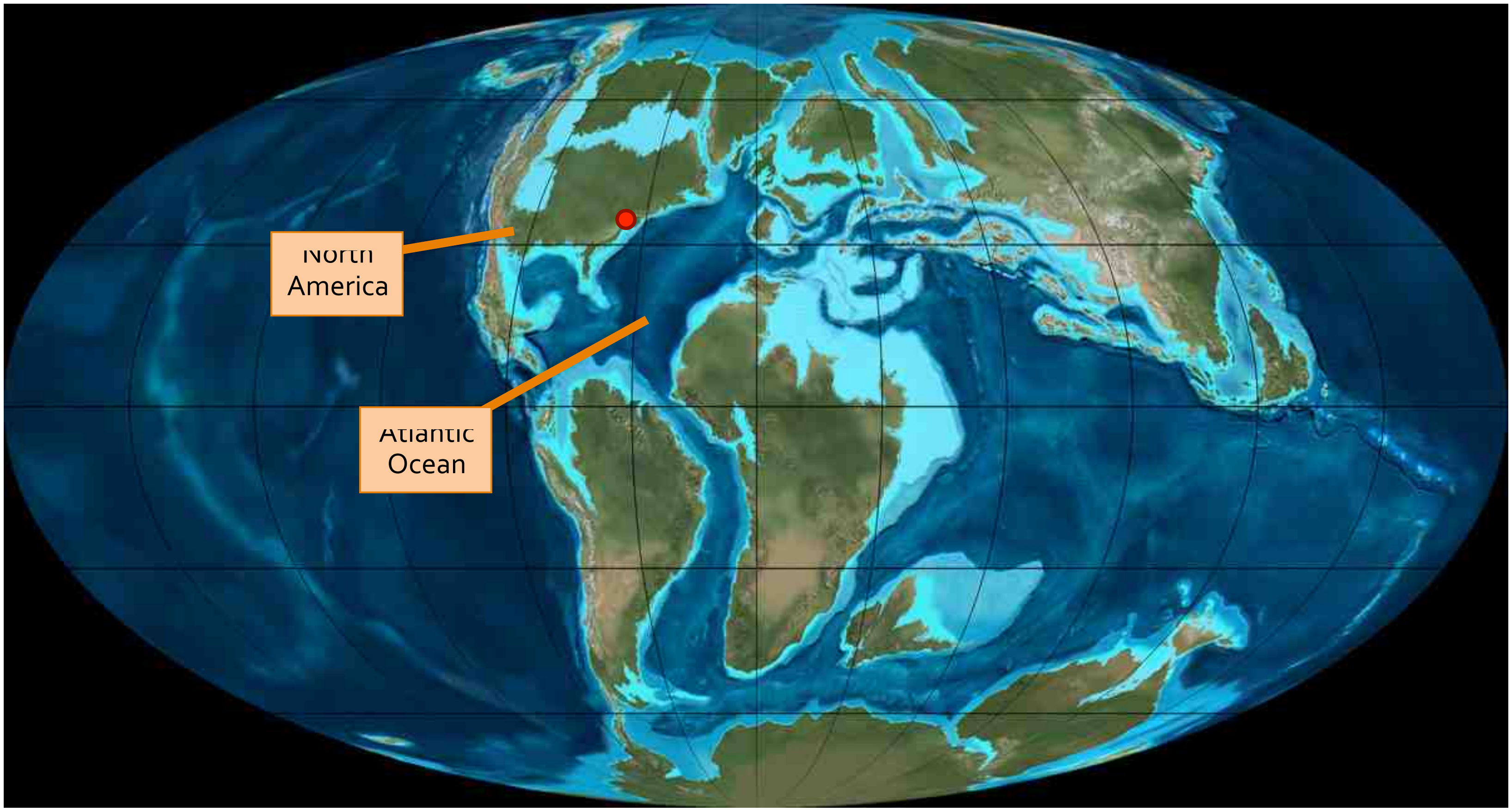


Figure 49: The Atlantic Ocean opened over the course of a couple hundred million years. Slowly widening the ribbon of oceanic crust that separates Africa and Europe from North and South America, until the continents arrived where they are today. Where do you think the continents will end up in the future if they continue to travel in the present directions? The red dot signifies the approximate location of Shenandoah National Park. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

Even through Africa and Europe tore free from our shore as Pangea rifted apart, pieces of the massive continent were left behind. Pieces of Nova Scotia, the southeastern states of Virginia, the Carolinas, and Florida, are, in fact, pieces of Africa donated to North America during the Alleghanian collision (Hatcher, 2002; Lillie, 2005; Horton and others, 1989) (Figure 50). Perhaps some day, we can repay the favor by loaning Africa a chunk of North America during the formation of the next supercontinent?

A new passive continental margin

Tracking new life

As Pangea collided together and then rifted apart, exciting things were occurring with life on Earth. At the end of the Permian Period (about 250 million years ago), over 95% of all life on Earth became extinct. A massive asteroid slammed into the Yucatan Peninsula (called the Chixiclub crater) in Mexico, while extreme changes in the atmosphere were occurring. The pair of events may be to blame for this mass extinction (Benton and Twitchett, 2003). Following the extinction, life diversified and the age of reptiles began (Sues and Olsen, 1990). Four-legged vertebrates, including dinosaurs and eventually early wooly mammals, evolved and ran through ancient forests of the Appalachian Mountains (Fraser, 1992). Shenandoah was literally a "Jurassic Park" as the mountain may have been swarming with little dinosaurs, bobbing and hunting, and climbing through the underbrush. These animals and insects have been found preserved as fossils in the soft sediment that once filled rift basins along the Eastern Coast (Blagoderov and others, 2007; Sues and Olsen, 1990; Fraser, 1992; Gore, 1986). Today, we can explore dinosaur tracks and other fossils in the Culpepper basin, east of Shenandoah.

Wearing down our Appalachian Mountains

As Pangea ripped open and a new coastline provided a calm home for thousands of new species of life, the massive Appalachians faced the same fate as their predecessors. The elements slowly tore apart the rocky peaks. Water collected far up in the mountain passes, forming streams that cascaded down rugged mountain terrain until they joined to form rivers. The rivers transported fragments of the mountains as sediment down from the peaks and away towards the sea. Slowly, the dramatic landscape evolved into more gentle topography. The intense erosion of the high topography helped fill in lower elevations, leading to the formation of the more easterly provinces including a broad coastal plain (Morgan and others, 2004).

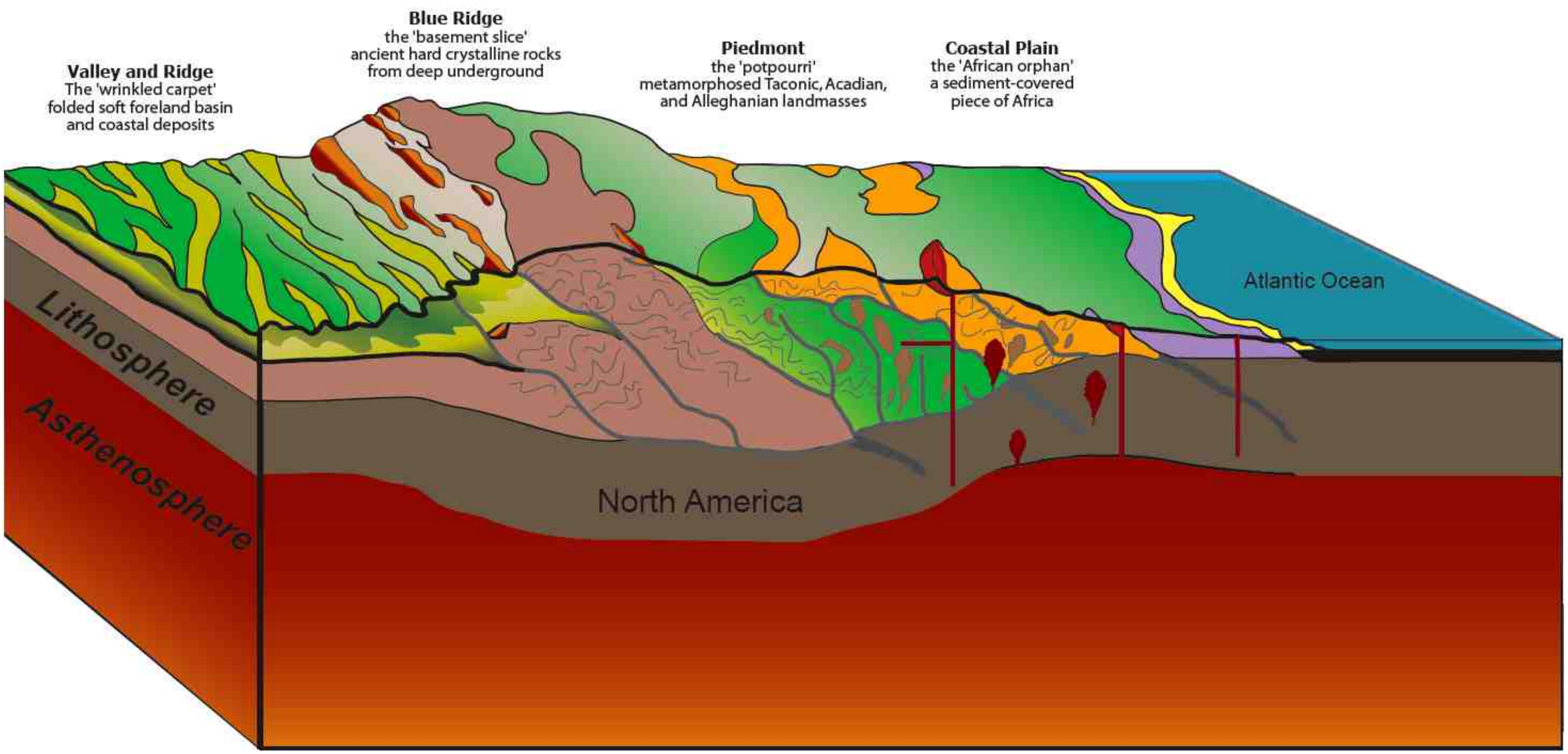


Figure 50: Today the East Coast is an amalgamation of land that tells the story of the geological processes that shaped this landscape. Like chapters in a book, each rock tells a part of the story, which can be read and retold. Pieces of ancient small continents, volcanic islands, Lava flows, and sedimentary deposits litter the landscape. All of these have been squeezed, shifted, covered, or eroded, making the area around Shenandoah National Park an enormous jigsaw puzzle.

It has been estimated that in the Shenandoah area, over 20,000 feet (4 miles or 6.5 kilometers) of rock has eroded off the tops of the Appalachians since the Alleghanian Orogeny (Southworth and others, 2009). Although some of the Appalachian Mountains were probably as high as the modern Himalayas (with peaks of over 20,000 feet), our Blue Ridge Mountains were around 8,000 or 9,000 feet tall when they first formed. This is because the area that is now Shenandoah National Park would have been positioned on the very western edge of the massive Appalachian Mountains when Pangea crushed together. After Pangea rifted apart and the Atlantic Ocean opened, the largest mountain peaks were pulled open as rift basins formed and slumped downwards across the landscape. The highest peaks of the original Appalachian Mountains were probably far to the east of Shenandoah National Park.

One of the major factors that caused serious erosion of the Appalachian Mountains was the occurrence of an ice age during the Pleistocene Epoch (about 33,000 to 20,000 years ago) (Clark and others, 2009; Litwin and others, 2004). Ice sheets expanded southwards across much of North America, covering Canada, New England, carving the great lakes, and scouring the Northern Appalachian Mountains. Although the extent of the glaciers was impressive, they terminated north of, but still impacted, what is now Shenandoah National Park (Figure 51). Recent studies have shown that various areas within the central and southern Appalachian Mountains have eroded at a rate of 82 to 98 feet every million years (25 to 30 meters per million years) since the end of the last mountain building event (for example Matmon and others, 2003). Interestingly, in the area of Shenandoah National Park, erosion rates have been even slower, at about 36 feet per million years (11 meters per million years) (Duxbury and others, 2009). The slow erosion of these mountains is, in part, because of the thick mountain root. As erosion removes rock material from the mountain surface, the thick continental crust miles underground slowly pushes upwards (refer to the **we've only scratched the surface** textbox on page 117). This *dynamic duo* of erosion and uplift is typical along mountain ranges, and extends the life of the topography. As erosion of mountain belts continues, interesting features can develop. One example is the Staunton klippe. Here, a portion of the rock above a thrust fault has been isolated as the surrounding rock eroded away. This process leaves a small island of foreign (or allothonous) rock stranded (Figure 52). Other small klippen can be found within the Shenandoah Valley that probably mark the old location of the Blue Ridge thrust fault (Evans, pers. comm.).

As erosion continues, the surface expression of the Appalachian faults will appear to recede eastward, leaving behind more klippen as high topographic points (Figure 52, 53).

Because of the amount of erosion that has occurred since their formation, portions of the intricate internal structure of the mountains are exposed directly at Earth's surface, including the mountain roots, which once were miles underground. Like Jules Verne's "Journey to the Center of the Earth", we think such a journey would simply be impossible. However, in a way, the Appalachian Mountains have made it possible for us. Instead of us having to journey anywhere, all we need to do is look around our feet to actually see deep within the Earth. So what do we see when we peer into the Earth? In the Appalachians, we see clues about how, when, and where the mountains formed – specific tangible features that help tell the story of mountain building when linked to intangible geological and universal concepts. For example, rock exposed along trails and summits showcase minerals that indicate depth of their formation by indicating metamorphic grade. When the Appalachians towered like the modern Rocky Mountains, they had a deep and extensive root (see the **We've only scratched the surface** textbox on page 117). The crustal root of the mountain range extended far down into Earth's mantle because of the weight of the mountain range above. The buoyancy of the root also forced the mountains above to grow. This is one form of isostasy that relates to erosion and uplift.

As the continental crust thickened during mountain building, rock pushed deep into high pressure and temperatures allowing very specific minerals to grow. We know that minerals can be very picky, only forming in very specific environments. We also know that minerals and metamorphic grade act like an accent of the rocks (textbox, **What is Metamorphism**? on page 89) – revealing the region in which the rocks 'grew up' just like our language accents reveal information about humans. By listening to the accent of the rocks, we can learn about where that rock has been. Like a French accent in downtown New York City, certain minerals are foreign – we know they didn't come from here! If you have ever traveled to Paris and visited the Eiffel Tower, or gone to the Tower of London, you were probably surrounded by hundreds of tourists that came from far away. You can think of the Appalachians as a busy geology tourist spot – swarming with minerals that are not local, minerals that formed deep within the heart of the mountains, miles away. The rocks and minerals arriving here, first-class, sent by 'the weathering and erosion U.S. Postal Service' that lifted the mountain root to Earth's surface. It is amazing that simple erosion can 'mail' the very heart of mountain ranges, once deeply buried, all the way to Earth's surface. Because of this, we get a unique opportunity to peer deep into the Earth simply by looking at the rocks under our feet.

We also are taking Jules Verne's "Journey to the Center of the Earth" when we look at Appalachian outcrops because of structural geology. The structural changes the mountains have undergone shifted around the rock's original positions. Once flat-lying rock and sedimentary layers were folded and faulted as the continents crunched together. These processes allowed huge chunks of old rock from deep underground to be lifted towards the surface as they slid overtop of younger, shallower rock layers. Stacking slices of land like this makes it much easier for us to see geological features that originated from the depths of Earth's crust because they have been transported upwards for us. The next section will explain this in detail.

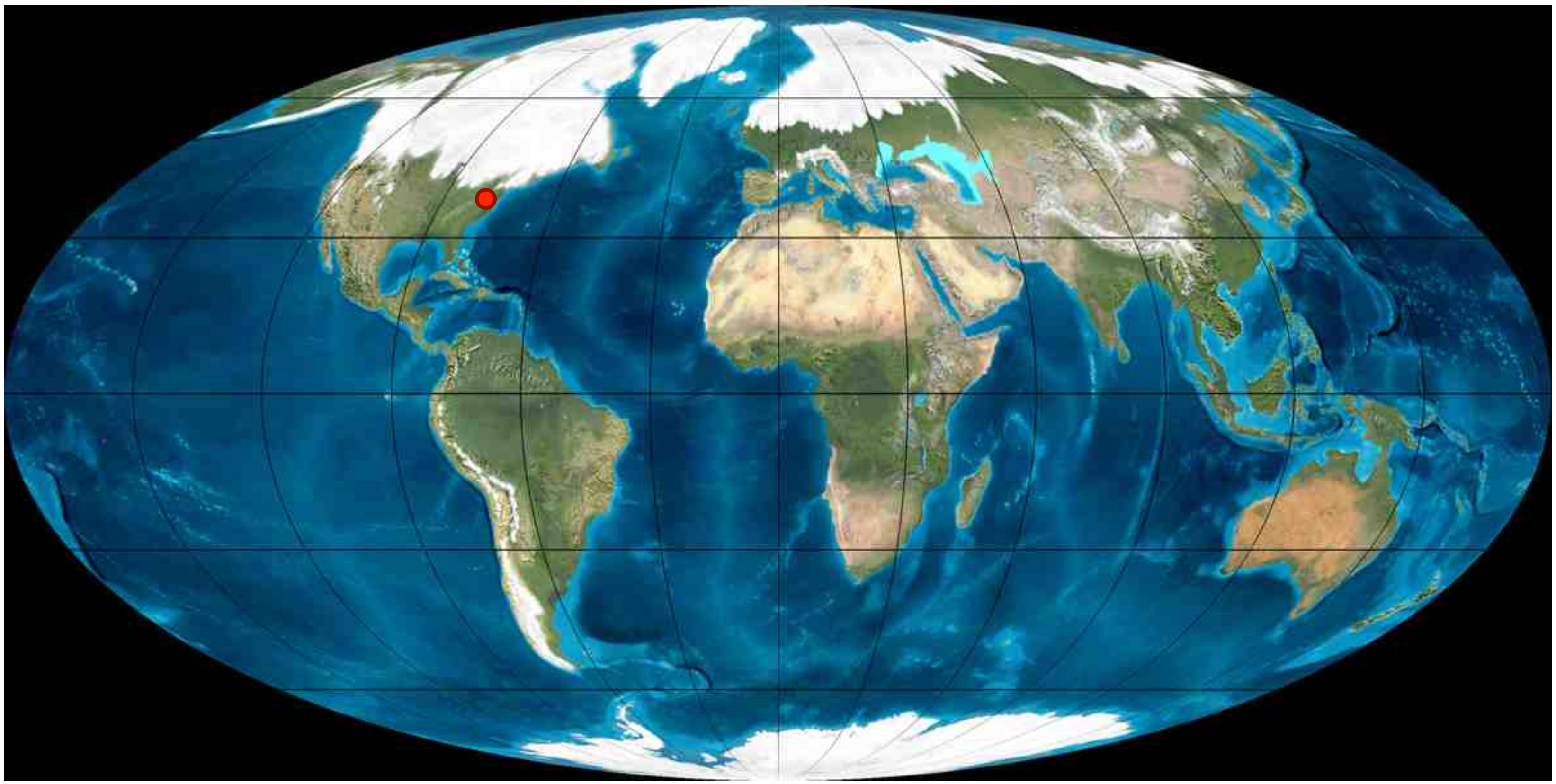


Figure 51: The last Ice Age greatly eroded the Appalachian Mountains. This process exposed rocks and formations that had remained buried for hundreds of millions of years within the mountain roots directly at Earth's surface for us to study today. The red dot is the location of Shenandoah National Park. (Map courtesy of Dr. Ron Blakey, Northern Arizona University)

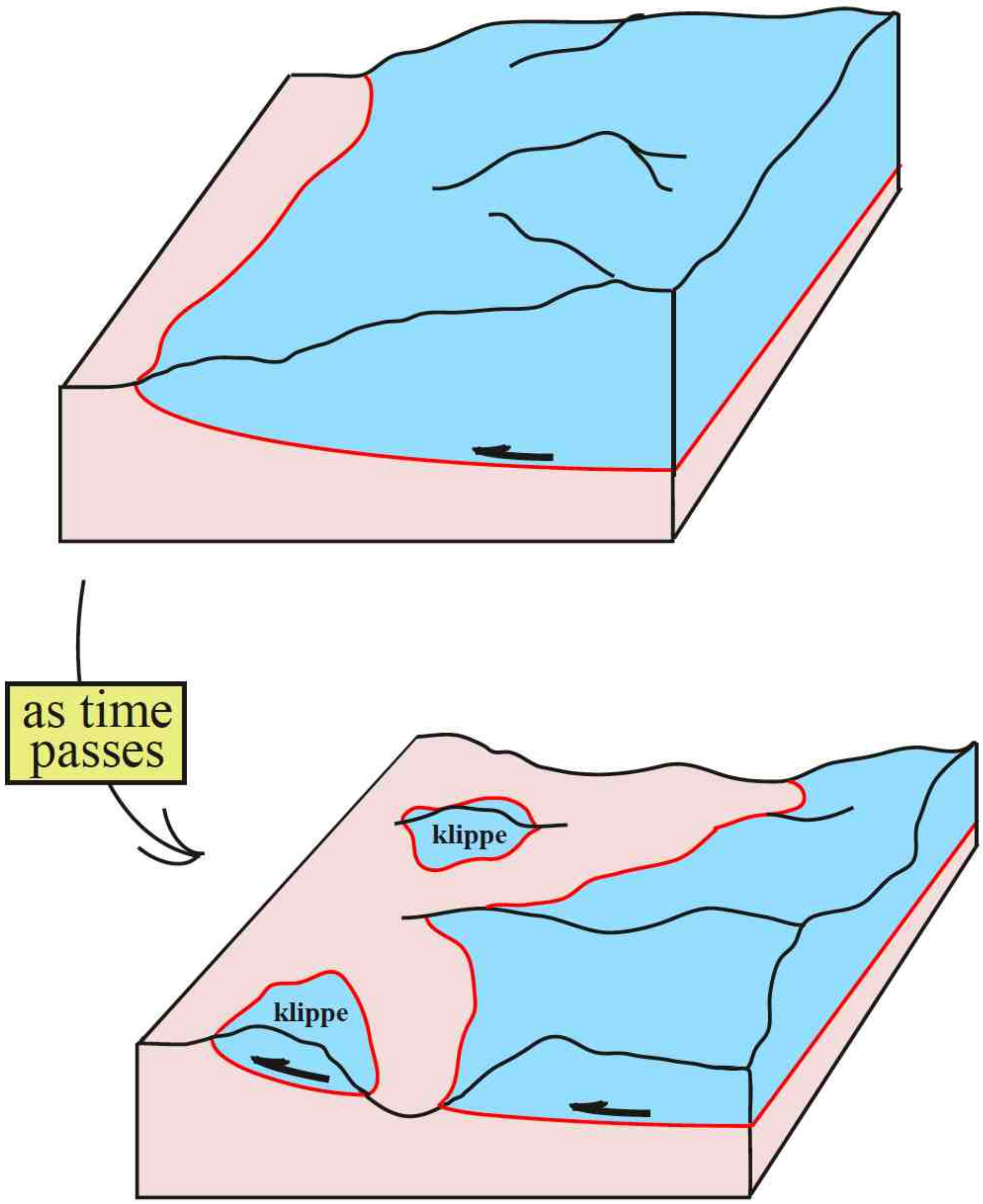
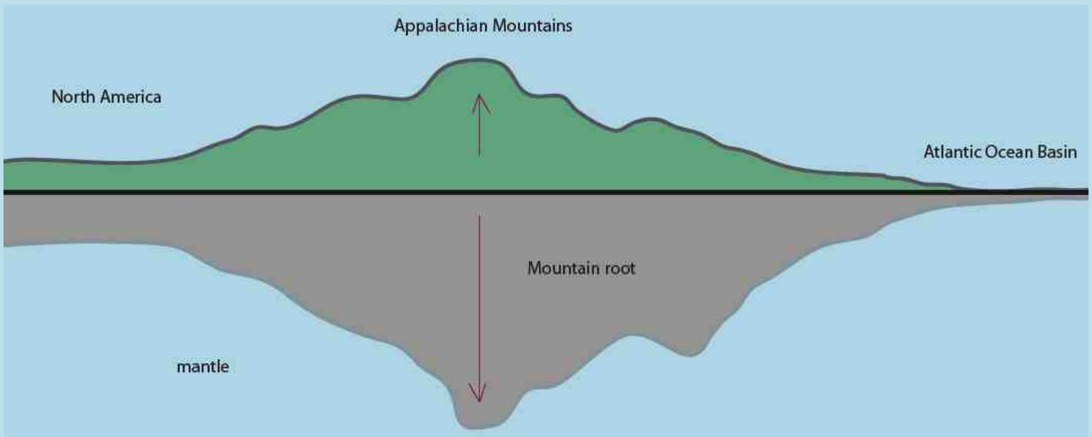


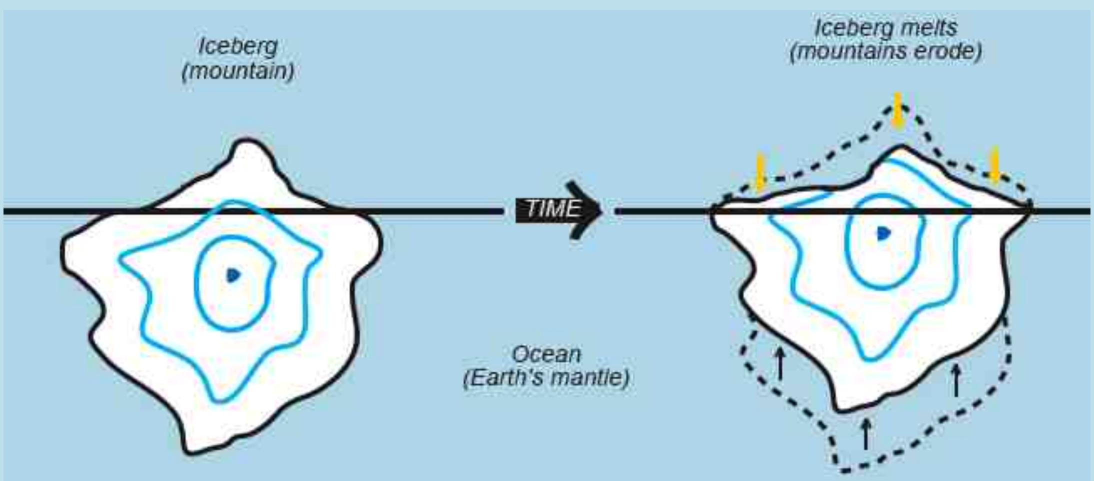
Figure 52: As the Appalachian Mountains erode away, interesting structural features appear. A klippe is a stranded piece of rock that was once attached to a thrust fault. One exists near the city of Staunton just south of Shenandoah National Park. Other small klippen may exist just west of Shenandoah, as little hills that resist erosion as the softer surrounding rock erodes away.

We've only scratched the surface

Imagine an iceberg. What we see bobbing on the surface of the sea is only a piece of the whole – that mass of ice has a 'root' that extends far below the ocean surface.



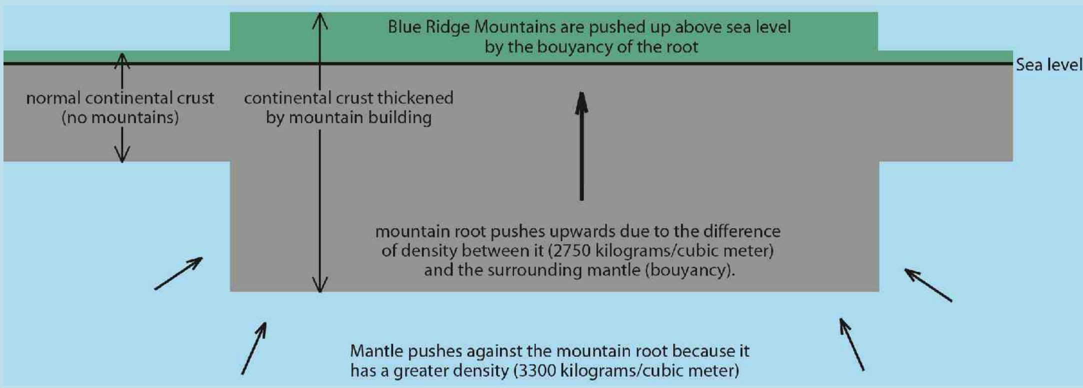
Many mountain ranges are similar - they not only extend upwards in elevation, but also pierce deep down into Earth's mantle. For example, a mountain range the size of the Himalayas, (reaching elevations well over 20,000 feet) will have a large root 5 to 7 times thicker than the elevations we see at Earth's surface. This is because the upward buoyancy of the thick root of the mountains (or iceberg) is needed to support the downward force (weight) of the rock above sea level. Thus, the mountains are sort of bobbing in a sea of mantle material below Earth's crust.



If you can imagine melting off the top of the Iceberg, the iceberg would shrink as it bobbed upward and its root became smaller. This is what happens over time as the mountains weather and erode away. Because of this, the innards, or roots, of the mountains slowly rise and become exposed at Earth's surface simply because of the slow biting processes of weathering and erosion. Further, what is exposed can tell us a story about how big the mountains originally were.

How do mountains form? Think about the Himalayan Mountains - they tower more than 20,000 feet above sea level. Large mountain ranges like these (including the early Appalachians) form because the crust thickens as continents collide. Let's demonstrate why mountains can get as high as the Himalayas when oceans close and thick blocks of continental crust collide.

Step 1 - understanding the basics: Normal continental crust is about 35 kilometers (22 miles) thick, but when continents collide, the crust can thicken to twice its normal thickness. As the crust thickens, mountains rise because of the buoyancy of the thickened crust. Some of the crust thus bobs up higher above sea level, creating just enough downward force (weight) of topography to counter the upward buoyancy of the thick crust.



Step 2 - doing the calculation: Let's make some mountains. How high could we build up a mountain range if we were to double the crustal thickness during a continental collision? Let's consider the extra thickness of crust (known as the "mountain root") that results when continents collide. This calculation will help us out:

$$\text{Thickness of mountain root} = \frac{(\text{elevation of mountains}) \times (\text{density of continental crust})}{(\text{density of mantle}) - (\text{density of continental crust})}$$

$$\text{Thickness of mountain root} = \frac{(\text{elevation of mountains}) \times (2750 \text{ kilograms/m3})}{(3300 \text{ kilograms/m3}) - (2750 \text{ kilograms/m3})}$$

$$\text{Thickness of mountain root} = \text{Elevation of mountains} \times 5$$

Cranking the numbers through, we get:
thickness of mountain root ~ elevation of mountains x 5

This equation illustrates that the elevation of a collisional mountain range is about 1/5 the extra thickness of the continental crustal ("mountain root"), meaning that if we doubled the crust (adding 35 kilometers or 22 miles of extra thickness) by crunching continents together, a mountain range of 4.4 miles or 23,000 feet in elevation would form! This is similar to heights of the Himalayas, and is probably a good estimate as to how high--at least in places-the Appalachians were in their prime.

Unfolding the land

The cacophony of geologic events that occurred over the past billion years are the reason why the landscape appears as it does today. But of all the geologic experiences the Appalachian Mountains have undergone, the most recent erosion may be of the most significance to us, as it is what we see and have experienced within our own lifetime. Looking at the Blue Ridge Mountains today, how would we know such a complex and dynamic series of geologic events have come to pass? The landscape of gently-rolling hills and low mountains is covered in thick forests of deciduous trees, moss, and lichen. It is difficult for us to understand the complexity and richness of the Appalachian Story simply by casting our eyes across the mountain range.

Every collisional event described so far caused deformation of the eastern landscape – folding and faulting rocks, and transporting those fragments across the land (Williams and Hatcher, 1983). Because of this, the land beneath our feet today is really a mish-mash of these folds, faults, and slivers. Geologists have the challenge of reading the story this cacophony has to tell because it has revealed so much about the history of our mountains and the Earth. But in order to read the entire story, structural geologists must literally *unfold* the landscape. This next section provides an in-depth view of how geologists do this to see how eastern Laurentia would have appeared before the Alleghanian Orogeny. The information presented will help park rangers thoroughly understand the three-dimensional structure of Virginia, giving a detailed perspective of how the Appalachian Mountains grew.

Step 1: What we have to work with today – making a geologic map

Standing at the top of Old Rag Mountain in Shenandoah National Park, we can cast our eyes across a beautiful landscape of rolling hills and mountains, soft rocky peaks and misty valleys. Gorgeous as this view is, in order to read our story as structural geologists and *see* into the Earth, we first have to remove all the plants, animals, houses, soil, and loose sediment that blanket our view. Once this mantle of loose stuff is removed, we can begin to see the real foundations of the landscape – the ground of hard rock that is the stage upon which we play out our lives. If we look around now, and color each different rock a distinct color, we would have a geologic map. A falcon flying above would view the Appalachian Mountains as strips of vibrant color (Figure 53).

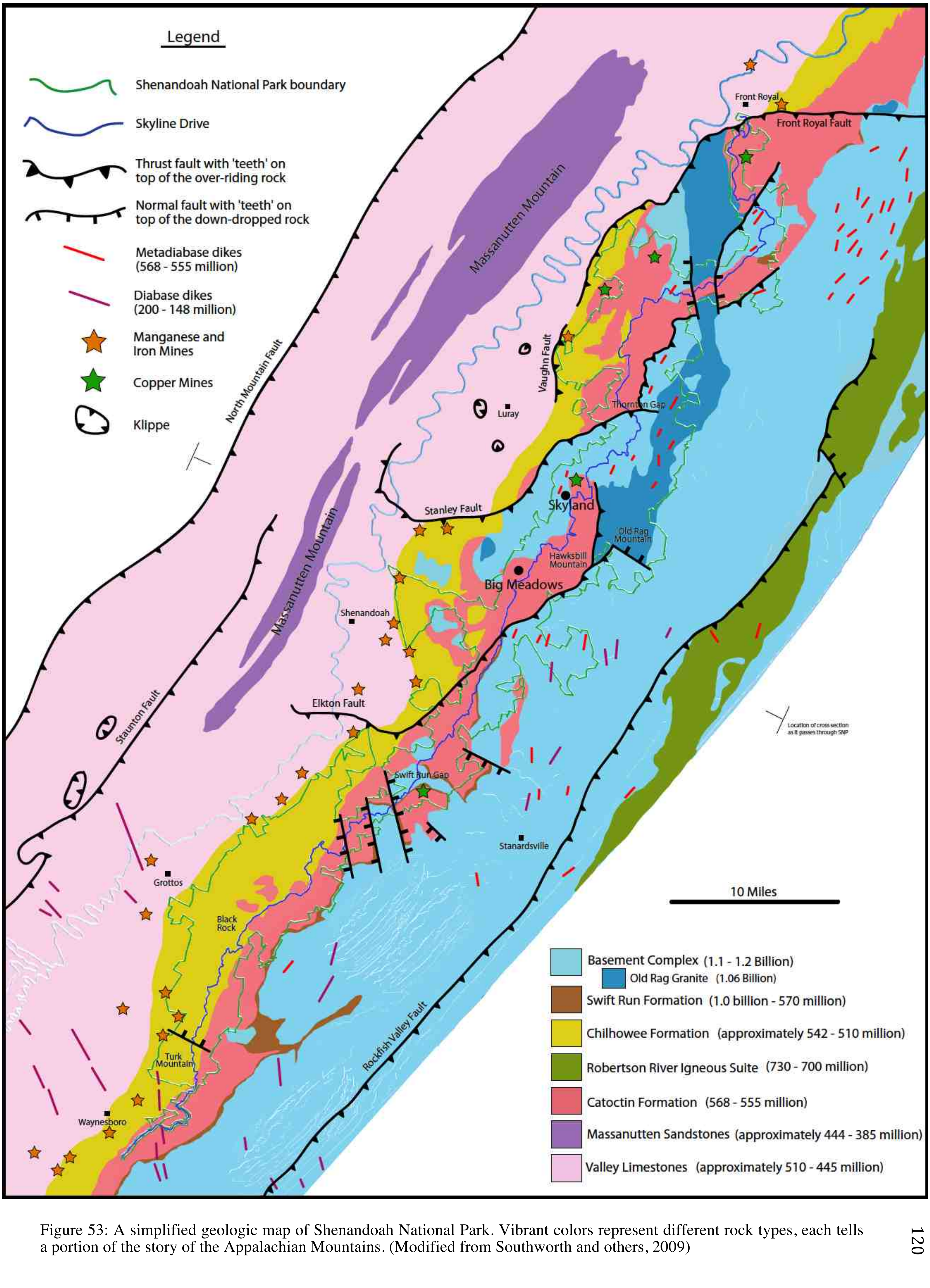


Figure 53: A simplified geologic map of Shenandoah National Park. Vibrant colors represent different rock types, each tells a portion of the story of the Appalachian Mountains. (Modified from Southworth and others, 2009)

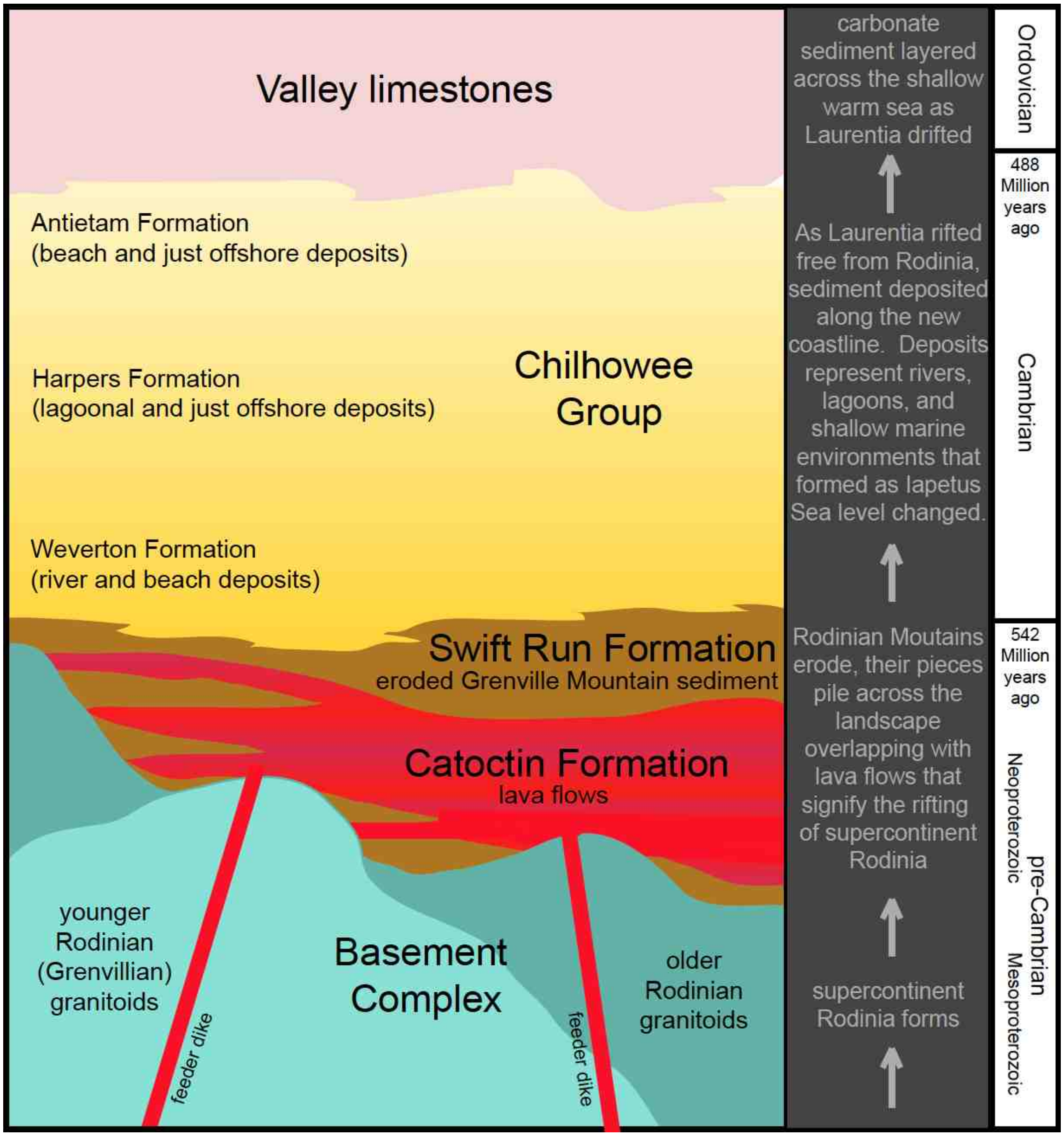


Figure 53b: A stratigraphic column of Shenandoah National Park. This illustration documents the placement and deposition of rocks through every step of Shenandoah's geologic history. Beginning with the unevenly eroded Basement Complex, a sequence of lava flows and sediments were deposited across the land as Laurentia shifted through a variety of depositional environments. Although this stratigraphic column illustrates the general rocks types found within the park, the complex structural changes resulting from the assembly of Pangea are not illustrated, and require a geologic cross section to reveal. (Modified from Bentley, 2008).

Geologists use geologic maps to see how the rocks under the soil appear from above - this hints at where they came from and how they may have moved in the past. Scattered across the map are lines that separate different colors, or rock types. These are called contacts and indicate where two different rock types come together. The most important lines on our geologic map will be thrust faults which appear as bold black lines with little black teeth pointing towards the overriding rock, or the hanging wall (Figure 53, 25). These faults indicate that rocks on either side have moved (see earlier section: ***Breaking Away***, **Phase I**, page 54). Faults form because rock is forced to deform when it is squeezed. If the rock is hard and cold, it will deform in a brittle sense, breaking along a single plane (fault) along which rock may travel. If the rock that is squeezed is warm, or deep within the Earth, it may deform in a ductile sense – instead of a single fault pane, a wide zone of strain (called a mylonite zone) will form, or the rock may fold. The squeezing that occurred during the Alleghanian Orogeny forced many brittle faults to crack as well as many ductile mylonitic zones to develop, in which the rock was strained. We can see high strain zones exposed at the surface today throughout the Shenandoah region because of intense erosion that followed mountain building. The mylonite zones can be tens of miles long and typically are within the Basement Complex, where faults end (Southworth and others, 2009).

Step 2: Seeing in three-dimensions – making a geologic cross section

Now we have a two-dimensional map view of the landscape. But in order to see the structure of the many rock types we must view the land in three dimensions. To begin, let's use a stratigraphic column to think about all of the different rock types we see in Shenandoah (Figure 53b). The stratigraphic column represents the accumulation of rocks on the landscape through time, giving us a quick idea of which rocks are oldest and youngest. Now that we can see the accumulation of rocks, let's look at how they have been deformed by mountain building. First, we must take a slice of the land (from the geologic map), like cutting a slice of cake, to see how it appears on the inside (Figure 54). Such a slice of the Earth is called a cross section. If we have a couple of cross sections from different locations along the Appalachian Mountains, we can connect them into three-dimensional blocks that allow us to see the land in three dimensions, like an architect drawing up blue prints for a house. Many of the illustrations in this thesis are block diagrams (for example, figures 23 and 34). Seeing the ground in three dimensions makes understanding the structural changes of the Appalachian Mountains much easier. Let's begin by examining a slice of land from the central Appalachian Mountains (Figure 55).

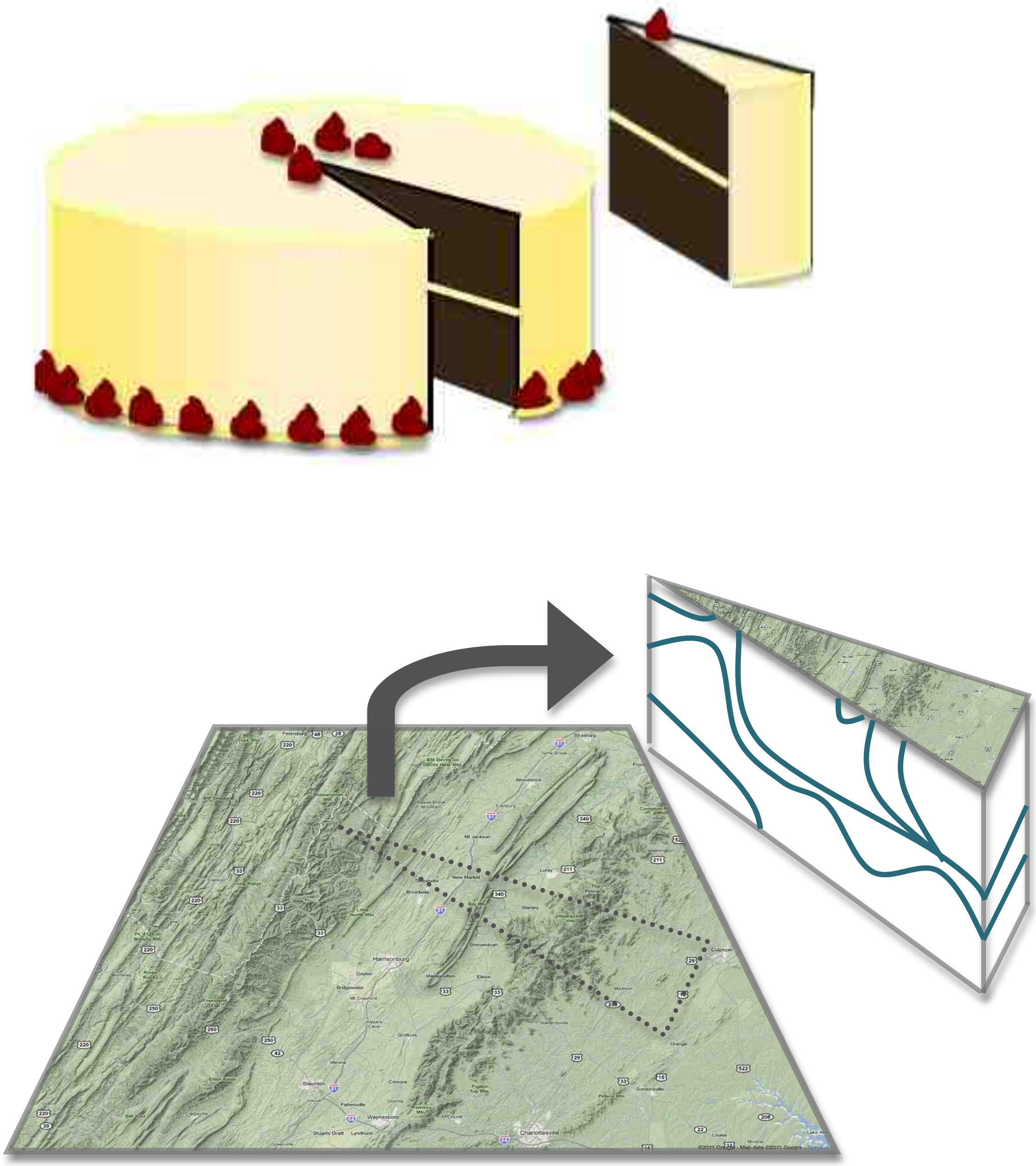


Figure 54: Taking a geologic cross section of the land is like cutting a slice of cake. A geological cross section is easy to understand if you can think in three dimensions – picture a giant knife cutting directly down through the Blue Ridge Mountains, now this 'slice' of land can be lifted up out of the surrounding landscape so that we can view it from the side. This side view of the landscape is called a cross section that reveals the internal geological structure, like folds and faults, of the rocks under our feet.

