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Natural Resource Stewardship and Science

Morristown National Historical Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2014/841





ON THE COVER
Cannon at Fort Nonsense overlooking Morristown. Photograph by Jared Kofsky (Creative Commons Attribution-Share Alike 3.0 Unported [CC BY-SA 3.0] license) available at: http://commons.wikimedia.org/wiki/File:Fort_Nonsense_of_Morristown.JPG (accessed 12 August 2014)

THIS PAGE
Split-rail fence at Jockey Hollow in the winter. Photograph by Daniel Beards, available at: http://albums.phanfare.com/isolated/CUUsqZbg/1/6144461_7039483 (accessed 12 August 2014)

Morristown National Historical Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2014/841

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Executive Summary

The Geologic Resources Inventory (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 for Morristown National Historical Park (New Jersey) on 10 July 2007 and a follow-up conference call on 8 August 2013, which were held by the Geologic Resources Division to determine geologic resources, the status of geologic mapping, and geologic resource management issues and needs. It is a companion document to previously completed GRI digital geologic map data.

This GRI report was written for resource managers to support science-informed decision making, but it may also be useful for interpretation. The report was prepared using available geologic information and the NPS Geologic Resources Division did not conduct any new fieldwork in association with this report. Sections of the report discuss distinctive geologic features and processes at Morristown National Historical Park, highlight geologic issues facing resource managers, describe the geologic history leading to the present-day landscape, and provide information about the GRI geologic map data. Posters (in pocket) illustrate these data. The Map Unit Properties Tables (in pocket) summarize report content for each geologic map unit.

Morristown National Historical Park commemorates the winter quarters of the Continental Army during the American Revolutionary War in January 1777 and the coldest winter on record, from December 1779 to June 1780. General George Washington chose this site, which is now in south-central Morris County and northern Somerset County, New Jersey, for its accessibility, defensibility, and views to the British encampments in New York 50 km (30 mi) away. The park now encompasses more than 690 ha (1,710 ac) of forested, hilly terrain; broad vistas over the undulating landscape; and narrow ravines within four units.

The park's geology influenced its human history. Fort Nonsense was located to take advantage of the view to the east provided by the Highland Front. Weathered bedrock provided local building material and substrates for soldiers' huts. The ridges of the Watchung Mountains also provided protection and narrow gaps for troop passage. Glacial deposits (terminal moraines) form natural, well-drained transportation routes through the Great Swamp that remain in use today.

The four park units straddle a major tectonic boundary in eastern North America between the Reading Prong (west) and Piedmont (east) physiographic provinces. At this boundary, the Ramapo Fault separates the New Jersey Highlands from the Newark Basin. Rock units occurring in the park can be divided into two major types: (1) hard, solid bedrock and (2) unconsolidated surficial deposits. The bedrock is further divisible into two groups: (1) Mesoproterozoic metamorphic and igneous rocks approximately 1.2–1.0 billion years old ("Y" geologic map units) and (2) Jurassic-aged sedimentary and igneous rocks that are approximately 200–150 million years old ("J" units). The Ramapo Fault (marking the Highland Front) sharply separates these two rock types. Surficial and unconsolidated units from the Quaternary Period ("Q" units) are also divisible based on the types of sediment composing them and the processes responsible for their formation into (1) glacial and (2) fluvial and slope deposits.

The Mesoproterozoic rocks represent the evolution of the North American continent as a result of the assembly and stabilization of fragments of oceanic and continental crust. They form the foundation atop which all other rocks in the Appalachians were deposited. They are predominant in the New Jersey Highlands in the western part of the park, underlying higher ground such as Mount Kemble, Tea Hill, Sugar Loaf, and Blachleys Hill. Over the course of their long history, the rocks were metamorphosed, deformed, and pushed westward during mountain-building events called "orogenies" during the Proterozoic and Paleozoic eras. The younger Mesozoic rocks formed as Earth's crust stretched along the eastern margin of the continent during the opening of the Atlantic Ocean. Large basins opened and ultimately filled with sediment and volcanic layers. The youngest, unconsolidated surficial deposits reflect weathering and erosion processes, active since the end of the Paleozoic orogenic events, which were responsible for the formation of the Appalachian Mountains. This history includes the significant ice ages of the Pleistocene Epoch, when glaciers descending from the Arctic reshaped the landscape.

Notable geologic features and processes at Morristown National Historical Park include:

- Glacial Features. During Early Pleistocene ice-age glaciation, massive amounts of ice moved across the region, covering the land now designated as the park. Stream erosion and slope processes have removed much evidence of the erosional and depositional effects of this event. During the most recent glaciation, the maximum extent of ice sheets was just a few kilometers north of the park's modern boundary. Many features in the park and surrounding area were deposited by glaciers, carved by moving ice, deposited

by rivers flowing out of glaciers, or deposited in lakes near glaciers, including stages of glacial Lake Passaic.

- Periglacial Bedrock Weathering and Thermokarst Topography. The colder climates of the Pleistocene ice ages fractured rocks, formed talus-covered slopes and colluvial deposits, and accelerated the rates of bedrock breakdown. Weathered bedrock deposits now mantle much of the existing bedrock at the park. Much of the Great Swamp and surrounding area has thermokarst topography, a term describing a hummocky landscape that develops when frozen ground thaws and the ground settles, which developed on stream-terrace sand.
- Postglacial Deposits. Upon the retreat of glaciers and draining of glacial lakes, river systems incised the thick layers of sediment, creating terraces, channels, and floodplains. Alluvium and colluvium continue to collect on the park's landscape.
- Gaps in the Watchung Mountains. Basalt-supported ridges compose the Watchung Mountains east of the park. Two sets of parallel gaps cut by the ancestral Hudson River punctuate these ridges. Gaps typically form in areas of pre-existing weakness in otherwise resistant rocks.
- Ramapo Fault and Other Structures. The Ramapo Fault is a major regional fault that formed when the Supercontinent Pangaea split apart and the Atlantic Ocean began to open. Its movement separated the New Jersey Highlands (uplifted to the west) from the Newark Basin (down-dropped to the east). A zone of modern, minor earthquake epicenters that defines an active seismic province in the New York City metropolitan area may have some association with the Ramapo Fault system, although evidence of post-Mesozoic movement along the fault is lacking.
- Bedrock Features. The rocks that form the foundation of Morristown National Historical Park contain myriad features indicative of their geologic history. The Mesoproterozoic metamorphic rocks of the New Jersey Highlands are among the oldest in the eastern United States. Metamorphic features include layering and foliation. The sedimentary rocks of the park contain mudcracks, ripple marks, bioturbated beds, and salt molds. The volcanic rocks of the Newark Basin (underlying First and Second Watchung mountains) exhibit relict volcanic features, such as vesicles, columnar joints, and pillow structures, which record a history of continental rifting.
- Paleontological Resources. The Jurassic-aged bedrock in the park has the potential to contain Mesozoic fossils, trace fossils such as plant remains, and footprints. Unconsolidated glacial deposits may also contain Pleistocene (ice-age) fossils. The park's fossil record has not yet been formally surveyed.

Geologic resource management issues identified during the GRI scoping meeting and follow-up conference call for Morristown National Historical Park include:

- Erosion. Exposed tree roots indicate areas of erosion on park slopes and along some visitor trails. Portions of trails along park streams are being undercut. The use of social trails is also creating areas of concern. An overpopulation of deer has removed stabilizing understory vegetation, which has exacerbated erosion on park slopes.
- Slope Movement Hazards and Risks. Minor landslides, slumps, rockfall, and slope creep occur at the park. These natural processes are to be expected on the park's steeply sloped landscape. Geologic, morphological, physical, and anthropogenic factors contribute to slope instability and erosion. The mitigation of slope hazards often involves the construction of stabilizing structures.
- Disturbed Lands. Historic mining within and surrounding the area now designated Morristown National Historical Park is represented by two abandoned mineral lands within the park and many mine features beyond its boundaries. Other disturbed land features include two small ponds and several pipes along the East Branch of Primrose Brook.
- Flooding. The Passaic River and its tributaries naturally meander across the landscape in the park. Flooding undercuts and erodes trails, alters river-channel morphology and sedimentation patterns, and can damage infrastructure. Increased precipitation during hurricanes and storms exacerbates these impacts.
- Seismic Activity. Earthquakes that are noticeable by humans are uncommon in New Jersey, although the August 2011 earthquake in central Virginia was felt in the park. A concentration of earthquake epicenters is associated with an active seismic province in the New York City metropolitan area. Earthquakes may damage infrastructure via shaking or trigger slope movements.

Products and Acknowledgments

The NPS Geologic Resources Division partners with institutions such as Colorado State University, the US Geological Survey, state geological surveys, local museums, and universities to develop GRI products. This section describes those products and acknowledges contributors to this report.

GRI Products

The objective of the GRI is to provide 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. To realize this objective, the GRI team undertakes three tasks for each natural resource park: (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 digital geologic map 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 compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (section 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). The "Additional References" section 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://www.nature.nps.gov/geology/inventory/. The current status and projected completion dates of products are at: http://www.nature.nps.gov/geology/GRI_DB/Scoping/Quick_Status.aspx.

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Additional thanks to all of the 2013 conference call participants (Appendix B). Rich Volkert (New Jersey Geological Survey) provided information regarding mining history and mica prospects.

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Geologic Setting and Significance

This section describes the regional geologic setting of Morristown National Historical Park and summarizes connections between geologic resources and other park resources and stories.

Morristown National Historical Park preserves the settings of the quarters for the Continental Army during two critical winters of the American Revolutionary War—January 1777 and December 1779–June 1780. Authorized on 2 March 1933, the park encompasses more than 690 ha (1,710 ac) of land within four units; from north to south, these are Washington's Headquarters (or Ford Mansion), Fort Nonsense, Jockey Hollow Encampment Area, and New Jersey Brigade Encampment Area (fig. 1). The park is located in south-central Morris County and northern Somerset County, near the center of northern New Jersey, 50 km (30 mi). west of New York City. Nearly 305,000 visitors came to Morristown National Historical Park in 2013. The park is located within the Great Swamp watershed and protects the stretches of several streams, including Indian Grave Brook, the Passaic River—both designated Wild Trout streams by the state of New Jersey—and the headwaters of Primrose Brook. Forested, hilly terrain, broad vistas over the undulating landscape, and narrow ravines characterize the landscape of Morristown National Historical Park. General George Washington chose this setting for its accessibility, defensibility, and views to the British encampments in New York (Stanford 2012).

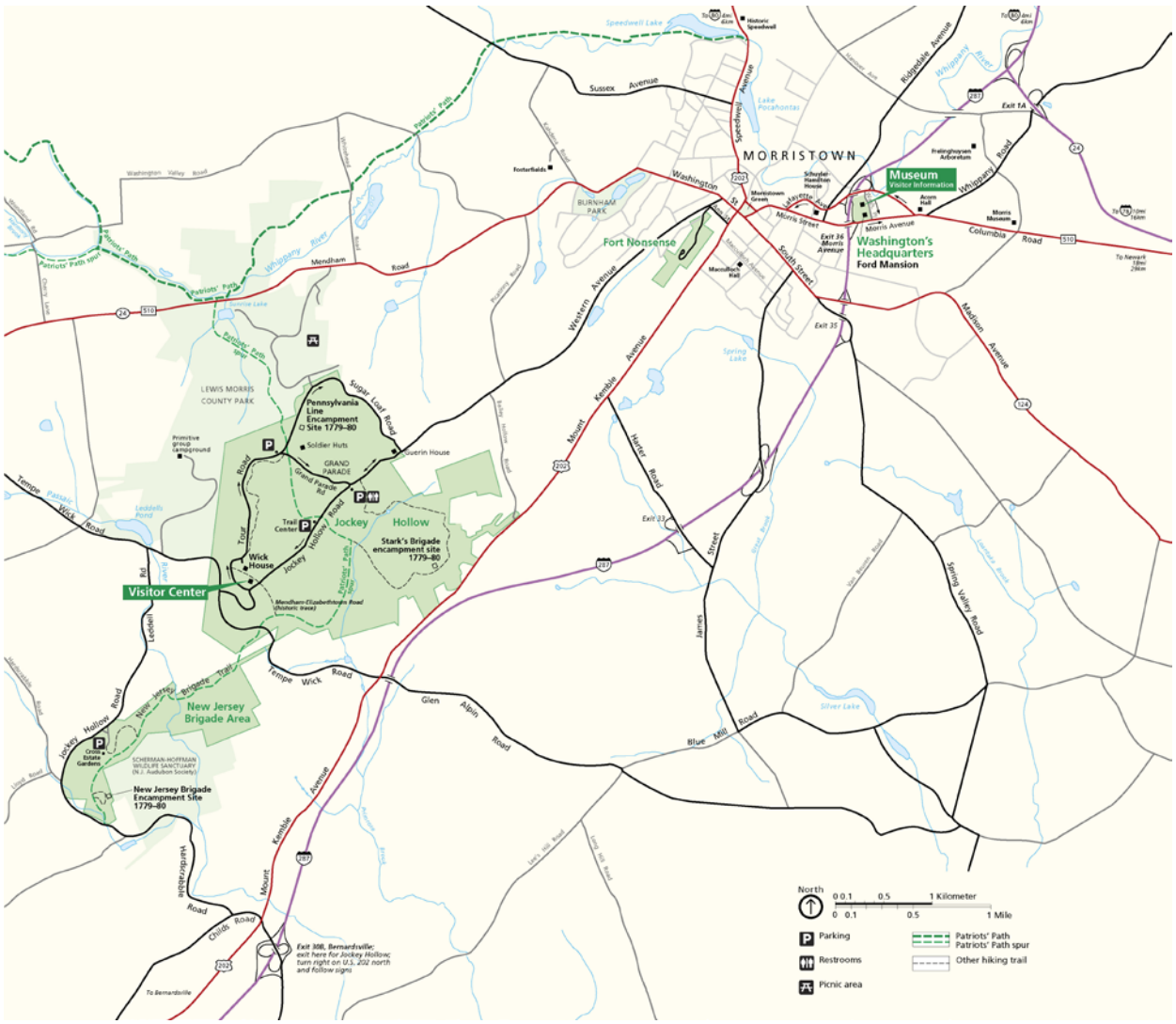


Figure 1. The four units of Morristown National Historical Park. From north to south, the units are (1) Washington's Headquarters, (2) Fort Nonsense, (3) Jockey Hollow Encampment Area, and (4) New Jersey Brigade Encampment Area. National Park Service graphic, available at: http://www.nps.gov/hfc/cfm/carto-detail.cfm?Alpha=MORR (accessed 12 August 2014).

Geologic Setting

The four units of Morristown National Historical Park straddle the border between the New Jersey Highlands and Piedmont physiographic provinces (fig. 2). The New Jersey Highlands are contiguous with the Reading Prong in Pennsylvania and the Hudson Highlands in New York. The Ramapo Fault marks the boundary between the two provinces. It is a major regional normal fault, meaning that rocks above the fault drop down with respect to rocks below it (fig. 3). The southwest–northeast-trending fault forms an escarpment that ranges from 60 to 250 m (200 to 800 ft) high along its length—the Highland Front. Fort Nonsense and the Jockey Hollow and New Jersey Brigade encampment areas are located in the New Jersey Highlands part of the park. The down-dropped block forms the foundation of the Newark Basin (which contains Washington's Headquarters in Morristown), one of a series of extensional basins along the eastern flanks of the Appalachian Mountains in the Piedmont (Eby 1976; Sykes et al. 2008).



Figure 2. Physiographic provinces of New Jersey. Morristown National Historical Park is located along the southern edge of the Highlands province. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Dalton (2003). Shaded-relief base map by Tom Patterson (National Park Service), available at: http://www.shadedrelief.com/physical/index.html (accessed 6 January 2014).

The bedrock ages and rock types exposed on either side of the Ramapo Fault contrast sharply. West of the fault are the approximately 1-billion-year-old crystallized, metamorphic and igneous rocks of the Highlands province ("Y" geologic map units) (figs. 4 and 5). East of the fault are Jurassic-aged sedimentary and igneous rocks ("J" and "JTR" units) that collected in the Newark Basin nearly 200 million years ago. The effects of weathering and erosion on these distinctly different rock types have formed the modern landscape. West of the Ramapo Fault, the erosion-resistant folded, faulted, and deformed rocks of the Highlands province underlie ridges and hills, such as Kemble Mountain (a long, narrow ridge), Mount Kemble (southern end of Kemble Mountain ridge), Tea Hill, Sugar Loaf, and Blachleys Hill—all part of the Trowbridge Range of the Reading Prong. These features are very different from the gently undulating landscape east of the fault and southeast of Morristown, where softer sedimentary rocks are common. In the Newark Basin, the layers of erosion-resistant volcanic basalt (geologic map units Jh, Jp, and Jo) stand out as ridges, such as First and Second Watchung mountains (fig. 6). Softer sedimentary rocks underlie the basin's many swampy areas, including Great Swamp. The Watchung Mountains have an arcuate trace, reflecting the canoe-shaped geometry of the Watchung Syncline (Stanford 2012), a feature consisting of downwarped, folded rocks.

Millennia of weathering and erosion have also contributed to the deposition of two major, unconsolidated, surficial rock unit types ("Q" units): (1) glacial and (2) fluvial and slope deposits. Ice ages during the Pleistocene caused repeated advances of glacial ice across or near the landscape now protected by the park. The park lies between the maxima of the most recent Wisconsinan and earlier pre-Illinoian glaciations (Witte 1998). These glaciers reshaped the landscape and deposited thick glacial sediments, such as till. Glacial lakes, including Lake Passaic, were particularly relevant to the glacial deposits occurring in the area of the present-day park. At its greatest extent (the Moggy Hollow stage), Lake Passaic filled the basin between the Watchung Mountains and the New Jersey Highlands, with Highland Front forming the west wall of the basin (fig. 7) (Stanford 2012). Following the most recent glacial retreat at the end of the Pleistocene (18,000–20,000 years ago), local streams and rivers deeply eroded the glacial deposits, reworking them into alluvial, swamp, and terrace deposits. Deeply weathered bedrock and slope deposits, such as colluvium and talus, mantle the slopes of the park and surrounding area.

Geologic Significance and Connections

The human history of Morristown National Historical Park is directly connected to its geology. From Fort Nonsense, established on Kemble Mountain of the uplifted Highland Front, American forces could see far to the east, through the gaps across the Watchung Mountains, toward the British encampments on Staten Island, New York (fig. 7) (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013).

The Jockey Hollow and New Jersey Brigade encampment area units, where 10,000 soldiers camped in 1,200 log huts, are also part of the Highland Front. Weathered gneiss and gneiss colluvium (Qwg and Qcg) provided building material (i.e., for chinking, fireplaces,

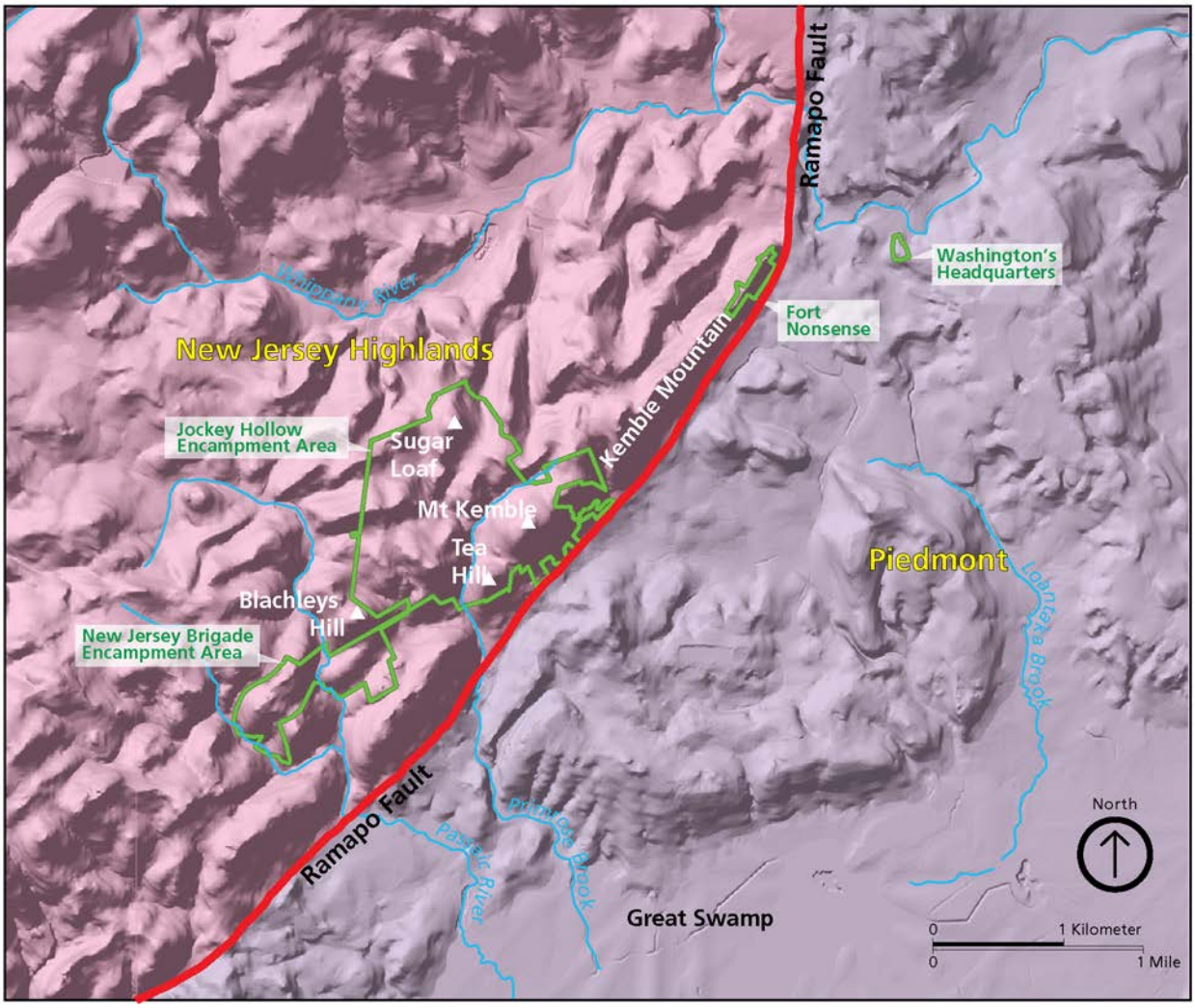


Figure 3. Trace of the Ramapo Fault. The fault (red line) separates the Piedmont (purple area) from the New Jersey Highlands (pink area). Note the stark contrast between landscapes on either side of the fault. The historic encampments abruptly ended along the Ramapo Fault to take advantage of the highlands on the western side. Green lines indicate park boundaries. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with assistance from Georgia Hybels (NPS Geologic Resources Division).

and chimneys) for the huts. Springs and streams, such as the Passaic River and Primrose Brook, provided ample, clean drinking water for the troops. Across the basin, the steep, sharp ridges of the Watchung Mountains, punctuated by only a few narrow gaps, formed a barrier and funneled significant troop movements. General Washington established outposts on the basalt flow ridges of the Watchung Mountains from which British troop movements from the east could be signaled. "Washington's Rock" is part of First Watchung Mountain (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013).

