National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Blue Ridge Parkway

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2020/2194

The production of this document cost $24,922, including costs associated with data collection, processing, analysis, and subsequent authoring, editing, and publication.

ON THE COVER
Photograph of the Blue Ridge Parkway in autumn. At milepost 423.3, the Blue Ridge Parkway passes through Beech Gap at an elevation of 1,628 m (5,340 ft). Gaps, worn by wind or water, are a common sight along the parkway. Abundant deciduous trees ensure a colorful autumn time. National Park Service photograph courtesy of Blue Ridge Parkway.

THIS PAGE
Photograph of Grassy Creek Falls. Many waterfalls are located adjacent to the Blue Ridge Parkway because of its topographically high position along ridges. Grassy Creek Falls is in Little Switzerland, at about milepost 334. National Park Service photograph courtesy of Blue Ridge Parkway.

Blue Ridge Parkway

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2020/2194

Trista L. Thornberry-Ehrlich

Colorado State University Research Associate
National Park Service Geologic Resources Inventory
Geologic Resources Division
PO Box 25287
Denver, CO 80225

November 2020

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the Geologic Resources Inventory publications site and the Natural Resource Report publication series site. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov

Please cite this publication as:

Thornberry-Ehrlich, T. L. 2020. Blue Ridge Parkway: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2020/2194. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2279838.

NPS 601/173851, November 2020

Contents

Figures

Tables

Executive Summary

The Geologic Resources Inventory (GRI) provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI.

This report synthesizes discussions from a scoping meeting held in 2000 and a follow-up conference call in 2017 (see Appendix A). Chapters of this report highlight the geologic setting, describe distinctive geologic features and processes within Blue Ridge Parkway, discuss geologic issues facing resource managers, summarize the geologic history leading to the present-day landscape, and provide information about the previously completed GRI map data.

As the longest road to be designated as a single park unit in the United States, Blue Ridge Parkway protects a755 km (469 mi) ribbon of mountain landscapes including high passes, lush vegetation, waterfalls, water and wind gaps, forests, and upland meadows. With 15 million visitors in 2019, the parkway was second only to Golden Gate National Recreation Area (California) for highest visitation in the National Park System. The parkway passes through 29 counties of Virginia and North Carolina and is an engineering marvel that includes 26 tunnels and 168 bridges designed in harmony with the local rock, including the Linn Cove Viaduct at milepost 304. The viaduct was constructed specially to avoid degrading the vulnerable ecosystem at Grandfather Mountain; the mountain itself is among the more significant geologic features of the southern Appalachians.

The geologic story of the parkway spans more than one billion years. The rocks exposed along the Blue Ridge Parkway are the core of an ancient mountain chain. The Appalachian Mountains are the remnants of a chain of mountains that may have rivaled the Himalayas when they formed more than 250 million years ago. The long geologic history, recorded in the rocks along the parkway, involves an early supercontinent, the opening and closing of an ancient ocean to form another supercontinent, followed by the rifting that opened the Atlantic Ocean. The rocks are broadly divisible into six groups: (1) Mesoproterozoic basement complex (more than 1 billion years old), (2) Neoproterozoic metasedimentary and metaigneous complexes (more than 541 million years old), (3) Neoproterozoic to Cambrian sedimentary and metamorphic rocks spanning the time across the Proterozoic into the Paleozoic (between 1 billion and 488 million years old), (4) Paleozoic sedimentary and mylonitic rocks, (5) Jurassic igneous rocks (more than 145 million years old), and (6) Cenozoic surficial deposits that are still forming on the landscape today.

This report is supported by three GRI-compiled maps of the geology of Blue Ridge Parkway: Carter et al. (2016), Merschat et al. (2008a), and Merschat et al. (2008b). The maps were developed by two groups of geologists: US Geological Survey (USGS) geologists developed the maps for the Virginia portion of the parkway; the GRI team compiled these maps into the blrn_geology.mxd data set. The North Carolina Geological Survey (NCGS) geologists developed the maps for the North Carolina portion of the parkway; the GRI team compiled these maps into the blrs_geology.mxd data set. The Virginia portion includes data in a broader buffer around the parkway boundary than the North Carolina portion. Additionally, surficial geologic mapping and geologic hazards mapping are part of the North Carolina GRI GIS data (brhz_geohazards.mxd). Map unit descriptions, reports, and hundreds of annotated photographs accompany the data. Many of these photographs are used in this report to help illustrate geologic features. The photographs correspond to geologic observation localities in the GRI GIS data.

Geologic features, processes, and resource management issues include the following:

- **The Blue Ridge, Black, Great Craggy, Pisgah, and Great Balsam Mountains**. The topographic relief along the length of the parkway is more than 1,700 m (5,700 ft). Traversing the Blue Ridge province, the parkway crests or skirts the slopes of these five mountain ranges. Each range has characteristic morphologies and ecosystems.
- **Gaps**. The imposing Appalachian Mountains long served as obstacles to east-to-west migration and travel. The ridges are punctuated by wind and water

gaps through which animals and people crossed. Modern roadways also pass through gaps. More than 100 named gaps are located within parkway boundaries.

- **Faults and Folds**. Faults and folds accommodate stresses within Earth's crust. They form where the rock has compressed, stretched, sheared, or fractured. Faults are mapped in the GRI GIS data. Folds are not mapped, but anticlines and synclines occur along the parkway at scales ranging from regional to less than a centimeter.
- **Bedrock Exposures: Metamorphic, Igneous, and Sedimentary Rocks**. Bedrock crops out along the length of the parkway, specifically as roadcuts, tunnels, and cliffs.
- **Earth Surface Processes: Surficial Units**. Because of the parkway's position along the crest of the mountains, eroded sediments tend to be transported away from the parkway by wind, water, and gravity. Unconsolidated, surficial slope deposits are mapped in the North Carolina portion of the parkway. Some deposits, such as debris flows, are geologic hazards; slope deposits have blocked the parkway periodically.
- **Wetlands**. Wetlands are areas that are covered (flooded) permanently or intermittently with shallow water or have soil saturated with moisture. The parkway protects half of the remaining high elevation wetlands in North Carolina as well as other wetland types such as southern Appalachian bog, high elevation seeps, swamp-forest bog complex, and bottomland (floodplain) forest.
- **Geologic Hazards: Slope Movements and Earthquakes**. The primary geologic hazard in the parkway is slope movements. Slope movements may include rockfalls, landslides, and debris flows. Triggers of slope movements include frost weathering, root wedging, water-saturated soils, human disturbance, and rock weakening due to chemical weathering (e.g., sulfides weathering to produce acid in percolating groundwater). USGS and NCGS geologists have photographed and analyzed hundreds of locations with the potential for slope failure along the parkway. Strong earthquakes are not common to the parkway area but are possible. Earth shaking would have the potential to trigger further slope movements and damage infrastructure.
- **Abandoned Mineral Lands, Disturbed Lands Restoration, and Structural Integrity of the Parkway**. Abandoned mineral lands are lands, waters, and surrounding watersheds that contain disturbances associated with past mineral exploration, extraction, processing, and transportation. Abandoned Mineral Lands, though not formally inventoried, occur along the length of the parkway and are included in the GRI GIS data. Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by development. Although the parkway itself is an example of a developed landscape, it is maintained as a primary resource and historical feature.
- **Paleontological Resource Inventory, Monitoring, and Protection**. Paleontological resources (fossils) are nonrenewable evidence of life preserved in a geologic context. The parkway protects examples of extremely old lifeforms as trace fossils, such as burrows, in sandstone more than 500 million years old.

Given the long, narrow nature of the parkway corridor, park managers divide the parkway into seven segments on the basis of shared geomorphology and geography (see maps in figs. 1a–e):

- Segment 1—Ridge, mileposts 0–106,
- Segment 2—Roanoke, mileposts 106–136,
- Segment 3—Plateau, mileposts 136–217,
- Segment 4—Highlands, mileposts 217–305,
- Segment 5—Black Mountain, mileposts 305–377,
- Segment 6—Asheville, mileposts 377–394, and
- Segment 7—Pisgah, mileposts 394–469.

These segments provide a convenient way to approach resource management and describe the parkway's geology. This report follows suit, beginning with descriptions that are applicable to the entire parkway, then discussions pertinent to each segment. Tables for each segment detail the geologic map units, including a brief description, for that segment and list geographic/geologic features, geologic hazards, infrastructure, and geologic sample localities.

Products and Acknowledgments

The NPS Geologic Resources Division partners with the Colorado State University Department of Geosciences to produce GRI products. The US Geological Survey and North Carolina Geological Survey developed the source maps and, along with NPS staff, reviewed GRI content. This chapter describes GRI products and acknowledges contributors to this report.

GRI Products

The GRI team undertakes three tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report (this document). These products are designed and written for nongeoscientists.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. The GRI team conducts no new field work in association with their products.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). The "Additional References" chapter and Appendix B provide links to these and other resource management documents and information.

Additional information regarding the GRI, including contact information, is available at http://go.nps.gov/gri.

Acknowledgments

Mapping a linear corridor over hundreds of miles through complicated geology is no small feat. To that end, the GRI team would like to thank the mappers for delivering such a robust and useful product. Mark Carter (US Geological Survey), Rick Wooten and Bart Cattanach (North Carolina Geological Survey) and Bambi Teague (Blue Ridge Parkway) provided excellent advice and review. John Andreoni (NPS and Natural Resources Conservation Service) supplied important information about slope stability and integration of geologic and soils mapping data along the parkway.

Review

Michael Barthelmes (Colorado State University)

Mark Carter (US Geological Survey)

Burt Cattanach (North Carolina Geological Survey)

Tim Connors (NPS Geologic Resources Division)

Jason Kenworthy (NPS Geologic Resources Division)

Rick Wooten (North Carolina Geological Survey)

Editing

Katie KellerLynn (Colorado State University)

Report Formatting and Distribution

Jason Kenworthy (NPS Geologic Resources Division)

Source Maps

Carl Merschat, Mark Carter, Rick Wooten, and Bart Cattanach (North Carolina Geological Survey)

Mark Carter, Allen Crider, and Scott Southworth (US Geological Survey)

GRI GIS Data Production

James Winter (Colorado State University)

Stephanie O'Meara (Colorado State University)

Derek Witt (Colorado State University)

Georgia Hybels (Colorado State University)

MP 0–106: Ridge

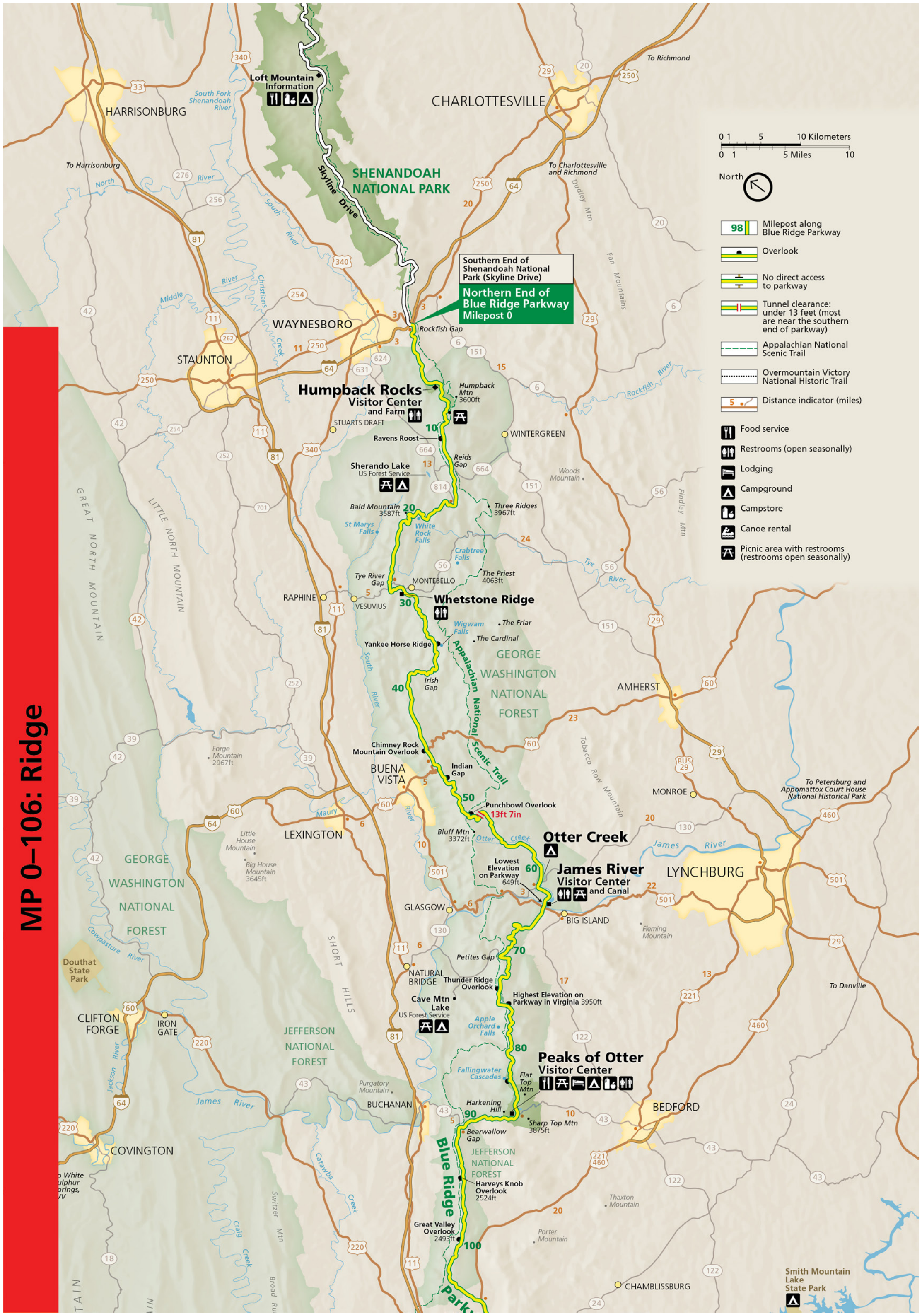


Figure 1a. Map of Blue Ridge Parkway, Ridge segment (MP 0–106).
The parkway traces the heights of the Blue Ridge Mountains in Virginia and North Carolina, where it traverses four other mountain ranges. The parkway is divided into seven segments (bound by mileposts ["MP"], denoted in green text along the parkway trace) for management purposes as illustrated in figures 1a–1e. Note the orientation of north is not directly towards the top of the map sections. The maps were rotated for ease of viewing. National Park Service map available at https://www.nps.gov/carto/app/#!/maps/alphacode/BLRI.

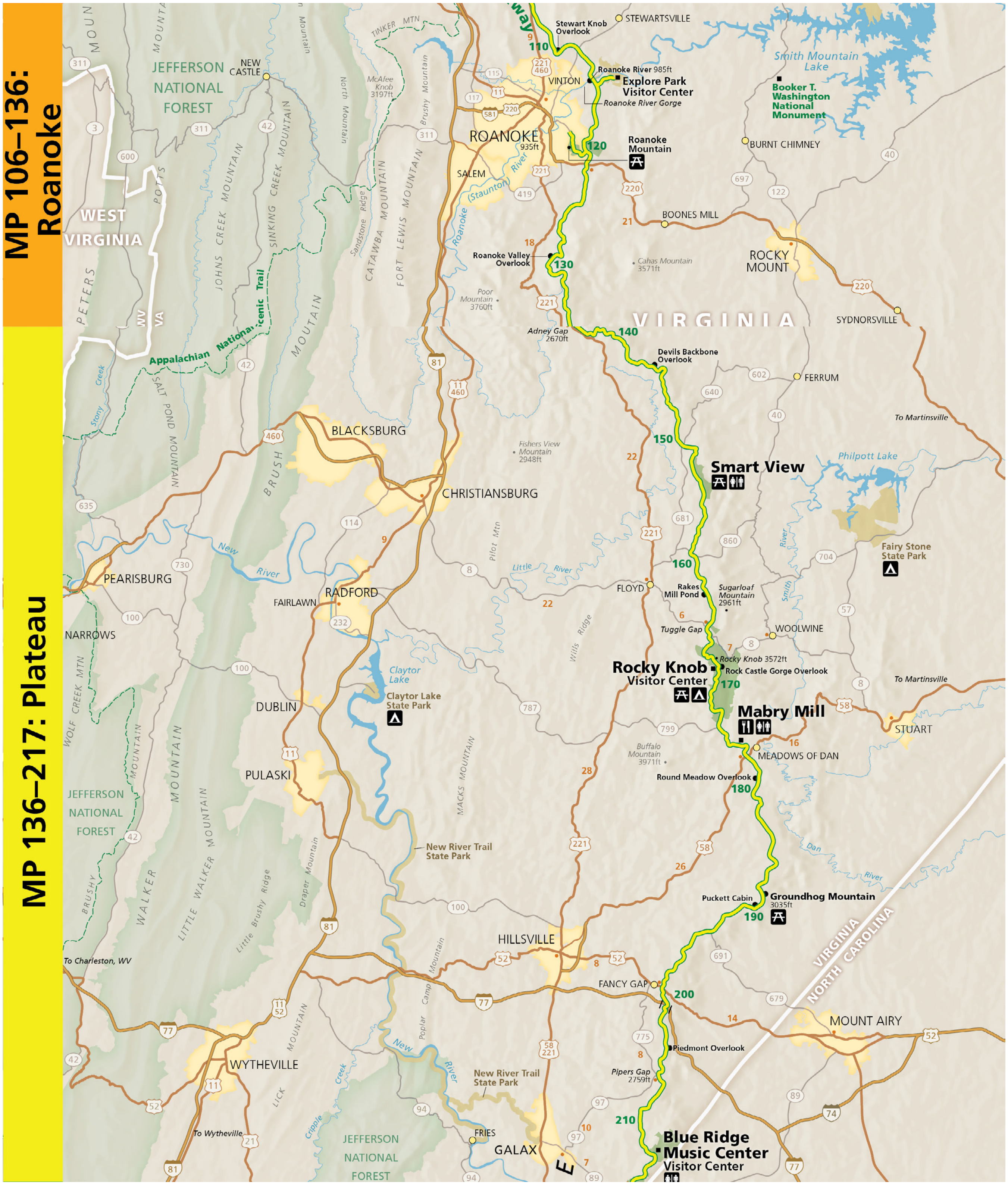


Figure 1b. Map of Blue Ridge Parkway, Roanoke (MP 106–136) and Plateau (MP 136–217) segments. The parkway traces the heights of the Blue Ridge Mountains in Virginia and North Carolina, where it traverses four other mountain ranges. The parkway is divided into seven segments (bound by mileposts ["MP"], denoted in green text along the parkway trace) for management purposes as illustrated in figures 1a–1e. Note the orientation of north is not directly towards the top of the map sections. The maps were rotated for ease of viewing. National Park Service map available at https://www.nps.gov/carto/app/#!/maps/alphacode/BLRI.

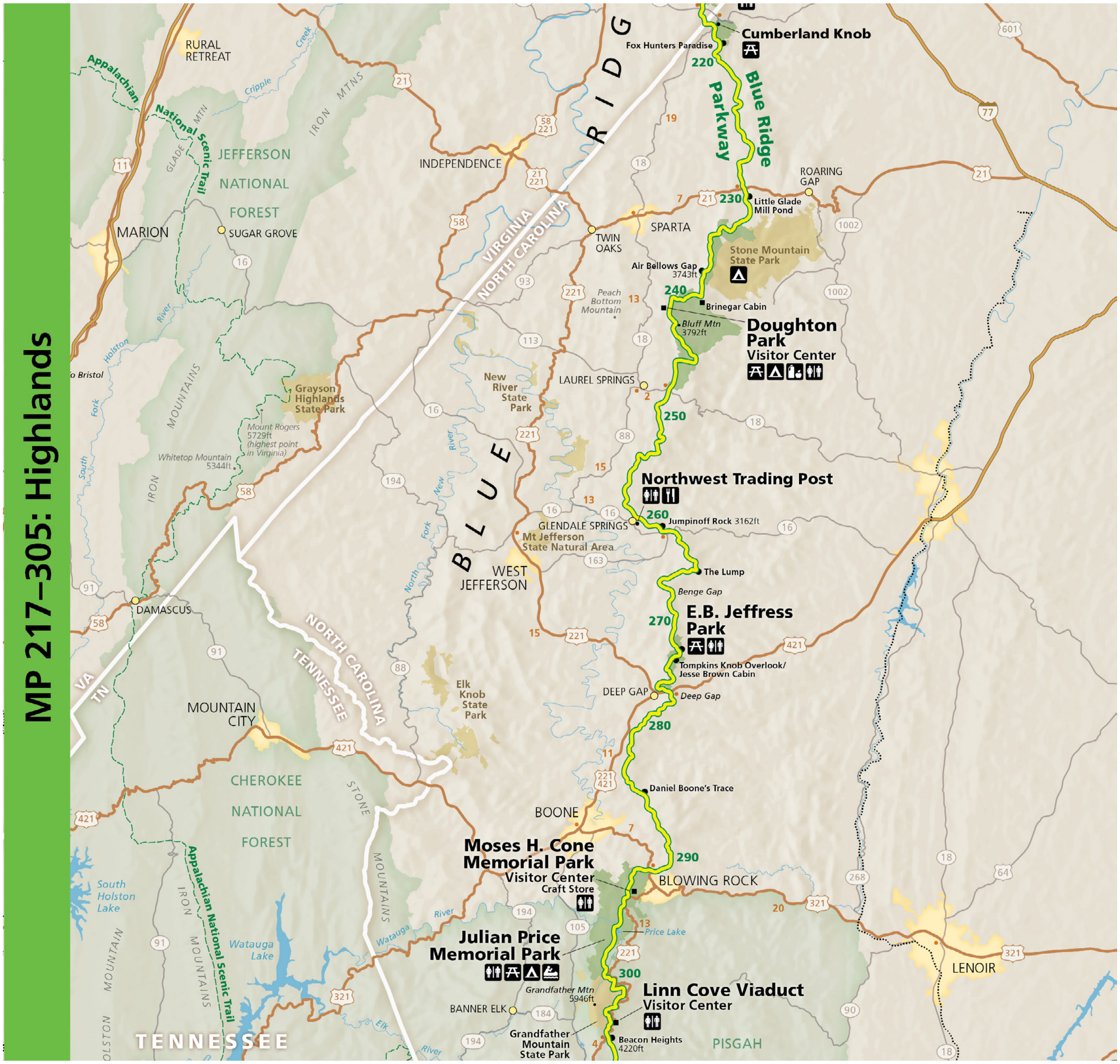


Figure 1c. Map of Blue Ridge Parkway, Highlands segment (MP 217–305).
The parkway traces the heights of the Blue Ridge Mountains in Virginia and North Carolina, where it traverses four other mountain ranges. The parkway is divided into seven segments (bound by mileposts ["MP"], denoted in green text along the parkway trace) for management purposes as illustrated in figures 1a–1e. Note the orientation of north is not directly towards the top of the map sections. The maps were rotated for ease of viewing. National Park Service map available at https://www.nps.gov/carto/app/#!/maps/alphacode/BLRI.

Figure 1d. Map of Blue Ridge Parkway, Black Mountain (MP 305–377) and Asheville (MP 377–394) segments.
The parkway traces the heights of the Blue Ridge Mountains in Virginia and North Carolina, where it traverses four other mountain ranges. The parkway is divided into seven segments (bound by mileposts ["MP"], denoted in green text along the parkway trace) for management purposes as illustrated in figures 1a–1e. Note the orientation of north is not directly towards the top of the map sections. The maps were rotated for ease of viewing. National Park Service map available at https://www.nps.gov/carto/app/#!/maps/alphacode/BLRI.

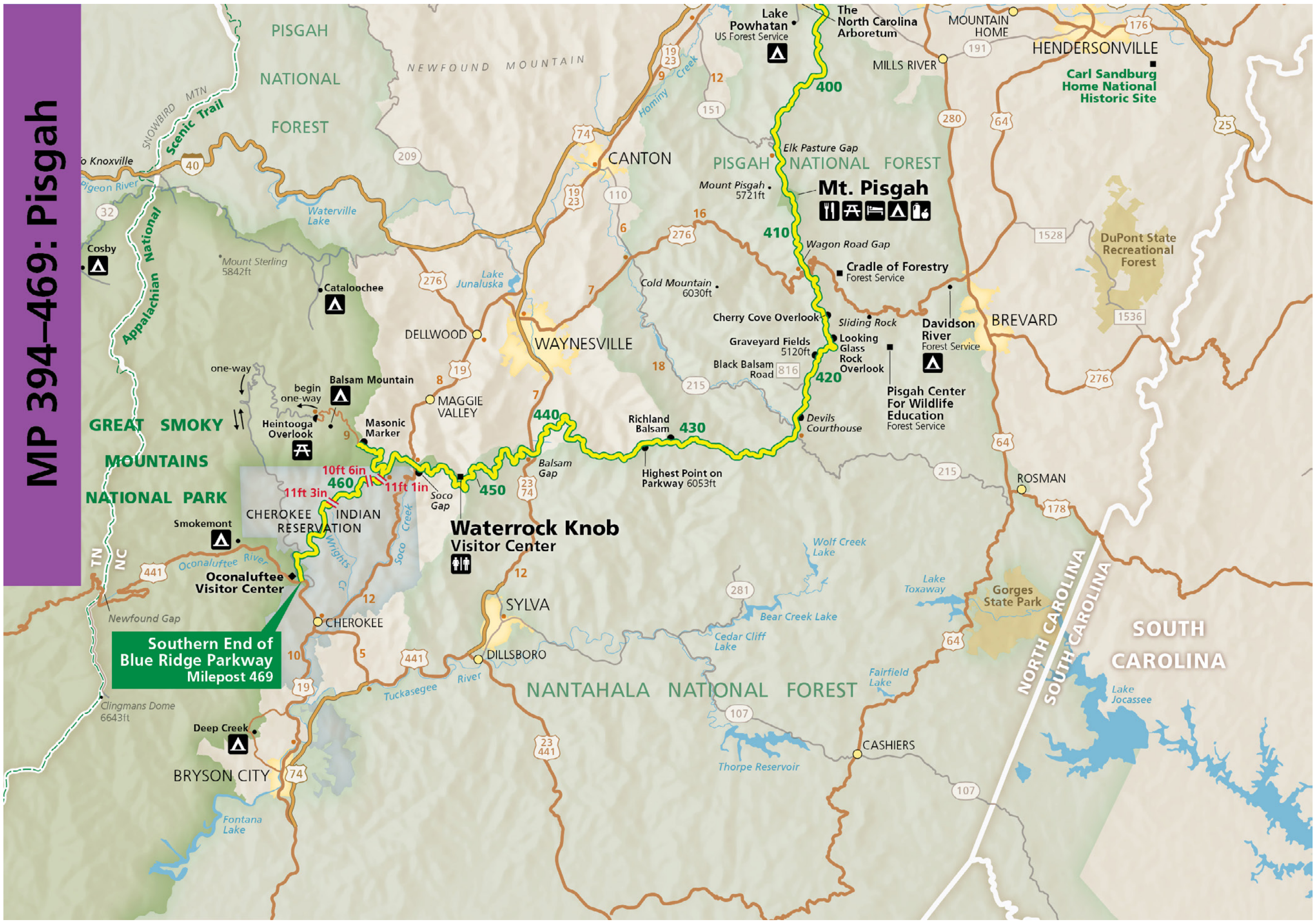


Figure 1e. Map of Blue Ridge Parkway, Pisgah segment (MP 394–469).
The parkway traces the heights of the Blue Ridge Mountains in Virginia and North Carolina, where it traverses four other mountain ranges. The parkway is divided into seven segments (bound by mileposts ["MP"], denoted in green text along the parkway trace) for management purposes as illustrated in figures 1a–1e. Note the orientation of north is not directly towards the top of the map sections. The maps were rotated for ease of viewing. National Park Service map available at https://www.nps.gov/carto/app/#!/maps/alphacode/BLRI.

Geologic Setting and Significance

This chapter describes the regional geologic setting of the parkway and summarizes connections among geologic resources, other park resources, and park stories.

Parkway Establishment

Conceived in 1933, construction of Blue Ridge Parkway (referred to as the "parkway" through this report) began in 1935 as part of the National Industrial Recovery Act (48 Stat. 195, Public Law 73-67) during the Great Depression to create jobs in an impoverished region by building a road with limited access. The goal was to supply pleasant motoring and recreation opportunities in a designed landscape while preserving natural and cultural resources. The parkway took 52 years to build and now is commonly the most frequently visited unit in the National Park System—it has been the most or second-most (behind Golden Gate National Recreation Area in California) visited unit every year between 2010 and 2019. Nearly 15 million recreational visits were recorded in 2019.

The parkway—a 755-km- (469-mi-) long, scenic ribbon of road tracing the crest of the Blue Ridge—forms a link between two iconic Appalachian national parks: Shenandoah in Virginia and Great Smoky Mountains in North Carolina (figs. 1a–1e). It also provides a link with Earth's past showing how the Appalachians formed through the collision of ancient continents. The parkway harmoniously winds through myriad ecosystems along a corridor naturally buffered from development. The parkway protects some of the most naturally rich, ecologically diverse, and culturally significant resources of the central and southern Appalachian Mountains. Across its approximately 34,000 ha (85,000 ac), the parkway corridor is a complex area of overlapping jurisdictions, interests, and responsibilities with about 1,900 km (1,200 mi) of boundary (National Park Service 2013). The parkway lands have an elevation range of 1,756 m (5,762 ft), rising from 198 m (649 ft) at the James River in Virginia to 1,954 m (6,411 ft) at the summit of Richland Balsam of the Great Balsam Range, the highest peak within the parkway. The parkway (road) itself climbs to 1,843 m (6,047 ft) above sea level at Richland Balsam in North Carolina.

According to the parkway's foundation document (National Park Service 2016), Blue Ridge Parkway is significant for the following reasons:

- it was the first national rural parkway to be initiated, designed, and built for a leisurely driving experience that included recreational opportunities based on resources
- it has an innovative design, lying lightly on the land and blending harmoniously into the landscape
- it is the highest and longest continuous road in the Appalachian region and allows access to five major mountain ranges
- it encompasses a wide range of elevation as well as globally imperiled natural communities with a diverse range of flora and fauna
- by connecting 29 counties, it contributes to a singular regional identity and preserves and interprets historically significant cultural resources associated with people of the central and southern Appalachian Mountains.

Geologic Setting

The parkway caps a lengthy section of the central and southern Blue Ridge physiographic province, its namesake, which stretches as a mountainous belt between the Piedmont (east) and the Valley and Ridge (west) from Pennsylvania southwestward to Georgia (fig. 2). The character and landscape expression of the province changes along its length, and the features visible along the trace of the parkway reflect this. In general, the Blue Ridge province comprises rugged mountains with steep slopes.

Staring into the core of an ancient mountain range, the geology of the parkway is complex; however, the geologic units mapped within the parkway are broadly divisible into six groups (Merschat et al. 2008a; Carter et al. 2016) (fig. 3 and table 1):

1. Mesoproterozoic basement complex ("**Y**" units);
2. Neoproterozoic metasedimentary and metaigneous complexes, including the Catoctin Formation (map units **Zcs**, **Zcm**, and **Zcb**), Ashe Formation (**Zacm**) or Ashe Metamorphic Suite ("**Za**" units), Alligator Back Formation ("**PZZab**" map units) or Alligator Back Metamorphic Suite ("**Zab**" units), Grandfather Mountain Formation ("**Zgf**" units), and Great Smoky Group ("**Zgf**" units)/Snowbird Group (map unit **Zsl**);
3. Neoproterozoic to Cambrian metamorphic Lynchburg Group ("**CZam**" units) and sedimentary Chilhowee Group ("**Cc**" units);
4. Paleozoic sedimentary rocks (**Ce**, **Cw**, and **Cs**) and magmatic gneiss (**PZmg**), pegmatite (**PZpeg**), mylonite (**PZmy**);
5. Jurassic igneous diabase (**Jd**), and
6. Cenozoic surficial deposits ("**Q**" units).

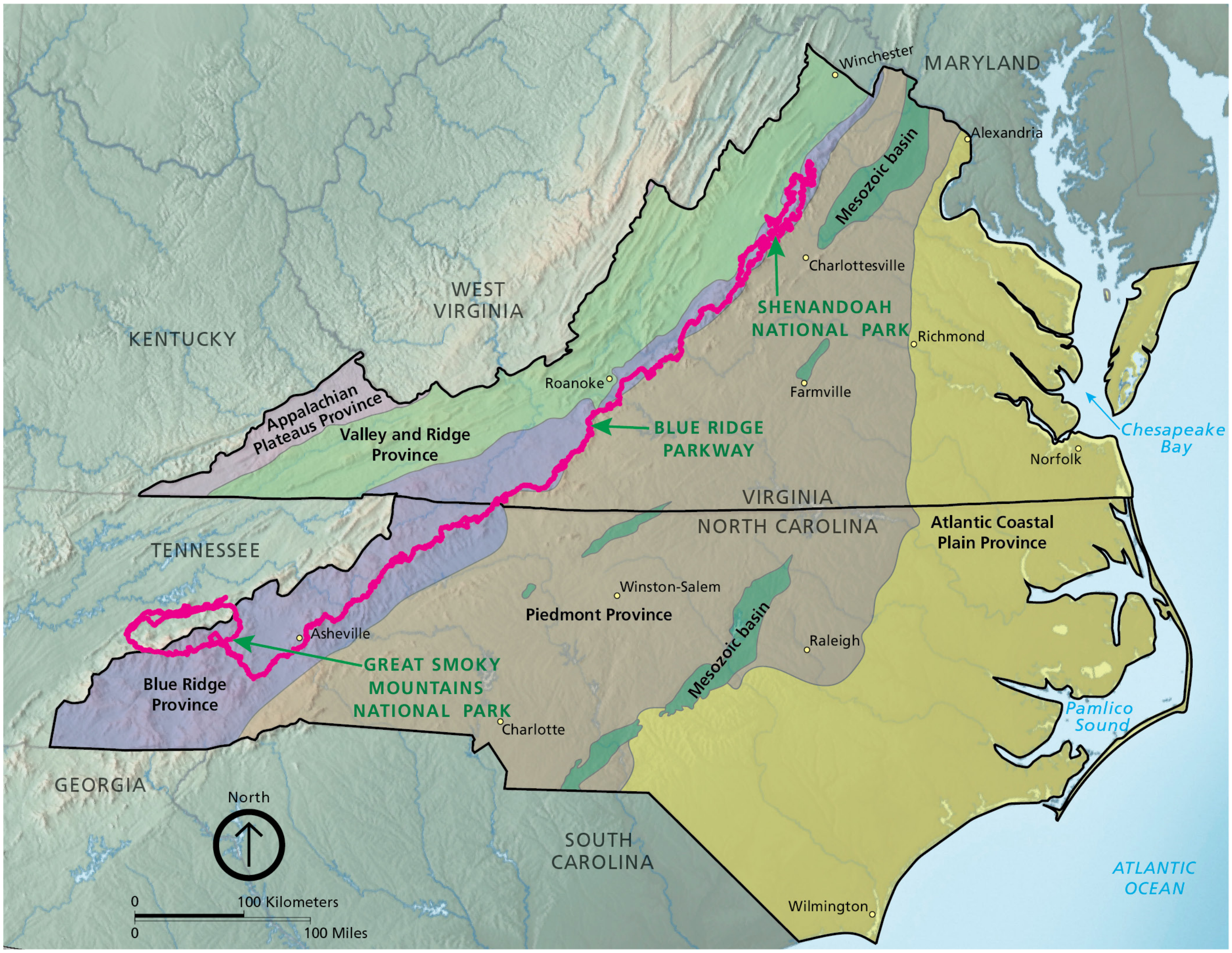


Figure 2. Map of physiographic provinces of Virginia and North Carolina.
Differential erosion across a landscape shaped initially by mountain building followed by deposition on the coastal plain have created the varying character of landforms in Virginia and North Carolina. Blue Ridge Parkway connects Shenandoah National Park and Great Smoky Mountains National Park, both of which have GRI GIS data available. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) adapted from Bailey (1999) and using information from the North Carolina Geological Survey website (http://www.geology.enr.state.nc.us/). Basemap by Tom Patterson (National Park Service), available at http://www.shadedrelief.com/physical/index.html.

Erosion-resistant rocks from the first three groups (mentioned in previous paragraph) form the heights of the Blue Ridge in Virginia (Carter et al. 2013, 2017). In the vicinity of Roanoke, the parkway dips for about 11 km (7 mi) into the Valley and Ridge province where Cambrian to Ordovician sedimentary rocks were faulted and folded into parallel, linear ridges that characterize the province. After this interlude, continuing along the parkway, the Blue Ridge province changes from a narrow band of steep ridges to scattered ridges and knobs. Here the rocks are part of a fault-bounded terrane of metamorphosed sedimentary and volcanic rocks (Lynchburg Group and Alligator Back Formation) that were squeezed between North America and colliding landmasses during the construction of the Appalachian Mountains (Carter and Merschat 2014).

Approaching the North Carolina border along the parkway, the escarpment, or sharp topographic rise that separates the gently rolling hills of the Piedmont from the mountains of the Blue Ridge, becomes more pronounced (fig. 4). The escarpment and views of Stone Mountain's isolated knob in the distance are mute witnesses to the effects of millions of years of weathering and erosion of the bedrock (Carter et al.