Looking across a slice of Virginia (Figure 55), we can see that the deformation of Laurentia due to the three continental collisions of the past few hundred million years have left a wide impression. The provinces help us understand this deformation by dividing the landscape based on visible differences (Figure 14). These visible differences tie directly to the geology. Here, the high Appalachian Plateau of western Virginia and West Virginia represents a pile of flat to lightly folded sedimentary rock layers (shales, sandstones, and conglomerates) that accumulated to the west of the Taconic, Acadian, and Alleghanian Mountains. Moving east, the Valley and Ridge Province holds many mountains of Virginia (including the Shenandoah Mountains) because this province is essentially a massive, bulldozed parcel of sedimentary layers that were folded and faulted as they were pushed westwards primarily during the Alleghanian Orogeny – think of a rumpled carpet (Evans, 2010; Bailey, 2007; Fichter and Baedke, 1999). Most of these rocks are metasedimentary and represent the position of the ancient seashore. Over time, erosion has erased the weaker or less resistant rock layers, leaving behind a beautiful view of sinuous ridges and valleys (Figure 11). The Blue Ridge province, home to Shenandoah National Park, is the exciting location of a large fold, called the Blue Ridge Anticline. This fold holds the oldest rocks in the region (the Precambrian crystalline basement complex) that snapshot a period of Earth's history over a billion years old. The Blue Ridge joins the Piedmont Province to the east, which contains a mishmash of rocks. Each collisional event crushed this province, leaving behind highly-metamorphosed rocks belonging to the closed ocean. Evidence of continental rifting also exists as rift basins filled with sediment and volcanic lava flows. The mountains that grew during the collisional events eroded into sediment that became the Coastal Plain. We will focus on unfolding the Valley and Ridge and Blue Ridge provinces to help illustrate how the land appeared before the Alleghanian Orogeny.

Step 3: Reversing time – unfolding the geologic cross section

Now that we have reviewed a cross section, we must literally unfold the land. Here we explore the structural geology of the central Appalachian Mountains. The importance of structural geology is that not only does it help us understand the process of building mountains, but it also helps us literally view the interior of the Earth. The thrust faults that laced their way through the Appalachian Mountains carried with them rocks from deep within the Earth up towards the surface, giving us a unique opportunity to explore an otherwise unviewable and unreachable land.

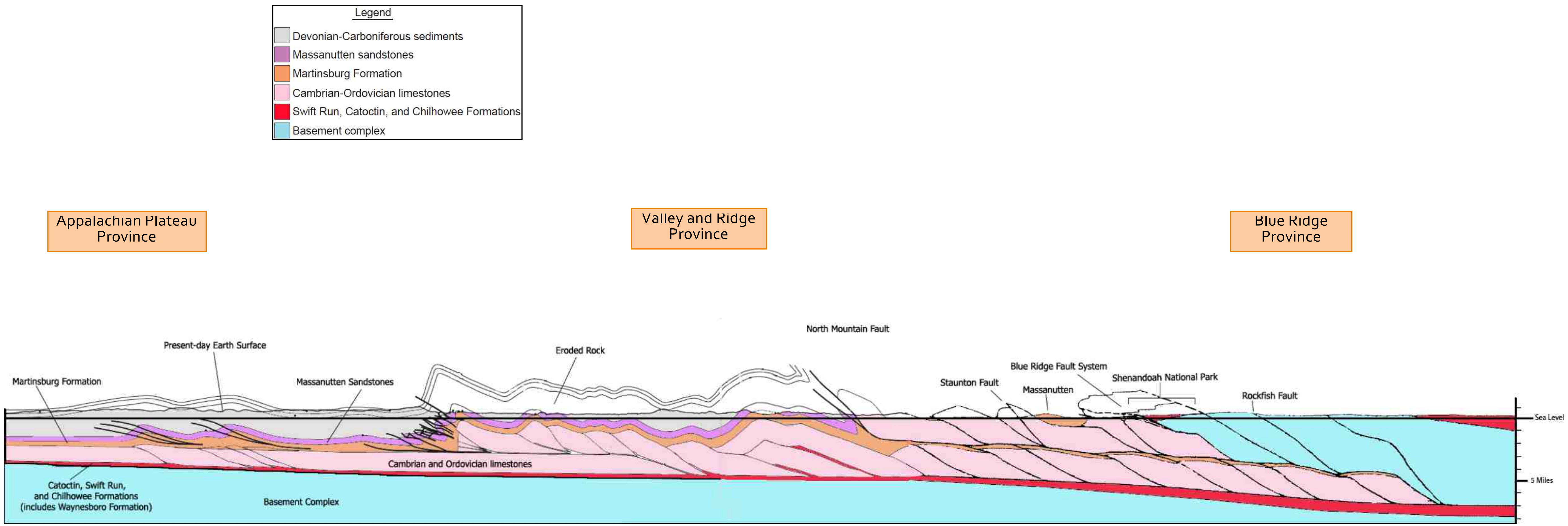


Figure 55: A geological cross section through Virginia. This slice of land crosses the Valley and Ridge Province to West Virginia and the Blue Ridge Province through Shenandoah National Park. This cross section reveals a complex structural geology beneath our feet hat reflects the complex series of geological events that shaped the Appalachian Mountains. The compression that occurred during the Alleghanian Orogeny forced many pieces of land up on top of each other. These pieces, called horses, make up three primary thrust sheets – the Lower Carbonate Duplex, the North Mountain Thrust Sheet, and the Blue Ridge Thrust Sheet. Shenandoah National Park sits on top of the Blue Ridge Thrust Sheet to the east, while the Valley and Ridge Province is above the Lower Carbonate Duplex to the west. (Modified from Evans, 2010 and Evans, 1989)

In order to simulate jumping into a time machine and going back in time, we have to reverse the motion each slice of land took as it was shoved along a fault. In the Appalachian Mountains, the crunching together of Laurentia with the Taconic, Acadian, and Alleghanian landmasses caused the landscape to squeeze together, or shorten up to 70 miles (Evans, 1989). When this occurred, sets of thrust faults (see Figure 23) formed three major thrust sheets that overlapped one another as they were shoved together like cards in a deck (Figure 56a, 47). These thrust sheets are large bodies of rock that were transported along major faults (décollements) that broke along layers of weak rock, like shale, rather than the hard resistant sandstones and granites that form outcrops and mountain ridges (Tollo and others, 2004). The Waynesboro Formation and the Martinsburg Formation are great examples of weak rock layers through which major décollements broke in the Shenandoah region (Evans, 1989). The Waynesboro Formation is a layer of Cambrian sedimentary rocks that formed when Laurentia had just rifted from Rodinia. The sediments collected in the shallow waters along the shore of Laurentia and provided a slippery plane that gave way when Gondwana crunched into the coast. The Martinsburg Formation is another layer of weak sedimentary rock that formed later, during beginning of the Taconic Orogeny in the Ordovician Period (Southworth and others, 2009; Horton and others, 1989). The Martinsburg Formation can be found in the core of Massanutten Mountain (a u-shaped fold, or syncline) and is composed of weak foreland basin sedimentary flysch deposits that were some of the first sediments to erode off the Young Taconic mountains (Southworth and others, 2009). This variability of weak and hard rock layers have contributed to the haphazard pattern of faulting within the Appalachian Mountains. If we were to fly north from Georgia, we would see multiple thrust sheets that are divided by major décollements and littered by minor fault splays because the coast was squished unevenly during the Alleghanian. (Twiss and Moores, page 123).

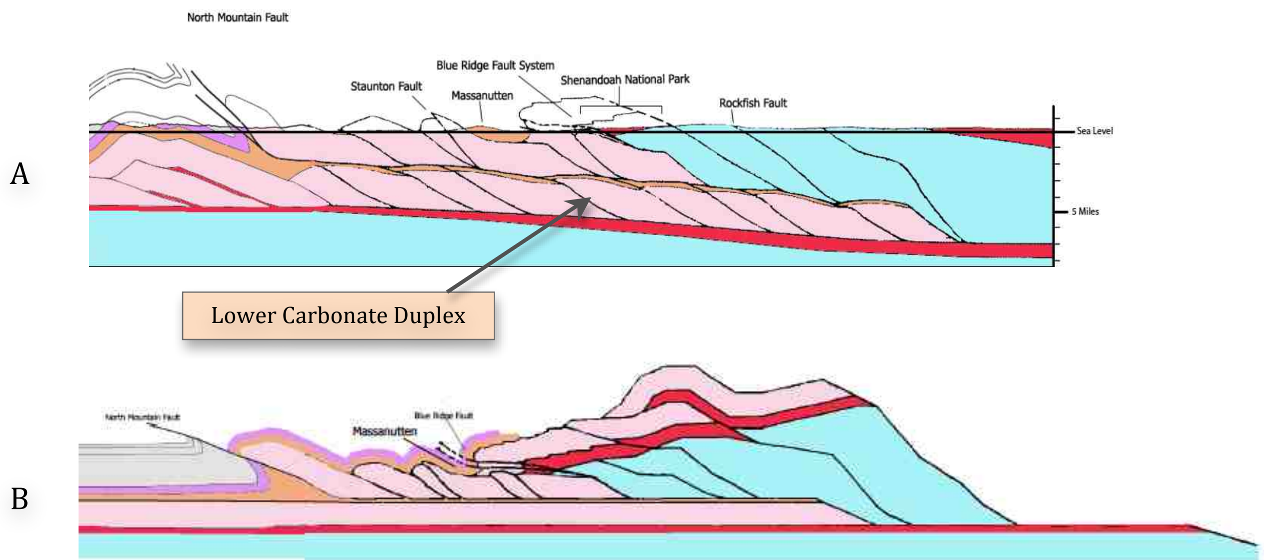
Therefore, the Appalachian Mountains are primarily a multitude of slices of land that overlap because they have been thrust overtop one another by the compressive force of the landmasses that collided with ancient Laurentia. What we see today in our cross section below Shenandoah is a good example of the deformation that has taken place all along the Appalachian Mountains. In the Shenandoah National Park area, the deformation involves three big thrust sheets. Lets unfold Shenandoah.

Atlantic Rift Basins

Imagine we are standing on Old Rag Mountain in Shenandoah National Park with a remote control. We push rewind. In the distance, we see the Culpepper Valley fill in as the floor of the valley rises. Raising our binoculars to our eyes, we see many of these ancient rift basins pop back upwards east of the Appalachian Mountains, all along the Piedmont and Coastal Plain Provinces. These rift basins formed during the Jurassic and Triassic Periods as the Atlantic rifted open, as chunks of land dropped along normal faults (Figure 25) and now we witness them climbing back up as we travel back through time. Looking west into the Shenandoah Valley, we see smaller chunks of land also slip quickly back up thousands of feet along normal faults that formed as Pangea had pulled apart. These smaller extensional displacements can be found all along the Appalachian Mountains. In Shenandoah there may be one of these faults near **Thornton Gap**, cutting the Catoctin formation at Mary's Rock (Whitmeyer, pers. comm.).

The Lower Carbonate Duplex Thrust Sheet

Again, we push rewind on our remote control. Instantly, the land drops from beneath our feet and a small tear rips across the ground near the base of Massanutten Mountain. We push pause. Although we can see no obvious change in the shape of the landscape, the topography just dropped hundreds of feet. About 2.5 miles (4 kilometers) beneath the ground, an elegant series of faults, called a duplex just un-cracked their way through the Lower Carbonate duplex (Figure 56a, 56b) (Evans, 1989). This lower carbonate duplex consists of many layers of metasedimentary rocks that extend under the Blue Ridge and through the Valley and Ridge Provinces of Virginia and West Virginia (Woodward, 1985). This elegant group of underground land slices (called horses) broke and was compressed together during the very end of the Alleghanian Orogeny, sliding along the soft shales and limestone of the Waynesboro Formation (Evans, 1989). The squeezing of the sedimentary layers forced them to shorten by about 9 miles (15 kilometers) (Evans, 1989). Think of squeezing a piece of saltwater taffy. When you push in the sides, the top has to bulge up because although you have changed the shape of the piece of candy, the volume must remain the same. Therefore, when the Carbonate duplex was squeezed from the sides, it had no choice, but to 'pop' upwards. This forms the rumpled carpet of the Valley and Ridge province, it is a series of folds that have ridden along a series of small thrust faults. Most of these fault duplexes remain hidden below ground as blind thrusts, but the land they pushed up can be seen today as elegant folds that form mountains and valleys.



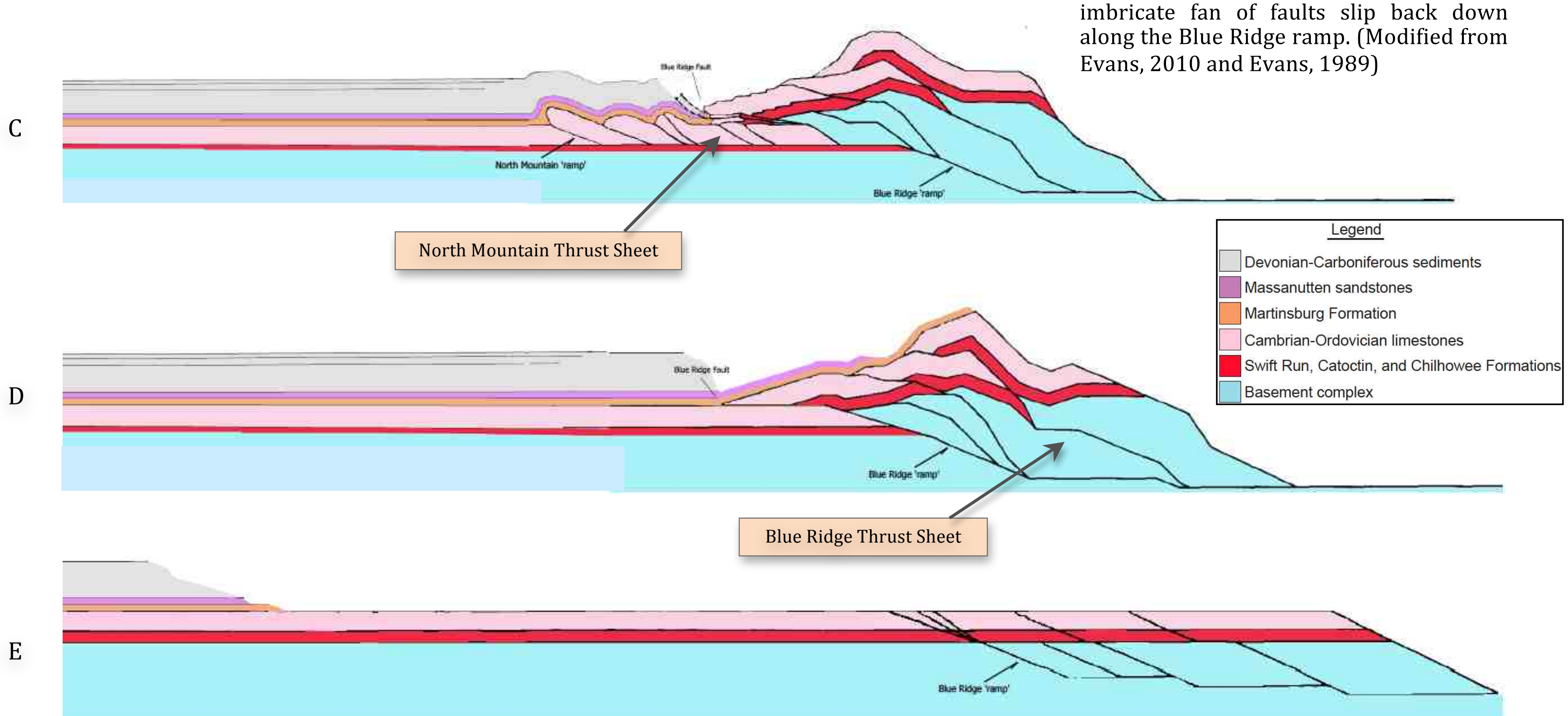


Figure 56: Unfolding the landscape in a geologic cross section. A. The area around Shenandoah National Park today is complexly folded and faulted. B. Reversing time, rocks that have been eroded away reappear as the lower carbonate duplex un-rumples. C. We slid miles to the east as the rock under our feet travels backwards along the slippery shales of the Martinsburg formation. D. Further back in time, the imbricate fan of faults in the North Mountain Thrust sheet disappear as each parcel of rock (called a horse) slips back along the Waynesboro formation. E. The Blue Ridge thrust sheet is the last to unfold as we reverse time. This parcel of basement rock returns to its original location miles underground as the imbricate fan of faults slip back down along the Blue Ridge ramp. (Modified from Evans, 2010 and Evans, 1989)

The complex tear that formed near the base of Massanutten Mountain is the Blue Ridge Fault system. Frequently referred to as “the very last breath” of the Alleghanian Orogeny, it is a small toe of rock that broke free and pushed outwards (Figure 53, 55, 56b, 56c). The Vaughn fault is probably a portion of the Blue Ridge fault (Evans, pers. comm.).

The North Mountain Thrust Sheet

Pushing rewind again, we are pulled back through time. Somewhere between the Alleghanian and the Acadian Orogeny, we would see the land tear near the border of West Virginia. This massive tear is the North Mountain Fault (Figure 53, 55, 56b). As the fault reverses its motion, we quickly drop down and eastwards as huge layers of metasedimentary rock a mile or so under our feet slides more than 40 miles (60 kilometers) to the east along the weak Waynesboro Formation and then the lower weak Martinsburg Formation (Evans, 1989). This massive chuck of land is the North Mountain thrust sheet and was pushed up and overtop of areas of western Virginia during the Alleghanian collision. It includes the limestones of Shenandoah Valley today. As the thrust sheet moved, smaller faults, such as the Staunton fault broke within it and can also be seen today in the Shenandoah Valley (Figure 53, 56b, 56c). This reversal along the North Mountain fault also erases a large fold that is called the Blue Ridge anticline. Motion along the North Mountain fault helped to pull this huge fold of land up and across the landscape to its current position beneath Shenandoah National Park (Hatcher, 1972).

The Blue Ridge Thrust Sheet

Pressing rewind again, we are transported further and further to the east, as the Blue Ridge thrust sheet directly under our feet continues to unfold (including the Blue Ridge anticline) and returns to its original position. We travel with the ground miles to the east, riding on top of this huge thick slab of metasedimentary (including the Swift Run formation), metavolcanics (Catoctin formation), and basement complex rocks. As we continue to rewind time, we see that the very first crunching that shaped the Shenandoah region may have occurred during the Taconic Orogeny. A series of faults that had spider-webbed through the Blue Ridge thrust sheet, un-crack. The Stanley, Front Royal, and Elkton faults near Shenandoah, and the Brevard fault of the Carolinas are part of this spiderweb (Southworth and others, 2009; Hatcher, 1981) (Figure 53, 56d, 56e). When Arvonia collided with the ancient coast, the hard crystalline basement complex fractured like cracked peanut brittle. These faults made up an imbricate fan of thrust faults. This imbricate fan of faults within the Blue Ridge is like overlapping shingles of a rooftop, these slices of hard crystalline basement rock have been placed one on top of another, one piggy-backing the next as the Appalachians were slowly squeezed together through time (Evans, 1989; Rankin, 1994). One of these faults includes the Rockfish Valley Fault (Fichter and others, 2010; Evans, 1989) (Figure 53), which is a major thrust that cuts through rock far to the south (connecting to the Hayesville-Fries fault system). As the Arvonian islands squeezed against the edge of the Laurentian coast, a major crack split through the foreland basin sediments and crystalline basement, forming a sliver of rock that slid westwards on top of Laurentia. This major fault separates Laurentia from the sutured-on Taconic landmasses of the southern Appalachians (Miller and others, 2006). The northern section (Rockfish-Fries fault) was also active during the Alleghanian (Fichter and others, 2010; Miller and others, 2006; Evans, 1989; Hatcher, 1981).

Prior to the Alleghanian Orogeny, the land under our feet did not change as much in a structural sense. If we continued to rewind time, we would be repeatedly submerged under water within foreland basins, surrounded by sediment, and eroded away as two sets of mountains grew and shrunk in front of our eyes a distance to the east. It is because of this intensive deformation that occurred during the Alleghanian Orogeny that we are able to stand directly on top of rocks that should be deep inside the Earth. This view allows us to see into the depths of mountains and continental crust, helping to review some of Earth's secrets. Therefore, the Alleghanian Orogeny was the main geological event that gave us the Appalachian Mountains of today, whereas we can think of the Taconic and Acadian Orogenies as providing the foundation for the Alleghanian.

It should be clear by now, that when we hike through the Appalachians, we are truly taking steps across time and space. A dynamic series of events formed the Appalachians. From the formation of the Rodinian supercontinent over a billion years ago, to the rifting of an ancient ocean, to the collision of small landmasses, and the dramatic formation of supercontinent Pangea, followed by a final rift that formed the Atlantic Ocean, these events have made our mountains a complex patchwork quilt of a landscape. When we hike through the Appalachians, we are not only taking steps through time, but also taking steps across space: into Africa, Europe, Canada, and Texas. By revealing the story of the Appalachians, we can amplify the experience of Shenandoah National Park visitors, inspiring them to see beyond what first meets the eye, and encouraging them to embrace and protect a land with a life story.

PART IV
The Shenandoah Story - A tale of life in the Blue Ridge Mountains

The rocky outcrops and sinuous valleys of the Blue Ridge form a dynamic setting for old and new visitors to Shenandoah National Park.

This section is written as a compelling story that summarizes the influence of geology on the life of Shenandoah National Park. It is designed for park rangers to use as a foundation for understanding and conveying how geological events have shaped Shenandoah within human history. Versions of this story might be told to Shenandoah visitors during ranger programs accompanied by visual props. This story is an extension of the previously developed Appalachian Story (Part II). We'll travel through time from the more recent past to the present, and into the future, establishing a sense of time and place for the Shenandoah landscape within the Appalachian Mountains.

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Even after hundreds of millions of years of erosion, the long chain of Appalachian Mountains that span the East Coast of North America has impacted many different human cultures in an assortment of ways. It all began about 200,000 years ago, when modern humans evolved on Earth (Tattersall, 2009; Wilson and Cann, 1992; Figure 13). Perhaps as early as 30,000 years ago, the first humans set foot on North American soil. One route they probably traveled was across the Bering Land Bridge from Siberia. Like the massive sinuous waves that bring in the ocean tides, Earth's climate rises and falls in cycles through time. At the time humans reached North America, a cooling trend formed huge sheets of ice over North America. At times, glaciers extended as far south as central Pennsylvania, digging their icy claws into the landscape (Figure 57). These monstrous ice sheets locked up Earth's water, forcing sea level to drop hundreds of feet. Land once underwater became exposed, including the shallow sea floor of the Bering Strait between Alaska and Siberia.

Figure 57: The last glacial maximum. The last ice age not only impacted human migration, but also influenced the erosion of mountains within Shenandoah National Park. Around 20,000 years ago, a large portion of North America was covered by a thick continental ice sheet. It extended as far south as central Pennsylvania. Drop in sea level exposed a land bridge connecting Siberia to Alaska. Traveling from Europe by sea along the southern edge of the ice sheet provided another possible route of travel for early humans to migrate into North America. (Modified from Dr. Ron Blakey, Northern Arizona University)

Imagine it is wintertime 13,000 years ago. Standing on the barren top of Hawksbill Mountain, you place a callused hand to your brow to block the sharp sun from your eyes as you peer to the North. There, in the distance, stands the white giant. A massive glacier has been straining its icy fingers to grasp our mountains. But it will never reach us. Turning away, you cannot help but smile. The harsh winters are crumbling these mountain peaks. You grab your stone axe and, straining against the bitter wind, descend down the summit to return to your family. Today you will hunt the elk, which will clothe and feed your family during the coming bitter winter months.

As the ice age drew to a close, early North Americans spread across the continent, developing unique cultures that would eventually become hundreds of modern Native tribes. Many of these early bands of people lived and traveled through the Appalachian Mountains, establishing camps that captured traces of their lives and cultures. A variety of stone tools uncovered within the Blue Ridge Mountains of Shenandoah National Park help to piece together the story of the mountains earliest inhabitants (Figure 58).

Now imagine that it is springtime 5,000 years ago. In the distance, you hear the evening call of wolves and owls and begin to daydream about the coming months. The warming weather means hunting and celebration at the old meeting place at the mountain summit. Behind you, a rustling branch brings your attention back to the moment. All around you is the sound of commotion. Your tribe is on the move. A group of perhaps a hundred people hike through the thick, green forests of the Blue Ridge Mountains. Up there, in those rocky summits, are plentiful resources of workable stone, and it's time you made a new spear.

Figure 58: A variety of ancient stone tools have been found within Shenandoah National Park. This point was made of vein quartz during the archaeological Woodland Period. (Photograph courtesy of Dr. Carole Nash, James Madison University)

As long ago as the 11th century, Erik the Red ventured from Greenland to explore land west of his Viking settlements. This venture probably marked the beginning of a long history of Europeans infiltrating North American soil. When Columbus crossed the wide Atlantic Ocean in 1492, he went looking for a westward route to Asia, but instead he stumbled upon – at least for Europeans - a new world. But it was not until 1584 that the beauty of inland Virginia and her smoothly rolling Mountains were explored by Philip Amadas and Arthur Barlowe. Ever since then, the Appalachian Mountains have shaped the livelihood of modern-day Americans (Figure 59).

> *We now jump to the summer of 1850. A bead of salty sweat trickles down your cheek as your arms strain to lift a heavy rock from the field. These rocks will soon shape the foundation of your new home. Turning your head, you spot your five year-old boy playing in the trickling stream. All day, he has been frolicking in the sun, pulling fly poison out of the fields and helping to collect wild delicious plants. This is the perfect place for the new home – a piece of flat ground tucked into the hollow with a spring nearby.*

By the 1900s, the Blue Ridge Mountains had been recognized as a place of beauty and attraction. Skyland Resort, Skyline Drive, President Hoover's fishing camp, and Shenandoah National Park were established to preserve this land, and visitors now explore the mountains in search of fun, adventure, and enlightenment about their natural and cultural world (Figure 60). But future explorers may experience a very different Shenandoah than the one we enjoy today. Human-driven climate change and the continual processes of weathering and erosion ensure a dynamic landscape that will continue to shape plants, animals, and cultures of the future.

> *It is the fall of 2100. The trees are lush with colorful autumn leaves. They crisply crunch underfoot as you breath in the clean air of the Appalachian Trail. Although you have never before attempted a hike as long as this, the fresh air forces your fear to subside and you find yourself smiling at the long trail that extends before you. Over the past 20 years, you have heard your grandfather speak of the changes up in these mountains. It is hard to believe that evergreens were ever here, or that once, long ago, one could see the Washington Monument from the top of these rocky peaks.*

Figure 59: The Mount Vernon iron furnace. The Blue Ridge Mountains provided rock rich in copper, manganese, and iron. Mines are scattered throughout Shenandoah National Park that highlight the use of these resources during the 1800's. (Photograph courtesy of the National Park Service)

Figure 60: Visitors appreciating the Shenandoah landscape. On top of Stony Man Mountain, the rocky outcrop provides an interpretive opportunity to relate landscape shape to natural and cultural history. (Photograph by Wendy Kelly)

PART V
The Shenandoah Story – Technical Review

The physical landscape of Shenandoah National Park has been the stage for generations of cultural, biological, climatological, and botanical change.

This section is written as a reference for Shenandoah National Park rangers. Its contents are more technical than that of section four, revealing specific connections between people throughout history and the physical landscape of Shenandoah. It is designed for park rangers to use as a foundation for understanding and conveying the geological events that have shaped Shenandoah National Park. Throughout this section, specific geological topics are connected to cultural and biological aspects of Shenandoah by detailing specific locations (written in **bold and underlined**) along Skyline Drive. Portions of this section may add depth to a variety of ranger programs.

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A. A Brief Overview

The geological setting of Shenandoah National Park greatly influences the cultural and biological features of the park. Now that we have taken a journey through the broad Appalachian Mountain geological history, we can delve into the details of why we see what we see today within the park itself. Our journey will take us through various sections of the Park, revealing the foundational nature of the local geology. We zoom in on the past 200,000 years of life in Shenandoah, and project into the future. This portion of the thesis targets specific, high-traffic locations within Shenandoah National Park. Such locations are explained in terms of the local geology, which is then put in context of the regional geology, local human history, and floral and faunal diversity.

The geology underlying Shenandoah National Park got there through a complex series of geological events. It is exactly because of these events that our landscape is what it is. The underlying rocks literally shape the landscape, develop the soils that determine and nourish the plants and animals, and influence human decisions that shape our lives.

In a broad sense, Shenandoah National Park sits on top of the western limb of a massive fold of hard crystalline rock that once lay deep within the Earth. The fold is now exposed as a high spine of rock called the Blue Ridge Mountains (Figure 61). Because it is primarily made of hard and resistant (igneous and metamorphic) rock, the Blue Ridge provided important tool material for early Americans. Its high peaks have also provided rocky retreats for ancient peoples as well as over a million modern visitors annually. The Shenandoah National Park boundary encircles a narrow band of land surrounding Skyline Drive from Front Royal south approximately 100 miles to the town of Waynesboro. Skyline Drive follows a sinuous path along the ridge of mountains. Numerous trailheads and overlooks allow visitors to explore the mountain forests and streams, and gaze over the surrounding Shenandoah and Culpeper valleys. Rock units within Shenandoah National Park capture the entire geologic history of the Appalachian Mountains, providing a useful teaching tool and site for further study (Figure 62). It has taken over a billion years worth of geological events to form what so many East Coasters now call home, but the same landscape has been the home of other cultures and creatures in the past, and will continue to be so in the future.

There are very few research studies focused on the early cultural settlement and interactions of early people with the Blue Ridge landscape. Because of this, discussing this topic in ranger programs should be approached with care. Research in this arena is a work in progress. Although many discoveries have been made, there are likely many more yet to come that will clarify our interpretation of the human component of the early Shenandoah story. As with other topics, be wary of resources that may be outdated and try to have direct conversation with experts on this topic, such as National Park Service research staff and university professors.

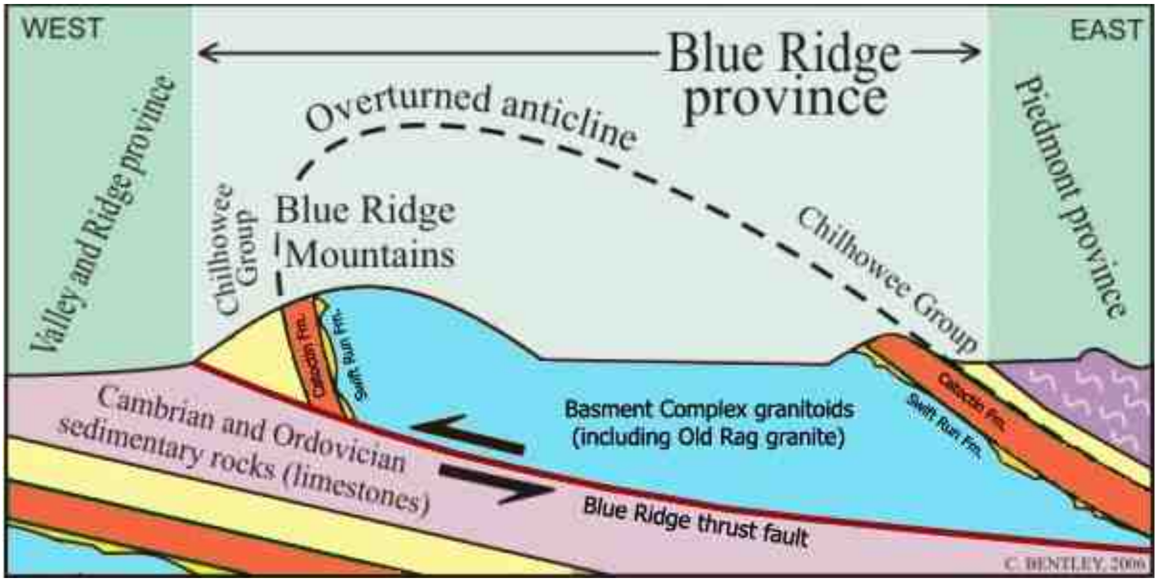


Figure 61: Shenandoah National Park sits on the Blue Ridge Mountains. During the last continental collision (the Alleghanian Orogeny), the Appalachian Mountains crunched together, driving a slice of deep basement rocks (granitoids) up and overtop of younger limestones along the Blue Ridge Thrust fault. As this parcel of rock slipped along the thrust fault, it was deformed, folding into a broad anticline. Today, weathering and erosion has exposed the heart of the Appalachian Mountains, revealing ancient rocks at Earth's surface that were once deep within the Earth's crust. (Modified from Bentley, 2006)

Rock Name	What rock is it?	When did it form?	How did it form?	Where can I find it?	Cool features
Basement Complex	different types of Granite & Gneiss	1.2 - 1.0 billion years ago Mesoproterozoic	Blobs of igneous magma collected beneath the ancient Grenville Mountains when supercontinent Rodinia formed and were later metamorphosed, uplifted, and exposed	400 feet North of Little Stony Man parking on AT, Old Rag Mountain, Hazel Mountain Overlook, Bacon Hollow Overlook	Wavy gneissic banding of minerals and hydrothermal alteration into red jasper swirls and unakite 
Metadiabase Dikes	Metadiabase	570-555 million years ago Neoproterozoic	As supercontinent Rodinia rifted apart, magma cut up through older rocks and solidified into dikes, like stretch marks that signify the birth of the Iapetus Ocean	Scattered throughout the park, including Marys Rock Tunnel	May contain pentagonal, hexagonal, or octagonal columnar jointing 
Catoctin Formation	Greenstone	570-555 million years ago Neoproterozoic	Basalt lava flows and dikes that spread through an ancient rift valley during the rifting of Rodinia. The lava flows were later metamorphosed into Greenstone.	Stony Man/Little Stony Man, Franklin Cliffs Overlook, Dark Hollow Falls trail, Peak at Bear Fence Trail	Includes remnants of ancient soil and basalt breccia between flows and columnar jointing 
Swift Run Formation	quartzites and pebble conglomerates	720 - 560 million years ago Neoproterozoic	Eroded pieces of the ancient Grenville Mountains that collected within the rift valley as Rodinia tore apart and were later metamorphosed	Bear Fence trail, Hawksbill Gap Parking	Contains pebbles of the ancestral Grenville Mountains 
Chilhowee Group: Weverton Formation	pebble quartzite, phyllite, and conglomerate	540 million years ago Early Cambrian	Coarse grained sediments (pebbles and sand) that were transported by rivers and collected on or near the coast of Laurentia and were later metamorphosed	Doyles River Overlook	Crossbedding in layers from shallow ocean waves 
Chilhowee Group: Harpers Formation	quartzites and metasiltstones	540 million years ago Early Cambrian	Fine grained sediments (sand and mud) that collected in the shallow Iapetus ocean off the ancient Laurentian coast and were later metamorphosed	Blackrock (dark quartzite)	*Skolithos linearis* trace fossil worm burrows 
Chilhowee Group: Antietam Formation	quartzites, metasiltstones, and metasandstones	540 million years ago Early Cambrian	Fine grained sediments (sand and mud) that collected on the beach or just offshore of ancient Laurentian coast and were later metamorphosed	Calvary Rocks	Crossbedded layers from ocean waves and *Skolithos linearis* trace fossil worm burrows
Conococheague Group	Limestone	490 million years ago Ordovician	Carbonate sediments that collected in the shallow, warm ocean and became cemented together into limestone that later dissolved forming caverns	Northern tip of Shenandoah, off trail	Dissolves forming caves and sink holes throughout the Shenandoah Valley 
Beekmantown Group	Limestone	470 million years ago Ordovician	Carbonate sediments that collected in the shallow, warm ocean and became cemented together into limestone that later dissolved forming caverns	Northern tip of Shenandoah, off trail	Dissolves forming caves and sink holes throughout the Shenandoah Valley 
Diabase Dikes	Diabase	200 million years ago Jurassic	As supercontinent Pangea rifted apart, magma cut up through older rocks and solidified into dikes, like stretch marks that signify the birth of the new Atlantic Ocean	Just east of Skyline Drive near Bear Fence Mountain	Tend to trend northeast to southwest in map view, mimicking the shape of the Atlantic Ocean 
Surficial Material	Unconsolidated sediments	34 - 0 million years ago Cenozoic	As the Appalachian Mountains slowly erode, their loose pieces collect forming boulder fields and talus slopes	Throughout Shenandoah especially near steep slopes and streams	Look like scars that break the view of trees 

Figure 62: A table of the rocks of Shenandoah National Park. Use this table as a quick reference to help understand basic geological features within the Park.

B. Our Ancestors: how geology shaped the landscape, plants, and people of the distant past

The dynamic geological events of the past have shaped the landscape and influenced the development of Paleo American life.

<u>How geology impacted Paleo-American life</u>

Geology influences many aspects of life. Modern humans evolved around 200,000 years ago in Africa (Tattersall, 2009; Wilson and Cann, 1992). Until about 11,000 years ago, the most dynamic geological change was one of climate. Changes in climate have not only modified the shape of the landscape, but also influenced how plants, animals, and humans have lived throughout history.

Past Climate Change - an Age of Glaciers

Geology is the study of the entire Earth, not simply the study of rocks, but what they can tell us about the dynamic nature of our planet. Geologists want to understand how Earth works and how it has, and will, change. One major field of geology is the study of climate. Climate, and climate change, is one of the many factors that contribute to the diversity of life and landscapes of our planet. Climate also impacts our day-to-day lives. Climate, unlike weather, is the long-term conditions of the atmosphere at a given location (see the **What is climate change?** and **Climate confusion** textboxes on page 150 and page 193 for details). Think about how your every-day existence is influenced by the current climate of your region. In Virginia, we have four distinct seasons. The winter months provide snow that melts in the spring, helping to refill our aquifers. The summer months provide us with temperatures warm enough to grow vegetable gardens, farm agricultural crops like corn, and enjoy a variety of outdoor sports in comfort. Paleoclimatology is the study of the climate of the distant past, which is very important because just like today, climate greatly influences how organisms, including humans, live and evolve throughout time. Climate has been changing on Earth for a very long time, leaving behind clues of what our planet was like long before we were here. If we can learn about the climate of the past, we can better understand the people, landscape and conditions of the past, and what climate change may mean for the future.

Earth's climate changes in cycles throughout time (Figure 63). The last ice age occurred from roughly 30,000 to 15,000 years ago, during the later part of the Pleistocene Epoch (for example

Clark and others, 2009) (Figure 64). During this cold period in Earth's history, massive ice sheets extended southward from the North Pole, carving out the Great Lakes, and soaking up water like a sponge as precipitation dropped snow that accumulated winter after winter, slowly packing into ice that added to the volume of the glaciers. As water became locked up in the growing ice sheet, less was available as ocean water. Slowly, sea level dropped, exposing the shallowest parts of the continental shelf. One shallow location was the thin strip of water that runs between Asia and Alaska. Called the Bering Strait, this area was exposed during the last glacial maximum, forming a narrow land bridge. Much research has suggested that this became an extremely important highway for humans to migrate into North America - a passageway that would not have been accessible if it were not for the climate conditions during that time (Dixon, 2000; Williams and others, 1985). Like a major artery, the Bering land bridge allowed the passage of thousands of humans and other animals that migrated on foot across the landscape (Figure 57). Other routes to North America have also been proposed. Currently, there is much debate about the possible arrival of early North Americans across the Atlantic Ocean, traveling by watercraft along the southern edge of the ice sheet that would have extended overtop of the northern Atlantic Ocean (for example Bradley and Stanford, 2004). In both the Pacific and Atlantic scenarios, climate greatly influenced the transport of humans (and other animals) across the continents.

Many researchers conclude that the first humans may have set foot in North America as early as 30,000 years ago as the first 'true' Americans. Many of these Pre-Clovis and Paleo-Indian people (Figure 65) developed unique cultures as they spread across North America and interacted with the landscape. There is evidence for human arrival in the mid-Atlantic region as far back as 17,000 years ago, at a site within the Coastal Plain Province (McAvoy and McAvoy, 1997; Nash, 2009). But when humans first arrived here, the climate was very different than it is today. Although other settlement sites have been discovered from the Pre-Clovis time period, they are small and none are within the boundary of Shenandoah National Park. To date they have yielded only a few quartzite tool artifacts (Nash, 2009). Later, Paleo-Indian foragers probably came and went through the mountains during the warmer seasons, hunting for large mammals, such as moose and elk, and looking for stone materials to help them hunt (Nash, 2009; Nash 2008; Nash 1998).

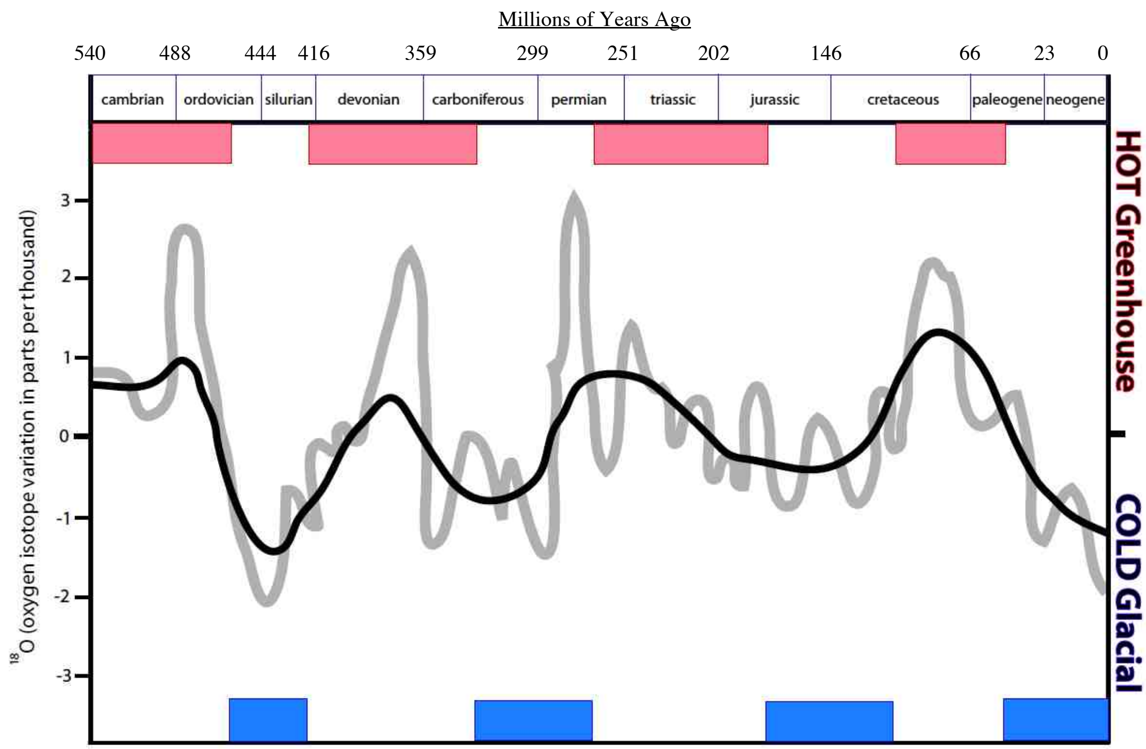


Figure 63: Earth's climate has changed throughout geological history. This graph illustrates how measurements of oxygen isotopes (left y-axis) from ice cores reveal shifts in Earth's climate from cold ice house conditions (blue blocks) to hot greenhouse conditions (red blocks) (right y-axis) throughout Earth's geologic history (top x-axis). Glacial periods have shifted into greenhouse conditions many times over the course of thousands of years, giving Earth a dynamic climate history. The most recent glacial period (during the Neogene Period) greatly modified the landscape of Shenandoah National Park. Visit the following National Park Service website for more information about climate change through geologic history: http://www.nature.nps.gov/geology/nationalfossilday/climate_change_past.cfm

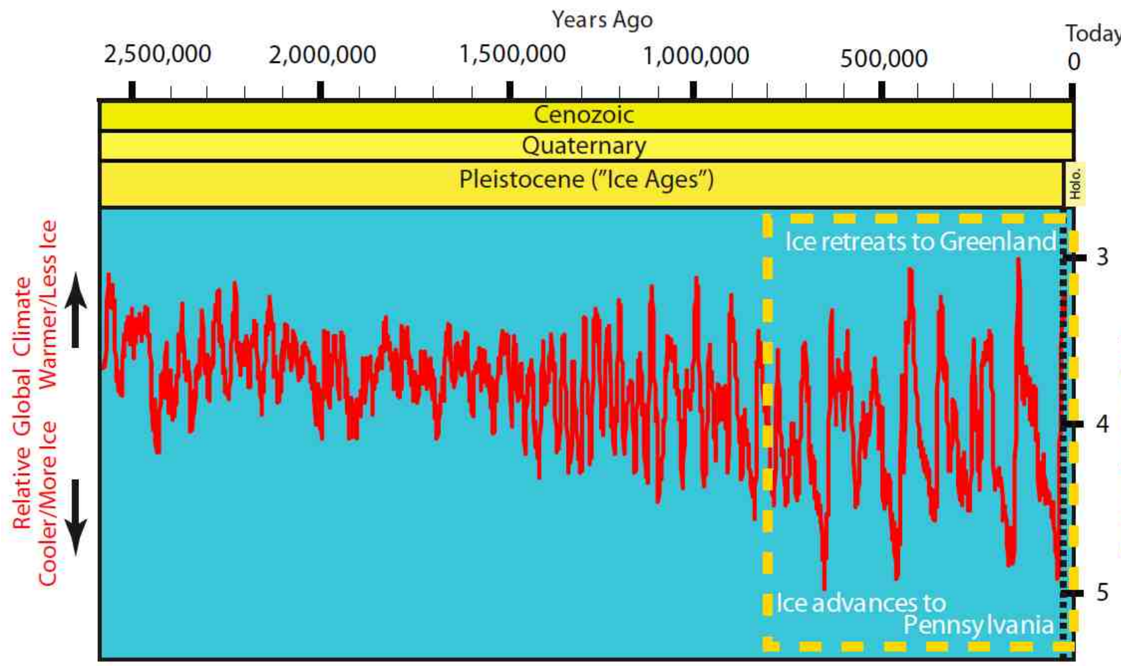


Figure 64: Over more recent geologic history, Earth's climate has gone in and out of ice ages. These cold periods have put the central Appalachians in a peri-glacial environment causing severe freeze thaw cycles that have greatly shaped the Blue Ridge Mountains. (Modified from Kentworthy, 2009)

PERIOD	AGE (years before present)	EVENTS
Pre-Clovis	18,000 - 13,500	Earliest inhabited site found in Virginia is in the coastal plain dating to 17,000 years b.p. - stone tools were found here!
PaleoIndian	13,500 - 11,000	Foraging people inhabited the Blue Ridge Mountains seasonally for hunting and left behind tools
Archaic	11,000 - 3,200	Antietam quartzite tools found in Shenandoah National Park at what were once large seasonal foraging camps.
Woodland	3,200 - 400	Quartzite projectile points and ceramics found at small, seasonal foraging campsand large hunting camps. The Blue Ridge considered a meeting place.
Historic Era	400 - Today	Many native tribes were forced to leave, although some stay within the foothills. Europeans exploit mountain resources (mining and logging).