Sand- and gravel-rich deltas (Qmpd) that extended into Lake Passaic during the Moggy Hollow stage underlie Washington's Headquarters in Morristown. These deposits mark the extent of the lake at that time. East of the present-day location of Morristown, terminal moraine deposits rose above the lake as islands. When the lake dropped to the Great Notch stage, the deltaic deposits and terminal moraine emerged as a continuous, well-drained sandy peninsula extending from the location of Morristown to those of Long Hill and Chatham (fig. 6). Due to its morphology and composition, this peninsula created a high-ground transportation corridor from New York City westward across New Jersey. Colonial-era roads, the Morris and Essex Railroad, and New Jersey Transit followed the corridor through the extensive swamps (e.g., the Great Swamp) that developed on poorly drained former lake-bottom deposits to the north and south (Stanford 2012; Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013).

Mining History

After the American Revolutionary War, Morristown's population grew along with an interest in its natural resources. Mica, graphite, iron, and limestone mining occurred throughout the area at various times. Small pits called "dog holes" are remnants of early prospecting

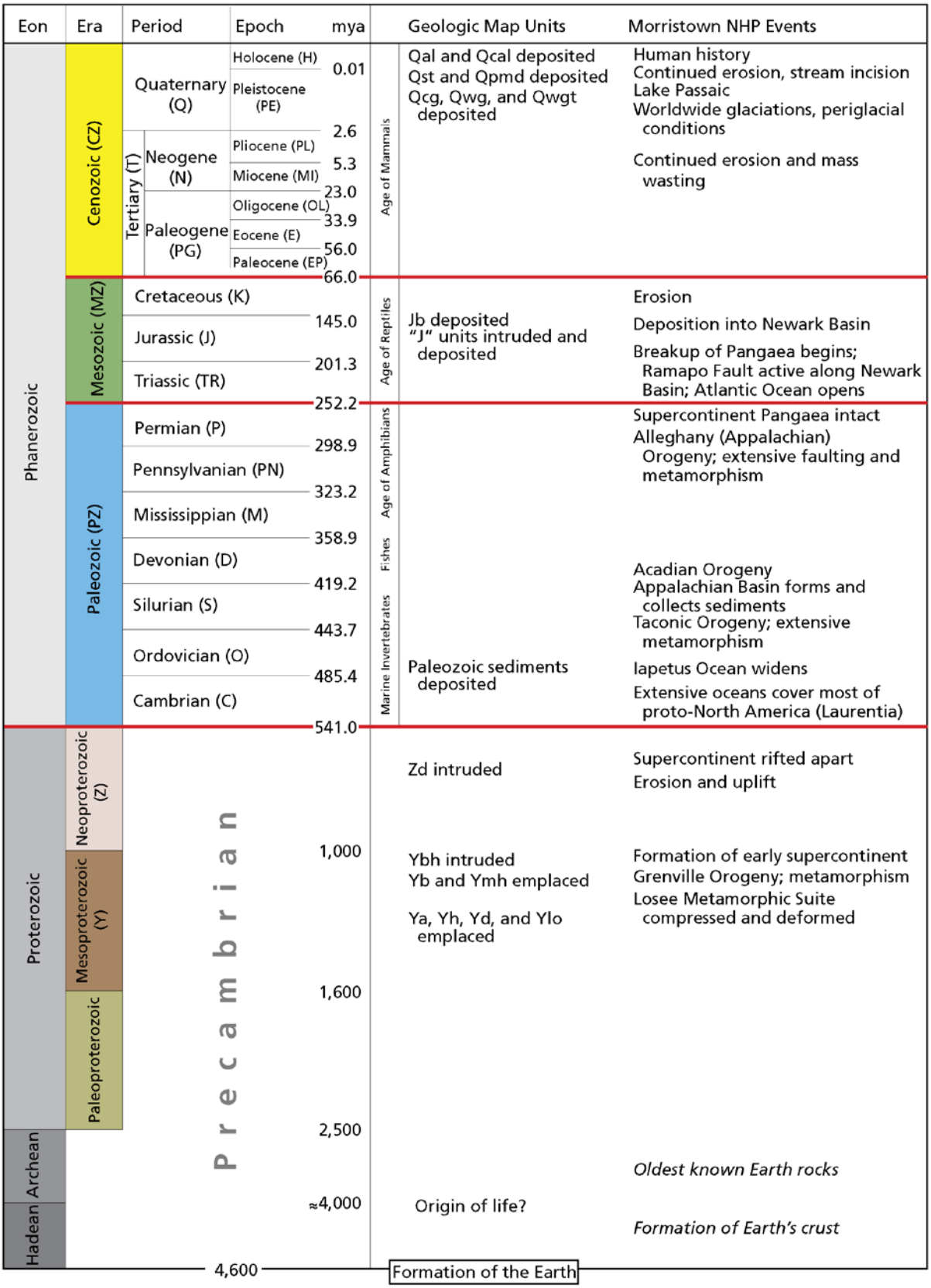


Figure 4. Geologic time scale. The divisions of the geologic time scale are organized stratigraphically, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division are in parentheses. Major tectonic events occurring in the park area are included. Red horizontal lines indicate major boundaries between eras; boundary ages are millions of years ago (mya). The geologic map units for Morristown National Historical Park are also listed stratigraphically. Graphic design by Trista Thornberry-Ehrlich (Colorado State University) and Rebecca Port (NPS Geologic Resources Division), with ages from the International Commission on Stratigraphy (http://www.stratigraphy.org/index.php/ics-chart-timescale; accessed 23 April 2014).

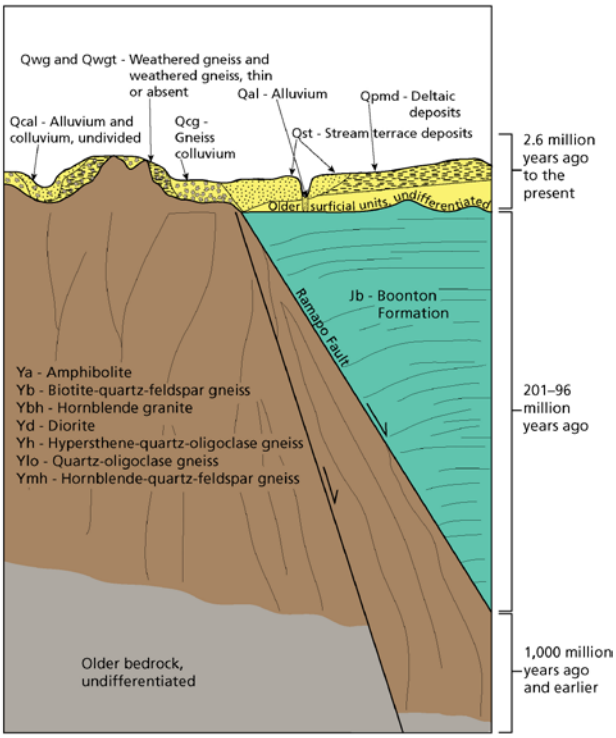


Figure 5. Schematic cross section. The Ramapo Fault separates Mesoproterozoic rocks (brown units) from Jurassic rocks (green units). Geologic map units included are exposed within the four units of Morristown National Historical Park. Colors are standard colors approved by the US Geological Survey to indicate different time periods on geologic maps; they also correspond to the colors on the Map Unit Properties Tables. See the Map Unit Properties Tables for more detail. Graphic is not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Stanford (2006, 2009), Drake et al. (1996), and Lyttle and Epstein (1987).

efforts. Spoil piles are visible at a mica mine that emerges from Lewis Morris County Park, southwest of Sunrise Lake, adjacent to the Jockey Hollow Encampment Area (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013). Another mica mine, consisting of a pair of small prospect pits is along the south side of Sugar Loaf Road in the Jockey Hollow Encampment Area unit (Rich Volkert, New Jersey Geological Survey, geologist, written communication, 21 April 2014). Mesoproterozoic biotite-quartz-feldspar gneiss (geologic map unit Yb) is the host rock for mica deposits for these local mine features (Rich Volkert, New Jersey Geological Survey, geologist, written communication, 21 April 2014). Several 19th-century mica mines were excavated along the banks of the West Branch of Primrose Brook. Sheets of mica minerals occur in fissure veins, which are tabular features, with two dimensions much greater than the third. Fissure veins usually form in two or more stages: (1) the fissure, or opening, forms; and (2) the fissure is then filled with minerals (ore), typically from aqueous or gaseous solutions. As transparent, flame-resistant material, mica sheets were used as windows in stoves and furnaces and in lanterns. Modern uses of mica take advantage of its electrical properties as an insulator and a dielectric. Mica can support an electrostatic field while dissipating minimal energy in the form of heat (Dolley 2010). As the electronics industry flourished after World War II, interest in mica increased (Thornberry-Ehrlich 2007).

A 30 × 30 × 1.5-m (100 × 100 × 5-ft) excavation of unknown origin in the Jockey Hollow Encampment Area unit, south of Jockey Hollow Road, may be a colonial-era graphite prospecting pit (Thornberry-Ehrlich 2007; Rich Volkert, New Jersey Geological Survey, geologist, written communication, 21 April 2014). Mesoproterozoic biotite-quartz-feldspar gneiss (geologic map unit Yb) is the host rock for graphite deposits in the New Jersey Highlands (Rich Volkert, New Jersey Geological Survey, geologist, written communication, 21 April 2014).

Iron-ore mining in the New Jersey Highlands began in the colonial period (Volkert 2002). Other significant mines were excavated in search of limestone and graphite. Graphite was extracted from biotite-quartz-feldspar gneiss (Yb) and marble (Yf). The Dickinson Mine, among the larger graphite mills, was established in 1855 in Morris County, about 21 km (13 mi) west of Morristown National Historical Park (Volkert 2002; Minedat.org 2012). Throughout the 18th and 19th centuries, iron was produced from magnetite deposits in calc-silicate gneiss and hornblende gneiss (e.g., Ymh), as well as some amphibolite layers (e.g., Ya), of the New Jersey Highlands (Mitchill and M'Neven 1828; Gunderson 1990). The first iron mine in New Jersey (and one of the first in the United States) was in Rockaway Township, about 16 km (10 mi) northwest of Morristown. Most iron mines in Morris County were located north and west of the land that the park now encompasses (Hopkins 1867). Lime was quarried from a small belt of Kittatinny Limestone at Peapack, New Jersey, 2 km (1 mi) southwest of the park. A 1902 *Daily Record* article described once-commercial caverns in this location, though their entrances have long been filled (Eckler 1976). The New Jersey Geological Survey maintains a map archive of abandoned mines, available at: http://www.state.nj.us/dep/njgs/enviroed/minemaps.htm (accessed 20 September 2013).

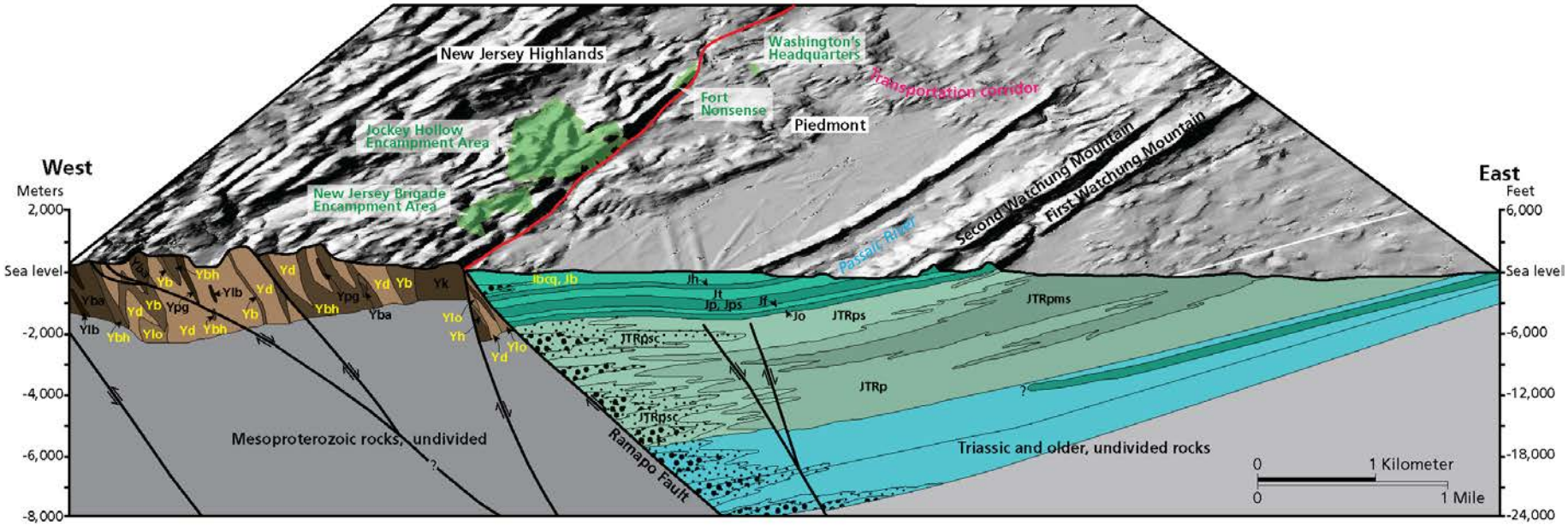


Figure 6. Schematic cross section across the Ramapo Fault with hillshade. Note the contrasting topography on either side of the fault trace (red line). Colors are standard colors approved by the US Geological Survey to indicate different time periods on geologic maps; they also correspond to the colors on the Map Unit Properties Table. Shading was applied to adjacent units for graphical clarity. Unit symbols presented for units in the GRI GIS data; those in yellow occur at Morristown National Historical Park. See the Map Unit Properties Table for more detail. Pink text refers to deltaic deposits that created a high-ground, well-drained transportation corridor through the Great Swamp. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with assistance from Georgia Hybels (NPS Geologic Resources Division) and information from Drake et al. (1996).

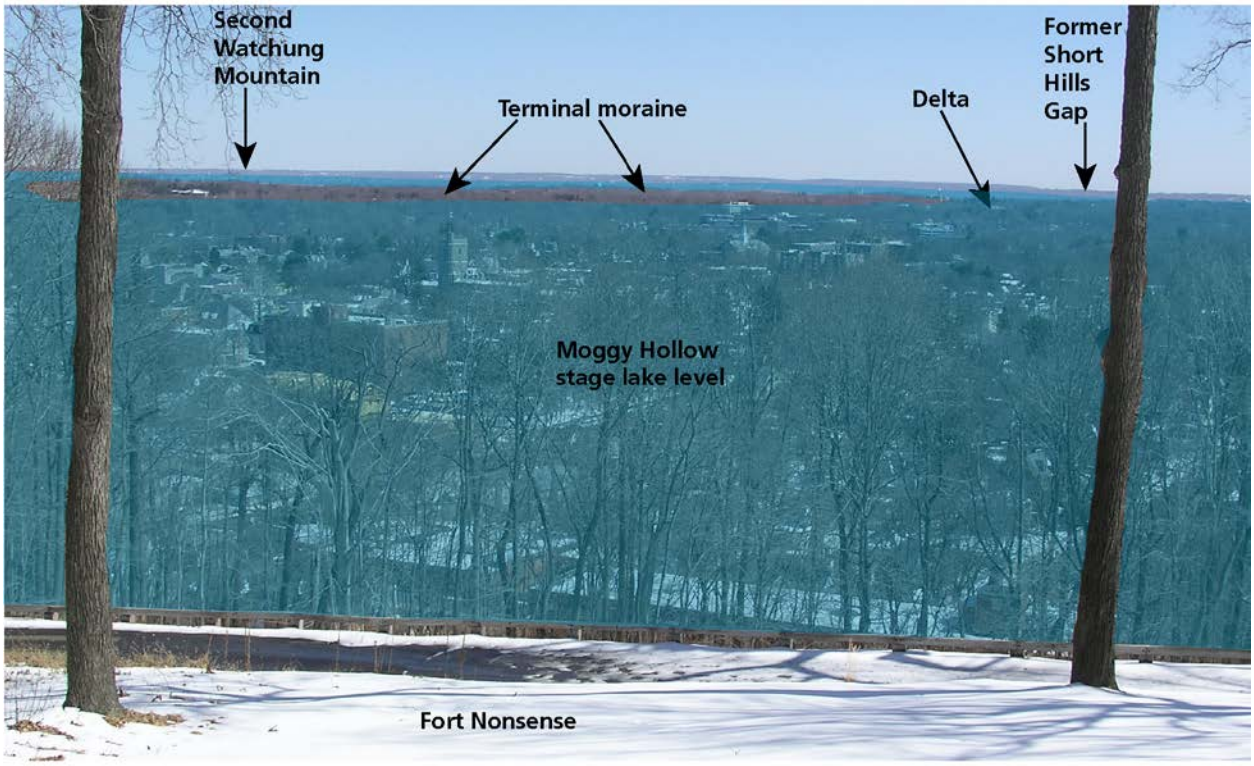


Figure 7. View east from Fort Nonsense. From this vantage point atop the Highland Front, colonial lookouts could see the British encampment in New York City, 50 km (30 mi) away. Transparent blue polygon depicts the lake level during the Moggy Hollow stage of Lake Passaic. Note the locations of the terminal moraine and Second Watchung Mountain. Photograph courtesy of Scott Stanford (New Jersey Geological Survey) with annotation by Trista L. Thornberry-Ehrlich (Colorado State University), after figure 6 in Stanford (2012).

Geologic Features and Processes

This section describes noteworthy geologic features and processes in Morristown National Historical Park.

During the 2007 scoping meeting (Thornberry-Ehrlich 2007) and 2013 conference call, participants (see Appendix A) identified the following geologic features and processes of significance at Morristown National Historical Park:

- Glacial Features
- Periglacial Bedrock Weathering and Thermokarst Topography
- Postglacial Deposits
- Gaps in the Watchung Mountains
- Ramapo Fault and Other Structures
- Bedrock Features
- Paleontological Resources

Glacial Features

Glacial History

Climate during the Pleistocene Epoch alternated between ice ages ("glacials") and relatively warm periods ("interglacials"), which were similar to the modern climate. During periods of glaciation, massive continental ice sheets descended south from the Arctic to cover broad expanses of northern North America (fig. 8). In the park area, glacial deposits record at least three major phases of glaciation. As described in Stanford (2012), the first was the pre-Illinoian glaciation, which occurred between 2.5 million and 800,000 years ago; those glaciers reached the furthest south of the ice-age glaciers in the region of present-day northern New Jersey. The second major glacial event, called the Illinoian glaciation, reached its maximum extent about 150,000 years ago. The third and most recent major glaciation to take place in the area of present-day Morristown is called the Wisconsinan; its maximum extent occurred about 25,000 years ago.

Two lobes of ice from the Wisconsinan ice age shaped the local landscape. The Hackensack Lobe filled the broad lowland between First Watchung Mountain and the Palisades, while the Passaic Lobe advanced over the Watchung Mountains (see fig. 22 in the "Geologic History" section). The Hackensack Lobe was unimpeded by topographic barriers, such as ridges, and descended farther south than the Passaic Lobe (Stanford 2012). Glacial ice and sediments intermittently filled local gaps or low spots in local ridges and impounded a series of glacial lakes that feature prominently in the geomorphological history of the Morristown area, particularly the Washington's Headquarters unit of the park.

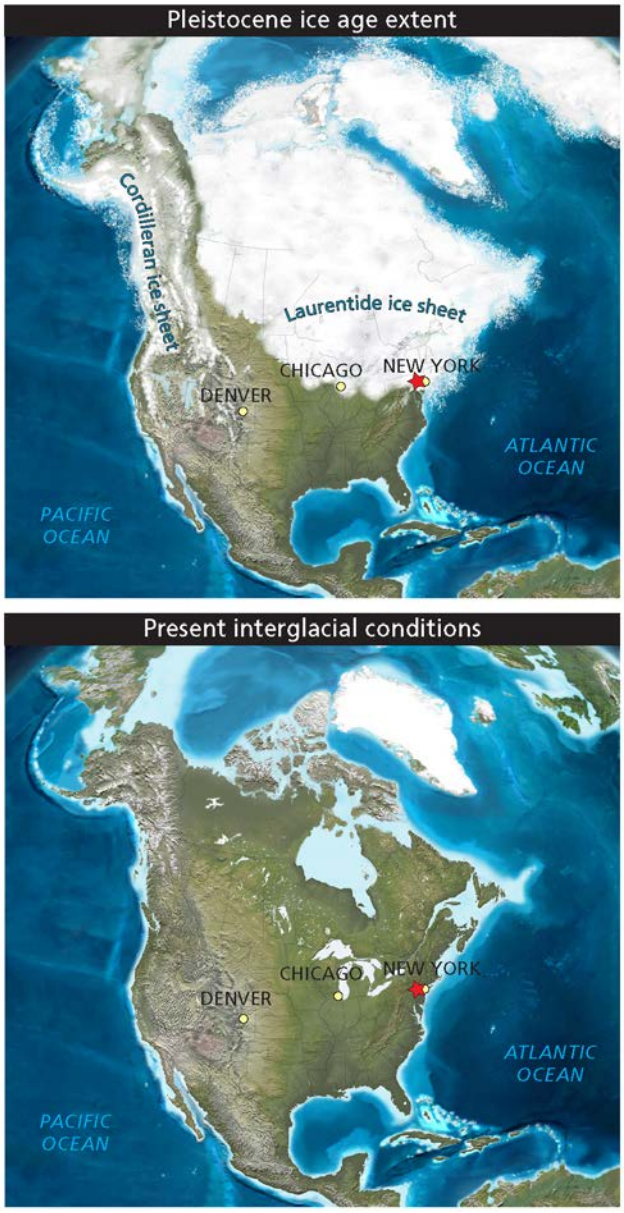


Figure 8. Ice-age *versus* interglacial conditions. Nearly half of North America was covered by sheets of ice during the Pleistocene glaciations. Relative sea level drops during glaciations (note the width of Florida). The location of Morristown National Historical Park is denoted by a red star. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), produced using base paleogeographic maps created by Ron Blakey (Colorado Plateau Geosystems, Inc.), available at: http://cpgeosystems.com/index.html (accessed 21 January 2014).