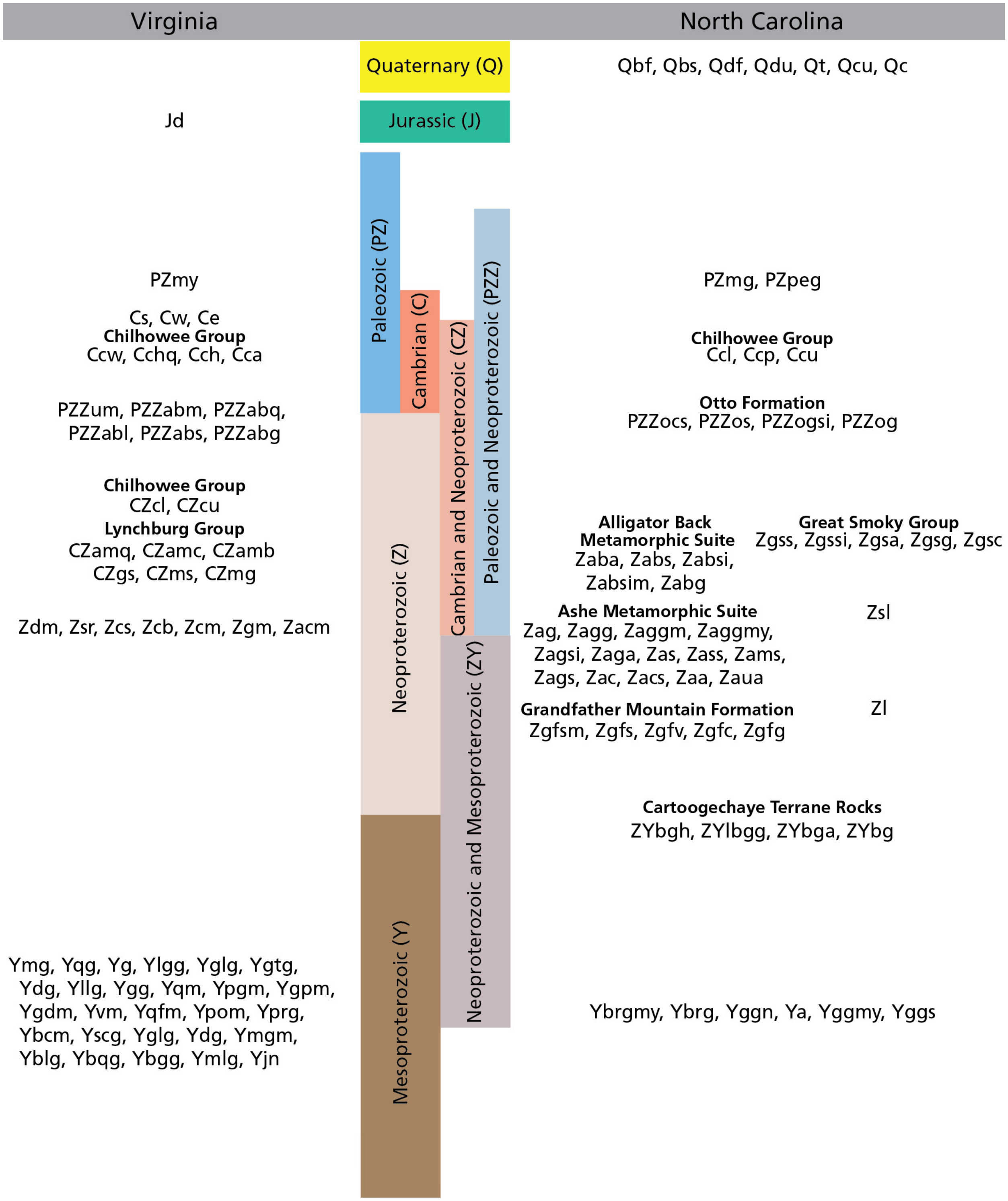


Figure 3. Diagram showing correlation of map units.
Geologic map units exposed along the Blue Ridge Parkway vary in rock type, composition, age, metamorphic grade, textures and fabrics, and history. The oldest units are the Mesoproterozoic basement rocks (“Y” units; more than one billion years old), whereas the youngest units are unconsolidated surficial deposits mapped in the North Carolina portion (“Q” units; span the past ~2 million years and include recent deposits). Some units span multiple time divisions. Colors are according to US Geological Survey standards for the various time periods. Graphic by Trista L. Thornberry-Ehrlich with information from Merschat et al. (2008a) and Carter et al. (2016).

Table 1. Geologic time scale.

The divisions of the geologic time scale are organized stratigraphically, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division are in parentheses. Geologic units mapped within the parkway only are included. For units in which many geologic map units occur in the GRI GIS map data, broad time abbreviations (e.g., "Y" for Mesoproterozoic) are presented. Map units are listed in tables 5–11. Boundary ages are millions of years ago (MYA). The Quaternary and Tertiary periods are part of the Cenozoic Era. The Triassic, Jurassic, and Cretaceous periods are part of the Mesozoic Era. The periods from Cambrian through Permian are part of the Paleozoic Era. Colors are according to US Geological Survey standards for the various time periods. Dates follow International Commission on Stratigraphy (2020).

Geologic Time Unit (GRI map abbreviation)	MYA	Geologic Map Units	Geologic Events
Quaternary Period (Q): Holocene Epoch (H)	0.01–today	**Qbf**, **Qbs**, **Qt**, **Qdf**, **Qdu**, **Qcu**, **Qc** continue to evolve and form	Continued erosion; debris flows
Quaternary Period (Q): Pleistocene Epoch (PE)	2.6–0.01	None mapped; surficial deposits form.	Worldwide glaciation, periglacial conditions
Tertiary (T): Neogene Period (N): Pliocene Epoch (PL)	5.3–2.6	None mapped; surficial deposits form.	Erosion and weathering
Tertiary (T): Neogene Period (N): Miocene Epoch (MI)	23.0–5.3	None mapped; surficial deposits form.	Erosion and weathering
Tertiary (T): Paleogene Period (PG): Oligocene Epoch (OL)	33.9–23.0	None mapped; surficial deposits form.	Erosion and weathering
Tertiary (T): Paleogene Period (PG): Eocene Epoch (E)	56.0–33.9	None mapped; surficial deposits form.	Erosion and weathering
Tertiary (T): Paleogene Period (PG): Paleocene Epoch (EP)	66.0–56.0	None mapped; surficial deposits form.	Erosion and weathering
Cretaceous Period (K)	145.0–66.0	None mapped	Erosion and weathering
Jurassic Period (J)	201.3–145.0	All units weathered **Jd** intruded	Extension along eastern North America
Triassic Period (TR)	251.9–201.3	None mapped	Breakup of Pangaea begins Atlantic Ocean opens
Permian Period (P)	298.9–251.9	None mapped	Supercontinent Pangaea intact
Pennsylvanian Period (PN)	323.2–298.9	None mapped	Alleghany (Appalachian) Orogeny, extensive faulting and metamorphism

Table 1, continued. Geologic time scale.

Geologic Time Unit (GRI map abbreviation)	MYA	Geologic Map Units	Geologic Events
Mississippian Period (M)	358.9–323.2	None mapped	Erosion and weathering
Devonian Period (D)	419.2–358.9	None mapped	Acadian Orogeny
Silurian Period (S)	443.8–419.2	None mapped	Appalachian basin forms and collects sediments
Ordovician Period (O)	485.4–443.8	Part of GRI GIS geologic map data; however, none mapped within parkway boundaries	Taconic Orogeny, extensive metamorphism
Cambrian Period (C)	541.0–485.4	**Ce**, **Cw**, **Cs** deposited "**Cc**" units deposited and/or erupted	Iapetus Ocean widens Extensive oceans cover most of proto-North America (Laurentia)
Proterozoic Eon: Neoproterozoic (Z)	1,000–541	"**CZ**" and "**PZZ**" units deposited and/or erupted "**Z**" units deposited and/or erupted	Supercontinent rifted apart Erosion and uplift Failed rift event
Proterozoic Eon: Mesoproterozoic (Y)	1,600–1,000	"**Y**" units accumulated, deformed, and/or metamorphosed	Formation of early supercontinent during Grenville Orogeny, metamorphism Igneous intrusions and deposition of sediments
Proterozoic Eon: Paleoproterozoic (X)	2,500–1,600	None mapped	Early plate tectonics
Archean Eon	~4,000–2,500	None mapped	Oldest known Earth rocks
Hadean Eon	4,600–4,000	None mapped	Formation of Earth's crust

2001). In northern North Carolina, the Blue Ridge consists primarily of Neoproterozoic metamorphosed sedimentary rocks (e.g., schist and gneiss of the Alligator Back Formation) interlayered with metamorphosed igneous rocks (e.g., amphibolite). The initial sediments accumulated in a basin off the coast of ancient North America (Carter et al. 2001; Merschat et al. 2008a).

Heading farther south, the parkway crosses great thrust faults along which tremendous masses of rocks were shoved some 320 km (200 miles) westward during the last great mountain-building orogeny of the Appalachian Mountains—the Alleghany Orogeny. It is here that the parkway enters one of the more significant geologic features of the eastern United States, the Grandfather Mountain window. This "window" is a result of localized weathering and erosion creating a "hole" in the pile of bedrock and downward through the major thrust faults to provide a glimpse of the rocks below (Carter et al. 2001). The rocks visible in the window include billion-year old metamorphic rocks (Blowing Rock Gneiss), the Neoproterozoic Grandfather Mountain Formation, as well as much younger Cambrian metasedimentary rocks of the

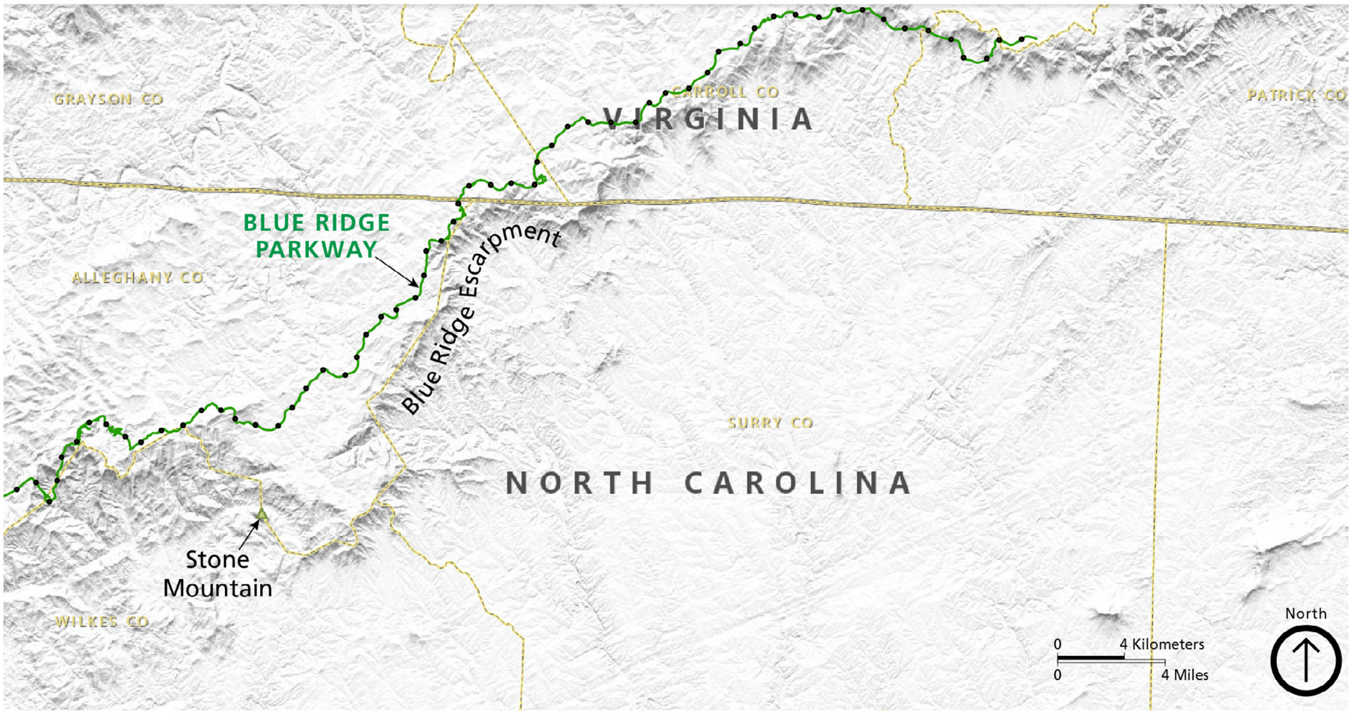


Figure 4. Map showing the Blue Ridge escarpment near the North Carolina-Virginia border. Stone Mountain is visible from milepost 232.5 as an isolated knob of erosion resistant granite in the distance from the parkway. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data, the US Geological Survey "The National Map" (https://viewer.nationalmap.gov/advanced-viewer/) and data from Blue Ridge Parkway.

Chilhowee Group formed less than 541 million years ago (Carter et al. 2001; Merschat et al. 2008a).

Moving out of the Grandfather Mountain area, the topography and geology along the parkway change again to encompass two prominent mountain ranges (fig. 5): the Black Mountains and the Great Craggies. This area has Neoproterozoic metasedimentary and metavolcanic rocks of the Alligator Back Formation and Ashe Metamorphic Suite that were once shed into a rift basin between spreading ancient continents; the situation is analogous to the modern Atlantic Ocean basin (Carter et al. 2001; Merschat et al. 2008a). The Black Mountains are the tallest mountains east of the Black Hills in South Dakota, rising to elevations of more than 1,980 m (6,500 ft) (Carter et al. 2001). The parkway then descends into the Asheville basin, drained by the French Broad River before climbing almost 610 m (2,000 ft) to Pisgah Ridge underlain by Neoproterozoic metamorphic gneiss and schist of the Ashe Metamorphic Suite (Carter et al. 2001; Merschat et al. 2008a). The parkway begins to turn westward away from the prominent Blue Ridge escarpment after it crosses the headwaters of the Pigeon River and approaches the heights of Great Smoky Mountains National Park.

The last 97 km (60 mi) of the parkway reveal rocks that were once deposited in basins along the edge of North America during the Neoproterozoic Era but were shoved westward along with older rocks along myriad faults during Paleozoic orogenies. Multiple faults in this area juxtapose rocks of different ages, and the parkway summits its highest point (1,843 m [6,047 ft]) at Richland Balsam of the Great Balsam Range. The rock pattern is complicated with rocks getting generally younger approaching the southern end of the parkway, from Mesoproterozoic gneiss to younger greywacke, schist, and quartzite (Great Smoky and Snowbird groups) to Neoproterozoic gneiss and schist (Ashe Metamorphic Suite) (Carter et al. 2001; Merschat et al. 2008a).

Earth surface processes of weathering and erosion have been acting on the rocks of the Blue Ridge Parkway for hundreds of millions of years. Mountains that may have once rivaled the modern Himalayas have been reduced greatly to rounded knobs and ridges. Visitors to the parkway are seeing the core of an ancient mountain chain, a window into the past (Lillie 1999). Surficial geologic units are recording the ongoing evolution of the landscape. Some changes are very gradual; the landforms literally wear away layer by layer. Other changes are much faster and more dramatic, for

Figure 5. Map of seven segments of the Blue Ridge Parkway and the major mountain ranges. For resource management purposes, Blue Ridge Parkway is divided into seven segments, bound by mileposts, along its length, from north to south: Ridge, Roanoke, Plateau, Highlands, Black Mountain, Asheville, and Pisgah. Refer to figures 1a through 1e for detailed park maps of these segments. Along its length, the parkway crests five major mountain ranges: Blue Ridge, Black, Great Craggy, Pisgah, and Great Balsam Mountains. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with GIS data from Blue Ridge Parkway. Basemap by Tom Patterson (National Park Service), available at http://www.shadedrelief.com/physical/index.html.

example, debris flows thundering down a slope. Block fields and streams, talus, colluvium, and debris are all slope deposits that attest to the efficacy of Earth surface processes to lower heights and accumulate sediments in low-lying areas (Merschat et al. 2008b). In these ways, the once incredibly high Appalachian Mountains have worn away, and thick layers of sediments shed from these mountains have collected on the coastal plain, building North America ever outward.

Geologic Significance and Connections

According to the parkway's purpose statement in the foundation document (National Park Service 2016), one of the reasons Blue Ridge Parkway was established was to preserve natural and cultural resources while providing opportunities for public recreation. Named for the Blue Ridge that forms the foundation of the landscape, connections between geology and the vast natural and cultural resources of the parkway are many. Geology is among the interpretive themes described as a key concept that visitors should understand after a visit (National Park Service 2016).

Design of the Blue Ridge Parkway

The bedrock, geologic structures (e.g., faults and folds), topography, and Earth surface processes dictated what needed to be constructed in order to create a leisurely driving experience along the parkway—one of the fundamental resources and values identified by National Park Service (2016). The parkway's design and innovative engineering were necessary because of the geologic complexity of the area. As the core of the ancient Appalachian Mountain range, the bedrock is typically erosion-resistant metamorphic rocks. Each geologic unit mapped in the park is described in detail in the GRI GIS data (blrs_geology.pdf and blrn_geology.pdf). Each unit's composition, deformation history, and location influence its resistance to weathering and erosion by wind and water. Geologic structures such as folds and faults also influence the morphology of the landscape. In areas such as Grandfather Mountain, huge thrust faults shoved rocks atop one another and created thick stacks of thrust sheets. Features such as the Blue Ridge (mountains) north of Roanoke, Virginia, are where rocks have buckled and folded into long, linear ridges. In areas such as Deep Gap, wind, water, and geologic conditions (e.g., fracture zones) combined to create a gap in the ridge. More than 100 gaps penetrate the parkway. Some of these gaps and river or stream valleys necessitated the construction of 168 bridges along the parkway (National Park Service 2013). Where the parkway encountered a particularly challenging rock formation, 26 tunnels were blasted through the bedrock to accommodate easy passage along the road (National Park Service 2013).

A testament to human ingenuity and intentional landscape design, the parkway took more than 50 years to complete. Its recreation areas, design, and scenic integrity are among the fundamental resources and values (National Park Service 2016). Engineering of the parkway took advantage of the heights of the Blue Ridge with 16 peaks above 1,500 m (5,000 ft) to afford 1,228 identified views of the surrounding landscape. The parkway has 281 road overlooks and 910 maintained roadside vistas to look out over features such as the Great Valley, Piedmont Plateau, Blue Ridge escarpment, Stone Mountain, Mount Pisgah, and Looking Glass Rock (Carter et al. 2001; National Park Service 2013).

Another parkway fundamental resource and value are the examples of Appalachian history and cultural features along its length. The parkway (roadway) itself is a historical structure, and the parkway (NPS unit) protects and interprets myriad cultural resources including 91 historic buildings, 20 cultural landscapes, more than 200 identified archeological sites, and a collection of artifacts including 2,400 geological, 10,500 archeological, and 32,000 biological specimens (National Park Service 2013). American Indians originally cleared some of the parkway fields (Sundin et al. 2013). European and early American settlements are preserved in locations such as Brinegar Cabin, Yankee Horse Railroad, Harris Farm, Humpback Rocks farmstead, Johnson Farm, Rock Castle Gorge, Peaks of Otter, and the Moses Cone estate. Cultural resources condition assessments and landscape inventories remain data needs for the parkway (Sundin et al. 2013; National Park Service 2016).

Blue Ridge Parkway Ecology

Spanning 755 km (469 mi) along the Blue Ridge and encompassing more than 1,700 m (5,800 ft) of elevation change within its boundaries, the parkway protects incredible biodiversity. Diversity of habitat is among the parkway's fundamental resources. Because temperatures drop an average of 2°C/300m (3.6°F/1,000 ft), the great heights of the Black Mountains support forests typical of Canada—red spruce (*Picea rubens*) and Fraser (balsam) fir (*Abies fraseri*), whereas the heights of the Great Craggies are covered with heath shrubs, nearly void of large trees or "bald" (Carter et al. 2001). The amphibolite-rich geology of the "spine" of the parkway hosts rare plants (Bambi Teague, Blue Ridge Parkway, chief of natural resources, conference call, 16 May 2018). Seventy-five distinct plant communities, 24 of which are considered globally rare and seven of which are considered globally imperiled, include rocky outcrops, granitic domes, grassy (heath) balds, and high-elevation wetlands. These communities harbor more than 1,600 types of plants and 412 macroinvertebrate-insect, 43 amphibian, 225 bird, 99 fish, 31 reptile, and 70 mammal species (Sundin et al. 2013; National Park Service 2013, 2016, 2017).

The parkway contains 115 stream headwaters, the tops of 15 major river watersheds, and more than 960 km (600 mi) of streams as part of the parkway's natural resources. These watersheds define the hydrological pattern of much of the southeastern United States (National Park Service 2013). The nature and characteristics of the parkway stream valleys change along its length. North of Roanoke, streams tend to be short and steep draining the narrow steep ridges of the Blue Ridge. The exception to this is the James River, draining across the Blue Ridge towards the Chesapeake Bay and occupying the lowest point on the parkway. South of Roanoke to just north of Jefferson, North Carolina, the Blue Ridge plateau, bounded on the southeast by the Blue Ridge escarpment, is drained almost completely by the west-flowing, low-gradient, meandering New River system (Carter et al. 2017; see GRI report about Bluestone National Scenic River, Gauley River National Recreation Area, and New River Gorge National River by Thornberry-Ehrlich 2017). The escarpment has steep, east-flowing Atlantic streams originating at its crest and is part of the eastern

Continental Divide separating flows to the Atlantic Ocean and the Gulf of Mexico.

Bedrock types influence the soils formed atop them and, in turn, the ecosystem. For example, magnesium- and calcium-rich soils derived from weathered amphibolite (e.g., geologic map unit **CZamq**) support grassy, prairie-like glade communities at high elevations. Mafic and ultramafic bedrock (e.g., **PZZum**) give rise to magnesium- and iron-rich soils that in some areas support mafic woodland seeps (Carter et al. 2017). The Chilhowee Group rocks (**CZcl**, **CZcu**, **Ccw**, **Cchq**, **Cch**, **Cca**, **Ccl**, **Ccp**, **Ccu**) decompose to a silty, gritty, non-fertile soil, which supports few bushes (e.g., mountain laurels) in cracks, and mosses and ferns in seep areas (Carter et al. 2001). The metagraywacke and metasiltstone of the Grandfather Formation break down to form thin, stony, relatively infertile acidic soils (Carter et al. 2001). These types of soils support particular flora such as Blue Ridge goldenrod (*Solidago spithamaea*), liverwort (*Frullania appalachiana*), and spreading avens (*Geum radiatum*). According to the Natural Resources Conservation Service, approximately 200 unique soil series, soil associations/consociations, complexes, and undifferentiated groups are found along Blue Ridge Parkway (Sundin et al. 2013).

Additional ecosystem information is available in the following resources:

- A Soil Resource Inventory including GIS data was completed in 2012 and is available at https://irma.nps.gov/DataStore/Reference/Profile/2184681.
- The NPS Water Resources Division provides technical and policy assistance for water resources. The division's Aquatic Systems Branch (https://www.nps.gov/orgs/1439/asb.htm) supports park management of fish, wetlands, water quality, hydrology, and information management. The division also has a Water Rights Branch (https://www.nps.gov/orgs/1439/wrb.htm). A baseline water quality project (1996) is available at https://irma.nps.gov/DataStore/Reference/Profile/13688, and a hydrographic and impairment statistics database (2019) is available at https://irma.nps.gov/DataStore/Reference/Profile/2260187.
- The vegetation inventory is still in progress. Products for other parks are available at https://www.nps.gov/im/vmi-products.htm.
- The Appalachian Highlands Network currently monitors natural resources such as water quality, exploited plants, and landscape change at the Blue Ridge Parkway (https://www.nps.gov/im/aphn/blri.htm).
- Acid producing potential is noted in GRI GIS data (blrn_geology.mxd) and discussed in reports by Sullivan et al. (2011a, 2011b).

Geologic Features, Processes, and Resource Management Issues

These geologic features and processes are significant to the parkway's landscape and history. Some geologic features, processes, or human activities may require management for human safety, protection of infrastructure, and preservation of natural and cultural resources. The NPS Geologic Resources Division provides technical and policy assistance for these issues.

During the 2000 scoping meeting (see National Park Service 2000) and 2017 conference call, participants (see Appendix A) identified the following geologic features, processes, and resource management issues:

- Blue Ridge, Black, Great Craggy, Pisgah, and Great Balsam Mountains
- Gaps
- Faults and folds
- Bedrock exposures: metamorphic, igneous, and sedimentary rocks
- Earth surface processes: surficial units
- Wetlands
- Geologic hazards: slope movements and earthquakes
- Abandoned mineral lands
- Disturbed lands restoration, and structural integrity of the parkway
- Paleontological resource inventory, monitoring, and protection

The parkway's general management plan (National Park Service 2013) describes seven segments of the parkway for resource management (see fig. 5):

- Segment 1—Ridge, mileposts 0–106
- Segment 2—Roanoke, mileposts 106–136
- Segment 3—Plateau, mileposts 136–217
- Segment 4—Highlands, mileposts 217–305
- Segment 5—Black Mountain, mileposts 305–377
- Segment 6—Asheville, mileposts 377–394
- Segment 7—Pisgah, mileposts 394–469

These segments were divided on the basis of shared geomorphology and geography and run from north in Virginia to south in North Carolina (see figs. 1 and 5). Given the long, narrow nature of the parkway, the segments provide a convenient way to approach resource management and describe the parkway's geology. The text in this chapter is organized accordingly, beginning with descriptions that are applicable to the entire parkway, then discussions pertinent to each segment. The general management plan also breaks each of the segments into management zones to define specific resource conditions, visitor experiences, appropriate recreational activities, and levels and types of development to be achieved and maintained in each area of the parkway. The eight designated management zones with their overall percentage of lands within the parkway are (1) special natural resources (12.2%), (2) natural (23.7%), (3) scenic character (41.8%), (4) recreation (9.4%), (5) visitor services (0.4%), (6) historic parkway (11.7%), (7) special cultural resources (0.5%), and (8) park support (0.2%). Most of these management zones have connections to geology and specific areas will be discussed per parkway segment below.

Geologic Resource Management

The parkway's foundation document (National Park Service 2016), natural resource condition assessment (Sundin et al. 2013), and general management plan (National Park Service 2013) are primary sources of information for resource management within the parkway. National Park Service (2013) lists the pertinent servicewide mandates and policy topics related to planning and managing the Blue Ridge Parkway (see table 1 in National Park Service 2013). Cultural landscape restoration and management are also addressed in publications such as National Park Service (2016) and Wheeler et al. (2008).

The Geologic Resources Division provides technical and policy support for geologic resource management issues in three emphasis areas:

- Geologic heritage,
- Active processes and hazards, and
- Energy and minerals management.

Contact the division (http://go.nps.gov/grd) for assistance with resource inventories, assessments and monitoring; impact mitigation, restoration, and adaptation; hazards risk management; law, policy, and guidance; resource management planning; data and information management; and outreach. Parkway staff can formally request assistance via https://irma.nps.gov/Star/.

Resource managers may find *Geological Monitoring* (Young and Norby 2009; http://go.nps.gov/geomonitoring) useful for addressing geologic resource management issues. The manual provides guidance for monitoring vital signs—measurable parameters of the overall condition of natural resources. Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies.

Parkway staff can receive geologic expertise through the Geoscientists-in-the-Park (GIP) and Mosaics in Science programs. These internship programs place scientists (typically undergraduate students) in parks to complete geoscience-related projects that may address resource management issues. Projects at Blue Ridge Parkway have included (as of January 2017):

- Energy and minerals, interpretation/education (2002)
- General geology, interpretation/education (1998)

Products created by program participants may be available by contacting the Geologic Resources Division. Refer to the programs' websites at http://go.nps.gov/gip and http://go.nps.gov/mosaics for more information.

Blue Ridge, Black, Great Craggy, Pisgah, and Great Balsam Mountains

Blue Ridge Parkway traverses the Blue Ridge physiographic province and the crests of five distinct mountain ranges therein (see fig. 4). The Blue Ridge Mountains are generally rounded and covered in dense forests. Elevations range from 300 to 2,037 m (980 to 6,684 ft), and 46 peaks rise to more than 1,820 m (5,970 ft) in the parkway. Geologists divide the Blue Ridge Mountains of the parkway into northern and southern subprovinces. North of Roanoke, Virginia, the northern subprovince is a narrow band of parallel ridges characterized by steeper slopes and narrower tops. The southern subprovince is a broad upland plateau with more moderate slopes and peaks rising above the plateau (Sundin et al. 2013). Near Mount Mitchell, the parkway skirts the Black Mountains and enters the Great Craggy Mountains; then after Asheville, the Pisgah. The Black Mountains are the highest peaks of the eastern United States. Their name stems from the dark appearance of the spruce and fir forests on their upper slopes. The range forms a rough J-shaped semicircle that opens to the northwest. The Black Mountains intersect the Great Craggy Mountains to the southwest at Balsam Gap. Commonly called the Craggies, the Great Craggy Mountains peak at an elevation of 1,861 m (6,105 ft) at Craggy Dome. The Blue Ridge Parkway runs along the Craggies' crest most of the way between Mount Mitchell and Asheville. The Pisgah range culminates in Mount Pisgah, just southwest of Asheville. Mount Pisgah is accessible via a hiking trail from the parkway near the Pisgah Inn. South of Asheville, North Carolina, the parkway turns northwest and crosses the Great Balsam Mountains. The Great Balsams are named for the "she balsams" or Fraser fir and the "he balsams" or red spruce that cover their higher slopes. The highest point on the parkway itself occurs at Richland Balsam. Other noteworthy peaks include Cold Mountain, Black Balsam Knob, and Shining Rock. The Great Balsams feature several high-elevation balds (areas not covered by trees).

Resources and References

In addition to data included in the GRI GIS data set and ancillary map information documents, the following references provide additional background information. The list is organized from top (park-specific) to bottom (general):

- Natural resource condition assessment: Sundin et al. (2013).
- The geology of Virginia: http://geology.blogs.wm.edu/blue-ridge/
- Geology of North Carolina State Parks and other protected lands: https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey/geoscience-education/geology-state-parks.
- NPS physiographic province maps and information: https://www.nps.gov/articles/blueridgeprovince.htm.
- NPS mountains website (in development): https://www.nps.gov/subjects/mountains/index.htm
- US Geological Survey topographic maps: https://www.usgs.gov/products/maps/topo-maps

Gaps

The imposing mountains, ridges, and escarpments of the Appalachian Mountains long served as barriers to east-to-west migration and travel. Breaks or gaps have long been utilized to cross the mountains, ridges, and escarpments of the Blue Ridge Province. Gaps form in various ways, including erosion and weathering due to a preexisting weakness (e.g., fracture, joints, or faults), or compositional change in the rock (fig. 6). A wind gap is a valley through which a stream once flowed but is now abandoned because of stream capture. A water gap still contains a flowing stream. Gaps commonly provide passages, which are suitable for trails, roads, and railroads through mountainous terrain. A famous example is the Cumberland Gap near the intersection of the borders of Virginia, Kentucky, and Tennessee that funneled thousands of people during westward expansion from the original 13 colonies (see the GRI report about Cumberland Gap National Historical Park GRI by Thornberry-Ehrlich 2011). Delaware Water Gap National Recreation Area is another NPS unit that preserves, and is named for, a gap (see GRI report by Thornberry-Ehrlich 2013). Named gaps punctuate the entire length of the Blue Ridge Parkway and are part of all seven segments.

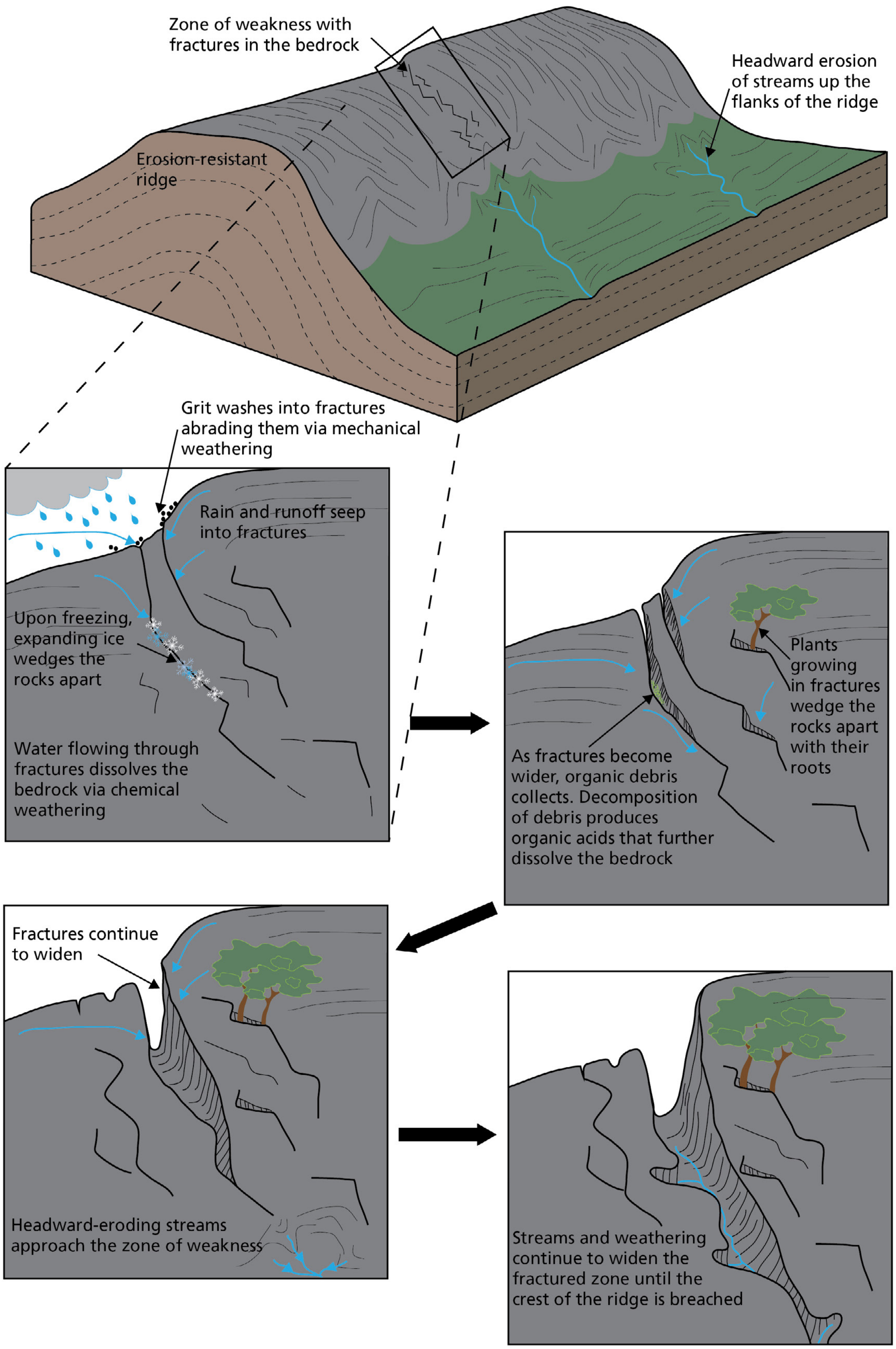


Figure 6. Schematic graphic of gap formation.
Gaps form where weathering is accelerated due to the presence of a preexisting weakness in the rock, e.g., a fault or fracture or composition change. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Resources and References

In addition to data included in the GRI GIS data set and ancillary map information documents, the following references provide additional background information. The list is organized from top (park-specific) to bottom (general):

- GRI reports for Cumberland Gap National Historical Park (Thornberry-Ehrlich 2011) and Delaware Gap National Recreation Area (Thornberry-Ehrlich 2013): http://go.nps.gov/gripubs.
- Information about gaps with pictures and examples: https://www.nationalgeographic.org/encyclopedia/gap/

Faults and Folds

Faults and folds occur where rocks have been compressed, stretched, sheared, or fractured. They are common structural features in areas where mountain building and translation have occurred, such as the Appalachian Mountains. A fault is a fracture in rock along which rocks have moved. The three primary types of faults are normal faults, reverse faults, and strike-slip faults (fig. 7). All three are mapped within the GRI GIS data for Blue Ridge Parkway. Faults are classified based on motion of rocks on either side of the fault plane (fig. 7). Thrust faults are reverse faults with a low angle (<45°) fault plane. Décollements, or detachment faults, are very low angle (nearly horizontal) reverse faults with large displacement (kilometers to tens of kilometers). The GRI GIS data include at least 21 major, named faults. Myriad small-scale faults (not necessarily mapped) are visible in rocks all along the parkway (fig. 7).

Folds are curves or bends in originally flat structures, such as rock strata, bedding planes, or foliation. The two primary types of folds are anticlines which are "A-shaped" (convex) and synclines which are "U-shaped" (concave) (fig. 8). Both types of folds can be overturned—tilted beyond the perpendicular so the sequence of strata appears reversed—by continued or future tectonic forces. Folds frequently "plunge," meaning the fold axis tilts. As bedrock is compressed, anticlines and synclines form adjacent to each other, as is characteristic in the linear folds of the Valley and Ridge province. Fold axes were not identified in the GRI GIS data; however, major fold structures are part of the parkway landscape, for example, the Blue Ridge anticlinorium in Virginia. Folds exist in the parkway bedrock at many scales ranging from regional to microscopic. Smaller scale folds are visible in bedrock exposures along the parkway's length (fig. 8).

Resources and References

In addition to data included in the GRI GIS data set and ancillary map information documents, the following references provide additional background information. The list is organized from top (park-specific) to bottom (general):

- Geology training manual: plate tectonics and the Grandfather Mountain-Linville Falls region (Lillie 1999)
- NPS websites about faults and folds: https://www.nps.gov/articles/faults-and-fractures.htm and https://www.nps.gov/articles/tectonic-folding.htm

Bedrock Exposures: Sedimentary, Igneous, and Metamorphic Rocks

Bedrock is the solid, very old rock that underlies the younger unconsolidated surficial deposits of the parkway. Bedrock is dramatically exposed along the length of the parkway, particularly in roadcuts, tunnels, and cliffs. Bedrock can be sedimentary, igneous, or metamorphic. Sedimentary rocks form from fragments of other rocks or chemical precipitation. Igneous rocks form by the cooling of molten material. Metamorphic rocks are those that have been altered by high temperature, high pressure, and/or fluids. All three major rock types are present in bedrock outcrops along the parkway (figs. 9 and 10).

Sedimentary Rocks

Three main types of sedimentary rocks are clastic, chemical, and organic (table 2). Clastic sedimentary rocks are the products of weathering, erosion, transportation, and deposition of rock fragments called "clasts." Chemical sedimentary rocks form when ions (microscopic particles of rock dissolved during chemical weathering) precipitate out of water. Organic sedimentary rocks (e.g., coal) are composed of organic remains or were produced by the physiological activities of an organism (e.g., secretion of calcium carbonate to form limestones of coral reefs).

Igneous Rocks

Igneous rocks are those that formed from molten material. Where molten material erupts, cools, and quickly solidifies at the Earth's surface, extrusive ("volcanic") igneous rocks form. Where molten material slowly cools beneath the surface, intrusive ("plutonic") igneous rocks form. Large bodies of igneous rocks may form plutons, stocks, or laccoliths, whereas some intrusions may be smaller such as dikes (fig. 10), which cut across the fabric of adjacent rocks, or sills, which intrude parallel to a preexisting bedrock layering such as bedding.