Figure 65: Modern time has been divided into archaeological periods. Each historical period snapshots important archaeological events that help us understand how the Blue Ridge landscape influenced ancient cultures.

Glacial events are also an important part of the Appalachian story because they greatly contributed to shaping the landscape through the processes of weathering and erosion. Since the end of the Alleghanian Orogeny, about 300 million years ago, up to 4 miles (6.5 kilometers) of rock has slowly eroded off the tops of the Appalachian Mountains as erosion slightly outpaced isostatic uplift of the region. In the vicinity of Shenandoah, mountains were probably around 9,000 feet tall when they first formed (Southworth and others, 2009). While other locations within the Appalachian Mountains may have been as high as the modern Himalayas, the mountains within Shenandoah National Park area were, during their prime, closer in height to the Alps of Europe or the Rocky Mountains of Colorado. Much of the erosion that has brought the mountains to their current height is due to the incredible gnawing action of the last glacial event.

We can see evidence of the harsh ice age all along the Appalachian Mountain range. In the Northern Appalachians, Pleistocene glaciers scoured out U-shaped valleys, left behind enormous scratches called glacial striations, and dropped giant boulders called glacial erratics. In the south, these signs of glaciation do not exist, because the glaciers extended only so far south as central Pennsylvania (Figure 51, 57). The Blue Ridge Mountains of Virginia were thus 'on the edge' of the glacial advance, in what is known as a periglacial environment. Thus, even though the glaciers and ice sheets did not stretch their sandpaper-like arms as far south as Shenandoah National Park, their peripheral effects did leave their mark on the landscape.

Valleys within and around the mountains would have received fresh water loaded with rich sediment from the tips of the melting continental ice sheets just to the north. The close proximity of the ice sheets also resulted in a colder, more-harsh climate in the Blue Ridge Mountains than what we experience today. Severe freeze-thaw cycles, permafrost, and harsh winter months produced piles of boulders, called block fields, along the mountain slopes (Southworth and others, 2009; Thornberry-Ehrlich, 2005; Means, 1995). Liquid water would seep into the small cracks of exposed rock and freeze into ice when the temperature dropped. When water freezes it expands, popping open new cracks and expanding old ones. Over numerous freeze-thaw cycles, chunks of the mountain literally broke free, rolled downhill, and collected in piles. Great examples of such block fields are found in the southwestern portion of the park above Chilhowee Group rocks (Antietam, Harpers, and Weverton formations). They include **Blackrock** (mile post 85; Figure 66), **Turk Mountain** (mile post 94), and various locations observed from overlooks.

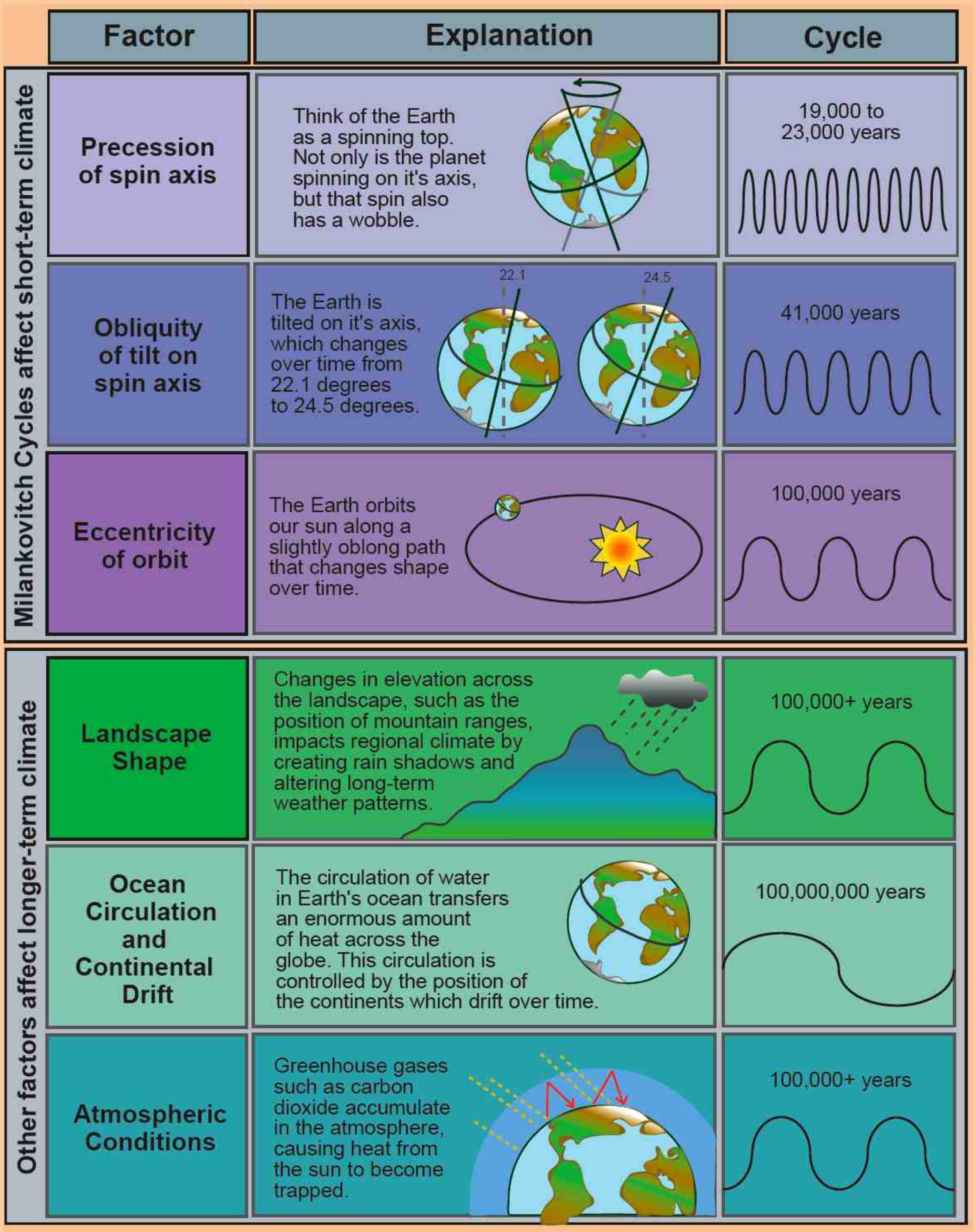
Figure 66: Block fields across the Appalachian Mountains are a product of the last glacial maximum. The harsh climate caused the mountains to break apart into large boulders. Black Rock, at Shenandoah National Park, is one of these locations. (Photograph by Wendy Kelly)

This severe weather lasted thousands of years throughout the ice age, allowing thousands of large (feet to meter sized) blocks of rock to accumulate on these rocky slopes. The majority of block fields within Shenandoah National Park are barren of plants because they still are actively moving, although quite a few have accumulated soil and been overcome by the forest (Southworth and others, 2009). The intensive erosion caused by the last ice age provided habitat for many species that today are important in the Shenandoah biome. The Shenandoah Salamander **(***Plethodon Shenandoah***)** is one of those creatures. Living only within the block fields and talus of **Hawksbill Mountain, Pinnacles**, and **Stony Man Mountain** of Shenandoah, this endangered amphibian needs the nooks and crannies within Pleistocene talus for its habitat (Carpenter and others, 2001; Jaeger, 1971). Other creatures, including the black bear, rattle snake, and bobcat, have also been known to make use of these block fields for their shelter.

The last ice age of the Pleistocene Epoch is one of the major geological events that has influenced local plant diversity (Figure 13). Imagine standing in the Rocky Mountains of Colorado today. As you look around, you see barren rocky peaks towering above the tree line - so harsh an environment that only sparse, very hearty tundra plants grow there. Now imagine standing in the Shenandoah Valley 15,000 years ago and peering up at Shenandoah National Park. Instead of the lush blue-green peaks of today, you would see a barren grey landscape like today's high Rocky Mountains. During the last ice age, lower elevations were spruce parkland and boreal forests, while higher elevations were completely above the tree line, in an alpine tundra (Nash, 2009; Thornberry-Ehrlich, 2005; Litwin, and others, 2003; Means, 1995). Today Shenandoah is dominated by oak forests (Litwin and others, 2003). It may be hard to imagine the Shenandoah landscape as anything other than what we see today. But when we cast our eyes through the mountaintop forests, many of the trees we see are remnants from this last shift in climate. Cool climate pine trees, such as the Eastern White Pine (*Pinus strobus)* and Red Pine (*Pinus resinosa*), were common in the East during the last ice age, perhaps even extending are far south as northern Florida, but today many of these species inhabit much more northerly locations (Jackson and others, 2000). Another species, the Balsam Fir (*Abies balsamea*), is found within the higher peaks of Shenandoah National Park today, but it became established during the glacial period. Most of these trees shifted northward as the glaciers receded, and now populate areas of eastern Canada and New England. However, isolated pockets of these cold-climate species have been left behind, especially within Shenandoah (Figure 67).

What is Climate Change?

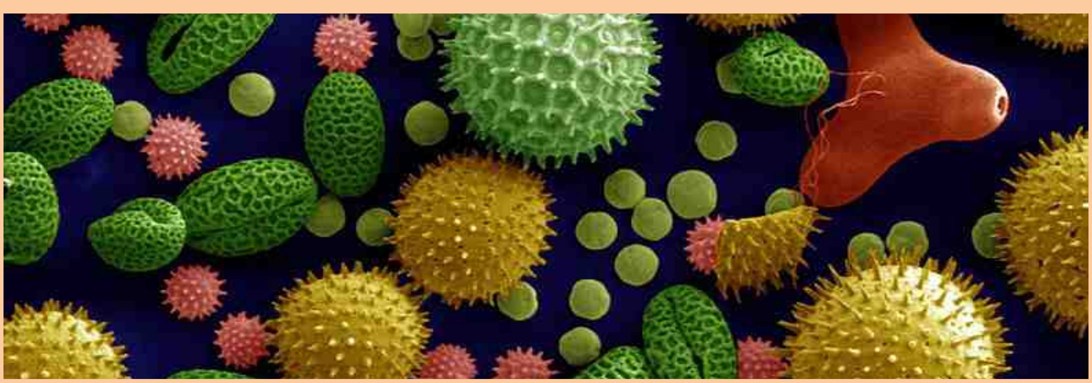
Earth's climate is determined by how much heat (or solar insolation) from our sun is received, distributed, and held in by the Earth. Many factors that operate over different timescales influence Earth's climate.



It is important to recognize that we live in a very dynamic environment. All of these climate change factors shift over time, influencing the amount of solar radiation that different parts of the Earth receive. Climate determines where and what sort of plants and animals live on Earth. Therefore, if there is a way for us to understand how climate was different in the past, we may have a better idea of living conditions thousands, hundreds of thousands, or even millions of years ago.

Over the past 150 years, scientists have collected a huge array of climate data from climate proxies such as glaciers and ice-sheet cores (right), sediment cores containing plant pollen (below), microfossils in ocean sediments (top), and tree rings, among other things. These data give us clues about Earth's paleoclimate.

Glacial cycles are common in Earth's history (Figure 63). They are important events that, like the seasons, greatly influence how humans and other organisms live out their lives. But recently our own human activities are modifying the typical, predictable climate cycles (See page 188 for a discussion about human-influenced climate change).



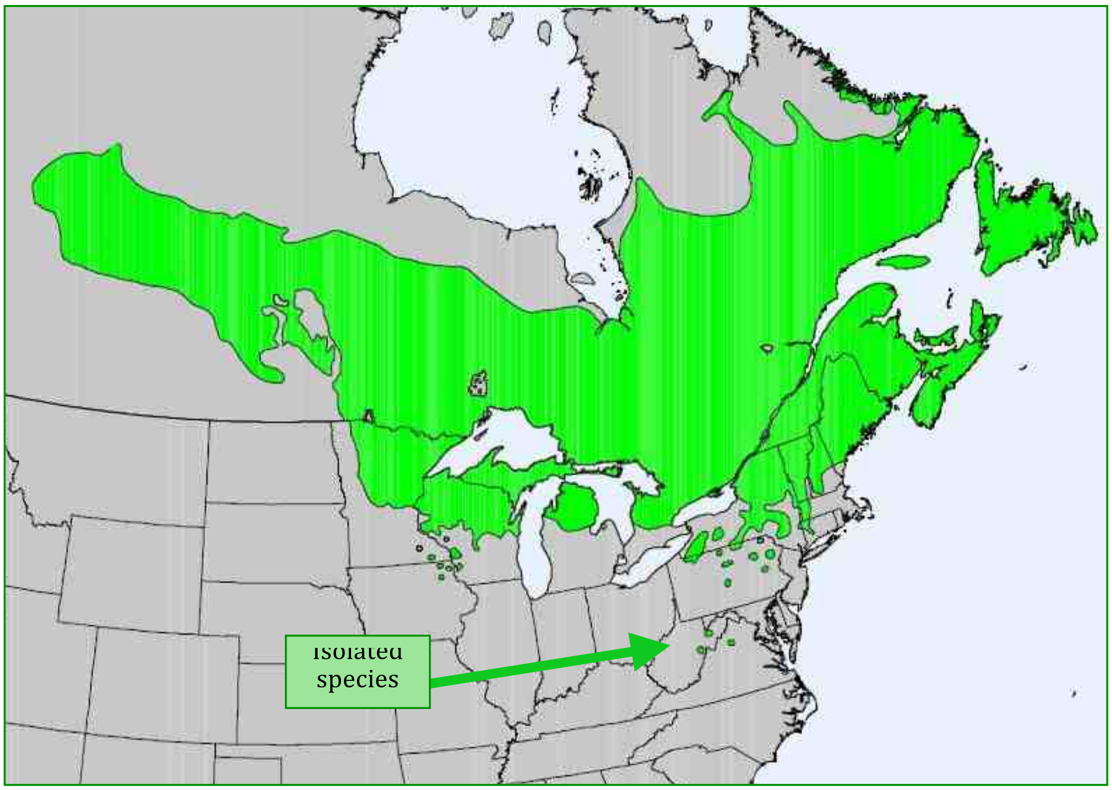


Figure 67: Many tree species have become isolated within the mountain peaks of Shenandoah. This map illustrates the distribution of *Abies balsamea*, or the Balsam Fir in green. Although it is common in New England and Canada, it is also found within Shenandoah National Park, but is becoming more and more isolated as climate change persists. The isolation results in a lack of genetic diversity, which leads to weakened species that are finding it more difficult to resist disease, infestation, and rapid modern climate changes. (Illustration courtesy of the U. S. Geological Survey)

How geology impacted prehistoric Indian life

This section focuses on the Archaic through Woodland archaeological Periods that spanned the time frame from 11,000 to 400 years ago (Figure 65). By the beginning of the Archaic period, the ice sheets of the last glacial period slowly receded, and familiar deciduous forests claimed the landscape. Humans also spread through the landscape, developing unique cultures that directly related to their ancestry and physical surroundings. These tribes eventually became the modern Native North American tribes that we are familiar with today. Many people traveled through the Appalachian Mountains and lived in seasonal camps leaving behind physical traces of their culture. By at least 10,500 years ago (8,500 B.C.), various bands of hunter-gatherer type people were exploring the Blue Ridge Mountains and traces of their lifestyle have been discovered within the park boundary (Nash, 2009; Crandall and Engle, 1997). Mountain locations near springs, streams, and sources for stone tools (such as **Big Meadows**) were used for food and celebratory gatherings during the warmer months of the year (Nash, pers. comm., 2011; Crandall and Engle, 1997). After 1200 years ago, many tribes settled into agricultural villages, traveling less, but still leading hunting parties from Big Meadows (Nash, 2009; Crandall and Engle, 1997).

Ancient Tools for Ancient People

Not only have geological processes influenced the lifestyle of early Americans by modifying climate, the physical landscape has also provided a variety of materials used for ancient tools. Many different rock types can be found within Shenandoah National Park, and each one tells part of the Story of the formation of the mountains (Figure 62). Because many rocks within the Blue Ridge Mountains are hard and can be worked into sharper objects, they make useful tools. For example, the Catoctin Formation and the Chilhowee Group Quartzites have been found in the shape of axe heads, projectile points, and grinding stones (Nash, 2009; Inashima, 1986). Other materials, such as granite and quartz from veins in the rock, were not as popular because they did not make very strong tools (Nash, pers. comm., 2010) (Figure 68a). Stone objects were essential for paleo Americans, for hunting, cooking, and everyday use. Artifacts made from quartzite of the Antietam Formation have been recovered through archaeological survey at many locations in the Park, indicating the movement of Native Americans from the Piedmont into higher elevations. The Antietam quartzite is a great material to work into tools because it has been slightly metamorphosed, causing the original grains of sand to recrystallize and interlock, meaning that this rock is hard, strong, and breaks in flakes with sharp edges. The Catoctin Greenstone was also used to make stone tools for similar reasons, especially heavy tools such as axes and grinding stones and have been found within the park (Nash, pers. comm., 2011; Crandall and Engle, 1997). There are also inclusions of jasper, which makes excellent flake tools, within volcanic breccia of the Catoctin formation and hydrothermally altered limestones of the Shenandoah Valley (Nash, pers. comm., 2011; Southworth and others, 2009).

The availability of stone resources may have been a deciding factor in locating longer-term settlement sites, which have been found in lower elevations within and around Shenandoah National Park. For instance, alluvial plains along the eastern side of Shenandoah were a popular settlement location during the Archaic (Nash, 2009). Ancient rivers that once flowed down the mountains deposited these large collections of loose material. The alluvial plains provided cobbles of useful tool-making material, such as of the Catoctin formation that had been eroded off the mountains (Southworth and others, 2009).

Archaeological materials found at dig sites in Shenandoah National Park do not always originate from the park itself, indicating that travel by early Americans was a common practice for various reasons. Tools from Maryland, Pennsylvania, the Piedmont, and especially the Shenandoah Valley have been found, supporting the idea that the area that is now Shenandoah National Park was an important crossroads for early peoples and cultures (Nash, 2009; Nash, 1999). Cherts and metarhyolites (metamorphosed volcanic ash) formed to the west and north (especially the northern Shenandoah Valley) have been found within the park (Nash, 2009). It seems that a common path of travel for these early migrating foragers was from the west and north to the east. The artifacts themselves tell this story, as they are made from rock material that originated from outside the park. For example, artifacts discovered within the park were made from quartzites of the Antietam Formation, but also from other rock materials like chert, chalcedony, and jasper that came from the Shenandoah Valley (Nash, 2009) (Figure 68b). Jasper, a popular working material, formed due to alteration of limestones beneath the Blue Ridge fault (includes the Front Royal Fault) (Nash, 2009; Southworth, 2009). Artifacts made from chert have been recovered at many locations in the Park, indicating the movement of Native Americans from the Shenandoah Valley into higher elevations. During the later Woodland Period (by 1,000 years ago), valley floodplains were locations of large, permanent agricultural camps, but the Blue Ridge Mountain resources were still exploited by traveling groups establishing large hunting camps (Nash, 2009).

Figure 68: Stone tools from the Archaic period. Early inhabitants of the Blue Ridge Mountains took advantage of the local supply of workable stone. A. Side-notched point made from vein-quartz. B. Triangular jasper projectile point made from metamorphosed valley limestone underneath portions of the Blue Ridge thrust fault. Both artifacts measure approximately 5 cm (2 inches) in length. (Photographs courtesy of Dr. Carole Nash, James Madison University)

The form of the landscape sets the scene

The landscape is the stage upon which we play out our lives (Lillie and others, 2011). This statement couldn't be more true. If you have ever been into the theatre, you know that the shape of the stage, the back-drop, and the array of props on the stage are all extremely important in determining what and how the actors will play out the scene. Literally, the stage of the landscape includes all of these factors, and the factors impact how humans have played out their lives.

The exposed rocks in Shenandoah National Park – the foundations of our stage- are products of processes that occurred deep inside the Earth hundreds of millions of years ago. The resistant mountains present a rare opportunity for visitors to peer into the depths of the Earth, seeing the landscape not only as simple surface topography, but also as a window downward and into the past, into a world not directly observable by human eyes. We can thus imagine the exposed roots of the Appalachian Mountains as the guts of a continental collision zone.

Visitors hiking Shenandoah National Park's mountain trails may not quite realize how important the shape, or topography, of the landscape was to earlier humans who traveled along similar trails. (But as you are puffing your way up the steep slopes of Hawksbill, you probably do get the point!). For example, many locations along the **Appalachian Trail** were used thousands of years ago during the archaeological Archaic and Woodland time periods (Figure 65) (Nash, 2009). We have the opportunity to greatly enrich park visitor experience by informing them that their own soul-searching journey along the Appalachian Trail was also a journey for many people of the past.

Two kinds of ancient settlement sites have been uncovered within Shenandoah National Park: ephemeral sites used for brief occupations and base camps, which were larger locations used for a variety of purposes during longer-term occupation. It is interesting, but also logical, that many locations we choose today to have a picnic, site a ranger station, place a campsite, or build a house may also have been the same locations early people chose for their own purposes. For this reason, archaeological dig sites have targeted popular locations within the park, such as campsites along the Appalachian Trail.

Realtors will tell us that there are three factors that determine the value of a property; location, location, and location! It cannot be denied that the setting is very important for situating any kind of settlement, past or present. Think of building your dream house, or deciding where to have your wedding – the place you choose holds a certain significance. Perhaps you just like the look of the trees in that area, or the waterfalls, or maybe that particular location holds emotional significance to you because it was where your grandparents were married, or it may even be as simple as the fact that you know there is good soil for gardening there. Previous studies of archaeological site locations within Shenandoah have focused on variables like these that would have determined where to place a settlement (Hoffman and Foss, 1980). Environmental variables that seem important in pinpointing old settlement locations include: proximity to a spring (water); level ground (such as a saddle in the mountains); relatively sheltered locations; access to suitable rock (such as the Hampton or Antietam Formations) for the production of tools; and accessibility to the lowlands (along a perennial stream or in a hollow that follows a path to the valley below).

Many locations along the Appalachian Trail have been considered high probability prehistoric settlement sites because they fit many of the environmental criteria. Recent archaeological excavations have confirmed this by turning up artifacts around the Appalachian Trail area. Locations near Hawksbill Mountain (Figure 69) may have housed large base camps during the Archaic Period used for longer-duration settlement due to their size (hundreds of square feet) (Nash, 2009). Other locations near the Appalachian Trail were also used as settlement sites within the mountains during the Archaic to early Woodland Periods (Nash, 2009). These spots along the Appalachian Trail provided a platform of relatively flat, protected land with access to fresh water, such as springs or streams. Mountain hollows or saddles form because of the shape of the underlying rock, rock type, position of faults, or pathway of surface water. For example, hard rocks, like the Basement Complex and the Catoctin Formation, tend to resist weathering, forming hard mountain peaks such as **Old Rag Mountain**, **Hawksbill**, and **Stony Man** (Figure 70). Softer rocks, like the Shenandoah Valley limestones tend to be in lower topographic areas because they weather and erode away more easily. Folds and faults also influence the shape of the terrain. **Pass Mountain shelter** (just north of Thornton Gap) sits on top of the crest of a fold, called a fold axis, in the Catoctin Formation, providing a small area that is almost horizontal. This site, as well as many of the other Appalachian Trail shelter locations, is very close to a spring. At the Pass Mountain hut, spring water flows down the mountainside and has eroded a hollow, providing a protective nook for shelter.

The environmental factors mentioned above were very important in locating a useful and comfortable site for past inhabitants, but at times may be overshadowed by other factors. For example, even though numerous sites within the park have been targeted by archaeological computer models designed specifically for predicting high probability settlement locations, some of those sites have not turned up any evidence of human occupation (for example, the University of Virginia Department of Anthropology conducted a model-based study in the 1970s). There could be many reasons for this, however one may be that it is not always environmental aspects that determine where people may want to settle. Other cultural aspects, such as ritual and religious practices, or hunter-gatherer travel patterns in and out of the mountains possibly due to animal migration, could also have been important (Nash 2000; Nash, 1997). Just like other animals and their survivability, humans need routes appropriate for travel. Even if one location was perfect for a settlement site, it may not have been used if it was too far off the highway. It is important for park rangers to understand that these early cultures were complex, having many aspects that determined daily life and lifestyle practices. There remains much work to be done in order for us to truly understand the cultures of the many different people who traveled and lived within the Blue Ridge Mountains.

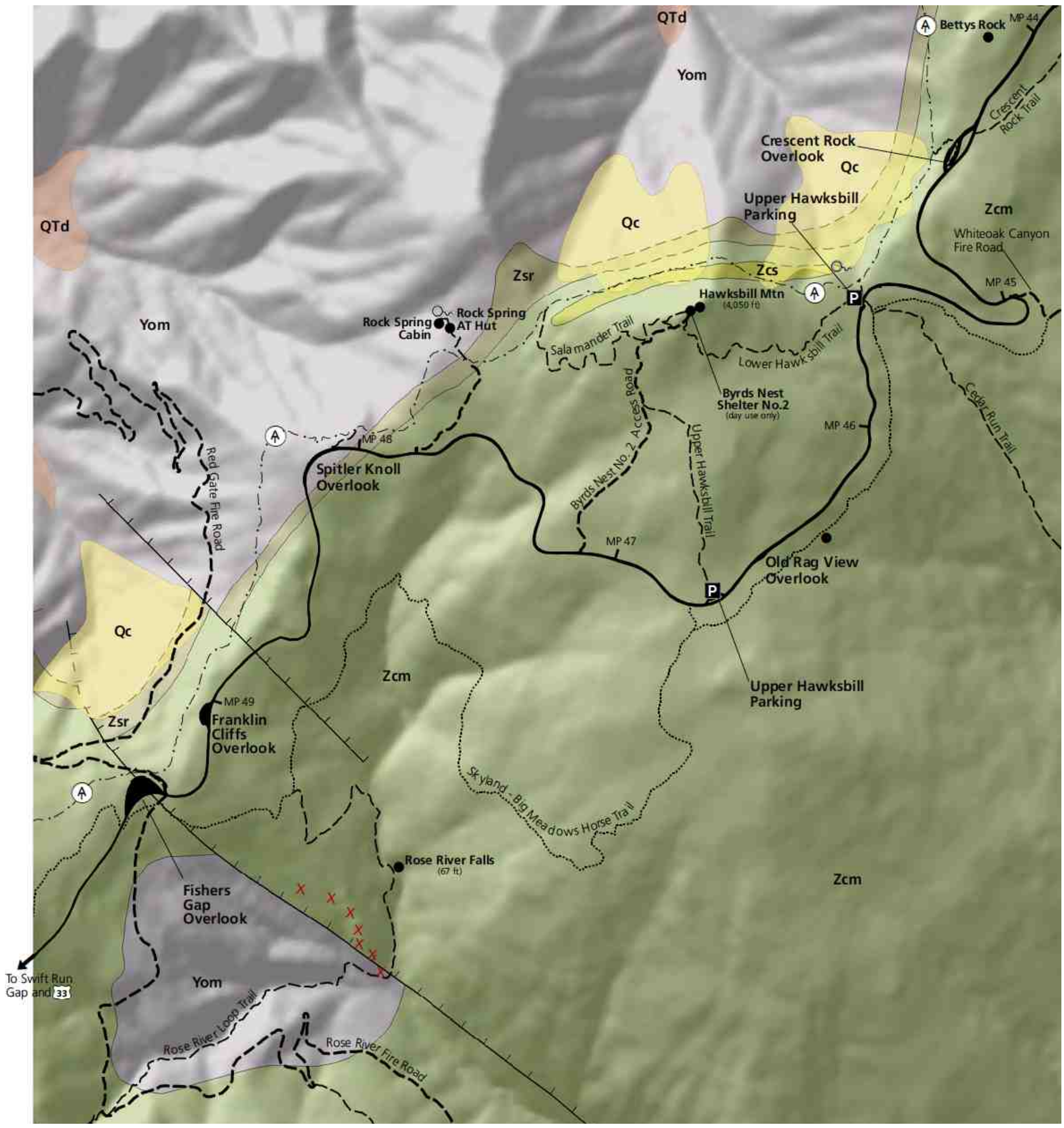


Figure 69: A geological map of the Hawksbill Mountain area. Many locations that today are around the Appalachian Trail we once used as settlement cites by Archaic people of the past. Archaeological digs have revealed stone artifacts in these areas. (Courtesy of the National Park Service)

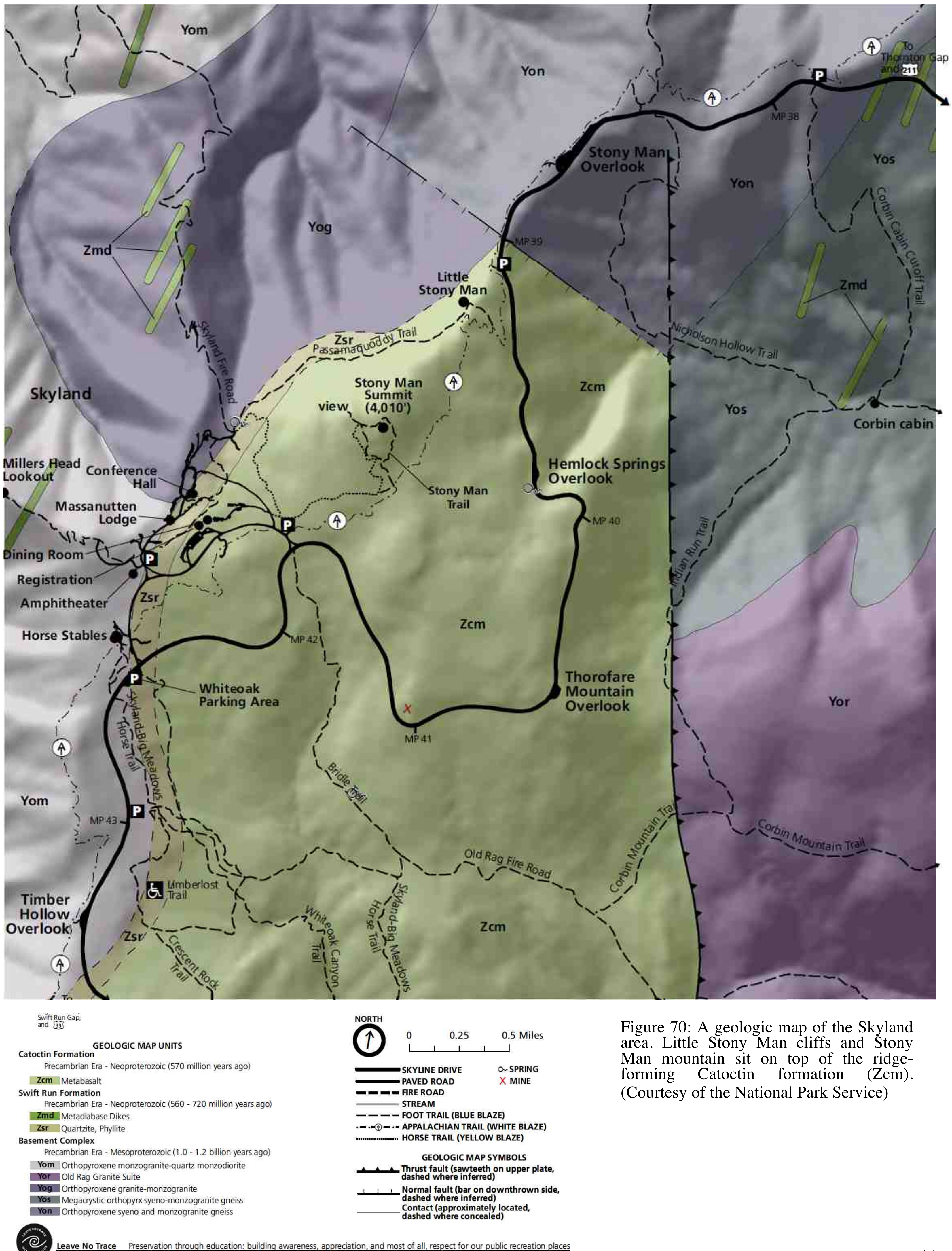


Figure 70: A geologic map of the Skyland area. Little Stony Man cliffs and Stony Man mountain sit on top of the ridge-forming Catoctin formation (Zcm). (Courtesy of the National Park Service)

C. Recent Life: how local geology shapes the landscape, plants, and people of the recent past

Dynamic geological events of the past, present, and future have shaped -and will continue to shape- the lifestyle of millions of Americans.

The European North Americans

Many tribal groups settled and traveled throughout Virginia before Europeans arrived, including the Monacan, Manahoac, and Monetan (Crandall and Engle, 1997). Although these groups tended to settle in the lowlands, the Manahoacs are believed to have crossed the Blue Ridge Mountains (Nash, pers. comm.; Crandall and Engle, 1997). Europeans began exploring the sinuous mountains of inland Virginia as early as the 1500's. By the early 1700s, the encroaching Europeans had forced most Indian tribes out of the interior of Virginia (Nash, 2009; Crandall and Engle, 1997). Just as the mountains had shaped earlier human lifestyle, the mountains also shaped the homes, battles, and livelihood of European Americans during the Historic Era (Figure 65).

The Mountain Barrier

Hunters and trappers were among the first Europeans to explore the Appalachian Mountain tops (Crandall and Engle, 1997). But the Blue Ridge Mountains were considered a great barrier that had to be overcome. During the late 1600's, Virginian explorers searching for a route to the Pacific avoided crossing the central Appalachians altogether by shifting their routes southward (Yarnell, 1998). It was not until 1716 that Alexander Spotswood (the governor of Virginia) decided to cross the barrier in order to stake his claim on the fertile Shenandoah Valley (Crandall and Engle, 1997). But the long, tall mountain ridges encountered by these European explorers were even higher and more continuous in the deep geological past. Erosion by rivers and other processes have formed low passes through which humans and other animals could travel. For example, the Potomac River used to flow along the mountain range until the Miocene Epoch (about 24 million years ago), when it cut across the mountains to form its current path to the Chesapeake Bay (Southworth and others, 2009; Zen and Prestegaard, 1994). Throughout the 1700s, Europeans crossed these mountain passes and settled in the Shenandoah Valley to make use of the local resources (Crandall and Engle, 1997).

Eventually, homes popped up farther and farther up the mountainsides, as roadways were cut across the lower gaps in the Blue Ridge Mountains (Crandall and Engle, 1997). With the increase in accessibility, the mountains slowly became clear cut – giant hemlocks, Oaks, and Chestnuts replaced by orchard trees (Crandall and Engle, 1997). This continued throughout the 1800's as railroads crisscrossed the land, including through Rockfish Gap (Crandall and Engle, 1997). Furnaces burnt millions of mountain trees into charcoal for fuel (Crandall and Engle, 1997). Throughout this time, over 400 families chose to settle within the high mountains. Referred to as Mountain People, these individuals lived out their peaceful mountain lives. They relied on selling their collected nuts, berries, and leather tanning products that were taken directly from the mountain forests (Crandall and Engle, 1997).

The shape of the Appalachians also contributed significantly to battles of the Civil War. Mountain passes were used for the quick and easy transport of troops, influencing the location or outcome of battles (Davis, 1975). General Thomas J. Jackson (popularly known as "Stonewall Jackson") utilized the shape and location of the Blue Ridge Mountains, especially Massanutten, to his advantage. Union troops were led astray, divided, and overrun by Jackson, who was more familiar with the mountain's intricate shape (Davis, 1975). New Market Gap, being the only passage through Massanutten large enough for hundreds of marching troops, was the only way through the high mountains (Figure 71). Troops would otherwise have to travel far distances to the north or south to get around the mountain. Jackson used the topographic variability of Virginia to help him during his Civil War battles, which may have turned out significantly differently in different topography.

Following the Civil War, new attention came to the Blue Ridge Mountains. **Skyland Resort** was established for the city people who wished to escape the heat of summer and explore the beauty of the mountain forests and wildlife. Even President Herbert Hoover established **Rapidan Camp** for fishing and leisure. Congress agreed to approve the beautiful site for the location of Shenandoah National Park in 1924 (Crandall and Engle, 1997) and by the very end of 1935, Shenandoah was an official National Park. As many of the mountain families were relocated to nearby valleys outside of the new park boundaries, Skyline Drive was built, carving a snaking line along the mountain tops. Meanwhile the Civilian Conservation Corps built hiking trails, walls, and planted trees after Franklin D. Roosevelt took office during the Great Depression.

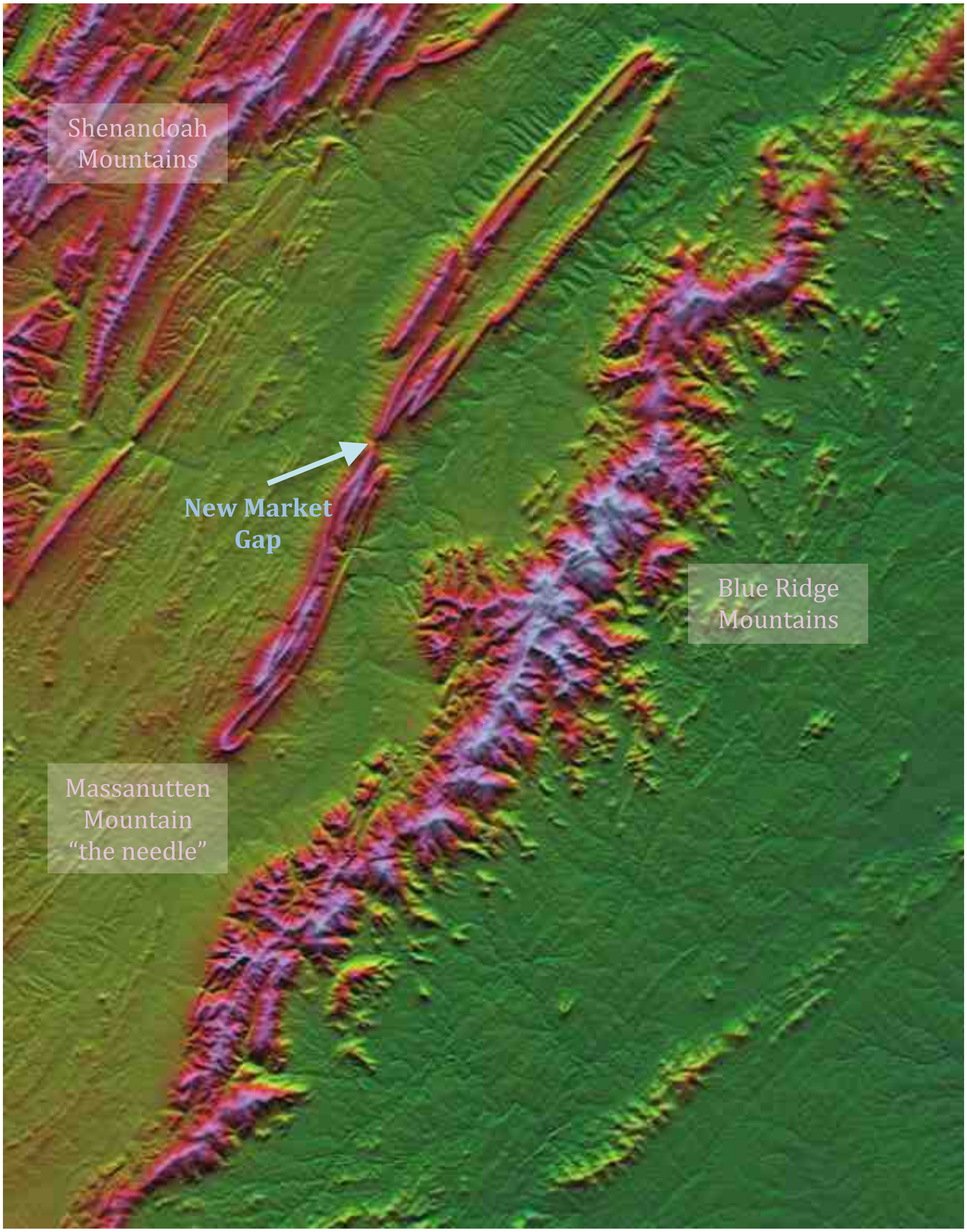


Figure 71: A color-enhanced aerial photo of the mountains surrounding Shenandoah National Park. Stonewall Jackson utilized the shape of the land to help win Civil War battles. Taking troops through New Market Gap helped to save time and energy, rather than having to travel around the mountain barrier. (Modified from Bentley, 2008)

Materials for the development of the park were typically local rock and wood, meaning that many of the retaining walls along trails, overlooks, and historic buildings are made from blocks of quartzite and greenstone, or basement complex granites and gneisses.

Stone for building and industry

Just as stone was an important resource for people of the distant past, it has been valuable for more recent humans. In fact, the first evidence of mining in this area goes back to the Woodland Period (Yarnell, 1998, Figure 65). By the 1800's, mining had become a common practice. Metals such as copper, manganese, and iron were especially sought after within the vicinity of what would become Shenandoah National Park (Southworth and others, 2009). As mines peppered the mountains, companies and prospectors pushed to develop mountain infrastructure such as railroads in order to better transport these valuable local resources through the difficult terrain (Yarnell, 1998; Crandall and Engle, 1997).

All along the western slopes of the mountains within Shenandoah you can find abandoned manganese and iron mines near the contact of Antietam Formation and the underlying Shenandoah Valley limestones (Figure 53). Observed from the **Crimora Lake Overlook** along Skyline Drive, the largest manganese mine was the Crimora Mine. The mine supplied manganese, which was used for the production of steel. Alluvial fan deposits form where rivers and streams drop sediment that they have carried from steep mountain slopes. These loose accumulations of sediment cover the western areas of Shenandoah and contain much iron and manganese ore (Southworth and others, 2009). Manganese forms when groundwater interacts with dolostone (a rock similar to limestone) or where the groundwater precipitates a cement-like matrix that holds chunks, or clasts, of metasandstone together into **breccia** (Southworth and others, 2009).

The most popular and frequent mines you will encounter within Shenandoah National Park are those extracting copper. Copper mines are peppered within the Catoctin Formation of Shenandoah National Park, including areas such as **Dickey Ridge**, **Hightop**, and **Stony Man Mountain** (Southworth and others, 2009) (Figure 53, 70). Copper is a metal element that forms when fluids interact with rock during metamorphism. Copper is common in the lower portions of the Catoctin formation, where this metal concentrated as it mineralized within joints and cleavage

Figure 72: Copper was commonly mined from the Blue Ridge Mountains. This piece of Catoctin Formation greenstone is flecked with turquoise-colored copper. Located near the summit of Stony Man, a handful of minimally-successful mines removed tons of ore for industrial purposes during the 1800's. Photograph by Wendy Kelly.

(Southworth and others, 2009). Miners found copper in veins through the greenstones and eventually abandoned many of the mines because the deposits were discontinuous and not very robust.

In addition to mining, local rock was used for construction during the Great Depression. At this time, president Roosevelt initiated a call to stimulate the economy. Thousands of young men across the country were employed to perform manual labor in exchange for a small pay. The establishment was called The Civilian Conservation Corps (CCC) and is an important part of the history of Shenandoah National Park (Yarnell, 1998). These young men greatly shaped how the trails and landscape of the park looks today by building retaining walls, establishing trail pathways, and planting thousands of trees. Many of the materials they used for retaining walls and trails were local rocks, including Antietam Formation quartzites with Skolithos trace fossils that can be seen along several overlooks (Figure 73, 74, 75). It is interesting because it is in large part due to the work of the CCC crews that we can more easily view the geology of Shenandoah National Park.