Glacial Deposits and Landforms

Glaciers deposit myriad types of sediment and create a variety of landforms (fig. 9). As described in detail in the Map Unit Properties Table and the "Geologic History"

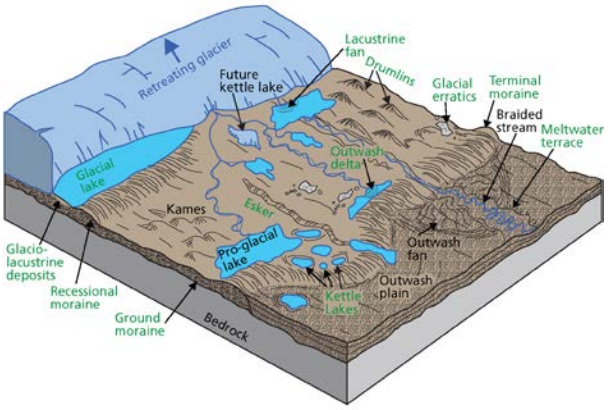


Figure 9. Glacial features and deposits. Glacial features that affected the landscape or are occurring in the area of Morristown National Historical Park are labeled in green. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

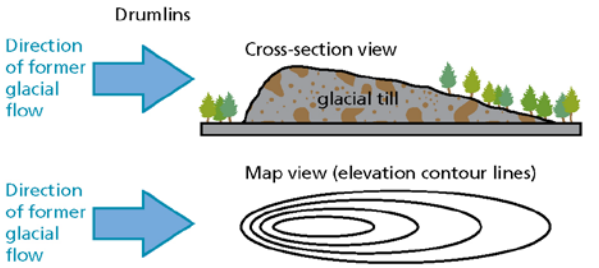


Figure 10. Drumlin formation. Drumlins are low, smoothly rounded, elongate oval hills that are formed by the movement of a glacier atop previously deposited glacial till. The long axis of the drumlin is parallel to the direction of glacial ice movement. Drumlin locations in Morristown National Historical Park are indicated in the GRI GIS data. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

section, glacial deposits in the area of present-day Morristown include those deposited directly by moving ice and those deposited by meltwater in rivers or lakes. Such features and deposits are significant in the mapped area, although none is mapped within the park. The weathered bedrock units mapped in the park are discussed in the "Periglacial Bedrock Weathering and Thermokarst Topography" section.

Mapped deposits and features associated with moving ice, included in the GRI GIS data, include till, moraines, drumlins, erratics, and kettles. Glacial till, a mixed assortment of sediments dumped in place when a glacier melts, mantles much of the bedrock in and around the town of Morristown. Distinct glacial tills include, from youngest to oldest: the Rahway Till (geologic map units Qr, Qry, Qtmr, and Qrt), the Netcong Till (Qn, Qtmn), the Flanders Till (Qtif), and the Bergen Till (Qb). Some till forms moraines, which are ridges of material that mark the edges of a glacier. Terminal moraines, also called "end moraines," mark the farthest advance of a glacier. They are included in the "Glacial Feature Lines" layer of the GRI GIS data, as are units Qtmr, Qtmn, and Qimt. One terminal moraine is located about 1 km (0.5 mi) northeast of the Washington's Headquarters unit. Drumlins, elongated linear hills formed when a glacier flowed over a mass of sediment, indicate the direction of glacial flow (fig. 10). They are mapped ("Glacial Feature Lines" layer in GRI GIS data) near Morristown Municipal Airport and are oriented northeast–southwest, indicating the direction of glacial movement in the area. Glacial erratics are large rocks transported some distance by ice and then deposited when the ice melted. Erratic rocks or boulders that were "ice rafted" into Lake Passaic can be found in units Qpmb, Qpc, and Qps. Erratics are also found in unit Qcb and pre-Illinoian till (e.g., Qpt). Kettles are low areas (now holding water or containing peat) formed when a large block of glacial ice, which was partially or totally buried by glacial sediment, melted, leaving a depression. Kettles are mapped along the Rahway Till terminal moraine from Convent Station to Chatham, southeast of the Washington's Headquarters unit. Glacial basins, which are "seasonally wet" and contain thin peat deposits, are mapped along the Rahway Till north from the town of Morristown.

Other glacial deposits from meltwater are termed "glaciofluvial" (deposited by rivers flowing out of glaciers) or "glaciolacustrine" (deposited in lakes near glaciers). Eskers, one type of glaciofluvial feature included in the GRI GIS data, are sinuous ridges of sand and gravel deposited beneath a stagnant (not moving) or retreating glacier and left behind when the glacier melted. They are mapped near Madison, about 5 km (3 mi) southeast of the Washington's Headquarters unit. Glaciolacustrine deposits are common in the map area and are associated primarily with Glacial Lake Passaic. The GRI GIS data differentiate a variety of lake-bottom, deltaic, and beach units (see Map Unit Properties Table).

Glacial Lake Passaic

Glacial Lake Passaic was prominent among a series of lakes, including Lake Watchung, which formed in basins during the ice ages, more than 10,000 years ago. As described in the "Gaps in the Watchung Mountains" section, differential erosion formed a 50 × 16-km (30 × 10-mi) basin bound by the Highlands Front to the west and the basalt ridges in the Newark Basin to the east (see fig. 22A in the "Geologic History" section). The basalt ridges are punctuated by two sets of gaps. When the first Pleistocene glaciation blocked these gaps, diverting the proto-Hudson River drainage, Lake Watchung formed in the southernmost part of the basin (Stanford 2012; Scott Stanford, New Jersey Geological Survey, geologist, written communication, 21 February 2014). Sediments deposited in this lake reveal that the elevation of the lake rose to more than 140 m (450 ft), approximately 30 m (100 ft) higher than Lake Passaic (Stanford 2012). As the glacier retreated, the course of the drainage system changed. The new local drainage network included courses of what would become the Passaic and Raritan river drainages (Stanford 2012).

Lake Passaic was the largest glacial lake located entirely within the modern boundaries of New Jersey; it filled the central Passaic River Basin between the Mesoproterozoic gneisses of the Highlands province and the Jurassic basalts of Second Watchung Mountain. As glacial ice advanced or retreated, the configuration opened or closed gaps in the Watchung Mountains, which altered

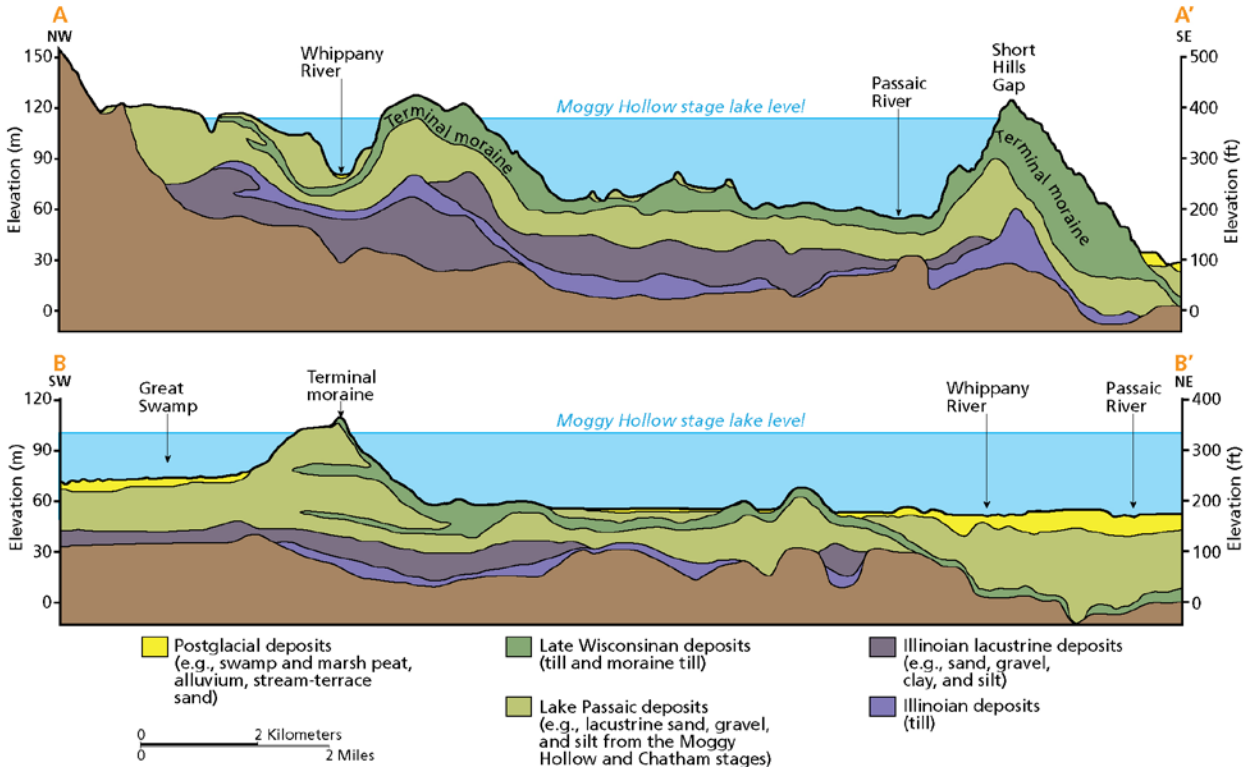


Figure 11. Stratigraphy and geomorphology of glacial and postglacial stages in Lake Passaic Basin. Approximate locations of cross sections are indicated by orange lines on figure 22G. Vertical scale is exaggerated to show distinct differences in the topographic expression of the deposits. Original graphic from Stanford (2012; figure 2), modified by Trista L. Thornberry-Ehrlich (Colorado State University).

Lake Passaic's depth and extent. These stages are called, from oldest to youngest, Chatham, Moggy Hollow, and Great Notch. Refer to the "Geologic History" section and fig. 22 for a detailed history. A shallower "Lake Passaic" also existed during the earlier Illinoian glacial, although the Wisconsinan Lake Passaic is much better represented in the geologic record (Stanford 2012).

Three postglacial lakes, called Totowa, Millington, and Stanley, were remnants of Lake Passaic after the Great Notch stage drained. A lacustrine fan blocked the Passaic Valley in a narrow reach downstream from Little Falls, damming the Totowa stage. The Millington stage filled the Great Swamp Basin, which was dammed by a terminal moraine and delta complex that blocked the Passaic River Valley in the current location of Chatham. A terminal moraine dammed the Passaic River at present-day Stanley (in the Passaic River Parkway, upstream from Mount Vernon Avenue in Summit, New Jersey), forming the stage of the same name. Each of these sediment dams slowly eroded away and the lakes drained, leaving broad floodplains and marshes that are underlain by lacustrine clay and sand (fig. 11) (Reimer 1984; Stanford 2012). Draining and channeling left a complex pattern of sandy islands, marshes, and swamps in the Great Swamp of today.

Lake Passaic deltaic deposits (Qpmd) have been mapped in the Washington's Headquarters unit of the park (Stanford 2006, 2007). Sand and gravel collected in deltas stretching toward the center of Lake Passaic during the Moggy Hollow stage, when the glacier blocked Short Hills Gap. These deltaic deposits are prominent at Summit, along the front of the terminal moraine in Chatham and Madison, at Morris Plains, and along the front of the terminal moraine between Morristown and Madison (Stanford 2006, 2007). The Jockey Hollow Encampment Area unit contains glacial lake clays, visible on a stream bench, which predate Lake Passaic (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013). These deposits are too small in extent to appear on the source geologic map.

Coarser, well-drained, sorted deposits, such as the deltaic deposits, were important to the history of Morristown National Historical Park. These deposits allow water to flow or percolate through them more readily than very fine-grained, clay-rich deposits, such as lake-bottom deposits (Qpml, not exposed at the park). A well-drained ridge of sandy material occurs across the Lake Passaic Basin from Morristown to Chatham. Its morphology and composition created a high-ground transportation corridor from New York City westward across New Jersey (fig. 6, pink text). Surface water does not shed easily from the clay-rich units in low-lying areas; they underlie swamps and marshes (Qs), such as the Great Swamp National Wildlife Refuge.

Periglacial Bedrock Weathering and Thermokarst Topography

The term "periglacial" describes processes, climates, areas, and topographic features produced by permafrost,

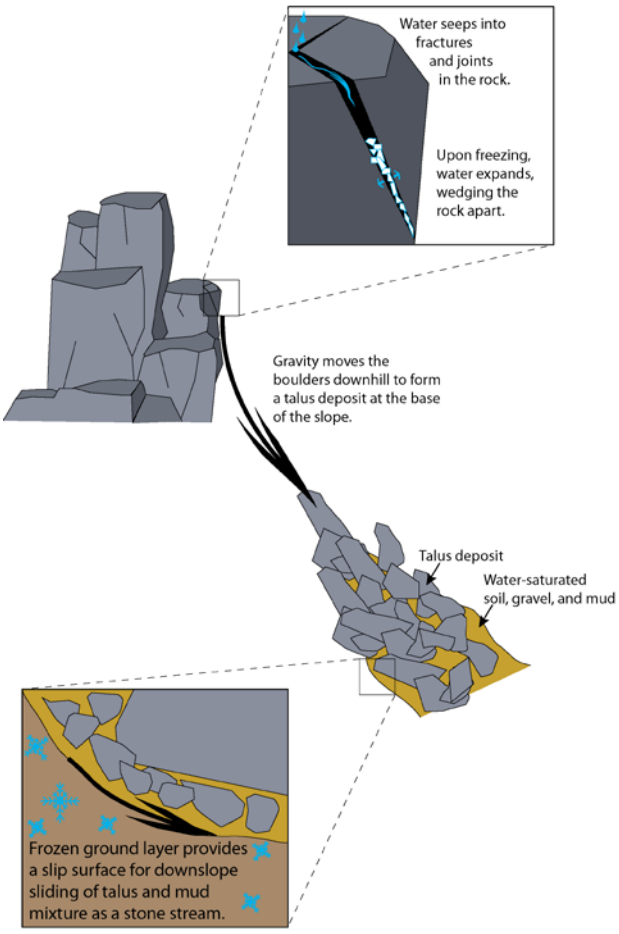


Figure 12. Frost weathering in fractured bedrock. Pinnacles or chimneys of rock remain standing while talus and colluvium litter the hillside below. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

frequently occurring at the margins of (but not covered by) former or existing ice sheets, that were influenced by the cold temperature of the ice. The term can also apply to environments in which frost weathering is an important factor. All four units of Morristown National Historical Park are within about 12 km (7.5 mi) of the maximum extent of Wisconsinan glaciation and within the area covered by pre-Wisconsinan glaciers. Rocks in what is now the park were thus significantly weathered (broken apart) by periglacial processes.

Frost weathering is common in periglacial conditions and occurs via the alternating freezing and thawing of water in rock or mineral particles (fig. 12). As described in Walder and Hallet (1985), Hallet (2006), and Matsuoka and Murton (2008), under temperature ranges of –4°C to –15°C (25–5°F), water seeps into cracks and fractures in rock and when it freezes and expands, the rocks are wedged apart to fall downslope under the force of gravity. Ice segregation also occurs as water migrates through porous rock or soil toward lenses of ice. The migration and subsequent enlargement of the ice lenses propagates cracks through the rock (Matsuoka and Murton 2008). Rocks that have been wedged apart by frost weathering can be transported downslope by water, gravity, or solifluction (a type of slope movement wherein water-saturated sediment slides downslope over impermeable frozen ground). Frost weathering continues to occur today, but was especially active during the Pleistocene glacial periods.

The predominant surficial units in Morristown National Historical Park are weathered gneiss (Qwg and Qwgt) and gneiss colluvium (Qcg), which formed during the Middle to Late Pleistocene as cold climates increased rates of frost weathering and solifluction. Weathered gneiss (a mixture of sand, silt, clay, and "rotten" cobbles of gneiss) has been mapped throughout the Fort Nonsense, New Jersey Brigade Encampment Area, and Jockey Hollow Encampment Area units (Stanford 2006, 2009; Stone et al. 2002). During times of colder climate, all types of bedrock were extensively weathered, as recorded in units of colluvium (a heterogeneous, jumbled slope deposit) that mantle slopes throughout the area, including conglomerate colluvium (Qcc), shale colluvium (Qcs and Qcsl), and basalt colluvium (Qcb and Qcbl). Gneiss colluvium (Qcg) has been mapped in the New Jersey Brigade and Jockey Hollow encampment area units (Stanford 2006, 2007, 2009; Scott Stanford and Don Monteverde, conference call, 8 August 2013). Colluvium units throughout the area display a cyclic pattern of heavily weathered clasts in the interior parts of thick deposits, beneath a surficial colluvium layer of fresh (unweathered) clasts (Stanford 2007; Scott Stanford, New Jersey Geological Survey, geologists, written communication, 21 February 2014). This stratigraphy records repeated deposition of colluvium during colder glacial periods, and relative slope stability and increased chemical weathering during warmer interglacial periods (Stanford 2007).

Thermokarst topography is a hummocky landscape that develops when "ground ice" (nonglacial ice buried in seasonally or perennially frozen ground) melts and the ground settles. Ground ice would have been very common during the ice ages. As mapped in the GRI GIS data, much of the Great Swamp and surrounding area includes thermokarst topography, developed on stream-terrace sand.

Postglacial Deposits

After the glaciers retreated from the landscape, the glacial lakes eventually drained. Prior to the re-establishment of vegetation, rivers incised the glacial deposits, creating terraces (Qst [mapped in a very small area along the Washington's Headquarters unit boundary] and Qstu), channels, and floodplains (fig. 11) (Stanford 2006, 2007, 2009; Stone et al. 2002). Winds swept across the bare earth and transported fine-grained sand and silt, depositing them in sheets and dunes of aeolian materials (Qe, not mapped in the park) (Stanford 2006, 2007, 2009). Loess (wind-winnowed silt) deposits scoured from lake sediments occur on the flanks of the hills bordering the ancient Lake Passaic Basin (Stanford 2007). During the past 10,000–12,000 years, deposits of Holocene alluvium and colluvium (Qal, Qcal) collected on the landscape now contained within the New Jersey Brigade and Jockey Hollow encampment area units. Alluvium is deposited by streams and rivers, including

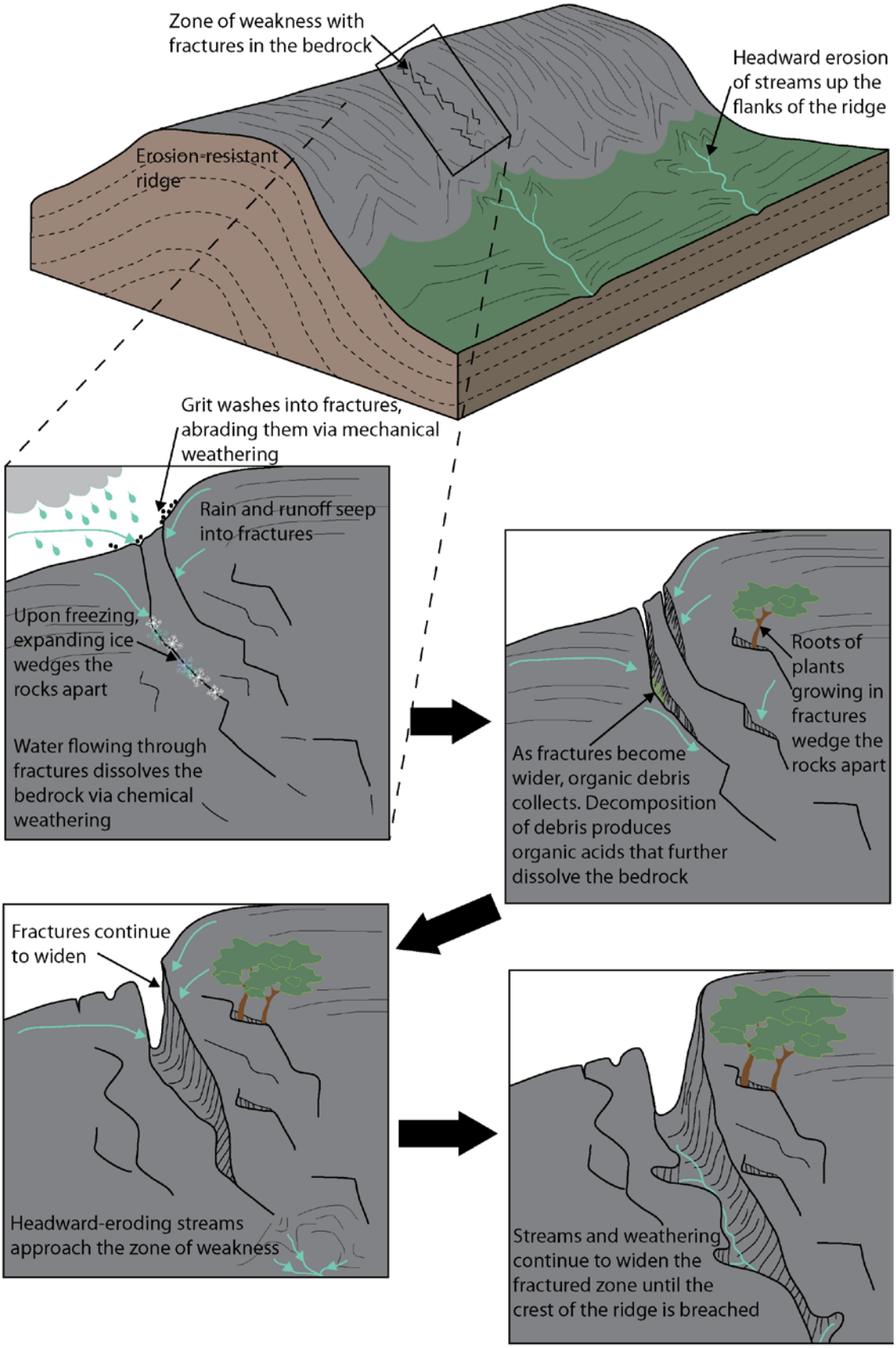


Figure 13. Gap formation. Weathering processes preferentially remove material from areas of weakness that result from processes such as faulting, fracturing, or folding in bedrock. Streams may or may not flow through gaps. Gaps in the area of Morristown National Historical Park include historically significant features in the Watchung Mountains: Short Hills, Paterson, Little Falls, and Millburn gaps. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Passaic River and Primrose Brook, along their channels. Colluvium collects as slope deposits weathered from a bedrock exposure that tumble downslope under the force of gravity.