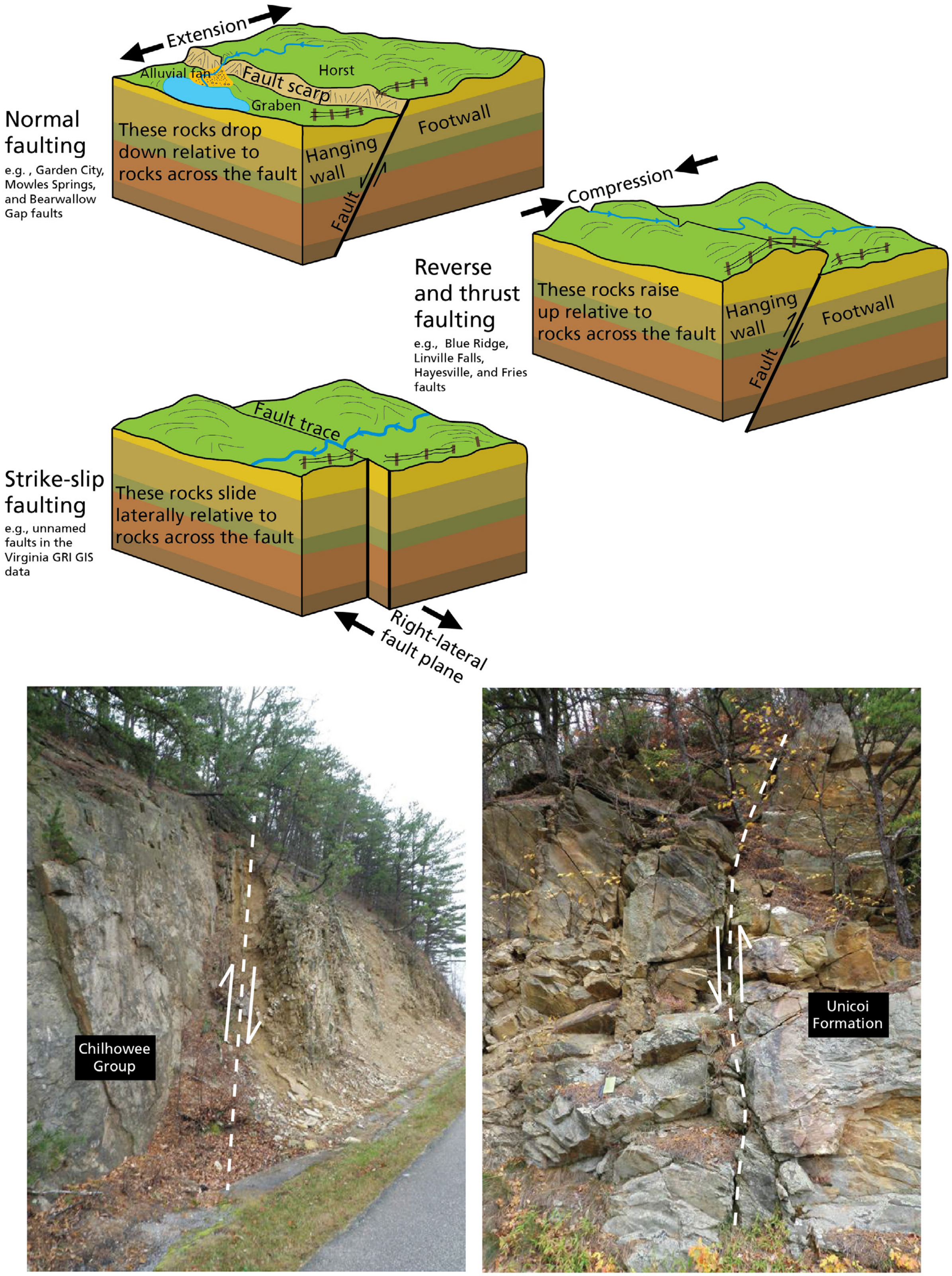


Figure 7. Diagram of fault types with parkway examples.
Faults are part of the GRI GIS data; all three fault types are mapped. White dashed lines on the photographs indicate fault traces, both of which are reverse faults. These faults accommodated deformation and shortening during mountain building. Breaks in the rock tend to preferentially weather and may lead to the formation of gaps. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using photographs of geologic observation localities CW-75 and BL-41 from Carter et al. (2016).

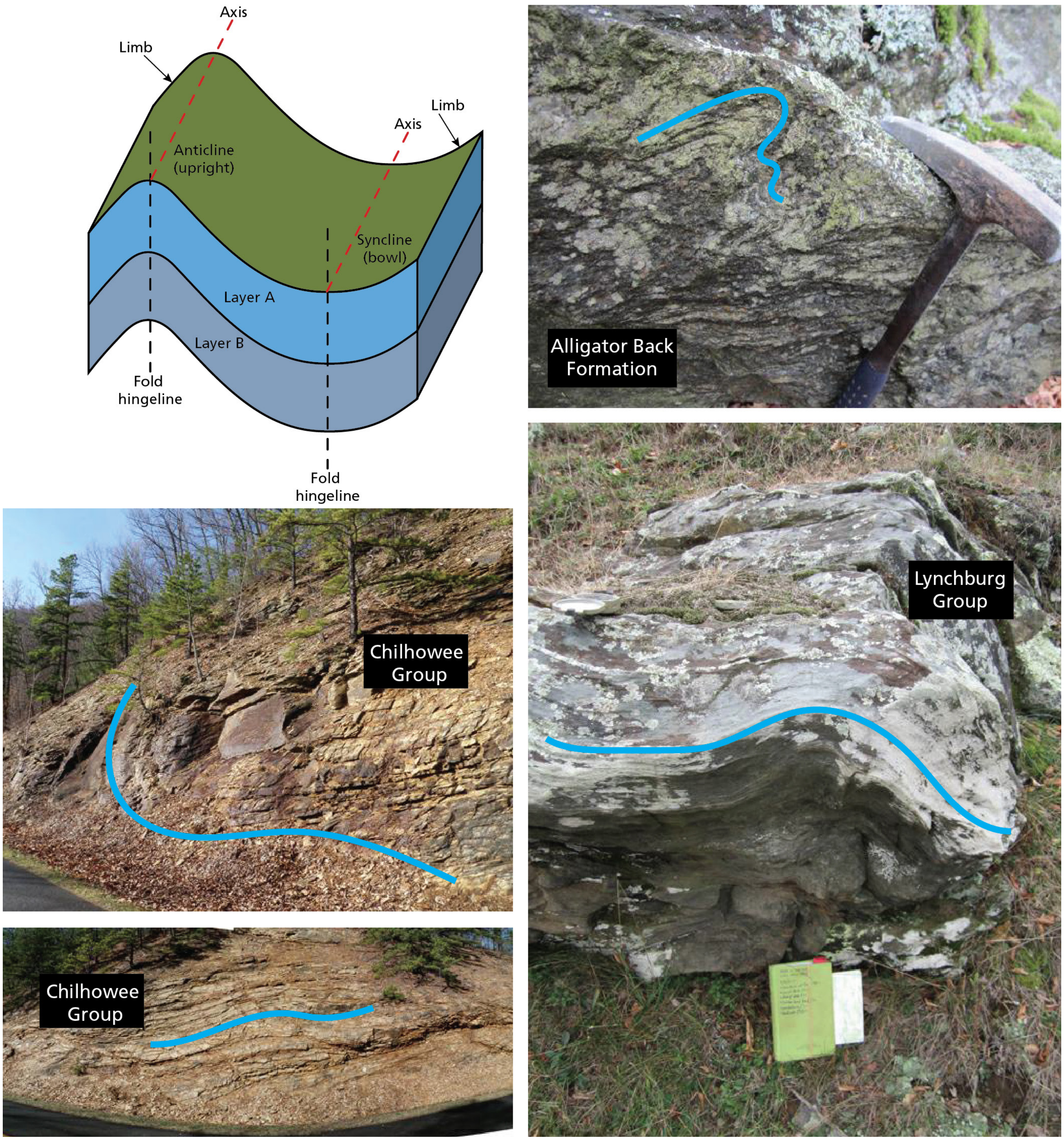


Figure 8. Diagram of folds with parkway examples.
Folds are not part of the GRI GIS data; but exist at many scales in the parkway. Folds accommodated deformation and shortening during mountain building. Blue lines highlight the fold traces. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using photographs of geologic observation localities FG-47, BV-122, EN-235, and BV-125 from Carter et al. (2016).

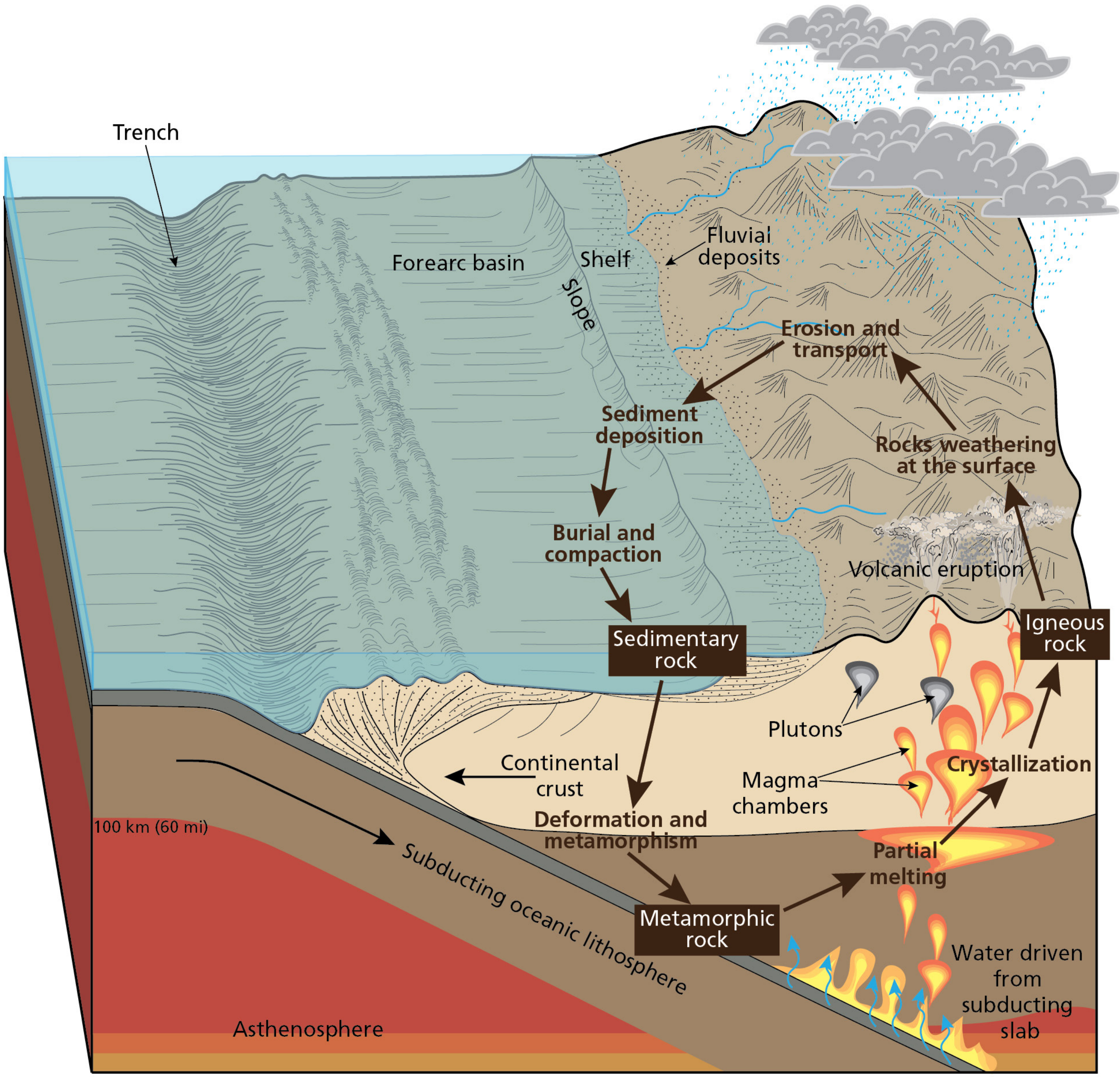


Figure 9. Diagram of the rock cycle.
As matter is neither created nor destroyed, rocks change from one type to another via geologic processes. Sedimentary, igneous, or metamorphic rocks can melt, forming new igneous rocks. Metamorphic, sedimentary, and igneous rocks break down to create new sediments that accumulate and may become sedimentary rocks. Igneous, metamorphic, and sedimentary rocks that are heated and/or exposed to pressure and deformation become new metamorphic rocks. All three rock types are found along the Blue Ridge Parkway (see tables 2 and 3). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from The Geological Society (https://www.geolsoc.org.uk/ks3/gsl/education/resources/rockcycle.html).

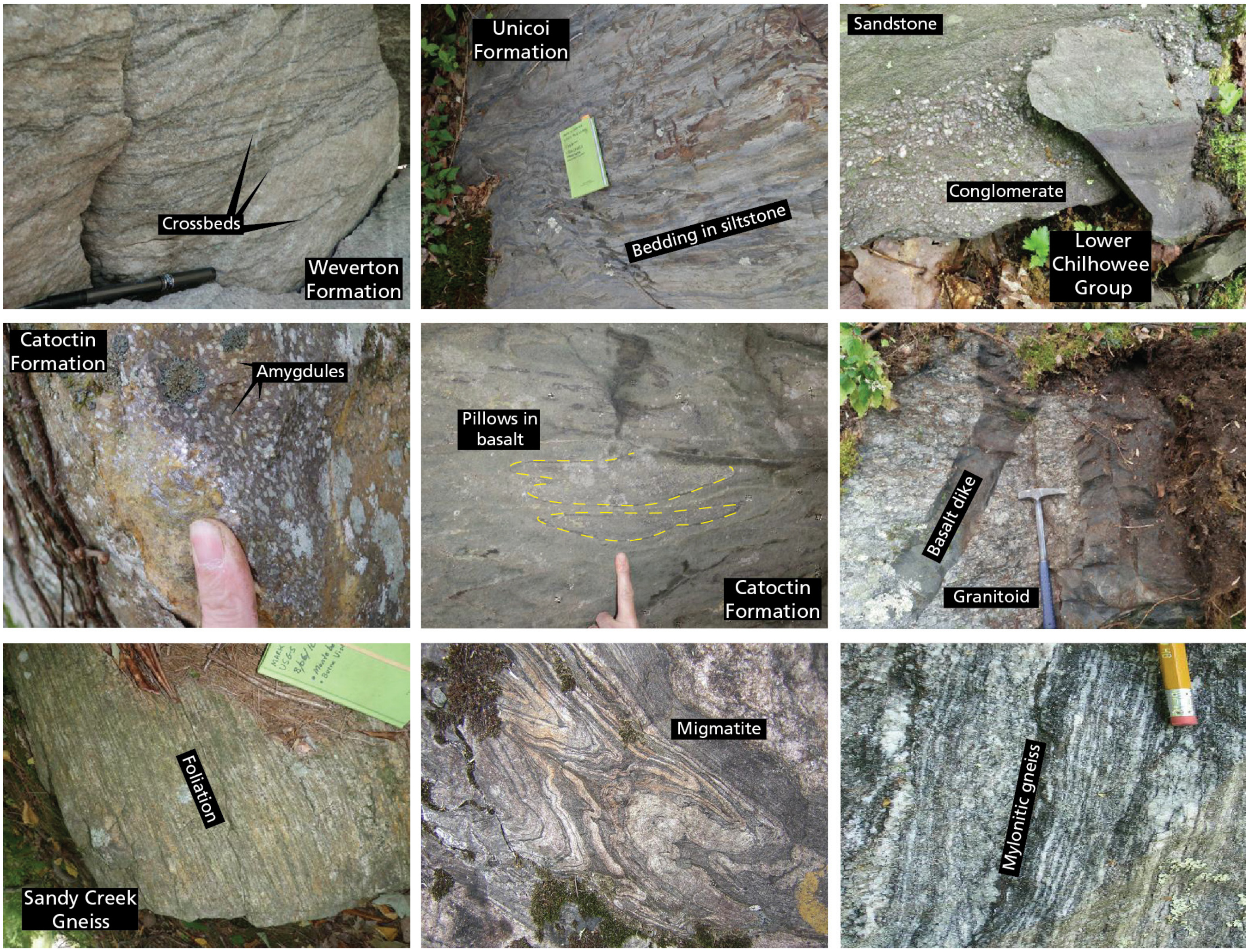


Figure 10. Photographs of bedrock types exposed along the parkway.
Sedimentary rocks (top three photographs) are only slightly metamorphosed, and original sedimentary structures such as cross-beds, bedding, and large pebbles in graded beds are visible. Similarly, some original volcanic features (middle three photographs) such as pillows and mineral-filled vesicles called amygdules are preserved. Volcanic feeder dikes intruded the adjacent granitoid country rock. As metamorphism and deformation progressed, rocks developed foliation, achieved partial melting in migmatite, or developed strained mylonitic fabrics (bottom three photographs). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using photographs of geologic observation localities from Carter et al. (2016) and Merschat et al. (2008a), top row (left to right): MB-1246, CW-81, MB-714; middle row (left to right): SH-73, BL-185, BM-51; and bottom row (left to right): CK-10 (3-1) from Carter et al. (2016), and DMR-015 and DMR-012 from Merschat et al. (2008a).

Igneous rocks are classified by texture (e.g., grain size, shape, and arrangement), as well as the percentage of major minerals (i.e., quartz, alkali feldspar, and plagioclase) present in the rock (fig. 11). Geologists use silica (silicon dioxide, SiO_2) content as a means for classifying volcanic igneous rocks (table 3). The term “mafic” refers to rocks with lesser amounts of silica, such as basalt and basaltic andesite. “Mafic” refers to the high magnesium and iron (ferric) content of minerals that characterize those rocks. Ultramafic rocks contain significantly less silica. The term “silicic” refers to rocks with higher amounts of silica, for instance, dacite, rhyodacite, and rhyolite. The percentage of silica influences many properties of magma, including viscosity and explosiveness. In general, lavas with more silica are more viscous and explosive (table 3). Volcanic rocks typically display features that provide clues as to their origin. For example, pillow basalts (fig. 10) indicate underwater eruptions, flow banding indicates the lava flowed across Earth’s surface, and vesicles or amygdules

Table 2. Sedimentary rock classification and characteristics.

*Claystones and siltstones can also be called "mudstone," or if they break into thin layers, "shale."

**Carbonate classification is based on Dunham's textural classification scheme (Dunham 1962).

***Units not exposed in Blue Ridge Parkway boundaries

Rock Type	Rock Name	Texture and Process of Formation	Blue Ridge Parkway Geologic Map Unit Examples
INORGANIC CLASTIC SEDIMENTARY ROCKS*	Conglomerate (rounded clasts) Breccia (angular clasts)	Cementation of clasts >2 mm (0.08 in) in size. Higher energy environment (e.g. rivers).	Conglomerate: **Ce, Cw, Ccw, CZcu, CZcl, Zsr** Breccia: **Ce**
	Sandstone	Cementation of clasts 1/16–2 mm (0.0025–0.08 in) in size.	**PZZabq, PZZabs, CZms, Zcs, Omb***, OCco***, Cw, Cca, Cch, Ccw, CZcu, CZcl, CZmg, CZms, CZgs, CZamb, Zacm, Zsr**
	Siltstone	Cementation of clasts 1/256–1/16 mm (0.00015–0.0025 in) in size.	**Cw, Cch, Cchq, Ccw, CZcu, CZcl, Zsr**
	Claystone	Cementation of clasts <1/256 mm (0.00015 in) in size. Lower energy environment (e.g., floodplains).	None identified in mapping
CARBONATE CLASTIC SEDIMENTARY ROCKS*	Fossiliferous limestone	Generic name for carbonate rock containing fossils.	**Omb***, OCco***, Ce, Cw**
	Boundstone	Fossils, fossil fragments, or carbonate mud fragments cemented together during deposition (e.g., reefs).	None identified in mapping
	Grainstone	Grain (e.g., fossil fragments) supported with no carbonate mud. High energy environment. Components cemented together following deposition.	None identified in mapping
	Packstone	Grain (e.g., fossil fragments) supported with some carbonate mud. Lower energy than grainstone. Components cemented together following deposition.	None identified in mapping
	Wackestone	Carbonate mud supported with more than 10% grains and less than 90% carbonate mud. Lower energy than packstone. Components cemented together following deposition.	None identified in mapping
	Mudstone	Carbonate mud supported with less than 10% grains and more than 90% carbonate mud. Lower energy than wackestone. Components cemented together following deposition.	**Zcm, Zsr, Omb, Cw, CZcu**

Table 2, continued. Sedimentary rock classification and characteristics.

Rock Type	Rock Name	Texture and Process of Formation	Blue Ridge Parkway Geologic Map Unit Examples
CHEMICAL SEDIMENTARY ROCKS	Limestone (carbonate mud)	Generic name. Formed by the precipitation of calcium (Ca) and carbonate (CO_3^{-2}) ions from water (e.g., lakes or marine environments).	**Omb***, OCco***, Ce, Cw, Cs**
	Travertine	Precipitation of calcium (Ca) and carbonate (CO_3^{-2}) ions from freshwater (e.g., terrestrial springs).	None identified in mapping
	Dolomite	Precipitation of calcium (Ca), magnesium (Mg), and carbonate (CO_3^{-2}) ions from water. Direct precipitation in shallow marine environments or post-depositional alteration by Mg-rich groundwater.	**OCco***, Ce, Cs, Cw**
	Chert	Dissolution of siliceous marine skeletons (e.g., sponge spicules) followed by precipitation of microcrystalline silica. Biochemical chert typically forms from marine invertebrates.	None identified in mapping
	Evaporites (e.g., gypsum)	Precipitation of salts to form evaporite minerals. Typical of hot, dry environments.	None identified in mapping
	Oolite	Precipitation of calcium carbonate in thin spherical layers around an original particle (e.g., fossil fragment) that is rolled back and forth by tides or waves. Typical of warm, shallow marine environments.	**OCco*****
ORGANIC SEDIMENTARY ROCKS	Coal	Peat (partly decomposed plant matter) is buried, heated, and altered over time. Typical of lagoon, swamp, and marsh environments.	None identified in mapping

Table 3. Volcanic rocks classification and characteristics.

*Silica content influences the color, viscosity, and eruption style of a volcano. Percentages from Bacon (2008).
The relative color of these rocks ranges from lighter (rhyolite) to darker (basalt).
The relative viscosity of magma ranges from less mobile flows (rhyolite) to more mobile flows (basalt).
The typical style of eruption ranges from more explosive (rhyolite) to less explosive (basalt).
The prefix "meta" indicates that the rock was metamorphosed.

Rock Name:	Rhyolite	Rhyodacite	Dacite	Andesite	Basaltic Andesite	Basalt
Silica (SiO_2) content*	≥72%	68%–72%	63%–68%	57%–63%	52%–57%	≤52%
Blue Ridge Parkway Examples	Dikes of rhyolite identified in Virginia	None identified in mapping	None identified in mapping	Meta-andesite in **CZcu**	None identified in mapping	**Zcb**, **CZcu**, **Zsr**

(filled vesicles) are indicative of gas bubbles trapped in lava.

The parkway's plutonic igneous rocks are classified by geologists based on the percentage of major minerals as metamorphosed granites, monzogranites, monzodiorites, monzonites, leucogranites, syenogranites, granodiorites, and diorites (fig. 11); in essence though, their compositions are broadly similar to granite and they can be collectively referred to as "granitoids." Moreover, foliated rocks (having a planar arrangement of grains) may have the qualifier "gneissic." The NPS Geologic Resources Division rocks and minerals website on igneous rocks explains more: https://www.nps.gov/subjects/geology/igneous.htm.

Metamorphic Rocks

Rocks can be metamorphosed (altered) by high temperature, pressure, or fluids to form metamorphic rocks. Metamorphism can occur in two primary

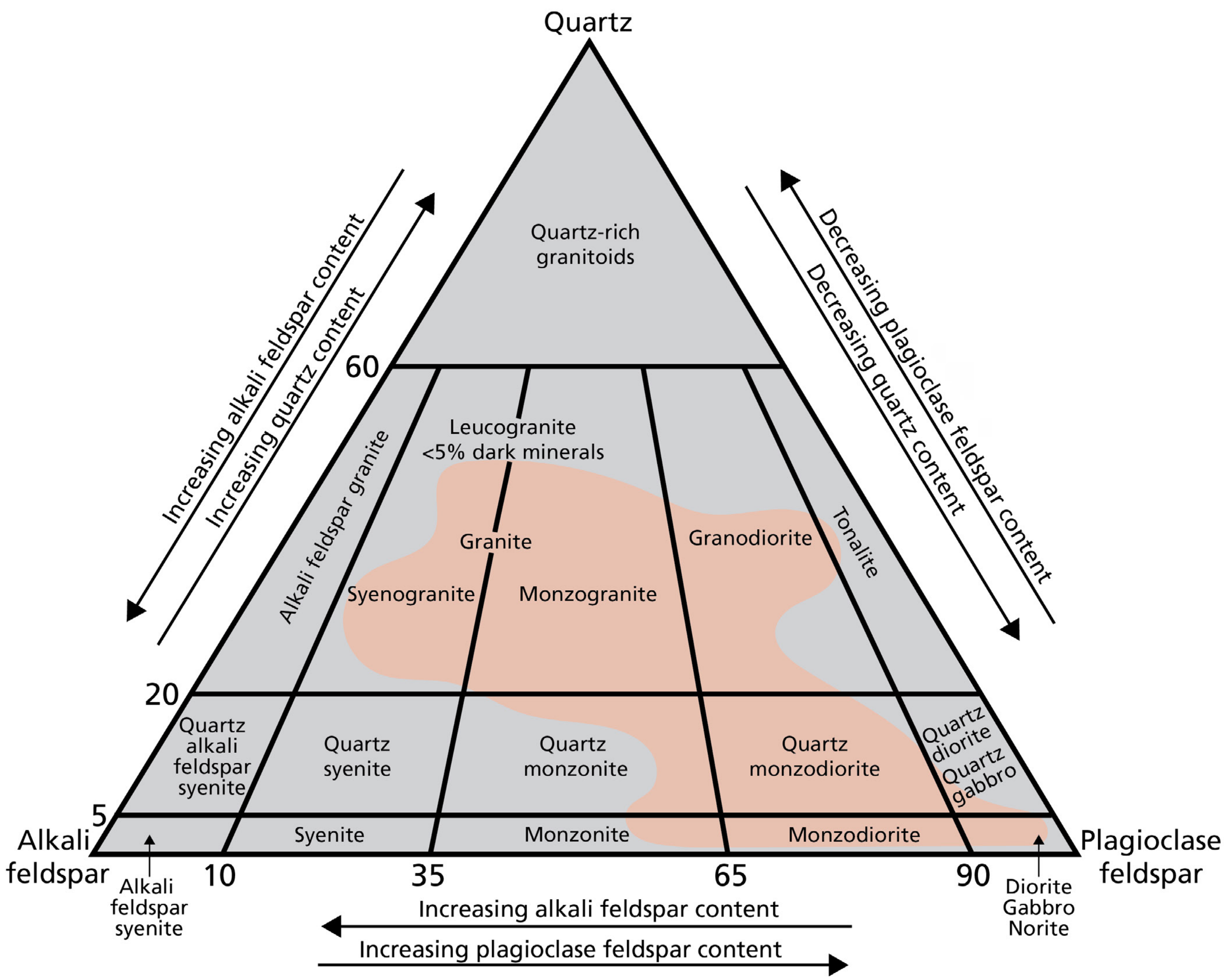


Figure 11. Diagram showing the classification of intrusive igneous rocks.
Orange area refers to compositions of units included in the GRI GIS data for Blue Ridge Parkway. Numbers refer to the percentage of the mineral constituent (quartz, alkali feldspar, or plagioclase feldspar) in the overall composition of the rock. Numbers 5, 20, and 60 refer to the overall quartz component, whereas numbers 10, 35, 65, and 90 refer to the contribution of plagioclase to the overall composition. The corners represent compositions very rich in the corresponding mineral and poor in the two other minerals, but not necessarily other possible component minerals. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) following standard International Union of Geological Sciences (IUGS) nomenclature.

settings: contact or regional. Contact metamorphism is associated with the intrusion of molten material where rocks adjacent to the intrusion are "baked" by the high temperatures. Regional metamorphism is associated with large-scale tectonic events, such as orogenesis (mountain building). The two main types of metamorphic rocks are foliated (minerals are aligned in "stripes") and non-foliated. Metamorphic rocks are further classified by degree of foliation, grain size, and parent rock. The prefix "meta" is commonly added to the original rock type to signify its origin. Certain minerals, for example, garnet, kyanite, and sillimanite, are used by geologists to determine the conditions or "grade" (i.e., heat, temperature, or presence of fluids) during metamorphism.

Some of the most common metamorphic rock types exposed along the Blue Ridge Parkway include gneiss, schist, and metagraywacke. Gneiss displays distinct foliation, representing alternating layers composed of different minerals. Schist was metamorphosed at lower temperature and pressure than gneiss and contains medium to large, flat, sheet-like grains in a preferred, roughly parallel arrangement. It has a composition with more than 50% platy (mica) and elongated minerals, commonly finely interlayered with quartz and feldspar. Metagraywacke is a term used to describe non-banded to faintly banded metamorphosed sedimentary rock (Carter et al. 2001). When temperature conditions are such that partial melting occurs, a migmatite forms, characterized by looping bands of light and dark minerals (see fig. 10).

Resources and References

In addition to data included in the GRI GIS data set and ancillary map information documents, the following references provide additional background information. The list is organized from top (park-specific) to bottom (general):

- Guide to the North Carolina portion of Blue Ridge Parkway: Carter et al. (2001)
- Museum of North Carolina Minerals (MP 331): https://www.nps.gov/blri/planyourvisit/museum-of-north-carolina-minerals-mp-331.htm.
- Virginia Division of Geology and Mineral Resources rocks, minerals, and fossils website: https://www.dmme.virginia.gov/DGMR/rocks.shtml.
- NPS Geologic Resources Division Rocks and Minerals website: https://www.nps.gov/subjects/geology/rocks-and-minerals.htm
- NPS Sedimentary Rocks website: https://www.nps.gov/subjects/geology/sedimentary.htm
- NPS Igneous Rocks website: https://www.nps.gov/subjects/geology/igneous.htm
- NPS Metamorphic Rocks website: https://www.nps.gov/subjects/geology/metamorphic.htm

Earth Surface Processes: Surficial Units

The central and southern Appalachian landscape is the result of initial uplift and ongoing erosion or weathering. These processes are strongly influenced by regional tectonics and climate change. Erosion rates vary with rock type and exposure, but for the Blue Ridge escarpment, erosion or retreat of the escarpment ranged between 6.5 and 49 m (21.3 and 161 ft) per million years with a positive relationship between erosion rate and average basin slope (Sullivan et al. 2007; Linari et al. 2017; Carter et al. 2017). The escarpment is eroding (on average) more rapidly than the Blue Ridge uplands to the west, which are eroding more rapidly that the Piedmont lowlands to the east (Linari et al. 2017). Some Blue Ridge rock types weather more readily than others; for example, quartzite (e.g., geologic map units **CZcl**, **Ccw**, and **Cchq**) weathers much more slowly than does carbonate (e.g., **Cs**). Such differential erosion is responsible for the persistence of some ridges and knobs adjacent to valleys and hollows.

Because the parkway follows the crest of much of the Blue Ridge province (i.e., away from basins), areas of sediment deposition are uncommon. Instead, most material is weathered and eroded from the heights of the mountains then transported by wind, water, and gravity downslope to lower elevations (fig. 12). Slope deposits such as block field (surficial geologic map unit **Qbf**); block stream (**Qbs**); talus (**Qt**); debris fan (**Qdf**); debris, undifferentiated (**Qdu**); colluvium, undifferentiated (**Qcu**); and composite block field, block stream, and talus (**Qc**) are mapped within parkway boundaries for the North Carolina portion of the parkway (Merschat et al. 2008b). Their distribution is testament to the Earth surface processes responsible for lowering the Appalachian Mountains from once-Himalayan heights to their current elevations. For example, in Virginia, surficial deposits vary along the length of the parkway, changing from coarse slope deposits (e.g., talus, colluvium, or block slope) that choke stream channels in the steep slopes north of the James River to well-rounded pebble, cobble, and boulder deposits that are smaller in size and magnitude to the south (Carter et al. 2017).

Resources and References

In addition to data included in the GRI GIS data set and ancillary map information documents, the following references provide additional background information. The list is organized from top (park-specific) to bottom (general):

- Rates of erosion and landscape change along the Blue Ridge escarpment: Linari et al. (2017)
- NPS Erosion website: https://www.nps.gov/subjects/erosion/index.htm.

Wetlands

Wetlands are areas that are covered (flooded) permanently or intermittently with shallow water or water-saturated soil and includes marshes, swamps, seeps, pools, and bogs. Wetlands in the parks may be covered in shallow water most of the year or be wet only seasonally. Wetlands provide several significant functions, including (1) provision of bird and other wildlife habitat, (2) surface water detention, (3) nutrient transformation, and (4) retention of sediments.

A discussion of wetlands is typically beyond the scope of a GRI report, but the parkway's wetlands warrant mention because of their geologic connections. Many of the wetlands in the parkway occur where groundwater, seeping through fractures in bedrock encounter an impermeable surface and flow laterally. Seeps and springs emerge where this flow intersects the surface. Other wetlands are located in natural depressions,

Figure 12. Photographs of surficial map units at Blue Ridge Parkway.
Frost weathering, water saturation, gravity, and root wedging contribute to the formation of surficial deposits, which are typically slope deposits. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with photographs CRR-003, DPR-001, DMR-008, and LFR-005 from Merschat et al. (2008a).

underlain by relatively impermeable clays. Unlike northern bogs of glacial origin (kettles), southern Appalachian bogs form in poorly drained depressions or on gentle slopes, typically in valley bottoms which do not experience significant flooding. They may vary from being constantly wet to intermittently dry and are commonly kept moist by seeps. Wet organic or mucky mineral soils, which are very acidic tend to underlie these bogs (North Carolina Wildlife Resources Commission, date unknown). The NPS Water

Resources Division is the primary contact for technical and policy assistance regarding wetlands.

The parkway protects half of the remaining high elevation wetlands in North Carolina (Sundin et al. 2013). Within its boundaries are a variety of wetland types, including southern Appalachian bog, high elevation seeps, swamp-forest bog complex, and bottomland (floodplain) forest (National Park Service 2017). The southern Appalachian bog is particularly rare within the southeastern US, supporting more species of rare, threatened, and endangered species than all other types of wetlands combined. Among some of the rarer of these species are the bog turtle (*Glyptemys muhlenbergii*), Gray's lily (*Lilium grayi*), large cranberry (*Vaccinium macrocarpon*), swamp pinks (*Helonias bullata*), and Cuthbert's turtlehead (*Chelone cuthbertii*) (Sundin et al. 2013; National Park Service 2017).

Wetland restoration remains an opportunity for Blue Ridge Parkway. The parkway's foundation document (National Park Service 2016) identified a survey of historic wetlands, namely with respect to diversity of habitat, as a data need for resource management. Determining the status and trends in vegetation and hydrologic changes to parkway wetlands was presented in Sundin et al. (2013) as an action item. In particular, the resource management staff wish to understand the geology of the Pisgah Bog (Bambi Teague, Blue Ridge Parkway, chief of natural resources, conference call, 16 May 2018).

Resources and References

In addition to data included in the GRI GIS data set and ancillary map information documents, the following references provide additional background information. The list is organized from top (park-specific) to bottom (general):

- Foundation document: National Park Service (2016)
- Natural resource condition assessment: Sundin et al. (2013)
- NPS Wetlands website: https://www.nps.gov/subjects/wetlands/index.htm
- NPS Water Resources Division is primary contact for wetlands policy and technical assistance: https://www.nps.gov/orgs/1439/wetlands.htm.
- Wetland types: Cowardin et al. (1979)

Geologic Hazards

A geologic hazard ("geohazard") is a geologic condition or process that may impact resources, infrastructure, or visitor safety. Risk is the probability of a hazard to occur combined with the expected degree of damage or loss that may result from exposure to a hazard, or the likelihood of a hazard causing losses (see Holmes et al. 2013). Alerting visitors to geologic hazards, for example, associated with rockfall near slopes, is a first step toward reducing the risk. Such information could be presented via the park website, brochures, signage, and/or verbal communication from park staff.

Primary resource management issues in the parkway are geologic hazards from slope movements and earthquakes (discussed below). The GRI GIS data include other geohazards layers: acid-producing rock potential areas, net neutralization potential localities, and visible sulfide localities. These layers indicate the potential impacts of exposing rocks that contain sulfide minerals to runoff, potentially decreasing the pH of local soils and streams. Included in the ancillary map document of the GRI GIS data (blrs_geology.pdf) is a summary of the geohazards data and data layers with information on how the layers were generated and explanations of the parameters presented (Merschat et al. (2008a, 2008b). For more information about acid-producing rock, see https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey/geologic-hazards/acid-producing-rock. Sullivan et al. (2011b) discussed acidification affects from atmospheric sulfur and nitrogen deposition.

Additional geological hazards in Virginia and North Carolina not discussed in this report are detailed on websites for the Virginia Division of Geology and Mineral Resources (https://www.dmme.virginia.gov/DGMR/hazards.shtml) and the North Carolina Geological Survey (https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey/geologic-hazards).

Slope Movements

Slope movements are the downslope transfer of soil, regolith, and/or rock under the influence of gravity. Soil creep, rockfalls, debris flows, and avalanches are common types of slope movements. These processes and the resultant deposits are also known as "mass wasting" and commonly grouped as "landslides." Slope movements occur on time scales ranging from seconds to years (see fig. 13). Slope movements create geologic hazards and associated risk in many parks, including Blue Ridge Parkway. Geohazard point features are included in the GRI GIS data for the North Carolina portion of the parkway (fig. 14); 243 points, including debris flows, rockfalls, rockslide, debris slide, and debris blowouts are mapped within parkway boundaries. Information associated with each point includes the slope-movement material and mechanism, movement date, activity level, hazard rating, nearest parkway milepost, slope elevations,

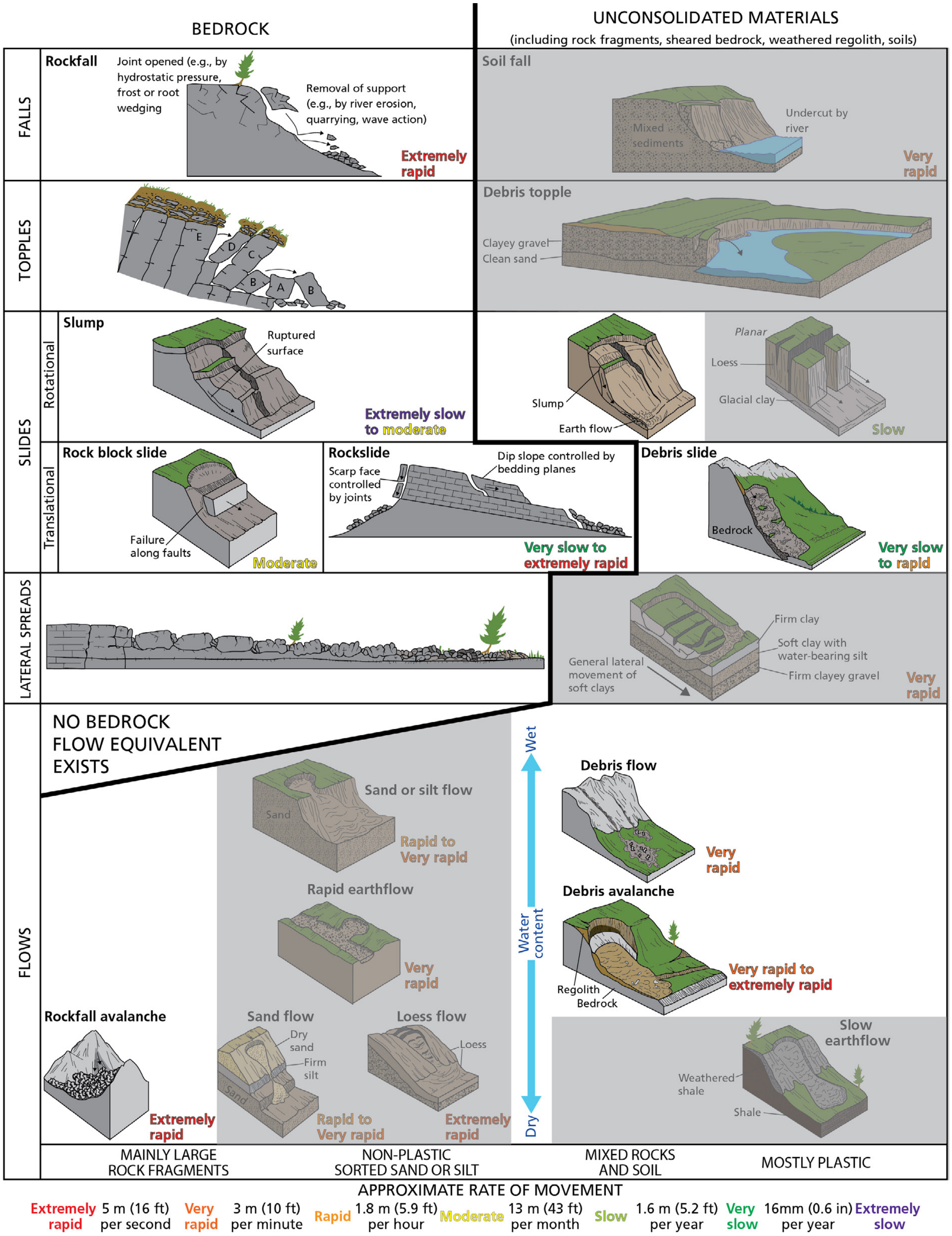


Figure 13. Schematic illustrations of slope movements.
Different categories of slope movement are defined by material type, nature of the movement, rate of movement, and moisture content. Grayed areas depict conditions unlikely to exist at Blue Ridge Parkway. The abundant vegetation in the parkway stabilizes many slopes, but active slides are present along the length of the parkway as recorded in the GRI GIS data. Slope issues could be exacerbated by natural or anthropogenic removal of vegetation. Graphic by Trista Thornberry-Ehrlich (Colorado State University) redrafted after a graphic and information in Varnes (1978) and Cruden and Varnes (1996).