The Mountain People

By the 1800s, the European population in North America had significantly increased. Demand for resources pushed people to look to the mountains for exploration and exploitation. Families slowly settled in the Appalachian Mountains, including areas that are today Great Smoky Mountains National Park and Shenandoah National Park (Williams, 2001; Horning, 1999). Within Shenandoah (**Weakley Hollow**, **Nicholson Hollow**, and **Corbin Hollow**) were popular settlement sites (Figure 76). Just like the prehistoric inhabitants of this region, the Mountain People sought resources to make a living. Chestnuts, bark for tanning, farming for produce or livestock, blacksmithing, and milling were common among the mountain residents (Horning, 1999). Weakley Hollow was probably popular because it was a level location between the mountain ridges with a water source. Although Nicholson Hollow was comparatively steep and rocky, the inhabitants removed rocks and employed a terracing system to improve farming (Horning, 1999). Removed rocks (which were likely Catoctin greenstones and Old Rag granite) were used for building (Horning, 1999). Mountain farmers used the terrain to their advantage, placing farms where rocky cliffs or steep valleys provided natural fencing to control the movement of herds (Yarnell, 1998). In the summer, mountain peaks were cleared and used for

Figure 73: The Civilian Conservation Corps used local rocks to build retaining walls. Many locations, including the Passamaquoddy Trail up to the Little Stony Man cliffs, have been modified by the construction of greenstone walls to reduce erosion and increase stability of park trails. (Photograph courtesy of the National Park Service)

Figure 74: The Civilian Conservation Corps used local rock. They constructed many retaining walls along trails and established trail pathways. (Photo courtesy of the National Park Service)

Figure 75: The local geology shapes the hiking trails within Shenandoah National Park. Rock outcrops shape ‘corridors of passage’ and local rocks form retaining walls that add to the aesthetic natural beauty of Shenandoah. (Photograph by Wendy Kelly)

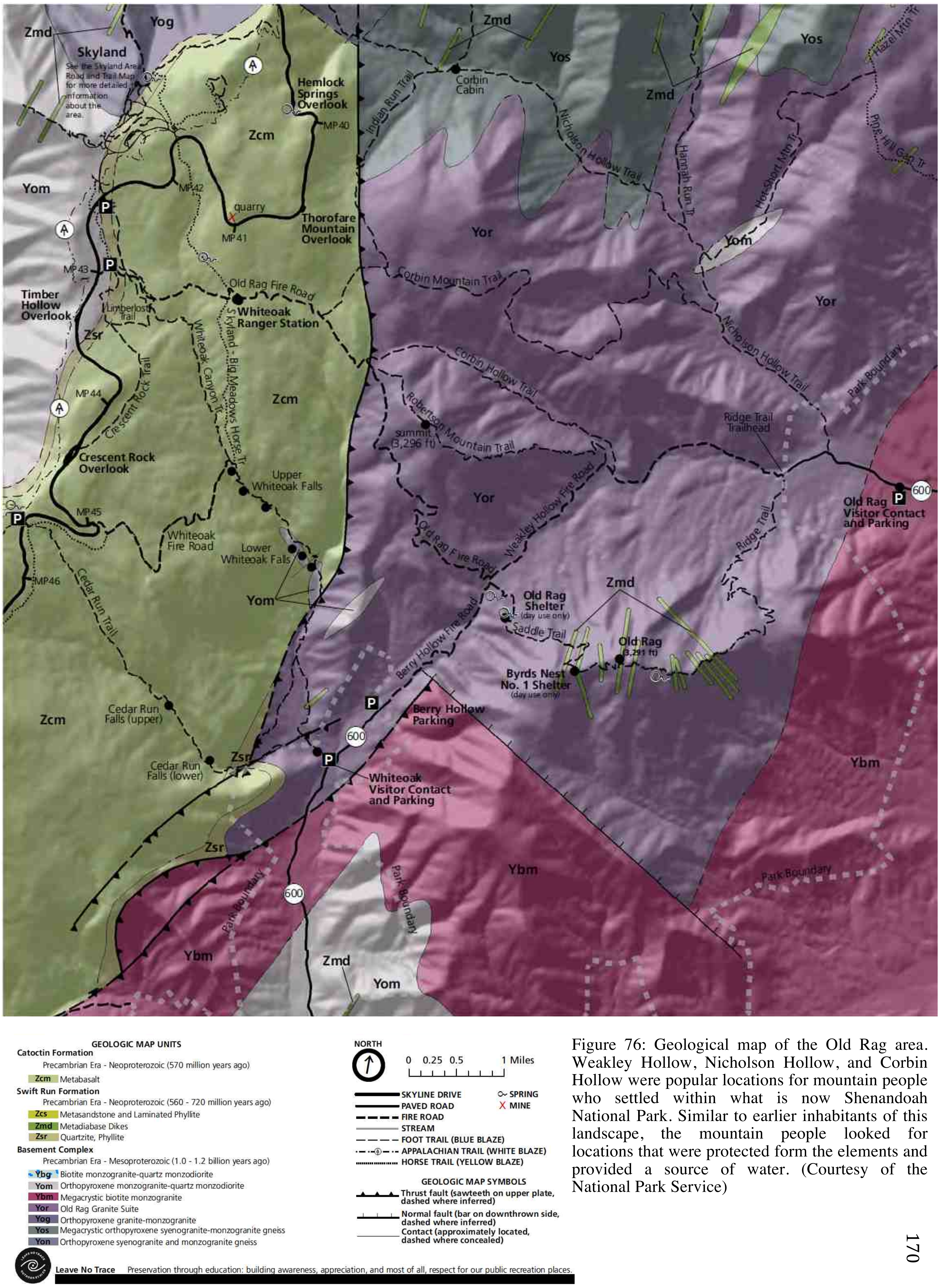


Figure 76: Geological map of the Old Rag area. Weakley Hollow, Nicholson Hollow, and Corbin Hollow were popular locations for mountain people who settled within what is now Shenandoah National Park. Similar to earlier inhabitants of this landscape, the mountain people looked for locations that were protected form the elements and provided a source of water. (Courtesy of the National Park Service)

grazing (Yarnell, 1998). Contrary to earlier interpretations of the Mountain People as leading an isolated lifestyle, they were quite integrated with the local community, had established infrastructure such as churches and schools, and some even worked at Skyland Resort (Horning, 1999). In the 1930's approximately 500 families were living within the mountains that now are Shenandoah National Park.

Soils and Plants

Many of the trees we see within Shenandoah have grown since the heavy logging of the 1800's ceased. There is an intricate connection between the plants that grow in a location, the soil, and the underlying bedrock. This is because soil develops over time by a complex process that involves the mixing of organic materials, the breakdown of the underlying bedrock, and the presence and movement of fungi, bacteria, and small creatures such as beetles and earthworms. But many other factors impact how, when, and what type of soil results. If you have ever tried to grow a vegetable or flower garden, this is something you may be familiar with. Soil type determines what type of plants can grow in it. This is because plants are kind of like humans – some of us prefer cold climates, some of us prefer warm climates, lots or little rain, tons of sun or little sun. A variety of soils can develop based on environmental factors such as climate, topography, time, bedrock type, and the presence of organisms (Sherwood and others, 2010). The soils that blanket Shenandoah are the main reason we see certain plants as we hike through the mountains. The underlying rock adds to the acidity and nutrient value of the soil, which in turn greatly determines what plants can grow. Soils form as the hard rock slowly breaks down into its component minerals and is mixed with other materials, contributing raw elements (nutrients) to form the soil. Like a recipe for cake, when you add different amounts of ingredients, it can completely change what the cake looks and tastes like.

The National Park Service and U.S. Geological Survey conducted a major vegetation mapping project from the year 2000 through 2006, in which the distribution of plants was correlated with soil and underlying bedrock type (Young and others, 2009). Data from this study also contributes to the Rock Outcrop Management Project (ROMP), a project geared towards identifying the rare and endangered plant species within Shenandoah National Park and recognizing the threats to such plant communities. The vegetation-mapping project used a variety of factors that impact vegetation type in order to do their assessment. Topography, or the shape of the landscape is very important. This includes slope (how steep a hillside may be), elevation (height above sea level), and aspect (the direction a hillslope faces). Recent reports indicate that steep slopes are the most dominant topography within the Shenandoah (Young and others, 2006). These steep angles develop soils differently than the flat valleys surrounding the park. Another important factor that determines soil type is soil moisture (including drainage and inundation frequency). Both landscape shape and drainage are influenced by the type of underlying rock, structural geology, and erosional processes that have occurred throughout geologic history of that area. Therefore, Shenandoah presents a diverse environment in which a wide variety of soils can develop.

Focusing on rock type, the south-western portions of Shenandoah National Park are generally underlain by the meta-sedimentary Chilhowee Group (540 million years old), including the Antietam, Harpers, and Weverton formations (Southworth and others, 2009) (Figure 53). The Chilhowee Group rocks tend to be silica-rich sediments (called felsic) (silt, sand, and pebbles) that collected in shallow ocean or beach environments as they weathered off an ancient mountainous landscape. Over time, the sediments cemented together and were lightly metamorphosed into rocks such as conglomerate and quartzite. The silica that dominates the chemistry of these rocks is the same material used to make glass – does glass seem like a nutritious substance to you? The silica-rich rocks are to the soils as iceberg lettuce is to our human stomachs – basically a filler with little nutritional value, compared to a darker, mixed greens salad. Because of this, Chilhowee rocks break down to produce relatively infertile (containing only high amounts of iron and aluminum) and very acidic soils (Young and others, 2009; Rock Outcrop Management Plan Environmental Assessment/Assessment of Effect, 2008; Sullivan and others, 2003).

Various types of granitoids (1.2 to 1.0 billion years old) underlie the northeastern sections of Shenandoah National Park (Figure 53). These rock types are also felsic. The granitoids of the basement complex are intrusive plutons of magma that were contaminated by continental crust. Basement complex rocks weather and break down to form soils that also tend to be poor and moderately acidic (Sullivan and others, 2003). Similar to the Chilhowee-based soils, basement complex soils usually cannot support a high diversity of plant types (Young and others, 2009). These soils, high in iron and aluminum and poor in calcium, are also not suitable for agricultural farming (Sherwood and others, 2010; Rock Outcrop Management Plan Environmental

Assessment/Assessment of Effect, 2008; Morgan and others, 2004). Certain plants prefer poor and acidic soils, such as Pine and Oak forests, and the common but beautiful Mountain Laurel (Young and others, 2009; Morgan and others, 2004) (Figure 77, 78). Other plants such as Maples, Chestnut Oaks, and Blueberries can tolerate Chilhowee and Basement Complex soils, but would prefer to be growing elsewhere (Sherwood and others, 2010) (Figure 77).

Along the southeastern portion of Shenandoah running up a narrow strip through the North district are the meta-volcanic Catoctin formation greenstones (568-555 million years old) (Southworth and others, 2009) (Figure 53). The Catoctin Formation is predominantly slightly metamorphosed lava flows from the rifting of supercontinent Rodinia hundreds of millions of years ago. These rocks contain less silica than the granitoids and meta-sedimentary rocks. They contain larger amounts of elements such as calcium, magnesium, manganese, and calcium, and thus break down to form soils with a higher nutrient value and low acidity (Young and others, 2009; Rock Outcrop Management Plan Environmental Assessment/Assessment of Effect, 2008; Sullivan and others, 2003). In areas underlain by the more mafic Catoctin formation, soils are occasionally considered well developed. In general, Hickory, White Oak, Red Oak, Witch Hazel, and Hay-scented Fern prefer these soils (Young and others, 2009) (Figure 77). In areas within the Piedmont province to the east of Shenandoah, large tracts of land have been cleared for farmland. These tracts match surprisingly well with the richer soils that overlie rock types such as the Catoctin greenstones (Sherwood and others, 2010). Areas above nutrient poor rocks tend to be left alone because they cannot support agriculture, and thus grow thin forests (Sherwood and others, 2010).

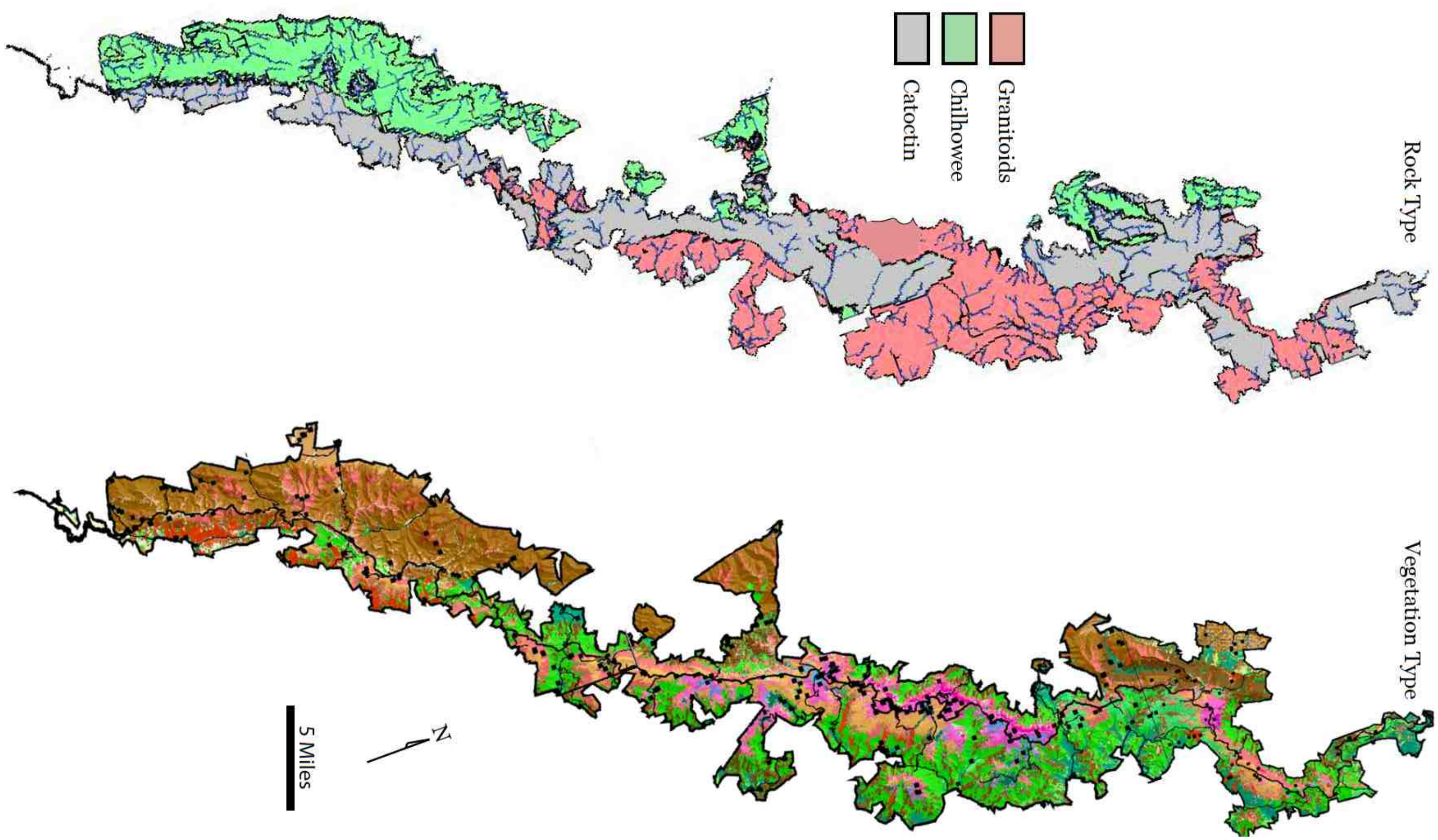
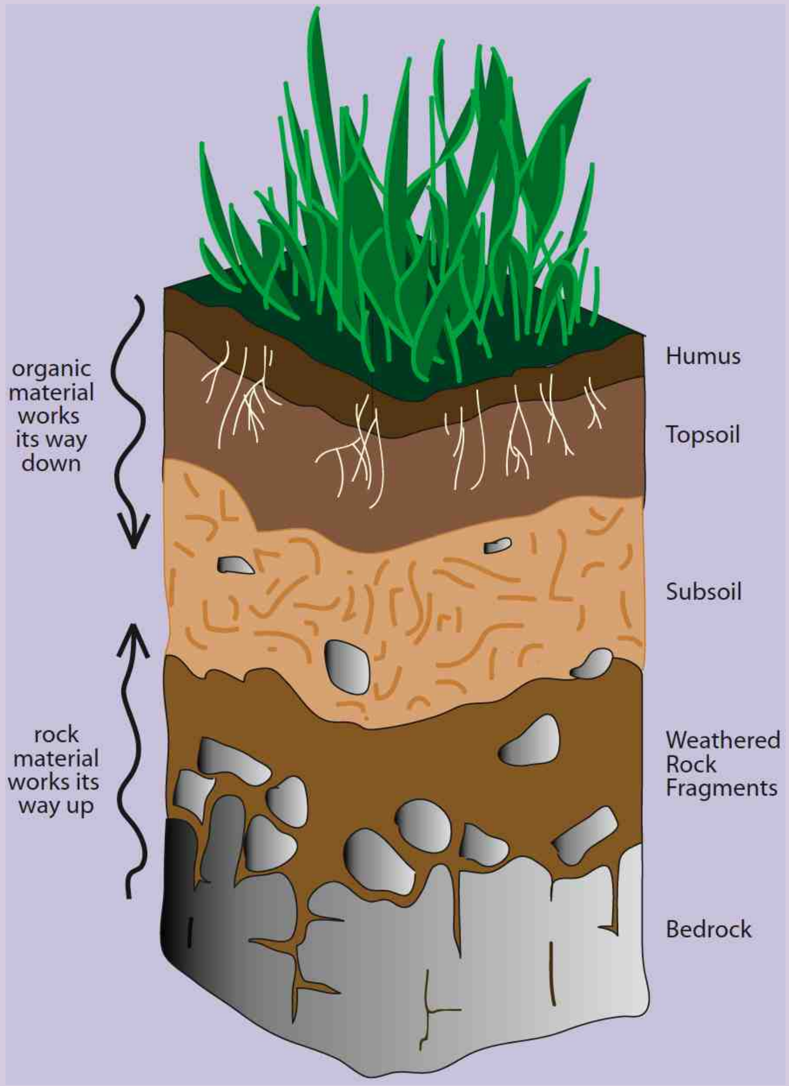


Figure 77: Plant species correlate to the underlying rock type. The map on the left illustrates the three dominant rock types within Shenandoah National Park. Compared to the second map, which identifies different assemblages of plant species, there is a clear correlation. This is strikingly so with the Chilhowee Group rocks, which are overlain by brown colors representing Chestnut-Oak and Mixed Oak Forests (including blueberry and Mountain Laurel). Mainly Oak-Hickory Forest (tan, green, and pink) grow overtop of the Catoctin metabasalts, and vibrant greens (Acidic Cove Forests including Eastern Hemlocks) grow over the basement complex granitoids. (Map modified from Young and others, 2006 and Snyder and others, 2006)

Figure 78: The Mountain Laurel is a common scrub in Shenandoah National Park. This plant, along with a handful of others, can tolerate the acidic soils that develop overtop of the siliciclastic Antietam, Harpers, and Weverton formations of the Chilhowee Group.

What is soil and how does it form?

Soil develops slowly over time, incorporating many components from the surrounding materials. Different types of soils exist across the globe and their type is dependent on many factors, including:



- regional climate (temperature and moisture)
- interaction with organisms (fungi, bacteria, earthworms and other animals)
- availability of organic material
- bedrock chemistry
- topography

Each one of these factors contributes to the variety of soils, and therefore plants, found within Shenandoah National Park.

Organics material, such as decomposing plants, contributes important nutrients to the uppermost soil layer, called humus. As water and burrowing animal moves through the soil, these organic nutrients are mixed in.

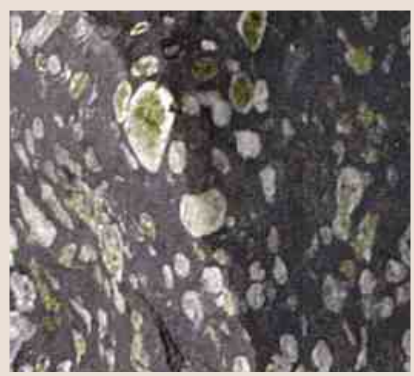
From below, the bedrock slowly weathers, breaking down into saprolite. Minerals from the bedrock are released during this process and mix with the organic materials that are provided from above. The soils type determines what plants can grow, which greatly impacts the appearance of Shenandoah National Park. For example, only acid-tolerant trees and scrubs such as oaks, chestnuts, mountain laurel, azaleas, and blueberries will grow in soils developing on top of the acidic Chilhowee Group rocks. Soils developing above the Catoctin formation, however, hold more nutrients and are less acidic, supporting a greater variety of plants. Combined with variability in elevation, and other factors mentioned above, these differences give Shenandoah a unique assemblage of plant species.

Common Minerals of Shenandoah

Minerals are the building blocks of rocks. Although some of the minerals that contribute nutrients to the soils of Shenandoah can be seen within the rocks themselves, many are too small to be seen with the naked eye. Here is a review of common minerals in the most common rock types of the park (photos modified from Bentley, 2008 and the NPS):

Basement Complex granitoids (granites and gneisses) were the heart of the ancient Grenville Mountains. These rocks formed as magma trapped underground cooled slowly into plutons. The basement complex was later metamorphosed during the formation of Pangea. These rocks contain a wide variety of minerals, including quartz, plagioclase, feldspar, biotite, amphibole, garnet, orthoclase, plagioclase, orthopyroxene, and clinopyroxene (right).

Rocks of the Swift Run formation were originally sedimentary deposits that had eroded off the Grenville Mountains into riverbeds, lakes, and flood-plains. Because of this, the Swift Run formation is composed of minerals from the basement complex. Silica-rich quartz and pinkish potassium feldspar are common (left).



The Catoctin formation consists of lava flows from the rifting of Rodinia that cooled into basalt and were later metamorphosed into greenstone. The greenstones have microscopic green chlorite and epidote and dark actinolite and pyroxene crystals that grew during metamorphism. Occasionally, the Catoctin formation will include amygdules, or filled gas vesicles, of white quartz, pink calcite, or green chlorite or epidote (right).

Chilhowee Group rocks are sedimentary deposits from rivers, beaches, and shallow marine environments that formed as the rifted edge of Laurentia became a passive continental margin (what the east coast of North America is today). These pebble, sand, and silt deposits were later metamorphosed into meta-conglomerates, quartzites, meta-sandstone, and meta-siltstone. These rocks contain pieces of the basement complex, Catoctin, and Swift Run formations. Quartz is most common in quartzite (left), but can include the element iron, which causes the dark, appearance of **Black Rock**.

Paleosols – Ancient Soils

Just as soils are developing today, they also formed across the ancient landscape. Evidence of ancient soils is preserved between the lava flows of the Catoctin Formation at the **Little Stony Man Cliffs** (below). Since the Catoctin formation is a thick accumulation of multiple flows of lava (approximately 2,000 feet of lava!) there was a lag of time in between each flow. As weathering occurred, the basalt surface began to break down to form a thin layer of soil. When the next lava flow rolled overtop, chunks of the soil were picked up and tumbled into the base of flow, forming pockets of fossilized soil along with volcanic breccia. Similar ancient soils can be found north of the park within the Swift Run formation. (Southworth and others, 2009; Nicholson, 1956; Reed, 1969)

Surface and groundwater

Perhaps you have noticed the many random wet spots along Shenandoah National Park's hiking trails and along skyline drive. These are natural springs, where groundwater discharges. These springs will be especially noticeable in the spring and early summer, when snow melt and spring rain are plentiful and frequent. The rocks and soils that lie beneath our feet are paramount to how water flows through and across the landscape. Shenandoah typically has thin soils, which means that rainwater that percolates down into the ground surface does not have far to go before it completely saturates the soil. In addition to thin soils, some of the rock types in Shenandoah are not spidered with fractures, meaning that water cannot escape by percolating beneath the soil into an aquifer. Therefore, water in Shenandoah does not have much of a place to go other than across the landscape. Deeper soils and highly fractured bedrock would lead to the percolation of surface water down through the soil and into the groundwater table. Because of the thin soils, rapid surface water runoff is typical in Shenandoah National Park, meaning that there is a low rate of groundwater recharge (Thornberry-Ehrlich, 2005), a very low groundwater residence time (approximately 0-3 years) (Plummer and others, 2001), and a variety of beautiful but intermittent waterfalls (Figure 79).

The most basic necessity of life is water. Springs have greatly impacted how humans, plants, and other animals interact with the Blue Ridge. Past human inhabitants placed their camps or homes directly next to or nearby water sources, typically springs or streams (Nash, 2000). Other organisms also rely on Shenandoah's water. Various species of stream salamanders in Shenandoah National Park need wet areas, such as seeps, in order to procreate and survive and can be indicators of stream health (Evan and others, 2005). The geology of the park ties directly to its water resources. Stream pH has been shown to depend on underlying rock type (Snyder and others, 2006). Recent studies have focused on the uptake of Mercury in Brook Trout of Shenandoah and have shown that these fish accumulate this harmful metal in greater quantities when they live in streams that run above siliclastic rocks – such as the Chilhowee Group. This is because the siliclastic rock types decrease the pH of the stream water, just as they decrease the pH of the soils that develop on top of them, making the water more acidic which allows heavy metals, such as mercury, to be absorbed (Snyder and others, 2006). As a unique habitat shaped by groundwater processes, **Big Meadows** supports both globally rare and state-rare plant species

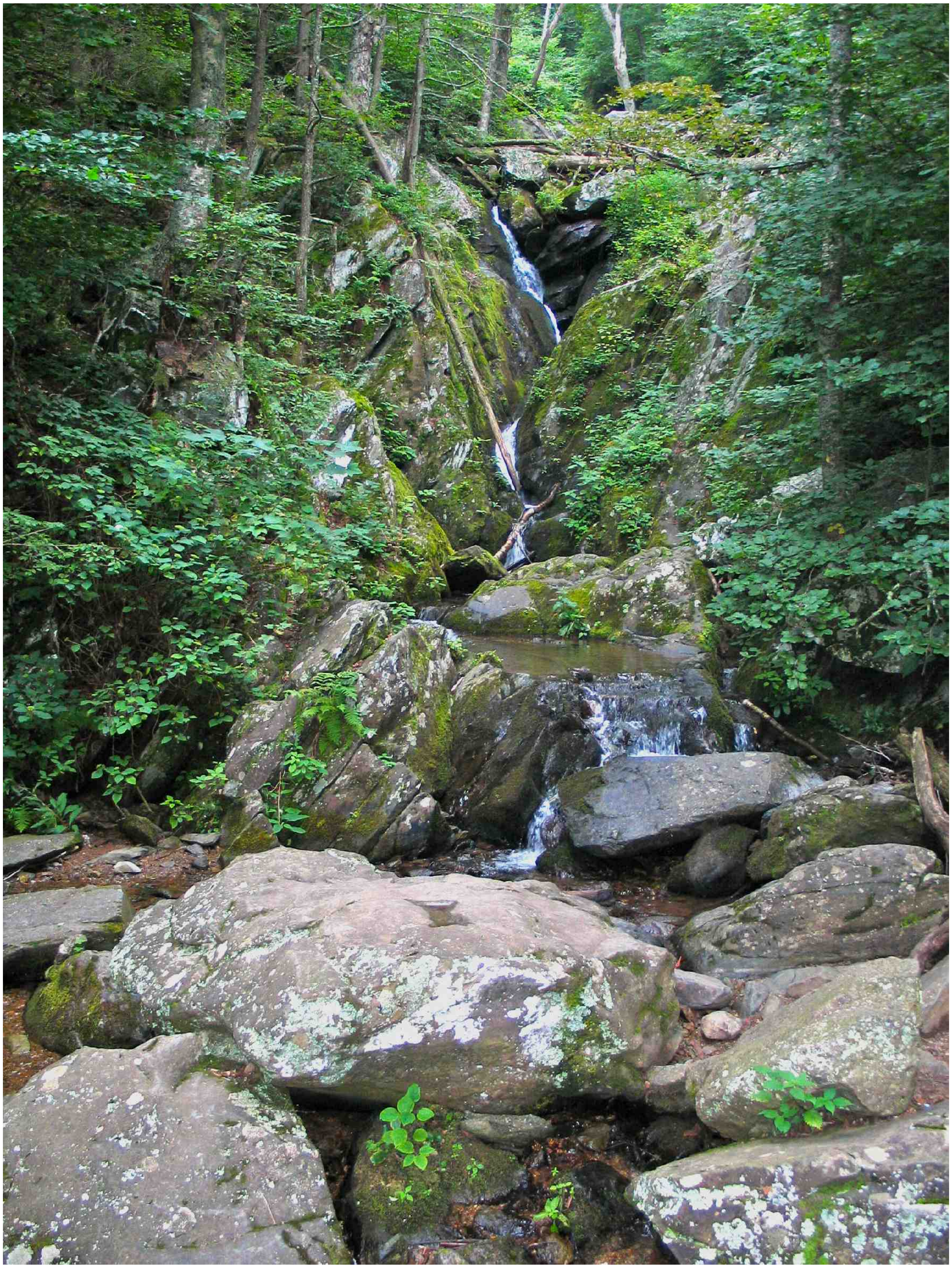


Figure 79: Many waterfalls flow over hard bedrock of Shenandoah National Park. At Dark Hollow Falls, water cascades down exposed Catoctin greenstone. Although these falls can be significant during the earlier months of the year, many tend to dry to a trickle due to a decrease in precipitation later in the summer. (Photograph by Wendy Kelly)

in addition to some rare and unusual reptiles, birds, insects, and amphibians (Hornberger and Lawrence, 2007).

Big Meadows is an interesting place to discuss groundwater. Here, thin soils mantle relatively unfractured greenstones of the Catoctin formation (Figure 80). This combined with the flat topography result in a rare pocket of temperate upland wetland (what is considered a mafic fen) at Big Meadows (Hornberger and Lawrence, 2007; Lawrence, 2007). This area provides habitat for plant species typical of more northerly latitudes. In addition, the soil in the meadow includes a clay-rich layer just over a foot below the ground surface (Litwin and others, 2003). Clay minerals, eroded from surrounding rock (Price and others, 2005), are flat – kind of shaped like a bunch of little plates. When packed together, the mineral grains overlap, creating a water-tight, and often air-tight surface. The shallow distance to unfractured bedrock, combined with a clay-rich soil layer, cause what is called a perched aquifer within the Big Meadows wetland (Litwin and others, 2003). Studies indicate that soil moisture within the meadow ranges significantly during the year (Lawrence and Hornberger, 2007), suggesting that the wetland is largely dependant on precipitation to maintain soil moisture (Lawrence, 2007). In very dry times of the year, the wetland may dry out significantly (Hornberger and Lawrence, 2007).

Water also shapes our Shenandoah experience by molding the surrounding topography. For example, the transport of groundwater dissolves caves and caverns within limestone rocks, such as those within the Shenandoah Valley, and the Conococheague and Beekmantown Formations that make up the northernmost 20 acres of Shenandoah National Park (Thornberry-Ehrlich, 2005). Many commercial caves line Shenandoah Valley, meaning that many visitors to the park may already have had the experience of exploring this geologic feature. Discussing surface and groundwater may be a great way to connect visitor's prior experiences to features within Shenandoah National Park. Unlike the valley caves, any caverns within the Park boundary should not be recreationally explored due to hazardously high levels of carbon dioxide gas (Thornberry-Ehrlich, 2005). The **Front Royal Entrance Station**, at the northern end of the park, sits almost directly on top of the Front Royal Fault, where the older Catoctin and Old Rag basement rocks have been pushed overtop of the younger sedimentary limestones of the Valley (Figure 53). As you drive in on route 340 from the north until you purchase your ticket at the entrance station on Skyline Drive, you are traveling on top of actively dissolving limestone!

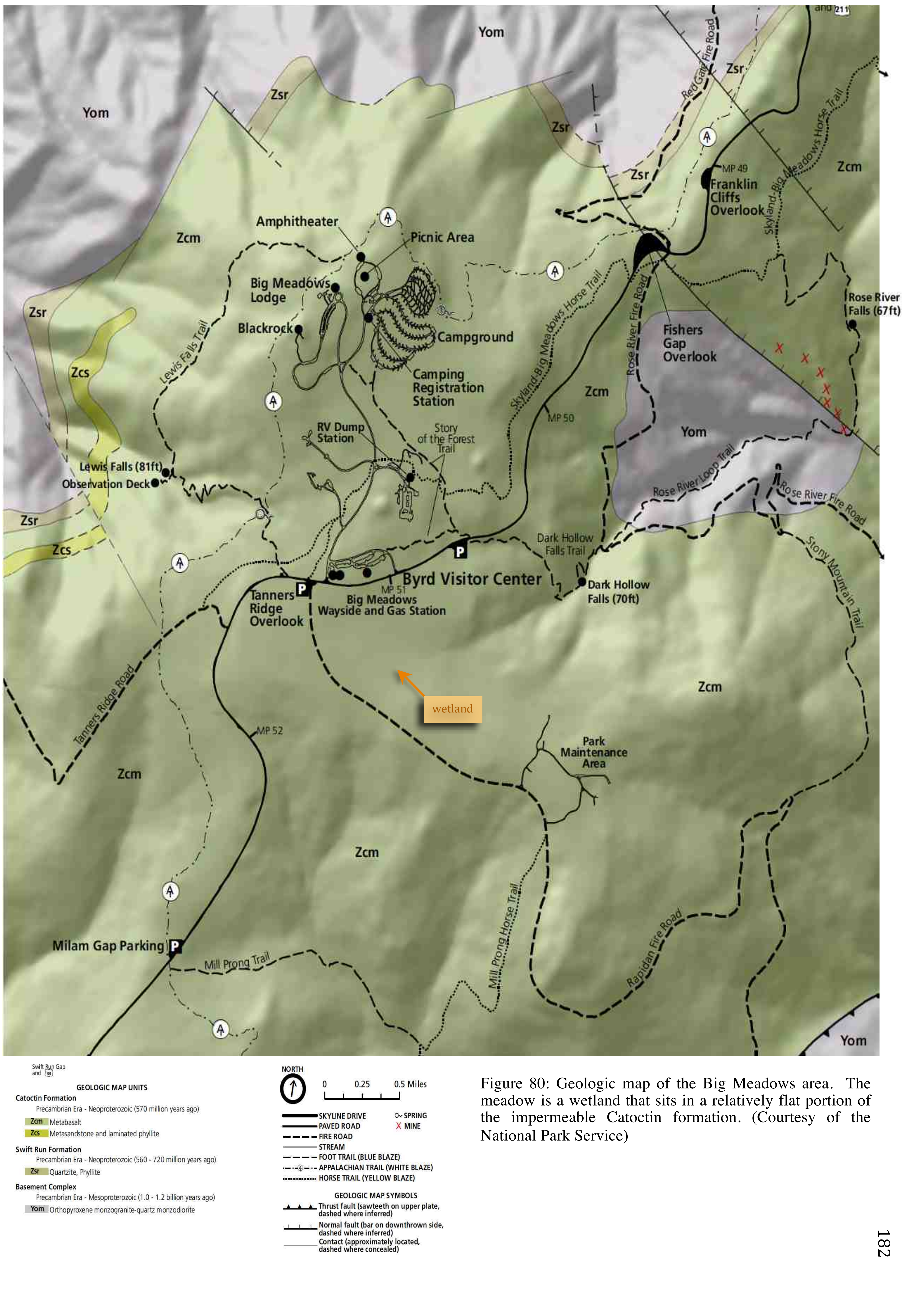


Figure 80: Geologic map of the Big Meadows area. The meadow is a wetland that sits in a relatively flat portion of the impermeable Catoctin formation. (Courtesy of the National Park Service)

<u>Shenandoah Visitors Today</u>

The complex story of the Blue Ridge Mountains has been preserved by the establishment of Shenandoah National Park. The geological processes that have shaped the lives and landscape of the past billion years are continuing to shape lives and the landscape today. However, recent human practices are influencing the fate of the mountains. In modern time (the Historic Archaeological Era – Figure 65), human populations have industrialized the east. Air quality and human-driven climate change are very important issues that should be addressed in national parks through ranger programs to help improve public understanding and clarify misconceptions.

Air Quality

Looking out across the beautiful mountains, it is common to see a slight haze. This is, in part, what makes the Shenandoah so beautiful. The haze is mostly suspended water vapor that disperses light and gives the Blue Ridge Mountains their name. Sunrises and sunsets are particularly gorgeous and inspire many visitors to climb mountain peaks early in the morning or late into the evening (Figure 81). Plants and the soil release water vapor into the air during the warm summer days (evapotranspiration), which condenses and hangs in the air as mist while evening temperatures drop. Mist and fog are also commonly seen in the late summer crawling up mountain hollows and 'jumping' overhead at overlooks. This is a beautiful sight and is particularly due to the topography of the mountains. The surrounding valleys average 600 ft (above sea level), mountain gaps are on average 2,200 ft in elevation, and mountain peaks average 3,100 ft, with **<u>Hawksbill</u>** as the tallest peak at 4,050 ft (Morgan and others, 2004). Shenandoah National Park is, on average, 10º F cooler than the surrounding valleys. This disparity in temperatures results in interesting atmospheric patterns that can influence the frequency and intensity of local storm events.

Added to the natural haze is very unnatural pollution (Figure 82). Although the National Park Service is committed to following clean air policies (the Clean Air Act), Shenandoah National Park's geographical and geological position is a larger determinant of air quality. The park receives air from the Ohio River Valley, Pennsylvania, West Virginia, and other portions of Virginia (the park's airshed) (Sullivan and others, 2003). These locations host industrial and electric utilities, such coal burning plants, that give off significant quantities of carbon monoxide,

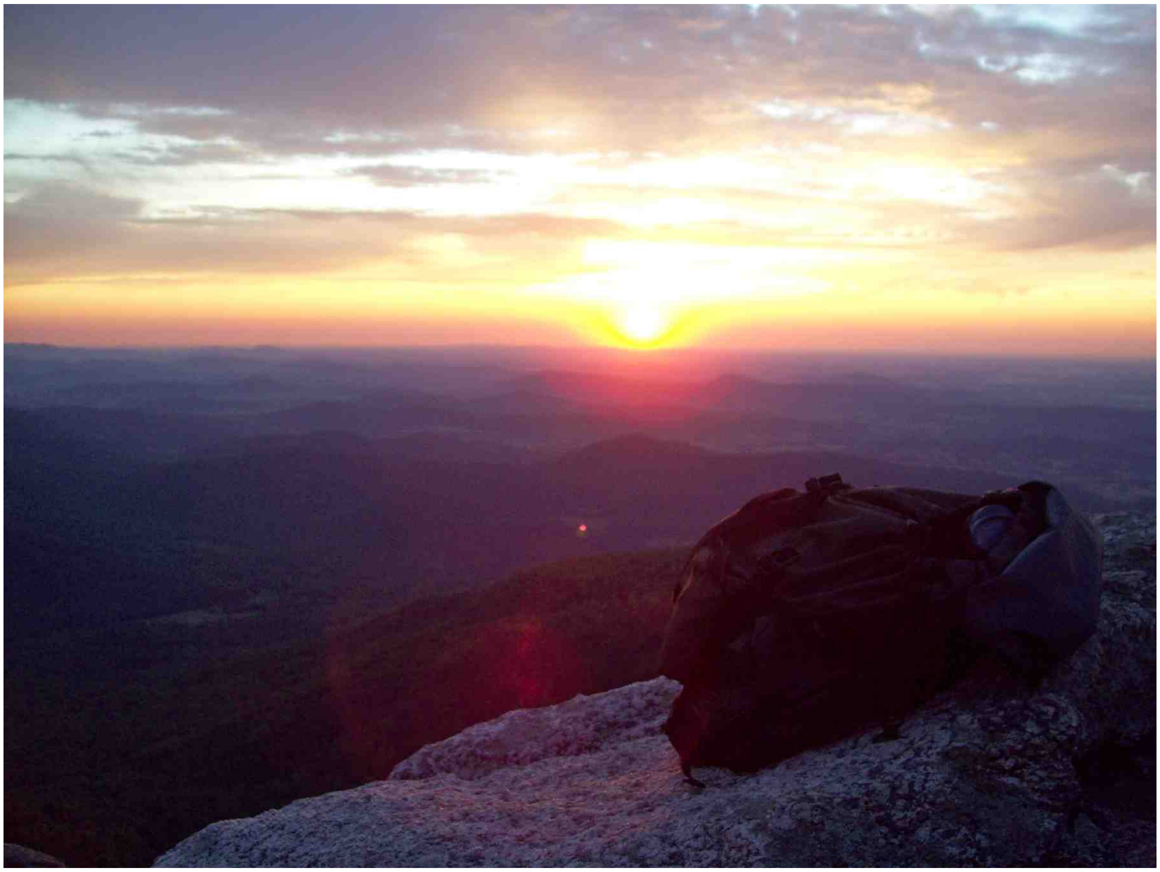


Figure 81: A gorgeous sunrise on Old Rag Mountain. The ancient Old Rag granite frames the view as you cast your eyes across a sea of water vapor, fog, and distant mountain peaks. (Photograph by Wendy Kelly)

Figure 82: Human-produced pollutants cause a blue-brown haze that steals the view from Dickey Ridge. Vistas are one of the primary attractions of Shenandoah National Park. Industrialization processes within the surrounding states contribute a variety of airborne pollutants that are impacting views, wildlife, and human health. (Photograph courtesy of the National Park Service)

volatile organic compounds, sulfur dioxide, nitrogen oxides, and coarse particulate pollutants (Sullivan and others, 2003). When the sun's ultraviolet (UV) rays interact with some of these pollutants, another dangerous pollutant, ozone (O_3) is produced. It is disconcerting that ozone levels within Shenandoah are some of the highest recorded in national parks (Sullivan and others, 2003). The combination of human-produced pollutants contribute to a sulfate-based haze that damages wildlife, affects human health, and frequently decreases the view by as much as 80% (Sullivan and others, 2003). Called the orographic effect, mountain topography tends to increase likelihood of precipitation as moisture in the air condenses as it is forced up and over the mountains. With greater moisture than the surrounding valleys, combined with a variety of pollutants, acid rain increases local acid deposition. This process increases soil and stream acidity, and may increase the occurrence of harmful mercury, especially in areas that overlie Chilhowee Group rocks (Sullivan and others, 2003). Recent monitoring of Brook Trout populations (fished along the **Rapidan River**) (Figure 83) suggests that changes in stream pH due to pollution probably decreases stream species diversity (Snyder and others, 2006).

These changes in air quality are only a few of the repercussions of human-produced pollutants. Human lifestyle has dramatically changed over the past few hundred years. Industrialization in the form of petroleum refineries, mining operations, pesticide application, and fossil fuel fired power plants and automobiles has dramatically increased the impact the human species has on the Earth. Government and state agencies have been making an effort to mitigate this impact, although it is the role of National Parks to increase public awareness and clarify misconceptions about this extremely important topic.

Figure 83: Stream acidification may be harmful to Brook Trout. Taken from the Rapidan River, this fish, along with others, are adversely impacted by increasing pollution that decreases air quality and can lead to acidification of park streams, especially those that flow overtop of the Chilhowee Group. (Photograph courtesy of Brian Hunt)

Human driven Climate Change

> "*Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level*." *(Intergovernmental Panel on Climate Change, 2007)*

Throughout Earth's history, climate change has occurred due to many measurable, natural variables (see textbox – **what is climate change?** and Figure 63). These natural variables have shifted our world in and out of glacial cycles that have controlled plant and animal diversity, extinction events, and the evolution of new species. Over the past 65 million years, natural cyclical climate change has been taking us from the greenhouse conditions of the age of dinosaurs, to the icehouse world of the woolly mammoths and early humans (Kentworthy, 2010) (Figure 84). Over that time, average global temperatures have dropped by approximately 20°F, becoming so cold that for the past two million years, we have been going in and out of ice ages. However, the climate change that is occurring in modern times is driven by a new set of factors.

Over the past two centuries, a new trend of warming has begun. This unusual trend is forcing climate to make a 180 degree turn - taking us in a different direction. Instead of moving slowly into an ice age, we are soaring into hot greenhouse conditions! This is because the natural cycles of climate variability have been greatly distorted by the human industrial practices of the past few hundred years. Anthropogenically (human) driven climate change is largely caused by the burning of fossil fuels, which releases large amounts of particulate pollutants and greenhouse gases (such as carbon dioxide and methane) that accumulate in Earth's atmosphere (for example Crowley, 2000).

During the last ice age, cooler climate caused the higher elevations of the Appalachian Mountains to be above the tree line (Litwin and others, 2003). Already, global average temperatures have increased by 1°C (1.8°F) since 1900 and are predicted to increase by another 0.2°C (0.36°F) every decade (IPCC, 2007) (Figure 85, 86). How will these rapid increases in temperature impact the flora and fauna of Shenandoah National Park?

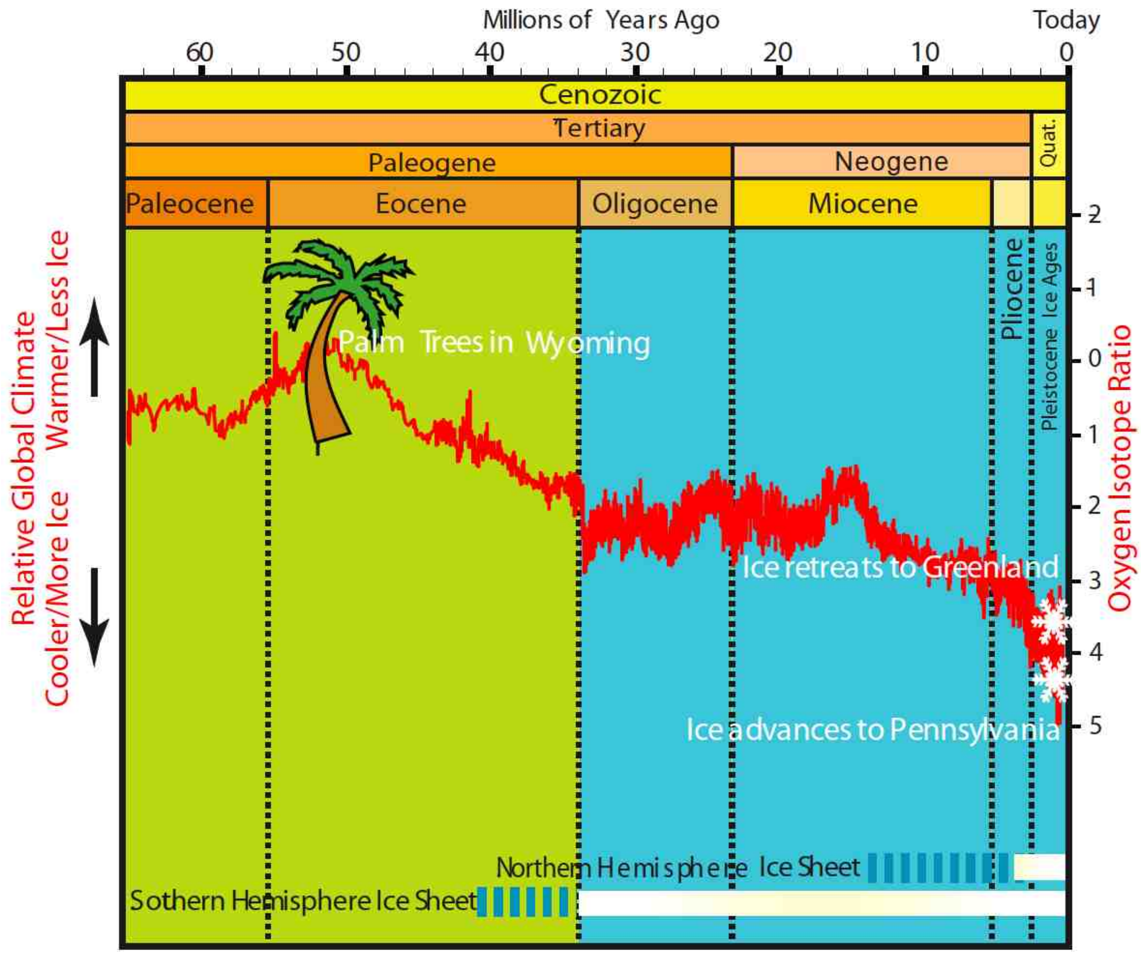


Figure 84: Natural climate has shifted from greenhouse into Icehouse conditions over the past 65 million years. During the Eocene Epoch, climate was warm enough to turn portions of northern North America into a palm tree paradise. Natural cycles of climate change should be taking us into ice house conditions, however recent, human-induced changes are reversing that trend. (Modified from Kentworthy, 2009)

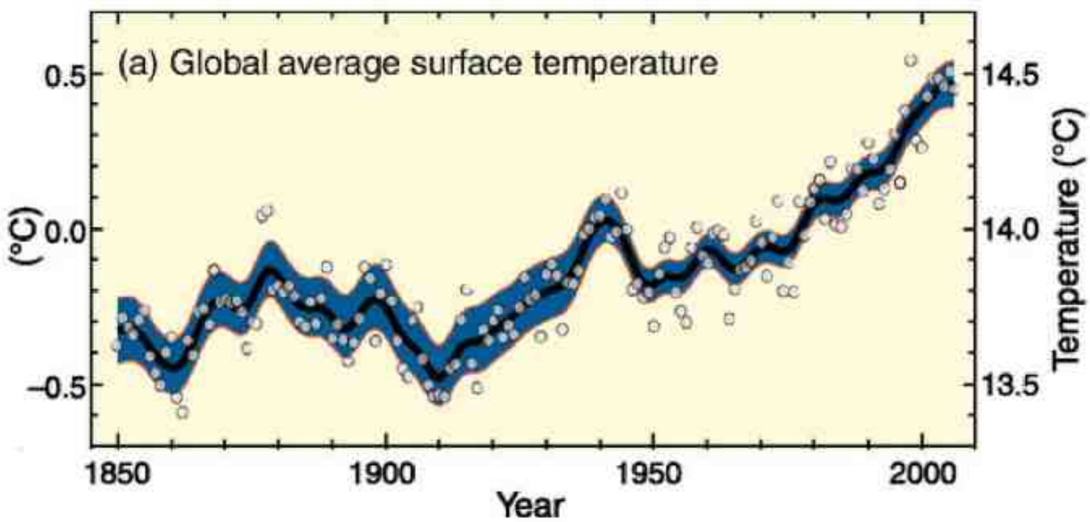


Figure 85: The global average temperature has risen over the past 150 years. A small increase of a single degree Celsius can result in significant changes in regional temperatures, precipitation, plant and animal diversity, and species shifts. (Courtesy of the National Park Service)

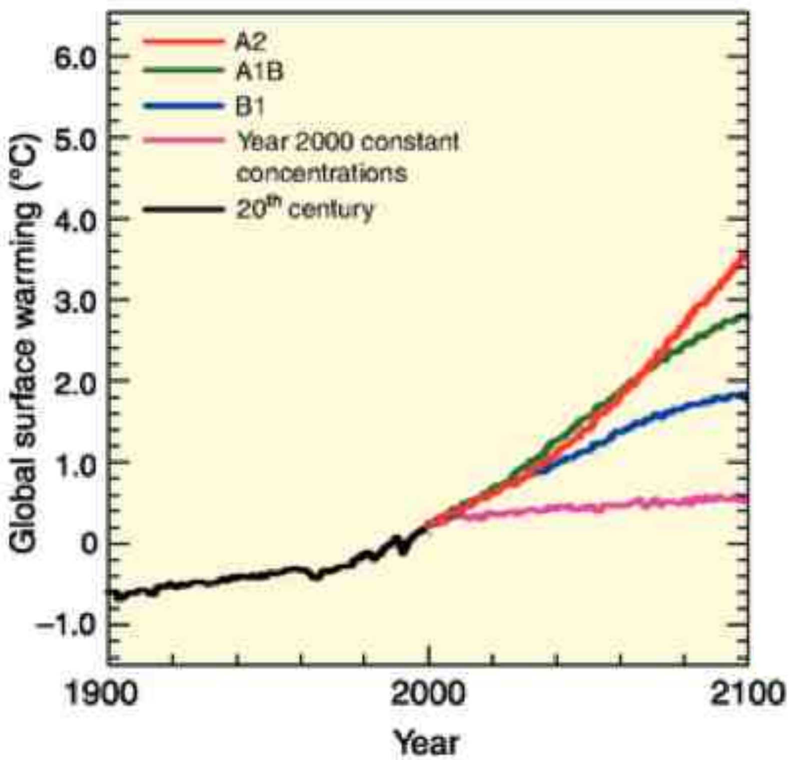


Figure 86: Global temperature projections for different emissions scenarios. Each line represents the global temperature anomaly predicted by a combination of climate models from the Special Report on Emissions Scenarios (SRES). The models predict changes in global surface temperature based on changes in emissions. In the orange A2 scenario, the world would increase in population while remaining economically fragmented, thus having slower economic growth. The green A1B scenario predicts warming based on rapid economic growth, but the introduction and use of more efficient technology, and an increasing global human population that peaks in the mid 21st century but then declines. The blue B1 scenario represents an increasing global human population that peaks in the mid 21st century but then declines, the introduction and use of more efficient technology, and rapid economic changes moving towards reduced material use and increased information technology. Pink "Year 2000 constant concentrations" indicates the shift in global surface temperature if the current input of emissions continued, but did not increase. The black line is simply a record of global warming that has occurred since the year 1900. (Modified from the IPCC Fourth Assessment Report: Climate Change 2007) For more information on these scenarios, visit the IPCC website: http://www.ipcc.ch/ or to read the Special Report on Emissions Scenarios visit: http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/.