Gaps in the Watchung Mountains

Throughout the Appalachian Mountains, erosion-resistant rocks, such as quartzites and basalts, form ridges after less-resistant surrounding rocks have been eroded away. First and Second Watchung mountains are supported by resistant Jurassic basalt flows (Jo and Jp, respectively). The Watchung Mountains form the eastern boundary of a 50 × 16-km (30 × 10-mi) basin that is bound on the west by the Highland Front. The basin is punctuated by only two sets of gaps: the adjacent gaps at Short Hills and Millburn, and the gaps at Little Falls and Paterson (fig. 6 and fig. 22A in the "Geologic History" section) (Stanford 2012). Gaps typically form where weathering processes exploit zones of weakness in otherwise erosion-resistant rocks (fig. 13). A zone of weakness can form as a result of continent-scale forces that break rocks, break and move rocks along a fault, or fold and deform rocks along a flexure (or "hinge," an area of maximum curvature or deformation in folded rocks). For example, Delaware Water Gap, namesake of Delaware Water Gap National Recreation Area (50 km [30 mi] west of Morristown National Historical Park), formed at a flexure or "kink" in the bedrock (Epstein 2001; see GRI report by Thornberry-Ehrlich 2013). The Hudson River cut the gaps in the Watchung Mountains in the Pliocene, between 5.3 million and 2.6 million years ago (see fig. 22A) (Johnson 1931; Stanford 2010). At present, the gap sites contain no known major structural or other weakness (Scott Stanford, New Jersey Geological Survey, geologist, written communication, 21 February 2014). Regardless of the mechanism of their formation, blockage of these gaps by glacial ice during the Pleistocene impounded a series of glacial lakes.

Ramapo Fault and Other Structures

A fault is a fracture in rock along which rocks have moved. The three primary types of fault are normal, reverse, and strike-slip faults (fig. 14). The Ramapo Fault is a regionally significant normal fault, meaning that rocks above (east of) the fault plane dropped down with respect to those below (west of) the plane. The Ramapo Fault created the Highland Front, an escarpment ranging from 60 to 250 m (200 to 800 ft) high, which marks the geologic boundary between the New Jersey Highlands and Piedmont provinces (fig. 3). The Ramapo Fault was active about 200 million years ago, as Pangaea split apart and the Atlantic Ocean began to form. Normal faults are common in such settings, but movement along the Ramapo Fault may have occurred earlier. Geologists have surmised that the fault is a much older structure, formed during the orogenies (mountain-building events) that created the Appalachians and assembled Pangaea (see the "Geologic History" section) (Ratcliffe et al. 1990; Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013). During those orogenies, the fault would have been

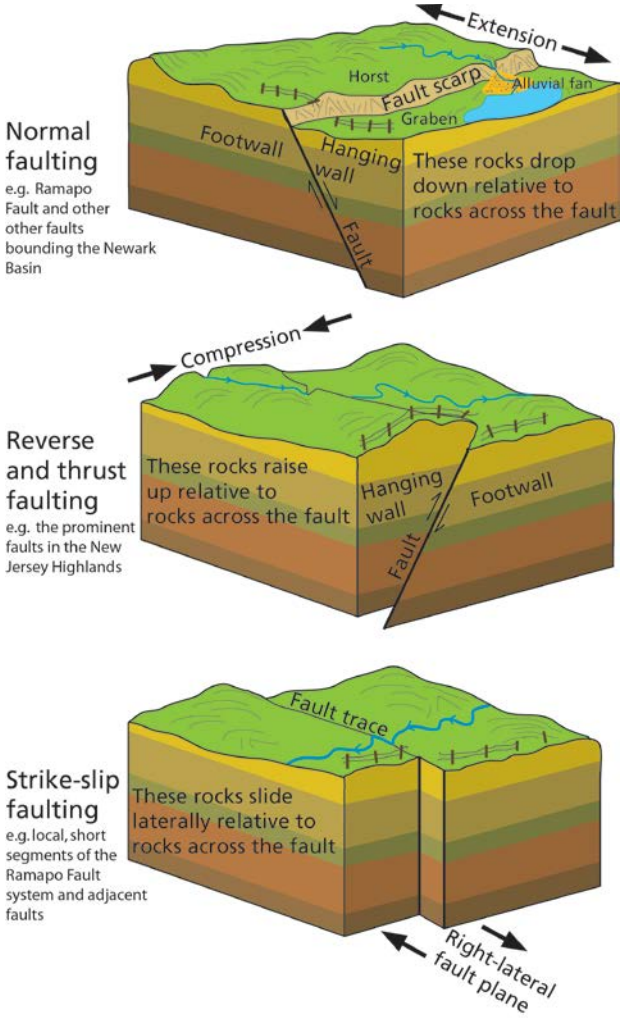


Figure 14. Schematic illustrations of fault types. Movement occurs along a fault plane. Footwalls are below the fault plane and hanging walls are above it. In a normal fault, crustal extension (pulling apart) moves the hanging wall down relative to the footwall. In a reverse fault, crustal compression moves the hanging wall up relative to the footwall. A thrust fault is similar to a reverse fault, but has a dip angle of less than 45°. In a strike-slip fault, the relative direction of movement of the opposing plate is lateral. When movement across the fault is to the right, it is a right-lateral (dextral) fault, as illustrated above. When movement is to the left, it is a left-lateral (sinistral) fault. A strike-slip fault between two plate boundaries is called a transform fault. Graphic by Trista Thornberry-Ehrlich (Colorado State University).

a reverse or thrust fault, with direction of motion opposite that of a normal fault (fig. 14). Such structures provided zones of weakness as the tectonic setting changed from compressional to extensional.

Several studies have explored the possibility that the Ramapo Fault remains active (Ratcliffe 1982; Ratcliffe et al. 1990). Quaternary deposits associated with the Whippany and Passaic rivers (which cross the fault in the park area) are undisturbed by the presence of the fault (i.e., no scarp or offset potentially indicating recent surface movement) (Aten 1977). Trenching at the base of Mount Kemble along the fault trace has also revealed no evidence of late Quaternary movement on the Ramapo Fault (Ratcliffe et al. 1990). Undisturbed surficial deposits reveal that modern seismicity, if controlled by

reactivation of the Ramapo Fault, has not propagated to the surface or is of a sufficiently low rate of recurrence that even cumulative offset events are not detectable (Ratcliffe et al. 1990). Some smaller active faults appear to cross the Ramapo Fault (Jacob et al. 2004). These faults may include those noted at the GRI scoping meeting and mapped in the GRI GIS data (Thornberry-Ehrlich 2007).

Earthquake epicenters are aligned roughly parallel to and west of that of the east-dipping Ramapo Fault System, forming part of a large, seismically active province in the northeastern United States. The province is marked by a generally southwest–northeast-trending pattern of earthquake epicenters extending from eastern Pennsylvania, through New Jersey, and into the Hudson Highlands in New York (fig. 15). Although the epicenters are scattered, they appear to cluster along several geologic features, including the Ramapo Fault System (Jacob et al. 2004). Because the Ramapo Fault dips eastward and the epicenters plot west of the fault trace (in the brittle gneissic bedrock of the Highlands), this seismicity is not likely due to movement along the Ramapo Fault (Scott Stanford, New Jersey Geological Survey, geologist, written communication, 21 February 2014).

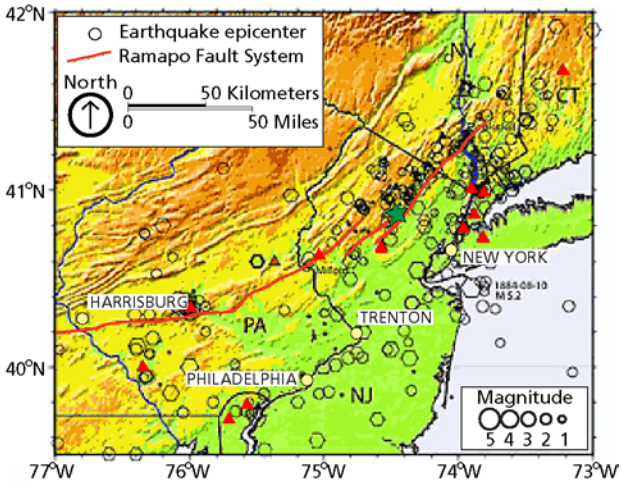


Figure 15. Epicenters of earthquakes occurring between 1627 and 2003 in the New York City metropolitan area. Seismographic stations are denoted by red triangles. The green star denotes the location of Morristown National Historical Park along the fault. Note the concentration of seismic events near the fault. Local earthquake epicenters are included in the GRI GIS data. Graphic from Jacob et al. (2004), adapted by Trista L. Thornberry-Ehrlich (Colorado State University).

Folds are curves or bends in originally flat structures, such as rock strata, bedding planes, or foliation. The two primary types of fold are anticlines, which are "A-shaped" (convex), and synclines, which are "U-shaped" (concave). Both types of fold can be overturned—tilted past vertical—by continued or future tectonic forces. Folds frequently "plunge," meaning that their axes tilt. The GRI GIS data include several folds and minor faults (see geologic map in pocket). The prominent New Vernon Anticline is in the midst of the canoe-shaped Watchung Syncline just east of the park. The anticlinal axis terminates at the trace of the Ramapo Fault and forms one of the axes of the New Vernon Dome (Ratcliffe et al. 1990). An overturned synform and parallel plunging antiform occur west of the Ramapo Fault in the Mesoproterozoic gneisses (Yb, Ybh, and Ylo) (Drake et al. 1996). The antiform axis crosses the southeastern corner of the New Jersey Brigade Encampment Area unit.

Small-scale normal faults radiate from the New Vernon Dome like spokes. Their offsets are identical to that of the Ramapo Fault—uplifted blocks on the west sides and down-dropped blocks on the east sides. A normal fault has been mapped between the Jockey Hollow and New Jersey Brigade encampment area units, and two parallel normal faults have been mapped just beyond the northeastern and southwestern ends of the Fort Nonsense unit (Drake et al. 1996).

Bedrock Features

Bedrock exposures are uncommon in Morristown National Historical Park (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013; see also the GRI GIS "Bedrock Outcrops" layer). Weathered bedrock, slope deposits, and regolith mantle and obscure much of the bedrock. Bedrock mapped in the park includes metamorphic and sedimentary rocks. The structures, fabrics, textures, and colors of the rocks provide information about the environments and conditions under which they formed and, thus, the geologic history of this part of New Jersey. These features are detailed for each geologic map unit in the Map Unit Properties Table. Volcanic rocks, although not mapped in the park, feature prominently in the park's story (see "Geologic Significance and Connections" section).

Metamorphic Rocks and Features

Rocks of the New Jersey Highlands are the roots of an ancient mountain chain constructed intermittently over hundreds of millions of years during several major orogenies (see the "Geologic History" section). These rocks, more than 1 billion years old (Middle Proterozoic Era; "Y" units), are by far the oldest in Morristown National Historical Park and among the oldest in eastern North America (Volkert 1988a, 1988b, 2004; Volkert and Drake 1999).

As described on the Map Unit Properties Table, Middle Proterozoic rocks in the park are predominantly gneiss. Gneiss is metamorphic, meaning that the original (in this case, marine or volcanic) rocks were altered by high temperature or pressure to form a new rock type. More specifically, gneiss is a "foliated" metamorphic rock in which the minerals are aligned, with common alternation between light and dark mineral bands resulting in a striped (foliated) appearance. Gneisses are named based on constituent minerals, for example, biotite-quartz-feldspar gneiss (Yb), hornblende-quartz-feldspar gneiss (Ymh), hypersthene-quartz-oligoclase gneiss (Yb), and quartz-oligoclase gneiss (Ylo) (Drake et al. 1996). The foliation of the rocks in the GRI GIS data is an indicator of metamorphic conditions—high temperature and

pressure on the order of 700–800°C (~1,300–1,500°F) and 12 kilobars (~170,000 lb/in^2)—associated with multiple continental collisions and deformation episodes over hundreds of millions of years. The mineral properties suggest that they formed many thousands of meters below the lofty peaks of the ancient mountain range. Morristown National Historical Park thus provides the opportunity to view the infrastructure of an ancient mountain belt—a window into Earth's ancient crust. See the "Geologic History" section for more information.

Sedimentary Rocks and Features

Sedimentary rocks are composed of rock fragments that were transported by moving water or wind and deposited as sediments, which then eventually solidified. Sedimentary rock features may contain clues as to the conditions at the time of deposition; some original sedimentary features may persist even in rocks that have undergone metamorphism. The only sedimentary rocks mapped in the park are those of the Jurassic Boonton Formation (Jb) in the Washington's Headquarters unit. They are not likely to be exposed, however. The Boonton Formation and similar sedimentary rocks are common in the Newark Basin. They contain mudcracks, ripple marks, symmetrical ripples, fining-upward sequences, burrows, and "pseudomorphs" of evaporite salts (Drake et al. 1996). Mudcracks form when mud and clay shrink upon drying. Ripple marks form in sediment shaped by moving water. Organisms create burrows for dwelling or feeding in soft sediment, which may remain when the sediment is lithified. "Pseudomorphs" occur when another mineral fills the space of, and therefore takes the shape ("morph") of, a previous mineral. In the Boonton Formation, the replaced minerals were salts, such as halite and gypsum, which originally precipitated when water evaporated.

All of these features can be found in modern environments and suggest the presence of flowing water in a climate sufficiently arid to allow the evaporation of stagnant water. Thus, geologists have inferred that the rocks of Newark Basin were deposited in nearshore environments, including alluvial fans, streams, deltas, and shallow-water basins (Drake et al. 1996).

Volcanic Rocks and Features

Igneous rocks form when molten material cools and solidifies at (extrusive ["volcanic"] igneous rocks) or beneath (intrusive ["plutonic"] igneous rocks) the Earth's surface. Igneous rocks are classified by texture (grain size, shape, orientation) and percentages of major minerals (quartz, alkali feldspar, and plagioclase) present. Geologists use silica content to classify volcanic rocks (table 1).

The percentage of silica influences many properties of magma, including viscosity and explosiveness. With respect to viscosity (internal friction), low-silica basalts form fast-moving, fluid, lava flows that spread out in broad, thin sheets up to several kilometers wide. The amount of dissolved gas in and viscosity of the magma determines the explosiveness of an eruption. Low-viscosity basalts allow the gases to migrate rapidly through the magma and escape to the surface. High-viscosity magmas, such as rhyolite, impede the mobility of gas and cause intense pressure and thus, explosive eruptions.

Table 1. Volcanic rock classification and characteristics.

Name	Percentage Silica (SiO_2)*	Viscosity	Explosiveness
Rhyolite	>72%	High	High
Rhyodacite	68%–72%		
Dacite	63%–68%		
Andesite	57%–63%		
Basaltic andesite	53%–57%		
Basalt	<53%	Low	Low

** from Clynne and Muffler (2010).*

Volcanic rocks have not been mapped in the park, but they form the Watchung Mountains, which played an important role in the selection of Morristown as a Revolutionary War winter encampment site (see the "Geologic Significance and Connections" section). Three primary basalt formations are included in the GRI GIS data: Hook Mountain Basalt (Jh), Preakness Basalt (Jp), and Orange Mountain Basalt (Jo). Basalt is a dark, low-viscosity (very fluid) basalt that typically erupts effusively (similar to Hawaiian volcanoes), rather than explosively (similar to the modern Cascades). Basalts mapped in the Morristown area contain vesicles and amygdules, pillow structures, columnar joints, and flow structures. When volcanoes erupt, dissolved gasses in the lava are released in a process similar to that occurring when a carbonated beverage is opened. The released gasses form bubbles or "vesicles" in the lava, which may be preserved as voids in the resultant rocks. "Amygdules" form when those cavities are later filled by minerals. Pillow structures form when lava erupts underwater and the outer edge cools rapidly upon contact with the water. The outer crust then cracks and oozes additional bulbous "pillows" as lava continues to flow from inside. Columnar joints form when thick flows of lava slowly cool and contract. "Ribbony" flow structures indicate that some of the basalt erupted near Morristown was lower-viscosity pahoehoe (pronounced "pah-hoy-hoy"), similar to the famous "lava rivers" of Hawai'i Volcanoes National Park in Hawaii (see GRI report by Thornberry-Ehrlich 2009).

Paleontological Resources

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). All fossils are non-renewable. Body fossils are remains of actual organisms, such as bones, teeth, shells, and leaves. Trace fossils are evidence of biological activity; examples include burrows, tracks, and coprolites (fossilized dung). Fossils in NPS areas occur in rocks and unconsolidated deposits, museum collections, and cultural contexts, such as building stones and archeological features. As of

July 2014, 245 parks had documented paleontological resources in at least one of these contexts. The NPS Geologic Resources Division Paleontology website, http://www.nature.nps.gov/geology/paleontology/index.cfm, provides more information.

No fossil has been discovered in Morristown National Historical Park. The Mesoproterozoic rocks that underlie most of the park are very unlikely to retain fossils, if any evidence of life ever existed in these rocks, due to their great age and metamorphic history. Graphite deposits (e.g., Yb) may represent metamorphosed organic matter, such as algal mats (Volkert et al. 2000; Tweet et al. 2010). Geologic units most likely to contain fossils in the park include the Jurassic Boonton Formation (Jb) and Quaternary sediments (Qwg, Qwgt, Qcg, Qpmd, and Qst) (Tweet et al. 2010).

Carbonized plant remains, spores, pollen, fish remains, coprolites, burrows, and reptile footprints all appear in the middle to upper parts of the Boonton Formation (Drake et al. 1996; Tweet et al. 2010). During the Jurassic, a series of lakes inundated the region, occupying basins created by the down-dropped fault block (Metz 1993). The Boonton Fish Bed in Boonton, New Jersey, 13 km (8 mi) northeast of Morristown National Historical Park, is particularly rich in fish remains, with abundant fossils of *Diplurus*, *Ptycholepis*, *Redfieldius*, and *Semiontus* (Olsen 1980; Tweet et al. 2010). Tracks of dinosaurs (*Anomoepus* and *Grallator*) and crocodile (*Batrachopus*) also occur in the Boonton Formation (Olsen 1980).

Quaternary deposits are present in all four park units. The glacial lake deltaic deposits (Qpmd) at the Washington's Headquarters unit are most likely to contain Pleistocene fossils, although no natural exposure is known (Tweet et al. 2010). Quaternary fossils found in the area surrounding the park include mammal bones, pollen, spores, and algal and invertebrate fossils (Tweet et al. 2010). Younger alluvial deposits associated with streams (Qst, Qal, and Qcal) have some potential to contain fossil remains of animals, such as ground sloths, giant beavers, stag moose, and caribous (Gallagher 1984; Tweet et al. 2010). Colluvium and other deposits associated with slope processes (Qcg, Qwg, Qwgt, and Qcal) are less likely to contain fossil remains, as they are primarily fragments of Mesoproterozoic rocks, although the potential for isolated material exists (Tweet et al. 2010).

Should fossils be discovered in the park, the chapter in *Geological Monitoring* about paleontological resources (Santucci et al. 2009) contains descriptions of five methods and vital signs for monitoring in situ paleontological resources: (1) erosion (geologic factors), (2) erosion (climatic factors), (3) catastrophic geohazards, (4) hydrology/bathymetry, and (5) human access/public use. All paleontological resources are non-renewable and subject to science-informed inventory, monitoring, protection, and interpretation, as outlined by the 2009 Paleontological Resources Preservation Act. Department of the Interior regulations associated with the Act were still being developed as of July 2014.

Geologic Resource Management Issues

This section describes geologic features, processes, or human activities that may require management for visitor safety, protection of infrastructure, and preservation of natural and cultural resources in Morristown National Historical Park. The NPS Geologic Resources Division provides technical and policy assistance for these issues.

During the 2007 scoping meeting (Thornberry-Ehrlich 2007) and 2013 conference call, participants (Appendix A) identified the following geologic resource management issues of significance at Morristown National Historical Park:

- Erosion
- Slope Movement Hazards and Risks
- Disturbed Lands
- Flooding
- Seismic Activity

Resource managers may find *Geological Monitoring* (Young and Norby 2009; http://go.nps.gov/geomonitoring) useful for addressing these 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 and suggested methods of monitoring.