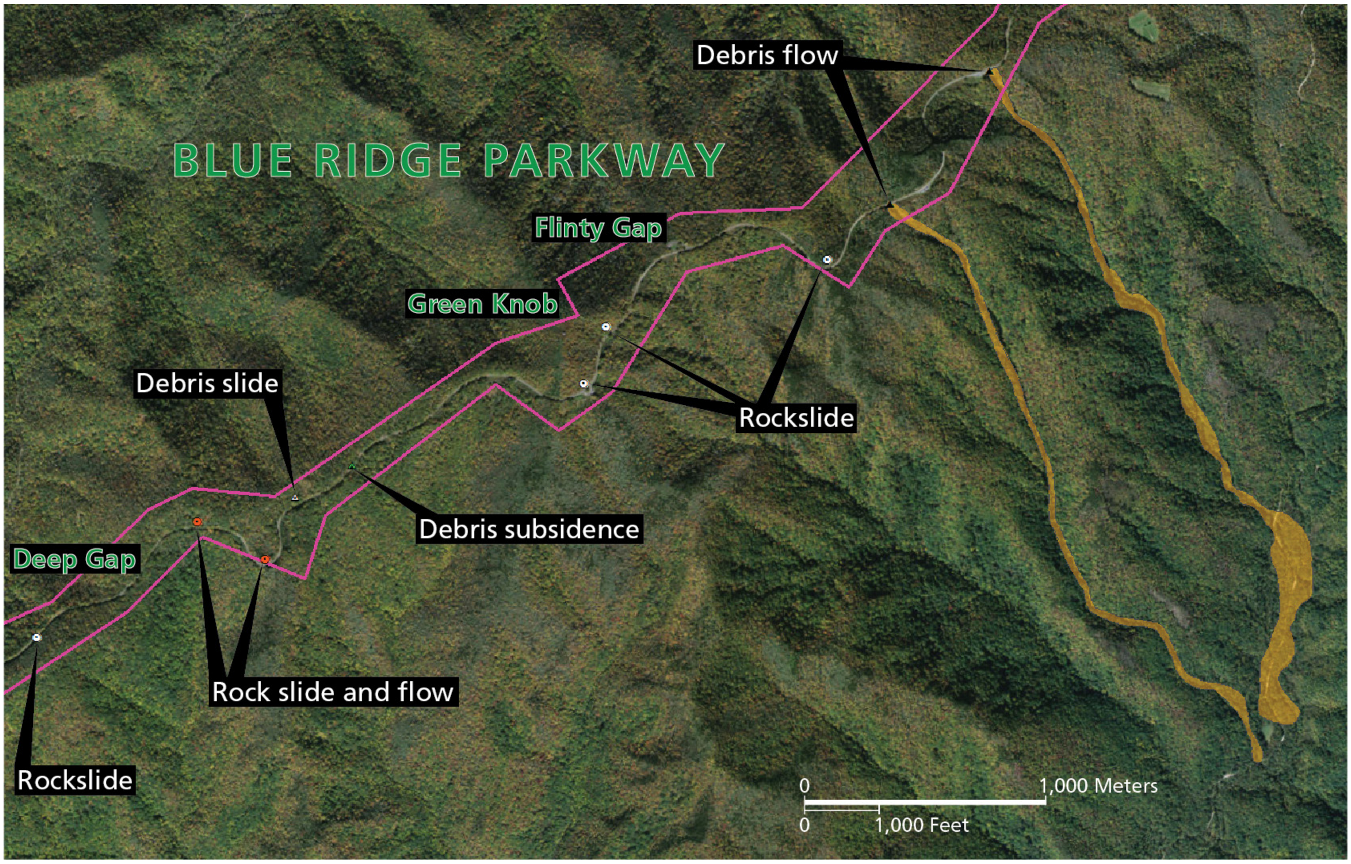


Figure 14. Aerial imagery of slope movements.
Many types of slope movements are possible along the length of the parkway as recorded in the GRI GIS data. At least five types of slope movements were observed near Green Knob (milepost 350). Graphic by Trista Thornberry-Ehrlich (Colorado State University) using ESRI imagery and data from Merschat et al. (2008b).

slope geomorphology, deposit dimensions, damage or impacts, associated geologic map unit, associated geologic structures (e.g., faults or bedding), slope vegetation, and movement history. Hazard-area features mapped within parkway boundaries include debris flows, debris slides, rockslides, debris slides and flows, and debris blowouts. These areas are large and significant enough to appear on 1:24,000-scale mapping (North Carolina Geological Survey 2008). Map units **Qcu** (colluvium, undifferentiated), **Qdu** (debris, undifferentiated), **Qdf** (debris fan), and **Qt** (talus) are all derived from slope movements and indicate areas where future slope movements are possible. Geohazards data for the Virginia portion of the parkway remain a resource management need; however, some areas are highlighted in Carter et al. (2017).

These processes are natural elements of landscape change. These natural processes become hazards when they undermine the integrity of the roadway or other infrastructure, or when visitors hike near the base of cliffs, along debris flows, across stone streams, or beneath overhanging rock (fig. 15). Particularly hazardous areas are those with visible cracks, loose material, or overhangs as well as settings where geologic fabrics such as foliation, cleavage, bedding, and jointing are sloping steeply into the road or trail surface (Carter et al. 2001). Water-saturated slopes may also be particularly at risk for debris flows (e.g., a slope near Mount Mitchell State Park failed following heavy rains from Hurricane Opal in 1995 forcing closure of the parkway for two weeks). Blocks from landslides have even fallen onto parkway automobiles (Bambi Teague, Blue Ridge Parkway, chief of natural resources, conference call, 16 May 2018). Parkway ditches are not always cleared of debris and fill with water during large storms (Bambi Teague, Blue Ridge Parkway, chief of natural resources, conference call, 16 May 2018). Portions of the parkway are often closed during heavy storms. The parkway resource managers submitted a technical assistance request in 2015, stating that with the likelihood of landslides increasing in the southern Appalachians, the parkway needs a defensible strategy/

Figure 15. Photographs of slope movements along Blue Ridge Parkway.
A) Some stretches of road may be undercut by adjacent slope failures, such as this one near Roanoke (milepost 128) in 2020. (B) In other areas, rockfall may cover the parkway surface, falling from above, such as at milepost 277 in 2018. (C) Rockfall may be a single boulder wedged from an upper slope, near milepost 411 in 2016. (D) Heavy rains and frost wedging contribute to slope movements along the parkway every season (closure from mileposts 367 to 355 in 2017). NPS photographs courtesy of the Blue Ridge Parkway.

criteria for parkway closures based on potential weather events. The geohazards data included in the GRI GIS geologic map data may provide justification to close sections of the parkway (Bambi Teague, Blue Ridge Parkway, chief of natural resources, conference call, 16 May 2018). See also figure 16 for for an example of compiled geohazard and slope stability data.

In areas where construction or other road work has cut or undermined slopes, the situation is no longer one of natural landscape change but of human disturbance of the system. Blue Ridge Parkway was engineered to "lie lightly" on the landscape, but some construction activities have nevertheless induced slope movements.

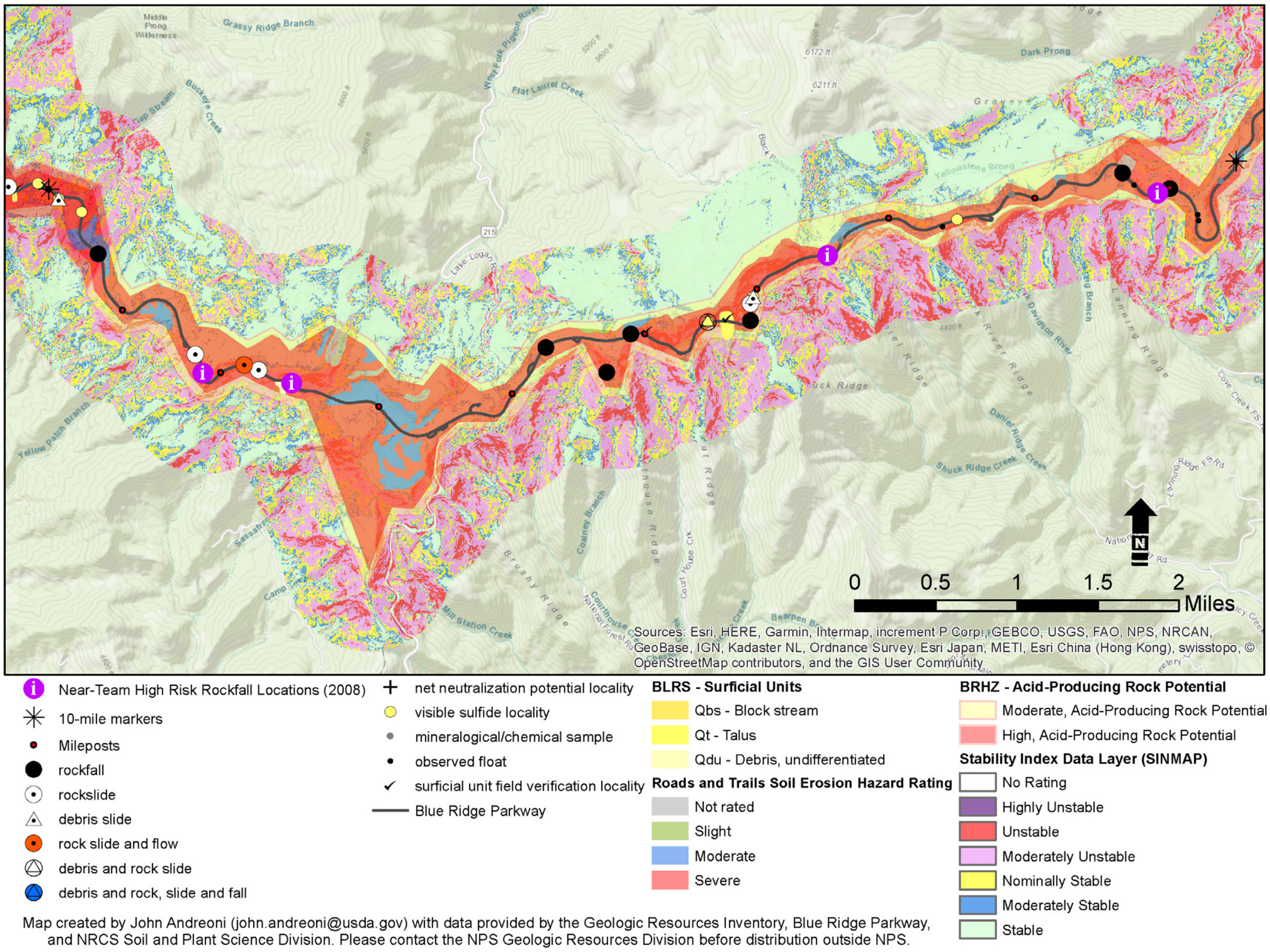


Figure 16. Example map displaying data sets relevant for slope stability information in North Carolina. This map incorporates data from three sets applied to mileposts 417–427: (1) GRI GIS data set (Merschat et al. 2008a, 2008b) includes the BLRS surficial units, BRHZ acid-producing rock potential, BRHZ hazard points and observation data; (2) USDA Natural Resources Conservation Service soil erosion interpretation (available via Web Soil Survey; https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm); and (3) North Carolina Geological Survey stability index ("SINMAP") provided to NPS staff. Parkway boundary, roadway, and milepost data layer provided by parkway staff. Map by John Andreoni (Natural Resources Conservation Service, Soil and Plant Science Division).

Geo-engineers determined that oversteepening of slopes during construction of the Blue Ridge Parkway has initiated failures in areas such as Buncombe County, North Carolina (Schnabel Engineering, LLC 2009). Rockfalls and topple are typical mass wasting features along the Blue Ridge Parkway. Wide catchment areas, mass grading, rock anchors, rock gluing, and retaining walls are potential engineering solutions to these hazards (Schnabel Engineering, LLC 2009; Carter et al. 2017). Tunnels excavated through solid rock can be unstable. The ceiling of many of the parkway tunnels are reinforced with large steel rock bolts and nets (e.g., Little Switzerland Tunnel). Other tunnels have weathered and weakened bedrock ceilings. This occurs particularly in rocks that have sulfide minerals which, when exposed to percolating water, react to form corrosive sulfuric acid that dissolves away rocks and cement. This so-called acid-producing potential was noted during field mapping and is included in the GRI GIS data for North Carolina. Some tunnels have been treated with concrete to prevent spalling (e.g., Wildacres Tunnel; Carter et al. 2001). Constant monitoring of the parkway infrastructure is necessary to maintain its integrity and limit risk to visitor safety.

If funding permits, resource managers could consider obtaining quantitative information to assess the frequency and magnitude of rockfall (and other slope movements) in high visitation areas. A photomonitoring program is one possibility. The Geoscientist-in-the-Parks program is an option to support such a project. The NPS Geologic Resources

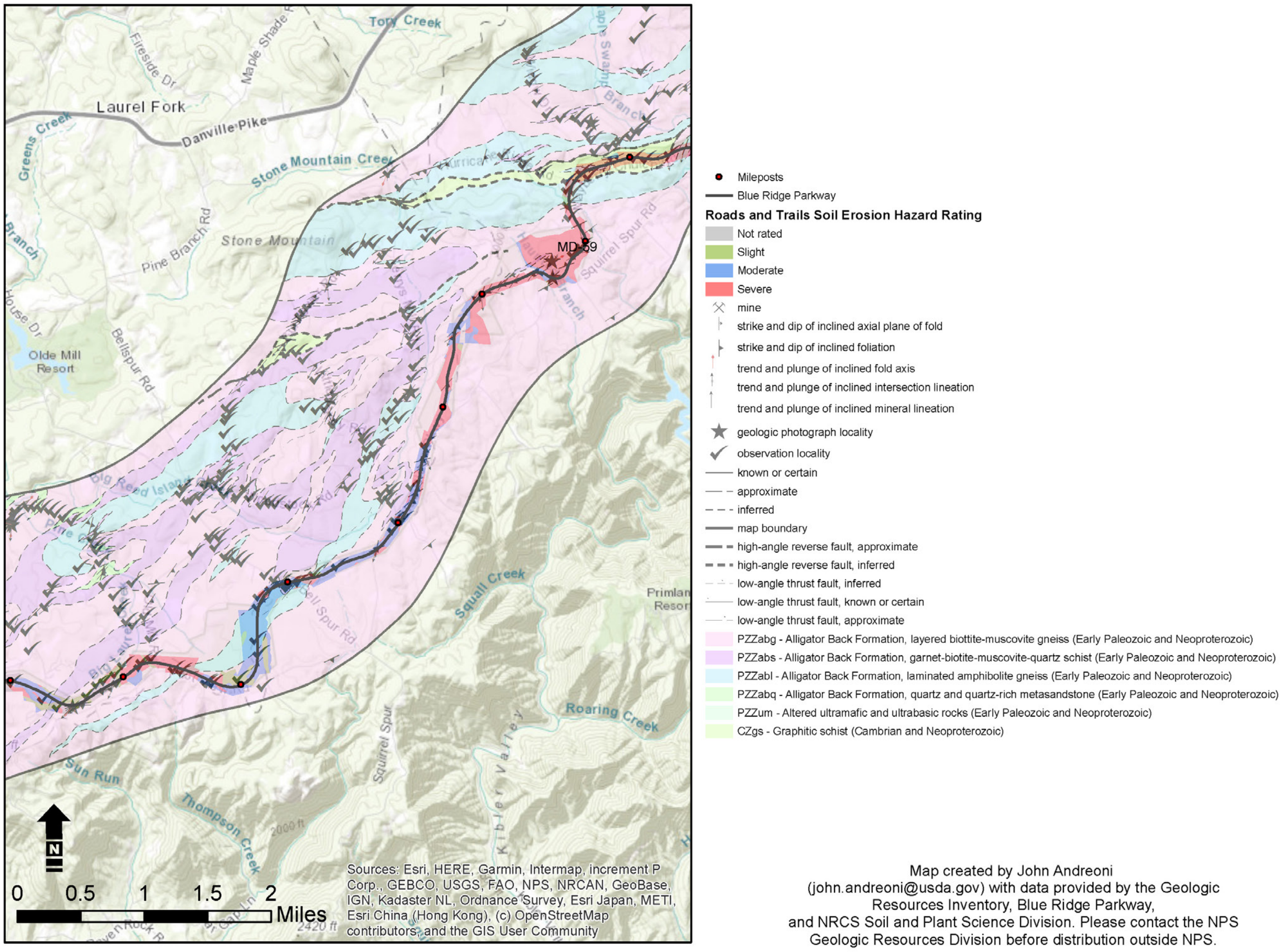


Figure 17. Example map displaying data sets relevant for slope stability information in Virginia. There is no dedicated geohazards map for the parkway in Virginia. This map incorporates data from two sets applied to mileposts 180–188: (1) GRI GIS data set blrn_geology.mxd (source map: Carter et al. 2016) includes the BLRN geologic units and observation data, and (2) USDA Natural Resources Conservation Service soil erosion interpretation (available via Web Soil Survey; https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm). Parkway boundary, roadway, and milepost data layer provided by parkway staff. Map by John Andreoni (Natural Resources Conservation Service, Soil and Plant Science Division).

Division Photogrammetry website (http://go.nps.gov/grd_photogrammetry) provides examples of how photographic techniques support structural analysis of rockfall areas. The Unstable Slope Management Program—a cooperative effort among the National Park Service, Federal Highways, University of Montana, and others—created and is populating a central database of unstable slopes with ranking. This database will support an unstable slope management tool to allow prioritization of mitigation to reduce slope hazard risks (see Bilderback et al. 2017). The slopes of Blue Ridge Parkway are ideal candidates for inclusion in the effort.

In late summer 2019, when this report was in final review, NPS Geologic Resources Division staff traveled to the parkway to train staff in using the Unstable Slope Management Program. As preparation for that training, John Andreoni (NPS and Natural Resources Conservation Service, presidential management fellow) created a set of maps to visualize the multiple sources of information that affects slope stability within and adjacent to the parkway. The data sets utilized include the GRI GIS data, Natural Resources Conservation Service soils data, and a raster data set from the North Carolina Geological Survey that shows slope stability and identifies points along the parkway with high, near-term rockslide risk. Andreoni used those points to map a 40-mile stretch, in 10-mile stretches, of segment 4 of the parkway near the Great Balsam Mountains that contains 15 of the 22 highest risk points. These maps helped inform locations for slope stability analysis (fig. 16). Andreoni also created an example map using GRI GIS data from the Virginia portion of the parkway, which does not have a dedicated geohazard mapping or surficial mapping component, to demonstrate what data are available to manage that section (fig. 17). Data sets that are not already part of the GRI GIS package were delivered to parkway staff along with this GRI report.

Andreoni collaborated with parkway and NPS Resource Information Services Division staff to query the road status database with regards to when different segments were closed or had warnings. A summary of that data is available as table 4 of this report. Although the causes of those closures and warnings were not available, parkway closures or warnings often result from slope movements or other hazards (GRI conference call participants, conference call, 16 May 2018). In the future, if causes were integrated into the database, that information could be used to develop predictive models for locations on the parkway particularly susceptible to natural hazard warnings or closures, and what weather conditions are associated with those hazards.

Resources and References

In addition to data included in the GRI GIS data set, the following references provide additional background information, suggested vital signs, and resources for assessing and documenting slope movements. The list is organized from top (park-specific) to bottom (general):

- Slope stability investigation and remediation suggestions (referencing MP 400.8): Schnabel Engineering, LLC (2009)
- Foundation document: National Park Service (2016)
- Stability map (raster data set) produced by the North Carolina Geological Survey in 2008. Contact GRI for this information.
- Recent landslides along the parkway in North Carolina available in GIS format (Rick Wooten, North Carolina Geological Survey, geologist, conference call, 16 May 2018).
- Virginia Division of Geology and Mineral Resources landslides website: https://www.dmme.virginia.gov/DGMR/landslides.shtml.
- North Carolina Geological Survey slope movements and landslides website: https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey/geologic-hazards/landslides.
- Case study of using an unstable slope management tool: Bilderback et al. (2017)
- *Geological Monitoring* chapter about slope movements (Wieczorek and Snyder 2009), which described five vital signs for understanding and monitoring slope movements: (1) types of landslide, (2) landslide causes and triggers, (3) geologic materials in landslides, (4) measurement of landslide movement, and (5) assessment of landslide hazards and risks
- NPS Geologic Resources Division Geohazards website: http://go.nps.gov/geohazards.
- NPS Geologic Resources Division Slope Movement Monitoring website http://go.nps.gov/geomonitoring.
- US Geologic Survey publication: The landslide handbook—A Guide to Understanding Landslides (Highland and Bobrowsky 2008)
- US Geological Survey Landslides website: http://landslides.usgs.gov/
- Natural hazards science strategy: Holmes et al. (2013)
- Landslide hazards and climate change: Coe (2016)

Table 4. Closures and warnings on the Blue Ridge Parkway.

Data were compiled and summarized by John Andreoni (Natural Resources Conservation Service) and NPS Resource Information Services Division staff from http://go.nps.gov/blri-roads). The table shows the number of weeks that portions of the parkway were closed or when warnings were posted. Data spans from 13 June 2016 to 12 September 2019, a total of 169.4 weeks. Currently the data do not differentiate closures or warnings due to different causes (weather, hazards, construction, etc.). However, this methodology could inform predictive models to show areas of frequent closure due to different causes and correlation with time of year should that information be collected and integrated into the database in the future.

Colors (red at highest value, yellow at 50th percentile, and green at lowest value) highlight length of closure/warning period.

POI = Point of interest located at indicated milepost (MP).

Management Segment	Mileposts and Name	Length	Total Weeks Closed	Total Weeks Warned
Segment 1: Ridge	000.0 to 013.6 Parkway	13.6 miles	89.5	0.0
Segment 1: Ridge	008.4 Humpback Rocks Picnic Area	POI	59.8	5.2
Segment 1: Ridge	013.6 to 027.1 Parkway	13.5 miles	39.3	0.1
Segment 1: Ridge	027.1 to 045.5 Parkway	18.4 miles	46.0	0.6

Table 4, continued. Closures and warnings on the Blue Ridge Parkway.

Management Segment	Mileposts and Name	Length	Total Weeks Closed	Total Weeks Warned
Segment 1: Ridge	045.5 to 061.2 Parkway	15.7 miles	24.1	0.0
Segment 1: Ridge	060.7 Otter Creek Campground	POI	78.6	0.0
Segment 1: Ridge	061.2 to 076.4 Parkway	15.2 miles	36.2	0.0
Segment 1: Ridge	076.4 to 091.0 Parkway	14.6 miles	27.9	1.0
Segment 1: Ridge	085.6 Peaks of Otter Lodge	POI	9.6	0.0
Segment 1: Ridge	085.7 Peaks of Otter Picnic Area	POI	65.9	0.0
Segment 1: Ridge	085.9 Peaks of Otter Campground	POI	78.6	0.0
Segment 1: Ridge	086.0 Sharptop Bus Access Road	POI	55.4	0.0
Segment 1: Ridge	091.0 to 105.7 Parkway	14.7 miles	14.0	37.3
Segment 2: Roanoke	105.7 to 121.2 Parkway	15.5 miles	40.5	0.0
Segment 2: Roanoke	115.0 Roanoke River Parkway	POI	10.7	0.0
Segment 2: Roanoke	120.4 Mill Mountain Picnic Area	POI	50.6	0.0
Segment 2: Roanoke	120.4 Mill Mountain Spur Road	POI	8.9	0.0
Segment 2: Roanoke	120.4 Roanoke Mountain Loop Road	POI	65.5	0.0
Segment 2: Roanoke	121.2 to 135.9 Parkway	14.7 miles	29.2	7.8
Segment 3: Plateau	135.9 to 167.2 Parkway	31.3 miles	20.3	0.0
Segment 3: Plateau	154.6 Smart View Picnic Area	POI	59.3	0.0
Segment 3: Plateau	167.2 Rocky Knob Campground	POI	61.0	0.0
Segment 3: Plateau	167.2 to 170.3 Parkway	3.1 miles	15.9	0.0
Segment 3: Plateau	169.0 Rocky Knob Picnic Area	POI	59.3	0.0
Segment 3: Plateau	170.3 to 198.4 Parkway	28.1 miles	15.0	0.8
Segment 3: Plateau	188.9 Groundhog Mountain Picnic Area	POI	59.3	0.0
Segment 3: Plateau	198.4 to 202.1 Parkway	3.7 miles	28.8	0.2
Segment 3: Plateau (through MP 217); Segment 4: Highlands (MP 217–234.1)	202.1 to 234.1 Parkway	32 miles	15.9	2.6
Segment 3: Plateau	212.7 Blue Ridge Music Center	POI	75.9	0.0
Segment 4: Highlands	217.5 Cumberland Knob Picnic Area	POI	59.3	0.0
Segment 4: Highlands	234.1 to 242.3 Parkway	8.2 miles	34.9	0.0
Segment 4: Highlands	239.3 Doughton Park Campground	POI	77.1	0.0
Segment 4: Highlands	241.1 Bluffs Mountain Lodge	POI	91.2	0.0
Segment 4: Highlands	241.1 Doughton Park Picnic Area	POI	58.6	0.0
Segment 4: Highlands	242.3 to 285.6 Parkway	43.3 miles	11.8	15.7
Segment 4: Highlands	285.6 to 294.6 Parkway	9 miles	54.4	68.0
Segment 4: Highlands	294.0 Cone Manor House Parking Area	POI	5.1	0.0
Segment 4: Highlands	294.6 to 305.1 Parkway	10.5 miles	51.7	4.5
Segment 4: Highlands	296.4 Price Park Picnic Area	POI	19.4	0.0
Segment 4: Highlands	297.0 Price Park Campground	POI	67.6	0.0
Segment 4: Highlands	304.4 Linn Cove Visitor Center	POI	88.4	0.0
Segment 5: Black Mountain	305.1 to 317.5 Parkway	12.4 miles	78.0	4.5

Table 4, continued. Closures and warnings on the Blue Ridge Parkway.

Management Segment	Mileposts and Name	Length	Total Weeks Closed	Total Weeks Warned
Segment 5: Black Mountain	316.4 Linville Falls Campground	POI	64.3	0.0
Segment 5: Black Mountain	316.4 Linville Falls Spur Road	POI	15.5	0.0
Segment 5: Black Mountain	316.5 Linville Falls Picnic Area	POI	70.9	0.0
Segment 5: Black Mountain	317.5 to 324.7 Parkway	7.2 miles	25.5	0.0
Segment 5: Black Mountain	327.7 to 342.1 Parkway	14.4 miles	58.0	9.4
Segment 5: Black Mountain	339.4 Crabtree Falls Campground	POI	78.5	0.0
Segment 5: Black Mountain	340.3 Crabtree Falls Picnic Area	POI	89.2	0.0
Segment 5: Black Mountain	342.1 to 355.5 Parkway	13.4 miles	31.1	3.2
Segment 5: Black Mountain	355.4 Mount Mitchell State Park	POI	17.3	0.0
Segment 5: Black Mountain	355.5 to 367.5 Parkway	12 miles	105.9	8.2
Segment 5: Black Mountain	367.5 Craggy Gardens Picnic Area	POI	59.7	0.0
Segment 5: Black Mountain (through MP 377); Segment 6: Asheville (377–394)	367.5 to 381.9 Parkway	14.4 miles	61.2	0.2
Segment 6: Asheville	381.9 to 393.6 Parkway	11.7 miles	29.5	0.0
Segment 6: Asheville	384.1 Parkway HQ & Visitor Center	POI	0.8	0.0
Segment 7: Pisgah	393.6 to 402.7 Parkway	9.1 miles	27.5	10.4
Segment 7: Pisgah	402.7 to 411.9 Parkway	9.2 miles	98.2	31.1
Segment 7: Pisgah	408.5 Mount Pisgah Lodge & Camp Store	POI	66.8	0.0
Segment 7: Pisgah	408.6 Mount Pisgah Campground	POI	49.6	0.0
Segment 7: Pisgah	411.9 to 423.2 Parkway	11.3 miles	102.9	0.6
Segment 7: Pisgah	423.2 to 443.0 Parkway	19.8 miles	40.4	7.9
Segment 7: Pisgah	443.0 to 455.7 Parkway	12.7 miles	40.3	7.7
Segment 7: Pisgah	455.7 to 469.1 Parkway	13.4 miles	54.1	7.7
Segment 7: Pisgah	458.2 Heintooga Spur Road	POI	64.9	0.0

Earthquakes

Earthquakes are ground vibrations—shaking—that occur when rocks suddenly move along a fault, releasing accumulated energy (Braile 2009). Earthquake intensity ranges from imperceptible by humans to total destruction of developed areas and alteration of the landscape. The "Richter magnitude" is a measure of the energy released by an earthquake. Earthquakes can directly damage park infrastructure or trigger other hazards such as slope movements that may impact park resources, infrastructure, or visitor safety.

Figure 18 of this report shows the likelihood of a magnitude-5 earthquake over the next 100 years for Blue Ridge Parkway. The parkway is not located near a known active seismic zone; however, earthquakes with magnitudes between 2 and 3 are not uncommon. A magnitude-5.0 or greater earthquake has a 2% to 10% probability of taking place within 100 years (fig. 18). Notably, in 2011, the 5.8-magnitude Virginia earthquake caused major damage as part of the Central Virginia seismic zone in an area that was likewise considered to be at relatively low risk for earthquakes and characterized by low-magnitude and infrequent events (Mark Carter, US Geological Survey, geologist, written communication, 21 July 2018).

Resources and References

In addition to data included in the GRI GIS data set, the following references provide additional background information, suggested vital signs, and resources for earthquakes. The list is organized from top (park-specific) to bottom (general):

- Virginia Division of Geology and Mineral Resources earthquakes website: https://www.dmme.virginia.gov/DGMR/earthquakes.shtml.
- US Geological Survey information about the 23 August 2011 earthquake near Mineral, Virginia: https://www.usgs.gov/natural-hazards/earthquake-hazards/science/m58-august-23-2011-mineral-virginia?qt-science_center_objects=0#qt-science_center_objects.
- North Carolina Geological Survey earthquakes in NC website: https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey/geologic-hazards/earthquakes-north-carolina
- US Geological Survey Earthquakes Hazards website: http://earthquake.usgs.gov/

Geological Monitoring chapter about earthquakes and seismic activity (Braile 2009; see http://go.nps.gov/geomonitoring), which described the following methods and vital signs for understanding earthquakes and monitoring seismic activity: (1) monitoring earthquakes, (2) analysis and statistics of earthquake activity, (3) analysis of historical and prehistoric earthquake activity, (4) earthquake risk estimation, (5) geodetic monitoring and ground deformation, and (6) geomorphic and geologic indications of active tectonics

Abandoned Mineral Lands

Abandoned mineral lands (AML) are lands, waters, and surrounding watersheds that contain facilities, structures, improvements, and disturbances associated with past mineral exploration, extraction, processing, and transportation. This also includes oil and gas features and operations for which the National Park Service takes action under various authorities to mitigate, reclaim, or restore in order to reduce hazards and impacts to resources. AML features can provide habitat for bats and other animals, some of which may be protected under the Endangered Species Act or state species listings.

Resource management of AML features requires an accurate inventory and reporting. All AML features should be recorded in the Servicewide AML Database; the NPS Geologic Resources Division can provide assistance. An accurate inventory identifies human safety hazards and contamination issues, and facilitates closure, reclamation, and restoration of AML features. When appropriate for resource management and visitor safety, AML features can also present opportunities for interpretation as cultural resources (Burghardt et al. 2014).

According to the NPS Abandoned Mineral Lands (AML) database and Burghardt et al. (2014), Blue Ridge Parkway does not contain any AML features at any sites. However, the GRI GIS data include at least 27 mine features (e.g., prospects, mines, borrow pits, and other pits) within parkway boundaries (fig. 19; Merschat et al. 2008a; Carter et al. 2016). AML features pose a variety of resource management issues such as visitor and staff safety and environmental quality of air, water, and soil. Old iron mine features around Roanoke are of historical significance to the city but pose safety threats because 60-m- (200-ft-) deep shafts remain open (Mark Carter, US Geological Survey, geologist, conference call, 16 May 2018). The parkway submitted a technical assistance request in 2017 for help interpreting the results of contaminant-monitoring wells adjacent to the Rutrough Landfill, near Roanoke, Virginia. An updated request (request 7068) is still active into FY 2020.

At Blue Ridge Parkway, many of the stone quarries were used during parkway construction for curbing stone, tunnel portal rocks, and overlook rocks and are candidates for historic status (Mark Carter, US Geological Survey, geologist, conference call, 16 May 2018). A historic resource study of these historic quarry features in Virginia and North Carolina would be a very useful and interesting interpretive tool (Bambi Teague, Blue Ridge Parkway, chief of natural resources, conference call, 16 May 2018).

Resources and References

In addition to data included in the GRI GIS data set and ancillary map information documents, the following references provide additional background information. The list is organized from top (park-specific) to bottom (general):

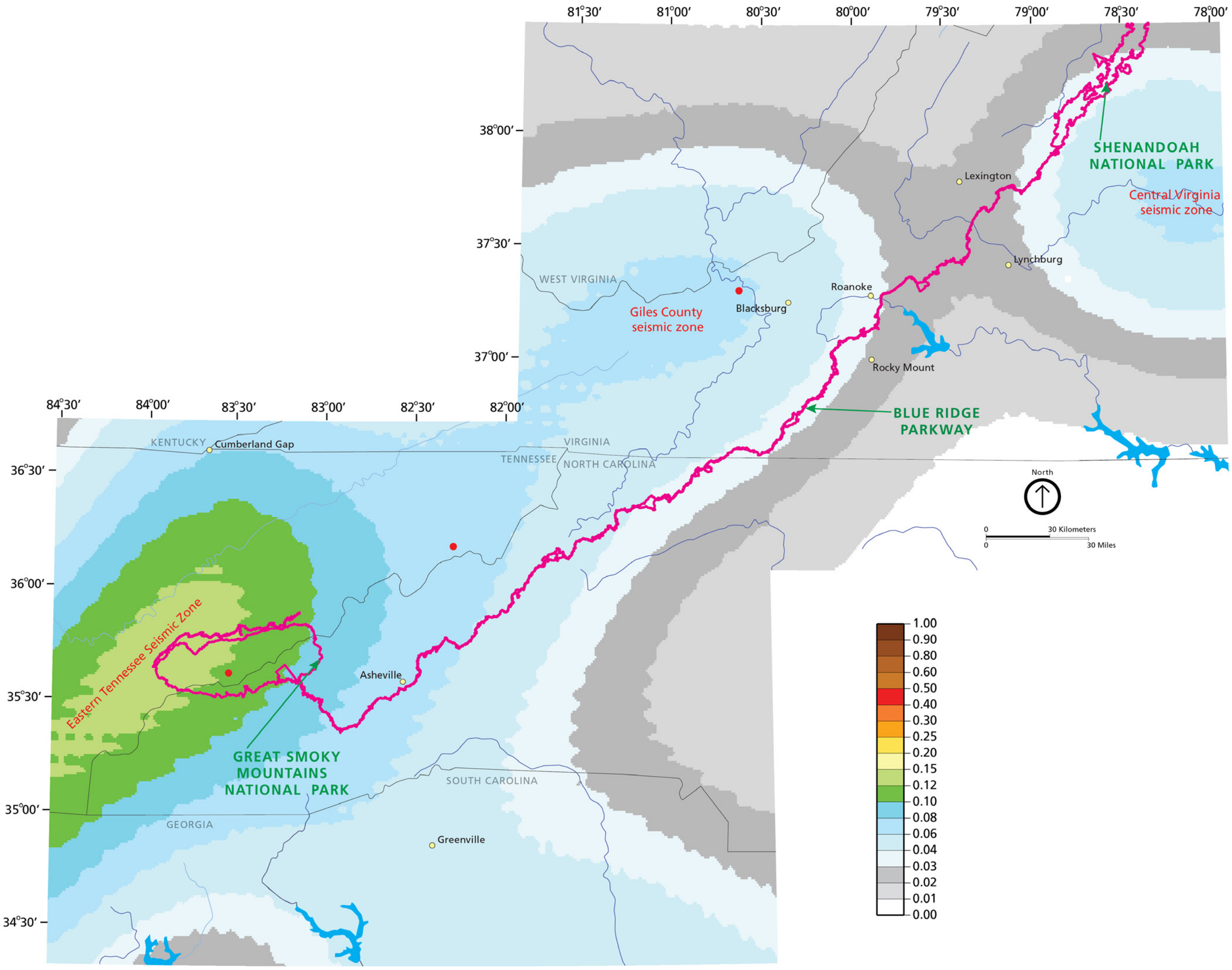


Figure 18. Map of probability of earthquakes with magnitude 5.0 and greater (moderate earthquake). This probability assumes a 100-year timespan and a 50-km (30-mi) radius around Asheville, North Carolina, and Roanoke, Virginia. An event that is certain to happen has a probability of 1. An event that cannot possibly happen has a probability of zero. If there is a chance that an event will happen, then its probability is between zero and 1. Epicenters for earthquakes of magnitude 5 or greater are shown as red dots. The higher probability area to the southeast is the Eastern Tennessee seismic zone. Other significant areas near the parkway include the Central Virginia seismic zone and the Giles County seismic zones. Shenandoah National Park, Blue Ridge Parkway, and Great Smoky Moutnains National Park are delineated in pink. Data do not include the 2011 Virginia earthquake (https://earthquake.usgs.gov/earthquakes/eventpage/se609212#executive). Graphic generated using the US Geological Survey earthquake probability mapping program (no longer available online).

- Virginia Division of Mined Land Reclamation website: https://www.dmme.virginia.gov/dmlr/dmlrlandingpage.shtml.
- North Carolina Geological Survey mineral resources website: https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey/mineral-resources.
- North Carolina Geological Survey mine and karst collapse website: https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey/geologic-hazards/ground-collapse-old-mines-and-prospects-and-sinkholes.
- NPS inventory of AML sites and features: Burghardt et al. (2014).
- NPS AML website (http://go.nps.gov/aml)

Figure 19. Photographs of AML features.
Small-scale mines, pits, and prospects are located in the heights of the Blue Ridge. Carter et al. (2016) documented many AML features, including these iron workings. Photographs from Carter et al. (2016) annotated by Trista L. Thornberry-Ehrlich (Colorado State University).