Shenandoah National Park surveys reveal that certain species are already suffering from climate change by decreasing in number (Thornberry-Ehrlich, 2005). Rare species that live in particular ecological niches can be stressed by even slight changes in local temperature and precipitation. Rising temperature forces cool climate species to move into higher elevations, or higher latitudes. However some cold-loving species are already occupying the highest niches that the mountains provide and will not have the luxury of climbing to higher cool temperatures. Changes in climate since the last ice age caused cold-climate plant species (such as the Balsam Fir) to become isolated in pockets. Studies have shown that these isolated areas of tree species have literally been stranded by modern climate change, resulting in interbreeding that weakens the trees, making it more and more difficult for them to fend off disease, infestation, and more rapid recent changes in climate (Shea and Furnier, 2002).

Predicted increases in carbon dioxide concentrations will alter the vegetation within Shenandoah National Park, which, in turn, will impact animal species (Burns and others, 2003; Thornberry-Ehrlich, 2005). For example, climate models suggest that the park's mammalian species assemblage could change considerably. Not only will certain species migrate out of the park, but new species (possibly including bats, insects, and rodents) will move into the park (Burns and others, 2003). This is because a change in climate will lead to a shift in species range. This change in plant and animal species will show up in soil core and fossil records thousands to millions of years in the future.

Climate change is also resulting in more unpredictable weather patterns, including a greater frequency of intense storm events (Thornberry-Ehrlich, 2005). Such occurrences will impact stream species by changing the amount of sediment carried by the stream (sediment load), the input and distribution of nutrients, and perhaps pH of Appalachian streams (Thornberry-Ehrlich, 2005). Intense storm occurrence will also contribute to erosion within the park, possibly triggering more frequent debris flows on mountain flanks. Imagine how this change in climate of the next few generations will alter the experience of visiting Shenandoah National Park? It is important to communicate the significance of climate change to the general public by addressing how future changes will impact the Shenandoah landscape. The National Park Service can play an important role in clarifying public misconceptions about this significant and serious situation (see the textbox **Climate Confusion** and visit - http://www.nature.nps.gov/climatechange).

Climate Confusion

Sometimes terminology associated with climate can be overwhelming. Here is a brief description of common phrases to help clarify confusion and misconceptions.

Natural Climate Change

Long-term trends in climate throughout Earth's history have been recorded by climate proxies like pollen and ice core data. These shifts are naturally-occurring and are caused by factors such as the roundness of Earth's orbit that are uncontrollable by humans. These cycles are well understood and modeled by scientists across the globe.

Anthropogenically driven Climate Change

In the past two centuries, some abnormal and rapid changes have been occurring with climate trends that can only be the result of human lifestyle. This anthropogenic climate change is caused by the addition of significant amounts of greenhouse gases into the atmosphere. Emissions from industrial factories and vehicles are a major contributor. Using the phrase 'climate change' is more accurate than using 'global warming' because climate shifts will be different in different areas of the world. Short-term, local changes may include an increase or decrease in precipitation, or an increase or decrease in temperature.

The Greenhouse Effect and Global Warming

When you step into a greenhouse it's usually balmy and warm. The sun's rays (solar radiation - ultraviolet, visible, and infrared light) enter the greenhouse, heat up the floor and walls, which then release heat (infrared light) back into the greenhouse. Some of the heat is trapped because it cannot pass through the glass walls and ceiling of the greenhouse.

This greenhouse effect is occurring now on a much larger scale. Solar radiation enters Earth's atmosphere, heats up the Earth, but not all of it can escape the atmosphere because greenhouse gases block the exit! Thus, much of the heat produced by the Sun's radiation is trapped beneath the greenhouse gas blanket that continues to form a more and more 'gas-tight' bubble in the atmosphere. The result, on a global scale, is called global warming.

Ozone Depletion and the Ozone hole

Another environmental issue is depletion of the Ozone. Ozone (O_3) is an important gas in the upper atmosphere that blocks harmful cancer-causing UV rays from the sun. Certain compounds, such as CFCs (Chlorinated fluorocarbons), are common in production of aerosol cans and refrigerants. When released, these CFC's work their way up into the atmosphere and cause a chemical reaction that destroys ozone gas, forming a 'hole' in the ozone layer. Although the use of certain CFC's have been regulated or banned, they are still used for certain industrial purposes. CFCs are also a harmful greenhouse gas.

Although ozone in the uppermost atmosphere is beneficial, ozone in the lower atmosphere is harmful and forms when sunlight reacts with industrially-produced chemical pollutants. Ozone levels in Shenandoah National Park are sometimes above Environmental Protection Agency public health standards and are monitored.

For more information about common climate change misconceptions, visit this NPS website: http://www.nature.nps.gov/climatechange/myths.cfm

Recreation

The geological processes that have shaped Shenandoah National Park are celebrated every day by hundreds of visitors. Recreational activities provide a great opportunity for visitors to explore the park while exploring various aspects of Shenandoah's geological story.

Popular activities within Shenandoah include rock climbing, bouldering, and ice climbing. Resistant cliffs are exposed all along the summits of the Blue Ridge Mountains. The Catoctin formation greenstones form rugged cliffs at **Little Stony Man** that are frequently peppered with groups of rock climbers (Figure 87). These cliffs exist because of the multiple lava flows that overlapped 570 million years ago during the rifting of supercontinent Rodinia. Following the deposition of one lava flow, time passed and the basalt began to weather as soils accumulated. Then, another lava flow poured overtop, picking up chunks of the old basalt and clods of soil. This amalgamation of volcanic material is called volcanic breccia (Figure 88, see the photograph in textbox **Paleosols – Ancient Soils** on page 178). At **Stony Man Mountain** volcanic breccia is beautifully exposed in between the now metamorphosed, uplifted, and eroded lava flows. The breccia is less resistant to weathering than that pure greenstone, allowing notches to form in the mountainside that clearly distinguish each lava flow (Figure 89).

Little Stony Man cliffs, in addition to many other heavy use rock outcrop areas within Shenandoah are being studied to better understand the diversity of rare plants and the impact of human usage. Increasing numbers of bouldering, rock climbing, camping, and hiking visitors are using these locations for recreation. The Rock Outcrop Management Plan assessed Shenandoah National Park rock outcrops from 2000 through 2005, concluding that rock outcrops within the park are unique habitats that contain nine globally rare ecological communities and two ecological communities that are endemic only to Shenandoah National Park (Rock Outcrop Management Plan Environmental Assessment/Assessment of Effect, 2008). High-elevation barren greenstone outcrops and greenstone boulder fields (such as **Franklin Cliffs**, **Hawksbill**, **Crescent Rocks**, **Stony Man Mountain**, and **Mount Marshall**), Chilhowee Group boulder fields and talus slopes (such as **Blackrock** and the **Trayfoot Saddle**), and basement complex rock outcrops (such as the summit of **Old Rag Mountain**) were found to be particularly important for endemic and globally rare species (Rock Outcrop Management Plan Environmental Assessment/Assessment of Effect, 2008). Unfortunately, many of these areas are also high-traffic

Figure 87: Resistant greenstone cliffs create a rock-climbers paradise. (Photograph by Wendy Kelly)

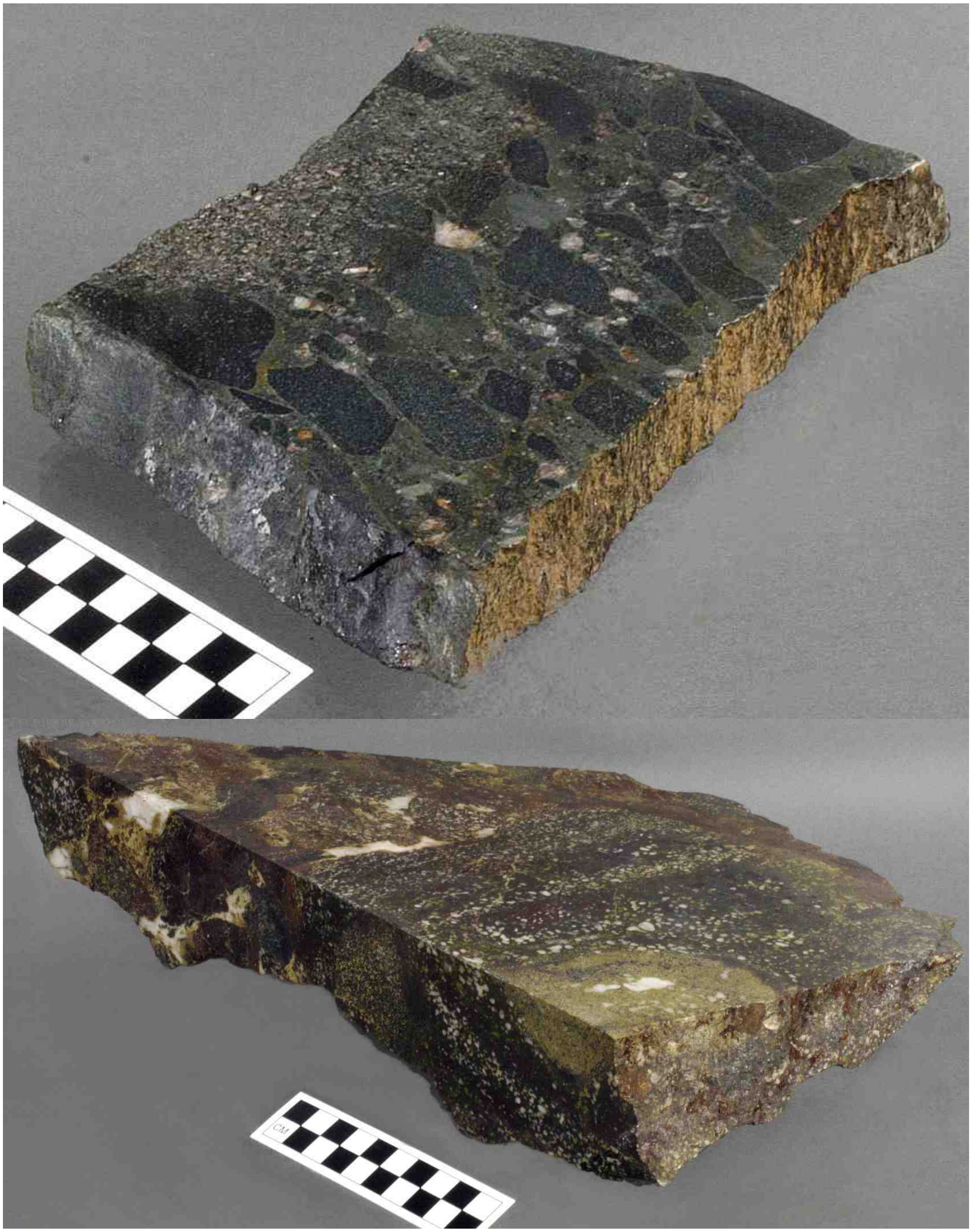


Figure 88: Examples of volcanic breccia within the Catoctin Formation. While Rodinia rifted apart, lava flowed over the landscape, picking up chunks of older volcanic debris which were incorporated into the base of the new flow. These volcanic breccias divide individual lava flows and weather more rapidly, forming steps within the Catoctin greenstone. (Photographs courtesy of the National Park Service)

Figure 89: The face at Stony Man Mountain. Layers of lava flows associated with the rifting of Rodinia are interlayered with volcanic breccia. Differences in resistance of these rock layers causes variable rates of erosion, leading to the apparent profile of an old man with a beard. (From Bentley, 2006)

destinations for humans. Old Rag Mountain alone feels the crushing feet of over 50,000 visitors a year (Rock Outcrop Management Plan Environmental Assessment/Assessment of Effect, 2008). Because of this, many rocky outcrop areas have been damaged by frequent foot traffic (Figure 90). Although these areas are important for recreation, the park service is attempting to balance recreational use with preservation. A number of different scenarios have been proposed that would limit or restrict access to certain highly sensitive areas, while enforcing strict climbing, bouldering, and ice climbing regulations. These options would help protect and preserve Shenandoah's extremely unique rocky habitats while continuing to support visitor recreation.

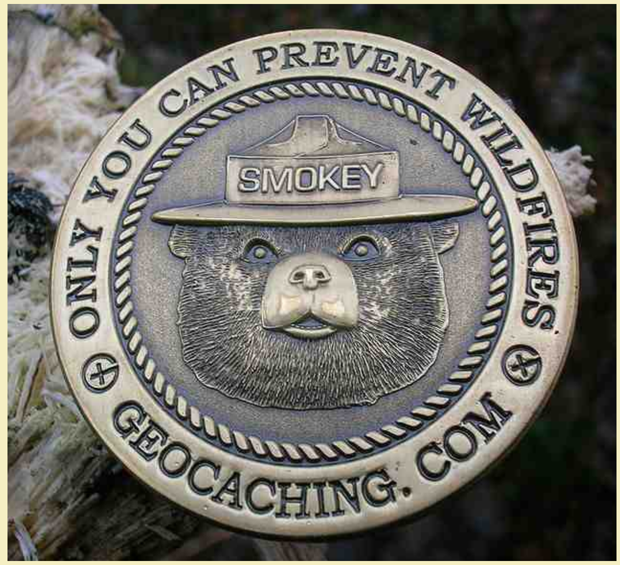
Another common recreational activity at Shenandoah National Park is swimming. The steep and rocky mountain hollows frequently have a stream that captures runoff from the surrounding slopes. Many visitors hike the long, steep trails to explore these waterfalls and take a dip in the cool pools that form along their flow path (Figure 91). These waterfalls are also helping to alter the landscape. As water flows over the rugged terrain, it washes away soils and exposes the hard bedrock, which will also slowly erode away over time.

Geology is inherently incorporated into visitor experience at Shenandoah National Park. Whether visitors are attending formal ranger programs, such as hikes or talks, or simply having an adventure on their own, the environment is a constant reminder of the geologic life story of the mountains. By providing visitors with interpretive information about the natural resources of Shenandoah, we can increase public connection to, appreciation of, and protection of our National Park lands.

Figure 90: The Rock Outcrop Management Plan studied visitor use versus ecological diversity. Certain areas of Shenandoah National Park, such as Marys Rock and Stony Man are popular locations for park visitors to explore. But these rocky outcrops are also habitat for a diverse assemblage of rare and endangered species. The Rock Outcrop Management Plan (ROMP) studied how visitor use has impacted the diversity of these rare species. Heavy use areas (the two photographs on the right) are greatly impacted by foot traffic, compared to more protected, less frequently traveled, park locations (the two photographs on the left). (Courtesy of the National Park Service)

Figure 91: Many waterfalls within Shenandoah are perfect for swimming. As water flows off the mountains, it collects in pools near waterfalls. Cave Falls (above) and the lower White Oak Canyon falls are some good examples. (Photograph by Wendy Kelly)

What is Earthcaching?



Another recreational activity in which many park visitors partake is the use of Global Positioning System (GPS) units to locate hidden treasures across the globe. Called Geocaching, these treasure hunts lead to a small hidden box with a logbook and a trinket (such as a Geocoin - right) at a specific location. By using the GPS units to pinpoint the treasure, participants across the globe have been able to take part in history's most extensive game of hide and seek.

Since leaving objects in National Parks is not allowed, the Geological Society of America, paired with the National Park Service, use Earthcaching as a Geocaching alternative. Rather than locating a hidden box, participants use their GPS unit to locate fun geological features within the National Parks. Shenandoah National Park has GPS units available at Big Meadows for park visitors to use during their visit. New treasure hunt locations that are updated and added provide visitors with an alternative way to learn about the history, geology, and significance of the National Park landscape.

For more information visit: http://www.earthcache.org/

D. Into the Future: how geology will shape the plants and people of the future

Dynamic geological processes of the past that have shaped the Blue Ridge landscape are ever-continuous, and will reshape the familiar mountains into a new land of the future.

Change is the only constant. Like looking at a photograph of yourself five years ago – at the time you may not have realized the changes that were yet to come, but now, you have lived them. You have experienced your changing body, home, and family. Perhaps you have moved to another state, or fallen in love. Perhaps you have gained a new hobby, or let one go. The physical landscape and its processes can be strikingly similar to our own human lives. We can read the events of the past in the rocks like looking back through a photo album, but determining what is yet to come is more challenging. We humans have begun new climate trends and shifted old ones. By projecting forward, we can appreciate the potential consequences of our actions and alter our lifestyles in an attempt to mitigate and adapt to these changes.

Weathering and Erosion – the fate of the Blue Ridge

If we look at the bedrock within Shenandoah National Park, we can see that great forces acting on it have left it distorted – folded, faulted, and metamorphosed (Figure 51). Although these mountain-building processes no longer occur within Shenandoah, they are continual on Earth, occurring in other locations across the globe. We can also look at the surficial geology, or loose accumulations of broken rock and sediment that sits on top of the bedrock, to understand part of the Shenandoah story. The surficial geology tells the story of an extremely important process that will dominate the Shenandoah landscape for the next few hundred million years: that of weathering and erosion.

Just as the Swift Run formation preserves eroded pieces of the ancient Grenville Mountains of supercontinent Rodinia, new rocks are forming right now that preserve pieces of the eroding Appalachian Mountains. Ever since the Appalachians reached their prime during the collisions that formed Pangea, the processes of weathering and erosion have impacted the mountains. The last Ice age (from 33,000 to 20,000 years ago) boosted weathering and erosion of the Appalachians. The continental ice sheets extended southward across the northern Appalachian Mountains, scrapping away soil and loose rock until it scratched the hard bedrock, and subjected the central Appalachians to intensive freeze-thaw cycles. Erosional features from these events in Shenandoah National Park include numerous block fields, such those observed at **Black Rock** and the summit of **Stony Man Mountain** (Southworth and others, 2009; Clark and others, 2009; Litwin and others, 2004) (Figure 92).

In modern time, erosion of the Appalachians has continued, although the rate and style of erosion differs from that of times in the past. Recent studies suggest that the Blue Ridge Mountains are eroding slowly compared to other locations within the Appalachians (Duxbury and others, 2009; Sullivan and others, 2006; Matmon and others, 2003). The rate of erosion over the scale of a millennium averages 36 feet per every million years (or about a half inch per every thousand years) (Duxbury and others, 2009). Over time, loose rock and sediment from the slowly-eroding mountains accumulate along the mountainsides. Alluvial fans and alluvial plains mark the path of old rivers off the mountainsides. These deposits have been important for providing settlement sites and tool making materials for early humans.

On an even shorter time scale, storms of the past 20 years (including the catastrophic rainstorm of 1995) have also transformed the landscape (Wieczorek and others, 2006; Wieczorek and others, 2004). The shape of the mountains increases the frequency and intensity of storms, resulting in a much higher average annual precipitation (at Big Meadows 52 inches with 37 inches of snow) compared to the surrounding valleys (Duxbury, 2009). By destabilizing the loose accumulations of weathered mountain material and soil, powerful rainstorms have sparked literally thousands of debris-slides and debris-flows (Southworth and others, 2009). This modern process alters the view and shape of the familiar Blue Ridge Mountains. From many overlooks along Skyline Drive, including the **Moormans River Overlook** (near mile marker 92) we can see the scars of this mass transport across the mountain range (Figure 93). These views remind us that the varying processes of erosion are ever continual, constantly shaping the land into new and different forms. Plants also greatly contribute to the break-down of the mountains. Tree roots dig deep into the soil and wedge their way into cracks and fractures within the bedrock. This root-wedging is an active process viewable along many of the Shenandoah Park trails, including **Stony Man**, and the trail down to **Cave Falls** (Figure 94, 95).

Figure 92: Eroded pieces of the mountains accumulate in block fields. At the Stony Man summit, Catoctin formation greenstone provides a habitat for Peregrine falcons, rattlesnakes, and other animals. These surficial deposits formed during the last ice age. (Photograph by Wendy Kelly)

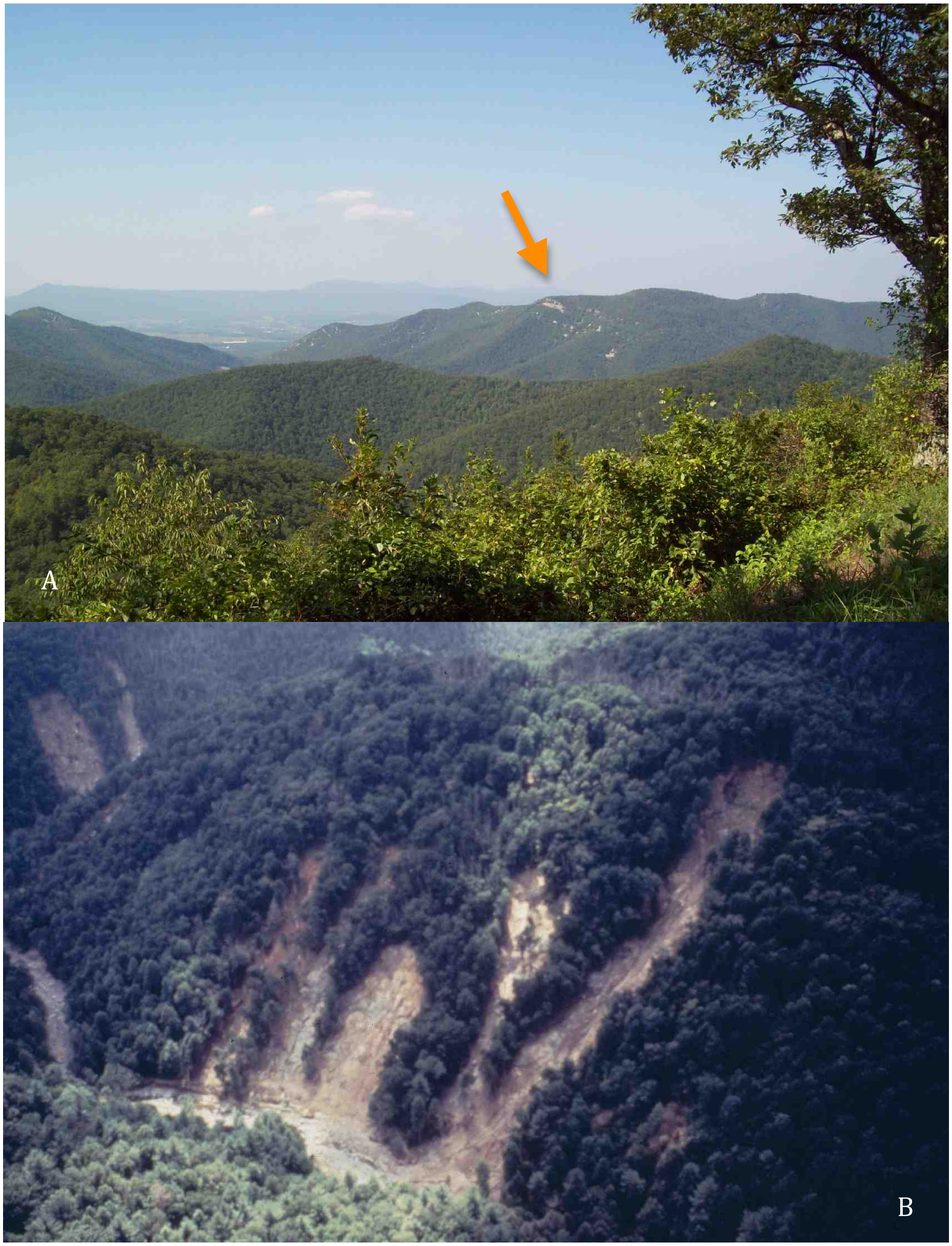


Figure 93: Debris-flows from recent storms have caused visually striking erosion. A. Many park vistas display mountain sides disturbed by this process. B. The debris flow scars near the Moorman's River following an intense rainstorm in 1995 are a striking reminder that the mountain break-down processes of weathering and erosion continue today. (Photograph A by Wendy Kelly, photograph B courtesy of the U. S. Geological Survey)

Figure 94: Root wedging along the Stony Man trail. This common feature within Shenandoah National Park is a testament to the significant contribution of flora to park weathering. The continual processes of weathering and erosion are not simply driven by large-scale geological processes such as glacial events, but also shaped by the more immediate and visible life cycle of plants. (Photograph by Georganne Kelly)

Figure 95: Another example of root wedging. A process that is actively breaking down the rocky peaks of Shenandoah's mountains, root wedging can be seen everywhere in the park. Trees can grow directly out of small cracks in the rock where small pockets of soil collect. Eventually, the roots will pry the rock apart, contributing to weathering. (Photograph by Wendy Kelly)

As the mountain peaks and valleys are eaten away, the mountain root pushes ever upward, this uplift maintains the mountain height, suggesting that the Blue Ridge will maintain a similar appearance for millions of years, continuing to influence the transportation, education, and recreation of millions of people in the future. Differences in rock type influence erosion of the mountains on a small scale. For example, the alluvial fans and alluvial plains along the western side of the Blue Ridge are mostly composed of very resistant Chilhowee Group quartzite cobbles that have been eroded off the mountains above. These deposits will break down very slowly, helping to extend the life of the western topography. In contrast, eastern flanks of the Blue Ridge are dominated by deposits of basement complex granitoid cobbles. These deposits break down much more easily, which will probably allow the topography to the east of the Blue Ridge Mountains to weather and erode more quickly. (Morgan and others, 2004)

In addition to differences in rock type, local geological structures also contribute to the large-scale and long-term topographic changes of the Blue Ridge Mountains. For example, the most resistant rocks within the park are quartzites of the Chilhowee Group. However, it is the less resistant Catoctin formation greenstones and basement complex granitoids that form the ridgetops. Thrust faults that formed during the Alleghanian Orogeny pushed these less-resistant rocks upwards overtop of the more resistant Chilhowee Group (Figure 51). With every erosional event, the roots of the mountains become more exposed. The topographic highs we see today were once the deeply-buried roots of the once high Appalachian Mountains. The sharp, jagged, and snow-capped peaks have disappeared, leaving lower portions of the mountains on display at Earth’s surface. Even though weathering and erosion will continue far into the future, the thick crustal root of the Appalachian Mountains will ensure that the topographic variability of the Blue Ridge will persist (Matmon and others, 2003). As more material is removed from the mountains, the entire mountain range will isostatically rise, and mountain streams and rivers will continue to carve mountain hollows and valleys. Given enough time, perhaps hundreds of millions of years, the Appalachians will erode into a flat plain, the hard mountain roots concealed beneath a blanket of soil and sediment.

The geological processes of the distant past have shaped a landscape that has been significant to more recent life. Flora, fauna, and human cultural history are all intricately tied to the geology of the Shenandoah landscape. Since our ancestors first crossed the lands of North America, the

Appalachian Mountains have influenced human practices and lifestyle. The rocks of the Blue Ridge have provided valuable resources and shaped the lifestyle patterns of early and modern people. The continual interaction between bedrock, water, soil, and climate has developed unique plant and animal communities observed today. The processes of past and present are what shape Shenandoah National Park. But the future of Shenandoah National Park is something we all can shape. As geological processes continue into the future, human practices will greatly influence this landscape. It is only with our active awareness, understanding, and continual protection that the artifacts of the past and unique Shenandoah environment of today can be preserved.

PART VI
Interpreting Geology of Shenandoah National Park

> *"While we are born with curiosity and wonder and our early years full of the adventure they bring, I know such inherent joys are often lost. I also know that, being deep within us, their latent glow can be fanned to flame again by awareness and an open mind."* - *Sigurd Olson*

This portion of the thesis deals specifically with the philosophy of interpretation, or how to bridge the gap between science and the general public. The first section addresses what interpretation is, and how to develop an interpretive program. It is a review of useful interpretive techniques, the art of learning outside of the classroom. This section will be especially helpful for new park rangers who have recently begun their career and would like a clearer idea of how to do their job. The second section specifies how to develop geology-related ranger programs and provides some examples.

✯

A. Overview of Interpretation

What is interpretation and why do we do it?

> *"Interpretation is the revelation of a larger truth that lies behind any statement of fact."* - *Freeman Tilden*

National Parks protect geologically and historically significant landscapes that tell the story of our heritage - as Americans, as humans, as organisms of planet Earth. Interpretation is the process through which the public comes to appreciate, and thus care for, our natural resources. Within national parks, interpreters are park rangers who spark interest in our natural and cultural resources. On a basic level, interpretive park rangers are educators, but more significantly, park rangers are inspirers. Park rangers present concepts and data that helps the public make emotional and intellectual connections to park resources. When the public makes these connections, they have a better understanding of the significance of our resources, value them more, and therefore are more likely to protect them.

Interpretation has the ability to bridge the gap between the scientific community and the general public by forging connections between important (but often misunderstood) scientific research and our environment. How do important scientific findings that shape politics and our daily lives make their way to the public? Various conduits of learning exist that transport new information to the receiving audience; the media, schools, libraries, museums, and national parks. Environments such as these can be divided into two categories: formal education (compulsory learning environments), and non-formal education (which occurs in free-choice learning settings) (Figure 96). Unlike compulsory learning environments, National Parks present opportunities for the public to interact with nature and interpreters in an informal setting (Figure 97).

According to recent studies, an individual learns largely outside of the classroom. Up to 50% of the learning any one person may experience within their lifetime will happen within free-choice learning environments (Falk and others, 2007; Dierking, 2005; Falk, 2002). Some studies suggest that even individuals who enter a non-compulsory learning environment with little to no interest or knowledge in environmental topics can significantly increase their knowledge and interest simply by having a non-traditional educational experience (Falk and Adelman, 2003). Therefore, National Parks, as one free-choice learning environment, present a great opportunity to educate the public about science and improve public science literacy (Falk and Needham, 2011; Falk and others, 2007; Dierking, 2005). Public perceptions of science greatly influence not only politics, but also daily life choices that may, in the long run, have a great impact on our environment and thus, our future as humans on this planet.

Within free-choice learning environments (such as museums, aquariums, and parks), educators (such as museum docents and park rangers) work with dynamic audiences over a limited period of time. Learning is shaped by many factors, including the physical setting, the socio-cultural context, and the personal perspective of the individuals involved. These components can make a huge number of possible combinations, presenting a widely diverse audience of learners. Interpreters thus have a very challenging task.

Geology and geology-related subjects tend to be interpreted far less within the national park setting than botany, zoology, or cultural history. Only 80 out of the 23,000 National Park Service (NPS) employees are geologists by training and only half of those actually work within the parks interacting with the public (Thomasson and others, 2004). This means there is only one geologist per every ten NPS sites! Of the 388 NPS sites across the country, almost half are considered to have "…significant geological phenomena" (Thomasson and others, 2004). Shenandoah National Park alone captures over a billion years of Earth's history. Natural park features in Shenandoah can be read like chapters in a book that tell the rich and dynamic autobiography of the Appalachian Mountains. This story, and the current geology of the park, is intimately connected to the local cultural history, botany, and zoology. Therefore, it is important to have at least a broad understanding of local geology and geological process in order to best be able to interpret other aspects of a Park's significance. Most NPS scientists are biologists by training, and although our parks preserve our geological heritage, it is exactly this heritage that frequently becomes overlooked.

It is estimated that hundreds of millions of visitors experience the national parks annually, and over one million of these visit Shenandoah National Park (Rock Outcrop Management Plan Environmental Assessment/Assessment of Effect, 2008; Thomasson and others, 2004). As a high traffic, free choice learning setting with a rich geological history, Shenandoah National Park presents an extremely important opportunity to educate the public. As NPS Rangers, it is our responsibility to take advantage of this opportunity, and provide the public with accurate, relevant, inspiring, and thought-provoking information that may, in the long run, impact how we as a society: view and treat our local, regional, and global wilderness environments; influence government policy-making; and mitigate and adapt to climate change.

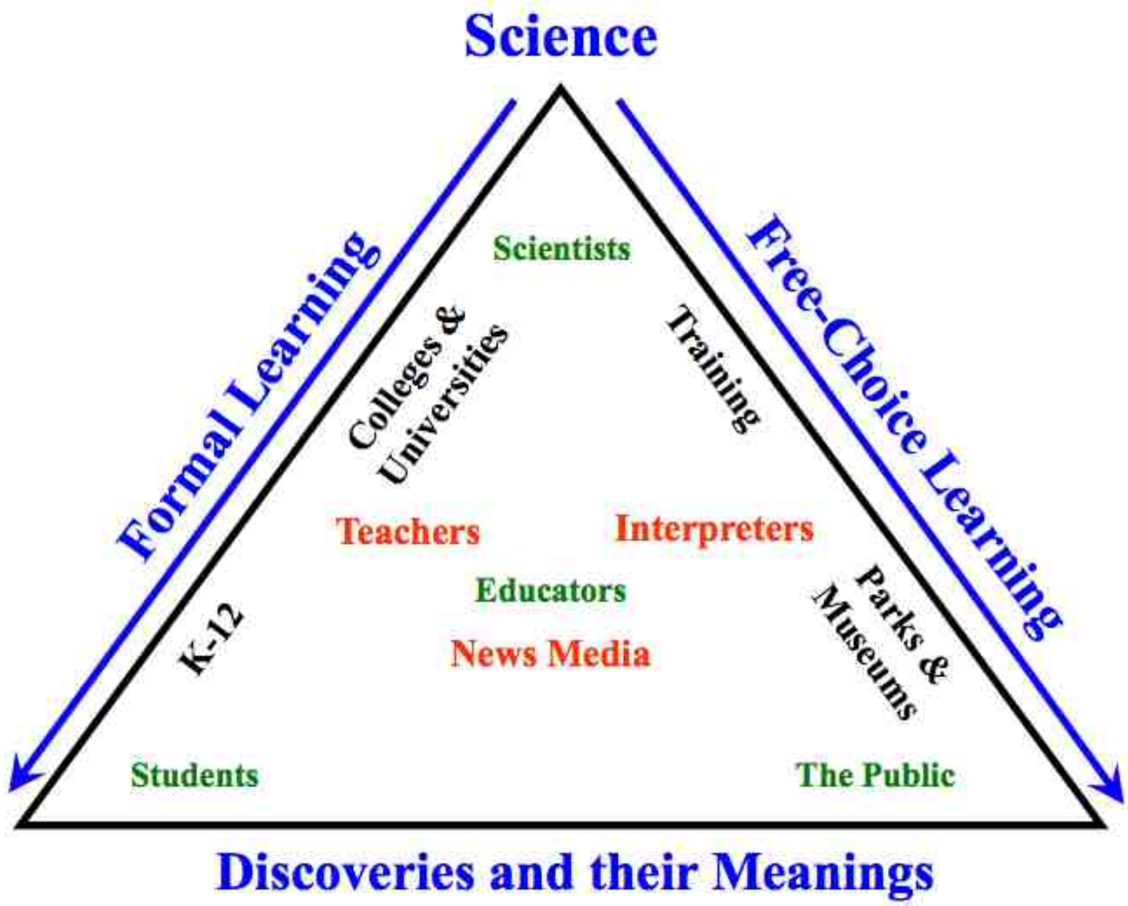


Figure 96: The science education pyramid. Science is communicated to students and the public through various conduits, including both compulsory and free-choice learning. Park rangers are interpreters who teach science in free-choice learning settings, which include national and state parks, museums, and other settings such as libraries. (Courtesy of Dr. Robert Lillie)

Figure 97: Park rangers are interpreters who can inspire the public. By revealing the connections between local landscape and other aspects of natural and cultural history, park rangers help visitors forge their own intellectual and emotional connections to park resources. (Photograph courtesy of the National Park Service)

<u>How do we do Interpretation?</u>

> *"Interpretation is a cohesive development of a relevant idea that creates opportunities for visitors to form their own intellectual and emotional connections to the meanings inherent in the resource." – National Park Service*

How do we actually do interpretation? In order to help the audience experience an enjoyable learning opportunity, there are several basic formulas that should be followed. Like climbing the steps of a ladder, you build the interpretive opportunity one step at a time.

Basic components to consider

The National Park Service uses a formal interpretive method (NPS Interpretive Development Plan, 2008). The interpretive method uses building blocks to help shape an interpretive opportunity. These building blocks are tangibles, intangibles (including universals), and an interpretive theme. Tangibles are actual physical objects, resources, or observations that exist within the setting of the program. Examples of common tangibles within Shenandoah National Park are the basement complex granitoids, or copper within a piece of Catoctin formation greenstone. Scientific intangibles are conceptual meanings derived from observing and studying those tangibles, for example: pressure within Earth's crust; changing landscape, or geological processes such as mountain building or uplift and erosion. Some intangibles are universals, meaning they are common concepts experienced by and understandable to everyone. Examples include time, beauty, love, home, change, death, happiness, and power.

A theme is a complete sentence that is a statement linking tangible park features to their intangible geological or universal meanings. The theme statement is the basic message conveyed during a ranger program, and answers the "so what?" question. A theme statement is used for every ranger program and helps to clarify the purpose of the interpretive opportunity (Figure 98). You can develop an interpretive program by choosing certain tangible park features and significant intangible meanings that you would like to convey – especially if they are things that you yourself are fascinated by! Your own interest in the subject matter will greatly increase the quality of your program. The goal of an interpretive program, such as a ranger talk or hike, is to increase the audience's understanding of a topic by increasing information, observations and meaning (relevance). Throughout your ranger program, both of these should be presented to the

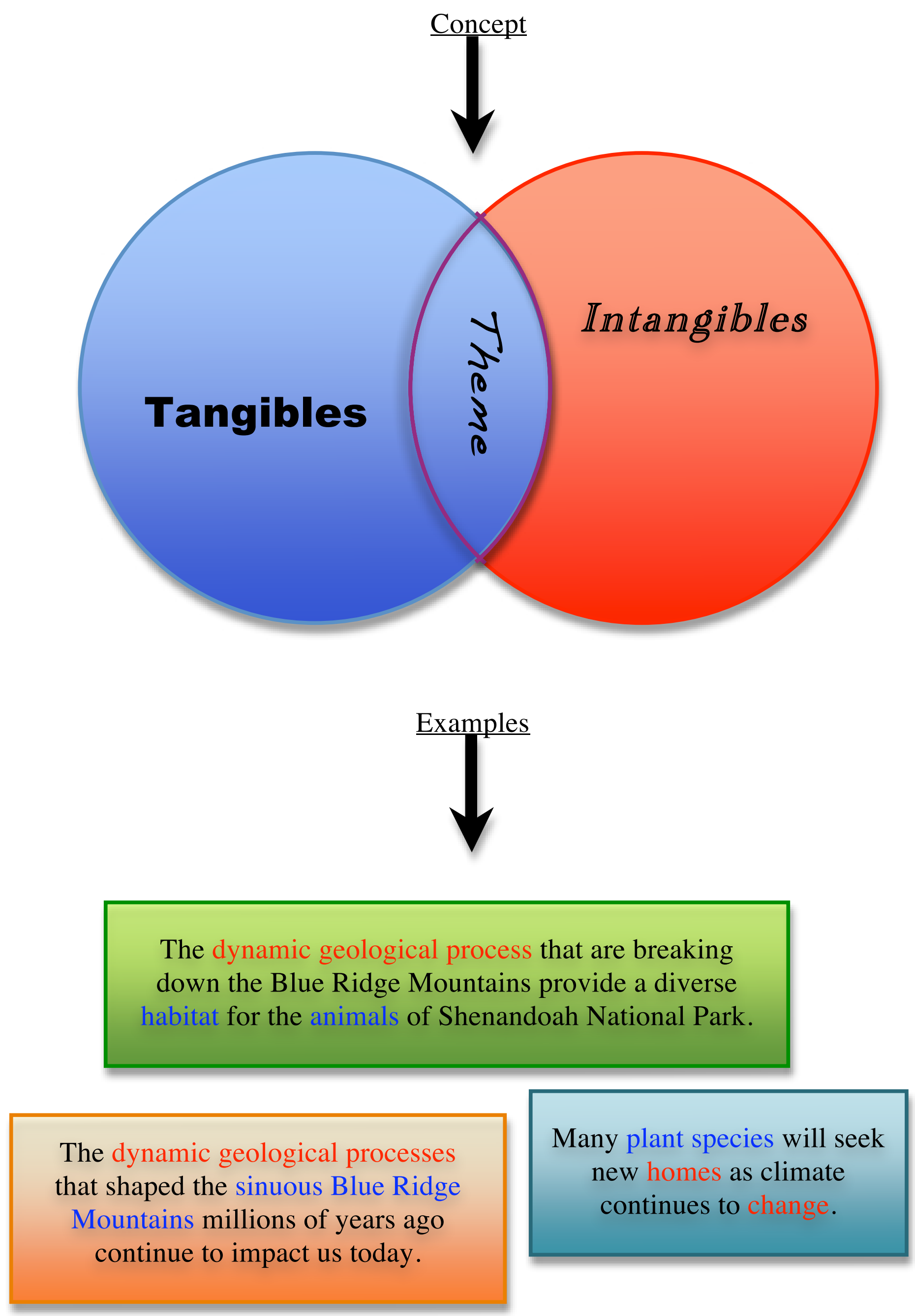


Figure 98: Develop a theme statement by linking tangibles with intangibles. Tangible park features, like rock outcrops or boulder fields can be linked to their intangible meanings or significance within a theme statement that shapes the interpretive program.