Erosion

Erosion is a natural process that alters the landscape. Wind, water, and gravity combine to transport eroded material downslope. Slope movements and flooding contribute to rapid erosion. Heavy visitor foot traffic also produces areas of increased erosion in Morristown National Historical Park, particularly along trails and around reconstructed soldier huts (Fortner 2001). Deer are another agent of erosion in the park, which preserves one of the last open tracts of land in the area. As the surrounding area is developed, deer are forced into the park, creating overpopulation (Greco 2001). Deer foraging removed much of the native, soil-stabilizing understory, allowing the establishment of aggressive exotic species, such as Japanese barberry (*Berberis thunbergii*). Uprooted trees expose significant amounts of soil to erosion. The high winds associated with Hurricane Sandy in 2012 caused significant tree loss at the park, and the protrusion of rootballs from the ground resulted in landform change; the depressions created by uplifted rootballs collect water (Debbie Conway, Morristown National Historical Park, acting superintendent, conference call, 8 August 2013; Robert Masson, biologist, Morristown National Historical Park, written communication, 26 March 2014).

Park resource managers are primarily concerned with the impacts of erosion on archeological sites, cultural resources, trail surfaces, and streams (Greco 2001).

Exposed tree roots and limited vegetative groundcover are evidence of erosion ("soil loss") throughout the park (Greco 2001), such as at the soldier hut complex on the slope above Indian Grave Brook (fig. 16A). In such settings, cultural resources located close to the surface are at risk of damage or loss (Greco 2001). Rill erosion (development of many small, closely spaced channels due to uneven removal of soil by running water) affects the system of trails leading to reconstructed soldier huts in the Pennsylvania Brigade area. Depressions cut into the slopes by Revolutionary War soldiers continue to erode, further muting these already subtle features. Streams such as the Passaic River, Primrose Brook, and unnamed gullies erode surficial deposits and may undercut slopes (fig. 16C–D). Erosion at the toes of some slope-mantling colluvium deposits may be caused by water flowing from local springs (Thornberry-Ehrlich 2007).

Waterbars and culverts on the New York Brigade Trail and crossing three intermittent streams, respectively, have effectively mitigated erosion along the trail (Greco 2001). Such measures may also help other areas where significant erosion occurs. However, the placement of erosion control structures may accelerate erosion in unvegetated areas adjacent to trails (Greco 2001).

High-resolution LiDAR data may help resource managers identify subtle depressions on park slopes, facilitating targeted cultural resource management and erosion monitoring (Thornberry-Ehrlich 2007). LiDAR reveals subtle features, such as mounds and ridges that may contain cultural resources. Comparison of past and present topography reveals areas that have lost material due to erosion and those that have gained material through deposition. Detailed LiDAR data with a resolution of 1 m (3 ft) for the New Jersey Highlands, including some of the park area, are available from the New Jersey Highlands Council (http://njhlc.rutgers.edu/; accessed 22 January 2014) (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013).

Greco (2001) recommended the establishment of a baseline inventory of eroding sites, followed by the implementation of a monitoring program to determine erosion rates and measure apparent trends in park units. She recommended the following monitoring methods: the use of erosion pins to detect sheet and rill erosion, use of sediment tracers to determine soil movement, installation of headcut markers, repeated profiling and slope measurement, temporal comparison using aerial photographs, and photo point monitoring (Greco 2001).

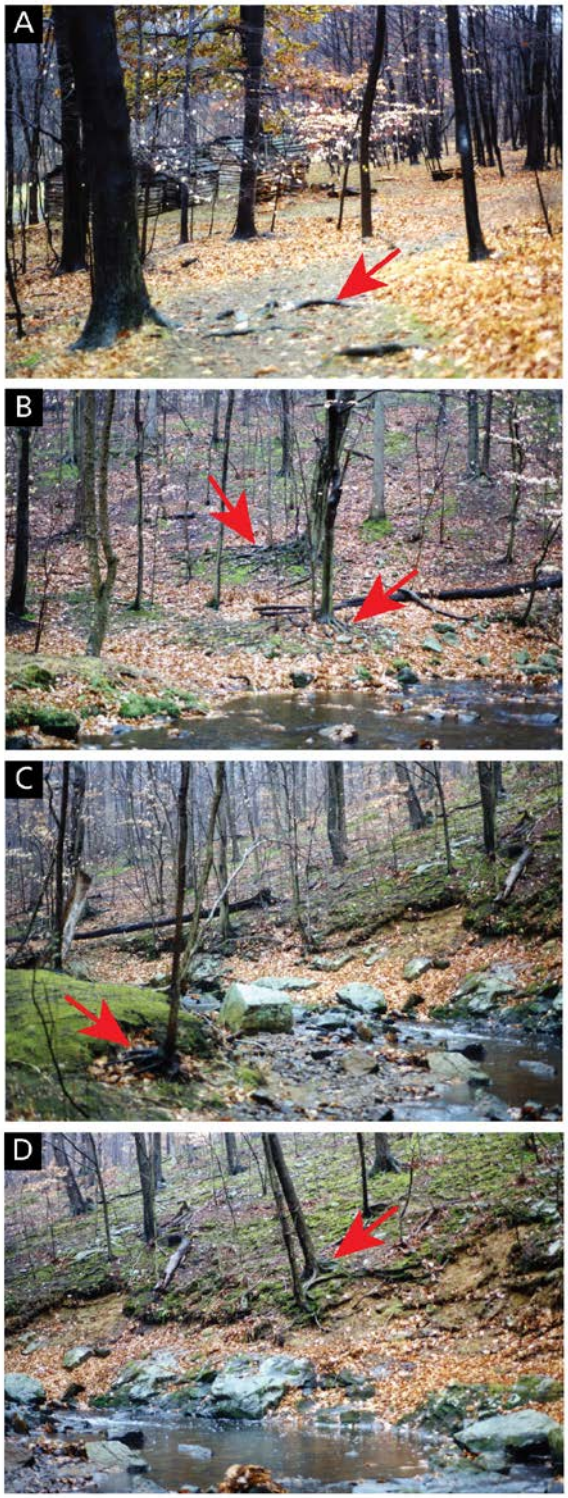


Figure 16. Exposed roots and undercutting erosion features. A) Exposed roots (red arrow) near reconstructed soldier huts may be exacerbated by visitor traffic on established and social trails. B) Exposed, extensive root networks (red arrows) illustrate a lack of stabilizing understory on park slopes. Trees exposed in this way are more susceptible to falling during high winds. C, D) Undercutting along the Passaic River. Erosion along river banks is a natural process, but it contributes to slope instability and undermines the root networks of trees (red arrows). Note the exposures of gneissic bedrock, "rubbly" groundcover, and loose boulders along park streams. National Park Service photographs by Deanna Greco (NPS Geologic Resources Division), taken in November 2000.

Permanently installed hillslope troughs that collect water and sediment also enable the seasonal, annual, and long-term estimation of erosion. Rates of soil erosion can then be estimated using predictive models, such as the universal soil loss equation (USLE) and revised USLE (Fortner 2001; Greco 2001). These applications are available from the US Department of Agriculture website (http://www.ars.usda.gov/Research/docs.htm?docid=5971; accessed 22 January 2014).

As a follow up to Greco's recommendations, a 2001 Geoscientist-in-the-Parks project established and assessed four erosion monitoring sites in the park (Fortner 2001). Two sites were in the Jockey Hollow Encampment Area unit, near the reconstructed soldier huts and on the Grand Loop Trail. The other two sites were in the New Jersey Brigade Encampment Area unit, near the Passaic River and the archeological site off of Patriot's Path. This study employed the USLE, an empirically derived equation using factors unique to soil type and region, such as rainfall, soil erodability, slope gradient and length, vegetation, and erosion control. Based on USLE estimates, these sites are losing 0.103–1.102 tons soil per acre annually (Fortner 2001). The park has collected no soil erosion data since 2001 (Robert Masson, Morristown National Historical Park, biologist, written communication, 26 March 2014). The erosion monitoring strategy outlined by Fortner (2001) may be applicable to repeated measurement and other sites in the park.

Slope Movement Hazards and Risks

Slope movement (fig. 17) is the downslope transfer of soil, regolith (weathered bedrock and overlying material), and/or rock under the influence of gravity. Soil creep, rockfalls, debris flows, and avalanches are common types of slope movement. These processes and the resultant deposits are also known as "mass wasting," commonly grouped as "landslides." Slope movements occur on time scales ranging from seconds to years. They are a common type of geologic hazard—a natural or human-caused condition that may impact park resources, infrastructure, or visitor safety. Risk is the probability of occurrence 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 also Holmes et al. 2013).

Landslides, slumps, minor rockfall, and slope creep occur on the slopes of the Fort Nonsense, Jockey Hollow Encampment Area, and New Jersey Brigade Encampment Area units of Morristown National Historical Park (Thornberry-Ehrlich 2007). The GRI GIS data include slumps, debris flows, and rockfall, but none of these has been mapped within park boundaries. Landslide point feature 5 (a debris flow from 1971) occurs between the Fort Nonsense and Washington's Headquarters units. Although old landslide scars on slopes in surrounding areas suggest that major slope failure is possible, slope creep is currently the dominant slope movement in Morristown National Historical Park (Thornberry-Ehrlich 2007). Landslide potential exists, particularly along the Passaic River (Scott Stanford and

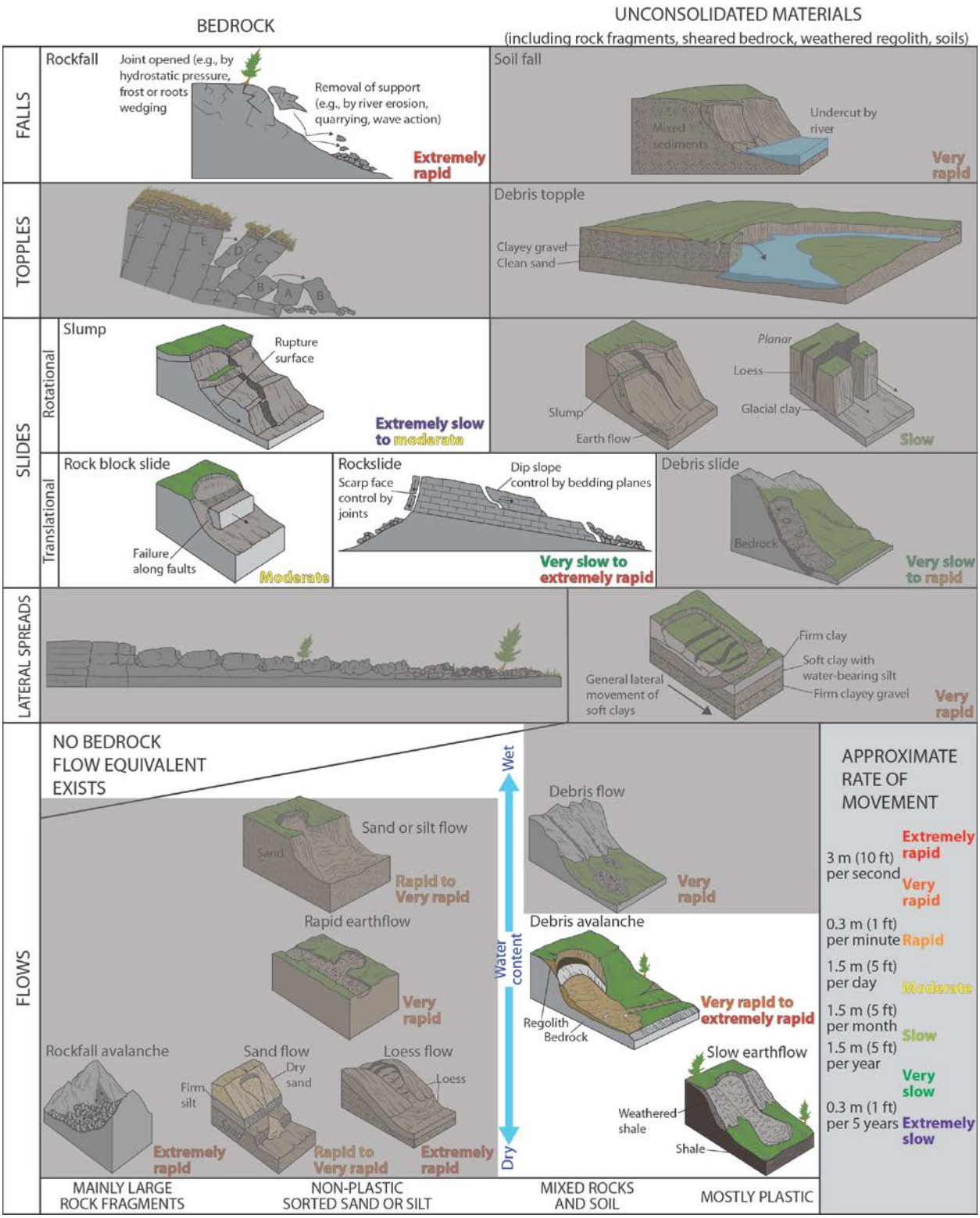


Figure 17. Schematic illustrations of slope movements. Slope movement categories are defined by material type, nature of the movement, rate of movement, and moisture content. Gray-shaded areas depict mass-wasting events that are not likely to occur in Morristown National Historical Park. Graphic by Trista Thornberry-Ehrlich (Colorado State University), redrafted after figure 4.33 and information in Varnes (1978).

Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013). Along Primrose Brook, west of Tea Hill, and in the "Gorge" of the Passaic River, southwest of Blachleys Hill, a few small steep banks are intermittently active, particularly when eroded at the base by floods (Scott Stanford, New Jersey Geological Survey, geologist, written communication 17 April 2014). With the exception of a few outcrops in the Jockey Hollow and Fort Nonsense areas, thick deposits of saprolite (deeply weathered bedrock), gneiss

colluvium (geologic map unit Qcg), and weathered gneiss (Qwg and Qwgt) mantle the bedrock (Stanford 2006; Stone et al. 2002; Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013). These unconsolidated units may become unstable on slopes if they become undercut, disturbed, and/or saturated with water, such as at groundwater seeps and springs or after storms.

Myriad causes of slope movement include frost weathering, root wedging, heavy rain, and undercutting by erosion (Thornberry-Ehrlich 2007). As described in the "Periglacial Bedrock Weathering and Thermokarst Features" section, frost weathering is active during the colder months of the year. Tree and plant roots penetrate cracks, furthering the mechanical breakdown of bedrock. Once loosened, soil and rocks move downslope under the force of gravity or are eroded (washed) away by running water. Erosion may undercut areas, increasing their susceptibility to slope movement. Slope movement can also create areas of unstable or unvegetated earth, which are further susceptible to erosion, as described in the "Erosion" section.

Park resource managers are interested in determining the vulnerability of a given slope to failure through slope stability analysis. Measurement of the thickness of unconsolidated regolith (e.g., saprolite) and weathered bedrock is critical to determine vulnerability. In 1995, drill cores were taken from seven monitoring wells in the park (Robert Masson, Morristown National Historical Park, biologist, written communication, 26 March 2014). If analyzed, these cores may help determine the depth to solid bedrock (Thornberry-Ehrlich 2007). Other factors involved in slope stability analysis include slope geometry; groundwater conditions (hydrogeology); presence of faulting, joints, or fractures; movement and tension in joints; and earthquake activity. Wieczorek and Snyder (2009), Highland and Bobrowsky (2008), the US Geological Survey landslides website (http://landslides.usgs.gov/), and the NPS Geologic Resources Division Geohazards (http://www.nature.nps.gov/geology/hazards/index.cfm) and Slope Movement Monitoring (http://www.nature.nps.gov/geology/monitoring/slopes.cfm) websites provide detailed information regarding slope movements, monitoring, and mitigation options. In the *Geological Monitoring* chapter about slope movement, Wieczorek and Snyder (2009) described five vital signs for understanding and monitoring this process: (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. The New Jersey Geological Survey maintains a landslide GIS database that contains locations of debris flows, rockfalls, rockslides, and slumps: http://www.state.nj.us/dep/njgs/geodata/NJlandslides.pdf (accessed 24 September 2013) (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013).

Disturbed Lands

Due to its long human history, the landscape of Morristown National Historical Park has been modified from its natural state. "Disturbed lands" are those impacted by human development, mining, quarrying, and agriculture.

Because the Mesoproterozoic gneisses and granites underlying the Highlands area are generally not productive aquifers, groundwater is relatively scarce and surficial water storage is necessary. In the early 1900s, an aqueduct was constructed in the park area to move water to nearby communities. As part of the aqueduct system, two impounded small ponds (covering approximately 0.2 ha [0.5 ac]) were constructed on two streams within the area now designated as the park. Park staff removed one pond, and the other (Catswamp Pond) is less than 2–3 m (7–9 ft) deep behind a 1.5-m- (5-ft-) high mud and soil berm impoundment (Thornberry-Ehrlich 2007). Other water-control features in the park include pipes along the East Branch of Primrose Brook. These pipes frequently clog with debris, and park resource managers are concerned that tree roots and erosion will compromise pipe and berm structures, as discussed in the "Slope Movement Hazards and Risks" section.



Figure 18. Mine-related features. The depression is an abandoned mica mine with an approximate area of 15 m² (50 ft²) and depth of 1 m (3 ft) in the Jockey Hollow Encampment Area unit of Morristown National Historical Park, near the western bank of Primrose Brook. Such pits are full of leaves and decaying logs, but likely pose no safety issue. National Park Service photograph by Deanna Greco (NPS Geologic Resources Division), taken in November 2000.

As described in the "Mining History" section, a series of pits and mines are present in the park and surrounding area. A small abandoned landfill is located in a broad flat area in the New Jersey Brigade Encampment Area unit. The landfill is a depression approximately 45 m (150 ft) long, 30 m (100 ft) wide, and 1 m (4 ft) deep (Greco 2001). Material debris was removed from the landfill in 1996 and its condition has not changed or been restored since 2001 (Robert Masson, Morristown National Historical Park, biologist, written communication, 26 March 2014). According to Greco (2001), two mine sites exist within park boundaries in the Jockey Hollow Encampment Area unit: a mica mine along the western bank of Primrose Brook and an abandoned mine just southeast of the Mt. Kemble Trail (fig. 18). Neither mine is currently included in the park's interpretive programs

(Greco 2001; Robert Masson, Morristown National Historical Park, biologist, written communication, 26 March 2014). Both pits are covered with leaf litter, duff, and decaying logs (Greco 2001). The New Jersey Geological Survey provides digital GIS data for abandoned mine locations at http://www.nj.gov/dep/njgs/geodata/dgs03-2.htm (accessed 24 September 2013). As of January 2014, neither feature met the criteria for cataloguing in the NPS abandoned mineral land database, and the park had no disturbed lands reclamation priority (Robert Masson, Morristown National Historical Park, biologist, written communication, 26 March 2014).

Flooding

Morristown National Historical Park contains the headwaters of several local streams, including the West Branch and most headwaters of the East Branch of Primrose Brook. The park is also near the southwestern headwaters of the Passaic River, which flows through the New Jersey Brigade Encampment Area unit and floods seasonally and during tropical storms (e.g., Lee and Irene in 2011, Sandy in 2012), and nor'easters (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013). Impermeable to low-permeability lake clays (Qmpl) underlie much of the valley upstream of Little Falls, located about 8 km (5 mi) northwest of Morristown, and prevent infiltration of floodwater, causing it to accumulate upstream toward the park (Stanford 2012). According to the Passaic River Basin Flood Advisory Commission (2011), more than 19 damaging floods have inundated the floodplain along the Passaic since 1810, with the most recent floods occurring in 2007, 2010, and two in 2011. Much of the flood danger occurs downstream of upland areas in the park, leading to a long and continuing history of flood control plans, levee construction and other engineering measures, and property buyouts (Thornberry-Ehrlich 2007; Stanford 2012).

Hazards associated with flooding in the park include inundation and damage of trails, walkways, roads, and other visitor use areas, as well as tree topple and increased sedimentation from increased erosion, which commonly accompanies high-precipitation events and floods (Thornberry-Ehrlich 2007). For example, floods scoured away sections of an unofficial (social) trail to Flat Rock (which protrudes into a pool of the Passaic River and is used for swimming and fishing), rendering the trail unsafe (Thornberry-Ehrlich 2007; Robert Masson, Morristown National Historical Park, biologist, written communication, 26 March 2014). Floods may undermine large trees growing near the channel by washing soil and regolith away from their roots, leading eventually to tree topple (Thornberry-Ehrlich 2007).

Fluvial Geomorphology

As described in the "Slope Movement Hazards and Risks" section, deer overpopulation has led to a decline in the natural forest understory and increased exotic species colonization and erosion. Increased surface runoff and erosion cause increased sedimentation in local waterways, change channel morphology, and may degrade aquatic habitats. The park contains portions of designated wild trout streams; the eastern brook trout (*Salvelinus fontinalis*) spawns in the East and West branches of Primrose Brook (Greco 2001; Robert Masson, Morristown National Historical Park, biologist, written communication, 26 March 2014). The state of New Jersey has listed this fish as a threatened species (Greco 2001), and protection of its habitat is critical to its successful recovery. Because data on brook trout in the park were last collected in 2001, the occurrence and nature of local population changes are unknown (Robert Masson, Morristown National Historical Park, biologist, written communication, 26 March 2014).

In the *Geological Monitoring* chapter about fluvial geomorphology, Lord et al. (2009) described the following methods and vital signs useful for inventorying and monitoring: (1) watershed landscape (vegetation, land use, surficial geology, slopes, and hydrology), (2) hydrology (frequency, magnitude, and duration of stream flow rates), (3) sediment transport (rates, modes, sources, and types of sediment), (4) channel cross section, (5) channel planform, and (6) channel longitudinal profile.