Disturbed Lands Restoration and Structural Integrity of the Parkway

Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by development, including facilities, military bases, roads, dams, and abandoned campgrounds; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; overuse; or inappropriate use. Some of these features may be of historical significance, but most are not in keeping with the mandates of the National Park Service. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities. Restoration activities return a site, watershed, or landscape to some previous condition, commonly some desirable historic baseline. According to the parkway's general management plan (National Park Service 2013), lands within the parkway include disturbed/engineered areas to be managed or restored per their designated management zone (e.g., special natural resources, scenic character, and recreation). Each zone has defined tolerances for human disturbance, resource protection, and cultural resource impacts. Through the parkway's preferred ecosystem-based approach, geologic resources and soils would receive added attention such as realigning erosion-prone trails. If parkway managers denote an area as zoned "natural" (e.g., Julian Price Park), this would require visitor impacts to be lowered and degraded areas to be restored.

The parkway's natural resource condition assessment (Sundin et al. 2013) identified landscape change (particularly in lands adjacent to parkway boundaries) among potential threats and stressors to natural resources. Additionally, deterioration of critical road infrastructure and facilities was identified as a key issue for the parkway (National Park Service 2016). The roadway itself has about 320 km (200 mi) that have not received needed asphalt rehabilitation in more than 30 years, thereby presenting hazards such as potholes and eroding shoulders for parkway users. Eroding roadway edges are also exacerbated by inefficient or derelict drainage systems. Two hundred drive-by vistas and overlooks, wildflower display areas, and other features have been lost due to the inability to perform regular roadway maintenance, including removal of vista-obscuring trees on slopes below the parkway (National Park Service 2016; Mark Carter, US Geological Survey, geologist, written communication, 21 July 2018). Recently, neighboring communities and partner organizations have provided funds for vista restoration which requires skilled arborists working with the original Park Land Use Maps designed for the parkway (National Park Service 2019).

The parkway's foundation document identifies the following data needs: guidance for hardening road edges, visual resource inventory, and land-use changes GIS layer. A preservation and maintenance plan, as well as planning for adaptation to climate change are high priority needs identified in the foundation document (National Park Service 2016).

Resources and References

In addition to data included in the GRI GIS data set and ancillary map information documents, the following references provide additional background information. The list is organized from top (park-specific) to bottom (general):

- NPS Erosion website: https://www.nps.gov/subjects/erosion/index.htm.
- NPS Climate Change Response Program website (https://www.nps.gov/orgs/ccrp/index.htm)

Paleontological Resource Inventory, Monitoring, And Protection

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). All fossils are nonrenewable. Body fossils are any remains of the actual organism such as bones, teeth, shells, or leaves. Trace fossils are evidence of biological activity; examples include burrows, tracks, or coprolites (fossil dung). Fossils in NPS areas occur in rocks or unconsolidated deposits, museum collections, and cultural contexts such as building stones or archeological resources. As of July 2020, 276 parks had documented paleontological resources in at least one of these contexts. Blue Ridge Parkway has documented fossils in limited contexts given the great age (most of the rocks within the parkway formed prior to the evolution of hard-bodied organisms) and pervasive deformation and metamorphism of the bedrock, which tends to obliterate any fossil remains. Fossils are known from the Chilhowee Group (Neoproterozoic to Lower Cambrian) as trace fossils of *Skolithos* (trace fossil consisting of vertical, cylindrical burrow; fig. 20), and the occasional trilobite (Santucci et al. 2008; Merschat et al. 2008a; Carter et al. 2016). The discovery of fossils in archeological contexts and unconsolidated deposits has potential. The parkway's museum collection includes some 2,400 geological specimens some of which may contain fossils (National Park Service 2013)

Santucci et al. (2008) prepared a paleontological resource summary for the parks of the Appalachian Highlands Network, including Blue Ridge Parkway. The summary was compiled through extensive literature reviews and interviews with park staff and professional geologists and paleontologists, but no field-based investigations was conducted. Resource-management recommendations from Santucci et al. (2008) for the parkway included the following:

- Undertake interviews with the geologists or paleontologists who are knowledgeable about Blue Ridge Parkway geology whenever possible. These interviews should be documented and archived.
- Park staff should continue to be made aware of the potential for discovery of fossil material during other field work or construction activities, particularly along road cuts, stream banks, gullies, and other erosional features within the parkway.
- Any documentation of paleontological localities at Blue Ridge Parkway can be considered as potential sites for future paleontological resource monitoring.

Resources and References

In addition to data included in the GRI GIS data set and ancillary map information documents, the following references provide additional background information. The list is organized from top (park-specific) to bottom (general):

- Paleontological resource summary of the Appalachian Highlands Network: Santucci et al. (2008).
- Common fossils of Virginia website: https://www.dmme.virginia.gov/DGMR/fossils.shtml.
- The NPS Fossils and Paleontology website: http://go.nps.gov/fossils_and_paleo
- *Geological Monitoring* chapter about paleontology (Santucci et al. 2009; see http://go.nps.gov/geomonitoring) described the following methods and vital signs for monitoring in situ fossils: (1) rates of erosion (geologic variables), (2) rates of erosion (climatic variables), (3) "catastrophic" geologic hazards or processes, (4) hydrology and bathymetry, and (5) human impacts.
- A summary of National Park Service fossils in a cultural resource context: Kenworthy and Santucci (2006)
- Celebrate National Fossil Day every October; search for partners in Virginia and North Carolina: https://www.nps.gov/subjects/fossilday/index.htm.

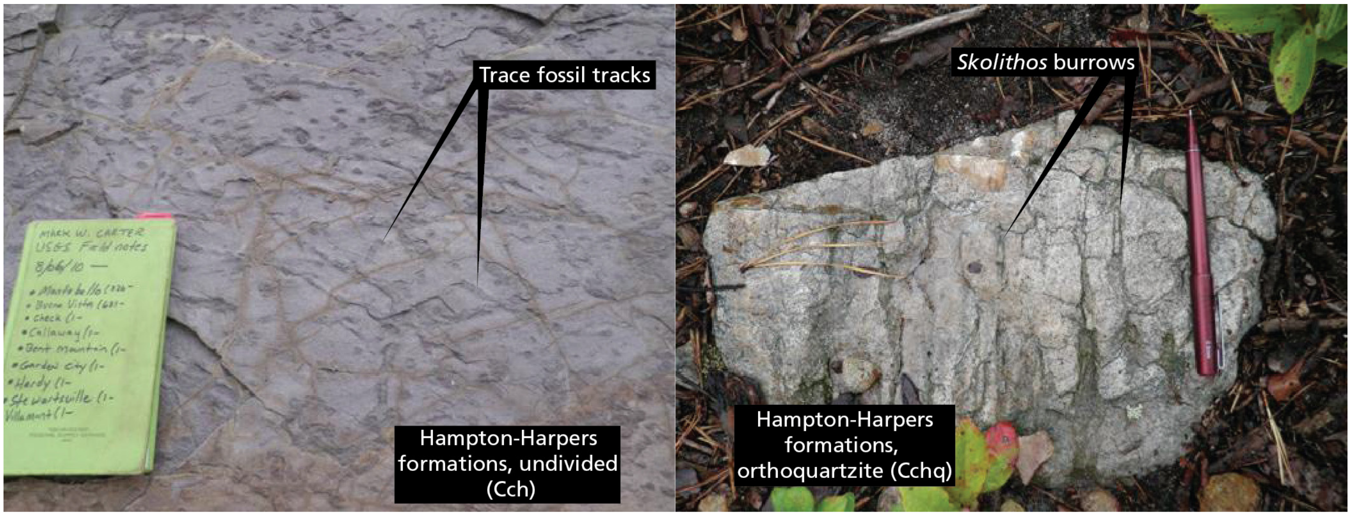


Figure 20. Photographs of trace fossils in sandstone.
Most of the bedrock in the parkway is too old, deformed, or metamorphosed to retain many fossil resources; however, burrows and other trace fossils are possible in float (blocks dislodged from their location of provenance) or outcrops from the Chilhowee Group. Photographs of geologic observation localities VM-86 and VM-119 from Carter et al. (2016) annotated by Trista L. Thornberry-Ehrlich (Colorado State University).

Blue Ridge Parkway Segments

Resource managers divide the parkway into segments (see fig. 5). The following discussion does the same, briefly describing each segment and the geologic units (listed generally from oldest to youngest) exposed within parkway boundaries and their connections with natural features, other GRI GIS data (e.g., radiometric age localities, mine point features, and geologic sample localities), cultural features, geologic hazards, and other geologic issues. Listing of features is generally north to south. Definitions of geologic terms used in a table are included in the table notes.

The Virginia and the North Carolina portions of the parkway were mapped at different times by different geologists. GRI GIS data for the North Carolina portion of the parkway is of an older vintage than that of the Virginia portion, resulting in some differences in nomenclature. For example, the Alligator Back Formation (Early Paleozoic and Neoproterozoic) of the Virginia data is referred to as the Alligator Back Metamorphic Suite (Neoproterozoic) in the North Carolina data. The US Geological Survey restricts the use of the Ashe Formation and Alligator Back Formation. Newer terminology defines these formations as metamorphic suites. Therefore, the Ashe Formation is equivalent to the Ashe Metamorphic Suite and the Alligator Back Formation is equivalent to the Alligator Back Metamorphic Suite (Mark Carter, US Geological Survey, geologist, written communication, 21 July 2018). The use of Lynchburg Formation is also changed to Ashe Formation for some units in more recent mapping. GRI GIS data for the North Carolina portion also includes surficial geologic map units and geologic hazards information. Both portions feature thousands of geologic attitude observation localities such as orientations of fold axes, joints, faults, mineral fabrics, and bedding. In addition to the reports accompanying the GRI GIS data with hundreds of annotated photographs, recent primary references for geologic information along the parkway in Virginia and North Carolina include Lillie (1999), Carter et al. (2001, 2013, 2017), Carter and Merschat (2014), and Pazzaglia et al. (2015). Many of the minerals listed in the descriptions are described at the NPS Geologic Resources Division rocks and minerals subject pages: https://www.nps.gov/subjects/geology/rocks-and-minerals.htm. Symbols of geologic time and unit groupings are detailed in the "Geologic Setting" section of this report. Definitions of the some of the geologic terms used in the tables are listed at the end of this section.

Segment 1—Ridge, Mileposts 0–106 (Virginia)

Segment 1 (Ridge) begins at the southern end of Shenandoah National Park at Rockfish Gap. Deep mountain forests, climbing and descending narrow ridgetops, and punctuating gaps characterize the Ridge segment. The bedrock in this segment is primarily Mesoproterozoic metamorphic and igneous rocks folded into the regional-scale Blue Ridge anticlinorium capped by younger metasedimentary and metavolcanic rocks (table 5). The bedrock's distribution is complicated by faults that juxtapose units of different ages and types. South of the James River, the Chilhowee Group and Mesoproterozoic basement rocks are part of the hanging wall for the Blue Ridge thrust fault. Mapped in the GRI GIS data for the Ridge segment are high-angle reverse faults, high-angle normal faults, left-lateral strike-slip faults, right-lateral high-angle normal faults, left-lateral high-angle normal faults, low-angle thrust faults. Large-scale, named faults include Snowden fault (high-angle normal fault), Bearwallow Gap fault (high-angle reverse fault and left-lateral high-angle normal fault), and the Blue Ridge fault (low-angle thrust fault). Bedrock exposures are abundant and recorded as 170 geologic photograph localities and 520 geologic observation localities in the GRI GIS data (see blrn_geology.pdf). Prehistoric sites abound, particularly in the Peaks of Otter area.

Table 5. Summary of geologic connections in the Ridge segment (MP 0–106).

Colors correspond to the GRI GIS data blrn_geology.mxd. See maps in figs. 1a and 5.

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Migmatite gneiss (**Ymg**)	• **Ymg** is a highly deformed metamorphic rock with some prominent garnets locally. • Irish Gap.
Megacrystic alkali-feldspar gneiss (**Yqg**)	• **Yqg** occurs as xenoliths in younger units. • Indian Gap, Licklog Springs Gap, Otter Creek.
Granitic gneiss (**Yg**)	• **Yg** is strongly banded or foliated. • Robinson Gap, Roundtop.
Lineated granitoid gneiss (**Ylgg**)	• **Ylgg** is interlayered with **Yllg**. • Petites Gap, Thunder Hill (highest Virginia parkway elevation: 1,204 m [3,950 ft]), Onion Mountain overlook, Wilkerson Gap. • Radiometric age locality.
Garnetiferous leucogneiss (**Yglg**)	• **Yglg** may have originated in a felsic volcano; contains prominent garnets, 1 cm (0.4 in) in diameter. • Powell Gap, Bearwallow Gap.
Porphyroblastic garnet-biotite leucogranitic gneiss (**Ygtg**)	• **Ygtg** has "spotty" garnet bands and is interlayered with **Yllg** and **Yg.** • Boston Mountain, Humphreys Gap, Licklog Springs Gap, Roundtop. • Radiometric age locality. • Slopes near Licklog Springs Gap are prone to slope processes (fig. 21).
Dioritic gneiss (**Ydg**)	• **Ydg** may have originated as intrusive dikes and silts, and basalt-like flows. • Whites Gap, Thunder Hill (highest Virginia parkway elevation: 1,204 m [3,950 ft]), Fallingwater cascades, Wilkerson Gap.
Leucogranitic gneiss (**Yllg**)	• **Yllg** is the most extensive Mesoproterozoic unit in the Blue Ridge Parkway corridor and is intruded by, and occurs as, xenoliths in all other Mesoproterozoic rock units in Virginia. • Irish Gap, Boston Mountain, Clarks Gap, Otter Creek, Thunder Hill (highest Virginia parkway elevation: 1,204 m [3,950 ft]), Onion Mountain overlook.
Megacrystic granodioritic gneiss (**Ygg**)	• **Ygg** contains large potassium feldspar clasts and xenoliths of **Yqg.** • Boston Mountain, Boston Knob.
Megacrystic alkali-feldspar metagranitoid (**Yqm**)	• **Yqm** contains prominent alkali-feldspar crystals. • Meadow Mountain, Round Mountain, Tye River Gap, Wigwam Falls, Yankee Horse Ridge where cross-cutting relationships in granitoids are exposed. • Granitoids in this segment were mined or prospected for tin, gold, lead, copper, arsenic, rubidium, silver, and thorium.
Megacrystic metagranitoid (**Ypgm**)	• **Ypgm** occurs as plutons, laccoliths, plugs, dikes, and sills that cut older rocks. • Peaks of Otter (Sunset Hill, Harkening Hill), Peaks of Otter Lake (Abbott Lake). • Johnson Farm (homestead of early residents who helped develop local tourism) designated a special cultural resource at the parkway; target for rehabilitation. • Radiometric age locality.
Mesocratic porphyritic metagranitoid (**Ygpm**)	• **Ygpm** occurs as small xenoliths within **Ypom.** • Radiometric age locality.

Table 5, continued. Summary of geologic connections in the Ridge segment (MP 0–106).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Metagranodioritoid (**Ygdm**)	• **Ygdm** occurs as stocks, plutons, plugs, dikes, and sills. • Meadow Mountain, Wigwam Falls. • Radiometric age locality.
Vesuvius megaporphyritic metagranitoid (**Yvm**)	• **Yvm** contains prominent alkali-feldspar crystals. • Irish Creek.
Quartz-feldspar leucocratic metagranitoid (**Yqfm**)	• **Yqfm** occurs as dikes and sills that cut older rocks, as well as two xenoliths within **Ypom**. • Peaks of Otter (Sharptop Mountain, Buzzards Roost). • Radiometric age locality.
Peaks of Otter metagranitoid (**Ypom**)	• **Ypom** occurs as a large pluton. • Peaks of Otter (The Pinnacle, Flat Top Mountain, Sharptop Mountain, Buzzards Roost), Peaks of Otter Lake (Abbott Lake). • Peaks of Otter type location—igneous origin is indicated by pegmatite dikes with identical mineral assemblage. • Saunders Farm (ruins of an African-American homestead near the picnic area) designated a special cultural resource at the parkway; target for rehabilitation. • Radiometric age locality.
Garnetiferous quartzo-feldspathic gneiss and pegmatite (**Yprg**)	• **Yprg** contains abundant pale red-purple garnets some of which are up to a few mm in diameter. • Radiometric age locality.
Greenstone (**Zdm**)	• **Zdm** occurs locally as narrow dikes (see fig. 10) and sills that intrude older Mesoproterozoic rocks. **Zdm** contains unakite (a semiprecious stone). • Harkening Hill.
Swift Run Formation (**Zsr**)	• **Zsr** consists of thin quartzite, conglomerate, laminated slate, and pebbly pyroclastic slate. • Irish Creek.
Catoctin Formation, metasandstone (**Zcs**)	• **Zcs** represents fluvial channel-fill deposits in **Zcb.** • Rockfish Gap, from the Afton overlook the Catoctin Formation is visible on the west limb of the Blue Ridge anticlinorium looking east, the highly deformed rocks of the Rockfish Valley high-strain zone crop out in the valley below the overlook.
Catoctin Formation, metabasalt (**Zcb**)	• **Zcb** contains vesicles, breccias, columnar joints, and pillow structures (see fig. 10). • Rockfish Gap, Elk Mountain, Humpback Gap, Humpback Rocks or "The Rocks," Greenstone trail, Ravens Roost, Laurel Springs Gap, Round Mountain. • Greenstone overlook: visible columnar jointing (formed as the ancient basalt flows cooled and contracted). • Mountain Farm (re-created subsistence homestead that represents regional architecture of the 19th and early 20th centuries): hog enclosures occur on **Zcb** near Mountain Farm. • Howardsville Turnpike (historic road trace that provided a link between the Rockfish and South Rivers). • Mine point feature: a greenstone quarry.
Catoctin Formation, metamudstone and phyllite (**Zcm**)	• Elk Mountain. • Howardsville Turnpike (historic road trace that provided a link between the Rockfish and South Rivers). • Reeds Gap.
Chilhowee Group: Lower Chilhowee Group, undivided (**CZcl**)	• **CZcl** contains metagraywacke, quartzite, metaconglomerate, and phyllite. Includes rocks previously mapped as **CZcu** and **Ccw**. • Otter Creek. • Howardsville Turnpike (historic road trace that provided a link between the Rockfish and South Rivers). • Whetstone Ridge may be named for the extremely hard, resistant quartzite beds within **CZcl**, which may have provided whetstone material.

Table 5, continued. Summary of geologic connections in the Ridge segment (MP 0–106).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Chilhowee Group: Unicoi Formation (**CZcu**)	• **CZcu** is heterogeneous containing phyllite, metamudstone, metasiltstone, metagraywacke, metaconglomerate, and locally interlayered metabasalt. • White Rock Gap, Whites Gap, Humphreys Gap, Otter Creek, Bearwallow Gap. • 20-Minute Cliff (in the months of June and July, sun shining off this north–south-oriented cliff alerted residents of White Rock of impending dusk).
Chilhowee Group: Weverton Formation (**Ccw**)	• **Ccw** is quartzite and metaconglomerate. • Whites Gap, Humphreys Gap, Otter Creek, Goblets Gap, Purgatory overlook, Harveys Knob, Blackhorse Gap, Great Valley overlook at 760 m (2,493 ft) above sea level. • Faults and pervasive fractures cause this unit to fall downslope near Whites Gap (see fig. 7).
Chilhowee Group: Hampton-Harpers formations, orthoquartzite (**Cchq**)	• **Cchq** contains quartzite and ***Skolithos*** (trace fossil consisting of vertical, cylindrical burrow). • Otter Creek.
Chilhowee Group: Hampton-Harpers formation, undivided (**Cch**)	• **Cch** contains sandstone, quartzite, and ***Skolithos***. • Bald Mountain, Otter Creek, Bearwallow Gap, Blackhorse Gap, Blue Knob, Curry Gap. • Mine point features: five hematite adits or shafts, one iron adit or prospect. • Rockfall and slumping possible in outcrops of **Cch** (fig. 22).
Chilhowee Group: Antietam Formation (**Cca**)	• **Cca** contains quartzite and ***Skolithos***. • Torry Ridge. • Scree slopes (fig. 23) and stone streams commonly form in **Cca** as a result of slope processes.
Waynesboro Formation (**Cw**)	• **Cw** is mudstone, sandstone, and siltstone, with some conglomerate and algal (fossil algae) limestone. • Mine point features: one limonite prospect, one iron adit or prospect.
Elbrook Formation (**Ce**)	• **Ce** is primarily dolomite to algal (fossil algae) limestone. • Roanoke Valley edge.
Mylonite (**PZmy**)	• **PZmy** is a heterogeneous unit with a banded or ribboned appearance that is the result of intense deformation within other, older rocks. • **PZmy** defines the Rockfish Valley, Peaks of Otter, and Powell Gap high-strain zones. • Otter Creek, Otter Lake, James River (lowest elevation on the parkway: 198 m [649 ft]), Battery Creek canal lock, Battery Creek, Peaks of Otter (Sunset Hill), Peaks of Otter Lake (Abbott Lake).
Diabase (**Jd**)	• **Jd** is present in dikes and tends to weather to produce round boulders. • Otter Creek.

Figure 21. Photograph of eroding slope near Licklog Springs Gap.
Bedrock unit is leucogneiss (Ygtg) with a dike of intruding nelsonite (arrow). Photograph of geologic observation locality BV-72 from Carter et al. (2016) annotated by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 22. Photograph of well-bedded and strongly cleaved bedrock adjacent to the parkway. Deformation fabrics and bedding can contribute to instability when aligned parallel to a slope. Bedrock unit is Hampton-Harpers Formation, undivided (Cch). Photograph of geologic observation locality BI-49 from Carter et al. (2016) annotated by Trista L. Thornberry-Ehrlich (Colorado State University).

Segment 2—Roanoke, Mileposts 106–136 (Virginia)

Approaching Roanoke, the largest urban area along the parkway, the character of the landscape changes from narrow, linear ridges to more open rolling hills and valleys. Management and interpretation of this segment of the parkway shifts towards land use through time and current issues of natural resource protection in the face of urban development. Like the Ridge segment, faults crisscross the Roanoke segment with high-angle normal faults, left-lateral high-angle normal faults, right-lateral low-angle thrust faults, and low-angle thrust faults mapped in the GRI GIS data. Of these, named faults include Masons Knob fault (right-lateral low-angle thrust fault), Mowles Springs fault (right-lateral high-angle thrust fault), Garden City fault (high-angle normal fault), and Blue Ridge fault (low-angle thrust fault). The Mowles fault has recorded several minor (less than magnitude [M] 3.1) earthquakes since 2000 (Carter et al. 2017). The bedrock in this segment is often deeply weathered and/or covered by surficial deposits but is primarily Mesoproterozoic metamorphic and igneous rocks capped by younger metasedimentary and sedimentary rocks (table 6). Bedrock exposures are recorded as 14 geologic photograph localities and 140 geologic observation localities in the GRI GIS data (see blrn_geology.pdf).

Table 6. Summary of geologic connections in the Roanoke segment (MP 106–136).

Colors correspond to the GRI GIS data blrn_geology.mxd. See maps in figs. 1b and 5.

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Bottom Creek metagranitoid (**Ybcm**)	• **Ybcm** contains feldspar crystals up to 10 cm (4 in) long. • Roanoke Valley overlook, Slings Gap, Lancaster Gap, Adney Gap at 814 m (2,670 ft). • Radiometric age locality.
Sandy Creek gneiss (**Yscg**)	• **Yscg** contains quartz, feldspar, pyroxene, garnet, hornblende, and biotite minerals.
Garnetiferous leucogneiss (**Yglg**)	• **Yglg** may have originated in a felsic volcano; contains prominent garnets, 1 cm (0.4 in) in diameter. • Blue Ridge southern end. • Radiometric age locality.
Dioritic gneiss (**Ydg**)	• **Ydg** may have originated as intrusive dikes and sills, and lava flows. • Blue Ridge southern end, Roanoke River gorge.
Leucogranitic gneiss (**Yllg**)	• **Yllg** is the most extensive Mesoproterozoic unit in the Blue Ridge Parkway corridor and is intruded by and occurs as xenoliths in all other Mesoproterozoic rock units in Virginia. • Roanoke River gorge, Roanoke River (elevation 300 m [985 ft]; more than 60 m [200 ft] higher than the James River crossing). • Mayflower Hills Park.
Massive metagranitoid (**Ymgm**)	• **Ymgm** contains bands showing uralitization (crystals of pyroxene slowly change to amphibole). • Roanoke River gorge, Roanoke River (elevation 300 m [985 ft]; more than 60 m [200 ft] higher than the James River crossing).
Greenstone (**Zdm**)	• **Zdm** occurs locally as narrow dikes (see fig. 10) and sills that intrude older Mesoproterozoic rocks. • **Zdm** contains unakite (a semiprecious stone).
Chilhowee Group: Lower Chilhowee Group, undivided (**CZcl**)	• **CZcl** contains metagraywacke, quartzite, metaconglomerate, and phyllite. Includes rocks previously mapped as **CZcu** and **Ccw**. • Roanoke Mountain, Lancaster Gap.
Chilhowee Group: Hampton-Harpers formation, undivided (**Cch**)	• **Cch** contains sandstone, quartzite, and Skolithos (trace fossil consisting of vertical, cylindrical burrow). • Chestnut Ridge, East Ridge. • Mine point features: iron mines.
Chilhowee Group: Antietam Formation (**Cca**)	• **Cca** contains quartzite and Skolithos. • Chestnut Ridge, East Ridge. • Mine point features: iron mines. • Scree slopes (fig. 23) and stone streams commonly form in this unit as a result of slope processes.

Table 6, continued. Summary of geologic connections in the Roanoke segment (MP 106–136).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Quartz tectonite (**Ccq**)	• **Ccq** is strongly foliated and likely derived from **Cca**, **Ce**, or **Cw**; associated with faults.
Shady Dolomite (**Cs**)	• **Cs** contains dolomite, interlayered with limestone, and calcareous shale. • Mine point features: crushed stone quarry, iron mines.
Waynesboro Formation (**Cw**)	• **Cw** is mudstone, sandstone, and siltstone, with some conglomerate and algal (fossil algae) limestone. • Coyner Mountain overlook (looks west), N&W Railroad overlook (looks east), Blue Ridge southern end. • Blue Ridge Park.
Elbrook Formation (**Ce**)	• **Ce** is primarily dolomite to algal (fossil algae) limestone. • Blue Ridge Park.
Mylonite (**PZmy**)	• **PZmy** is a heterogeneous unit with a banded or ribboned appearance that is the result of intense deformation within other, older rocks. • Slings Gap, Lancaster Gap, Adney Gap at 814 m (2,670 ft). • **PZmy** defines the Fries high-strain zone (anastomosing faults and mylonite zones); displacement estimates along this episodically reactivated structure range from 30 km (18 mi) to as much as 100 km (60 mi).
Diabase (**Jd**)	• **Jd** is present in dikes and tends to weather to produce round boulders.

Figure 23. Photograph of scree slope.
Slope processes cause accumulations of blocks of resistant quartzite from the Antietam Formation (Cca). Photograph is from Big Levels and not in the Roanoke segment of the parkway but is meant to be representative of geologic features found in the Roanoke segment. Photograph of geologic observation locality BL-369 from Carter et al. (2016).

Segment 3—Plateau, Mileposts 136–217 (Virginia)

The character of the landscape changes once again as the parkway climbs out of the Roanoke Valley (part of the Valley and Ridge physiographic province) and across the great plateau that overlooks Virginia's piedmont towards the North Carolina border. Traveling south, the base of the Plateau segment starts at milepost 128 near Metz Run overlook. Once on top of the Plateau at milepost 135 south of Poor Mountain overlook near Adney Gap, the landscape changes to rolling hills, bucolic settings, and isolated hills and knobs. The bedrock changes in the Plateau segment as well, from being dominated by Mesoproterozoic basement rocks and younger cover rocks to metamorphic rocks of the Lynchburg Group, Ashe Formation, and Alligator Back Formation (table 7). These units are interpreted to have originated as rocks that were squeezed between colliding continents. Throughgoing faults are prominent in this segment, juxtaposing bedrock units of different types and ages. Named faults are Red Valley fault (right-lateral low-angle thrust fault between Devils Backbone and Pine Spur overlooks), Callaway fault (right-lateral low-angle thrust fault near milepost 151), Shortts Knob fault (left-lateral low-angle thrust fault near milepost 156), Haycocks fault (left-lateral low-angle thrust fault near milepost 161), and Rock Castle Creek fault (high-angle reverse fault that crosses the parkway at Rock Castle Gap near milepost 174). The Red Valley fault or ductile deformation zone is the boundary between Mesoproterozoic basement rocks and younger, overlying metasedimentary and metaigneous rocks of the eastern Blue Ridge. Along the parkway, the Callaway fault juxtaposes rocks assigned to the Lynchburg Group against rocks of the Ashe Formation. The Shortts Knob fault is a zone of several faults that cuts through a high concentration of ultramafic rock bodies. The Rock Castle Creek fault separates the Alligator Back Formation from the Ashe Formation rocks (Carter et al. 2017). Bedrock exposures are a frequent site along this stretch of the parkway as evidenced by 69 geologic photograph localities and 585 geologic observation localities in the GRI GIS data.

Table 7. Summary of geologic connections in the Plateau segment (MP 136–217).

Colors correspond to the GRI GIS data blrn_geology.mxd. See maps in figs. 1b and 5.

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Biotite leucogneiss (**Yblg**)	• **Yblg** appears mylonitic in areas and occurs as xenoliths in younger gneisses. • Mine point features: crushed stone quarry. • Radiometric age locality.
Blue-quartz gneiss (**Ybqg**)	• **Ybqg** has distinctive augen ("eyes") of blue to gray quartz. • Radiometric age locality.
Biotite granitic augen gneiss (**Ybgg**)	• **Ybgg** is intruded by **Zgm** and **Ymlg** and contains xenoliths of **Yblg.** • Boat Rock Hollow, Snuffers Ridge, Devils Backbone overlook (**Ybgg** is well-exposed here). • Mine point features: flagstone quarry.
Biotite-muscovite leucogneiss (**Ymlg**)	• **Ymlg** intrudes **Ybgg** and has a strong foliated (banded) appearance. • Radiometric age locality.
Bottom Creek metagranitoid (**Ybcm**)	• **Ybcm** contains feldspar crystals up to 10 cm (4 in) long.
Sandy Creek gneiss (**Yscg**)	• **Yscg** contains quartz, feldspar, pyroxene, garnet, hornblende, and biotite minerals. • Radiometric age locality.
Noritic jotunite and nelsonite (**Yjn**)	• **Yjn** consists of noritic jotunite (orthopyroxene, clinopyroxene, plagioclase, and hornblende) and nelsonite (ilmenite, apatite, rutile, zircon, magnetite, pyroxene, amphibole) as dikes, sills, and small laccoliths. • Nelsonite dikes were historically mined for phosphate. • Nelsonite is named for rocks near Piney River and Roseland in Nelson County, Virginia.
Metagranitoid (**Zgm**)	• **Zgm** consists of small plutons, stocks, and a few dikes, most too small to accurately separate and map.
Greenstone (**Zdm**)	• **Zdm** occurs locally as narrow dikes (see fig. 10, BM-51) and sills that intrude older Mesoproterozoic rocks. **Zdm** contains unakite (a semiprecious stone).
Ashe Formation, conglomeratic metagraywacke (**Zacm**)	• **Zacm** contains abundant sheared pebbles of quartz and feldspar. • Dodd Creek, The Saddle, Rockcastle Gorge. • Rakes Millpond, Rockcastle Gorge settlement.

Table 7, continued. Summary of geologic connections in the Plateau segment (MP 136–217).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Lynchburg Group: Quartz-layered amphibolite (**CZamq**)	• **CZamq** contains distinctive layers, lenses, pods, stringers, and boudins of quartz and feldspar; **CZamq** has several generations of folds.
Lynchburg Group: Clinozoisite-bearing amphibolite (**CZamc**)	• **CZamc** contains several textural and mineralogical varieties of amphibolite. • Shortts Knob
Lynchburg Group: Biotite-bearing amphibolite (**CZamb**)	• **CZamb** consists primarily of hornblende, feldspar, and varying amounts of biotite interlayered locally with graphitic schist, mica schist, mica-bearing metagraywacke, and quartz-rich metasandstone. • Cannaday Gap. • Kelley School House.
Lynchburg Group: Graphitic schist (**CZgs**)	• **CZgs** shows graphite- and mica-rich layers alternating with quartz-rich layers. • Graphitic schist is acid-producing. • Rocky Knob at 1,089 m (3,572 ft), The Saddle, Grassy Knoll.
Lynchburg Group: Graphite-muscovite-quartz metasandstone (**CZms**)	• **CZms** is locally interlayered with graphitic schist, muscovite schist, and amphibolite. • Grassy Knoll.
Lynchburg Group: Muscovite-biotite metagraywacke (**CZmg**)	• **CZmg** contains garnet, muscovite, biotite, quartz, and feldspar. **CZmg** is likely correlative to the Ashe Formation. • Meadow Creek, Tuggles Gap. • Kelley School House, Harris Farm.
Altered ultramafic and ultrabasic rocks (**PZZum**)	• **PZZum** is primarily altered, low-silica rocks high in talc, amphibole, and serpentine minerals. • Altered ultramafic rock ("soapstone") was mined extensively for use in nearby Floyd, Virginia, beginning in 1849. • Shortts Knob; overlook exposes **PZZum**, as well as Rocky Knob at 1,089 m (3,572 ft) above sea level. • The highest concentration of ultramafic rock bodies occur as dismembered pods mantled by amphibolite and may be of ophiolitic (oceanic crust) origin.
Alligator Back Formation*: Marble (**PZZabm**)	• **PZZabm** occurs as small lenses within **PZZabs.**
Alligator Back Formation*: Quartz and quartz-rich metasandstone (**PZZabq**)	• **PZZabq** is deformed by several generations of folds. • Twelve O'Clock Knob, Willis Gap, Wards Gap, Fancy Gap, Flint Ridge.
Alligator Back Formation*: Laminated amphibolite gneiss (**PZZabl**)	• **PZZabl** is distinctly thin layered with dark biotite- and hornblende-rich bands alternating with light seams of quartz and feldspar. • Twelve O'Clock Knob, New Brammer Spur, Willis Gap, Linard Creek. • Mabry Mill.
Alligator Back Formation*: Garnet-biotite-muscovite-quartz schist (**PZZabs**)	• **PZZabs** contains garnet crystals as much as 1 cm (0.3 in) in diameter. • New Brammer Spur, Big Laurel Creek, Fancy Gap, Groundhog Mountain at 925 m (3,035 ft) above sea level, Pipers Gap at 841 m (2,759 ft) above sea level, Linard Creek, Flint Ridge. • Blue Ridge Music Center.
Alligator Back Formation*: Layered biotite-muscovite gneiss (**PZZabg**)	• **PZZabg** shows thin layers defined by aligned mica- and quartz-rich bands, all of which have been folded several times. • New Brammer Spur, Big Laurel Creek, Volunteer Gap, Orchard Gap, Elk Spur, Groundhog Mountain at 925 m (3,035 ft) above sea level, Linard Creek, Fisher Peak Mountain (fig. 24), West Fork Chestnut Creek. • Puckett Cabin, Blue Ridge Music Center. • Mine point features: stone quarry.

Figure 24. Photograph of view from Fisher Peak.
From the heights of the Blue Ridge, visitors to the parkway have dramatic views toward the Piedmont to the east and Great Valley to the west. Fisher Peak is underlain by units such as the Alligator Back Formation (PZZabg). Photograph of geologic observation locality LB-226 from Carter et al. (2016).

Segment 4—Highlands, Mileposts 217–305 (North Carolina)

Stretching from the Virginia–North Carolina state line to south of Blowing Rock at Grandfather Mountain, the Highlands segment winds through high mountain pastures on some of the oldest constructed segments of the parkway. The natural integrity of this segment lends a feeling of getting away from it all with diverse views of adjacent knobs, narrow ridges, the Blue Ridge escarpment edge at Cumberland Knob, and deep forests. Grandfather Mountain features some of the most significant natural habitat and rare species in the southern Appalachians. Bedrock of the Alligator Back (type locality at Alligator Back overlook, named so for "ribs" of gneiss radiating from the crest of Bluff Mountain) and Ashe Metamorphic Suites dominate the northern part of this segment, changing to metamorphosed volcanic and sedimentary rocks of the Grandfather Mountain Formation at the southern end (table 8). These rocks originated as sediments that were later uplifted, deformed, and metamorphosed during the construction of the Appalachian Mountains (see "Geologic History" chapter). They may be older than the Alligator Back and Ashe Metamorphic Suites (Bart Cattanach, North Carolina Geological Survey, geologist, written communication, 21 August 2018). Much older Mesoproterozoic basement rocks are exposed near Blowing Rock. Faults are less prevalent in the map data for the Highlands segment compared to the northern part of the parkway. Faults traverse the corridor and include faults with unknown offset/displacement as well as thrust faults. Named faults are the Linville Falls fault (thrust fault—marks the outline of the Grandfather Mountain window) and the Fries fault (thrust fault). Geologic hazards data include acid-producing rock potential which transitions from moderate to low as the segment stretches from north to south. Along the Highlands segment, 187 geologic observation localities attest to the abundant bedrock and surficial features. Two geologic cross sections provide a view of a slice through the mountains that illustrate the structures and relationships contributing to the today's landscape (see GRI GIS data and blrs_geology.pdf document).

Table 8. Summary of geologic connections in the Highlands segment (MP 217–305).

Colors correspond to the GRI GIS data blrs_geology.mxd. See maps in figs. 1c and 5.

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Mesoproterozoic Metaplutonic Rocks: Blowing Rock Gneiss, mylonitic (**Ybrgmy**)	• **Ybrgmy** contains the same rocks as **Ybrg**, but with a pervasive deformation that appears as very fine foliations (bands). • Raven Rocks (differential weathering along joints and foliation cause mass wasting to create cliffs and overhangs), Thunder Hill (overlook has exposures of basement complex rocks, including a surveyor's benchmark), Flat Top Branch, Bass Lake. • Julian Price and Moses H. Cone Memorial Parks. • The Grandfather Mountain window exposes **Ybrgmy.** • Geologic hazards: one debris flow. • Two geologic sample localities.