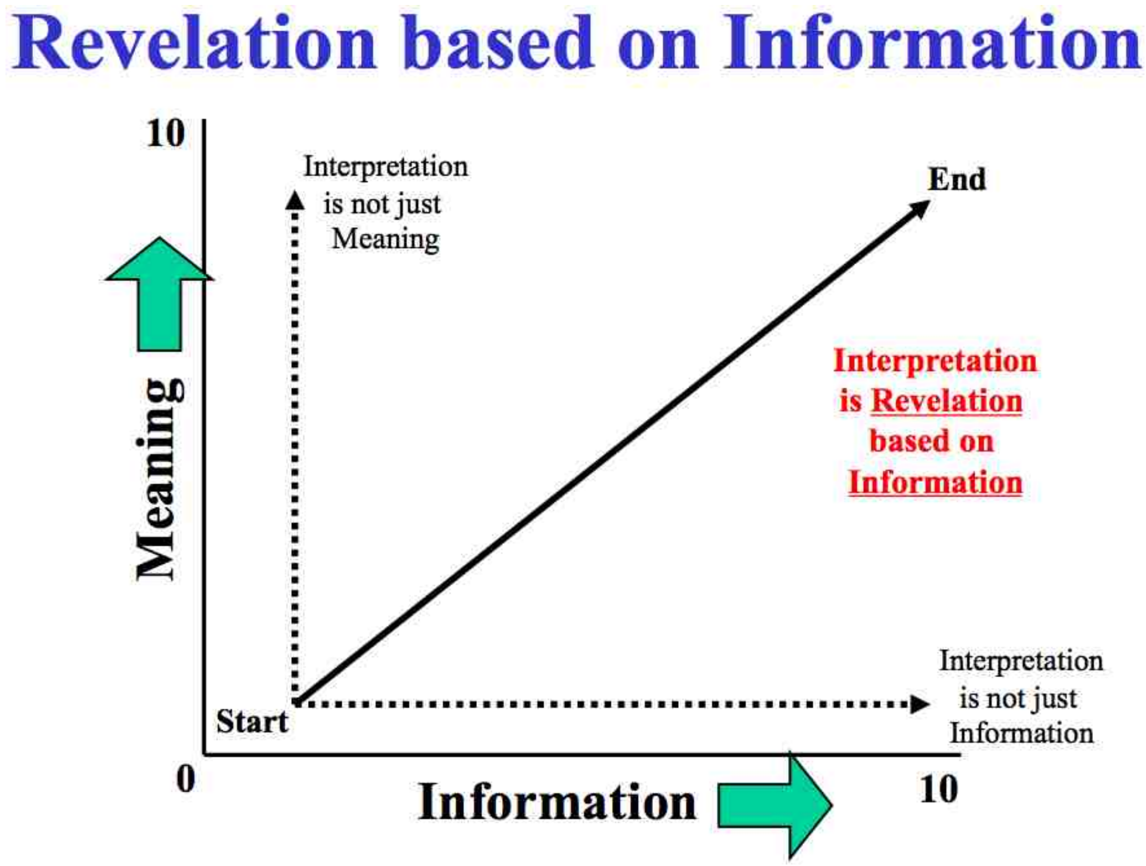


Figure 99: The goal of interpretation is revelation based on information. At the beginning of an interpretive program (marked 'start'), the audience may have little knowledge or understanding of the meaning of the resource. As the interpretive program begins, the park ranger provides the audience with opportunities to make intellectual and emotional connections with the park by discussing information (facts, numbers, data) about the park resources and meanings (concepts, significance) of that resource. By the end of the program, park visitors have a better understanding of, and an appreciation for the park resource. (Courtesy of Dr. Robert Lillie)

audience to help encourage 'revelation based on information' (Figure 99). Research your topic carefully so that you can present accurate information to your audience. Involve your audience so that they feel connected to the information and the interpretive experience. Occasionally you will encounter a park visitor who is an expert in the very subject matter you are presenting! Situations like these can be great opportunities to increase your own understanding of the subject and increase the public's understanding by weaving in the audience's contributions to your program. During the program, climb the ladder of successful interpretation by constantly linking the intangible concepts to tangible objects (Figure 97). Be sure not to overwhelm them with too much detailed information, because this can lead to a boring program. Provide concepts and thoughts that are backed up with solid, tangible objects, viewable sights, or actual data.

Build the skeleton of the program you are developing by considering tangibles, intangibles, and your theme. Next, you can use a couple of formulas to help you structure the program so that visitors can more easily make intellectual and emotional connections to the park resource. A visual formula for interpretive success is called the PAIR equation developed by ranger Allyson Mathis from Grand Canyon National Park (Mathis, 2009). This equation 'pairs' visitors with national parks by helping interpreters structure meaningful and effective programs (Figure 100). The concept is that each of four links help to form a chain that will break if any one link is weak. A strong chain will lead to a successful interpretive opportunity. The PAIR method requires that you, as an interpreter, must consider each link, or the different factors that make up a program. Know and understand the specific presentation setting, have a good idea of who your audience will be, know which interpretive methods you are going to apply, and most importantly, understand the subject or resource about which you are going to speak.

Each link of the chain is variable, meaning that there are a number of workable combinations that can lead to a successful interpretive program. For example, (A) audience characteristics (i.e. age, prior knowledge) are extremely variable and should shape how you intend to develop and deliver a program. The presentation setting (P) could also vary, as you may be giving a seated campfire program, or an athletic 2-hour mountain hike. There are many different interpretation methods (I) that you can use as a park ranger to enhance your program. You might engage the audience by using the story telling technique, or you might ask your audience to imagine a situation or setting

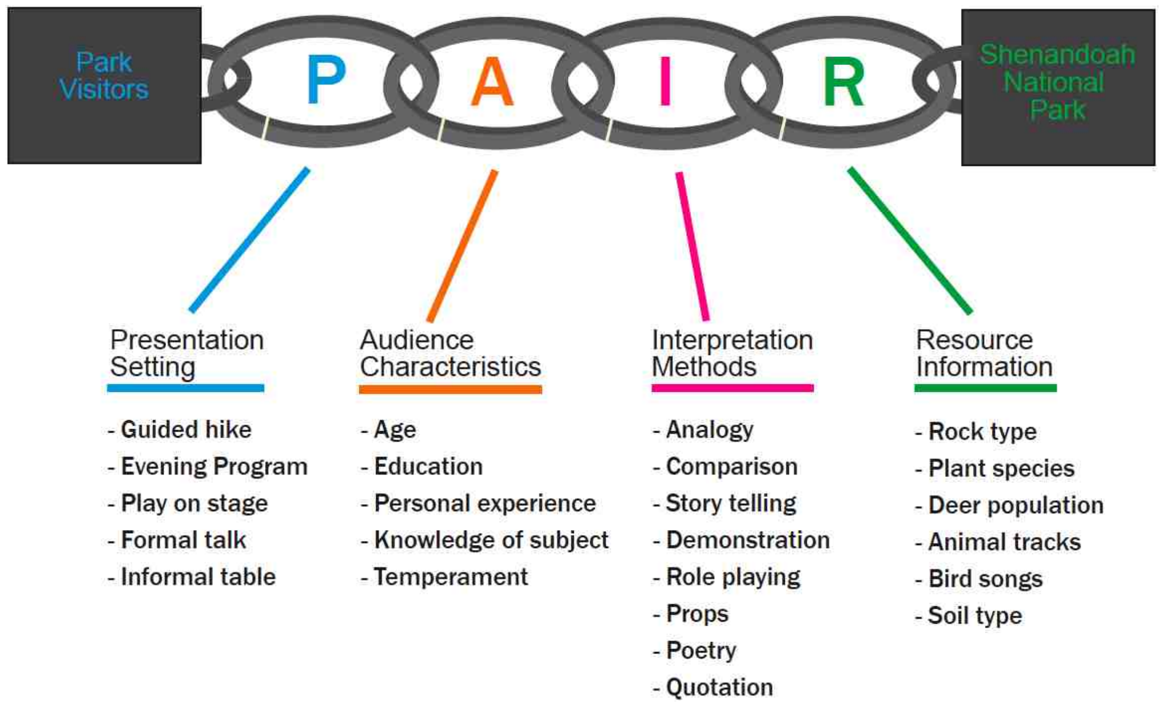


Figure 100: Use the "PAIR" method to develop an interpretive program. Each link in the chain represents an important component of developing a ranger program. A chain is strong and flexible, yet when one of the links is weak, the chain breaks! (Adapted from Mathis, 2009)

(such as a dynamic landslide, or the ancient Shenandoah landscape barren of all plants) in order to better make intellectual or emotional connections. The park resource (R) that you are centering your program around is also variable. You may be presenting a ranger program on rocks and soil, animal tracks left behind in the mud, or dynamic geological processes and how they exposed the once deeply-buried basement complex. Each of these components are important to consider and when combined, will shape a unique and engaging ranger program. If each of these components is well thought out, then your interpretive opportunity should be fun and effective. If any of these four components is lacking, than the interpretive opportunity may not be as effective or fun for either yourself or your audience.

Another useful interpretive tool is an equation, such as the one developed by the National Park Service:

$$(Kr + Ka) \times AT = IO$$

In the NPS interpretive equation, a knowledge of the resource (Kr) added to knowledge of the audience (Ka) together with an appropriate interpretive technique (AT) will lead to an interpretive opportunity (Larsen, 2003). Note the similarities between the PAIRing model and the NPS interpretive equation. The "P" and "I" represent the "AT," while "A" corresponds to "Ka" and "R" is the same as "Kr". The entire chain represents the Interpretive Opportunity "IO". Elements of the PAIRING model as applied to geology interpretation of Shenandoah National Park are discussed below.

P – Presentation Setting

Perhaps the most obvious and important component to successful, enjoyable interpretation is considering your setting. The physical surroundings and physical props that a visitor interacts with during a visit to Shenandoah National Park can greatly influence their learning experience (for example, Falk and Dierking, 2000). If the trail along which you are hiking is narrow and busy, and you have a large group of visitors, you may need to modify your program stops so that passing visitors and lack of space do not interfere with their ability to engage in the program. Also avoid 'decontextualizing' your program by introducing tangibles that are not relevant to the setting. For instance, avoid bringing up rock formations that you do not have samples of, or that do not contribute to your overarching theme.

<u>A – Audience Characteristics</u>

As interpreters, we hold a unique position in which to educate and influence the public. Interpreting geology within the setting of a national park means that you are sharing science with a diverse audience. Visitors to Shenandoah come from all over the world, carrying a variety of previous experiences, perspectives, and biases (for example, Falk and others, 2008). Gaining a general knowledge of your visitors can be beneficial to program development. Research suggests that both personal (age, identity, motivation, interest, emotion, prior knowledge and experience) and socio-cultural aspects (belief systems, social class, social norms, social structure, interaction, schooling, and cultural background) can influence how visitors learn outside the classroom (Falk and Dierking, 2000). Factors such as these should influence how you might develop and deliver a ranger program. For example, before and during ranger programs, consider your visitor's prior knowledge and experiences. Perhaps one of your visitors has stood within the great Rift Valley of eastern Africa, or seen lava flowing from a Hawaiian volcano. Memories such as these can be very powerful and, when linked to aspects of your program, enhance visitor's ability to make intellectual and emotional connections to the geological story of Shenandoah National Park.

Socio-cultural and personal perspectives of park visitors may also present challenges. Discussing certain geological topics, such as geologic time, the age of the earth, evolution, and climate change, can be more challenging than discussing other topics due to the variability of audience personal backgrounds and belief systems. As park rangers we represent the federal government and have a responsibility to deliver accurate and unbiased scientific observations and interpretations to the public. In cases such as these, it is important to maintain that perspective, but remember that our job is not to force the public to agree. Agreeing to disagree or reaching a similar unemotional stance is appropriate. See Appendix B "Interpreting Geology", "What is Science?", "Interpreting Geologic Time and the Age of the Earth", and "NPS Policy, Interpretation, and Creationism (including "intelligent design")" for suggestions of how to address these topics.

Knowledge of the audience also means being aware of their basic needs. At the very beginning of your program as you wait at the trailhead, greet the growing crowd of visitors and think about Maslow's hierarchy of needs (Figure 101). Something as simple as needing to take a restroom break, wearing uncomfortable shoes, or not knowing what to expect from the ranger program can cause a distraction and decrease the opportunity for an effective interpretive moment (for example 'rules of behavior' in behavior settings, Falk and Dierking, 2000). Give an introduction to the program to orient first-time visitors so that they feel comfortable and know what to expect. Include a safety message to inform visitors about poison ivy, deer ticks, slippery rocks, or other hazards along the way so that visitors feel aware. Bring a first aid kit and inform the audience that you carry one to help the visitors feel safe. Quickly check for sandals and recommend closed-toed shoes if you are planning on delivering hiking program and give visitors the opportunity to change their shoes, get a rain jacket, or visit the restroom before you begin.

Once the basic needs are seen to, you can really begin the program. Help visitors 'ascend' the needs pyramid (Figure 101) by making them feel as though they belong. Remember and use visitor names, encourage and reward participation, and be enthusiastic about this awesome experience and the group of wonderful and diverse people who are joining you. Next, provide visitors with opportunities to make their own intellectual and emotional connections with park resources. Let your own passion for the subject drive your enthusiasm and dialog. Encourage conversation, provide data, pose questions, and make opportunities for visitors to pursue concepts beyond the scope of the program by recommending relevant readings, and resources.

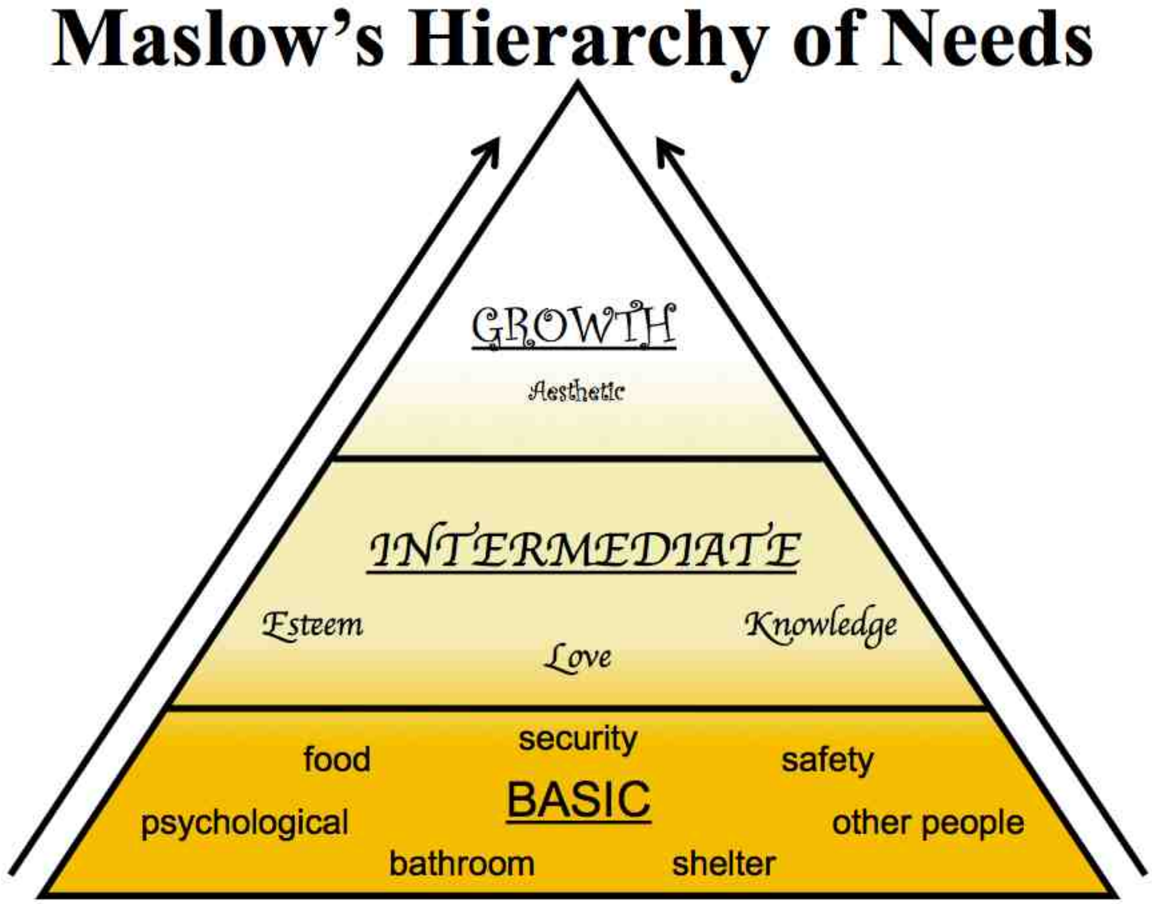


Figure 101: Addressing Maslow's hierarchy of needs. Before giving an interpretive program, it is wise to pay attention to the basic needs of your audience. It is only when they are physically and psychologically comfortable that they can ascend the pyramid and make intellectual and emotional connections with the park resources.

I – Interpretive Methods

By implementing an interpretive technique that is appropriate for the physical setting, resource, and audience you can increase the effectiveness of your program. For example, you may choose to use story telling at the beginning of an evening program to capture the imagination of your audience. Sometimes using an analogy or comparison can help clarify a complex geologic concept. Using food analogies, such as an Oreo cookie to demonstrate the upper layers of the Earth and plate tectonic motions is always a hit and great for educational or Junior Ranger programs. It may be helpful to employ other hands-on activities to help engage children during Junior Ranger programs.

The diversity of visitors also means that you should consider delivering a diverse program. Try to appeal to auditory (learn by hearing), verbal (learn by reading), visual (learn by seeing), and kinesthetic (learn by interacting) learners by incorporating different interpretive techniques. In general, people retain 10% of what they hear, 30% of what they read, 50% of what they see, and 80% of what they do. Try not to simply talk at your audience! Consider bringing along a variety of props. Presenting simple, hands-on activities, such as using Oreo cookies to demonstrate Earth's layers and the motions of tectonic plates, or folding colored silly putty layers to demonstrate rock deformation and geological principles (such as original horizontality – the concept that rock layers are typically deposited horizontally, and must have been deformed in some way if they presently are tilted, folded, or not in a horizontal position) can help engage kinesthetic and visual learners. Reading from typed, poetic quotes that capture the dynamic nature of the Shenandoah landscape can appeal to verbal and auditory learners.

R – Resource Information

Developing and delivering an effective program requires that you, as a ranger, have a solid understanding of what it is you are going to talk about. The previous chapters of this thesis have provided both a summarized and thorough review of the regional and local geology and it's impact on other aspects of Shenandoah National Park. Use these chapters to help fortify your current knowledge of the park and its geological and related resources.

The resource is not simply the physical rock outcrops or trees, but the entire landscape. This landscape is the setting for your ranger programs and can influence the visitor's experience and their ability to learn. By being more knowledgeable about the physical program setting, you can improve the quality of your program.

Think of standing in your raingear on a chilly day, the rain dripping down your cheek, your feet in a puddle of mud, straining your ears to hear your park ranger discuss the intricacies of climate change impact on shifting species assemblages while a group of hikers push past you on the narrow trail. Now imagine sitting in the shade at a beautiful summit on a warm, clear day, a pleasant breeze keeping the bugs at bay, and easily hearing an interesting conversation about what kind of tracks bobcats leave behind. Which scene would you prefer?

B. Developing geology in ranger programs

You do not need to be a professional geologist in order to appreciate and deliver geology ranger programs. Because so many other aspects of the national park tie directly or indirectly to geology, it is a great way to round out any interpretive topic. Because science literacy develops over time, the more frequently national parks provide dialog and interactive opportunities, the greater the likelihood that foundational scientific concepts will become established within the general public (Ash, 2004). Incorporating an aspect of geology within ranger programs can help visitors understand the intricate connectivity of the natural world, thus increasing public science literacy. An increased understanding of the scientific or natural world leads to a greater appreciation for it, and thus the motivation to protect our National Park resources.

Developing geology-based programs

Developing and delivering geology-based programs should not be like teaching a geology school-room class. A variety of activities can be performed (especially in junior ranger programs) that present interpretive opportunities to reveal the significance of the local geology and integrate geological concepts with everyday life. Making analogies between the park's natural resources and humans can be useful because visitors can compare the unknown with their own experiences (Ash, 2003). For these family activities, social interaction is extremely important to learning. Involve parents in Junior ranger programs – the interaction and dialog they have with their children may help children learn by increasing science dialog that can lead to increases in science literacy (Ash, 2004).

Geology-based Junior Ranger programs can include activities about learning to 'shape the landscape' by making silly-putty molds of the mountains and asking the question: Why are the valleys low and the mountains high? This can open interpretive opportunities to discuss variable rock types, the processes of weathering and erosion, people of the past, bigger-picture concepts such as tectonic uplift and isostasy, and the opportunity to take visitors on a journey across the world by comparing our mountains to other mountain ranges on Earth. This strategy teaches visitors about geography and leads to a better appreciation of their own home landscape. Ranger programs like this can also begin with a foundation of geology and then branch out into flora, fauna, and cultural history of the Park. For example, discussing rock types within Shenandoah can reveal connections to plant diversity through soils, groundwater, and elevation.

For stationary Junior Ranger or Ranger Insight programs, visitors can learn how to create a topographic map and thus better understand its usefulness by actually making one. In this activity, use silly-putty to shape a mountainous landscape within a plastic tub, pour in water until the tub is ¼ full, then use a soft (waterproof) marker or wax pencil to draw a line where the water meets the putty landscape. Pour in more water, until the tub is ½ full and redraw. Repeat this process until the landscape is completely underwater. Empty the water and then place a piece of rigid clear plastic overtop of the tub. Looking down from the top, draw on the plastic the trace of each topographic line. The plastic sheet is now your topographic map – a two-dimensional representation of the 3-dimensional landscape. These supplies can also be purchased as map-making kits online from educational supply companies.

Integrating geology into other programs

Most ranger programs are not based on geology. Many integrate multiple topics and concepts, including cultural history, local flora, and local fauna. These programs provide a great opportunity to stress the connectivity between different fields of study, reminding visitors that our planet is connected in ways that are sometimes hidden.

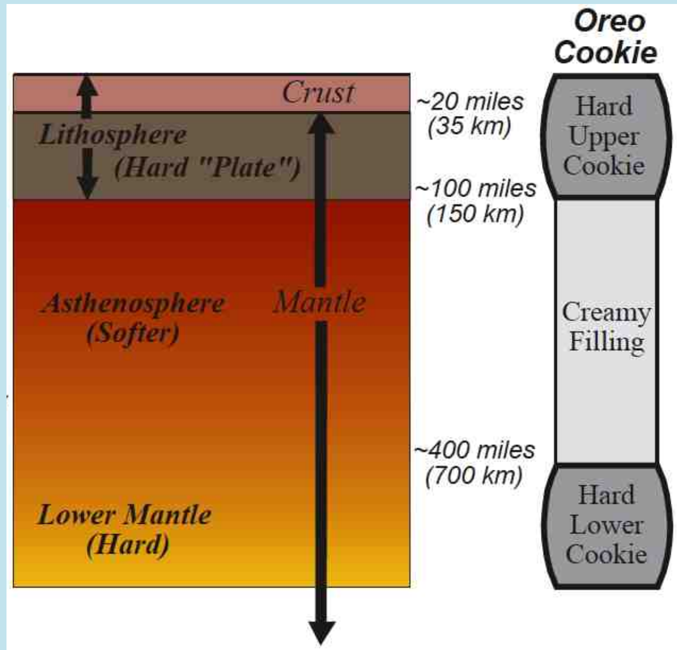
I encourage park rangers to experiment with integrating geology in some way into their own programs. For education programs, incorporating big picture ideas is a great way to weave geology into activities. For example, simply proposing the question: Where are we? can ignite a conversation and activities that reveal Earth's variable layers, plate tectonic motions, and the dynamic nature of Earth over the geological timescale. This question can also link geology to Earth's climate zones, soils, and plants of the high mountain elevations. The question: Where would you live? brings about discussion of rocky habitats, recent erosion and glacial cycles, climate change, and threatened or rare species of Shenandoah National Park.

Another fun activity is map making. In my experience, many individuals do not fully understand the usefulness of topographic maps as a safety tool. Map-making activities are perfect for non-stationary Junior Ranger, short hikes, or educational programs. Have visitors make a map by drawing out your path of travel during a hike. Each visitor should have a compass, a couple sheets of graphing paper, and a pencil. As you hike a short trail, have visitors estimate the directional curve of each turn using their compass. Also mark landmarks along the trail to help visitors pay attention to the significance of their surroundings. This is also a safety activity, providing an interpretive opportunity to educate the public about using a compass and wilderness awareness during outdoor exploration. This activity can address big-picture questions such as: Where are we, and where are we going? These questions open opportunities to discuss topography, changing landscapes, and plate tectonics.

Below are four different example ranger programs (an evening campfire program, two hikes, and a ranger insight talk) that are both geology-based and non-geology based. Outlines for these programs should also be available in the park archives. These provide ideas for IDP format, geology-based and non-geology based interpretive programs specific for Shenandoah National Park.

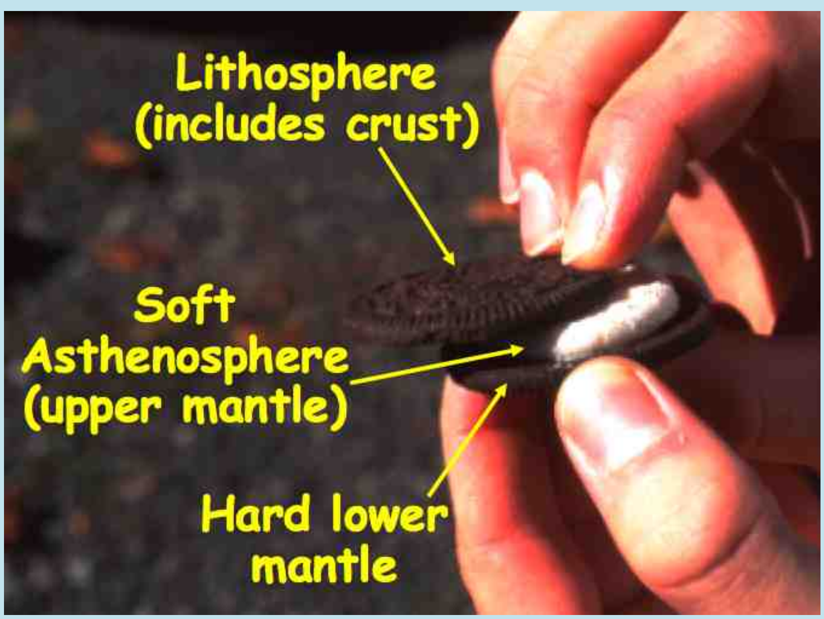
Rocks and Props

Some activities for ranger programs can really help visitors make intellectual connections to Shenandoah's natural history. Short, visitor-led demonstrations can be useful during ranger hikes. For example:



The Oreo Cookie Analogy –

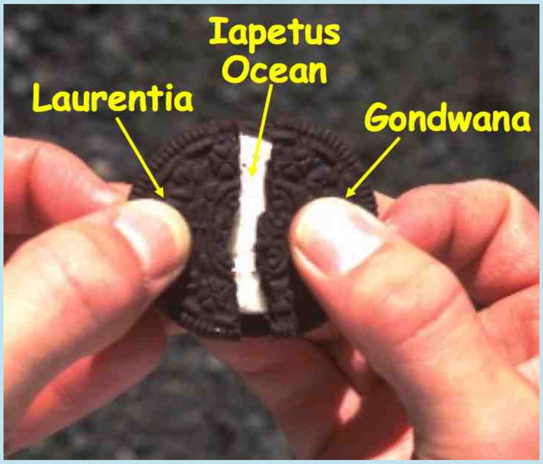
Oreo cookies can be used as an analogy of Earth's layers to demonstrate how the Appalachian Mountains formed and how tectonic plates shift along plate boundaries. The upper hard cookie represents the rigid Lithosphere of the Earth. The crust (both continental and oceanic) is part of this lithosphere.



The crust of the Earth is broken into tectonic plates that shift overtop of the softer upper mantle (also called the Asthenosphere). This layer is the double stuff creamy filling of the Oreo.

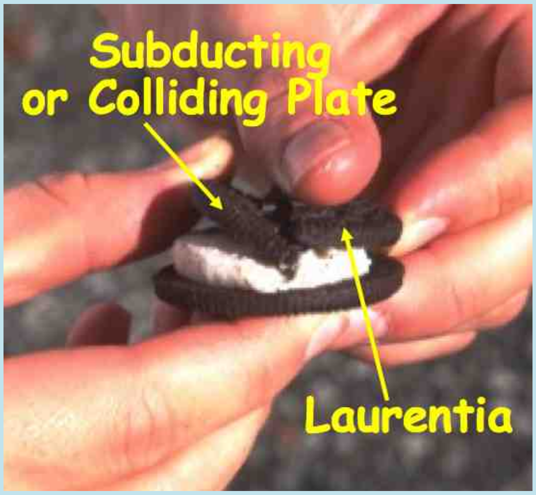
The bottom Oreo cookie represents the harder portion of Earth's lower mantle.

To perform the demonstration, give each visitor a double stuff Oreo cookie and step through the formation of a plate boundary by gently cracking the upper cookie. Next, demonstrate the motion along a divergent plate boundary by having the visitors slide the two cookie halves apart above the white creamy filling - right).



Demonstrate a transverse plate boundary such as the San Andreas Fault of California by sliding the two plate cookie halves next to each other (below).

A convergent plate boundary can be demonstrated by sliding one cookie half down into the creamy filling (the Asthenosphere) (below). This represents a subduction zone, such as the ones that pulled the Taconic Island Arc into Laurentia during the Taconic Orogeny, and the Arvonia Island Arc into Laurentia during the Acadian Orogeny.



In order to demonstrate a convergent plate boundary like the one that existed when Gondwana collided with Laurentia during the Alleghanian Orogeny, slip one cookie half directly beneath the other, allowing the cookie to essentially double in size. This process formed the Appalachian Mountains and is occurring today underneath the Himalayan Mountains.

This is a great demonstration that engages visitors and quickly conveys important concepts of a dynamic Earth and plate tectonics.

Program example 1: Interpretive Evening talk
Amphitheatre Campfire Program
Wendy Kelly
45 minute stationary powerpoint presentation
Typical audience – Middle-aged couples, families, elderly

Title:
Explore the universe to explore your park

Theme:
The unique geology of these rocky mountains can transport you to diverse landscapes across the world.

Tangibles:

Plants	Jagged mountains	Beach
Granite	Sediment	Worms
Mars	Destination	Skolithos fossils
Lava	Outer space	Landscape
Beach sand	Rift zone	Rocky mountains
Trace fossils	Earth	

Intangibles:

Geologic time	Time	Dreams
Home	Space	Memories
Travel	Global connectivity	Diversity
Exploration	Adventure	Geology
Weathering and erosion	Interconnections	

Outline:
Introductory presentation slides:
(Automatic flip through a series of paleogeographic maps that illustrate how different our Earth has been in the past compared to the familiarity of it to us now) (plate tectonics).
Welcome and introduction.

Hew far from home have you been? Slides:
Tonight, we will have a 45 minute program about exploring the universe! But first I want you to think for a minute about the home you grew up in. Now think how far from that home you have been during your life. How far from home have *you* traveled? Perhaps some of you have been to the far reaches of the globe. Perhaps some of you have only strayed 40 miles from home. Either way, tonight we are going to embark on a journey that will allow you to claim you've traveled further from home than anyone else on Earth. Our journey will take us far and wide and by doing so, will actually teach us about our own home – these mountains.

Sometimes you uncover bizarre connections between people, places or things that never before would you have thought connected. We'll be boarding our teleportation station and asking Scotty to 'beam us up' as we discover how simply being here, in this very park, allows us to explore not only far distant lands, but also perhaps other planets…

What you may find tonight is that although the places you may never have been to, some of them are closer than you may imagine… Not only that but the far distant places we'll be exploring tonight are each highly important in revealing the character of Shenandoah.

Teleportation Station transition slide:
So, let's go! Jump onto the teleportation station and you'll see just exactly what I mean…

Mars slides:
Our first destination will be Mars! You may be thinking – How does mars have anything to do with this national park, and how could we even get there? (travel to Mars using slides)
As we look across the Martian surface, how can we compare this planet to these mountains? What is the most important thing that is missing? Plants!

What is really cool is that right where we are sitting now used to look like the Martian surface over a billion years ago! This fun snapshot in Earth's history is captured in Shenandoah today by our basement complex rocks – granites and gneisses that you would have seen if you hiked up Old Rag Mountain. In this way, we can say that we have stepped foot on the surface of Mars, simply by touching the ancient rocks within Shenandoah.

Teleportation Station transition slide:
Let's travel a little closer to home now – to a place that is excitingly dynamic…

East Africa slides:
How is eastern Africa like Shenandoah National Park? Eastern Africa sits on the Afar triple junction – a massive tear in Earth's crust where three tectonic plates are pulling in opposite directions! If we were to travel there today, we would see bizarre volcanic eruptions and a harsh but beautiful landscape that is constantly changing. One feature we may see are fissures that cut through the ground – these fissures grow over time until lava spews overtop of them, flowing across the landscape. This dynamic landscape is strikingly similar to what Shenandoah looked like 570 million years ago!

Where could we go to see evidence of this? Anyone been up Stony Man Mountain? Or seen the bizarre rocks near Compton's peak or along the Limberlost trail? These rocks, called the Catoctin formation were once lava flows very similar to those we can see today in eastern Africa, because 570 million years ago, the very ground beneath our feet was tearing apart, just like it is today in eastern Africa!

Teleportation Station transition slide:
So now we can say that we have been to Africa! Let's travel now to a much more calm environment…

Florida slides:
Has anyone been to Florida? My favorite thing to do in Florida is to visit the beaches. What do you like to do when you are at the beach? I love the way it feels to squish my toes into the warm sand. If we could zoom back in time 540 million years ago, we could see this Florida-like landscape right here where we sit. Little worms would be burrowing into the beach sands on warm, sunny days leaving behind burrows.

Today, we can see evidence of this beach landscape in the Chilhowee Group rocks – hike up to Blackrock, or Calvary Rock in the southern part of Shenandoah, and know that when you see these sharp, blocky stones, you are actually stepping on top of solidified (lithified and metamorphosed) beach sand! If you look closely, you can even see the traces left behind by those burrowing worms – called Skolithos trace fossils.

Teleportation Station transition slide:
Now we can say that we have been to Florida! Now let's travel even further from home…

Scotland slides:
If you have been to this country, you know how gorgeous it is. This landscape is uniquely tied to us, right here, because hundreds of millions of years ago, the Scottish highlands were literally squished next to the Appalachian Mountains. Keep your eyes on the red dots that signify Scotland and Shenandoah National Park and you will see that as we reverse time, these mountains were once the same. In this way, we can say that we have experienced the mountainous Scottish highlands, because we have traveled through Shenandoah National Park!
Teleportation Station transition slide:
Let's travel even further away, now to a rough and rocky landscape…

Andes Mountains slides:
If any of you have traveled into the Andes Mountains, you probably saw towering, jagged, pointy, rough peaks that climbed so high you couldn't even imagine hiking to the very tops. Where can we see such a view closer to home? Right here, within Shenandoah. The Andes Mountains capture a view of what our very own Blue Ridge Mountains would have looked like when they first formed hundreds of millions of years ago. In order to see those thousands of feet of rocky, high mountains, we would have to follow their crumbled pieces as they have been carried away by the small mountain streams, across waterfalls, into bigger valley rivers, that eventually led to the ocean. Those massive mountains are now sediments that have built out the coastal plain of Virginia and the continental shelf.

So perhaps we can say that not only have we journeyed to different places within the eastern US, but that we have also experienced places elsewhere across the Americas, even more exotic locations across the entire globe. And perhaps, we can even get away with saying that we have explored the far distant reaches of our solar system, simply by exploring the land beneath our feet right here.

Final thoughts:
So again, I ask you – how far from home *have* you traveled?
Perhaps, now you will see that question in a whole new light. Perhaps, you can agree that by visiting Shenandoah National Park, you've actually had a rare opportunity to access far distant lands and times that, perhaps, you otherwise would never have visited…

<u>Cohesive Development of a Relevant Idea (CDRI)</u>
The program presented the relevant idea that: Many connections exist that tie the landscape of Shenandoah to other exotic locations, allowing us to virtually experience the world, and even our solar system, simply by hiking Shenandoah's trails.

~~ End ~~

Program example 2: Interpretive Hike
Volcano Hike
Wendy Kelly
2 hour easy hike
Typical audience – Middle-aged couples and families

Title:
Traces

Theme:
Traces are left behind by humans, other animals, and natural processes that help us better understand Shenandoah's dynamic story.

Tangibles:

Granite	Skins	Shenandoah
Mountains	Tracks	Humans
Vegetation	Ice Age	Traces
Unakite	Animals	Treasure
Boulders	Plants	Columnar joints
Scat	Autobiography	

Intangibles:

Time	Pressure	Dynamic story
Change	Heat	Natural processes
Remnants	Habitat/home	

Outline:
Welcome, safety message (ticks, wet rocks, snakes, bears, water), introduction.
Have you ever experienced the excitement of being on a real treasure hunt? Today, that is what we are going to do – hunt for clues that reveal the treasure of the Shenandoah Story.

Stop 1: A few feet below trailhead on top of the large granite outcrop.
What do you see when you cast your eyes across the mountains? The observations you are making are applicable to now – to this era of time. But can you imagine what this landscape used to look like when the rock beneath our feet was forming? What we see now – this outcrop of rock – is a trace left behind by the dynamic processes that shape our environment. Each trace we detect on this hike will help tell a story about what processes have shaped this land and what life has inhabited it. Cast your eyes across the valley once more imagine a barren landscape – no plants or animals… neither had evolved yet. When this rock we are standing on formed, that is exactly how the Earth looked. Over a billion years ago, ancient mountains of supercontinent Rodinia were squeezing together, and this rock (part of the basement complex) was a blob of hot magma slowly cooling inside the mountain's heart. As time passed, the crunching action of mountain building caused this rock to crack and up through the crack a streamer of magma. This vein is Unakite – a trace left behind that reveals a part of the Shenandoah story.

Transition:
We are going to be detectives, making observations like this along our hike. Watch your footing and consider what traces the animals of Shenandoah leave behind as we move to our next stop.

Stop 2: Next to boulder field on left
A great variety of habitats exist in the park today. Here, we have a boulder field that is a remnant from the last Ice Age. The rocks are great habitat for many plants and animals. What wildlife have you seen so far in the park? One creature that loves the rocks are our snakes (explain two poisonous types, safety reminder). How might we know whether a snake had been through this boulder field? (show snake skin). What other animals might enjoy the rocky outcrops like this? What are other common traces that animals leave behind? (pass out scat, tracks, images)

Transition:
Now consider traces that humans can leave on the landscape.

Stop 3: Large dying oak and old cattle paddock
Before Shenandoah was established in 1935, this land was used by people. Look out into the woods – what do you notice? The undergrowth is minimal, trees tend to be relatively young with the occasional large oak tree. How might people have used this spot of land? This may have been a prime location for a pasture. If we search, we can find these pockets of land throughout the park that once were cleared by the mountain people hundreds of years ago (potentially introduce local wild medicinal and wild edible plants, and the use of fly poison).

Transition:
Now think about how animals might leave traces in the landscape as we walk to our next stop.

Stop 4:
Bear scratch on birch tree
Like mail delivered at the post office, many animals leave traces on the landscape for other animals to read. Humans can also read some of these traces. Here is a great sign left behind by a black bear. The scratches are a territorial marking that leaves the message "this is my spot!" (this is a great interpretive opportunity to pass around bear claws, and discuss how the Shenandoah bears interact with the rest of the environment).

Transition:
From now on, we will look at some ancient traces left behind by Mother Nature. Can you think of a kind of trace that might have been left behind hundreds of millions of years ago?

Stop 5: Outcrop of Swift Run Formation directly next to and behind the bear scratch tree
We can think of the Earth as a giant animal that also leaves many traces through time. For example, if you look at this rock up close, you can see that it is made up of billions of tiny fragments of rock. These fragments - rocks, pebbles, and sand grains once broke free from ancient mountains and traveled down an ancient river. They were lithified (like being cemented) together into a rock that is today called the Swift Run Formation (this is a good opportunity to bring up plate tectonics and the processes of weathering and erosion). Rock outcrops like these are also traces that reveal the secrets of Earth's (and Shenandoah National Park's) geologic past.

Transition:
A the next stop we will see traces that take us all the way to Iceland

Stop 6: Massive outcrop of Catoctin Formation greenstone

Sometimes simply the shape of an outcrop can tell us its story. The columnar jointing in this rock tells us that it formed when the landscape was dramatically different than it is today. 570 million years ago, an ancient supercontinent, called Rodinia, was ripping (called rifting) apart. As it did, thousands of feet of lava flows poured over the land. Look how big this rock outcrop is - can you imagine standing in this spot surrounded by hot, steaming lava flows? (pass around images of Iceland or East African rift zone and associated lava flows) When this lava cooled it was basalt and looked just like many rocks you would see if you traveled to Hawaii today (pass around rock sample of Hawaii basalt). Since then, the rock was heated and pressured by the collision of many small landmasses and continents that squeezed together these Appalachian Mountains. The metamorphism altered the basalt into the grey-blue greenstone rock we see today.

Transition:

We'll take a closer look at the shape of these columns just down the trail

Stop 7: Columnar joints in small outcrop on right side of trail

At the last stop we mentioned how the basalt was squeezed and metamorphosed, but these rocks were not squeezed so much that they lost their awesome columnar jointing features. Columnar jointing occurs as lava cools – slowly it contracts forming cracks that extend down through the lava flow as it continues to cool completely. This feature is very distinctive of lava flows, so even though we are at the top of a mountain, this very rock is a trace, or clue, that geologic time has left behind telling us that once, lava covered this landscape.

Transition:

At the next stop we can see exactly where that lava spewed up from the ground

Stop 8: Spatter cone traces within large outcrop on left

Many of the traces we have seen along the trail have been very old – geological in age. In geology we say "the present is the key to the past" meaning that geological processes occurring today were likely occurring in the same way hundreds of millions of years ago. Therefore, when we visit a location like Hawaii and watch volcanic flows and eruptions, it helps us to better understand the ancient volcanic rocks in our own backyard. Within this boulder we see a bizarre pattern. This trace was left behind as blobs of lava shot out of what is called a spatter cone along a fissure. The blobs cooled a little as they flew through the air and then plopped onto the ground holding a little of their shape. As time passed, all of these blobs accumulated in a pile near the fissure. Today, what was the spatter cone has been squeezed, transported, and cracked in half, exposing a great fresh surface of ancient spatter! It's amazing what we can discover when we take a closer look at our surroundings.

Transition:

Let's ponder what kind of traces nature is leaving today as we hike to our last stop.

Stop 9: Giant cliff of Catoctin Formation greenstone

This massive cliff was once solid lava. It is a trace that helps us understand how much lava actually accumulated over the ancient Shenandoah landscape - over 2,000 feet of lava flows! Flows like this filled low topography when it first spread across the land, but today these rocks form the very crest of the Blue Ridge Mountains. It is a reminder of how dynamic nature can be.

Conclusions:
Think of all of the traces we have seen along this hike – traces that would have been easy to overlook, but when we open our eyes, it is amazing what secrets these mountains reveal about the recent and ancient life and processes that continue to shape our experience at Shenandoah National Park.

Cohesive Development of a Relevant Idea (CDRI)
The program presented the relevant idea that: Animals, plants, and rocks leave behind traces of the past that tell the autobiography of the changing landscape in Shenandoah National Park.

~~ End ~~

Program example 3: Interpretive talk
Insider's Insight
Wendy Kelly
20 minutes, free choice topic talk, stationary, outdoors
Typical audience – elderly, families

Title:
Reading the Blue Ridge Mountain Autobiography
or
Phases of life and landscape

Theme:
Just like us, the Mountains of Shenandoah National Park have experienced different phases of life that leave stunning, life-altering impressions.

Tangibles:

Rolling Mountains	Sandstone	Granodiorite
Hard rocks	Quartzite	Shenandoah NP
Landscape	Fossils	
Streams	Greenstone	

Intangibles:

Stress	Time	Rifting
Calm	Individuality	Erosion
Home	Continental drift	Weathering
Life	Tectonic plates	Phases
Power	Rock Cycle	Life-altering
Change	Mountain building	Impressions

Interpretive Techniques: Personal reflection, description, explanation, comparison/ contrast, personal narrative, map, rock samples, word choice, questioning

Outline:
Earth is alive. Like us, the Blue Ridge Mountains have experienced many different phases during their life. Every phase of life experienced by these majestic mountains has left its unique imprint, and has been captured within the main rock types of Shenandoah. The Blue Ridge Mountains display those phases like chapters in an autobiographical book that is just waiting to be read! Let's read the BRM autobiography!

Four main phases have shaped this landscape into the current Blue Ridge Mountains, what are the main changes/phases that have shaped you?

Phase 1: Childhood
Approximately 540 million years ago, this very spot was a calm, warm beach. The predecessor to the Atlantic Ocean – the Iapetus existed close by (show tectonic plate images), creating a calm relaxing landscape in which sediments provided a home to creatures, including the worms (annelids) that created these scolithus tube trace fossils (show sandstone/quartzite). These worms loved to burrow down into the warm beach sands looking for food (show trace fossil rock or

picture). Can you think of a phase in your life that is similar to this calm phase of the Blue Ridge? I like to parallel this phase to childhood – calm, relaxing, and simple, nothing to worry about!

Transition: Can you think of another life phase that was a bit more stressful as you were growing up?

Phase 2: Puberty
This very land was also ripped apart about 570 million years ago, allowing hot ash and 2,000 feet of steaming lava to flow overtop of the landscape (show Hawaii basalt sample with vesicles). This is similar to the chaotic mess of puberty! A rift zone had formed tearing what will end up being Africa and South America from ancient North America (pass around global plate tectonic images).

Transition: The third phase this land has experienced is perhaps even more dramatic than that of puberty… Have you ever experienced a phase of life when you were under extreme pressure? How did it affect you?

Phase 3: Adulthood
The Blue Ridge Mountains were put under tremendous heat and pressure multiple times over the past billion years. Tectonic plates crunched together folding and faulting the older rocks, pushing up the mountains to amazing heights. Sometimes us humans can achieve marvelous things when we are under pressure - like publishing a paper, raising children, or preparing a presentation. These mountains are no different. Under the pressure and stress forced on them by other continental plates, these mountains pushed their way up to the skies, similar in height to the current Himalayas. The heat and pressure formed rocks like the granites found in the park (show basement complex). Formed deep in the heart of the mountains, the rock cooled slowly, allowing big crystals to form. It was also due specifically to this pressure that veins of copper, unakite, and quartz amygdules formed. This phase reminds me of adulthood. The pressure of responsibility from a boss, supervisor, or advisor, but the opportunity to do and create great things!

Transition: Do these mountains look like the Himalayas today? They don't because over the past 300 million years, these mountains have been experiencing a new phase of life.

Phase 4: Retirement
Finally, another more-subtle phase of life these mountains have experienced is that of weathering and erosion. The Blue Ridge is experiencing this phase today! No more pressure of mountain building, the mountains have surpassed their more active phases. Now these mountains are very slowly wearing down. As they do so, the old rocks (like granites) that formed in the heart of the mountains are exposed at the surface. Has anyone hiked up Old Rag? Some of the rocks that form the very crest of these mountains today, once were deep underground. Weathering and erosion breaks up the rock and carries it away. How is it broken up? Have you seen signs of this on other trails? Where does the rock go? Has anyone been to New Orleans? What about the Chesapeake, or Virginia Beach? The mountains are weathered and eroded by many processes including harsh freeze-thaw cycles, root wedging, and even the acidic enzymes secreted by lichen. What human phase best compares to this? I think retirement is appropriate – no more stress of a career, freedom to go where you please, extended vacations, relaxing!

Final thoughts:
The rocks of Shenandoah National Park capture the phases of life of the mountains like chapters in a book. Each phase has left a unique impression on the landscape that is ironically similar to the phases of life that we humans experience. The protection of this rich landscape allows us to read and appreciate this autobiography of the mountains. What phase of life are you in?