Seismic Activity

Large earthquakes are not common in the mid-Atlantic region; however, minor earthquakes (rarely felt by humans) occur along local faults. Normal faults are denoted by the GRI GIS data between the Jockey Hollow and New Jersey Brigade Encampment Area units and bracketing the Fort Nonsense unit. These data indicate the epicenters of seven earthquakes ranging in magnitude from 1.4 to 3.1 that occurred between 1880 (unknown magnitude) and 2003. A magnitude-1.5 earthquake in 1979 was located immediately adjacent to the Jockey Hollow Encampment Area unit of the park. Park staff and local residents reported shaking from the magnitude-5.8 earthquake that occurred in central Virginia in August 2011 (Debbie Conway, Morristown National Historical Park, acting superintendent, and Scott Stanford, and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013). Shaking from that earthquake was felt throughout the eastern seaboard, particularly along the fall zone—the line marking the boundary between the Atlantic Coastal Plain and the Piedmont province (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013). This event caused no damage in the park, but it serves as a reminder that earthquakes, although rare, can shake this area. Any moderate earthquake has the potential to damage park infrastructure or trigger slope movements, although such effects are unlikely. According to the US Geological Survey 2009 Earthquake Probability Map (https://geohazards.usgs.gov/eqprob/2009/index.php; accessed 9 January 2014), the probability that a magnitude-5.5 earthquake will occur near Morristown in the next century is 2–3%.

In the very distant past (hundreds of millions of years ago), the area now containing Morristown National

Historical Park was seismically active. Geologists suspect that Ramapo Fault was originally a thrust (compression) fault and was reactivated as a normal (extension) fault during the Mesozoic opening of the Atlantic Ocean upon the breakup of the supercontinent Pangaea (Scott Stanford and Don Monteverde, New Jersey Geological Survey, geologists, conference call, 8 August 2013). This border fault, like many similarly located faults along the east coast of North America, has the potential to be seismically active (Thornberry-Ehrlich 2007). Studies conducted along the Ramapo Fault have suggested that levels of crustal stress in the northeastern United States are sufficient to reactivate fractures within this fault system (Jacob et al. 2004). However, accurate prediction of when, where, and to what severity an earthquake may occur is not possible. Refer to the "Ramapo Fault and Other Structures" section for more information.

In the *Geological Monitoring* chapter about earthquakes and seismic activity, Braile (2009) described the following methods and vital signs useful for understanding these processes: (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. The US Geological Survey maintains an earthquake monitoring website: http://earthquake.usgs.gov/eqcenter/recenteqsus/ (accessed 24 September 2013). The Lamont Dougherty Cooperative Seismographic Network (http://www.ldeo.columbia.edu/LCSN/index.php; accessed 18 September 2013) at Columbia University operates the seismic station closest to Morristown National Historical Park. The New Jersey Geological Survey also maintains a GIS database with earthquake epicenters at http://www.nj.gov/dep/njgs/geodata/dgs04-1.htm (accessed 24 September 2013).

Geologic History

This section describes the chronology of geologic events that formed the present landscape of Morristown National Historical Park.

Four groups of rocks reflect the geologic history in Morristown National Historical Park: (1) Mesoproterozoic metamorphic and igneous rocks deformed during the early construction of North America, (2) Jurassic sedimentary and igneous rocks deposited in the Newark Basin, (3) Pleistocene glacial and glacial lake deposits, and (4) Holocene alluvium and colluvium. Rocks in and around the park thus represent a period of time from the Mesoproterozoic (approximately 1.1 billion years ago) to the present (fig. 4). The geologic history of Morristown National Historical Park involves an ancient orogeny, long-term marine deposition, construction of the Appalachian Mountains and Pangaea, and the breakup of Pangaea and associated volcanism, followed by millions of years of weathering, erosion, and ice-age glaciation (figs. 19 and 20). These events and the resulting rocks formed the geologic landscape that made Morristown a strategic location for winter encampments during the American Revolutionary War.

Mesoproterozoic and Neoproterozoic Eras (1.6 Billion–542 Million Years Ago): Grenville Orogeny and the Supercontinent Rodinia

The bedrock underlying parts of the New Jersey Highlands in Morristown National Historical Park is among the oldest in the eastern United States, dating to the Mesoproterozoic Era (more than 1 billion years ago) (Drake et al. 1996). A group of metamorphosed igneous rocks known as the Losee Metamorphic Suite (geologic map units Ya, Yh, Yd, Ylo, and Ylb); overlying metamorphosed sedimentary and volcanic rocks (Yk, Yb, Ymh, Ymp, Yp, and Yf); and groups of igneous intrusive rocks, including the Byram Intrusive Suite (Yba and Ybh), are the basic components of the local bedrock. All of these rocks were emplaced, deformed, and metamorphosed during several phases of the Grenville Orogeny from approximately 1.3 billion to 900 million years ago (Gunderson 1990; Harris et al. 1997; Tollo et al. 2006; Southworth et al. 2010; see Shenandoah National Park GRI report by Thornberry-Ehrlich 2014; Matt Heller, Virginia Division of Geology and Mineral Resources, geologist, written communication, 16 July 2013). Compression was intermittent, and periods of quiescence were accompanied by extensive erosion of the new mountains (Volkert and Drake 1999). The Losee Metamorphic Suite records one of the earliest phases of the Grenville Orogeny (fig. 21A) (Volkert and Drake 1999). At this time, the proto–North American landmass called "Laurentia" was part of the supercontinent Rodinia, which included most continental crust in existence at the time.

Plate tectonic forces moved continents, fragments of continents, and "arcs" of volcanoes (similar to the modern Aleutian Islands) together to form Rodinia during the Grenville Orogeny. Extensive volcanic eruptions, mountain building, faulting, and metamorphism accompanied the assembly of Rodinia over hundreds of millions of years (fig. 21B). Much of the metamorphism occurred between 1.025 billion and 900 million years ago (Volkert and Drake 1999).

Grenville-era Mesoproterozoic rocks form a geologically complex basement upon which all other rocks of the Appalachians were deposited (Southworth et al. 2008). At Morristown National Historical Park, these overlying rocks have since eroded from the landscape, exposing the ancient core of the mountain range.

Rifting of Rodinia and Opening of the Iapetus Ocean

During the Late Proterozoic, approximately 760 million years ago, tectonic forces (extension) began to pull Rodinia apart (fig. 21C) (Volkert and Drake 1999). Weathering and erosion reduced the highlands that formed during the Grenville Orogeny to low-rolling hills similar to the modern Piedmont; breaking up of the supercontinent formed a basin that eventually became the Iapetus Ocean (Sykes et al. 2008). In a setting analogous to a modern-day East African rift and the Red Sea, many normal faults (fig. 14) developed to accommodate the extension (pulling apart) and molten material flowed through the fractures, which are now preserved as igneous dikes. Rifting was completed by the start of the Paleozoic Era, and the Iapetus Ocean separated Laurentia from the other continents (Volkert and Drake 1999).

Paleozoic Era (542 Million-251 Million Years Ago): Continued Opening of the Iapetus Ocean and Transition to a Passive Margin; Longstanding Marine Margin; Appalachian Mountain Building

At the dawn of the Paleozoic Era, the rifted continental margin began to stabilize as the Iapetus Ocean widened. The margin collected sediments eroded from the highlands in series of fluvial and nearshore marine environments (fig. 21D). Beach and tidal-flat sands (later metamorphosed into quartzites, such as Hardyston Quartzite [Ch]) blanketed the ancient coastline in the region of present-day northern New Jersey. Carbonates (e.g., dolomite of the Leithsville Formation [Cl]) were also deposited in shallow- to deep-marine environments (Drake et al. 1996). Carbonate deposition continued into the Ordovician Period as part of a well-developed, shallow ocean platform adjacent to the continent. These rocks are not exposed in the park, but occur west of the New Jersey Highlands in Kittatinny Valley.

After millions of years of tectonic stability in the Early Paleozoic, tectonic unrest began again along the eastern

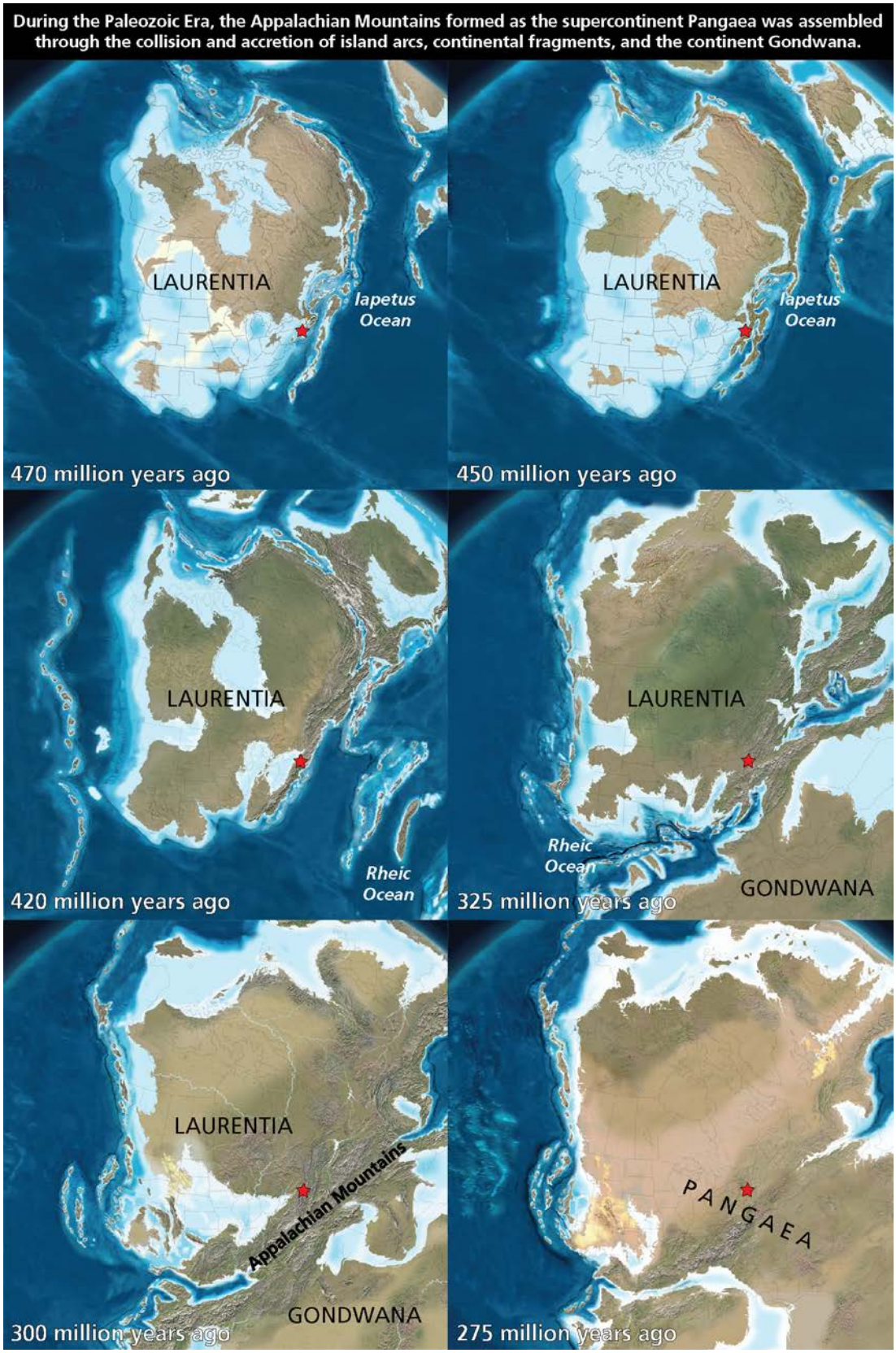


Figure 19. Paleogeographic maps: 470 million–275 million years ago. The bedrock geologic units of Morristown National Historical Park are tied to intense deformation and intrusion of molten material that occurred during the formation of the Appalachian Mountains and culminated with the assembly of Pangaea. Red stars indicate approximate present-day location of Morristown National Historical Park. Graphic compiled by Jason Kenworthy (NPS Geologic Resources Division). Base paleogeographic maps created by Ron Blakey (Colorado Plateau Geosystems, Inc.), available at http://cpgeosystems.com/index.html (accessed 14 May 2014). Annotations by Trista Thornberry-Ehrlich (Colorado State University).

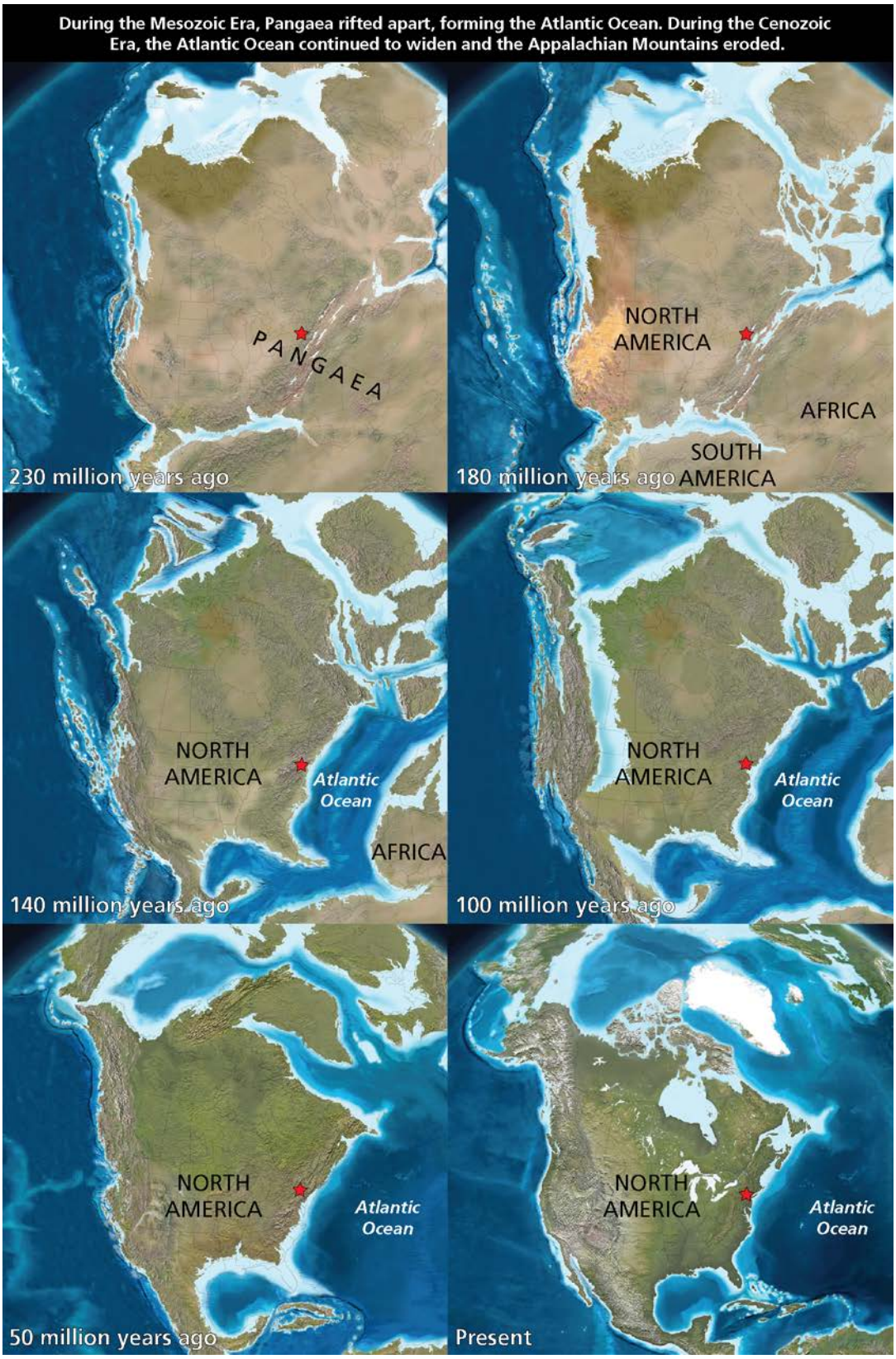


Figure 20. Paleogeographic maps: 230 million years ago–present. Pangaea began to split apart during the Mesozoic and the Appalachian Mountains began to erode. Today, the Atlantic Ocean continues to widen and erosion has exposed the core of the Appalachian Mountains. Red stars indicate approximate present-day location of Morristown National Historical Park. Graphic compiled by Jason Kenworthy (NPS Geologic Resources Division). Base paleogeographic maps created by Ron Blakey (Colorado Plateau Geosystems, Inc.), available at http://cpgeosystems.com/index.html (accessed 14 May 2014). Annotations by Trista Thornberry-Ehrlich (Colorado State University).

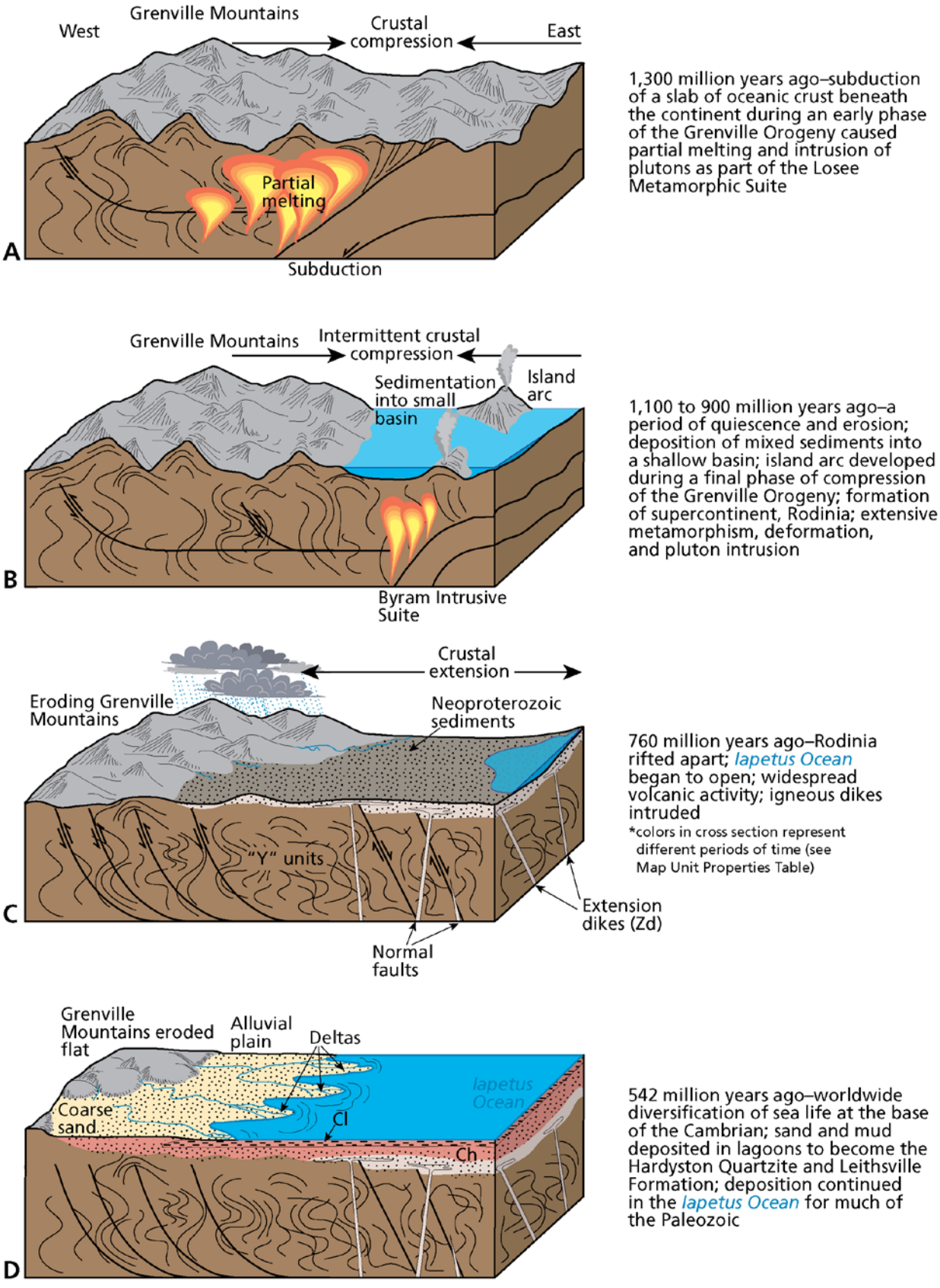


Figure 21 A–D. Evolution of the landscape and geologic foundation of Morristown National Historical Park. Figure continues on the next page. Time spans from the Mesoproterozoic through the present. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), created with information from Volkert and Drake (1999), Stanford (2012), and Drake et al. (1996). Drawings not to scale.