Table 8, continued. Summary of geologic connections in the Highlands segment (MP 217–305).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Mesoproterozoic Metaplutonic Rocks: Blowing Rock Gneiss (**Ybrg**)	• **Ybrg** includes distinctive potassium feldspar augen ("eyes") and is interlayered with biotite gneiss, amphibolite, and phyllonite. • Story Branch, Thunder Hill (overlook has exposures of basement complex rocks, including a surveyor's benchmark), Flat Top Branch, Middle Fork South Fork New River, Bass Lake. • Julian Price and Moses H. Cone Memorial Parks. • The Grandfather Mountain window exposes **Ybrg.** • Geologic hazards: one visible sulfide location. • Two geologic sample localities.
Mesoproterozoic Metaplutonic Rocks: Granitic gneiss (**Yggn**)	• **Yggn** is metamorphosed plutonic granite in layers as thin as a few centimeters or as thick as tens of meters. • East Fork South Fork New River. • Daniel Boones Trace. • One geologic sample locality.
Grandfather Mountain Formation: Siltstone and mafic volcanics (**Zgfsm**)	• **Zgfsm** is metamorphosed layers of siltstone and mafic (silica-poor) volcanic rocks. • Flat Top Mountain, Raven Rocks (differential weathering along joints and foliation cause mass wasting to create cliffs and overhangs), Moses Cone. • Julian Price and Moses H. Cone Memorial Parks. • The Grandfather Mountain window exposes **Zgfsm.** • Geologic hazards: one debris flow. • Two geologic sample localities.
Grandfather Mountain Formation: Siltstone (**Zgfs**)	• **Zgfs** has slaty cleavage (tends to break into thin, planar sheets). • Martin Knob, Price Lake (impounded Boone Creek). • Julian Price and Moses H. Cone Memorial Parks. • The Grandfather Mountain window exposes **Zgfs.** • Geologic hazards: two debris flows. • One geologic sample locality.
Grandfather Mountain Formation: Felsic volcanics (**Zgfv**)	• **Zgfv** has some scant pyrite (popularly referred to as "fool's gold"). • East Fork South Fork New River, Flat Top Mountain. • Julian Price and Moses H. Cone Memorial Parks. • The Grandfather Mountain window exposes **Zgfv.** • Geologic hazards: one debris flow. • Two geologic sample localities.
Grandfather Mountain Formation: Metaconglomerate (**Zgfc**)	• **Zgfc** is conglomerate with clasts as large as boulders (fig. 25). • Buck Knob, Black Rock Cliffs Cave. • Julian Price and Moses H. Cone Memorial Parks, Grandfather Mountain State Park, Linn Cove Viaduct (379-m- [1,243-ft-] long structure traverses a steeply sloping boulder field, in which shallow caves are formed). • The Grandfather Mountain window exposes **Zgfc.** • Geologic hazards: three debris flows.
Grandfather Mountain Formation: Feldspathic metagraywacke (**Zgfg**)	• **Zgfg** features more feldspar than typical graywackes. • Rich Mountain, Green Knob, Bull Mountain, Boot Camp Branch, Price Lake (impounded Boone Creek), Pigpen Knob, Cold Prong, Ash Bearpen Knob, Green Mountain. • Julian Price and Moses H. Cone Memorial Parks, Grandfather Mountain State Park. • The Grandfather Mountain window exposes **Zgfg.** • Geologic hazards: two debris flows, one rockslide and flow.
Alligator Back Metamorphic Suite*: Amphibolite (**Zaba**)	• **Zaba** is nearly all dark hornblende and light plagioclase and quartz. • Little Glade Millpond ("pinstriped" gneiss exposures), Bluff Ridge, Fire Scald Mountain. • Brinegar Cabin (some **Zaba** stones were used as part of the early construction), EB Jeffress Park. • Geologic hazards: three visible sulfide locations, one rockslide, one debris subsidence location.

Table 8, continued. Summary of geologic connections in the Highlands segment (MP 217–305).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Alligator Back Metamorphic Suite*: Mica schist (**Zabs**)	• **Zabs** contains nearly 50% muscovite (a shiny, flaky mica mineral). • Cumberland Knob, High Piney Spur, Big Pine Creek, Deep Gap (eastern continental divide), Air Bellows Gap at 1,156 m (3,792 ft) above sea level, Bluff Ridge, Flat Rock Ridge. • Cumberland Knob Recreation Area, Fox Hunters Paradise, view of the Blue Ridge escarpment. • Schist from **Zabs** was used in building cabin foundations, chimneys, and stepped walkways of this segment; small-scale mica mines occur in this unit (Carter et al. 2001). • Geologic hazards: one debris subsidence location. • One geologic sample locality.
Alligator Back Metamorphic Suite*: Schistose metagraywacke (**Zabsi**)	• **Zabsi** appears "pinstriped" with alternating dark and light layers. • Low Piney Spur, Big Pine Creek, Little Glade Millpond ("pinstriped" gneiss exposures), Mahogany Rock Mountain (overlooks the Ararat River synclinal fold structure), Air Bellows Gap at 1,156 m (3,792 ft) above sea level, Bluff Mountain at 1,554 m (5,100 ft) above sea level, Alligator Back, Cedar Ridge, Bell Ridge, Flat Rock Ridge, Grassy Gap, Alder Gap, Sheets Gap, Miller Gap, Meditation Mountain, Daniels Gap, Benge Gap. • Cumberland Knob Recreation Area, Northwest Trading Post (near Ore Knob copper mine), Jumpinoff Rock at 983 m (3,225 ft) above sea level is a good location to see the Blue Ridge escarpment, EB Jeffress Park. • Gneiss from **Zabsi** was used in building overlooks of this segment. • Wildcat Rocks (once the site of an animal den); Ice Rocks (cliffs covered in winter with sheets of ice). • Geologic hazards: three debris subsidence locations, one rockfall, 15 debris flows, four visible sulfide locations, one rockslide and flow, one debris slide, two rockslides. • One geologic sample locality.
Alligator Back Metamorphic Suite*: Metagraywacke (**Zabg**)	• **Zabg** is a "dirty" sandstone, meaning it is approximately half quartz with abundant secondary mineral components. • **Zabg** is more mica-rich than metagraywackes of the Ashe Metamorphic Suite. • Cumberland Knob, Big Pine Creek, Brush Creek, Little Glade Creek, Air Bellows Gap at 1,156 m (3,792 ft) above sea level, Bluff Mountain at 1,156 m (3,792 ft) above sea level, Cedar Ridge, Hanging Valley, Dark Hollow, Bell Knob, Flat Rock Ridge, Flat Rock Knob, Alder Gap, Horse Gap, Meditation Mountain, Phillips Gap, Pine Swamp Creek, Husons Ridge. • Cumberland Knob Recreation Area, EB Jeffress Park, Cascades trail. • Geologic hazards: one rockfall, three visible sulfide localities, three debris slides, one rockslide, one debris slide and flow, 13 debris flows. • Two geologic sample localities.
Neoproterozoic Metaplutonic Rocks, Linville Metadiabase (**Zl**)	• **Zl** occurs as intrusive bodies (e.g., dikes and sills) in other, older rocks (Grandfather Mountain Formation) and is poorly exposed. • Boot Camp Branch. • Julian Price (**Zl** is exposed under a clump of oak trees next to the barn) and Moses H. Cone Memorial Parks, Grandfather Mountain State Park.
Migmatitic gneiss (**PZmg**)	• **PZmg** is a deformed result of local melting during metamorphism that resulted in bodies, lenses, and vein-like areas; **PZmg** is gradational with coarse-grained pegmatite. • Gillam Gap, The Lump, Calloway Gap, Thomkins Knob, Husons Ridge, Firescald Mountain, Deep Gap, Carroll Gap. • EB Jeffress Park, Cascades trail, and a knickpoint along the Blue Ridge escarpment (Cascades of Falls Creek). • Geologic hazards: one rockslide, three visible sulfide locations, 13 debris flows, four debris slides and flows, one debris slide. • One geologic sample locality.

Table 8, continued. Summary of geologic connections in the Highlands segment (MP 217–305).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Debris, undifferentiated (**Qdu**)	• **Qdu** is the most widespread surficial unit in the Blue Ridge province, lining some valleys and filling lower areas. • **Qdu** is compositionally similar to **Qdf** but lacks a distinctive lobe or fan shape. • Cumberland Knob Recreation Area, EB Jeffress Park, Julian Price and Moses H. Cone Memorial Parks.
Debris fan (**Qdf**)	• **Qdf** contains deposits derived from slope movements and possibly streamflow that occurs in a lobe, fan, or coalescing fan shape. • Julian Price and Moses H. Cone Memorial Parks.
Block stream (**Qbs**)	• **Qbs** is a linear accumulation of boulders and angular blocks of rock with little to no fine-grained component.

Figure 25. Photograph of potential rockfall area above the parkway.
Blocks of bedrock are poised unstably over portions of the parkway. The most dangerous areas are those in which a fabric within the bedrock parallels or is undercut by the slope. The rock is metasandstone from the Grandfather Mountain Formation near Rough Ridge. Photograph is part of photomosaic GFMR-001 from Merschat et al. (2008a).

Segment 5—Black Mountain, Mileposts 305–377 (North Carolina)

The Black Mountain segment of the parkway was named for the rugged peaks that include the highest mountain east of the Mississippi River, Mount Mitchell, which towers at 2,037 m (6,684 ft) above sea level; Mount Mitchell is outside the parkway boundary. The Black Mountain segment climbs and descends ridgetops and gaps while winding through globally imperiled high-elevation spruce/fir forest communities. Adjacent Pisgah National Forest protects natural views of the valleys below the parkway. Of particular geologic interest in this segment is the Museum of North Carolina Minerals with more than 300 specimens from across the state. The park hires an interpreter with a geologic background to talk about the minerals on display (Bambi Teague, Blue Ridge Parkway, chief of natural resources, conference call, 16 May 2018). The museum's building itself is faced with rocks from the Grandfather Mountain Formation, with walkways and fountains constructed from quarried Alligator Back Formation rocks. A variety of metamorphic rocks composing the Ashe and Alligator Back Metamorphic Suites dominate the bedrock of this segment, and the parkway leaves the Grandfather Mountain window by crossing the Linville Falls fault (table 9). Four thrust faults are mapped in the Black Mountain segment. Of these, named faults are the Linville Falls fault and the Table Rock fault (located within the Grandfather Mountain window thrusting younger Chilhowee Group rocks [**Ccu**, **Ccp**, **Ccl**] over older granitic gneiss [**Yggmy**, **Yggn**]). Debris avalanches scar the Black Mountains, scouring everything down to bedrock in their path and leaving large deposits at the base of the slopes. Slope failures are a significant hazard in this segment (Carter et al. 2001). Geologic hazards data include acid-producing rock potential which transitions from low to moderate from northeast to southwest. Seventy geologic observation localities along the Black Mountain segment attest to the abundant bedrock and surficial features. One geologic cross section line (A–A') across this segment provides a view of a slice through the Great Craggy Mountains. Between Craggy Gardens and Mount Mitchell is an abandoned mine; the parkway managers are considering actions to prevent trespass and mineral collection (Bambi Teague, Blue Ridge Parkway, chief of natural resources, conference call, 16 May 2018).

Table 9. Summary of geologic connections in the Black Mountain segment (MP 305–377).

Colors correspond to the GRI GIS data blrs_geology.mxd. See maps in figs. 1d and 5.

*The Tallulah Falls Formation is quasi-equivalent to the Ashe Metamorphic Suite (i.e., the rocks are the same; Mark Carter, US Geological Survey, geologist, written communication, 21 July 2018).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Mesoproterozoic Metaplutonic Rocks: Amphibolite (**Ya**)	• **Ya** contains dark bands of hornblende and black opaque minerals alternating with light bands of plagioclase, quartz, and epidote.
Mesoproterozoic Metaplutonic Rocks: Mylonitic granitic gneiss (**Yggmy**)	• **Yggmy** has prominent mylonites (deformation zones) amidst foliated (banded) gneiss. • Camp Creek, Linville River (mylonite near the Upper Linville Falls marks the Linville Falls fault, where rocks were deformed by heat and pressure into thin bands). • Blue Ridge Parkway spur, Chestoa View overlook (overview of the Grandfather Mountain window).
Mesoproterozoic Metaplutonic Rocks: Granitic gneiss (**Yggn**)	• **Yggn** is metamorphosed plutonic granite in layers as thin as a few centimeters or as thick as tens of meters. • One geologic sample locality. • Linville River (gneiss forms the prominent rock ledge of the Upper Linville Falls over the metasandstone **Ccu**).
Grandfather Mountain Formation: Siltstone (**Zgfs**)	• **Zgfs** has slaty cleavage (tends to break into thin, planar sheets). • Camp Creek. • The Grandfather Mountain window exposes **Zgfs.**
Grandfather Mountain Formation: Metaconglomerate (**Zgfc**)	• **Zgfc** is conglomerate with clasts as large as boulders. • One geologic sample locality. • The Grandfather Mountain window exposes **Zgfc.** • Flat Rock trail displays exposures of the rounded quartz pebbles and other resistant rocks in the original conglomerate rock; circular depressions on Flat Rock are weathering pits formed by erosion (solution, frost action, and abrasion) focused along cracks or fractures.

Table 9, continued. Summary of geologic connections in the Black Mountain segment (MP 305–377).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Grandfather Mountain Formation: Feldspathic metagraywacke (**Zgfg**)	• **Zgfg** features more feldspar than typical graywackes. • Geologic hazards: one rockfall. • The Grandfather Mountain window exposes **Zgfg.** • Beacon Heights, Grandmother Gap, Deep Gap. • The north portal of the Little Switzerland tunnel, building stones for the restaurant and store at Crabtree Meadows, and the overpass at Buck Creek Gap are formed from hewn blocks of **Zgfg.**
Ashe Metamorphic Suite*: Tallulah Falls Formation, metagraywacke (**Zag**)	• **Zag** is a heterogeneous mixture of quartz, plagioclase, biotite, muscovite, garnet, epidote, hornblende, and other minerals. • **Zag** has mica-rich schist interlayered with less metaconglomerate. • Geologic hazards: one rockfall, three debris flows, seven rockslides, three debris slides, six rockslide and flows, two debris subsidences. • 26 geologic observation localities; one geologic sample locality; 13 visible sulfide localities. • Green Knob (outcrop here shows reddish brown [iron oxide] and black [manganese oxide] stains resulting from weathering of the bedrock), Deep Gap, Hemphill Creek, Cherry Log Ridge, Black Mountain Gap (northeast corner of the Asheville watershed and entrance to the Black Mountains), Balsam Gap (boundary between the Black and Great Craggy Mountains), Walker Knob, Locust Ridge, Bullhead Mountain, Bullhead Gap, Craggy Dome, Pinnacle Gap, Craggy Gardens, Craggy Knob, Bearpen Gap, Wolfpen Knob, High Swan. • The erosional resistance of the metagraywacke supports the high topography of the Black Mountains.
Ashe Metamorphic Suite*:Tallulah Falls Formation, gneissic metagraywacke (**Zagg**)	• **Zagg** is coarsely foliated (banded) into light and dark, mica-rich layers. • Geologic hazards: two rockfalls, one debris slide, two rockslides and flows. • Six geologic observation localities; five visible sulfide localities. • Rich Knob, Rocky Knob, Bull Mountain, Bull Gap.
Ashe Metamorphic Suite*:Tallulah Falls Formation, schistose metagraywacke (**Zagsi**)	• **Zagsi** locally contains iron sulfide minerals, pyrrhotite, and pyrite (popularly referred to as "fool's gold"). • Geologic hazards: two rockslides, one debris slide, one debris slide and flow. • Eight geologic observation localities; four visible sulfide localities. • Black Mountain Gap, Locust Knob, Bullhead Mountain, Bullhead Gap, Pinnacle Gap, Bearpen Knob. • Craggy Dome overlook shows outcrops of rocks full of garnets and kyanite, two minerals used to determine the conditions (heat and pressure) of metamorphism.
Ashe Metamorphic Suite*:Tallulah Falls Formation, garnet mica schist **(Zas)**	• **Zas** is very micaceous and has local sulfide-rich layers. • Geologic hazards: two rockfalls, one rockslide, two rockslides and flows, one debris and rock, slide and fall. • Nine geologic observation localities; one geologic sample locality; six visible sulfide localities. • Hemphill Creek, Cherry Log Ridge, Bald Knob, Walker Knob, Craggy Pinnacle (kyanite in the vicinity of Craggy Pinnacle is among the gems and minerals targeted by collectors, illegally, in 2012), Craggy Gardens (slanting trees here indicate the wind gap), Craggy Knob, Bearpen Gap, Lone Pinnacle, Rice Knob.
Ashe Metamorphic Suite*:Tallulah Falls Formation, sillimanite/kyanite schist (**Zass**)	• The kyanite and sillimanite in **Zass** indicate high pressure metamorphism. • One geologic sample locality; one geologic observation locality. • Blue kyanite in the vicinity of Craggy Pinnacle is among the gems and minerals targeted by collectors, illegally, in 2012.
Ashe Metamorphic Suite*:Tallulah Falls Formation, megacrystic muscovite schist (**Zams**)	• **Zams** is nearly half mica with crystals as large as 3 cm (1 in) in diameter. • One geologic sample locality; two geologic observation localities. • Local mica mines are reflected in local features such as Glass Rock Knob and Glassmine Branch and Falls. The mica was once called "isinglass" and used as a heat-resistant material for furnace and oven-door windows.

Table 9, continued. Summary of geologic connections in the Black Mountain segment (MP 305–377).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Ashe Metamorphic Suite*:Tallulah Falls Formation, graphitic two-mica schist **(Zags)**	• **Zags** contains graphite, the same mineral used in pencil leads. • Geologic hazards: one debris slide, one rockslide and flow. • Two visible sulfide localities. • Craggy Dome overlook.
Ashe Metamorphic Suite*:Tallulah Falls Formation, metaconglomerate (**Zac**)	• **Zac** is nearly all quartz and feldspar. • Two geologic observation localities, one geologic sample locality.
Ashe Metamorphic Suite*:Tallulah Falls Formation, amphibolite (**Zaa**)	• **Zaa** is very rich in hornblende, foliated with plagioclase and other minerals. • One geologic sample locality.
Ashe Metamorphic Suite*:Tallulah Falls Formation, altered ultramafic rock (**Zaua**)	• **Zaua** is a very low-silica rock consisting of olivine, pyroxenes, plagioclase, and alteration minerals such as serpentine, tremolite, talc, vermiculite, chlorite, and hornblende. • Geologic hazards: one rockslide and flow. • One geologic observation locality, one geologic sample locality, one visible sulfide locality.
Alligator Back Metamorphic Suite*: Amphibolite (**Zaba**)	• **Zaba** is nearly all dark hornblende and light plagioclase and quartz. • Geologic hazards: one rockslide, two rockslides and flows. • One geologic sample locality, two visible sulfide localities. • Gillespie Gap, Stony Knob, Three Knobs (outcrop at overlook [fig. 26] shows thinly layered nature of the local rock prized by builders for decorative facing stone), Horse Gap, Osborn Knob. • Nettle Patch, Crabtree Falls (**Zaba** forms the face of the falls).
Alligator Back Metamorphic Suite*: Metasomatic schistose metagraywacke (**Zabsim**)	• **Zabsim** has some very coarse flaky mica crystals that are attributed to contact metamorphism from nearby igneous intrusions. • Geologic hazards: one debris flow, one rockslide. • Three visible sulfide localities. • Bear Den (roadcuts expose large mica flakes).
Alligator Back Metamorphic Suite*: Mica schist (**Zabs**)	• **Zabs** contains nearly 50% muscovite (a shiny, flaky mica mineral). • Geologic hazards: two debris flows, one debris slide, one rockslide; foliation in the schist slopes steeply into the road surface causing dip-slope failures. • One geologic observation locality; one geologic sample locality; five visible sulfide localities; three net neutralization potential localities. • Deer Lick Gap, Horse Gap, Buck Creek Gap, Horsetrail Gap.
Alligator Back Metamorphic Suite*: Schistose metagraywacke (**Zabsi**)	• **Zabsi** appears “pinstriped” with alternating dark and light layers. • Geologic hazards: three rockfalls. • One geologic sample locality; five visible sulfide localities. • Grassy Mountain, Bearwallow Gap, Coots Gap.
Alligator Back Metamorphic Suite*: Metagraywacke (**Zabg**)	• **Zabg** is a “dirty” sandstone, meaning it is approximately half quartz with abundant secondary mineral components. • **Zabg** is more mica-rich than metagraywackes of the Ashe Metamorphic Suite. • Geologic hazards: one debris flow, one rockfall (fig. 27), four rockslides, two debris slides, one rockslide and flow. • Three geologic sample localities, three geologic observation localities, eight visible sulfide localities, three net neutralization potential localities. • Heffner Gap, McKinney Gap, Swafford Gap, Gillespie Gap, Lynn Gap, Sandy Gap, Grassy Mountain, Bearwallow Gap, Osborn Knob, Big Laurel Gap, Flinty Gap. • Altapass, Overmountain Victory National Historic Trail, Museum of North Carolina Minerals, Little Switzerland (exit bridge constructed from local roadcuts), Crabtree Falls (eastern continental divide between Crabtree Creek and Armstrong Creek), Green Knob overlook.
Neoproterozoic Metaplutonic Rocks, Linville Metadiabase (**Zl**)	• **Zl** occurs as intrusive bodies (e.g., dikes and sills) in other, older rocks and is poorly exposed.

Table 9, continued. Summary of geologic connections in the Black Mountain segment (MP 305–377).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Chilhowee Group: Lower Chilhowee Quartzite (**Ccl**)	• **Ccl** is nearly three-quarters quartz grains interlayered with feldspar-rich layers, metasiltstone, slate, and quartz pebble conglomerate. • **Ccl** includes Skolithos (trace fossil consisting of vertical, cylindrical burrow). • One geologic sample locality. • The Grandfather Mountain window exposes **Ccl.** • Camp Creek.
Chilhowee Group: Chilhowee Phyllite (**Ccp**)	• **Ccp** is flaky phyllite and contains sericite, quartz, chlorite, and minor accessory minerals. • The Grandfather Mountain window exposes **Ccp.** • Camp Creek.
Chilhowee Group: Upper Chilhowee Quartzite (**Ccu**)	• **Ccu** contains slightly less quartz than **Ccl** with similar interlayers. • **Ccu** includes Skolithos. • One geologic sample locality, one geologic observation locality. • The Grandfather Mountain window exposes **Ccu.** • Camp Creek, Linville River. • Blue Ridge Parkway spur.
Migmatitic gneiss (**PZmg**)	• **PZmg** is a deformed result of local melting during metamorphism that resulted in bodies, lenses, and vein-like areas; **PZmg** is gradational with coarse-grained pegmatite. • Geologic hazards: one rockslide, two rockslides and flows. A rockslide in 2003 closed the parkway south of Potato Field Gap for a week; potential causes included heavy rainfall, frost wedging, and sulfide-mineral weathering (see discussion of CPR-001, p. 26, in blrs_geology.pdf). • Six geologic observation localities, three visible sulfide localities. • Beetree Gap, Potato Field Gap.
Pegmatite (**PZpeg**)	• **PZpeg** consists of coarse-grained intrusive rocks that cut across older rocks in lenticular to tabular bodies. • In the past, pegmatite was locally mined for feldspar, ultra-high pure quartz, and mica (Spruce Pine District near Gillespie Gap).
Composite block field, block stream and talus (**Qc**)	• **Qc** includes talus, block field, and block stream deposits found in upslope areas.
Colluvium, undifferentiated (**Qcu**)	• **Qcu** consists of slope movement deposits that mantle hillsides and lack distinctive fan or lobe shapes. • Colluvium is a general term (for these maps) applied to slope deposits that show no apparent emplacement mechanism (slope creep is typically assigned to these deposits).
Talus (**Qt**)	• **Qt** refers to rocks of any size or shape, derived from and laying at the base of a slope.
Debris, undifferentiated (**Qdu**)	• **Qdu** is the most widespread surficial unit in the Blue Ridge province, lining some valleys and filling lower areas. • **Qdu** is compositionally similar to debris fans (**Qdf**) but lacks a distinctive lobe or fan shape.
Block field (**Qbf**)	• **Qbf** is an accumulation of boulders or angular rock blocks with little or no finer grained material. • Block fields usually occur on high mountain slopes but without a cliff or a ledge above as an apparent source of material.
Block stream (**Qbs**)	• **Qbs** is a linear accumulation of boulders and angular blocks of rock with little to no fine-grained component.

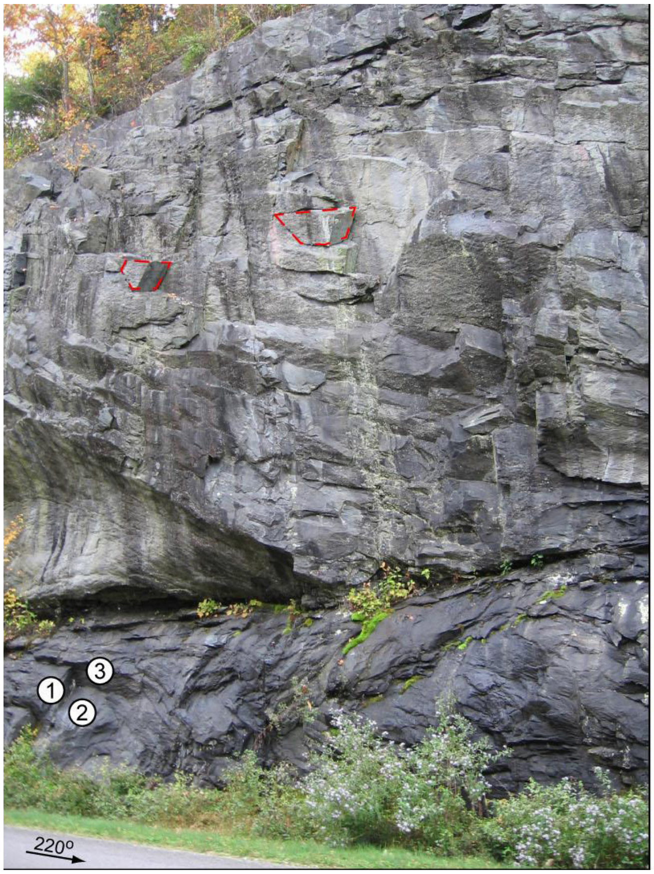


Figure 26. Photograph of amphibolite at Three Knobs overlook.
Amphibolite is part of the Alligator Back Metamorphic Suite (Zaba). Red dashed areas indicate potential rockfall zones. Numbers (1, 2, 3) refer to geologic attitude observation measurements taken at the outcrop. Graphic is part of photomosaic CER-007 from Merschat et al. (2008a).

Figure 27. Photograph of huge rockfall blocking the Blue Ridge Parkway.
On 15 June 1999, a rockslide covered the parkway, causing its closure for several days. The rock is metagraywacke from the Alligator Back Formation (Zabg) near Crabtree Meadows. Arrow and azimuth, which are part of original graphic, indicate direction N63°E. Graphic is part of photomosaic CER-001 from Merschat et al. (2008a).

Segment 6—Asheville, Mileposts 377–394 (North Carolina)

The Asheville segment runs through the second largest urban area after Roanoke. Unlike the Roanoke corridor, however, the Asheville segment encompasses an urban forest with few views of the city landscape besides crossing over city streets, rivers, and streams. Cultural and visitor use centers feature prominently in this segment, including the Blue Ridge National Heritage Area and the North Carolina Arboretum. The bedrock of this segment consists only of the Ashe Metamorphic Suite, including metagraywacke and flaky schist (table 10). The Asheville basin forms the largest intermontane basin in the Blue Ridge province, an area of about 1,000 km^2 (400 mi^2) (Carter et al. 2001). Anticlinal folds are visible in the metagraywacke but are not mapped in the GRI GIS data. No faults, cross sections, or mine features are mapped in the Asheville segment. Geologic hazards include acid-producing rock potential, which is moderate for the entire Asheville segment.

Table 10. Summary of geologic connections in the Asheville segment (MP 377–394).

Colors correspond to the GRI GIS data blrs_geology.mxd. See maps in figs. 1d and 5.

*The Tallulah Falls Formation is quasi-equivalent to the Ashe Metamorphic Suite (i.e., the rocks are the same; Mark Carter, US Geological Survey, geologist, written communication, 21 July 2018).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Ashe Metamorphic Suite*: Tallulah Falls Formation, metagraywacke (**Zag**)	• **Zag** is a mixture of quartz, plagioclase, biotite, muscovite, garnet, epidote, hornblende, and other minerals. • **Zag** has mica-rich schist and metaconglomerate interlayers. • Geologic hazards: three rockfalls, one debris slide, three rockslides and flows, two rockslides. • Nine sulfide observation localities. • One geologic sample locality. • Hemphill Knob, Gashes Creek, French Broad River (an entrenched Mississippi River tributary that is cutting 120 to 150 m [400 to 500 ft] down through an older former basin floor).
Ashe Metamorphic Suite*: Tallulah Falls Formation, schistose metagraywacke (**Zagsi**)	• **Zagsi** locally contains iron sulfide minerals, pyrrhotite, and pyrite (popularly referred to as "fool's gold"). • Geologic hazard: one rockfall. • One geologic observation locality (fig. 28).
Ashe Metamorphic Suite*: Tallulah Falls Formation, garnet mica schist (**Zas**)	• **Zas** is very micaceous and has local sulfide-rich layers. • Geologic hazards: one debris and earth slide, one rockslide. • One sulfide observation locality. • One geologic sample locality. • Ball Mountain, Riceville, Swannanoa River, Hemphill Knob, Gashes Creek.
Ashe Metamorphic Suite*: Tallulah Falls Formation, sillimanite/kyanite schist (**Zass**)	• The kyanite and sillimanite in **Zass** indicate high pressure metamorphism. • One geologic sample locality. • Hemphill Knob, Gashes Creek.
Debris, undifferentiated (**Qdu**)	• **Qdu** is the most widespread surficial unit in the Blue Ridge Province, lining some valleys and filling lower areas. • **Qdu** is compositionally similar to debris fans (**Qdf**) but lacks a distinctive lobe or fan shape. Debris flows are mapped in the Bent Creek Forest adjacent to the parkway.

Figure 28. Photographs of a rockslide near Town Mountain Road.
On 14 April 2005, a rockslide sent blocks of schistose metagraywacke (Zagsi) tumbling down the steep slope leaving a bare scarp above. The lower image is a close-up view of the scarp, as indicated by the black arrow. Graphic is part of photomosaic CPR-102 from Merschat et al. (2008a).

Segment 7—Pisgah, Mileposts 394–469 (North Carolina)

Rising some 610 m (2,000 ft) out of the French Broad River valley and Asheville basin, the Blue Ridge Parkway passes through nine tunnels and returns to remote natural areas with views of high mountains. The parkway passes through the Pisgah and Nantahala National Forests, the Shining Rock Wilderness, and ancestral lands of the Eastern Band of Cherokee American Indians before ending at Great Smoky Mountains National Park. More than half of the Pisgah segment is designated as a special natural resource (National Park Service 2013). This segment includes critically globally imperiled high-elevation spruce/fir forest and the highest point along the parkway at Richland Balsam (1,843 m [6,047 ft] above sea level), the summit of the Great Balsam Range. The bedrock of this segment is primarily Ashe Metamorphic Suite metagraywacke transitioning westward into older Mesoproterozoic gneiss before the last exposures of metagraywacke, schist, and quartzite of the Great Smoky and slightly older Snowbird Groups(table 11). Eleven fault traces are mapped in this segment, including thrust faults and faults of unknown offset/displacement. Named faults of this segment include the Holland Mountain-Chattahoochee, the Soque River, the Hayesville, and the Greenbrier faults; these faults accommodated westward movement of metamorphosed sedimentary rocks over the Mesoproterozoic basement during the construction of the Appalachian Mountains. Geologic hazards include areas of acid-producing rock potential that transitions from moderate for the first half of the segment to alternating bands of high and low after the prominent change in parkway direction to the northwest near Mount Hardy Gap. In this segment, 203 visible sulfide localities are significant because their presence may increase weathering in the bedrock (see "Geologic Hazards: Slope Movements" section). In addition, 148 geologic observation localities along the Black Mountain segment attest to the abundant bedrock and surficial features. No cross sections were included in the GRI GIS data for this segment.

Table 11. Summary of geologic connections in the Pisgah segment (MP 394–469).

Colors correspond to the GRI GIS data blrs_geology.mxd. See maps in figs. 1e and 5.

* The Tallulah Falls Formation is quasi-equivalent to the Ashe Metamorphic Suite (i.e., the rocks are the same; Mark Carter, US Geological Survey, geologist, written communication, 21 July 2018).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Mesoproterozoic Metaplutonic Rocks, granitic gneiss (southern segment) (**Yggs**)	• **Yggs** contains mylonitized (heavily deformed under hot conditions) zones and biotite granitic gneiss layers. • Fed Cove, Soco Gap. • Jonathan Creek overlook, southern terminus of the Blue Ridge parkway at the Oconaluftee River (exposure with mylonitic deformation texture).
Cartoogechaye Terrane Rocks: Hornblende biotite granitoid gneiss (**ZYbgh**)	• **ZYbgh** includes many minerals: plagioclase, biotite, hornblende, quartz, potassium feldspar, muscovite, garnet, epidote, and accessory minerals. • Standing Rock where a fallen rock about 4 m (13 ft) tall is perched on the side of the mountain.
Cartoogechaye Terrane Rocks: Layered biotite granitic gneiss (**ZYlbgg**)	• **ZYlbgg** contains zircon, a common radiometric dating mineral. • Redbank Branch, Standing Rock where a fallen rock about 4 m (13 ft) tall is perched on the side of the mountain.
Cartoogechaye Terrane Rocks: Amphibolite (**ZYbga**)	• **ZYbga** is dark greenish gray to black rocks, well foliated with lighter mineral layers in layers or pods. • Near Balsam Gap, several younger igneous dikes and biotite-bearing pegmatites (not mapped) intrude the older basement rocks.
Cartoogechaye Terrane Rocks: Biotite granitic gneiss (**ZYbg**)	• **ZYbg** is locally migmatitic, indicating nearly melting conditions during metamorphism and deformation. • Redbank Branch, Balsam Gap marks the boundary between two mountain ranges: Plott Balsams to the south and Great Balsams to the north.

Table 11, continued. Summary of geologic connections in the Pisgah segment (MP 394–469).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Ashe Metamorphic Suite*^: Tallulah Falls Formation, metagraywacke (**Zag**)	• **Zag** is a heterogenous mixture of quartz, plagioclase, biotite, muscovite, garnet, epidote, hornblende, and other minerals. • **Zag** has mica-rich schist and metaconglomerate interlayers. • Geologic hazards: five rockslides, one rockfall, three rockslides and flows, and one debris and rock, slide and flow. • One mineralogical/chemical sample locality. • Shut-in Ridge, Glenn Bald, Lance Mountain, Reynolds Gap, Grassy Knob, Sleepy Gap, Chestnut Cove Gap, Pine Mountain, Bent Creek Gap, Shell Knob, Glady Fork Gap, Stony Bald, Elk Pasture Gap, Bennett Gap, Fork River Bald, Devils Courthouse (migmatitic areas similar to **Zaggm**; so-called cave is a widened joint or fissure). • Pine Mountain tunnel (402 m [1,320 ft] long), Ferrin Knob tunnel No. 1 and No. 2, Young Pisgah Ridge tunnel.
Ashe Metamorphic Suite*^: Tallulah Falls Formation, gneissic metagraywacke (**Zagg**)	• **Zagg** is coarsely foliated (banded)into light and dark, mica-rich layers (fig. 29). • Geologic hazards: five rockslides and flows, eight rockslides, two debris slides, six rockfalls, one debris subsidence, one debris and rockslide, and three debris and rock, slide and falls. • One mineralogical/chemical sample locality. • Two net neutralization potential localities. • Candler Knob, Buck Spring Gap, Buck Spring, Little Bald Mountain, Flat Laurel Gap, Big Bald, Fryingpan Gap, Wagon Road Gap (outcrops of typical "marble cake" mica gneiss and migmatitic zones), Pigeon Gap, Green Knob, Second Falls, Oaklog Gap, Chestnut Bald, Beech Gap, Tanassee Bald, Mount Hardy Gap, Herrin Knob, Mount Hardy, Wolf Bald, Buckeye Gap, Horsebone Gap, Parker Knob, Haywood Gap, Rough Butt Bald, Bearpen Gap, Spot Knob, Little Bearpen Gap, Reinhart Gap. • Little Pisgah Ridge tunnel, Buck Spring tunnel.
Ashe Metamorphic Suite*^: Tallulah Falls Formation, migmatitic gneissic metagraywacke (**Zaggm**)	• **Zaggm** was deformed and heated to partial melting conditions. • One mineralogical/chemical sample locality. • Cherry Gap, Chestnut Ridge, Tunnel Gap, South Spring Top, Bridges Camp Gap, Seniard Mountain.
Ashe Metamorphic Suite*^: Tallulah Falls Formation, mylonitic gneissic metagraywacke (**Zaggmy**)	• **Zaggmy** was strongly deformed under intense heat and pressure conditions as indicated by mylonitic textures and deformed or recrystallized garnets.
Ashe Metamorphic Suite*^: Tallulah Falls Formation, amphibolitic metagraywacke (**Zaga**)	• **Zaga** includes prominent dark and light layers with a variety of metamorphic textures including migmatitic zones and foliation. • One mineralogical/chemical sample locality. • Geologic hazards: two rockfalls, one rockslide and flow. • Yellowstone Falls occurs ata knickpoint caused by uplift and intense erosion of the land surface; the falls were named for the yellowish stain caused by chemical weathering of iron-bearing minerals.
Ashe Metamorphic Suite*^: Tallulah Falls Formation, schistose metagraywacke (**Zagsi**)	• **Zagsi** locally contains iron sulfide minerals, pyrrhotite, and pyrite (popularly referred to as "fool's gold"). • Geologic hazards: two debris flows, two rockslides, one rockslide and flow. • Shut-in Ridge, Glenn Bald, Lance Mountain, Reynolds Gap, Sleepy Gap, Chestnut Cove Gap, Elk Pasture Gap, Candler Knob, Seniard Mountain. • Young Pisgah Ridge tunnel, Little Pisgah Ridge tunnel.
Ashe Metamorphic Suite*^: Tallulah Falls Formation, garnet mica schist **(Zas)**	• **Zas** is very micaceous and has local sulfide-rich layers. • Geologic hazards: three rockfalls, one rockslide, one debris slide. • Bennett Gap, Shuck Ridge, Chestnut Bald, Devils Courthouse (migmatitic areas similar to **Zaggm**; so-called cave is a widened joint or fissure), Beech Gap, Herrin Knob, Buckeye Gap, Haywood Gap.
Ashe Metamorphic Suite*^: Tallulah Falls Formation, sillimanite/kyanite schist (**Zass**)	• The kyanite and sillimanite in **Zass** indicate high pressure metamorphism. • Bent Creek Gap.