Cohesive Development of a Relevant Idea (CDRI)
The program presented the relevant idea that: The mountains of Shenandoah National Park are constantly changing through a life cycle that is similar to the phases that humans go through in life.

~~ End ~~

Program example 4: Interpretive hike
Little Stony Man Hike
Wendy Kelly
2 hour moderate hike
Typical audience – middle-aged couples, families

Title:
What lay underfoot

Theme:
Many things we may or may not notice under our hiking feet reveal the four dimensional aspect of Shenandoah's story

Tangibles:

Granite	Black Bear	Steam
Crystals	Snake	Hemlock Wooly Ad.
Mountains	Bats	Gypsy Moth
Appalachian Trail	Columnar Jointing	Scat
Basalt	Shoes	Feet
Greenstone	Insects	4-dimensions
CCC cable	Salamander	Through-hiker
Bobcat	Rocky outcrops	

Intangibles:

Shelter	Happiness	Preservation
Pressure	Spirituality	Stress
Time	Adventure	Protection
Change	Depth	Recreation
Journey	Metamorphosis	Home
Fear	Invasive	Shenandoah's story

Program Outline:
Introduction and safety message.
Frequently we hike looking down right at our feet, as we want to avoid tripping and looking foolish. Perhaps during your life, someone has told you: "stop looking down, look up and see what you're missing!" Well, for this hike, I want you to embrace looking down at your feet because there are many things that pass by underfoot that reveal important fragments of the story of Shenandoah National Park.

Stop 1:
AT intersection about 50 feet from the Stony Man parking lot.
The Appalachian Trail is more than simply a forest path. This trail that we will largely be hiking on holds hours, days, months of fear, hope, tears, elation, and various other emotions of the thousands of hikers who have attempted its path. Imagine the physical, emotional, and even spiritual journey many hikers have taken on this trail, especially through hikers who venture the entire distance. Every step we take will place our feet atop of these experiences – compounded through the many hikers that have attempted such an adventure.

Transition:
Imagine, as we hike to our next stop, the variety of emotions a through hiker experiences along his/her journey, and think about what lies even deeper beneath our exploring feet.

Stop 2:
Lichen-covered basement outcrop on left.
This rock is the heart of these Blue Ridge Mountains. Anyone have granite counter tops? This rock is also granite, its large crystals interlocked during their growth underground. Granites like this form deep inside mountains, and here represent an ancient landscape that existed over a billion years ago. The only reason we can now see this rock, is because of the long journey these mountains have experienced – shifting squeezing, and slowly breaking down to expose what once was deep inside Earth's crust.

Transition:
Imagine what it was like to live on Earth a billion years ago when this ancient rock was forming. What other rocks may reveal part of Shenandoah's past?

Stop 3:
Stop along the rockslide to view Stony Man's face.
We'll be moving across a new rock soon – one that we can see now above us, up on Stony Man. His face, a profile reclined in the mountainside, is really a series of lava flows that spread across the landscape 570 million years ago. Has anyone visited Hawaii? Imagine that landscape here - walking across lava flows!

Transition:
The rocks under our feet hold secrets of the landscape, all we need to do is take a closer look to reveal them!

Stop 4:
Hydrothermal alteration within large basement outcrop on left.
Have you ever put your hand too close to the kettle when it was boiling? Or breathed hot steam to help clear your sinuses when you've had a cold? Just as heat and water can be healing or harmful to us, so too, can they impact the rocks. The granites here are riddled with beautiful swirly red patterns. This is jasper, which formed because somewhere close by, a large fissure (dike) opened in the ground up through which boiling hot lava flowed. As the hot lava rose to the land surface, it steamed water held within the rocks. That steaming action caused minerals like this jasper to form, tattooing the rocks.

Transition:
The journey to our next stop will take us through 600 million years of time travel!

Stop 5:
Fault between Catoctin and Basement complex.
You've just become a time traveler! We walked across a fault that puts 570 million year old rock directly next to rock that is over a billion years old. Although it is difficult to see, this fault is a very important landmark because it reveals the actual process of building the Blue Ridge Mountains. 300 million years ago, all the continents on Earth crushed together, compressing the

rocks into folds, or splitting the rocks along faults like this, along which slivers of land, like cards in a deck, slid past and piled on top of each other.

Transition:
Although all the rocks in Shenandoah were compressed, some retained some of their original curious features; see if you can find some ahead…

Stop 6:
Columnar jointing a few hundred feet beyond the fault.
Even under intense stress, we sometimes prevail. Look at this outcrop on the hill – do you notice a pattern? This is called columnar jointing and occurs when lava cools. Five, six, or eight-sided columns form as the lava cools and contracts. This pattern is so bizarre, but so distinct. We can tell by this pattern, that this rock has stood the test of time. All of these rocks in the park were squished and squeezed when the Appalachian Mountains formed. The heat and pressure from this event would have been astounding, and yet, the columnar jointing remained as the basalt was metamorphosed into greenstone.

Transition:
Think about how other things in the park may have been tested and stressed…

Stop 7:
Dead tree or rotting log a few hundred feet up the trail.
We have been walking along the trail, the passing things underfoot that impact the story of Shenandoah, but we are also carrying something *on* our feet that may impact the story. Think about all the places you have been wearing the shoes you have on. Where have your shoes been? Maybe to different lands and countries, across grazing fields and pastures, through farmland, or busy city streets. Imagine how easily even our own shoes may carry and transport seeds, bacteria, all sorts of small life forms. It truly is a small world. We travel, export, import almost everything you can imagine. How easily then do you think we could accidentally transport a tiny beetle? What about a spider egg sac the size of a pencil eraser? You have probably noticed some of the dead standing trees of decaying logs in the park. Some of these are the result of little unwanted creatures that have made a large impact. The Hemlock Wooly Adelgid, Chestnut Blight fungus, Gypsy Moth (and potentially the Emerald Ash Borer) have all majorly altered the landscape at Shenandoah simply because they snuck in uninvited.

Transition:
How else might humans have left an imprint on this landscape?

Stop 8:
CCC telephone cable exposed along the trail before the dogleg turn.
This rusting cable has been under our feet for quite some time, but we would never know it unless it popped up here. The heavy telephone cable is part of the archaeological remains of a group of young men who poured blood, sweat, and tears into making Shenandoah what it is today. The Civilian Conservation Corps planted trees, built trails, and laid cable to develop and restore this landscape into a National Park. Traces left behind reveal bits and pieces of their life, experience, and hardship. Thankfully, it is only because the mountains are eroding that this artifact has been revealed – a historical treasure!

Transition:
For a time, the CCC boys called this landscape home. What other creatures may have or do currently live in this environment?

Stop 9:
Stony rockslide on left (also on the CCC retaining wall)
This spot is home. Look at all the nooks and crannies in between the rocks that open up under our feet and into the mountainside. What great shelter! Many different species need such habitats in order to thrive in the Park. While black bear hibernate in rocky caves, bobcats and bats sleep the day away here. Snakes need these rocky areas for sunning, while the Shenandoah salamander hides from the sun underneath. What evidence is left behind by such animals that we may walk by on the trails? Scat, tracks, and skins are all great evidence of life, and reveal life habit of many different creatures.

Transition:
Our last stop is the cliffs. We have just discussed some animals that need these environments for survival – what organisms may enjoy the rocky summits that we are about to see?

Stop 10:
Top of the Little Stony Man cliffs.
Look around you. See how dramatic a place this is – wind whipping, sun and the elements bearing down on us. We may love visiting such dramatic locations for recreation (climbing), but typically, we humans don't remain long. The wind, sun, or rain usually encourages our retreat after a while! But for some organisms, this setting is ideal. Many plants and some animals need these areas for their survival. The Park has been working on a Rocky Outcrop Management Plan – a study to determine what creatures thrive in such habitats. We have discovered that untrammeled, these harsh environments are home to many species, some regionally or globally rare and endangered. In order to protect such species, the Park together with the public, needs to better understand these locations and protect them.

Final Thoughts:
Along this hike, we have uncovered many pieces of the Shenandoah story. Each step we have taken has brought us in contact with important plants, habitats, and short and long-term events. Challenge yourselves to pay attention to the intricacies that pass underfoot, knowing that what may be revealed, are the secrets of the landscape.

<u>Cohesive Development of a Relevant Idea (CDRI)</u>
The program presented the relevant idea that: With every step we take Shenandoah's story reveals itself through clues that commonly pass underneath our feet unnoticed.

~~ End ~~

PART VII - Conclusions

Interpretation can increase public understanding and appreciation of complex geological landscapes by inspiring minds to see the land as a storybook waiting to be read.

✯

As free-choice learning environments, national parks are important contributors to public education. Shenandoah National Park is an exceptional learning environment because it captures such a long period of Earth's history and a variety of dynamic Earth processes. Because of this, Shenandoah park rangers have the opportunity to improve public science literacy by communicating the significance of the park's geological features.

Shenandoah National Park is a portion of a collisional mountain range that formed through a complex series of geological events over the past billion years of Earth's history. Multiple cycles of oceans opening and closing have torn apart, and then pieced together the landscape into a patchwork quilt that is now the East Coast of North America. In the most recent collisional episode, super continent Pangea formed, crushing the East into the extensive Appalachian Mountain range. Today, the eroded roots of the Appalachian Mountains display important clues to this complex series of events that produced, and will continue to shape, the natural and cultural history of the eastern United States. Each rock type within Shenandoah National Park is thus a chapter in the autobiography of the Appalachian Mountains.

This thesis is the precursor to a geology training manual for Shenandoah National Park. Its purpose it to review the geological story of the Blue Ridge Mountains and connect that story to tangible features within the Park. Story telling chapter Part II presents an engaging overview of the big picture significance of Appalachian geology. Technical chapter Part III follows with an in-depth orientation to the geological story of this extensive and dynamic mountain range. The thesis then shifts to focus on Shenandoah National Park. Part IV is a storytelling version of the recent history of the Shenandoah region, while Part V delves into the significance of Shenandoah's geological foundations by linking park geology with other aspects of the park's natural and cultural history. The story telling portions provide park rangers with a brief, fun overview, while technical sections help park rangers increase their understanding and appreciation for the four-dimensional (space and time) processes that shape Shenandoah. Once rangers have a better understanding of the significance of the local and regional geology, the goal is that they will become better interpreters of the landscape, increase public science literacy, and inspire public stewardship of Shenandoah National Park.

The ultimate purpose of the geology training manual will be to help rangers improve public science understanding by making connections between geology and other aspects of the park's natural and cultural history. I hope that this thesis and the resulting manual will be used as a tool that will improve both new and seasoned park ranger ability to understand and appreciate the amazing national park in which they work and play. By helping park rangers 'see' the landscape, its broader significance will be more easily communicated to the public.

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Appendix A: Survey of Shenandoah National Park Rangers

In the summer season of 2010, 26 surveys were distributed to park employees, including interpretive rangers, Visitor Use Assistants (VUAs), and members of the education staff at Shenandoah National Park. The surveys consisted of three sections geared towards understanding park ranger needs for improving their interpretation of geology. The first section provided an opportunity for staff to reveal commonly asked visitor questions as well as the staff responses. This section helps reveal the interests of many visitors to the park. Frequently, questions concern locations of major attractions, such as waterfalls, the best hiking trails, and aesthetic overlooks. By tallying the commonly asked questions and responses, high traffic areas within Shenandoah may be targeted. Section II gathers information about ranger demographics including educational background. This section also asks questions concerning employee current knowledge of geological concepts important to accurate interpretation of the Blue Ridge region. Space is also provided for staff to pinpoint geological concepts that are confusing or difficult to explain to visitors. Finally, section III asks the individual to review example training manuals developed for other National Park sites around the country.

Survey results have guided the development of this thesis and will shape the training manual for Shenandoah National Park. Ranger input has helped to enrich the thesis by targeting specific geological concepts that Shenandoah staff find challenging, but are important to understand in order to best educate the public. The feedback about other National Park geology training manuals provides a foundation for developing a more effective and user-friendly manual for seasonal and permanent ranger staff at Shenandoah National Park.

Below is a copy of the actual survey that was distributed to park staff, followed by a compilation of survey results.

Shenandoah National Park staff survey

A geology-based training manual is being developed for Shenandoah National Park interpretive staff. In order to maximize its relevance and effectiveness, we would appreciate your input. You have been given an anonymous survey and a geology-based training manual (or two) from other National Parks. These manuals were developed in previous years by Oregon State University graduate students for National Park sites across the country. Your responses in this survey will greatly contribute to the formatting, content, and overall development of a training manual specifically for employees at Shenandoah National Park. Please fill out the entire questionnaire and return the survey to myself, or your supervisor by **August 1st 2010** so that the results may be collected and incorporated into the manual in a timely manner. Please write clearly and note that each of the three portions is equally important!

Thank you for your input!

Wendy Kelly

SNP Interpretive Ranger

Oregon State University graduate student

Part I: Common Visitor questions

Please list five or more of the most commonly asked visitor questions concerning trails or interests ***and*** your typical responses or recommendations to those questions.

For example:

Best trail to get away from people?
Best place to go backcountry camping?
Flattest short hike?
Best place to see wildflowers?
Popular half-day/full-day loop hike?
Etc…

Question:

Response:

Question:

Response:

Question:

Response:

Question:

Response:

Question:

Response:

Question:

Response:

Question:

Response:

Part II: Staff Background

Please circle the most appropriate answer or answers below to provide feedback on your prior knowledge (no need to look anything up, simply answer to the best of your current knowledge).

1. Age: ___________

2. What is your position at Shenandoah (VUA, Interpretive ranger, etc.)?
____

3. Number of months you have worked at Shenandoah or any other park service sites?
____

3. College degree(s) (for example, BA English, MS Biology):
____

4. Total number of Earth science courses taken (geology, oceanography, physical geography):
____
____

5. How well do you feel you understand geological processes and landforms?

not at all | a little bit | moderately | significantly

6. To my best knowledge, the Blue Ridge Mountains formed:

a few thousand years ago | a few hundred thousand years ago | a few hundred million years ago | I'm not sure

7. To my best knowledge, the primary process that formed the Blue Ridge Mountains was:

erosion by glaciers | collision of continents | volcanic activity | I don't know

8. The Blue Ridge Mountains formed:

during the last ice age | before the Atlantic Ocean opened up | after the Atlantic Ocean opened up | I don't know

9. The conclusion that Earth's climate has been changing rapidly over the past 200 years is:

well substantiated by scientific data

not well substantiated by scientific data

Inconclusive

I don't know

10. Columnar jointing occurs when:

lava is metamorphosed

lava dries

lava cools

greenstone weathers

I don't know

11. We know how old the rocks are because of:

Radiometric dating

Carbon dating

Cosmogenic age dating

I don't know

12. Shifts in climate are caused by changes in:

Earth's wobble

human activity

Earth's orbit

Earth's tilt

13. When the Appalachian Mountains first formed:

they were the size of the Andes

they were connected to Europe

dinosaurs roamed Earth

supercontinent Pangea existed

14. If I knew more about Shenandoah's geology, I would probably better understand the region's:

human history

archaeology

plant life

animal life

weather patterns

15. Do you incorporate geology into your programs? If so, how many programs and which ones? In what way do you incorporate geology? If not, why?

____
____
____
____
____
____
____
____
____
____
____
____
____

16. Are there any specific geological concepts or processes that you have difficulty explaining to visitors because you feel as though you don't fully understand them yourself? If so, please list them so that they may be incorporated into the training manual for Shenandoah (for example: "How do we really know how old the rocks are?")

____
____
____
____
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____
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____
____
____

17. In terms of geology, which props and illustrations would you like that we currently do not have?

Part III: Other National Park Service training manuals

You have been provided with either one or two geology training manuals from other National Park sites. Please comment on both the presentation and content of these manuals, as your thoughts will help shape the manual developed for Shenandoah.

1. To which geology training manual(s) are you referring? ______________________________

2. Is the number of diagrams appropriate? too few just right too many

3. Is the font size/spacing appropriate? too small just right too large

4. Is the amount of text appropriate? too little just right too much

5. Any other thoughts about the formatting or presentation?

____
____
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____

6. Please take a moment to review the table of contents at the beginning of the manual(s). Do you feel as though the breadth of material is appropriate?

7. Please take some time to read or skim one chapter or section of your manual. Which chapter did you choose?

What are your thoughts about the content?

too technical just right too elementary

8. Any other comments, suggestions, or thoughts about manual content for Shenandoah?

Thank you for your participation!

Please be sure that your survey has been completed in full and return to myself or your supervisor **by the first of August**, 2010.

If you have any comments or concerns, you are welcome to contact me directly:

kellyw@geo.oregonstate.edu

wendy_kelly@nps.gov

Shenandoah National Park staff survey results

Ranger Survey 2010 – Part I: Common Visitor questions

1. Where is the closest waterfall? (16 out of 26 respondents indicated that this was a common question)

Dark Hollow (13 – frequency this answer was given)	White Oak
Overall run (but dry in summer) (3)	

2. Best trail to see bears and other wildlife? (16/26)

Less popular trails, everywhere (13)	crossing drive (3)
check wildlife logbook at BVC (3)	morning or evening more likely

3. Best short hike for kids/elderly? (13/26)

Story of the Forest (5)	Fox Hollow
Limberlost (7)	Snead Farm
The Meadow (5)	North Marshall from mp 15.9
AT north from Milam Gap to Tanner's ridge (3)	Little Stony Man
Stony Man (2)	Dark Hollow Falls
Rapidan Road	Bear Fence (for older kids)

4. Best place to see a waterfall? (6/26)

Dark Hollow Falls (5)	Hazel River
Rose river (2)	Jones
Lewis (2)	White Oak Canyon (5mi. round trip)
Doyles (2)	

5. Best short hike to a vista? (6/26)

Hawksbill (3)	Bearfence
Stony Man (2)	Frasier discovery trail
Mary's rock	Blackrock

6. Best place to see wildflowers? (5/26)

- Meadow
- Millprong
- Skyland amphitheatre field
- In springtime on any of the trails
- Pocosin Mission

7. Best short hike? (5/26)

- Limberlost (2)
- Stony Man (2)
- Story of the Forest (2)
- The meadow (2)
- Hawksbill
- Fox Hollow
- Dark Hollow
- Miller’s Head
- Bushy Top
- AT north of Milam gap
- AT north of fisher’s gap
- Black Rock
- Rose River to unnamed falls at bridge

8. Where can I swim? (4/26)

- White oak (2)
- Cedar Run
- Rose River

9. What is there to do here? (4/26)

- Views
- Hikes

10. Best short loop hike 3-4 miles? (3/26)

- Rose river loop (4 miles) (2)
- Sugarloaf circuit hike (North district)
- Hawksbill circuit (3 miles)

11. Where can I hike an easy section of the AT? (3/26)

- Milam Gap (2)

12. How do I get to Luray caverns? (3/26)
    - Rte 211 from Thornton gap (3)

13. What plant/bird is that? (3/26)
    - Identify if possible

14. What do you do if you see a bear – are they dangerous? (2/26)
    - Look big
    - Respect them
    - don't approach they are wild animals and unpredictable

15. Best trail to see birds? (2/26)
    - Milam gap
    - Mill prong trail
    - Limberlost

16. How did big meadows get here? (2/26)
    - We do not know
    - It's been here a long time, we manage it today

17. Why the dead trees? (2/26)
    - Invasives/non-natives
    - Storms-lightening
    - Fire
    - Winds
    - Ice storms

18. Where can I see Mountain Laurel in bloom? (2/26)
    - Early June on various trails
    - Limberlost

19. Why no waterfalls along the road? (2/26)
Topography – drive built at op of ridge

20. Are there too many deer in the park? (2/26)

Deer counts	still studying this issue
damage surveys	Yes

21. Where is stony man?

22. What is the highest peak?
Hawksbill

23. Can I eat the berries?
Yes

24. Did the glaciers reach this far south?
No (VA was not covered by glaciers during the last ice age – continental ice sheets traveled as far south as the Pennsylvania turnpike and the Ohio river)

25. Good trail for geology?

AT north from Crescent rock overlook (columnar jointing)	Riprap trail
Compton peak (columnar jointing)	Turk Mountain (quartzite)
Limberlost	Old Rag
Cedar run-White Oak Canyon	

26. Best long loop?
    Cedar run-White Oak Canyon
    Old rag
    Corbin cabin cutoff loop w/Nicholson hollow
    Brown's gap loop

27. Best 12-14 mile hike for overnight?
    Jeremy's run/Knob mtn loop

28. Best trail to get away from crowds?
    Jeremy's run
    Nicholson hollow
    big run

29. Were there any battles fought here?
    No

30. When did this park become established?
    1926-dedicated, 1936

31. What mountain is that?
    Massanutten
    Alleghany
    Shenandoah Mountains

32. Why are the Blue Ridge Mountains blue?
    Respiration from trees – water vapor, dust, carbon molecules

33. Is it always this hazy?
    Respiration from trees – water vapor, dust, carbon molecules

34. Where to see sunset?
    West-facing overlook

35. What is your favorite hike?
    Jeremy's run-knob mtn (2)
    Old Rag
    Rose River loop
    HB loop
    SM
    Blackrock
    Frasier trail
    Laurel branch loop to Rapidan

36. Is gravel on trail natural?
    Limberlost brought in, most natural

37. How do I get to Natural Bridge?

38. How long to drive all of park?
    3.5 hrs

39. Are there any biking trails in the park?
    There are limited options for bicycling in the park

40. Common Education Program questions -
    Can we climb on the rocks?
    Are we lost?
    Is that scat?
    Can we pet the deer?

41. When are the movies shown?

42. Where can I go horseback riding?
    Skyland stables

43. Where can I get something to eat?
    Wayside, lodges

44. Are there cougars in the park?
    No evidence

45. When do the leaves change color in the fall?
    Mid to late October – depends on moisture, elevation, temp which is variable

46. Where can I back country camp?
    *unfortunately, no location was specified

Ranger Survey 2010 – Part II: Staff Background

Age:	Position:	Months employed	# geology courses taken	College degree earned
28	Interpretive Ranger	30	2	BS recreation Management, Environ. Studies
29	Interpretive Ranger	10	2	MA History
63	Interpretive Ranger	52	1	BS home Ec Ed, MS Human Ecology Ed
56	Interpretive Ranger	60	3	BBA
old	Interpretive Ranger	324	0	BS Parks and Recreations
24	Interpretive Ranger	2 yrs	1	MA US History, BA Anthropology
55	Interpretive Ranger	22 yrs	maybe 1	BA journalism, BS Recreatn and Parks
31	Interpretive Ranger	27	5 or 6	BA Environmental Studies
51	Interpretive Ranger	15 yrs	20	MS and BS Geology
58 Ma!	Interpretive Ranger	35	0	BS Botany
41	Interp/education Ranger	19 yrs	2	BS Biology, BS fish/wildlife, MA Education
54	Education	28 months	2	MA Education
48	Education	20 yrs	65 hours	MS resource interpretation
42	Interp program manager/ed	136 months	1	BA Creativity and Arts in Education
38	Visitor Use Assisstant	44 months	2	BA Biology, MAT Science Education
31	Visitor Use Assisstant	20	0	BA Recreation and Leisure
55	Visitor Use Assisstant	80	4	Business
33	Visitor Use Assisstant	27	0	none
49	Visitor Use Assisstant	12 yrs	2	BA Journalism
67	Visitor Use Assisstant	48	0	AA Engineering
69	Visitor Use Assisstant	45	3	BS biology/Chemistry a little grad in Bio
no answer	Visitor Use Assisstant	32	0	BS W&FS
49	Visitor Use Assisstant	9 years	4	AAS criminal justice and legal research
21	Visitor Use Assisstant	10	3	BA Political Science
50	Visitor Use Assisstant	1.5	0	none
55	SCA intern	3	0	BS Accounting

How well do you feel you understand geological processes and landforms?

not at all	a little bit	moderately	significantly
0	12	11	2

To my best knowledge, the Blue Ridge Mountains formed:	a few thousand years ago	0
	a few hundred thousand years ago	0
	a few hundred million years ago	26
	I'm not sure	0
To my best knowledge, the primary process that formed the Blue Ridge Mountains was:	erosion by glaciers	1
	collision of continents	21
	volcanic activity	5
	I don't know	0
The Blue Ridge Mountains formed:	during the last ice age	4
	before the Atlantic opened up	13
	after the atlantic opened up	5
	I don't know	4
The conclusion that Earth's climate has been changing rapidly over the past 200 years is:	well substantiated by scientific data	21
	not well substantiated by scientific data	0
	inconclusive	4
	I don't know	1
Columnar jointing occurs when:	lava is metamorphosed	1
	lava dries	0
	lava cools	21
	greenstone weathers	1
	I don't know	3
We know how old the rocks are because of:	no answer	1
	radiometric dating	16
	carbon dating	2
	cosmogenic dating	3
	I don't know	8
Shifts in Earth's climate are caused by:	no answer	4
	Earth's wobble	7
	human activity	12
	Earth's orbit	6
	Earth's tilt	11
When the Appalachian Mountains first formed:	they were the size of the Andes	10
	they were connected to Europe	6
	dinosaurs roamed Earth	1
	supercontinent Pangea existed	13
If I knew more about Shenandoah's geology, I would probably better understand the region's:	All	10
	human history	8
	archaeology	3
	plant life	8
	animal life	3
	weather patterns	3
	no answer	1

Into which programs do you incorporate geology?	
*each box represents an individual's response --->	None - I only do historical programs
	Stony man (weathering and erosion, mtns and climate, shen salamander) Little Stony Man (geologic sequence - granite to greenstone, columnar jointing, settlement of Blue Ridge) Hawksbill (Peregrine habitat) Matthews Arm (greenstone formation)
	No - I have no training and don't feel that I know enough
	Yes - a little in campfire program, and a litle in meadow walk and junior ranger
	No - I don't because I don't think it is necessary, I only talk about animals, plants, flowers
	No
	No, not yet
	No, talks are only on wildlife and limited in time
	Extensively in 5th grade geology - otherwise rocks and soil are spoken of as part of habitat/ecosystem
	Journey to a volcano Limberlost - columnar jointing
	No - I don't give programs (DRVC?)
	Yes - most of my programs - Stony Man (Habitats/rock type/rock cycle/mtn building/erosion) Watersheds (topography/hydrology/rock type/stream erosion) Adaptation/Habitats (physical geology/habitats) Educache (Fox Hollow) (Rock types/acid rain/erosion/splash erosion) Educaches (Big Meadows) (Physical geology/habitats)
	Bearfence, Hawksbill, Stony man, litle stony man, volcano hike (mtn formation, rock type, plant/animal habitat
	I don't give programs - but will on occasion give geo information (explanation of Big Meadows on greenstone that formed from lava flows in the past and how dark hollow falls flows over these same basaltic formations
	No - I only do a terrace talk about bobcats and an occasional bear talk, into which I incorporate NO geology. I do not have a good enough knowledge of geology to talk about it and I am not interested in it.
	Do not have a geology-based short talk, although I include bits here and there - why the meadow exists, etc.
	Education programs - 5th grade geology and 6th grade watersheds and occasionally 2nd grade habitats. Stony man - greenstone formation impacts diversity of lplant and animal life, and waterfalls, human settlement patterns (mines) Volcano hike if I did more interp I would include geo into Massanutten, Little Stony Man, Meadow walk, AT, Discovery
	Yes - Meadow walk (Big Meadows as a globally rare plant community (N. Blue Ridge Mafic Fen), partially because the soil pulls minerals from the rocks below (greenstone - high in magnesium/iron because mafic), the wetlands exisits because the the water cannot seep through the rock easily, rather comes out as springs and seeps. Evening program - what's so special about Shen? - ancient mountains (1.2 billion!) Columnar jointing, High elevation rock outcrops important for rare plants and animals (shen salamander, peregrine falcon, etc.)
	No I'm not knowledgable enough about geology to give programs about it and answe questions
	Yes - LSM (role of rocks in impacting plant/animal life), SM, HB & BF (how the views got here)
	Not often - preparred a geology terrace talk but not using it currently - mtn ranges as seen from DRVC
	yes (this was Sally, so every way possible...)
	Yes - Bearfence (how the swift run formation rocks were formed, how greenstone rocks were formed, columnar jointing, how rocks break down and impact plant and animal life.
	No - I don have the proper geological training
	Yes - (SM, LSM, Disc, MW, AT, SMEW, MAEW, HBJR) I don't mention it in Bear, RI, Rapidan, BOP, CCC because subject matter does not include geology. LSM is the most geological one I do. SM and SMEW and MW coming in behind.

Are there any specific geological concepts or processes that you have difficulty explaining to visitors because you feel as though you don't fully understand them yourself?	
*each box represents an individual's response ---->	I'm never asked
	How are rocks dated? Hydrothermal alteration
	Plate tectonics - how it affected this area and other areas How do we date rocks?
	How we date rocks - a simple way to explain it to visitors, but background enough for ranger to really understand
	How old is the earth? How were the blue ridge formed?
	I don't ge many questions about it - if I do I refer them to a book in the store
	Im never asked
	I don't have a basic understanding of any of the geological processes
	"I still don't understand how magma metamorphozed into greenstone and quartzite"
	How do we know how old the rocks are? In what order did the events occur here? - a good timeline but simple
	How tall were the original Appalachians? Are the Appalachians still being uplifted? Where can I see an old volcano?
	I often state that "we don't know everything, we are still learning..."
	If there was lava flowing, where were the volcanos? Can you have lava without volcanos? I would like to have a more in depth knowledge of rifting and the volcanic forces that laid down the basement rx
	How did these mountains form? How did the valley form? How old are the mountains? How far back is human history in this area?
	I have difficulty explaining plate tectonics to 5th graders in the field
	How do we know how old the rocks are? A timeline that parallels other events with the formation of Shen mountains - first plants appear, first sea creatures, 1st insects, land mammals, etc. How to respond to visitors who DO NOT believe that the rocks/processes are as old as we are telling them - please provide specific examples to tell the story accurately without alienating those visitors.
	How the mtns formed - differences between the Blue Ridge, Alleghanies, Massanutten. Plate tectonics versus volcanic versus continental drift?
	Why continents drift/come back together Age of rocks Different minerals in rock
	Why the Shen river flows north Where the Blue Ridge mtns begin and end and why?
	Concise, easily understandable explanation of how rocks are dated (radiometric, and carbon, etc.) Simple explanation of how we determine uplift and erosion rates (cosmogenic dating)
	Why does greenstone have a layered appearance and break down into flat and thin rocks?
	Many concepts confuse me, such as the example of how we know hhow old rocks are, etc.
	Nothing specific - if I don't bring it up the visitors rarely do. I talk about what I know and we speculate the rest.
	The concept of TIME - especially with kids. Billions or millions of years has no anchor. I try to utilize analogies. it would be great to have the perfect analogy for when things occurred in the park (grenville to today)

In terms of geology, which props and illustrations would you like that we currently do not have?	
*each box represents an individual's response --->	More pictures from today of where similar geological events are occurring
	Better rock samples of each of the major formations in the park illustrated powerpoint available showing each geologic stage labeled
	A quick reference guide to refer to behind visitor desk (type of rocks, where with a breif description of how formed and how old)
	a time sequence of cross sections as props - like images for ppt
	I don't know
	Maybe more examples of rocks we have here?
	using people to demonstrate plate shifting, seismic waves, etc. visitor participation in some way
	Basic timeline of geologic events of the Appalacian Mountains
	Local area rock samples Fossil samples
	Some of the current laminated photos and illustrations need to be renewed - they are getting old
	Releif map display table with geological formations and how they formed - a progression of continents colliding, mountains rising, seas forming, and the power of erosion grinding down the once great mtns!!
	Make a well-labeled, easily ttransportable rock collection?
	touchable samples of major rock types in Shen
	Props to use in the field to help explain plate tectonics to 5th graders Simplified geologic map of Shen and the region - including valley limestone and massanutten and key locations such as Luray caverns, Big meadows, and towns labeled.
	Show timeline of processes and formation of mtns along with other global events (first plants, mammals, dinos) Better way to store the rock samples More pieces of recent lava (Hawaii?) We need good copyright-free diagrams to use for evening programs and hikes that match those in the manual
	Relief maps of US mountain ranges in North America
	Updated pix with new names of rock formations - basement complex, etc. Better, less technical diagrams of the different rock layers in Shen
	Images of what the valley looked likek millions of years ago
	A 3-d block diagram of milestone tectonic events, showing where Shenandoah fits in the general scheme Good photos of banded zircon to show when explaning radiometric dates
	Good pictures of columnar jointing here in the park with descriptions of where visitors can go to see it Samples of greensone with obvious gas bubbles that show the transformation from lava to greenstone.
	I'm open to anything
	I generally try to minimize props and illustrations, preferring iin situ examples and word pictures, so I have no partiular need for any additional materials.

Ranger Survey 2010 – Part III: Other National Park Service training manuals

Manual	Diagrams	Font	Text	Formatting thoughts	Content	Breadth	Comments
Craters of the Moon	too many	Good	Good	I like the photos up front - sets the tone for the landscape of area. The diagrams are very good, just a few too many	Good	Yes, but not sure if "in depth" chaptersare necessary	I like the use of rocks, people, etc… gives the children a good visual anf keeps them inerested by participation.
	Good	Good	Too much	Good formatting. Elementary to slightly technical. Enjoy the interpretive themes and examples. Children's sections are a good addition.	Good	Yes, enough for the beginner or intermediate	Keep this more toward interpratation. Possibly a bit less technical. You need to capture the attention of the interpreter before you can capture the audience. Nobody will utilize this as their only source of info. For their talks. Zooming in - Geology of the East Snake River Plain
	Good	Too small	Good	Nice use of color, well laid out.	Good	Seems to be, but I can't really tell	No suggestions - Chapter 2
	Good	Good	Too much	Difficult to say until I actually try to apply the manual to my geologic knowledge	Good	Yes	Having a limited knowledge of geologic vocabulary it would be helpful to have a detailed glossary of terms used specifically with regard to SNP. I am aware that it is difficult to comprehend geologic time, however, in order to have a better understanding of the various processes I think it is important to include a timeframe, to be able to compare time of one process to another
	Good	Too small	Good	no answer	a bit too technical	yes	No suggestions - Chapter 4

Manual	Diagrams	Font	Text	Formatting thoughts	Content	Breadth - table of contents?	Comments
	Good	Good	Good	I almost wanted to say that there was too much text,but it is all essential and important, so it is all needed in there.	Good	Yes. I especially like the geology/ecology connections to help connect the geology with current residents-plants, animals, and us. Also the FAQ chapter is very useful for quick reference.	no answer - Chapter 2: Forming the foundation: Plate Tectonics
	Good	Good	Good	The diagrams really help in understanding what is being presented	Good	Yes	no answer - Chapter 2: plate tectonics
	Good	Good	Good	I like the shaded boxes that highlight interpretive techniques (i.e.oreo cookie demo on page 5)	Good	Yes - it looks like a good blend of interp concepts, geological concepts, and connections between geology, living organisms, and cultural history	Make sure that when you describe a specific place in the text, you show its location on a map or figure. sometimes in the Yosemite manual, she refers to things that you have no idea where they are. Maybe the local rangers do, but someone reading the text for the first time and isnt familiar with the area wont know what she is talking about (like a seasonal ranger).
Yosemite	Good	Good	Good	Some picture/photos are very small, e.g. page 8 - Common minerals - can't see them!	Good	Yes - there's some basic info, some specific to the park features, connections between geology and other resources, geology and park history,Sample outline - perfect!	I think Shen's manual could be much like Yosemite's, but adapted, of coarse, to our geologic story. I love the specific incidences relating to current park happenings (e.g. p42 "rock fall Hazard map" - we could include a similar map for the continuou rock fall area in south district along the Drive (I can't remember mile post - it's between Swift Run Gap andPowell Gap), etc. I LOVE the program outline ideas - it would be great to include several for SHEN (Volcano hike, Little Stony Man, Bearfence, etc.
	Good	Good	Good	I liked the "top ten" geology related questions	Good	Material very appropriate. Liked the "living" among the rocks section to connect geology and interpretation	I like a mix of technical (so I can discuss the geology of the area w/ a geologist or ecologist) and layman (so I can get people who think geology is boring or too technical to enjoy, appreciate, or understand geology and processes) terms.
	Good	Good	Good	The guide seemed to flow smoothly with appropriate figures and boxes, etc. I especially like the various food analogies - all three manuals contained some that might be put together in one place for easy reference.	okay, but could expand to include categories in Redwood	Yes, it condenses down a great amount of knowledge to the essentials needed by rangers and others for their interp duties. Geology is a very broad and in-depth science- however, the basics are here to work with.	In the Appendices, the catergories could be broken down into easier to use programs by the audience category, eg. Young Naturalist, Junior Ranger, campfire Programs. Inclusion of common questions and answers is a great idea.

Yosemite	Good	Good	Good	For me diagrams are very helpful in explaining something new. This manual seems to have plenty which seems to go great with the text.	Good	Yes. Compared to the others, I think this appendix is very easy to read and I really like most common questions asked part!	This chapter has a lot of easy to understand metaphores. These comparisons make it easier for people with little or no geology background easier to understand.
	Good	Too small	Good	Generally, the format of the book is good with enough images and insets to break up the text. The font size is suitable for reading, but making it slightly larger (especially the sub section headings) would be helpful in making it appear less like a textbook.	Good	The material does a good job covering not just geo formation but present relevancy as well (climate change, climbing, Native American connections). The acivities used to demonstrate cliff processes and programs scattered throughout the book were very useful.	1. Plenty of photos to illustrate complex processes. 2. sugested activities to incorporate geology into programs. 3. Recreational connections (climbing, ROMP, App Trail terrain in SNP vs. rest of the trail) 4. Climate change - acid precip, visibility imparement connections 5. Historical connections - past, present descendants. 6. Wildlife - shenandoah salamander, Peregrine falcon, etc.
	Good	Too small	Good	Attractiveness of cover is key - make cover an "interpretive hook" pretty pictures and rangers doing their job (a geologic demonstration perhaps).	Good	Looks good - catchy and descriptive titles - can tell that it is focused on interpreting geology and not just explaining geology.	Liked the intro - convinced me that all interps should/could interp geo. Made connection btwn YOSE, geo, interp. Thank you, it will be a great resource! I particularly appreciate analogy of geo time (p. 15) with the note about respecting diff perspec on age of Earth

Manual	Diagrams	Font	Text	Formatting thoughts	Content	Breadth	Comments
Redwood	Good	Good	Good	Text could be a little less and larger font	Good	yes	Needs to be as simple as possible - Tsunami
	Good	Too small	Too much	Font is hard to read	Good	yes	No suggestions - Chapter 2: Plate Tectonics
	Good	Good	Good	Easy to understand	Good	very specific to place which works well	Specific to the park - Linking visitors to geology
	Good	Too small	Good	No	Too technical	I think so	No suggestions - Chapter 3

Manual	Diagrams	Font	Text	Formatting thoughts	Content	Breadth	Comments
Blue Ridge Parkway	Good	Good	Good	Spell check - intro "cease the moment" I <u>loved</u> the use of site-based pictures to show events (Fig 19)	Good	More examples of how geologic information may be connected to meanings that are relevant to all ages.	Place diagrams with text (or nearby) for understanding then have all masters located in the back of book. Present potential interpretive oportunities within text and possible techniques could be used to develop opportuniy. For example, An interpretive opportunity for visitors to understand how the layers of the earth physical state changes due to temperature and pressure. This understanding could be developed using explanation and props (oreo cookie). Tectonic evolution of S. Appalachians

Manual	Diagrams	Font	Text	Formatting thoughts	Content	Breadth	Comments
Yosemite and Redwood	Good	Good	Good	Both well written covering info in layman's terms with good photos diagrams and inserted info boxes (Tsunamis, brass knuckles, Sierra yellow-legged frog, etc.)	Good	The Yosemite table of contents was more detailed, but either works wel for me!	Really looking forward to the Shen manual - I know I will use it for programs and personal knowledge growth - thank you!
Yosemite and Redwood	Good	Good	Good	I preferred the font in the Yosemite manual. I loved the use of an M&M and oreo and everything we could actually use to show things to people. Loved a glossary.	Good	Not being an expert its hard for me to know if all topics have been addressed. It seems the basics have been explored knowing what visitors ask is an integral part.	I think this is a great project. There is so much to the geology of shenandoah. I think it would be great to have something that takes technical aspects and breaks then down. Please highlight any cool features or unique aspects that would be fun to share with visitors. Chapter 1
Yosemite and Redwood	Good	Good	Too much	The amount of info and presentation is great, but difficult to boil down to suitable presentation at the short talks level, but that will be my next topic when the Shen version of these book come out.	no answer	Yes. The oreo cookie demo is great	A time sequence of a cross section of what became Shen through the formation and erosion would be a great tool. Redwood - Chapter 2
Grand Canyon and Yosemite	no answers given			Use serif font because it is much easier to read. Some of the box margins are intrusive	no answer	very comprehensive - more than enough for interpretation requirements	I think it is very useful to have a geology manual specifically for the park. While its good to have a background, for interpretation we need location-specific information and these manals bring it all together, without me having to wade through lots of reference material.

Appendix B:
Addressing Controversial Geological Topics

This appendix provides perspectives from other National Park employees on how to address occasionally controversial topics in geology interpretation. This can be used as a reference and preparatory tool for designing geology-related ranger programs. These articles can also help park rangers learn how to think about geology. As representatives of the United States government, these articles help clarify how National Park rangers should respond to difficult situations when the occasional park visitor disagrees with certain scientific topics.

The first article, written by Lauren Becker of the Center For Inquiry, recounts her personal experience as a young park ranger at Grand Canyon National Park. Her thoughts may help new and returning park rangers understand the perspectives of some park visitors who disagree with the scientific age of the Earth.

Following Lauren's article, are four articles written for the National Park Service by Allyson Mathis. Allyson is an employee at Grand Canyon National Park. Her writings will help park rangers understand the perspective of the National Park Service on how to interpret geology in the parks and how to address sensitive topics, such as geologic time and creationism.

300 Million Year Old Rock by Lauren Becker

The summer before my senior year of college I worked as a park ranger guiding hikes in one of the most beautiful state parks in the country. Its central feature was a 256-foot waterfall that plunged down through a gorgeous natural amphitheater, cutting through bands of limestone and sandstone and collecting in a deep pool, the perfect hangout for summer swimming. My favorite program was the hike to the base of the falls. Layers of rock are like chapters in a history book and this canyon, carved so deeply, told an ancient story. Standing at the bottom, calling out over the roar of the falls, I got to teach the exciting conclusion – the layers of slate and shale beneath our feet tell us that 300 million years ago, this deciduous forest was a tropical jungle.

"What book did ya get that out of?" came the reply one day. And thus it began, for this waterfall was not only located in ancient rock, it was also in the heart of the Bible-belt. I had heard there were people who believed the Earth was only 6,000 years old, but I never thought I would actually meet any. That summer, and every other summer I worked teaching science to the public, I met a lot of them. Though most objectors would just walk away from the program, some mothers would cover their children's ears to protect them from the "blasphemous park ranger." One man, after I patiently explained how we know the age of rocks, finally just threw up his hands, exclaimed, "The Devil made that rock look that old to turn you away from God," and led his family back up the trail.

At the time, to a college kid with a summer job, these responses seemed bizarre but relatively harmless – they were local, everyone's entitled to their own beliefs; no skin off my back, whatever. But now, 15 years later, I understand these taunts to be the threat they truly are: dangerous beliefs made more dangerous be-cause more and more people believe them.

How does believing a 300 million year-old rock is only 6,000 years old become dangerous? It is a reflection of where and how we find answers. A 300 million year-old rock is the answer resulting from decades of observation, research, field study, laboratory testing, comparative studies and critical thinking. A 6,000 year old rock is the answer because God said so.

Is the accurate age of a rock really important? Interesting, yes, but important? Maybe not. But what if the question is about Polio? Should we seek an answer from decades of observation, research and field study, discover a vaccine and destroy a worldwide plague or does the answer lie in God's plan?

What if the question is about food? Decades of observation, research and field study have shown us there is only so much arable land that can produce only so many calories of food energy. Currently, we burn 10 calories of oil energy to make 1 calorie of food energy. Our world population of 6 billion people is barely sustainable, let alone the 12 billion projected in another 40 years. Should we answer with conservation or with prayer?

What about your right to vote or just your rights in general? Eons of history, research, comparative studies and critical thinking have brought us to the advantages of a representative democracy based on individual rights and the checks and balances of limited governmental power. Is government of, by, and for the people the answer for life, liberty, and the pursuit of happiness or would we prefer one nation, under God, defined by his will and authority?

Let's think about this: If, as many people are demanding today, we want our government to be based on God’s authority, the first problem is to decide exactly which God we want to follow. There are many. God is a very ambiguous, schizophrenic deity. This is why, as Carl Sagan explained, “When you ask, ‘Do you believe in God,’ if I say yes or if I say no, you have learned absolutely nothing.” So we have to be more specific. How do we get 300 million people to agree to a specific definition of God’s identity and will? We can’t, of course. A democratic populace with the freedom to think for itself never will. Okay, forget individual freedoms. The answer is a theocratic dictatorship that can force the people to live according to its particular interpretation of God’s will.

And that’s how a 6,000 year old rock becomes dangerous. But it was just a little rock! Yes, but it is a big metaphor.

The man who claimed that the Devil had made the rock look that old to turn me away from God was trying to warn me that I shouldn’t believe everything I see. He believes the Devil works through deception so anything learned from observation can't be trusted. The church tells him Satan sends demons to trick his senses and his mind. Consequently, according to him and the 30 million Americans who agree with him, we can be saved only through faith.

Of course, there’s no denying that our minds can be easily fooled. After all, it is the basic premise underlying all marketing, entertainment, and campaign policies. But the idea that we must turn to faith for our salvation is fundamentally flawed. Credulity is a disastrous reaction to deception. If we wish to succeed in life, we need a more skeptical way to react to the world around us. How can we possibly work through the deceits of the world and the whims of our minds and come to a true understanding of reality?

That answer is the Scientific Method. It is a process of constant questioning, testing, verifying and questioning again, until the smoke and mirrors are removed and reality is revealed. Then you do it all over again. It is an adaptive mechanism, a hybrid of contemplation and observation and the best technique we've invented to help us figure stuff out. Constant questions. Constant testing. If an idea doesn't hold up, we throw it out. It’s ruthless, but it works. There is no argument from authority because authorities make mistakes. And, as Sagan re-minds us, “Intellectual brilliance is no guarantee against being dead wrong.” Nothing is sacred and that is how lots of very diligent people figured out that a 6,000 year-old rock was really 300 million years old. Cherished ideas often must fall by the wayside, but at its best, the method keeps us honest.