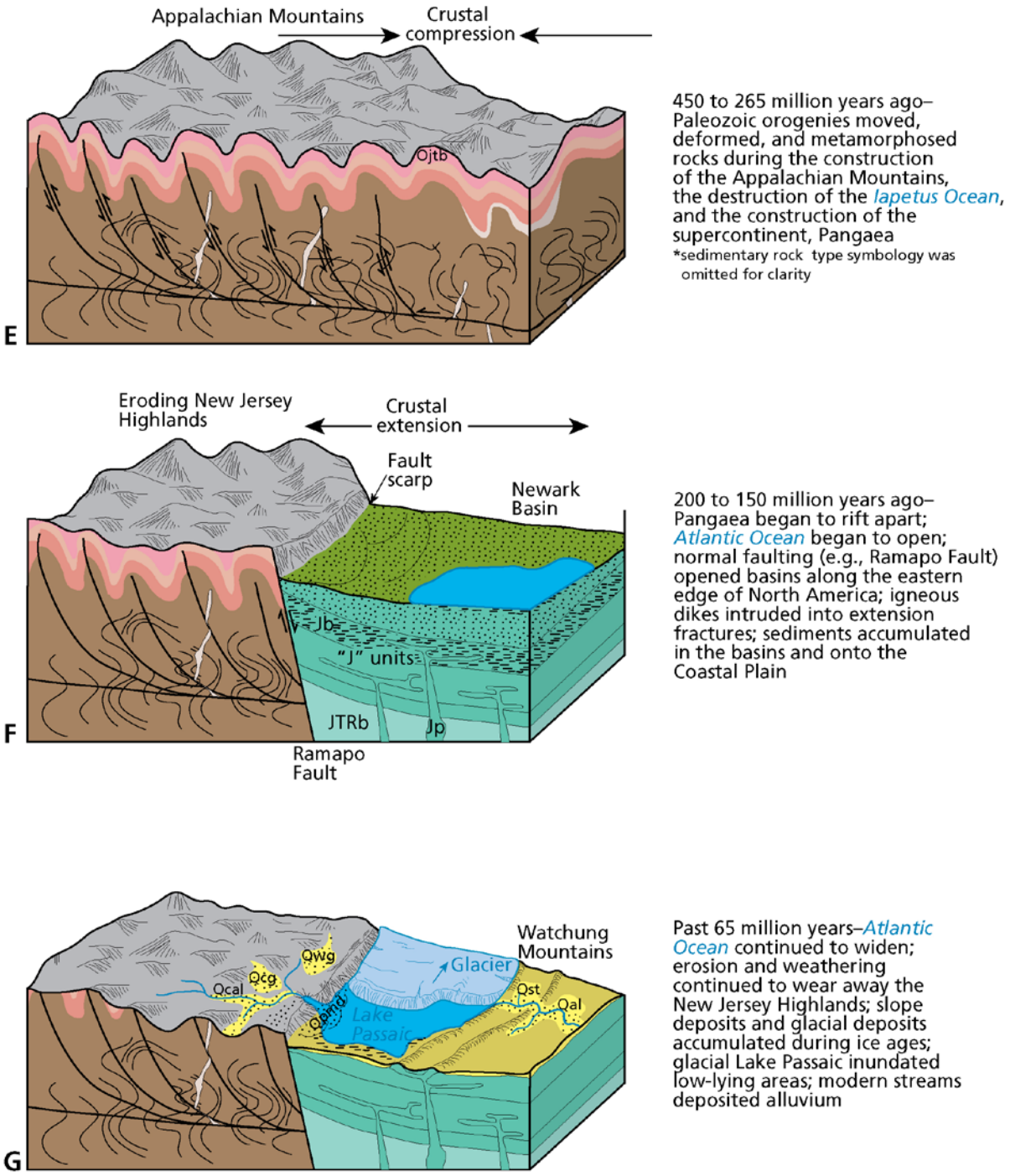


Figure 21 E–G. Evolution of the landscape and geologic foundation of Morristown National Historical Park. Figure continues from previous page. Time spans from the Mesoproterozoic through the present. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), created with information from Volkert and Drake (1999), Stanford (2012), and Drake et al. (1996). Drawings not to scale.

margin of North America. A series of landmass collisions and mountain-building orogenies throughout the Paleozoic (fig. 21E) culminated in the formation of another supercontinent—Pangaea.

Taconic, Acadian, and Alleghany Orogenies—the Assembly of Pangaea

The Taconic Orogeny began during the Ordovician Period, approximately 488 to 440 million years ago. It involved the collision of volcanic island arcs with the eastern margin of what would become North America. The timing, extent, and exact nature of these collisions continue to be debated and studied intensively. In general, the Taconic Orogeny involved the collision of one or more volcanic arcs with the North American continent, the subduction of oceanic crust, and the beginning of the closing of the Iapetus Ocean, a predecessor to the Atlantic Ocean. Ocean basin

sediments were disrupted and, in some cases, transported long distances (tens of kilometers) to the west by thrust faults. Volcanic arcs formed above subduction zones, and fragments of crust that formed elsewhere (terranes) were accreted to the eastern margin of North America. As a result of accretion, the eastern margin of the continent shifted farther eastward and the Taconic mountain range developed.

By the Middle Devonian Period, about 375 million years ago, landmasses were converging again along the eastern seaboard of ancient North America and the Iapetus Oceanic Basin continued to shrink as the African continent approached (Harris et al. 1997). These processes marked the onset of the Acadian Orogeny, which did not deform rocks as far southwest as present-day northern New Jersey. Acadian folds, faults, and igneous intrusions are located farther north and east, as this event was focused in the region of present-day New England (Epstein and Lyttle 2001). Similar to the Taconic Orogeny, the Acadian Orogeny involved land mass collision, mountain building, and regional metamorphism (Means 1995).

Later in the Paleozoic, approximately 325 to 265 million years ago, the African continent collided with the North American continent during the Alleghany Orogeny. This event closed the Iapetus Basin forever and was the last major orogeny to contribute to the formation of the Appalachian Mountains. The prominent folds in Paleozoic rocks at Delaware Water Gap National Recreation Area, northwest of Morristown, formed during the Alleghany Orogeny (Epstein and Lyttle 2001; Thornberry-Ehrlich 2013). Vast masses of rock were transported westward on major thrust faults. An extreme amount of southeast–northwest crustal contraction was associated with folding and faulting during the Alleghany Orogeny. An estimated 50–70% total shortening, or 125–350 km (75–125 mi) lateral translation or movement, occurred (Hatcher 1989; Harris et al. 1997; Southworth et al. 2009). At the culmination of the Alleghany Orogeny, the area of present-day New Jersey was located in the core of the supercontinent Pangaea, which comprised nearly all continental crust in existence. Extensional forces began to pull the supercontinent apart at the onset of the Mesozoic Era.

Mesozoic Era (251 Million–65.5 Million Years Ago): Breakup of Pangaea, Crustal Extension, and Volcanism

During the Triassic, the supercontinent Pangaea began to rift apart, forming the continents that persist today; the consequences of its breakup are on display at Morristown National Historical Park and its surroundings. As the African continent moved away from North America and the Atlantic Ocean began to develop, extension of the Earth's crust formed down-dropped, normal fault–bounded basins called "grabens" (fig. 12) along the eastern margin of North America (Harris et al. 1997). The Ramapo Fault along the eastern edge of the New Jersey Highlands is one of the normal faults forming the western boundary of the Newark Basin (fig. 21F). The Newark Basin is part of a series of rift basins along the eastern flanks of the Appalachian Mountains extending from Canada to the southern United States. Vast amounts of sediment eroded from the Appalachian Mountains, referred to collectively as the Newark Supergroup, filled these basins. The Newark Basin contains a continuous sedimentary record covering nearly 35 million years that is more than 3,000 m (10,000 ft) thick (Olsen 1980). The oldest of these sedimentary units in the park area is the Passaic Formation (JTRp, JTPpms, and JTSpsc) (Drake et al. 1996). This thick formation is a mixture of mudstone, siltstone, shale, sandstone, and conglomerate deposited in terrestrial to nearshore environments in the Newark Basin. Younger sedimentary formations in the basin include the Feltville (Jf), Towaco (Jt and Jtc), and Boonton (Jb and Jbcq) formations (Olsen 1980; Drake et al. 1996). The Boonton Formation is the youngest unit of the Newark Supergroup in New Jersey (Olsen 1980; Ghatge and Hall 1989). Carbonaceous layers in the Feltville Formation attest to the presence of abundant organic material in the basin at that time in the Lower Jurassic. The Towaco and Boonton formations contain coarse pebble conglomerates, carbonized plant remains, and reptile footprints (Drake et al. 1996), which suggest a nearshore to terrestrial environment. The presence of coarse-grained conglomerate and feldspar and micaceous minerals in these sedimentary rocks indicates that they were deposited relatively close to bedrock that was weathering and eroding to supply the sediment. The degree to which rock particles have been mechanically worn into finer grain sizes and dissolved or altered by chemical weathering increases with the distance that the material was transported.

Volcanic eruptions and intrusion of molten material (now preserved as dikes) accompanied crustal extension over a period of approximately 580,000 years about 200 million years ago (Olsen et al. 1996). Volcanism in the Newark Basin was part of what may have been the largest known eruptions on Earth, extending basalt flows over much of what was central Pangaea (Marzoli et al. 1999). Igneous units present in the vicinity of the park, in age-ascending order, are the Orange Mountain (Jo), Preakness (Jp and Jps), and Hook Mountain (Jh) basalts (Olsen 1980; Drake et al. 1996).

Minor folding and faulting in the Newark Basin and small earthquakes along the Ramapo Fault System, but no large tectonic event, have occurred in the park area since the Jurassic Period (Sykes et al. 2008). Weathering and erosion dominated the geologic history of the park area throughout the Late Mesozoic and subsequent Cenozoic Era. Rivers transported sediments worn from the highlands to build the Coastal Plain outward into the widening Atlantic Ocean. Due to differences in the erosion resistance of rock types, some areas eroded faster than others. The resistant metamorphic and igneous rocks of the New Jersey Highlands remain as topographic highs. In the Newark Basin, erosion-resistant flood basalts underlie historically significant ridges, such as First and Second Watchung mountains (Jo and Jp, respectively) (Drake et al. 1996).

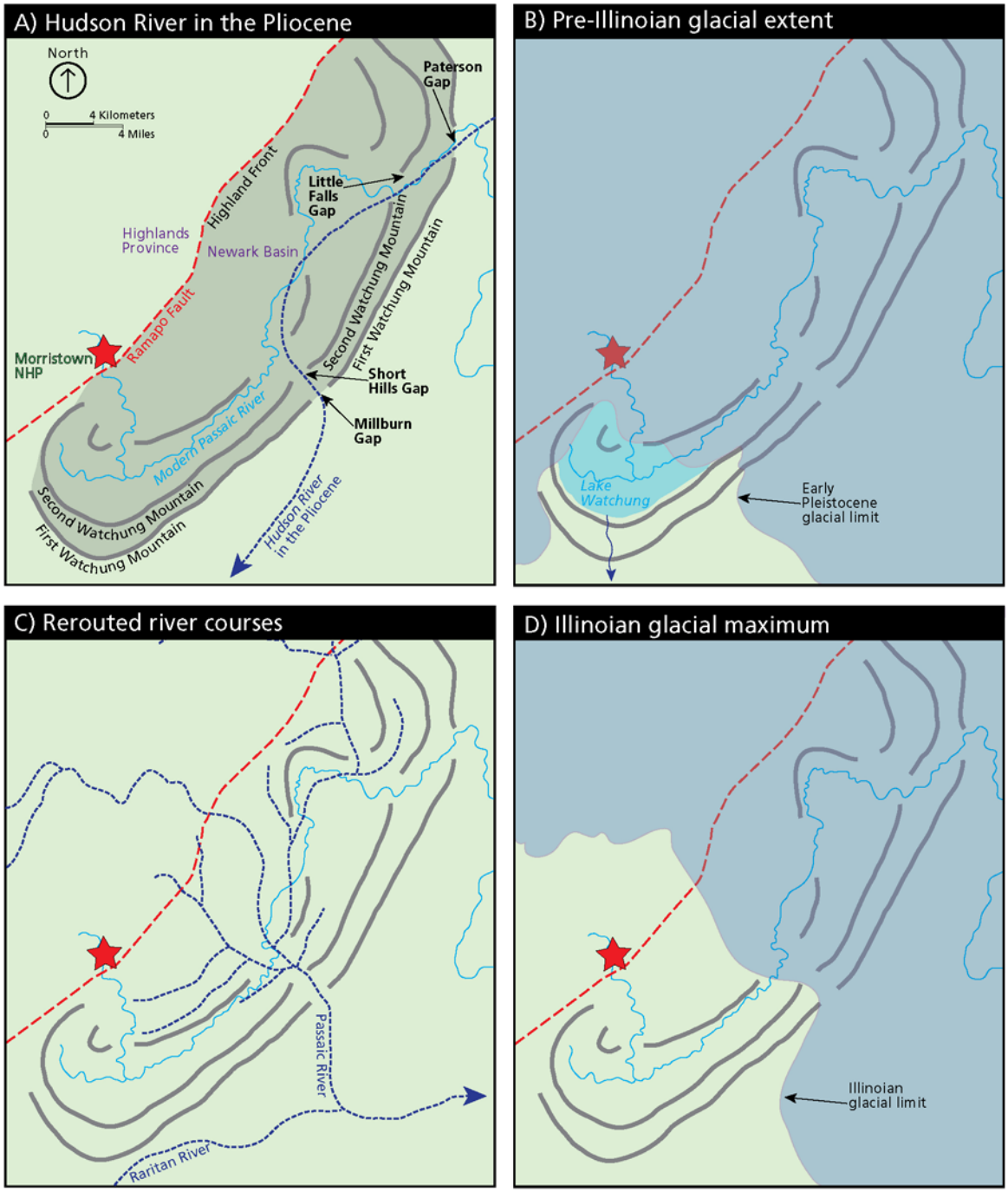


Figure 22 A–D. Glacial history of Morristown area. Figure continues on subsequent pages. Shaded area in box A denotes the basin formed by the Highland Front and Watchung Mountains. Red star indicates the location of Morristown National Historical Park. Dashed line indicates the location of the Ramapo Fault, marking the boundary between the Piedmont to the east and New Jersey Highlands to the west. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Stanford (2012; fig. 1).

Cenozoic Era (the Past 65.5 Million Years): Continual Weathering and Erosion; Pleistocene Ice Ages; Postglacial Modification of the Landscape and Modern Geomorphological Development

Since the Mesozoic breakup of Pangaea, North America's eastern margin has been passive, collecting sediments eroding from the Appalachian Mountains. Rivers, depositing alluvium, incised valleys throughout the Neogene. Only one unit in the greater park area, the Pensauken Formation (Tp), reflects this early landform development (Stanford 2007). During the Pliocene (5.3–2.6 million years ago), the Hudson River flowed through the area and cut two sets of gaps through the basalt ridges of First and Second Watchung mountains (fig. 22A) (Stanford 2012). Glaciers were another powerful agent of landscape change that sculpted landforms in the New Jersey Highlands and Piedmont provinces (figs. 6 and 21G).

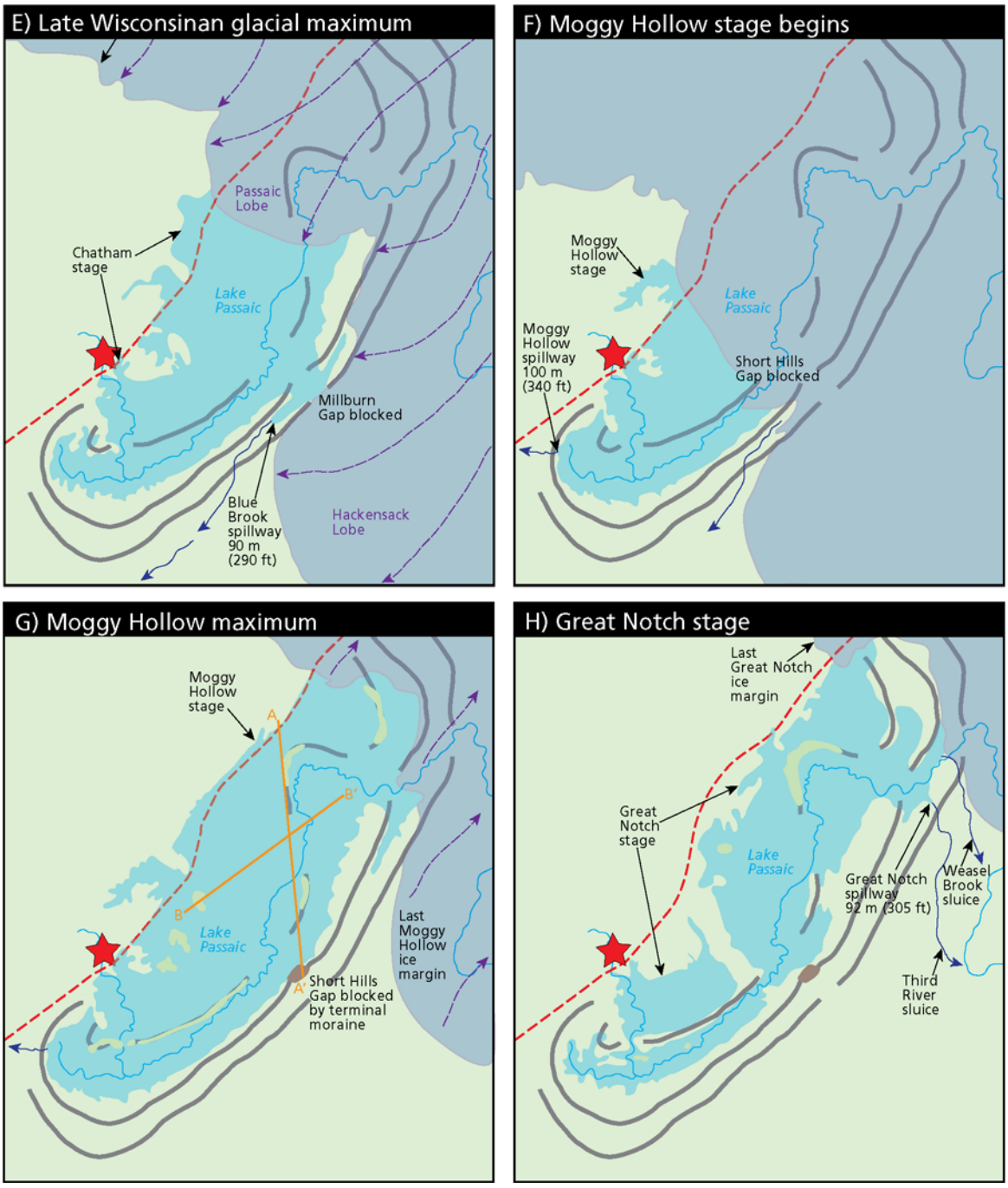


Figure 22 E–H. Glacial history of Morristown area. Figure continues on subsequent pages. Orange lines in box G denote the locations of the cross sections in figure 11. Red star indicates the location of Morristown National Historical Park. Dashed line indicates the location of the Ramapo Fault, marking the boundary between the Piedmont to the east and New Jersey Highlands to the west. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Stanford (2012; fig. 1).

As described in the "Glacial Features" section, during the Pleistocene Epoch, global climate shifts brought alternating cold periods—ice ages—and relatively warm periods (similar to modern climate). Continental ice sheets descended south from the Arctic, reshaping the landscape of much of the present-day northern United States. At least three separate glaciations affected the region of present-day northern New Jersey. The pre-Illinoian, the oldest event, advanced farthest south and completely covered the Morristown National Historical Park area. This Early Pleistocene glaciation, occurring between 2.5 million and 800,000 years ago, blocked the Moggy Hollow Gap in Second Watchung Mountain, and a deep glacial lake, Lake Watchung, developed at the glacial margin (fig. 22B). This glaciation left till and some glaciolacustrine (glacial lake) and deltaic deposits (Qpt, Qpsl, and Qps) that occur south of the park (Stanford 2007, 2009). Following the retreat of this glacier, between 2 million and 150,000 years ago, a new drainage system

developed that would become the Passaic and Raritan rivers (fig. 22C).

The subsequent Illinoian (fig. 22D) and Wisconsinan glaciations did not cover the park area, but their proximity had profound effects on the park's landscape, including the burial of pre-existing river drainages and rerouting of flows (Ghatge and Hall 1989). During the late Wisconsinan glaciation, Lake Passaic formed when the advancing Hackensack Lobe of the glacier blocked the Millburn Gap of Second Watchung Mountain and established the Chatham stage of Lake Passaic (fig. 22E). The spillway between First and Second Watchung mountains at the head of Blue Brook Valley controlled the level and depth of Lake Passaic at an elevation of 90 m (290 ft). Water in this lake buoyed the Passaic Lobe ice, allowing it to advance to a terminal position without eroding the underlying sediments. The continued advance of the Hackensack Lobe then blocked the second Short Hills Gap of Second Watchung Mountain and established the Moggy Hollow stage of Lake Passaic (fig. 22F). Water levels rose 15 m (50 ft) in Lake Passaic during the Moggy Hollow stage. Drainage of this stage was through the Moggy Hollow spillway, across Second Watchung Mountain near Far Hills, into the Raritan River drainage. Upon its initial retreat, the Hackensack Lobe deposited a terminal moraine in the Short Hills Gap to an elevation of more than 120 m (400 ft), 15 m (50 ft) higher than previously (fig. 22G). This deposition allowed Lake Passaic to expand northward to fill the space previously occupied by ice, creating the greatest extent of the Moggy Hollow stage. As the glacier retreated to the gap at Great Notch in First Watchung Mountain, 10.4 km^3 (2.5 mi^3) water flowed down the Third River sluice (fig. 22H). The lake level dropped 24 m (80 ft) to the Great Notch stage, which in turn drained as Paterson Gap was uncovered and 5.0 km^3 (1.2 mi^3) water flowed down the Weasel Brook sluice about 19,500 years ago. As glaciers finally retreated from the area, Lake Passaic continued to shrink during the postglacial Totowa, Millington, and Stanley stages (fig. 22I). These lakes eventually drained, disappearing by about 14,000–10,000 years ago (Reimer 1984; Stanford 2012).

Because of the proximity to the glaciers, the region experienced periglacial conditions and accelerated frost weathering. Frost weathering wedged untold numbers of boulders from the bedrock of the Highlands to form talus (Qta) and colluvium (Qcal, Qcc, Qcs, Qcg, Qcb, and Qcbl) at the bases of slopes (Stone et al. 2002; Stanford



Figure 22 I. Glacial history of Morristown area. Figure continues from previous pages. Red star indicates the location of Morristown National Historical Park. Dashed line indicates the location of the Ramapo Fault, marking the boundary between the Piedmont to the east and New Jersey Highlands to the west. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Stanford (2012; fig. 1).

2006, 2007, 2009). Thick layers of partially weathered bedrock (saprolite; Qwc, Qwg, Qwgt, Qwb, Qwbt, Qws, and Qwst) that formed in situ in the extreme climates mantle local bedrock (Stone et al. 2002; Stanford 2006, 2007, 2009).

Late Pleistocene and Holocene deposits include alluvium (Qal) collecting along creeks, streams, and rivers; alluvium and colluvium adjacent to slopes (Qcal); swamp and marsh deposits (Qs); alluvial fan deposits (Qaf); eolian deposits (Qe); and stream terrace deposits recording previous river levels (Qst and Qstu).