Table 11, continued. Summary of geologic connections in the Pisgah segment (MP 394–469).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Ashe Metamorphic Suite*^: Tallulah Falls Formation, calc-silicate (**Zacs**)	• **Zacs** has minerals rich in calcium and/or silica including hornblende, diopside, hedenbergite, epidote, garnet, and quartz. • Flat Laurel Gap, Pigeon Gap.
Ashe Metamorphic Suite*^: Tallulah Falls Formation, amphibolite (**Zaa**)	• **Zaa** is very rich in hornblende, as much as 86%, foliated with plagioclase and other minerals. • Reynolds Gap.
Snowbird Group, Longarm Formation (**Zsl**)	• **Zsl** includes massive, buff-colored, cross-bedded (original sedimentary feature) feldspathic quartzite. • Geologic hazards: one rockfall, two rockslides. • Docks Gap. • Plott Balsam overlook, Raven Fork overlook (outcrop with crumbly weathered quartzite), Oconaluftee River overlook.
Great Smoky Group, schist (Zgss)	• **Zgss** is thinly foliated and rich in muscovite, biotite, and quartz. • Geologic hazards: one rockslide, one rockslide and flow. • Wolf Laurel Gap (fault contact between the Snowbird and Great Smoky Groups), Lickstone Ridge, Mollie Gap, Big Witch Gap. • Lickstone tunnel, Lickstone overlook, Mile High overlook, Horsetrough Ridge overlook, Jenkins Ridge overlook, Big Witch tunnel.
Great Smoky Group, schistose metagraywacke (**Zgssi**)	• **Zgssi** has migmatitic layers indicating metamorphism and deformation under intense heat (partial melting) conditions. • Geologic hazards: three rockslides and flows, six rockfalls, seven rockslides, two debris slides. • Two mineralogical/chemical sample localities. • Five net neutralization potential localities. • One breccia observation location. • Cutoff Ridge, Browning Knob, Waterrock Knob, Fed Cove, Bunches Bald, Barnett Knob. • Yellow Face overlook (outcrop with rusty brown and greenish-yellow stains from decomposition of iron-sulfide minerals), Waterrock Knob overlook (exposures of metagraywacke cut by quartz veins and pegmatites), Cranberry Ridge overlook (massive metagraywacke outcrop with black biotite mica), Hornbuckle Valley overlook (schist exposure with garnet [an index mineral] used to determine the temperature and pressure conditions during metamorphism), Fed Cove overlook, Bunches Bald overlook, Bunches Bald tunnel, Thomas Divide overlook, Ballhoot Scar overlook (outcrops with nearly vertical bedding; nearby exposures of **Zsl** feldspathic quartzite separated by the Greenbrier fault).
Great Smoky Group, arkosic metasandstone (**Zgsa**)	• **Zgsa** contains mostly potassium feldspar, quartz, and plagioclase. • Geologic hazards: two rockslides, one rockfall. • Campbell Lick. • Hornbuckle Valley overlook (schist exposure with garnet [an index mineral] used to determine the temperature and pressure conditions during metamorphism), Thunderstruck Ridge overlook.
Great Smoky Group, metagraywacke (**Zgsg**)	• **Zgsg** includes layers of gneissic metagraywacke, calc-silicate, garnet mica schist, and graphitic mica schist. • Geologic hazards: one rockslide, one rockfall. • One mineralogical/chemical sample locality. • One net neutralization potential locality. • Cutoff Ridge, Bunches Gap, Sherill Cove. • Big Witch overlook, Rattlesnake Mountain tunnel, Sherrill Cove tunnel.
Great Smoky Group, granule metaconglomerate (**Zgsc**)	• **Zgsc** contains granules and pebbles of subrounded clear to white quartz, feldspar, finer blue quartz, and some rare lithic (multimineral) fragments. • Geologic hazards: one debris and rock, slide and fall.

Table 11, continued. Summary of geologic connections in the Pisgah segment (MP 394–469).

GRI GIS map units within parkway (map unit symbol)	Natural features, GRI GIS data connections, cultural connections, and/or geologic hazards and issues within parkway boundaries
Otto Formation, calc-silicate (**PZZocs**)	• **PZZocs** includes quartz, plagioclase, amphibole, garnet, epidote, biotite, and accessory minerals. • Geologic hazards: one rockfall, one rockslide, one rockslide and flow. • Flat Gap.
Otto Formation, garnet-mica schist (**PZZos**)	• **PZZos** is silvery gray, mica-rich schist with prominent crystals of sillimanite, garnet, and quartz. • Richland Balsam.
Otto Formation, schistose metagraywacke (**PZZogsi**)	• **PZZogsi** includes iron sulfide minerals, pyrrhotite, and pyrite. • Geologic hazards: one rockslide, one rockfall, one debris slide and flow, one rockslide and flow. • Licklog Gap, Laurel Patch Bald, Deep Gap, Steestachee Bald, Grassy Bald, Wesner Bald, Pinnacle Ridge.
Otto Formation, metagraywacke (**PZZog**)	• **PZZog** has metamorphic layering up to 2 m (6 ft) thick. • Mine point features: Locust Gap prospects. • Geologic hazards: four rockfalls, one rockslide and fall, two rockslides, three rockslide and flows, and one debris and rock, slide and flow. • One net neutralization potential locality. • Reinhart Knob, Beartrail Ridge Gap, Richland Balsam, Richland Gap, Spruce Ridge, Lone Bald, Locust Gap, Long Swag, Old Bald, Flat Gap, Pinnacle Ridge.
Migmatitic gneiss (**PZmg**)	• **PZmg** is a deformed result of local melting during metamorphism that resulted in bodies, lenses, and vein-like areas; **PZmg** is gradational with coarse-grained pegmatite. • Geologic hazards: one rockslide, three rockslides and flows, two rockfalls. • Six geologic observation localities; three visible sulfide localities. • Wagon Road Gap (outcrops of typical "marble cake" mica gneiss and migmatitic zones), Tunnel Gap, Mount Hardy Gap. • Ferrin Knob tunnel No. 2 and No. 3, Park Mountain tunnel.
Colluvium, undifferentiated (**Qcu**)	• **Qcu** consists of slope movement deposits that mantle hillsides and lack distinctive fan or lobe shapes. • Colluvium is a general term (for these maps) applied to slope deposits that show no apparent emplacement mechanism (slope creep is typically assigned to these deposits).
Talus (**Qt**)	• **Qt** refers to rocks of any size or shape, derived from and laying at the base of a slope.
Debris, undifferentiated (**Qdu**)	• Given the high elevation of the parkway in the Blue Ridge province, surficial units are not prevalent, but **Qdu** is the most widespread, lining some valleys and filling lower areas. • **Qdu** is compositionally similar to debris fans (**Qdf**) but lacks a distinctive lobe or fan shape.
Debris fan (**Qdf**)	• **Qdf** is similar to **Qdu** but has a characteristic lobe or fan-shaped form at the base of slopes or emerging from a valley.
Block field (**Qbf**)	• **Qbf** is an accumulation of boulders or angular rock blocks with little to no finer grained material. • Block fields usually occur on high mountain slopes but without a cliff or a ledge above as an apparent source of material.
Block stream (**Qbs**)	• **Qbs** is a linear accumulation of boulders and angular blocks of rock with little to no fine-grained component.

Figure 29. Photographs of mica-rich metagraywacke of the Ashe Metamorphic Suite. Biotite mica grains may be as large as a hand palm (Photo A). At outcrop scale, fractures in the rock pose a rockfall hazard. This outcrop occurs near the Little Pisgah tunnel. Graphic is part of photomosaic DMR-011 from Merschat et al. (2008a).

Definitions of Selected Geologic Terms in Tables 5–11

anticlinorium. A large anticlinal (convex upward) structure of regional extent composed of lesser folds.

augen. Describes large lenticular minerals that are eye-shaped in cross section.

boudinage. A structure in highly deformed sedimentary or metamorphic rocks, in which an originally continuous layer or bed has been stretched, thinned, and broken at regular intervals into bodies resembling "boudins" (sausages).

breccia. A coarse-grained, generally unsorted sedimentary rock consisting of cemented angular clasts more than 2 mm (0.08 in) across.

breccia (volcanic). A coarse-grained, generally unsorted volcanic rock consisting of partially welded angular fragments of ejected material.

dike. A narrow igneous intrusion that cuts across bedding planes or other geologic structures.

felsic. Derived from feldspar+silica to describe an igneous rock having abundant light-colored minerals such as quartz, feldspars, or muscovite; also describes those minerals.

graywacke. A dark gray, firmly indurated, coarse-grained sandstone that consists of poorly sorted angular to subangular grains of quartz and feldspar, with a variety of dark rock and mineral fragments embedded in a compact clayey matrix.

greenstone. A general term for any compact, dark green, altered or metamorphosed basic (low in silica, commonly high in magnesium and iron) igneous rock with a green color due to chlorite, actinolite, or epidote mineral content.

knickpoint. Any interruption or break in slope.

laccolith. A mushroom-shaped pluton that has intruded sedimentary strata and domed up the overlying sedimentary layers.

micaceous. Consisting of, containing, or pertaining to mica; also, resembling mica, for example, a "micaceous mineral" capable of being easily split into thin sheets.

pegmatite. An intrusive igneous rock consisting of exceptionally coarse-grained, interlocking crystals, generally granitic in composition and commonly in irregular dikes, lenses, and veins, especially at the margins of batholiths (large, intrusive, igneous body of rock having an extent of 40 mi2 [100 km2] or more and no known floor).

phyllite. A metamorphic rock, intermediate between slate and mica schist, with minute crystals of graphite, sericite, or chlorite that impart "schistosity" (a silky sheen).

plug. A vertical, pipelike body of magma that represents the conduit to a former vent. Also, a lava-filled crater whose surrounding material has been removed by erosion.

pluton. A deep-seated igneous intrusion.

radiometric age. An age (in years) calculated from the quantitative determination of radioactive elements and their decay products. The preferred term is "isotopic age."

schist. A medium- to coarse-grained, strongly foliated, metamorphic rock with eminently visible mineral grains, particularly mica, which are arranged parallel, imparting a distinctive sheen, or "schistosity," to the rock.

sill. An igneous intrusion that parallels the bedding of preexisting sedimentary rock or the foliation of preexisting metamorphic rock.

stock. A relatively small plutonic body having an extent less than 100 km2 (40 mi2) and no known floor.

stone stream. An accumulation of boulders or angular blocks, with no fine sizes in the upper part, over solid or weathered bedrock, colluvium, or alluvium; usually occurs at the head of a ravine but may extend into forests or fill a valley floor; may exist on any slope angle, but ordinarily not steeper than 40°.

subrounded. A descriptor used to define a clasts overall roughness that falls on the scale between very angular (corners sharp and jagged), angular, sub-angular, sub-rounded, rounded, and well-rounded (corners completely rounded and smooth).

terrane. A fault-bounded body of rock of regional extent, characterized by a geologic history different from that of contiguous terranes or bounding continents.

vesicle. A cavity of variable shape formed by the entrapment of a gas bubble during solidification of lava.

xenolith. A rock particle, formed elsewhere, entrained in magma as an inclusion.

Geologic History

This chapter describes the chronology of geologic events that formed the present landscape.

Mesoproterozoic Era (1.6 billion to 1.0 billion years ago)—Ancient Mountain Building and the Construction of a Foundation

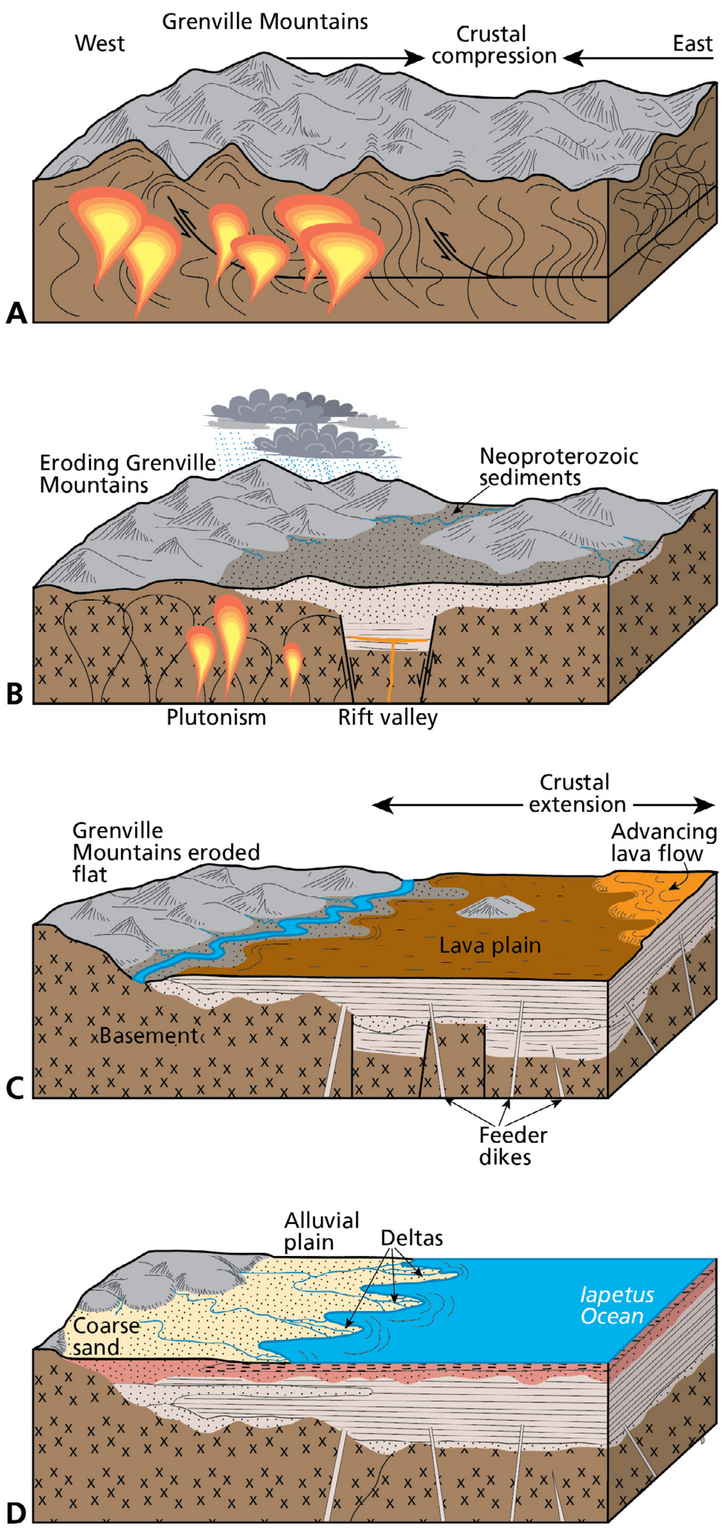
The rocks along the Blue Ridge Parkway contain evidence of geologic events (see table 1) that span more than one billion years of Earth's history. The very oldest rocks ("**Y**" geologic map units, i.e., the granitic gneisses and granitoids) were emplaced, deformed, and metamorphosed in a series of mountain-building events collectively called the Grenville Orogeny. The Grenville Orogeny spanned from approximately 1,300 million to 900 million years ago (fig. 30A). Over several phases, this orogeny encompassed most of the continental crust in existence at that time, creating a supercontinent known as Rodinia including what would become North America (Tollo et al. 2006; Southworth et al. 2010). During this event about 1.1 billion years ago, two or more continents collided, deforming and metamorphosing the rocks along their margins and all the rocks squeezed between them (Carter et al. 2001). Today, these are collectively known as "basement" rocks because they form a foundation upon which all other rocks of the Appalachians were stacked (Southworth et al. 2008).

Neoproterozoic Era (1.0 billion to 541 million years ago)—Continental Rifting and Sedimentation, Creating Rocks of the Backbone of the Blue Ridge

About 800 million to 700 million years ago, convective forces within Earth began to create rifts in Rodinia, opening jagged valleys between the separating landmasses (fig. 30B). In a setting analogous to the modern-day East African rift and the Red Sea, many normal faults (see fig. 7) developed to accommodate the stretching of the crust. The thinning crust sagged and cracked along normal faults, began to subside, and collected vast amounts of sediment that was eroded from the Grenville Mountains. Interlayered with these sediments were volcanic rocks extruded from Earth's crust as hot material welled up from below and forced its way upwards through the cracks. Magma that did not reach the surface solidified as igneous plutons in Earth's crust. These mixed sediments and igneous rocks would later be compressed and forced upwards during Paleozoic mountain building into the metamorphic suites and rock groups spanning the Neoproterozoic into the Cambrian Period ("**Z**", "**CZ**", and "**PZZ**" geologic map units; Merschat et al. 2008c; Carter et al. 2016). These include the widespread Ashe Metamorphic Suite and its contemporary, though possibly younger, finer-grained, more thinly layered to laminated, mica-rich Alligator Back Metamorphic Suite (Carter et al. 2001). As the landmasses rifted 533 million to 520 million years ago (fig. 31), sedimentary and volcanic rocks of the Swift Run (**Zsr**) and Catoctin formations (**Zcs**, **Zcm**, **Zcb**) in Virginia (fig. 30C), and the overlying Chilhowee Group (**CZcl**, **Ccw**, **Cchq**, **Cch**, **Cce**, **Cca** in Virginia and **Ccl**, **Ccp**, **Ccu** in North Carolina) were deposited unconformably (after a time gap) over Mesoproterozoic basement (Merschat et al. 2008c; Southworth et al. 2008; Carter et al. 2016, 2017). These rocks are associated with continental rifting and the ultimate opening of the Iapetus Ocean at the beginning of the Paleozoic Era (Carter et al. 2017).

Paleozoic Era (541 million to 252 million years ago)—Appalachian Mountains Rise Up during the Formation of a New Supercontinent

As the Iapetus Ocean continued to widen over 200 million years or more, the North American continental shelf evolved into a carbonate platform along the passive margin in the Cambrian–Ordovician Periods (figs. 30D and 32E). The Shady Dolomite (**Cs**), Waynesboro Formation (**Cw**), and Elbrook Limestone (**Ce**) were deposited in this setting (Carter et al. 2016). The broad continental shelf along what would become the eastern margin of North America collected an 8-km- (5-mi-) thick stack of Cambrian and Ordovician sediments (fig. 32F; Bailey et al. 2006). Organisms flourished in the tropical setting, as evidenced by bioturbation (stirred sediments, tracks, and burrows) and marine fossils in Cambrian and Ordovician rocks, respectively. Around 550 million years ago, Earth forces beneath the Iapetus Ocean began to change and reverse direction of the overlying tectonic plates. Throughout the Paleozoic Era, landmasses ranging in size from volcanic island arcs to continents collided intermittently with the eastern edge of North America. These events ranged in size and scope and their impacts differed geographically. About 475 million years ago in the Ordovician Period (see table 1), a chain of volcanic islands collided with North America during an event called the Taconic Orogeny (fig. 32G). Compression from this event forced the mix of rocks deposited and erupted along the continental margin (e.g., the Ashe and Alligator Back Metamorphic Suites; Grandfather Mountain Formation; and the Great Smoky, Chilhowee, and Snowbird Groups) upwards over the basement rocks and inwards towards the continental center along huge faults in Earth's crust, such as the Holland Mountain, Hayesville, Linville, and Greenbrier faults, as well as the Blue Ridge thrust



1,300 million to 900 million years ago—Grenville Orogeny and the formation of supercontinent **Rodinia**; extensive metamorphism, deformation, and pluton intrusion

960 million to 680 million years ago—Uplift and erosion; sediments shed from Grenville Mountains; plutons intruded 730 million to 700 million years ago as part of a failed rift event; deposition of Swift Run formation at about 730 million to 680 million years ago; sedimentation into rift valleys mixed with volcanic layers

600 million years ago—**Rodinia** rifted apart; *Iapetus Ocean* began to open; widespread volcanic activity; Catoctin Formation deposited atop Grenville basement and sedimentary deposits

541 million years ago—worldwide explosion and diversification of sea life at the beginning of the Cambrian Period; sand and mud deposited in lagoons to become the Weverton and Harpers Formations atop the Catoctin Formation

Figure 30. Schematic graphic illustrating the evolution of the Blue Ridge Parkway landscape. The graphic progresses from older (A) to younger (D) landscapes. Unit colors presented in cross section are US Geological Survey colors corresponding with divisions of geologic time. Individual blocks are not to scale and very generalized for the area. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), modified from Gathright (1976, figures C–D) with information from Gathright (1976), Means (1995), Lillie (1999), Bailey et al. (2006), Bentley (2008), Merschat et al. (2008a), Southworth et al. (2009), Arthur J. Merschat (US Geological Survey, geologist, written communication, 16 July 2013), and Carter et al. (2016).

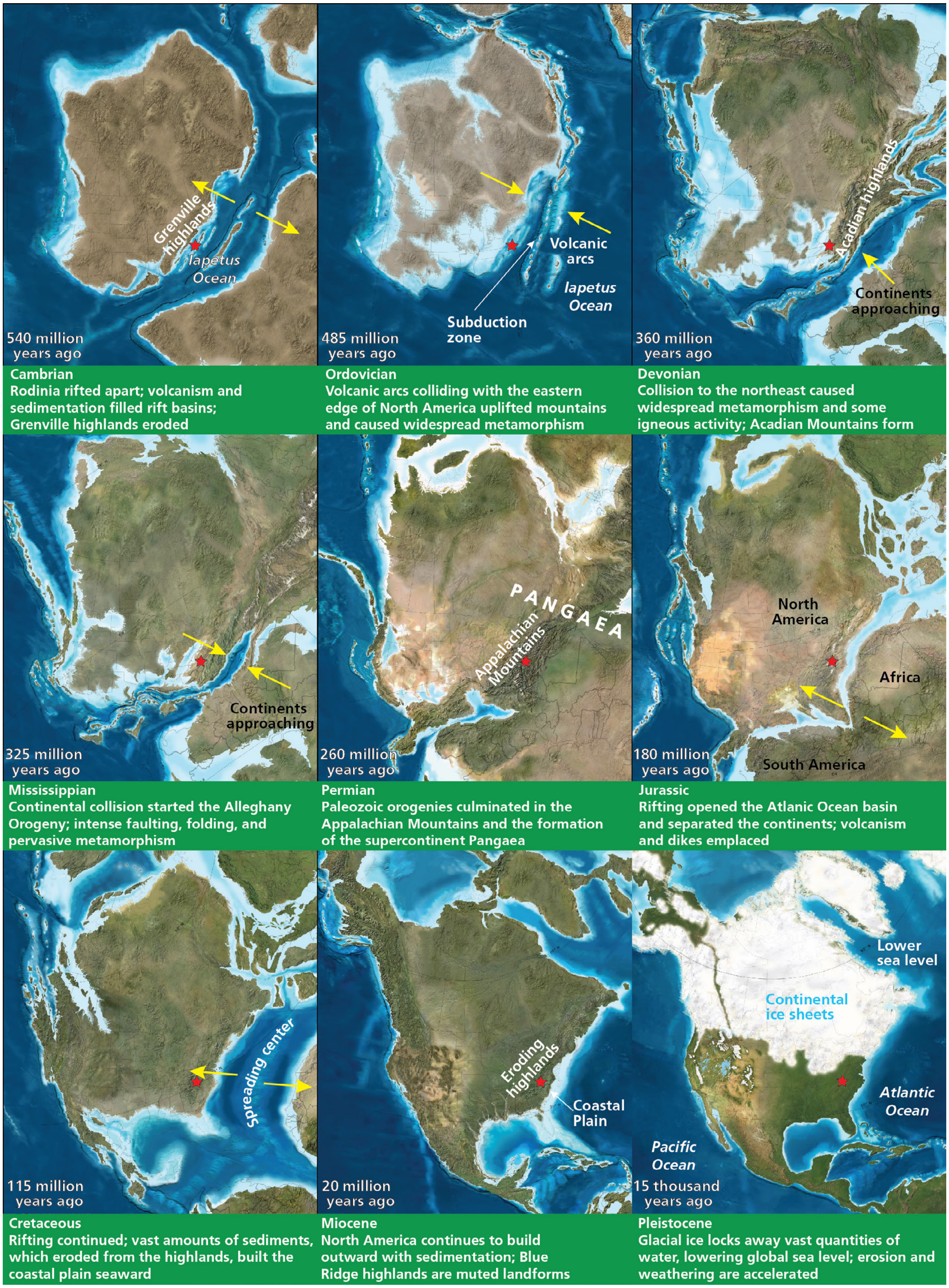


Figure 31. Paleogeographic maps of North America during the Paleozoic, Mesozoic, and Cenozoic Eras. Red star indicates the location of Blue Ridge Parkway Base paleogeographic maps created by Ron Blakey (North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc.), additional information is available at https://deeptimemaps.com/. Annotated by Trista L. Thornberry-Ehrlich (Colorado State University).

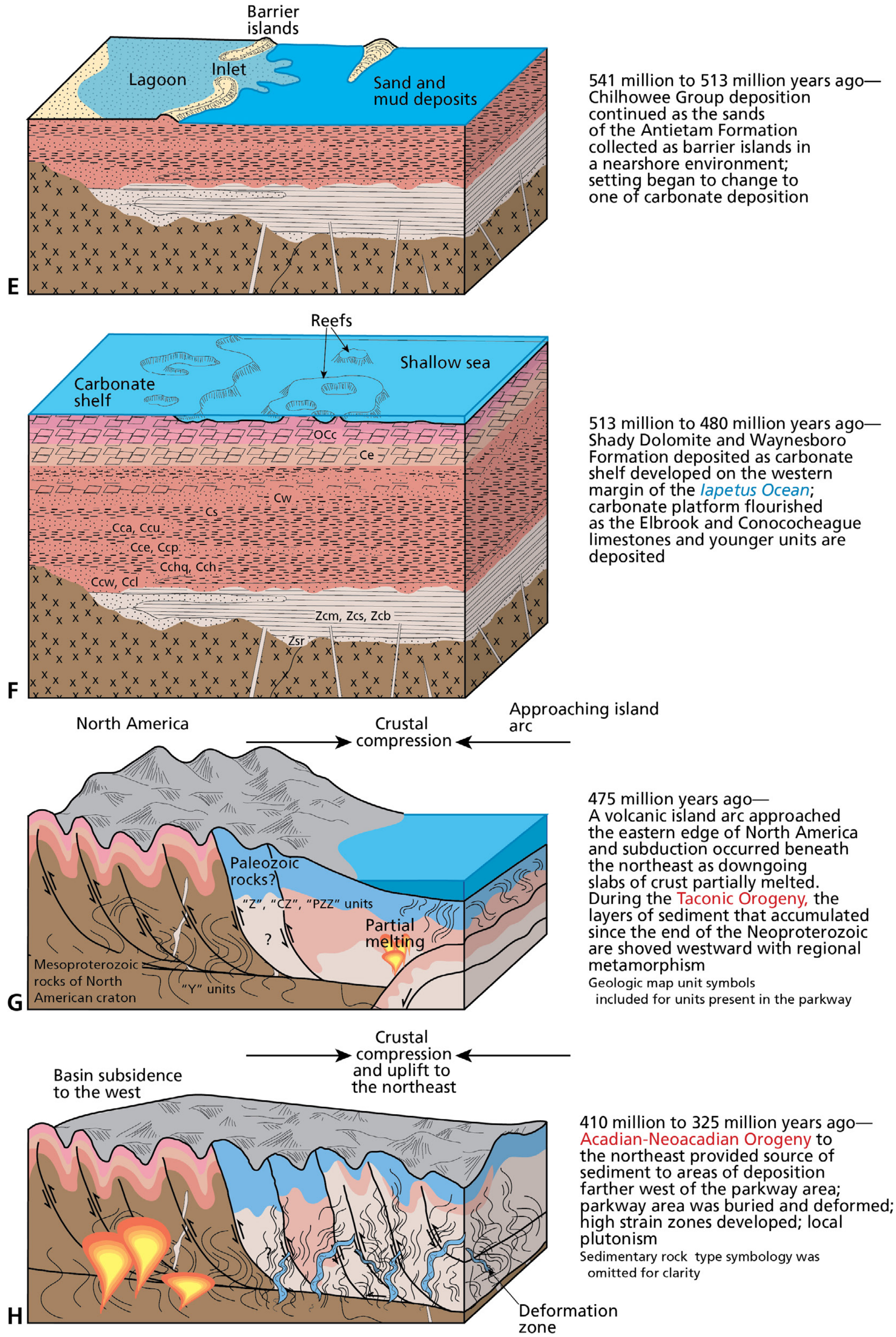


Figure 32. Schematic graphic illustrating the evolution of the Blue Ridge Parkway landscape. The graphic progresses from older (E) to younger H) landscapes. Graphics are not to scale and very generalized for the area. Graphics by Trista L. Thornberry-Ehrlich (Colorado State University), modified from Gathright (1976, figures E–F) with information from Gathright (1976), Means (1995), Lillie (1999), Bailey et al. (2006), Bentley (2008), Merschat et al. (2008a), Southworth et al. (2009), Arthur J. Merschat (US Geological Survey, geologist, written communication, 16 July 2013), and Carter et al. (2016).

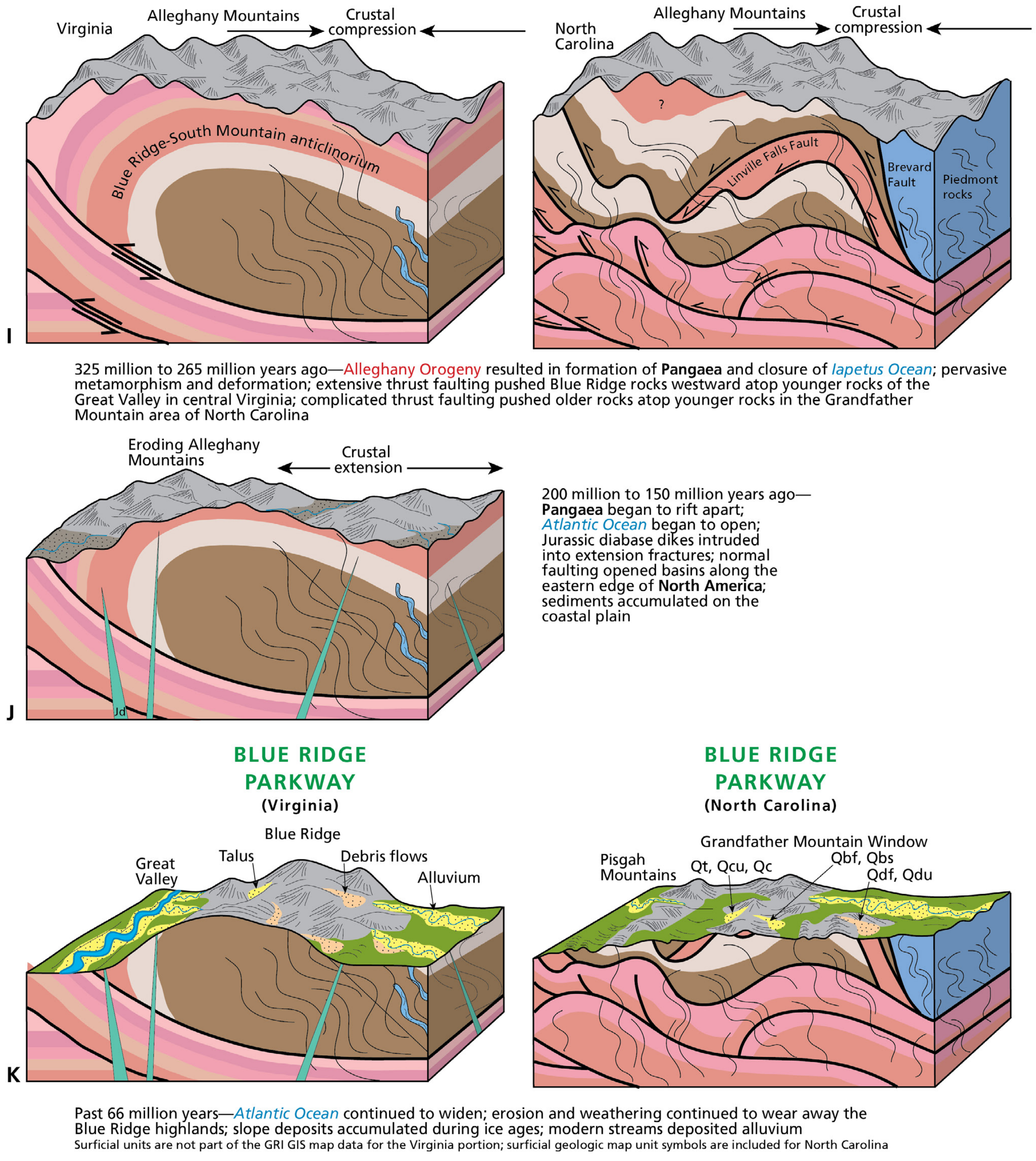


Figure 33. Schematic graphic illustrating the evolution of the Blue Ridge Parkway landscape. The graphic progresses from older (I) to younger (K) landscapes. Individual blocks are not to scale and very generalized for the area. Virginia and North Carolina settings are broken out to show the variety of geologic structures along the parkway. Graphics by Trista L. Thornberry-Ehrlich (Colorado State University), with information from Gathright (1976), Means (1995), Lillie (1999), Bailey et al. (2006), Bentley (2008), Merschat et al. (2008a), Southworth et al. (2009), Arthur J. Merschat (US Geological Survey, geologist, written communication, 16 July 2013), and Carter et al. (2016).

fault (Carter et al. 2001). The rocks buckled, folded, and were metamorphosed together with the basement rocks. Taconic uplift occurred sporadically for about 55 million years while weathering and erosion wore down the highlands (Carter et al. 2017).

Another event, the Acadian Orogeny, occurred during the Devonian Period about 360 million years ago (see figs. 3 and 32H). Much of its effects were focused in New England, northeast of the Blue Ridge region; local effects ("Neoacadian" Orogeny) may have included some deformational shortening, plutonism (e.g., Stone Mountain and Looking Glass Rock, North Carolina), and metamorphism (Carter et al. 2001, 2017; Kunk et al. 2005; Bailey et al. 2006; Merschat and Hatcher 2007).

The Iapetus basin closed completely during the late Paleozoic Era as the North American and African continents collided during the Alleghany Orogeny, about 325 million to 265 million years ago (see table 1). This was the last major orogeny to contribute to the Appalachian Mountains evolution, forming a mountain chain perhaps rivaling the modern Himalayas with elevations potentially exceeding 6,100 m (20,000 ft) (Means 1995). Erosion and weathering may have removed about 6.5 km (4.0 mi) of rock since the Alleghany Orogeny (Southworth et al. 2009). The amount of southeast-to-northwest crustal contraction associated with folding and faulting during the Alleghany Orogeny was extreme. Estimates are of 50%–70% total shortening, which translates to 125–350 km (75–125 mi) of lateral movement or massive blocks of rocks being shoved atop other rocks along faults (fig. 33I; Hatcher 1989; Harris et al. 1997; Southworth et al. 2009). Many Taconic structures were reactivated during this event. The Alleghany Orogeny culminated with the assembly of the major continents (North America, Africa, South America, Antarctica, India, and Australia) into the supercontinent Pangaea—the largest of all landmasses ever to occur on Earth (Carter et al. 2001).

Mesozoic and Cenozoic eras (252 million years ago to present)—The Breakup of Pangaea and the Evolution of the Present-Day Parkway Landscape

The processes of mountain building and weathering and erosion are in a constant state of "competition". If weathering and erosion act more quickly than the mountains are uplifted, mountain peaks are reduced to gently rolling hills. By contrast, if the landscape is uplifted faster than weathering and erosion can wear it down, mountains are created. At the end of the Paleozoic Era, when the continents were no longer colliding along the eastern coast of North America, the balance tipped towards weathering and erosion, and the Appalachians have been wearing away ever since. Areas such as the Grandfather Window demonstrate how erosion can carve a gap in the pile of thrusted rock to expose younger rocks below the thrust fault plane. The surficial deposits exposed along the Blue Ridge Parkway were produced by Earth surface processes as part of the landscape evolution since at least the Mesozoic Era (Carter et al. 2017).

During the Late Triassic Period, approximately 80 million years after the Alleghany Orogeny (Southworth et al. 2009), rifting of the supercontinent Pangaea began to form separate landmasses that would become the modern continents (see fig. 31). As the African continent moved away from North and South America and the Atlantic Ocean began to form, extension of Earth's crust formed grabens (down-dropped basins; see fig. 7) along the eastern margin of North America (Harris et al. 1997; Southworth et al. 2008). The Danville, Farmville, Scottsville, and Culpeper basins east of Blue Ridge Parkway are examples. As with previous episodes of rifting, dikes of molten material were commonly associated with crustal extension. Such dikes intruded the parkway's bedrock about 200 million to 150 million years ago during the Jurassic Period (geologic map unit **Jd**; see figs. 3 and 33J) (Southworth et al. 2009; Carter et al. 2016).

Other than some small-scale, sporadic uplift, weathering and erosion became the dominant processes shaping the Appalachian Mountains (see fig. 12; Carter et al. 2001). Immense amounts of gravel, sand, and silt were eroded and carried eastward to accumulate on the passive-margin of the Atlantic Coastal Plain (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2008b). The amount of material removed from the now-exposed metamorphic mountain core must have been immense because many of the rocks now exposed at the surface were buried at least 20 km (12 mi) below the surface prior to regional uplift and erosion.

During the Pleistocene Epoch, global climate shifts brought alternating periods of prolonged cold—ice ages—and relative warmth similar to modern climate. Continental ice sheets descended south from the Arctic reshaping the landscape of much of northern North America (see fig. 31). Though glaciers from the Pleistocene ice ages never reached Virginia and North Carolina (the southern terminus was in central Pennsylvania), the colder climates of the ice ages played a role in the formation of the landscape at the topographically high Blue Ridge Parkway. Within what would become the parkway, periglacial conditions included discontinuous permafrost, tundra-like vegetation, and frost weathering (Braun 1989). Frost weathering wedged boulders and small rocks from the bedrock to form block fields (**Qbf** and **Qc**), block streams (**Qbs**), colluvium (**Qcu**), and talus (**Qt**) (Morgan et al. 2003; Merschat et al. 2008c).

When warmer climates returned during the Holocene Epoch, erosion of the parkway's steep slopes continued. Debris and debris fan deposits (**Qdu** and **Qdf**) record episodes of mass wasting (fig. 33K; Morgan et al. 2003; Merschat et al. 2008c). Alluvium is not mapped in the GRI GIS data for the parkway but is among the youngest geologic units on the landscape collecting along streams and rivers. Fluvial processes take place throughout the region as the James, New, French Broad, and Cane Rivers carve channels and meander across their floodplains, transporting and depositing material eroded from the Appalachian Mountains into adjacent valleys and ultimately to the coastal plain. Today, visitors enjoy the picturesque landscape of Blue Ridge Parkway. The parkway's beautiful vistas, mountains, hollows, and valleys record a geologic history when and where supercontinents were created and destroyed, oceans opened and closed, and mountains rose and were worn away.

Geologic Map Data

A geologic map in GIS format is the principal deliverable of the GRI program. GRI GIS data produced for the parkway follows the source maps listed here and includes components described in this chapter. Complete GIS data are available at the GRI publications website: http://go.nps.gov/gripubs.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age (see fig. 3 and table 1) and lowercase letters indicating the formation's name. Other symbols depict structures such as faults or folds, locations of past geologic hazards that may be susceptible to future activity, and other geologic features. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps. The American Geosciences Institute website, http://www.americangeosciences.org/environment/publications/mapping, provides more information about geologic maps and their uses.

Geologic maps are typically one of two types: surficial or bedrock. Surficial geologic maps typically encompass deposits that are unconsolidated and formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type. The GRI GIS data consist of a bedrock map for the entire parkway and some surficial units and geohazards data for the southern (North Carolina) portion of the parkway.

Source Maps

The GRI team does not conduct original geologic mapping. The team digitizes paper maps and compiles and converts digital data to conform to the GRI GIS data model. The GRI GIS data set includes essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, cross sections, figures, and references. These items are included in the blrn_geology.pdf and blrs_geology.pdf. The GRI team used the following sources to produce the GRI GIS data set for Blue Ridge Parkway. These sources also provided information for this report.

- Northern portion geologic map: Carter et al. (2016)
- Southern portion geologic map: Merschat et al. (2008a)
- Southern portion geologic hazards: Merschat et al. (2008b)

This report is supported by maps of the bedrock and surficial geology of Blue Ridge Parkway. The maps were developed by geologists from the North Carolina Geological Survey, Virginia Department of Geology and Mineral Resources, and the US Geological Survey. The maps are separated into the North Carolina and Virginia portions of the parkway. Geohazards data were incorporated into the GRI geologic map data for the southern (North Carolina) portion of the map. Geohazards data were not produced for the northern (Virginia) portion of the map.

GRI GIS Data

The GRI team standardizes map deliverables by using a data model. The GRI GIS data for Blue Ridge Parkway was compiled using data model version 2.2, which is available at http://go.nps.gov/gridatamodel. This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software.

GRI GIS data are available on the GRI publications website http://go.nps.gov/gripubs and through the NPS Integrated Resource Management Applications (IRMA) portal https://irma.nps.gov/App/Portal/Home. Enter "GRI" as the search text and select a park from the unit list.