Honesty is difficult. It requires heroic efforts of introspection and self-awareness. This honest portrayal of reality is at the heart of the conflict between science and religion. While science is a natural response to real-ity, religion demands that we distrust our senses and our intellect, instead relying on a supernatural explanation. In this way, faith robs us of the best tool we have for learning about our world and understanding our true position within it. Religions, especially fundamentalist religions, get stuck because they are based on an immovable, unchangeable, unquestionable authority. But without doubt and questioning, there is no way to acknowledge, much less correct for errors. That is how a 6,000 year-old rock becomes dangerous.

It also explains the hostility on the hike that day because the danger goes both ways. If we want to believe that the universe was created for our benefit, almost every scientific discovery of the past 400 years has been a real downer. First we find out that the universe, literally, does not revolve around us. Next, we discover that our Sun is really a quite average star and, not only that, we live out in the boon-docks of an average spiral galaxy that is just one of 20 other galaxies (given the appropriately non-superlative name The Local Group) zip-ping through space outward from the center of the cosmos which, did we mention, is very far away from us. As if that wasn't bad enough, this planet that was supposedly created for us was hanging out for almost 5 billion years before we even showed up and, by the way, we didn't look like this when we first got here.

If your sense of self-worth, your purpose in life, is based on the belief that you and the universe were created specially for one another, science is truly a harbinger of doom. You can shoot the messenger, but ignoring reality is no guarantee that it will go away. Like a talk-show celebrity, the significance you desire is, sadly, based on unmerited importance. Truth be told, though the performance was entertaining, your show is just a dot among 6 billion dots on a bigger dot flying around a brighter dot lost amid a billion, billion more dots separated by vacuous space.

But here's the cool thing: at least you are a dot. I am a dot, too. This means that, though we are insignificant to the cosmos, we are incredibly significant to each other. We and our fellow dots. What should we do? Don't be afraid. The lack of a deity is not an opening for chaos. It is a call for responsibility. Besides, there are some really smart dots over there that have figured out how to learn and they can teach us how to survive. It's all really quite amazing. Did you know that this rock is over 300 million years old?

Our species has continuously found meaning, purpose and comfort in the idea of god or gods. Unfortunately, if we want to know what is actually going on, and our survival depends on understanding reality, religion is utterly bereft of explanatory power. A belief in God's existence is a useful and powerful illumination of our own desires for life, but it is not a reflection of what life is.

The discovery that a rock is 300 million years old is the result of lots of questions by lots of people who devised lots of different ways to ask the Earth about itself. Much to our delight, she is talking. Science is how we listen and the scientific method is how we understand what she says.

To deny that a rock is 300 million years old is to deny the process that got us to that understanding. Since this process of inquiry is our best tool for succeeding in the world, its denial is a grave threat to our future prosperity. Far from making us stronger, faith cripples us because it takes away our greatest advantage: our ability to question, to learn, to adapt and, therefore, to live.

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Lauren Becker is a science interpreter who has taught at museums and parks around the country. She is Public Relations Assistant for the Center for Inquiry in Amherst, New York. She can be contacted at:
Lauren Becker
Center for Inquiry
P.O. Box 703
Amherst, NY 14226
Telephone: (716) 636-4869 Fax: (716) 636-1733
E-mail: lbecker@centerforinquiry.net
Web: www.centerforinquiry.net
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Interpreting Geology

Interpreting geology is mostly just like interpreting anything else.

- Know your stuff (i.e., the resource).
- Know your audience.
- Make it relevant.
- Present it effectively.

Interpreting geology is different than other topics.

- The public and the interpreter often do not have as much knowledge of geology relative to other topics.
- Geology is more "foreign" relative to other natural history or cultural history topics. We relate better to what is closer to "home"—i.e., what we are more familiar with and to other living things (biophilia hypothesis, Edward O. Wilson).
- Geologic Time
- There are few references and geology publications at a level between the technical and those intended for general audience, so it is hard for interpreters to build the knowledge base they need. There is a "cross section" of geologic information interpreters need to have: In depth knowledge about park resources plus a broad knowledge of geologic context and basic geology.

Making Geology Relevant.

- Point out scenery. (Relate geology to audience's immediate sensory experience.)
  - Scenery is a main reason why people visit many park areas.
  - Scenery at many parks is predominantly geologic. (If your park has scenery, your park has geology.)
  - Tell the story of the landscape. Landscape reveals lithology (rock type), geologic history, structural geology, earth processes, etc.

- Think like a visitor. Visitors are novices, interpreters are experts.
  - Novices and experts think differently. Experts have different categories of thought (schemas) for objects, etc. than novices. Experts have fine-tuned their senses to perceive details, new and different objects and relationships that novices may not perceive.
  - When we learn or see or experience something new, we process the new knowledge or experience through what we already know and have experienced. Experts have different sets of knowledge and experiences than novices.
  - Use thinking like a visitor to meet the visitor where they are at and to answer visitor questions. Remember what you first wondered about when you saw your park's landscape. Listen to visitor questions. Never forget your first awe.

- Use geo-ecology and geo-history. It's all a matter of rocks! Geology influences everything.
  "Geography is life's limiting factor. Speciation—life itself—is ultimately a matter of warm and cool currents, rich and bare soils, deserts and forests, fresh and salt waters, deltas and jungles and plains. Species arise in isolation. A plaster cast is as intricate as its mold; life is a gloss on geography. And if you dig your fists into the earth and crumble geography, you strike geology. Climate is the wind of the mineral earth's roundure, tilt, and orbit modified by

local geologic conditions. The Pacific Ocean, the Negev Desert, and the rain forests in Brazil are local geologic conditions….It is all, God help us, a matter of rocks." --Annie Dillard
  - Earth systems: The lithosphere relates to the biosphere relates to the hydrosphere relates to the pedosphere relates to the cryosphere relates to atmosphere relates to the cosmosphere…..
  - Geo-ecology is sometimes called biogeography.
  - Example: *To understand the Everglades one must first understand the rock.* --Marjory Stoneman Douglas (1947)
  - These connections can be demonstrated by starting with living things and going to geology; or starting with geology and then going to living things. Living things generally are easier for people to relate to and geo-ecology relationships can make geology more relevant for many people.
  - Geology influences human history, and humans impact geology. *We are shaped by the land; and we shape the land. "History is subject to geology."* --Will and Ariel Durant

- Do geology on a human timescale.
  - Geologic change that people can see: volcanic eruptions, earthquakes, floods, landslides, geo morphology, etc.
  - Use the short-term as a link to the long-term: *The present is the key to the past.*
  - "Rare" and "common" have different meanings on different timescales. Geology looks at both long-term and short-term events (a "bifocal" science).
  - Geo-indicators: geomorphic and physical factors in ecosystems that access change within a human time frame.

- Demystify geology *("it's not rocket science; it's just rock science").*
  - Explain how we do geology, how geologists "know" what we know, and where geologic knowledge come from.
  - Describe current geologic research and the tools (like seismometers) that geologists use to understand the earth.
  - Geologists can be described as "earth detectives"….there are many analogies between geology and forensic science.
  - Explain the techniques of geology. Show the "method behind the madness" of the science.
  - Examples of demystifying geology include: explaining how rocks are named, and what a formation is; explaining the basics of radiometric dating; explaining tools that volcanologists use to monitor volcanoes.
  - Build on the information that visitors already have. (For example, many more people know what earthquakes are than who could define a fault.)
  - It is not necessary to "dumb down" geology. What is necessary is to use everyday language, to think like a visitor, to make links to visitors' pre-existing knowledge in order to reach the "aha" moment.
  - Put geology in a social and cultural context (using real world applications of geology).
  - Reveal hidden stories.

- Use analogies, similes, and metaphors.
  - For geologic time (compare to day, year, yardstick, etc.). Use relative scales to put into perspective.

- Compare geologic events/things to ordinary events/things (i.e., plates move at rates that fingernails grow; clay minerals shaped like dinner plates; Strombolian volcanic [cinder cone] eruptions are "volcanic fire works;" lava flows like honey; sedimentary strata are stacked like pancakes.)

- Make links to geologic "current events" and research (for example, EarthScope)
  - Tie your park's geology to geologic current events (for example, volcanic parks can relate to a current or recent eruption, parks with prominent faults can use current or recent earthquakes.)
  - Links are also possible to science fiction, pop culture (i.e., movies like Dante's Peak, Jurassic Park).
  - Explain the importance of research.

- "Commune" with rocks.
  - Use all senses to examine rocks: sight, touch, smell, hearing, (taste).
  - At different scales. Different scales reveal different aspects of geology. (Hand sample shows textures [like grain size]; outcrop shows structures [like crossbedding]; landscape pattern shows unit thickness, hardness, extent, etc.)
    ("*as different as rock and cliff, a small rock you can pick up in your hands, a cliff that drowns you with the wrong step*" –Jimmy Santiago Baca)
  - "Read" history – look at sedimentary structures, other structures. Use rocks to "time travel." "*Rocks are windows into the world the way it was at other times.*" –John McPhee.
  - Demonstrate physical properties of rocks (hard, soft, etc.) (Break shale or soft sandstone with your hand.)

- Look at rocks in different ways, from different perspectives. "A rock is not a rock is not a rock."
  - Rocks as landforms. *Building blocks of a landscape.*
  - Rocks that tell geologic history. *"Every rock tells a story." "Rocks remember."*
  - Rocks as habitat. Rocks as home. *At the largest scale, the Earth is our home.*
  - Rocks as resources. Raw materials for Native American use, mining history, and resources we use daily in our lives.
  - *"I find people are fascinated by the thought that sand is not just sand."* --Rachel Carson

- Look at landscapes in different ways, from different perspectives. Stories from and in the land.
  - Every park is a place. Every park is a landscape.
  - Landscapes as systems.
  - Landscapes as habitat.
  - Landscapes as resource wealth.
  - Landscapes as history.

- Avoid unnecessary big words (i.e., jargon). Define basic terms (even "sandstone" if necessary). Use informal terms (where appropriate) that visitors are more likely to understand. For example, metamorphism is like "geologic pressure cooking."
  - <u>Issue</u>: The balance between accuracy and understanding.

- Provide geologic context….for both space and time
  - Put your park in context of geologic/geographic region, in plate tectonic context, with other national park or public land sites with similar resources ("geologic themes"), etc.
  - Put rock types in context (igneous, metamorphic, sedimentary; or hardness, etc).
  - We can't assume that the public can put things in context with geology like they do for other subjects.
  - What is "old" for a rock? What is "hard" for a rock? What is a "fast" geologic process? What is a "steep" gradient for a river?, etc.
  - Provide context for geologic history/history of life.

- Relate parts of your park's story to facts that the public is likely to know or be familiar with.
  - Relate your park's information to what the public is likely to know from "Earth Science 101" or popular geology: 3 major types of rocks, plate tectonics (continental drift), dinosaurs, etc.
    - The real "Jurassic parks."
    - Compare modern environments to depositional environments of sedimentary rocks (beach and coastal, sand dune, etc. Ask people to recall their own experiences on a beach or sand dune, etc.)
  - Compare unknowns with knowns.

- Organization! "Back to basics" interpretation.

- Interpret geologic processes (i.e., change: The Dynamic Earth).
  - Make connections between things (objects) and processes (i.e., use tangible/intangible links). Highlight relationships and connections.
  - Relate the texture of volcanic rocks to how volcanoes work; relate crossbedding to how dune fields migrate, relate a fault scarp to what happens in an earthquake.
  - Note that the same processes that formed your park's landscape and its rocks are ongoing today.

- Interpret what is "up close and personal" instead of overall "big picture" geologic story. (The "big picture" that is in the geology books may not be relevant to some park audiences, especially at first when they may be in an unfamiliar landscape).
  - What are people curious about when they see your park's geology? What are the most obvious/unusual geologic features in your park?
  - Tell the "story behind the scenery."
  - Use tangible/intangible links.
  - For in-park audiences, use the power of the place.

- Use "Emotional" geology
  - Beauty *The art of geology*
  - Discovery and curiosity: *"wow feeling" in science*
  - Change….*not everlasting hills, but neverlasting hills.* *"Given enough time, nothing is more changeable than rocks."* --Enos Mills
  - "Grand Canyon makes me feel young"….geologic time
  - "Disasters" – really are just the way the world works, but can be devastating to us.
  - Earth = home. Bedrock.

    - Geology and the human perspective: Two time scales: Ours and the geologic.*"To understand man's significance, I saw, you must first accept his insignificance. Only then could you focus him into importance against his stupendous, unshruggable background."* --Colin Fletcher (writing about the Grand Canyon)
    - Have fun!
    - **Note:** There is an intimate interrelationship between the emotional and intellectual; they really cannot be separated. For example, if you think something different, you will feel different. If you feel something different, you will think differently.

- Personalize the geologist
    - The "John McPhee technique"
    - History of geology (many national parks are classic geologic locales where pioneering work has been done.)
    - Tell the story of famous or everyday geologists working in your park/area.

- Describe the relevance and importance of geology.
    - Geology puts things into perspective beyond a human timescale.
    - Geology is bedrock. Our lives depend on geology.
    - *"Geology is a way of looking back and seeing into the past. The hope is that by looking backward, we can see into the future."* –Paul R Bierman

Tips for Interpreting Geology

- Separate the parts of your park's geologic story.
    - At Grand Canyon, there are two primary stories: 1. The rocks (deposition, formation, etc.). 2. The Canyon (uplift and erosion, the current landscape)
    - Separate mountain building from glaciation, erosion from deposition, tectonics from eolian processes….
    - Separate the "*here and now from the there and then."*

- Interpret the *genius loci* of your park and its geology.

- There is more than one way to interpret your park's geologic story. Not every geology program has to follow a rote formula, i.e., at Grand Canyon, not every geology program should be "deposition, uplift, and erosion."
    - Put yourself and your own interests, expertise, and experience in your program.
    - What is it about your park's geology that you have a unique perspective on? How can you use that to make your park's geology more meaningful and understandable to your audience?

- Don't try to tell your park's entire geologic story in one program/exhibit/brochure. Pick a part of it, make it into a cohesive whole (a complete story), and make that your interpretive product.

- Interpret geologic ("deep") time. (Stephen Jay Gould wrote that the concept of geologic time is the greatest contribution of the geosciences to human thought.)
    - Interpret geologic time matter-of-factly. Geologic time and geologic dating techniques are not at all controversial within the scientific community.

  - NPS policy requires that interpretation of natural processes and the history of earth be based on current scholarship and research and the best scientific evidence.

- Avoid saying "*geologists say…*" in your programs, like you would avoid saying "*biologists say…*" Programs are more credible and powerful with matter-of-fact information and interpretation.

- Begin geology interpretive programs where visitors are at—what is relevant to their park experience. Answer visitor questions in programs.
  - Ex: How wide, deep, long? Or, how did it happen?

- Incorporate information about the nature of science and scientific method into geology interpretive programs. (An effective way to explain why there may be a variety of imperfect hypotheses to explain some features in your park.)
  - Science is a method of inquiry that aims to reveal the truth. Science is always a work in progress. A scientific truth is never the final truth.
  - Much of the geologic record is missing. As a historical science, geology reconstructs past events based on partial data.

- Aim to promote understanding of your park's geologic resources and of geologic processes.
  - To produce understanding, an explanation must invoke what is familiar and known, then it must point out hitherto unseen connections between these familiar principles and the phenomena being explained.
  - *"It always means so much more when you know what you are looking at."*
  - Understanding leads to appreciation leads to preservation.

- Avoid mixing nongeology (myth, stories, etc.) with geology (science) in geology programs. (Myths, storytelling, etc. is valid interpretation and is definitely appropriate in interpretive programs, particularly those related to cultural and historical aspects of parks and landscapes. However, it is less effective, and potentially confusing, to the public to mix geology and nongeology in a program without being absolutely clear about what is and is not science.)
  - Most audiences will not have a clear understanding of science and geology. Promoting science literacy promotes stewardship of park resources and support for NPS management.

A. Mathis
9/2009

To say that something is solid as the ground under one's feet is not to say much: that ground may be lifted miles into the air. Forests and grasslands and deserts flow like rivers. Stability, dominance and security are short-term words. We haven't a long enough view to really know what is even now in the process of happening to our earth or its populations, or what fateful changes are taking place….
--Joseph Wood Krutch

Surface appearances are only that; topography grows, shrinks, compresses, spreads, disintegrates, and disappears; every scene is temporary, and is composed of fragments from other scenes. --John McPhee

Keats was quite wrong when he asked, rhetorically, "Do not all charms fly … at the mere touch of cold philosophy?" The word "philosophy" standing in his day, for what we call "physical science….there is more charm in one cold simple "mere" fact, confirmed by observation and linked to other facts through coherent theory into a rational system, than in a whole brainful of fancy and fantasy. I see more poetry in a chunk of quartzite than in a make-believe wood nymph; more beauty in the revelations of a verifiable intellectual construction than in misty empires of obsolete mythology.

The moral I labor toward is that a landscape as splendid as that of the Colorado Plateau can best be understood by poets with their feet firmly planted in concrete – concrete data – and by scientistss whose heads and hearts have not lost the capacity for wonder. Any good poet, in our age at least, must begin with the scientific view of the world; while the scientist must be something of a poet, must possess the ability to communicate to the rest of us his sense of love and wonder at what his work discovers.

--Edward Abbey, The Journey Home

Unfortunately, stone has an undeserved reputation for being uncommunicative. The expressions stone deaf, stone cold, stony silence, and simply, stoned reveal much about the relationship most people have to the rocks beneath their feet. But to a geologist, stones are richly illustrated texts, telling gothic tales of scorching heat, violent tempests, endurance, cataclysm, and reincarnation. – Marcia Bjornerud

Interpreting Geologic Time and the Age of Earth

Just Do It!

NPS policy

Excerpts from 2006 National Park Service Management Policies, Chapter 7, Interpretation and Education.

- From Section 7.1
  Factual information presented will be current, accurate, based on current scholarship and science, and delivered to convey park meanings, with the understanding that audience members will draw their own conclusions.
- From Section 7.5.3
  Acknowledging multiple points of view does not require interpretive and educational programs to provide equal time or disregard the weight of scientific or historical evidence.
- From Section 7.5.4
  Interpretive and educational programs will be based on current scholarship and research about the history, science, and condition of park resources, and on research about the needs, expectations, and behavior of visitors.

The First Amendment prohibits the government from promoting any specific religion or religion in general; and also prohibits the government from interfering with the rights of citizens to practice any religion.

Creationism, including "creation science" is inherently a religious perspective (as decided repeatedly by the courts), and as such, the National Park Service cannot promote it.

Tips for interpreting geology and the age of the earth

Interpret geologic time matter of factly. *Just do it!* Don't apologize, don't hesitate, don't put "disclaimers" on your programs, just include information on the age of geologic features and events, and for earth like you would any other bit of information.

Create and cultivate respect with your audiences.

- Be nonjudgmental about audience beliefs. Clarify what you are talking about; that science excludes the supernatural and that science can say nothing about "meaning" or "value." Just as science cannot say that God did it; science also can't say that God didn't do it.
- You can say "*there is no scientific (or factual) evidence for x creationist claim….*" respectfully and nonjudgmentally. You are talking about evidence and our best scientific understanding of the natural world, not criticizing someone's beliefs.
- Give audience members options and ways to balance science and religion. Science and religion complement each other and address different questions about the world and our existence (see below).
- Being respectful does not mean or imply that the audience is always right.

Maintain your credibility, particularly in front of diverse audiences.

- You do not have to be a geologist to do this. Do as much research as you can, and be confident in yourself and your material.
- There is no scientific evidence that earth is on the order of thousands of years old, that a single "Noah's Flood" denuded the earth, carved Grand Canyon, etc.
- The statement that earth is 6000 years old can be described as "17th Century science" and has been scientifically disproved innumerable times. The validity of modern geologic dating techniques (such as

those based on radiometric decay) has been demonstrated repeatedly. Any dating technique developed before 1950 is invalid because of incorrect assumptions.
- There may be questions about, for example, how and when the Colorado River carved Grand Canyon, but the river did it. Science may be a quest for the factual truth about how the material world works, but the fact that there are unanswered questions does not discredit the validity of scientific inquiry. It is actually just a part of the way that science works.

Use analogies with detective work (or forensic science) and/or historic research.
- Like geologists, detectives work with incomplete evidence to determine what the best explanation (theory) that fits the data (facts).
- Just because "no one was there," doesn't mean that there are not other valid ways of knowing.

Avoid using "disclaimers" regarding geologic time in your programs.
- Disclaimers confuse the audience and may put doubt in their minds regarding the scientific validity (which issupported by huge amounts of evidence) of the age of earth and the findings of the science of geology. Disclaimers may actually invite questions or challenges from the audience because they introduce the idea that some people may have cultural or religious reasons to reject the findings of science.
- It is my opinion that, legally, disclaimers may be questionable as it could be seen as promoting a religious view.
- Interpreters cite other facts that may be culturally sensitive without using disclaimers and without attributing facts to certain groups (like scientists). Geologic time, the history of earth, and evolution should be interpreted in the same way. Singling out these subjects for special treatment is not justified.
- Most people are not aware of the issues relating to social/political controversy regarding the teaching of evolution (and geologic time) in schools. Therefore, introducing the idea that some people may view this as socially or politically controversial actually may introduce controversy in a program in a way that is not constructive. A geology program communicates the findings of science and the age of earth and its long history—topics that are not scientifically controversial at all.

If a creationist is disruptive during a program, maintain control of your program as you would with any other disruptive person.
- It is your program, and your responsibility is to the entire audience to promote understanding (scientific and otherwise) of and stewardship for park resources.
- Be firm, and steer your program back to your theme and program organization. Refer to NPS policy if necessary.
- If possible, segue back to your program outline making a transition that describes the proper roles of science and religion, and how science and religion properly address different questions and are complementary to each other. Try to build a bridge and demonstrate to the entire audience that a scientific understanding of the world does not have to invalidate their beliefs.
- Do not argue, particularly in front of diverse audiences. If necessary, agree to disagree, or invite the individual to talk privately with you after the program.

Explain how science and religion are not incompatible.
- It is a false dichotomy that science and religion must be in conflict. This false conflict is generally set up by creationists. Most religious scholars, theologians, and scientists agree that science and religion complement each other and address different issues and questions.
- Use a constructionist and integrative approach….You may ask the visitor is they know their pastor's or the Pope's position on creation, etc., or you can explain the limitations on science (i.e., it only investigates the natural world; it says nothing about the supernatural). If possible, try to acknowledge and perhaps even support people's right to pursue religious activities, but show how religious beliefs do not have to be in conflict with science. For example, many scientists are deeply religious and find scientific research a source of spirituality. [Note: A governmental employee cannot do anything to promote a specific religious view as this would be against the Establishment Clause of the

Constitution. By "support people's religious activities," I mean in a Free Exercise type of a way; i.e., support the right of all citizens to exercise religious practices.]

Know and deflect creationists' false arguments, particularly ones related to your site. This helps build and maintain your creditability.

Examples:

- Erroneously old K-Ar (potassium-argon radiometric) dates for basalts in western Grand Canyon. (These are the result of the wrong technique being used on the wrong rock. For example, a blood test is not an invalid technique for testing blood if it gives erroneous results on a urine sample. Furthermore, you can't weigh a diamond on a scale designed to weigh a person. Also, any geologic dating technique will not work on all rocks, but that doesn't indicate that the technique is invalid.)
- Analogies with Mount St Helens for rapid deposition and erosion of volcanic tuffs and mudflows with deposition and erosion at Grand Canyon. (Limestone is deposited in a very different and slower manner than tuffs. Also the size of the ditches eroded in Mt St Helens is very, very tiny compared to the canyons of the Colorado River.)

Things to keep in mind:

- If a dating technique gives one erroneous date, it doesn't mean that the technique is invalid (every measurement has an error…). Radiometric dating techniques are so powerful that creationists are reduced to sniping at them.
- To support their claims, creationists generally use pseudoscience, selected facts, recycled old arguments (that have been disproved again and again), or some discovery that they or someone they know have made that disagrees with accepted scientific evidence, etc. Furthermore, they commonly take advantage of audiences that do not have a sophisticated understanding of science by using of selected facts and false arguments. Creationists do not produce peer-reviewed scientific literature.

Be able to give short answers on how geologic dating works and the methodologies of other scientific techniques. Explain how we know, and what the factual evidence is, etc.

Learn as much as you can, not only about the nature of science and the scientific method, but also about the sociopolitical controversy that has produced the antievolution/creationism and Intelligent Design cultural movements.

Refer to NPS Policy and/or separation between church and state.

- The values of our society include the separation of church and state. We cannot use an interpretive program to let someone promote their religious point of view. Science and religion are different things; neither religion nor supernatural causation is appropriate content in a NPS program about how Grand Canyon or another natural system works.

Explain what science is and why there are so many unanswered questions about the history of our planet and delineate the appropriate role of science (particularly in a national park).

- Science is not a worldview. Science is a method of inquiry; and science is a way of knowing about the natural world. Science can only address the natural world, and can say nothing about the supernatural, including whether the supernatural exists.
- Science should be presented as a methodologically naturalistic system of thought, not as one that is metaphysically naturalistic (i.e., a philosophy that only the natural world exists).
- Science as a way of knowing about the natural world is used virtually all people, on every continent, and in every culture. Science is universal.

Avoid mixing myths and science in geology (and nature) programs (unless you do so very, very, very carefully).

- The goal of geology and most nature programs is to explain how the natural world works. Science is the most effective tool to do that. Mythology (as viewed by the study of anthropology) expresses some of the most important and most powerful ideas within a culture. Myths communicate values and ideas and cultural truths. The purpose of myths, including origin myths, is to present, in symbolic form, the values most important to the culture. They are also about a culture's relationship to the landscape. Myths and scientific explanations are fundamentally very, very different in terms of purpose, methodology, and scope (i.e., science is very limited).
- Generally, the public generally is illiterate and usually does not have an anthropological understanding of the importance of myths in cultures. As the two are so different, and because the public does not understand the difference, using myths in a geology (and nature) program is like mixing apples and oranges and will not lead to increased understanding.
- Referring to myths and cultural traditions is much more appropriate in other programs and has a very important role in interpreting the cultural resources of a park, and interpreting cultural values associated with park resources.

To Keep in Mind…(Know your audience)

"Religious" point of view does not equal young earth creationism.

- Most organized religions do not have a problem with science, an old earth, evolution, and the Colorado River carving Grand Canyon. For example, old earth creationists reject the young earth creationist claim that Grand Canyon's sedimentary strata were deposited by Noah's Flood and that the canyon itself was caused by receding flood waters.
- Religion and science are not in conflict. They are complementary and equally vital, but are completely different systems of thought. *Science gets the age of rocks, and religion the rock of ages; science studies how the heavens go; religion how to go to heaven.*
- *Voices for Evolution* is a compilation of statements supporting evolution education by civil rights groups, religious organizations, and educational and scientific organizations. It is a maintained by the National Center for Science Education and is located on the internet at: http://ncseweb.org/voices.

All creationists are not alike: for example, there is Young Earth Creationism, Old Earth Creationism, Gap Creationism, Progressive Creationism, Intelligent Design and more. It is not appropriate cannot equate creationism and anti-evolutionism with a "religious" perspective. Whose religion?

- There is a wide spectrum and continuum of beliefs about ways to interpret the Bible.
- There are a wide variety of religions.

"Creation science" and "Intelligent Design" are NOT science.

- Most contemporary Christian denominations (including the Catholic Church) consider the Bible a book about the relationship between God and humans, not a book of science.
- Creation Science and Intelligent design are pseudoscience. Neither field has produced any peer-reviewed scientific publications.
- Most creationists and creationist organizations have a cultural agenda, which generally is to promote their religious views and values, such as Bible literalism. For example, the Young Earth Creationist organization Answers in Genesis describes the organization's purpose: *"In addition to proclaiming the truths of Genesis, [Answers in Genesis] endeavors to show that a false view of origins (i.e. evolution) is at the foundation of many of the ills that plague our society. Conversely, the book of Genesis provides answers to these problems and is the foundation to all Christian doctrine."* Also, the Institute for Creation Research describes itself as a *"Christ-focused Christian Ministry."*

Most Americans are at least somewhat scientifically illiterate; therefore, you can assume that your audiences may be at least somewhat scientifically illiterate, especially regarding geology. (This does not mean that you dumb things down for your audience, your goal is to promote understanding of, and to "demystify" geology, and to promote park stewardship. Interpretation means that you must meet the audience where they are at in terms of knowledge, understanding, and meaning. You simply cannot expect you audience to do what they do not have the knowledge or skills to do. It is especially important in geology interpretation to be very explicit.)

- A gentle reminder: This is just like someone not knowing how to how to fix a car; they aren't stupid, they don't have the skills or the knowledge.

Many people who profess to be religious do not know much about the content of the Bible (or other religious texts) and may not know the position of their church (or other religious institution) regarding issues like the age of the earth and evolution.

In general, two categories of people that may bring up creationist/young earth/antievolution issues during a geology talk.

- Young Earth Creationists with an agenda of promoting their religious beliefs.
- People who are confused and questioning and are trying to integrate what you are saying with half-remembered or vague knowledge of creationist claims.

    The way you handle questions and statements from the two groups of people differ. Using the constructionist approach and building a bridge between religion and science is best with questioning audience members. With Young Earth Creationists who are trying to promote their own religious views, it is best to stop the dialog as soon as possible (when in front of an audience), and then to use the constructionist and bridge-building approach in regards to the rest of the audience. It also helps to define science (as only a method of inquiry about the natural world and not a worldview) and to assert just how strong (i.e., "rock solid") the scientific evidence is for the age of earth, evolution, the role of the Colorado River carving Grand Canyon, and how the canyon's stratigraphic record reveals changing depositional environments over long period of time, etc. Cite specific examples when possible.

- My experience is that confused and questioning folks are much more likely to ask a question regarding creationism during a program. Confrontations with Young Earth Creationists are relatively rare in interpretive settings.

Multiple Points of View……what does it mean relative to geologic time and age of earth?

- There are multiple perspectives and meanings associated with landscapes such as Grand Canyon. Landscapes and places can mean a lot of different things to a lot of different people and can be viewed in different ways. All meanings are valid to the people who hold them.
- Science, as a method of inquiry, is the best tool to understand the physical origin and evolution of landscapes like Grand Canyon.
- Multiple Points of View is usually about values, associations, and meanings, and is not applicable to factual evidence (unless those facts are tentative based on incomplete evidence). It may be applicable to interpretations of facts. (*Everyone is entitled to their own opinion, but not their own facts*. --Daniel Patrick Moynihan)
- NPS policy explicitly states that addressing Multiple Points of View does not mean disregarding factual evidence.
- Mythology and story (whether it is a Native American story or even a Christian creationist story) is best used when talking about cultures, or about people's relationship with the land. All cultures are shaped by the land and all peoples have important meanings associated with their homelands. For example, it would be enlightening to refer to a Hopi Grand Canyon story when talking about the culture and history of the Hopi people; it would be less enlightening to refer to a Hopi story when talking about the geologic origin of Grand Canyon. (Ethnogeology is a science of our planet that comes out of, and speaks specifically to aboriginal peoples. As a result, it is most appropriately used in programs targeted to native audiences.)

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The National Center for Science Education website: http://ncseweb.org/

A. Mathis
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Second Draft. Please send feedback to Allyson_Mathis@nps.gov. All opinions and suggestions in the sections "Tips for interpreting geology and the age of the earth" and "To Keep in Mind…(Know your audience)" are mine.

What is Science?

Science is a particular way of knowing about the world. In science, explanations are limited to those based on observations and experiments that can be substantiated by other scientists. Explanations that cannot be based on empirical evidence are not a part of science.

In the quest for understanding, science involves a great deal of careful observation that eventually produces an elaborate written description of the natural world. Scientists communicate their findings and conclusions to other scientists through publications, talks at conferences, hallway conversations, and many other means. Other scientists then test those ideas and build on preexisting work. In this way, the accuracy and sophistication of descriptions of the natural world tend to increase with time, as subsequent generations of scientists correct and extend the work done by their predecessors.

Progress in science consists of the development of better explanations for the causes of natural phenomena. Scientists never can be sure that a given explanation is complete and final. Some of the hypotheses advanced by scientists turn out to be incorrect when tested by further observations of experiences. Yet many scientific explanations have been so thoroughly tested and confirmed that they are held with great confidence.
--National Academy of Sciences, 1999, *Science and Creationism: A View from the National Academy of Sciences, 2nd Edition*, p. 1.

Definitions and Descriptions of Science

- Fundamentally, observing events or things and drawing conclusions about our activities and surroundings. *--Learning from the Fossil Record*
- Science—a teaching authority dedicated to using the mental methods and observational techniques validated by success and experience as particularly well suited for describing, and attempting to explain, the factual construction of nature. --*Steven Jay Gould*
- Science is a method of explaining the natural world. It assumes the universe operates according to regularities and that through systematic investigation we can understand these regularities. The methodology of science emphasizes the logical testing of alternative explanations of natural phenomena against empirical data. Because science is limited to explaining the natural world by means of natural processes, it cannot use supernatural causation in its explanations. *--National Science Teachers Association*
- Science is not teleological; the accepted processes do not start with a conclusion, then refuse to change it, or acknowledge as valid only those data that support an unyielding conclusion. Science does not base theories on an untestable collection of dogmatic proposals. Instead, the processes of science are characterized by asking questions, proposing hypotheses, and designing empirical models and conceptual frameworks for research about natural events. *--National Association of Biology Teachers*
- The disciplined interplay of data and imagination. *--Learning from the Fossil Record*

Fact

- A *confirmed observation*.
- An observation that has been repeatedly confirmed and for all practical purposes is accepted as "true." Truth in science, however, is never final, and what is accepted as a fact today may be modified or even discarded tomorrow.

Theory

- Theories explain facts. Theories are *explanations*.
- Logical construct of facts and hypotheses that attempts to explain a range of natural phenomena.
- A well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses.
- The most important scientific explanations are called "theories." In ordinary speech, "theory" is often used to mean "guess" or "hunch," whereas in scientific terminology, a theory is a set of universal statements which explain the natural world. Theories are powerful tools. Scientists seek to develop theories that
    1. are internally consistent and compatible with the evidence
    2. are firmly grounded in and based upon evidence
    3. have been tested against a diverse range of phenomena
    4. possess broad and demonstrable effectiveness in problem solving
    5. explain a wide variety of phenomena
- In science, a theory is not a guess or an approximation but an extensive explanation developed from well-documented, reproducible sets of experimentally-derived data from repeated observations of natural processes.

Hypothesis

- A *tentative statement* about the natural world leading to deductions that can be tested. If the deductions are verified, it becomes more probable that the hypothesis is correct. If the deductions are incorrect, the original hypothesis can be abandoned or modified. Hypotheses can be used to build more complex inferences and explanations.
- An educated guess, usually stated in the form of a definite assertion, with the understanding that it may or may not be true.
- A speculation within the realm of science.

Law

- A *descriptive generalization* about how some aspect of the natural world behaves under stated circumstances.
- The rules that nature has been observed to follow.
- "Theories don't become laws, they explain laws."
- Laws describe phenomena; whereas theories explain phenomena.

The Two Major Types of Science

- Empirical (Experimental) Science
- Historical Science

Empirical (Experimental) Science

- chemistry, physics, most of molecular biology
- relies on observations that are not expected to change with time (in other words, are time independent processes)

Historical Science

- much of geology, paleontology, evolutional biology, astronomy, and anthropology
- deals with evidence from a sequence of events, each dependent upon the previous one.
- reconstructs such histories by observing, as much as possible, evidence for each past event. Logical inferences are made, then tested against the data
- generally has a greater margin of error than experimental science because scientists much view the results of events through a filter of deep time
- uses and includes experimental sciences
- uses investigative processes, deductions and inferences much like forensic science (e.g. detective work)

The Scientific Method is usually described as a simple, step-by-step process of:

- Gathering data
- Developing hypotheses
- Testing hypotheses with specific data
- Negating hypotheses, then developing new hypotheses
- Elevating hypotheses to theory

In reality, the scientific process is less orderly…..
Science never ceases to ask "why."

Key scientific skills include:

- critical thinking
- evidential reasoning
- curiosity
- skepticism

Explanations

Science is devoted to providing explanations. Explanations that really explain the phenomena will produce understanding. Scientific explanations are:

- based on evidence accumulated through empirical observations and/or experiments
- made public (peer-reviewed, shared with others, including nonscientific audiences)
- tentative (may change with new or additional data)
- historical and cumulative. Past explanations are the basis for new explanations.

- concerned with identifying cause and effect relationships
- are limited. They are limited by technology and they are limited by the constraints of using empirical standards, logical arguments, and skepticism. Scientific explanations are also limited to those that fall within the parameters of science. Science cannot answer questions about the meaning of life, ethics and theology. Scientific explanations preclude use of any supernatural causation.

Important Tenets of Science and Scholarship

- Extraordinary claims require extraordinary evidence; whereas minor claims require minor evidence.
- To make a strongly supported, specific claim, it is not sufficient to discredit opposing claims; one must make a positive case for one's own assertions.

Occam's Razor (Principle of Parsimony) – if two explanations explain a phenomena equally well, we should prefer or chose the simpler of the two explanations.

Pseudoscience relies on the use of particular facts, beliefs, unconfirmed opinions to foster a false understanding of events and things. Pseudoscience generally

- utilizes selected beliefs, data, authorities, and half-truths,
- proposes irrefutable hypotheses that are untestable,
- uses faulty metaphors, analogies, and comparisons,
- confuses causes and correlations,
- makes false arguments, such as claiming whatever has not been proved false must be true, and vice versa,
- may be teleological (i.e., have a pre-determined conclusion).

References and Further Reading

Fezer, Karl Dietrich, 2001, *Scholarly World, Private Worlds: Thinking critically about science, religion and your private beliefs*: Xlibris, 434 p.

Gould, Steven Jay, 1999, *Rocks of Ages: Science and Religion in the Fullness of Life*: The Ballantine Publishing Group, New York, 241 p.

Lipps, Jere H., 1996, The decline of reason?: Learning from the Fossil Record, Paleontological Society Papers, v. 2, p. 3 – 10.

VandenDolder, Evelyn M., 1995, *How Geologists Tell Time*: Arizona Geological Survey Down-to-Earth Series 4, 33 p.

National Academy of Sciences, 1999, *Science and Creationism: A View from the National Academy of Sciences, 2nd Edition*: National Academy Press, Washington DC, 35 p.

National Academy of Sciences, 1998, *Teaching about Evolution and the Nature of Science*: National Academy Press, Washington DC, 140 p.

A. Mathis
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NPS Policy, Interpretation, and Creationism (including "intelligent design")

NPS Policy

Excerpts from 2006 National Park Service Management Policies, Chapter 7, Interpretation and Education.

From Section 7.1:

> Factual information presented will be current, accurate, based on current scholarship and science, and delivered so as to convey park meanings, with the understanding that audience members will draw their own conclusions.

From Section 7.5.4:

> Interpretive and educational programs will be based on current scholarship and research about the history, science, and condition of park resources, and on research about the needs, expectations, and behavior of visitors.

From Section 7.5.3:

> Acknowledging multiple points of view does not require interpretive and educational programs to provide equal time, or to disregard the weight of scientific or historical evidence.

Excerpts from NPS Directors Order 6, Interpretation, 2005:
8.3 Resource Issue Interpretation and Education

Interpretive and educational programs can build public understanding of, and support for, resource management decisions, and for the NPS mission in general. Therefore, parks should thoroughly integrate resource issues and initiatives of local and Service-wide importance into their interpretive and educational programs.

8.4 Research

8.4.1 *In General*. Quality interpretive programs and media require sound research. The content of interpretive and educational services must be accurate, inclusive, respect multiple points of view and be free of cultural, ethnic, and personal biases. However, in accordance with section 7.5.5 of Management Policies, "[a]cknowledging multiple points of view does not require interpretive and educational programs to provide equal time, or to disregard the weight of scientific or historical evidence." Programs presented by cultural demonstrators should be introduced as clearly representing the particular culture being presented.

8.4.2 *Historical and Scientific Research.* Superintendents, historians, scientists, and interpretive staff are responsible for ensuring that park interpretive and educational programs and media are accurate and reflect current scholarship. To accomplish this, an on-going dialogue must be established. Questions often arise round the presentation of geological, biological, and evolutionary processes. The interpretive and educational treatment used to explain the natural processes and history of the Earth must be based on the best scientific evidence available, as found in scholarly sources that have stood the test of scientific peer review and criticism. The facts, theories, and interpretations to be used will reflect the thinking of the scientific community in such fields as biology, geology, physics, astronomy, chemistry, and paleontology. Interpretive and educational programs must refrain from appearing to endorse religious beliefs explaining natural processes. Programs, however, may acknowledge or explain other explanations of natural processes and events.

US Constitution

Amendment I: Congress shall make no law respecting an establishment of religion, or prohibiting the free exercise thereof; or abridging the freedom of speech, or of the press; or the right of the people peaceably to assemble, and to petition the government for a redress of grievances.

The First Amendment prohibits the government from promoting any specific religion or religion in general; and also prohibits the government from interfering with the rights of citizens to practice any religion.

Creationism, including “creation science” and “intelligent design,” is inherently a religious perspective (as decided repeatedly by the courts, see excerpts from *Kitzmiller v. Dover* decision below), and as such, the National Park Service cannot promote it, nor incorporate it into interpretive or other media.

Kitzmiller v Dover Memorandum Opinion

December 20, 2005
http://www.pamd.uscourts.gov/kitzmiller/kitzmiller_342.pdf

Excerpts:
p. 24
We initially note that John Haught, a theologian who testified as an expert witness for Plaintiffs and who has written extensively on the subject of evolution and religion, succinctly explained to the Court that the argument for ID [Intelligent Design] is not a new scientific argument, but is rather an old religious argument for the existence of God. He traced this argument back to at least Thomas Aquinas in the 13th century, who framed the argument as a syllogism: Wherever complex design exists, there must have been a designer; nature is complex; therefore nature must have had an intelligent designer. (Trial Tr. vol. 9, Haught Test., 7-8, Sept. 30, 2005). Dr. Haught testified that Aquinas was explicit that this intelligent designer "everyone understands to be God." Id. The syllogism described by Dr. Haught is essentially the same argument for ID [Intelligent Design] as presented by defense expert witnesses Professors Behe and Minnich who employ the phrase "purposeful arrangement of parts."

p.64
After a searching review of the record and applicable caselaw, we find that while ID [Intelligent Design] arguments may be true, a proposition on which the Court takes no position, ID [Intelligent Design] is not science. We find that ID [Intelligent Design] fails on three different levels, any one of which is sufficient to preclude a determination that ID [Intelligent Design] is science. They are: (1) ID [Intelligent Design] violates the centuries-old ground rules of science by invoking and permitting supernatural causation; (2) the argument of irreducible complexity, central to ID, employs the same flawed and illogical contrived dualism that doomed creation science in the 1980's; and (3) ID's [Intelligent Design] negative attacks on evolution have been refuted by the scientific community. As we will discuss in more detail below, it is additionally important to note that ID [Intelligent Design] has failed to gain acceptance in the scientific community, it has not generated peer-reviewed publications, nor has it been the subject of testing and research.

p.65
In deliberately omitting theological or "ultimate" explanations for the existence or characteristics of the natural world, science does not consider issues of "meaning" and "purpose" in the world. (9:21 (Haught); 1:64, 87 (Miller)). While supernatural explanations may be important and have merit, they are not part of science. (3:103 (Miller); 9:19-20 (Haught)). This self-imposed convention of science, which limits inquiry to testable, natural explanations about the natural world, is referred to by philosophers as "methodological naturalism" and is sometimes known as the scientific method. (5:23, 29-30 (Pennock)). Methodological naturalism is a "ground rule" of science today which requires scientists to seek explanations in the world around us based upon what we can observe, test, replicate, and verify. (1:59-64, 2:41-43 (Miller); 5:8, 23-30 (Pennock)).

p. 69-70
Initially, we note that NAS, the "most prestigious" scientific association in this country, views ID [Intelligent Design] as follows:

> Creationism, intelligent design, and other claims of supernatural intervention in the origin of life or of species are not science because they are not testable by the methods of science. These claims subordinate observed data to statements based on authority, revelation, or religious belief. Documentation offered in support of these claims is typically limited to the special publications of their advocates. These publications do not offer hypotheses subject to change in light of new data, new interpretations, or demonstration of error. This contrasts with science, where any hypothesis or theory always remains subject to the possibility of rejection or modification in the light of new knowledge.

p. 136-138
The proper application of both the endorsement and Lemon tests to the facts of this case makes it abundantly clear that the Board's ID [Intelligent Design] Policy violates the Establishment Clause. In making this determination, we have addressed the seminal question of whether ID is science. We have concluded that it is not, and moreover that ID [Intelligent Design] cannot uncouple itself from its creationist, and thus religious, antecedents.

Both Defendants and many of the leading proponents of ID [Intelligent Design] make a bedrock assumption which is utterly false. Their presupposition is that evolutionary theory is antithetical to a belief in the existence of a supreme being and to religion in general. Repeatedly in this trial, Plaintiffs' scientific experts testified that the theory of evolution represents good science, is overwhelmingly accepted by the scientific community, and that it in no way conflicts with, nor does it deny, the existence of a divine creator.

To be sure, Darwin's theory of evolution is imperfect. However, the fact that a scientific theory cannot yet render an explanation on every point should not be used as a pretext to thrust an untestable alternative hypothesis grounded in religion into the science classroom or to misrepresent well-established scientific propositions.

The citizens of the Dover area were poorly served by the members of the Board who voted for the ID [Intelligent Design] Policy. It is ironic that several of these individuals, who so staunchly and proudly touted their religious convictions in public, would time and again lie to cover their tracks and disguise the real purpose behind the ID [Intelligent Design] Policy.

With that said, we do not question that many of the leading advocates of ID [Intelligent Design] have bona fide and deeply held beliefs which drive their scholarly endeavors. Nor do we controvert that ID [Intelligent Design] should continue to be studied, debated, and discussed. As stated, our conclusion today is that it is unconstitutional to teach ID [Intelligent Design] as an alternative to evolution in a public school science classroom.

Those who disagree with our holding will likely mark it as the product of an activist judge. If so, they will have erred as this is manifestly not an activist Court. Rather, this case came to us as the result of the activism of an ill-informed faction on a school board, aided by a national public interest law firm eager to find a constitutional test case on ID [Intelligent Design], who in combination drove the Board to adopt an imprudent and ultimately unconstitutional policy. The breathtaking inanity of the Board's decision is evident when considered against the factual backdrop which has now been fully revealed through this trial. The students, parents, and teachers of the Dover Area School District deserved better than to be dragged into this legal maelstrom, with its resulting utter waste of monetary and personal resources.

For more information on evolution:

Websites:
The Understanding Evolution website:
http://evolution.berkeley.edu/
The National Center for Science Education:
http://ncseweb.org/
The National Academy of Science:
http://www.nationalacademies.org/evolution/
Recommended Book:
Scott, Eugenie C., 2008, *Evolution vs. Creationism: An Introduction, Second Edition*: Greenwood Press, 272 p.

A. Mathis