The following components are part of the data set:

- A GIS readme file (blri_gis_readme.pdf) that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information;
- Data in ESRI geodatabase GIS format;
- Layer files with feature symbology;
- Federal Geographic Data Committee (FGDC)–compliant metadata;
- Ancillary map information documents (blrn_geology.pdf and blrs_geology.pdf) that contain information captured from source maps such as map unit

descriptions, geologic unit correlation tables, legends, cross-sections, and figures;

- A version of the data compatible with Google Earth (blrn_geology.kmz, blrs_geology.kmz, blrs_geology.kmz, and brhz_geohazards.kmz); and
- ESRI map documents (blrn_geology.mxd, blrs_geology.mxd, and brhz_geohazards.mxd) that display the GRI GIS data.

GRI GIS data layers for Blue Ridge Parkway—Virginia portion (blrn_geology.mxd).

- Geologic Attitude Observation Localities
- Bedrock Contacts
- Bedrock Units
- Geologic Observation Localities
- Geologic Sample Localities
- Mine Point Features
- Faults

GRI GIS data layers for Blue Ridge Parkway—North Carolina portion (blrs_geology.mxd and brhz_geohazards.mxd).

- Geologic Attitude Observation Localities (blrs)
- Geologic Contacts (blrs)
- Geologic Units (blrs)
- Surficial Contacts (blrs)
- Surficial Units (blrs)
- Geologic Cross Section Lines (blrs)
- Faults (blrs)
- Acid-Producing Rock Potential Boundaries (brhz)
- Acid-Producing Rock Potential (brhz)
- Geologic Observation Localities (brhz)
- Geologic and Other Point Features (blrs)
- Geologic Sample Localities (brhz)
- Mine Point Features (blrs)
- Hazard Area Features (brhz)
- Hazard Area Feature Boundaries (brhz)
- Hazard Point Features (brhz)

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided here. Please contact the GRI team with any questions.

Based on the source map scales (1:24,000 and 1:100,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are expected to be horizontally within 12 m (40 ft) and 51 m (167 ft), respectively, of their true locations.

Further Geologic Data Needs

The GRI GIS data is restricted to bedrock and some surficial coverage that encompasses the narrow corridor of the parkway boundary. Detailed geomorphic mapping would provide useful baselines of current conditions and substantive support to intermittent closures due to hazards posed by geologic features and processes.

Ongoing geologic mapping efforts include the following:

- Virginia Division of Mineral Resources is mapping 7.5-minute quadrangles in the parkway area. The investigators of the mapping project submitted a permit request with Blue Ridge Parkway for access (Bambi Teague, Blue Ridge Parkway, chief of natural resources, conference call, 16 May 2018).
- The US Geological Survey is partnering with the Virginia Division of Mineral Resources as part of the StateMap Program to map quadrangles across Virginia, including near the parkway and I-81 corridor; four to six of these maps are nearing publication and release (Mark Carter, US Geological Survey, geologist, conference call, 16 May 2018).
- Geologic mapping of quadrangles such as the Craggy Pinnacle are also being completed in North Carolina and upon completion will be available in digital, open-file format (Bart Cattanach, North Carolina Geological Survey, geologist, conference call, 16 May 2018).
- The North Carolina Geological Survey completed hazards maps for several counties, including some through which the parkway runs. These data include landslide information and are available from the survey in GIS format (Rick Wooten, North Carolina Geological Survey, geologist, conference call, 16 May 2018).

Literature Cited

These references are cited in this report. Contact the Geologic Resources Division for assistance in obtaining them.

Bacon, C. R. 2008. Geologic map of Mount Mazama and Crater Lake caldera, Oregon (scale 1:24,000). Scientific Investigations Map SIM 2832. US Geological Survey, Washington, DC. http://pubs.usgs.gov/sim/2832/.

Bailey, C.M. 1999. Generalized geologic terrane map of the Virginia Piedmont and Blue Ridge. College of William and Mary, Williamsburg, Virginia. http://www.wm.edu/geology/virginia/terranes.html.

Bailey, C. M., S. Southworth, and R. P. Tollo. 2006. Tectonic history of the Blue Ridge, north-central Virginia. Pages 113–134 in F. J. Pazzaglia, editor. Excursions in geology and history; field trips in the Middle Atlantic states. GSA Field Guide 8. Geological Society of America, Boulder, Colorado.

Bentley, C. 2008. An overview of Shenandoah National Park's geologic story. Online information. Northern Virginia Community College, Annandale, Virginia. http://www.nvcc.edu/home/cbentley/shenandoah.

Bilderback, E., J. LaForge, D. Sharrow, and D. Weeks. 2017. Rockfall and landslide assessments and an unstable slope management system, Zion National Park. Crossroads in Science (Fall 2018):50–55.

Braile, L.W. 2009. Seismic monitoring. Pages 229–244 in R. Young, R. and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. http://go.nps.gov/geomonitoring.

Braun, D. D. 1989. Glacial and periglacial erosion of the Appalachians. Geomorphology 2:233–256.

Burghardt, J. E., E. S. Norby, and H. S. Pranger II. 2014. Abandoned mineral lands in the National Park System: comprehensive inventory and assessment. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2014/906. National Park Service, Fort Collins, Colorado. http://go.nps.gov/aml_publications.

Carter, M. W., and A. J. Merschat, 2014. Stratigraphy, structure, and regional correlation of eastern Blue Ridge sequences in southern Virginia and northwestern North Carolina: an interim report from new USGS mapping. Pages 215–241 in C. M. Bailey and L. V. Coiner, editors. Elevating geoscience in the southeastern United States: new ideas about old terranes. Field guides for the GSA Southeastern Section Meeting, Blacksburg, Virginia. Geological Society of America Field Guide 35. Geological Society of America, Boulder, Colorado.

Carter, M. W., C. E. Merschat, and W. F. Wilson. 2001. A geologic adventure along the Blue Ridge Parkway in North Carolina. Bulletin 98. North Carolina Geological Survey, Raleigh, North Carolina.

Carter, M. W., S. Southworth, and J. N. Aleinikoff. 2013. Proterozoic to Cenozoic geology above, within and beneath the Blue Ridge composite thrust sheet as exposed along the Blue Ridge Parkway in the Peaks of Otter region, central Virginia Blue Ridge. Guidebook for the 43rd Annual Virginia Geological Field Conference, 30 September 2013, Williamsburg, Virginia.

Carter, M. W., E. A. Crider, C. S. Southworth, and J. N. Aleinikoff, 2016. Detailed geologic mapping geodatabase for the Blue Ridge Parkway in Virginia with station point photographs. US Geological Survey data release (updated 20 March 2020). US Geological Survey, Reston, Virginia. https://catalog.data.gov/dataset/detailed-geologic-mapping-geodatabase-for-the-blue-ridge-parkway-in-virginia-with-station-point.

Carter, M. W., S. Southworth, R. P. Tollo, A. J. Merschat, S. Wagner, A. Lazor, and J. N. Aleinikoff. 2017. Geology along the Blue Ridge Parkway in Virginia. Pages 1–58 in C. M. Bailey and S. Jaye, editors. From the Blue Ridge to the beach: geological field excursions across Virginia. Geological Society of America Field Guide 47. Geological Society of America, Boulder, Colorado.

Coe, J. A. 2016. Landslide hazards and climate change: a perspective from the United States. Pages 479–523 in Slope safety preparedness for impact of climate change. CRC Press, https://pubs.er.usgs.gov/publication/70179748.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS 79/31. US Fish and Wildlife Service, Washington, DC.

Cruden, D. M., and Varnes, D. L. 1996. Landslide types and processes. Pages 36–75 (chapter 3) in A. K. Turner and R. L. Schuster, editors. Landslides: investigation and mitigation. Special Report 247. Transportation Research Board, National Research Council, Washington, DC.

Duffy, D.F. and G. R. Whittecar. 1991, Geomorphic development of segmented alluvial fans in the Shenandoah Valley, Stuarts Draft, Virginia. Geological Society of America Abstracts with Programs 23(1):24.

Dunham, R. J. 1962. Classification of carbonate rocks according to depositional texture. Pages 108–121 in W. E. Ham, editor. Classification of carbonate rocks—a symposium. AAPG Memoir 1. American Association of Petroleum Geologists, Tulsa, Oklahoma.

Evans, T. J. 2016. General standards for geologic maps. Section 3.1 in M. B. Carpenter and C. M. Keane, compilers. The geoscience handbook 2016. AGI Data Sheets, 5th edition. American Geosciences Institute, Alexandria, Virginia.

Gathright, T. M. 1976. Geology of the Shenandoah National Park, Virginia. Bulletin 86. Virginia Division of Mineral Resources, Charlottesville, Virginia.

Harris, A. G., E. Tuttle, and S. D. Tuttle. 1997. Geology of national parks. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Hatcher, R. D. Jr. 1989. Tectonic synthesis of the US Appalachians. Pages 511–535 in R. D. Hatcher Jr., W. A. Thomas, and G. W. Viele, editors. The Appalachian-Ouachita Orogen in the United States. The Geology of North America, Volume F-2. Geological Society of America, Boulder, Colorado.

Highland, L. M. and P. Bobrowsky. 2008. The landslide handbook—a guide to understanding landslides. Circular 1325. US Geological Survey, Reston, Virginia. http://pubs.usgs.gov/circ/1325/.

Holmes, R. R. Jr., L. M. Jones, J. C. Eidenshink, J. W. Godt, S. H. Kirby, J. J. Love, C. A. Neal, N. G. Plant, M. L. Plunkett, C. S. Weaver, A. Wein, and S. C. Perry. 2013. US Geological Survey natural hazards science strategy—promoting the safety, security, and economic well-being of the nation. Circular 1383-F. US Geological Survey, Reston, Virginia. http://pubs.usgs.gov/circ/1383f/.

International Commission on Stratigraphy. 2020. International chronostratigraphic chart (v2020/03). Drafted by K. M. Cohen, D. A. T. Harper, P. L. Gibbard, and J.-X. Fan (March 2020). International Union of Geological Sciences (IUGS), International Commission on Stratigraphy, Durham, England [address of current ICS Executive Committee chair]. https://stratigraphy.org/chart.

Kunk, M. J., R. P. Wintsch, C. W. Naeser, N. D. Naeser, C. S. Southworth, A. A. Drake Jr., and J. L. Becker. 2005. Contrasting tectonothermal domains and faulting in the Potomac terrane, Virginia-Maryland: discrimination by 40Ar/39Ar and fission-track thermochronology. Geological Society of America Bulletin 117:1347–1366.

Lillie, R. 1999. Geology training manual: plate tectonics and the Grandfather Mountain-Linville Falls region. Geoscientists-in-the-Parks document 1999-BLRI. National Park Service, Denver, Colorado.

Linari, C. L., P. R. Bierman, E. W. Portenga, M. J. Pavich, R. C. Finkel, S. P. H. T. Freeman. 2017. Rates of erosion and landscape change along the Blue Ridge escarpment, southern Appalachian Mountains, estimated from in situ cosmogenic 10Be. Earth Surface Processes and Landforms 42(6):928–940.

Means, J. 1995. Maryland's Catoctin Mountain parks: an interpretive guide to Catoctin Mountain Park and Cunningham Falls State Park. McDonald & Woodward Publishing Company, Blacksburg, Virginia.

Merschat, A. J., and R. D. Hatcher Jr. 2007. The Cat Square terrane: possible Siluro-Devonian remnant ocean basin in the Inner Piedmont, southern Appalachians, USA. Pages 553–565 in R. D. Hatcher Jr., M. P. Carlson, J. H. McBride, and J. R. Martínez Catalán, editors. 4-D Framework of Continental Crust. Memoir 200. Geological Society of America, Boulder, Colorado.

Merschat, C., M. Carter, and R. Wooten. 2008a. Digital geologic map and inventory for the North Carolina segment of the Blue Ridge Parkway and Carl Sandburg Home National Historic Site (scale 1:24,000). Unpublished N.C. Geological Survey data and GIS data layers prepared for the National Park Service under study BLRI-00065.

Merschat, C., M. Carter, and R. Wooten. 2008b. Digital geohazard map and inventory for the North Carolina segment of the Blue Ridge Parkway and Carl Sandburg Home National Historic Site (scale 1:24,000). Unpublished North Carolina Geological Survey data and GIS data layers prepared for the National Park Service under study BLRI-00065. North Carolina Geological Survey, Raleigh, North Carolina.

Merschat, C. E., R. M. Wooten, B. L. Cattanach, R. S. Latham, G. N. Bozdog, A. C. Witt, and M. W. Carter. 2008c. Digital geologic and geohazard maps and inventories for the North Carolina segment of the Blue Ridge Parkway and Carl Sandburg Home National Historic Site. Unpublished North Carolina Geological Survey data and GIS data layers prepared for the National Park Service under study BLRI-00065. North Carolina Geological Survey, Raleigh, North Carolina.

Morgan, B. A., L. S. Eaton, and G. F. Wieczorek. 2003. Pleistocene and Holocene colluvial fans and terraces in the Blue Ridge region of Shenandoah National Park, Virginia. Open-File Report 03-0410. US Geological Survey, Reston, Virginia. http://pubs.er.usgs.gov/publication/ofr03410.

National Park Service. 2000. Geologic Resources Inventory workshop summary, Blue Ridge Parkway and Carl Sandburg Home NHS. Unpublished report. National Park Service, Geologic Resources Division and Natural Resources Information Division, Fort Collins, Colorado.

National Park Service. 2013. Blue Ridge Parkway, Virginia and North Carolina, final general management plan/environmental impact statement. NPS 641/108779. Blue Ridge Parkway, Asheville, North Carolina.

National Park Service. 2016. Foundation document: Blue Ridge Parkway, North Carolina/Virginia. BLRI 601/134161. Blue Ridge Parkway, Asheville, North Carolina.

National Park Service. 2017. Blue Ridge Parkway NC, VA. Online information. Blue Ridge Parkway, Asheville, North Carolina. https://www.nps.gov/blri/index.htm.

National Park Service. 2019. Scenic vistas. Online information. Blue Ridge Parkway, Asheville, North Carolina. https://www.nps.gov/blri/learn/nature/scenicvistas.htm.

North Carolina Geological Survey. 2008. Summary of geohazards data and data layers for the Blue Ridge Parkway in North Carolina, and the Carl Sandburg Home National Historic Site. Document to accompany C. Merschat, M. Carter, and R. Wooten, mappers. Digital geohazard map and inventory for the North Carolina segment of the Blue Ridge Parkway and Carl Sandburg Home National Historic Site (scale 1:24,000). Unpublished North Carolina Geological Survey data and GIS data layers prepared for the National Park Service under study BLRI-00065. North Carolina Geological Survey, Raleigh, North Carolina. Attached to the blrs_geology.pdf in the GRI GIS data.

North Carolina Wildlife Resources Commission. Date unknown. Mountain bogs and fens. Draft action plan. North Carolina Wildlife Resources Commission, Raleigh, North Carolina. http://www.ncwildlife.org/Portals/0/Conserving/documents/ActionPlan/Habitat_Assessment_Rpts/Mountain/WET_Mountain_Bogs_and_Fens.pdf.

Pazzaglia, F. J., M. W. Carter, C. Berti, R. Counts, G. Hancock, D. Harbor, R. Harrison, M. Heller, S., Mahan, H. Malenda, R. McKeon, M. Nelson, P. Prince, T. Rittenour, J. Spotila, and R. Whittecar. 2015. Geomorphology, active tectonics, and landscape evolution in the Mid-Atlantic region. Pages 109–169 in D. K. Brezinski, J. P. Halka, and R. A. Ortt Jr., editors. Tripping from the Fall Line: field excursions for the GSA Annual Meeting, Baltimore, 2015. Geological Society of Field Guide 40. Geological Society of America, Boulder, Colorado.

Santucci, V. L., R. T. P. McKenna, J. P. Kenworthy, and T. Connors. 2008. Paleontological resource inventory and monitoring Appalachian Highlands Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/080. Natural Resource Program Center, National Park Service, Fort Collins, Colorado.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 in R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. http://go.nps.gov/geomonitoring.

Schnabel Engineering, LLC. 2009. Final geological engineering report Blue Ridge Parkway, MP 400.8, Buncombe County, North Carolina. EFLHD reference no. HFAC-15. Report submitted to the Federal Highway Administration. Schnabel Engineering, LLC, Gaithersburg, Maryland.

Southworth, S., D. K. Brezinski, R. C. Orndorff, P. G. Chirico, and K. M. Lagueux. 2008. Geology of the Chesapeake and Ohio Canal National Historical Park and Potomac River Corridor, District of Columbia, Maryland, West Virginia, and Virginia. Professional Paper 1691. US Geological Survey, Reston, Virginia, USA. http://pubs.usgs.gov/pp/1691/.

Southworth, S., J. N. Aleinikoff, R. P. Tollo, C. M. Bailey, W. C. Burton, P. C. Hackley, and C. M. Fanning. 2010. Mesoproterozoic magmatism and deformation in the northern Blue Ridge, Virginia and Maryland: application of SHRIMP U-Pb geochronology and integrated field studies in the definition of Grenvillian tectonic history. Pages 795–836 in R. P. Tollo, M. J. Bartholomew, J. P. Hibbard, and P. M. Karabinos, editors. Memoir 206. Geological Society of America, Boulder, Colorado.

Southworth, S., J. N. Aleinikoff, C. M. Bailey, W. C. Burton, E. A. Crider, P. C. Hackley, J. P. Smoot, and R. P. Tollo. 2009. Geologic map of the Shenandoah National Park Region, Virginia (scale 1:100,000). Open-File Report 2009-1153. US Geological Survey, Reston, Virginia. http://pubs.er.usgs.gov/publication/ofr20091153.

Sullivan, C., P. R. Bierman, L. Reusser, M. Pavich, J. Larsen, and R. C. Finkel. 2007. Cosmogenic erosion rates and landscape evolution of the Blue Ridge escarpment, southern Appalachian Mountains. Geological Society of America Abstracts with Programs 39(6):512.

Sullivan, T. J., T. C. McDonnell, G. T. McPherson, S. D. Mackey, and D. Moore. 2011a. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: Appalachian Highlands Network (APHN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/302. National Park Service, Denver, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2168594.

Sullivan, T. J., G. T. McPherson, T. C. McDonnell, S. D. Mackey, and D. Moore. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: Appalachian Highlands Network (APHN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/350. National Park Service, Denver, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2170563.

Sundin, G., L. Worsham, N. P. Nibbelink, M. T. Mengak, and G. Grossman. 2013. Natural resource condition assessment for Blue Ridge Parkway. Natural Resource Report NPS/BLRI/NRR—2013/699. University of Georgia, Warnell School of Forestry and Natural Resources, Athens, Georgia. https://irma.nps.gov/DataStore/Reference/Profile/2198325.

Thornberry-Ehrlich, T. L. 2011. Cumberland Gap National Historical Park: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2011/458. National Park Service, Fort Collins, Colorado. http://go.nps.gov/gripubs.

Thornberry-Ehrlich, T. L. 2013. Delaware Water Gap National Recreation Area: geologic resources inventory report. Natural Resource Report. NPS/NRSS/GRD/NRR—2013/717. National Park Service. Fort Collins, Colorado. http://go.nps.gov/gripubs.

Thornberry-Ehrlich, T. L. 2017. Bluestone National Scenic River, Gauley River National Recreation Area, and New River Gorge National River: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2017/1532. National Park Service, Fort Collins, Colorado. http://go.nps.gov/gripubs.

Tollo, R. P., J. N. Aleinikoff, E. A. Borduas, A. P. Dickin, R. H. McNutt, and C. M. Fanning. 2006. Grenvillian magmatism in the northern Virginia Blue Ridge: petrologic implications of episodic granitic magma production and the significance of postorogenic A-type charnokite. Precambrian Research 151:224–264.

Varnes, D. J. 1978. Slope movement types and processes. Pages 11–33 in R. L. Schuster and R. J. Krizek, editors. Landslides: analysis and control. Special Report 176. Transportation and Road Research Board, National Academy of Science, Washington, DC.

Wheeler, B., D. Hasty, L. Lawliss, P. Beasley, T. Gibney, L. Heller, and I. Firth. 2008. Brinegar Cabin: cultural landscape inventory, Blue Ridge Parkway-Highlands District, National Park Service. 550138. National Park Service, Southeast Regional Office, Atlanta, Georgia. https://irma.nps.gov/DataStore/Reference/Profile/2188675.

Whittecar, G. R. and D. F. Duffy. 2000. Geomorphology and stratigraphy of late Cenozoic alluvial fans, Augusta County, Virginia, USA. Pages 259–279 in G. M. Clark, H. H. Mills, and J. S. Kite, editors. Regolith in the Central and Southern Appalachians. Southeastern Geology 39(3-4).

Wieczorek, G. F. and J. B. Snyder. 2009. Monitoring slope movements. Pages 245–271 in R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. http://go.nps.gov/geomonitoring.

Young, R. and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado. http://go.nps.gov/geomonitoring.

Additional References

These references, resources, and websites may be of use to resource managers. Refer to Appendix B for laws, regulations, and policies that apply to NPS geologic resources.

Geology of National Park Service Areas

- NPS Geologic Resources Division (Lakewood, Colorado) Energy and Minerals; Active Processes and Hazards; Geologic Heritage: http://go.nps.gov/grd
- NPS Geoscience Concepts: http://go.nps.gov/geoeducation
- NPS Geodiversity Atlas: http://go.nps.gov/geodiversity_atlas
- NPS Geologic Resources Inventory: http://go.nps.gov/gri
- NPS Geoscientist-In-the-Parks (GIP) internship and guest scientist program: http://go.nps.gov/gip
- NPS Mosaics in Science internship program: http://go.nps.gov/mosaics

NPS Resource Management Guidance and Documents

- Management Policies 2006 (Chapter 4: Natural resource management): http://www.nps.gov/policy/mp/policies.html
- 1998 National parks omnibus management act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf
- NPS-75: Natural resource inventory and monitoring guideline: https://irma.nps.gov/DataStore/Reference/Profile/622933
- NPS Natural resource management reference manual #77: https://irma.nps.gov/DataStore/Reference/Profile/572379
- Geologic monitoring manual (Young, R., and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado): http://go.nps.gov/geomonitoring
- NPS Technical Information Center (TIC) (Denver, Colorado; repository for technical documents): https://www.nps.gov/dsc/technicalinfocenter.htm

Climate Change Resources

- NPS Climate Change Response Program Resources: http://www.nps.gov/subjects/climatechange/resources.htm
- US Global Change Research Program: http://www.globalchange.gov/home
- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/

Geological Surveys and Societies

- North Carolina Geological Survey: https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey
- Virginia Division of Geology and Mineral Resources: https://www.dmme.virginia.gov/dgmr/divisiongeologymineralresources.shtml
- US Geological Survey: http://www.usgs.gov/
- Geological Society of America: http://www.geosociety.org/
- American Geophysical Union: http://sites.agu.org/
- American Geosciences Institute: http://www.americangeosciences.org/
- Association of American State Geologists: http://www.stategeologists.org/

US Geological Survey Reference Tools

- National geologic map database (NGMDB): http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- Geologic names lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/search
- Geographic names information system (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/
- GeoPDFs (download PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator")
- Publications warehouse (many publications available online): http://pubs.er.usgs.gov
- Tapestry of time and terrain (descriptions of physiographic provinces): http://pubs.usgs.gov/imap/i2720/

Appendix A: Scoping Participants

The following people attended the GRI scoping meeting, held on 10-12 May 2000, or the follow-up report writing conference call, held on 16 May 2017. Discussions during these meetings supplied a foundation for this GRI report. The scoping summary document is available on the GRI publications website: http://go.nps.gov/gripubs.

2000 Scoping Meeting Participants

Name	Affiliation	Position
David Anderson	NPS Blue Ridge Parkway	Not documented at scoping meeting
Mark Carter	North Carolina Geological Survey	Geologist
Tim Connors	NPS Geologic Resources Division	Geologist
Nick Evans	Virginia Geological Survey	Geologist
Joe Gregson	NPS Natural Resources Information Division	Geologist
Lindsay McClelland	NPS Geologic Resources Division	Geologist
Carl Merschat	North Carolina Geological Survey	Geologist
Scott Southworth	US Geological Survey	Geologist
Bambi Teague	NPS Blue Ridge Parkway	Not documented at scoping meeting
Chris Ulrey	NPS Blue Ridge Parkway	Not documented at scoping meeting
Warren Weber	NPS Carl Sandburg National Historic Site	Not documented at scoping meeting

2017 Conference Call Participants

Name	Affiliation	Position
David Anderson	NPS Blue Ridge Parkway	Landscape architect, GIS coordinator
Mark Carter	US Geological Survey	Geologist
Bart Cattanach	North Carolina Geological Survey	Geologist
Tim Connors	NPS Geologic Resources Division	Geologist
Jason Kenworthy	NPS Geologic Resources Division	Geologist, GRI reports coordinator
Bambi Teague	NPS Blue Ridge Parkway	Supervisory biologist
Trista L. Thornberry-Ehrlich	Colorado State University	Geologist, graphic designer
Rick Wooten	North Carolina Geological Survey	Geologist

Appendix B: Geologic Resource Laws, Regulations, and Policies

The NPS Geologic Resources Division developed this table to summarize laws, regulations, and policies that specifically apply to NPS minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act). The table does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available. Information is current as of December 2019. Contact the NPS Geologic Resources Division for detailed guidance.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Caves and Karst Systems	**Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309** requires Interior/Agriculture to identify "significant caves" on Federal lands, regulate/restrict use of those caves as appropriate, and include significant caves in land management planning efforts. Imposes civil and criminal penalties for harming a cave or cave resources. Authorizes Secretaries to withhold information about specific location of a significant cave from a Freedom of Information Act (FOIA) requester. **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of cave and karst resources. **Lechuguilla Cave Protection Act of 1993, Public Law 103-169** created a cave protection zone (CPZ) around Lechuguilla Cave in Carlsbad Caverns National Park. Within the CPZ, access and the removal of cave resources may be limited or prohibited; existing leases may be cancelled with appropriate compensation; and lands are withdrawn from mineral entry.	**36 CFR § 2.1** prohibits possessing/ destroying/disturbing…cave resources…in park units. **43 CFR Part 37** states that all NPS caves are "significant" and sets forth procedures for determining/ releasing confidential information about specific cave locations to a FOIA requester.	**Section 4.8.1.2** requires NPS to maintain karst integrity, minimize impacts. **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. **Section 4.8.2.2** requires NPS to protect caves, allow new development in or on caves if it will not impact cave environment, and to remove existing developments if they impair caves. **Section 6.3.11.2** explains how to manage caves in/ adjacent to wilderness.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Paleontology	**National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of paleontological resources and objects. **Paleontological Resources Preservation Act of 2009, 16 USC § 470aaa et seq.** provides for the management and protection of paleontological resources on federal lands. **Archaeological Resources Protection Act of 1979, 16 USC §§ 470aa – mm Section 3 (1)** Archaeological Resource—nonfossilized and fossilized paleontological specimens, or any portion or piece thereof, shall not be considered archaeological resources, under the regulations of this paragraph, unless found in an archaeological context. Therefore, fossils in an archaeological context are covered under this law. **Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309 Section 3 (5)** Cave Resource—the term "cave resource" includes any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems. Therefore, every reference to cave resource in the law applies to paleontological resources.	**36 CFR § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof. **Prohibition in 36 CFR § 13.35** applies even in Alaska parks, where the surface collection of other geologic resources is permitted. **43 CFR Part 49** (in development) will contain the DOI regulations implementing the Paleontological Resources Preservation Act.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. **Section 4.8.2.1** emphasizes Inventory and Monitoring, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria.
Recreational Collection of Rocks Minerals	**NPS Organic Act, 54 USC. § 100101 et seq.** directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law. **Exception: 16 USC. § 445c (c)** Pipestone National Monument enabling statute. Authorizes American Indian collection of catlinite (red pipestone).	**36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units. **Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown. **Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Geothermal	**Geothermal Steam Act of 1970, 30 USC. § 1001 et seq. as amended in 1988**, states ● No geothermal leasing is allowed in parks. ● "Significant" thermal features exist in 16 park units (the features listed by the NPS at **52 Fed. Reg. 28793-28800** (August 3, 1987), plus the thermal features in Crater Lake, Big Bend, and Lake Mead). ● NPS is required to monitor those features. ● Based on scientific evidence, Secretary of Interior must protect significant NPS thermal features from leasing effects. **Geothermal Steam Act Amendments of 1988, Public Law 100--443** prohibits geothermal leasing in the Island Park known geothermal resource area near Yellowstone and outside 16 designated NPS units if subsequent geothermal development would significantly adversely affect identified thermal features.	None applicable.	**Section 4.8.2.3** requires NPS to ● Preserve/maintain integrity of all thermal resources in parks. ● Work closely with outside agencies. ● Monitor significant thermal features.
Mining Claims (Locatable Minerals)	**Mining in the Parks Act of 1976, 54 USC § 100731 et seq.** authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas. **General Mining Law of 1872, 30 USC § 21 et seq.** allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA. **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.	**36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law. **36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart A** requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.	**Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at **36 CFR Parts 6 and 9A**. **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Nonfederal Oil and Gas	**NPS Organic Act, 54 USC § 100751 et seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). Individual Park Enabling Statutes: • **16 USC § 230a** (Jean Lafitte NHP & Pres.) • **16 USC § 450kk** (Fort Union NM), • **16 USC § 459d-3** (Padre Island NS), • **16 USC § 459h-3** (Gulf Islands NS), • **16 USC § 460ee** (Big South Fork NRRA), • **16 USC § 460cc-2(i)** (Gateway NRA), • **16 USC § 460m** (Ozark NSR), • **16 USC § 698c** (Big Thicket N Pres.), • **16 USC § 698f** (Big Cypress N Pres.)	**36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights outside of Alaska to • demonstrate bona fide title to mineral rights; • submit an Operations Permit Application to NPS describing where, when, how they intend to conduct operations; • prepare/submit a reclamation plan; and • submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska.	**Section 8.7.3** requires operators to comply with 9B regulations.
Soils	**Soil and Water Resources Conservation Act, 16 USC §§ 2011–2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources. **Farmland Protection Policy Act, 7 USC § 4201 et. seq.** requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and assure that such Federal programs are compatible with State, unit of local government, and private programs and policies to protect farmland. NPS actions are subject to the FPPA if they may irreversibly convert farmland (directly or indirectly) to nonagricultural use and are completed by a Federal agency or with assistance from a Federal agency. Applicable projects require coordination with the Department of Agriculture's Natural Resources Conservation Service (NRCS).	**7 CFR Parts 610 and 611** are the US Department of Agriculture regulations for the Natural Resources Conservation Service. **Part 610** governs the NRCS technical assistance program, soil erosion predictions, and the conservation of private grazing land. **Part 611** governs soil surveys and cartographic operations. The NRCS works with the NPS through cooperative arrangements.	**Section 4.8.2.4** requires NPS to • prevent unnatural erosion, removal, and contamination; • conduct soil surveys; • minimize unavoidable excavation; and • develop/follow written prescriptions (instructions).

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Federal Mineral Leasing (Oil, Gas, and Solid Minerals)	**The Mineral Leasing Act, 30 USC § 181 et seq., and the Mineral Leasing Act for Acquired Lands, 30 USC § 351 et seq.** do not authorize the BLM to lease federally owned minerals in NPS units. **Combined Hydrocarbon Leasing Act, 30 USC §181**, allowed owners of oil and gas leases or placer oil claims in Special Tar Sand Areas (STSA) to convert those leases or claims to combined hydrocarbon leases, and allowed for competitive tar sands leasing. This act did not modify the general prohibition on leasing in park units but did allow for lease conversion in GLCA, which is the only park unit that contains a STSA. **Exceptions: Glen Canyon NRA (16 USC § 460dd et seq.), Lake Mead NRA (16 USC § 460n et seq.), and Whiskeytown-Shasta-Trinity NRA (16 USC § 460q et seq.)** authorizes the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration. American Indian Lands Within NPS Boundaries Under the **Indian Allottee Leasing Act of 1909, 25 USC §396, and the Indian Leasing Act of 1938, 25 USC §396a, §398 and §399, and Indian Mineral Development Act of 1982, 25 USCS §§2101-2108**, all minerals on American Indian trust lands within NPS units are subject to leasing. **Federal Coal Leasing Amendments Act of 1975, 30 USC § 201** prohibits coal leasing in National Park System units.	**36 CFR § 5.14** states prospecting, mining, and…leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law. **BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing. **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM. Regulations re: Native American Lands within NPS Units: • **25 CFR Part 211** governs leasing of tribal lands for mineral development. • **25 CFR Part 212** governs leasing of allotted lands for mineral development. • **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development. • **25 CFR Part 224** governs tribal energy resource agreements. • **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the **Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938** (codified at **25 USC §§ 2101-2108**). • **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases. • **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases. • **30 CFR §§ 1206.50-1206.62 and §§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases. • **30 CFR § 1206.450** governs the valuation coal from Indian Tribal and Allotted leases. • **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.	**Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Nonfederal minerals other than oil and gas	**NPS Organic Act, 54 USC §§ 100101 and 100751**	NPS regulations at **36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a **§ 5.3** business operation, and **§ 5.7 – Construction of buildings or other facilities**, and to comply with the solid waste regulations at **Part 6**.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with **36 CFR Parts 1 and 5**.
Coal	**Surface Mining Control and Reclamation Act of 1977, 30 USC § 1201 et. seq.** prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.	**SMCRA Regulations at 30 CFR Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation, and employee protection. **Part 7** of the regulations states that National Park System lands are unsuitable for surface mining.	None applicable.
Uranium	**Atomic Energy Act of 1954** Allows Secretary of Energy to issue leases or permits for uranium on BLM lands; may issue leases or permits in NPS areas only if president declares a national emergency.	None applicable.	None applicable.
Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)	**Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units. **Reclamation Act of 1939, 43 USC §387**, authorizes removal of common variety mineral materials from federal lands in federal reclamation projects. This act is cited in the enabling statutes for Glen Canyon and Whiskeytown National Recreation Areas, which provide that the Secretary of the Interior may permit the removal of federally owned nonleasable minerals such as sand, gravel, and building materials from the NRAs under appropriate regulations. Because regulations have not yet been promulgated, the National Park Service may not permit removal of these materials from these National Recreation Areas. **16 USC §90c-1(b)** authorizes sand, rock and gravel to be available for sale to the residents of Stehekin from the non-wilderness portion of Lake Chelan National Recreation Area, for local use as long as the sale and disposal does not have significant adverse effects on the administration of the national recreation area.	None applicable.	**Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and: ● only for park administrative uses; ● after compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment; ● after finding the use is park's most reasonable alternative based on environment and economics; ● parks should use existing pits and create new pits only in accordance with park-wide borrow management plan; ● spoil areas must comply with Part 6 standards; and ● NPS must evaluate use of external quarries. Any deviation from this policy requires a written waiver from the Secretary, Assistant Secretary, or Director.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Coastal Features and Processes	**NPS Organic Act, 54 USC § 100751 et. seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). **Coastal Zone Management Act, 16 USC § 1451 et. seq**. requires Federal agencies to prepare a consistency determination for every Federal agency activity in or outside of the coastal zone that affects land or water use of the coastal zone. **Clean Water Act, 33 USC § 1342/ Rivers and Harbors Act, 33 USC 403** require that dredge and fill actions comply with a Corps of Engineers Section 404 permit. **Executive Order 13089** (coral reefs) (1998) calls for reduction of impacts to coral reefs. **Executive Order 13158** (marine protected areas) (2000) requires every federal agency, to the extent permitted by law and the maximum extent practicable, to avoid harming marine protected areas. *See also "Climate Change"*	**36 CFR § 1.2(a)(3)** applies NPS regulations to activities occurring within waters subject to the jurisdiction of the US located within the boundaries of a unit, including navigable water and areas within their ordinary reach, below the mean high water mark (or OHW line) without regard to ownership of submerged lands, tidelands, or lowlands. **36 CFR § 5.7** requires NPS authorization prior to constructing a building or other structure (including boat docks) upon, across, over, through, or under any park area. *See also "Climate Change"*	**Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.8.1** requires NPS to allow natural geologic processes to proceed unimpeded. NPS can intervene in these processes only when required by Congress, when necessary for saving human lives, or when there is no other feasible way to protect other natural resources/ park facilities/ historic properties. **Section 4.8.1.1** requires NPS to: ● Allow natural processes to continue without interference, ● Investigate alternatives for mitigating the effects of human alterations of natural processes and restoring natural conditions, ● Study impacts of cultural resource protection proposals on natural resources, ● Use the most effective and natural-looking erosion control methods available, and avoid new developments in areas subject to natural shoreline processes unless certain factors are present. *See also "Climate Change"*

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Climate Change	**Secretarial Order 3289** (Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources) (2009) requires DOI bureaus and offices to incorporate climate change impacts into long-range planning; and establishes DOI regional climate change response centers and Landscape Conservation Cooperatives to better integrate science and management to address climate change and other landscape scale issues. **Executive Order 13693** (Planning for Federal Sustainability in the Next Decade) (2015) established to maintain Federal leadership in sustainability and greenhouse gas emission reductions.	*No applicable regulations, although the following NPS guidance should be considered:* **Coastal Adaptation Strategies Handbook (Beavers et al. 2016)** provides strategies and decision-making frameworks to support adaptation of natural and cultural resources to climate change. **Climate Change Facility Adaptation Planning and Implementation Framework**: The NPS Sustainable Operations and Climate Change Branch is developing a plan to incorporate vulnerability to climate change (Beavers et al. 2016b). **NPS Climate Change Response Strategy** (2010) describes goals and objectives to guide NPS actions under four integrated components: science, adaptation, mitigation, and communication. **Policy Memo 12-02** (Applying National Park Service Management Policies in the Context of Climate Change) (2012) applies considerations of climate change to the impairment prohibition and to maintaining "natural conditions". **Policy Memo 14-02** (Climate Change and Stewardship of Cultural Resources) (2014) provides guidance and direction regarding the stewardship of cultural resources in relation to climate change. **Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks. *Continued in 2006 Management Policies column*	**Section 4.1** requires NPS to investigate the possibility to restore natural ecosystem functioning that has been disrupted by past or ongoing human activities. This would include climate change, as put forth by Beavers et al. (2016). *NPS guidance, continued:* **DOI Manual Part 523, Chapter 1** establishes policy and provides guidance for addressing climate change impacts upon the Department's mission, programs, operations, and personnel. **Revisiting Leopold: Resource Stewardship in the National Parks** (2012) will guide US National Park natural and cultural resource management into a second century of continuous change, including climate change. **Climate Change Action Plan** (2012) articulates a set of high-priority no-regrets actions the NPS will undertake over the next few years **Green Parks Plan** (2013) is a long-term strategic plan for sustainable management of NPS operations.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Upland and Fluvial Processes	**Rivers and Harbors Appropriation Act of 1899, 33 USC § 403** prohibits the construction of any obstruction on the waters of the United States not authorized by congress or approved by the USACE. **Clean Water Act 33 USC § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US [including streams]). **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also **D.O. 77-2**) **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also **D.O. 77-1**)	None applicable. *2006 Management Policies, continued:* **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human-caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams. **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include…erosion and sedimentation…processes. **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.	**Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems. **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks, unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding. *continued in Regulations column*

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 601/173851, November 2020

National Park Service
U.S. Department of the Interior

Natural Resources Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

https://www.nps.gov/nature/index.htm

EXPERIENCE YOUR AMERICA™