The youngest geologic units in the park area are anthropogenic. Long after George Washington's soldiers excavated shallow pits for their huts, humans continued to modify the landscape to suit their needs. Artificial fill and trash fill (Qf and Qaft, respectively) units are the most recent deposits represented on the geologic map.

Geologic Map Data

This section summarizes the geologic map data available for Morristown National Historical Park. Posters (in pocket) display the map data draped over imagery of the park and surrounding area. The Map Unit Properties Tables (in pocket) summarize this report's content for each geologic map unit. Complete GIS data are included on the accompanying CD and are also available at the GRI publications website: http://go.nps.gov/gripubs.

Geologic Maps

Geologic maps facilitate an understanding of an area's geologic framework and the evolution of its present landscape. Using designated colors and symbols, these maps portray the spatial distribution and temporal relationships of rocks and unconsolidated deposits. Geologic maps can be divided into two primary types: surficial and 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.

Geologic maps often depict geomorphic features, structural interpretations (such as faults or folds), and locations of past geologic hazards that may be susceptible to future activity. 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.agiweb.org/environment/publications/mapping/index.html, provides more information about geologic maps and their uses.

Source Maps

The GRI team digitizes paper maps and converts digital data to conform to the GRI GIS data model. The GRI digital geologic map product includes essential elements of the source maps, such as map unit descriptions, a unit correlation chart, a map legend, map notes, references, and figures. The GRI team used the following sources to produce the digital geologic data set for Morristown National Historical Park. These sources also provided information for this report.

Surficial Data

Pallis, T. and W. Marzulli. 2006. Landslides in New Jersey (scale 1:100,000). Digital geodata series 06-03. New Jersey Geological Survey, Trenton, New Jersey.

Pristas, R. P. 2007. Surficial geology of New Jersey (scale 1:100,000). Digital geodata series 07-2. New Jersey Geological Survey, Trenton, New Jersey.

Stanford, S. D. 2006. Surficial geology of the Morristown Quadrangle, Essex and Morris counties, New Jersey (scale 1:24,000). Open-file map 67. New Jersey Geological Survey, Trenton, New Jersey.

Stanford, S. D. 2007. Surficial geology of the Chatham Quadrangle, Morris, Union, and Somerset counties, New Jersey (scale 1:24,000). Open-file map 69. New Jersey Geological Survey, Trenton, New Jersey.

Stanford, S. D. 2009. Surficial geology of the Bernardsville Quadrangle, Morris and Somerset counties, New Jersey (scale 1:24,000). Open-file map 74. New Jersey Geological Survey, Trenton, New Jersey.

Stone, B. D., S. D. Stanford, and R. W. Witte. 2002. Surficial geologic map of Northern New Jersey (scale 1:100,000). Miscellaneous investigations series map I-2540-C. US Geological Survey, Reston, Virginia.

Bedrock Data

Drake, A. A., R. A. Volkert, D. H. Monteverde, G. C. Herman, H. F. Houghton, R. A. Parker, and R. F. Dalton. 1996. Bedrock geologic map of Northern New Jersey (scale 1:100,000). Miscellaneous investigations map I-2540-A. US Geological Survey, Reston, Virginia.

Ghatge, S. L. 2004. Earthquakes epicentered in New Jersey (scale 1:500,000). Digital geodata series 04-1. New Jersey Geological Survey, Trenton, New Jersey.

Pallis, T., R. Volkert, and R. F. Dalton. 2003. Abandoned mines of New Jersey (scale 1:24,000). Digital geodata series 03-2. New Jersey Geological Survey, Trenton, New Jersey.

Pristas, R. P. 2004. Bedrock geology of New Jersey (scale 1:100,000). Digital geodata series 04-6. New Jersey Geological Survey, Trenton, New Jersey.

Volkert, R. A. 1988. Geologic map of the Mendham Quadrangle, Morris County, New Jersey (scale 1:24,000). Geologic map series 88-3. New Jersey Geological Survey, Trenton, New Jersey.

Volkert, R. A. 1988. Provisional geologic map of the Proterozoic rocks of the Morristown Quadrangle, New Jersey (scale 1:24,000). New Jersey Geological Survey, Trenton, New Jersey.

GRI GIS Data

The GRI team implements a GIS data model that standardizes map deliverables. The data model is included on the enclosed CD and is also available at http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm. This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI team digitized the data for Morristown National Historical Park using data model version 2.1. The GRI Geologic Maps website, http://www.nature.nps.gov/geology/inventory/geo_maps.cfm, provides more information about GRI map products.

GRI digital geologic data are included on the attached CD and are available through the NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/App/Reference/Search?SearchType=Q). 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 (PDF) that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information
- Data in ESRI geodatabase and shapefile GIS format
- Layer files with feature symbology (tables 2 and 3)
- Federal Geographic Data Committee (FGDC)–compliant metadata
- An ancillary map information document (PDF) that contains information captured from source maps, such as map unit descriptions, geologic unit correlation tables, legends, cross sections, and figures
- An ESRI map document (.mxd) that displays the digital geologic data

Table 2. Surficial geology data layers in the Morristown National Historical Park GIS data.

Data Layer	On Poster?
Geologic Cross Section Lines	No
Geologic Observation Localities	No
Geologic Measurement Localities	No
Landslide Point Features	No
Mine Point Features	No
Glacial Feature Lines	No
Ridge Crest Line Features	Yes
Bedrock Surface Elevation Contours	No
Point Geologic Units	Yes
Glacial Area Feature Boundaries	No
Glacial Area Features	No
Artificial Fill and Trash Fill Boundaries	No
Artificial Fill and Trash Fill Units	No
Excavation Limit Lines	No
Excavation Area Feature Boundaries	No
Excavation Area Features	No
Bedrock Outcrop Boundaries	Yes
Bedrock Outcrops	Yes
Surficial Geologic Units	Yes
Surficial Geologic Contacts	Yes

Table 3. Bedrock geology data layers in the Morristown National Historical Park GIS data.

Data Layer	On Poster?
Geologic Cross Section Lines	No
Geologic Attitude Observation Localities	No
Earthquake Epicenters	No
Mine Point Features	No
Map Symbology	Yes
Folds	Yes
Faults	Yes
Linear Dikes	Yes
Linear Geologic Units	No
Bedrock Geologic Contacts	Yes
Bedrock Geologic Units	Yes

Geologic Map Posters

Posters of the GRI digital geologic data draped over shaded relief images of the park and surrounding area are included with this report. Not all GIS feature classes are included on the posters (tables 2 and 3). Geographic information and selected park features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data set, but are available online from a variety of sources. Contact GRI for assistance in locating these data.

Map Unit Properties Tables

The Map Unit Properties Tables list the geologic time division, symbol, and a simplified description for each geologic map unit in the GRI GIS data. Following the structure of the report, the tables summarize the geologic features, processes, resource management issues, and history associated with each map unit.

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 GRI with any questions.

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the posters. 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 horizontally within 12 m (40 ft) and 51 m (167 ft), respectively, of their true locations.

Glossary

This section contains brief definitions of selected geologic terms relevant to this report. Definitions are based on those in the American Geosciences Institute Glossary of Geology *(5th edition; 2005). Additional terms are defined at http://geomaps.wr.usgs.gov/parks/misc/glossarya.html.*

accretion (sedimentary). The gradual addition of new land to old by the deposition of sediment, for example, on a beach by the washing up of sand from the sea.

accretion (structural geology). The addition of island-arc or continental material to a continent collision, welding, or suturing at a convergent plate boundary. Compare to "obduction."

active margin. A tectonically active plate boundary where lithospheric plates are converging, diverging, or sliding past one another. Compare with "passive margin."

aeolian. Describes materials formed, eroded, or deposited by or related to the action of wind.

alaskite. An intrusive (plutonic) igneous rock with a high percentage of sodium- or potassium-rich feldspar minerals and a low percentage of mafic minerals.

alkalic. Describes a rock that is enriched in sodium and potassium.

alluvial fan. A low, relatively flat to gently sloping, fan-shaped mass of loose rock material deposited by a stream, especially in a semiarid region, where a stream issues from a canyon onto a plain or broad valley floor.

alluvium. Stream-deposited sediment.

amphibole. A group of silicate (silicon + oxygen) minerals composed of hydrous calcium and magnesium with the general formula $(Ca_2Mg_5)Si_8O_{22}(OH)_2$.

amphibolite. A metamorphic rock consisting mostly of the minerals amphibole and plagioclase, with little or no quartz.

amygdule. A gas cavity or vesicle in an igneous rock, which is filled with secondary minerals.

andesite. An extrusive (volcanic) igneous rock characteristically medium dark in color and containing 57%–63% silica and moderate amounts of iron and magnesium.

anhydrite. A sulfate (sulfur + oxygen) mineral composed of anhydrous calcium sulfate, $CaSO_4$; readily alters to hydrous calcium sulfate (gypsum).

anticline. A fold, generally convex upward ("A"-shaped) whose core contains the stratigraphically older rocks. Compare with "syncline."

apatite. A group of phosphate (phosphorus + oxygen) minerals composed of calcium together with fluorine, chlorine, hydroxyl, or carbonate in varying amounts and having the general formula $Ca_5(F,OH,Cl)(PO_4,CO_3)_3$.

aphanitic. Describes the texture of fine-grained igneous rock in which different components are not distinguishable by the unaided eye.

aquifer. A rock or sedimentary unit that is sufficiently porous to hold water, sufficiently permeable to allow water to move through it, and saturated to some level.

arkose. A commonly coarse-grained, pink or reddish sandstone consisting of abundant feldspar minerals.

augite. A dark-green to black silicate (silicon + oxygen) mineral of the pyroxene group that contains large amounts of aluminum, iron, and magnesium.

basalt. An extrusive (volcanic) igneous rock that is characteristically dark in color (gray to black), contains 45%–53% silica, and is rich in iron and magnesium; more fluid than andesite or dacite, which contain more silica.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie rocks exposed at the surface, commonly sedimentary. In many regions the basement is of Precambrian age, but it may be much younger. Also, Earth's crust below sedimentary deposits that extends down to the Mohorovicic discontinuity.

basin (structural). A doubly plunging syncline in which rocks dip inward from all sides.

basin (sedimentary). Any depression, from continental to local scale, into which sediments are deposited.

bed. The smallest sedimentary stratigraphic unit, commonly ranging in thickness from about 1 cm (0.4 in) to 1 to 2 m (40 to 80 in) and distinguishable from beds above and below.

bedding. Depositional layering or stratification of sediments.

bedrock. Solid rock that underlies unconsolidated, superficial material and soil.

block (fault). A crustal unit bounded completely or partially by faults.

biotite. A dark-colored, shiny silicate mineral (silicon + oxygen) of the mica group composed of magnesium and/or iron, $K(Mg,Fe)Si_3O_{10}(OH)_2$; characterized by perfect cleavage, readily splitting into thin sheets.

bioturbation. The reworking of sediment by organisms.

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

braided stream. A sediment-clogged stream that forms multiple channels that divide and rejoin.

calcareous. Describes a substance that contains calcium carbonate. When applied to a rock name it implies that as much as 50% of the rock is calcium carbonate.

calc-silicate rock. A metamorphic rock consisting mainly of calcium-bearing silicates and formed by metamorphism of impure limestone or dolomite.

calcic. Describes a mineral or igneous rock containing a significant amount of calcium.

calcite. A carbonate (carbon + oxygen) mineral of calcium, $CaCO_3$; calcium carbonate. It is the most abundant cave mineral.

carbonaceous. Describes a rock or sediment with considerable carbon, especially organic material, hydrocarbon, or coal.

carbonate. A mineral group composed of carbon and oxygen plus an element or elements; for example calcite, $CaCO_3$; and dolomite, $CaMg(CO_3)_2$.

carbonate rock. A rock, for example, limestone, calcite, and dolomite, that consist primarily of carbonate minerals.

cementation. The process by which clastic sediments become lithified or consolidated into hard, compact rocks, usually through deposition or precipitation of minerals in the spaces among the individual grains of the sediment; may occur simultaneously with sedimentation or at a later time.

chemical sediment. A sediment precipitated directly from solution (also called "nonclastic").

chemical weathering. Chemical breakdown of minerals at Earth's surface via reaction with water, air, or dissolved substances; commonly results in a change in chemical composition providing more stability in the current environment.

chert. An extremely hard sedimentary rock with conchoidal fracturing, consisting mostly of interlocking crystals of quartz.

clast. An individual constituent, grain, or fragment of a rock or unconsolidated deposit, produced by the mechanical or chemical disintegration of a larger rock mass.

clastic. Describes rocks or sediments made of fragments of preexisting rocks.

clay. Refers to clay minerals and sedimentary fragments that are less than 1/256 mm (0.00015 in) across.

clinopyroxene. A group name for pyroxene minerals that crystallize in the monoclinic system and sometimes contain considerable calcium with or without aluminum and the alkali metals.

columnar joints. Parallel, prismatic columns, polygonal in cross section, in basaltic flows and sometimes in other extrusive and intrusive rocks; form as a result of contraction during cooling.

colluvium. A loose, heterogeneous, and incoherent mass of rock fragments and soil material deposited via surface runoff or slow continuous downslope creep; usually collects at the base of a slope or hillside, but includes loose material covering hillsides.

conglomerate. A coarse-grained, generally unsorted, sedimentary rock consisting of cemented, rounded clasts larger than 2 mm (0.08 in) in diameter.

conodont. One of a number of small, separated fossil elements assigned to the order Conodontophorida; commonly toothlike in form but not necessarily in function.

continental crust. Earth's crust that is rich in silica and aluminum and underlies the continents and the continental shelves; ranges in thickness from about 25 km (15 mi) to more than 70 km (40 mi) under mountain ranges, averaging about 40 km (25 km) thick.

continental rifting. Process by which a region of crust undergoes extension (pulling apart), resulting in the formation of many related normal faults, and often associated with volcanic activity.

convergent plate boundary. A boundary between two plates that are moving toward each other. Essentially synonymous with "subduction zone" but used in different contexts.

craton. The relatively old and geologically stable interior of a continent.

creep. The slow, imperceptible downslope movement of mineral, rock, and soil particles under gravity.

cross-bedding. Uniform to highly varied sets of inclined beds deposited by wind or water that indicate flow conditions such as direction and depth.

cross section. A graphic interpretation of geology, structure, or stratigraphy based on mapped and measured geologic extents and attitudes, depicted in a vertical plane (i.e., a cut or profile view).

crust. Earth's outermost layer or shell. Compare to "oceanic crust" and "continental crust."

crystalline. Describes a regular, orderly, repeating geometric structural arrangement of atoms.

cutbank. A steep, bare slope formed by lateral erosion of a stream.

debris flow. A moving mass of rock fragments, soil, and mud, with more than half of the particles larger than sand size. Slow debris flows may move less that 1 m (3 ft) per year; rapid ones reach 160 kph (100 mph).

deformation. The process of folding, faulting, shearing, or fabric development in rocks as a result of Earth stresses.

delta. The low, nearly flat, alluvial tract of land at or near the mouth of a river, commonly forming a triangular or fan-shaped plain of considerable area; resulting from the accumulation of sediment supplied by the river in such quantities that it is not removed by tides, waves, and currents.

detritus. Loose rock and mineral material that is worn off or removed by mechanical processes.

diabase. An intrusive (plutonic) igneous rock consisting primarily of the minerals labradorite and pyroxene.

differential erosion. Erosion that occurs at irregular or varying rates due to differences in the resistance and hardness of surface material: softer and weaker rocks are rapidly worn away, whereas harder and more resistant rocks remain to form ridges, hills, or mountains.

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

diorite. A coarse-grained, intrusive (plutonic) igneous rock characteristically containing plagioclase, as well as dark-colored amphibole (especially hornblende), pyroxene, and sometimes a small amount of quartz; diorite grades into monzodiorite with the addition of alkali feldspar.

dip. The angle between a bed or other geologic surface and the horizontal plane.

dip-slip fault. A fault with measurable offset where the relative movement is parallel to the dip of the fault.

divergent plate boundary. A boundary between two plates that are moving apart, characterized by mid-ocean ridges at which sea-floor spreading occurs.

dolomite (rock). A carbonate sedimentary rock containing more than 50% of the mineral dolomite (calcium-magnesium carbonate).

downcutting. Stream erosion in which cutting is directed primarily downward, as opposed to laterally.

drainage basin. The total area from which a stream system receives or drains precipitation runoff.

drift. All rock material (clay, silt, sand, gravel, and boulders) transported and deposited by a glacier, or by running water emanating from a glacier.

drumlin. A low, smoothly rounded, elongated oval hill, mound, or ridge of till that formed under the ice margin and was shaped by glacial flow; the long axis is parallel to the direction of ice movement.

epicenter. The point on Earth's surface directly above the initial rupture point of an earthquake.

epidote. A characteristically green silicate (silicon + oxygen) mineral, commonly occurring as slender, grooved crystals in hand specimens.

erratic. A rock fragment carried by glacial ice deposited at some distance from the outcrop from which it was derived, and generally, though not necessarily, resting on bedrock of different lithology; size ranges from a pebble to a house-size block.

escarpment. A steep cliff or topographic step resulting from vertical displacement on a fault or as a result of slope movement or erosion. Synonymous with "scarp."

extension. A type of deformation where Earth's crust is pulled apart.

extrusive. Describes igneous rock that has been erupted onto the surface of the Earth.

facies (metamorphic). The pressure and temperature conditions that result in a particular suite of metamorphic minerals.

fan delta. A gently sloping alluvial deposit produced where a mountain stream flows out onto a lowland.

fault. A break in rock characterized by displacement of one side relative to the other.

feldspar. A group of abundant silicate (silicon + oxygen) minerals, comprising more than 60% of Earth's crust and occurring in all types of rocks. Compare to "alkali feldspar" and "plagioclase."

felsic. A mnemonic adjective derived from ***fe***ldspar +***l***enad (feldspathoid) +***si***lica +***c***, that describes an igneous rock having abundant light-colored minerals; also, describes those minerals (quartz, feldspars, feldspathoids, muscovite). Compare to "mafic."

floodplain. The surface or strip of relatively smooth land composed of alluvium and adjacent to a river channel, constructed by the present river in its existing regimen and covered with water when the river overflows its banks. A river has one floodplain and may have one or more terraces representing abandoned floodplains.

fold. A curve or bend in an originally flat structure, such as a rock stratum, bedding plane, or foliation; usually a product of deformation.

foliation. A preferred arrangement of crystal planes in minerals. Primary foliation develops during the formation of a rock and includes bedding in sedimentary rocks and flow layering in igneous rocks. In metamorphic rocks, the term commonly refers to a parallel orientation of planar minerals such as micas. Secondary foliation develops during deformation and/or metamorphism and includes cleavage, schistosity, and gneissic banding.

footwall. The lower wall of a fault. Compare to "hanging wall."

formation. Fundamental rock-stratigraphic unit that is mappable, lithologically distinct from adjoining strata, and has definable upper and lower contacts.

fracture. The breaking of a mineral other than along planes of cleavage. Also, any break in a rock such as a crack, joint, or fault.

frost wedging. A type of mechanical disintegration, splitting, or breakup of a rock by which jointed rock is pried and dislodged by ice acting as a wedge.

gabbro. A group of dark-colored, coarse-grained intrusive (plutonic) igneous rocks composed of plagioclase, pyroxene, amphibole, and olivine.

garnet. A hard silicate (silicon + oxygen) mineral with a glassy luster, and commonly well-defined crystal faces; characteristically dark red but occurs in a variety of colors.

geomorphology. The study of the general configuration of surface landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features.

glauconite. A greenish silicate (silicon + oxygen) mineral, $(K,Na)(Fe,Al,Mg)_2(Si,Al)_4O_{10}(OH)_2$, characterized by a micaceous structure, commonly interstratified with smectite; may serve as an indicator of very slow sedimentation.

gneiss. A foliated metamorphic rock with alternating bands of dark and light minerals. Varieties are distinguished by texture (e.g., augen gneiss), characteristic minerals (e.g., hornblende gneiss), or general composition (e.g., granite gneiss).

Gondwana. The late Paleozoic continent of the Southern Hemisphere and counterpart of Laurasia of the Northern Hemisphere; both were derived from the supercontinent Pangaea.

granite. A coarse-grained, intrusive igneous (plutonic) rock in which quartz constitutes 10%–50% percent of the felsic ("light-colored") components and the alkali feldspar/total feldspar ratio is generally restricted to the range of 65% to 90%; perhaps the best known of all igneous rocks.

graben. An elongated, downdropped trough or basin, bounded on both sides by high-angle normal faults that dip toward one another. Compare to "horst."

granodiorite. A coarse-grained intrusive (plutonic) igneous rock intermediate in composition between quartz diorite and quartz monzonite, containing quartz, plagioclase, and potassium feldspar as the felsic ("light-colored") components, with biotite, hornblende, or, more rarely, pyroxene, as the mafic ("dark-colored") components.

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.

gully. A small channel produced by running water in unconsolidated material.

gypsum. A sulfate (sulfur + oxygen) mineral of calcium and water, $CaSO_4 \bullet 2H_2O$.

hanging valley. A tributary glacial valley whose mouth is high above the floor of the main valley, which was eroded by the main body of the glacier.

hanging wall. The upper wall of a fault. Compare with "footwall."

hornblende. A silicate (silicon + oxygen) mineral of sodium, potassium, calcium, magnesium, iron, and aluminum; the most common mineral of the amphibole group; commonly black and occurring in distinct crystals or in columnar, fibrous, or granular forms in hand specimens.

horst. An elongated, uplifted block that is bounded on both sides by normal faults that dip away from one another. Compare to "graben."

hypersthene. A silicate (silicon + oxygen) mineral of the pyroxene group consisting of magnesium and iron.

igneous. Describes a rock or mineral that solidified from molten or partly molten material; also, describes processes leading to, related to, or resulting from the formation of such rocks.

incision. Downward erosion by a stream, resulting in a deepened channel and commonly a narrow, steep-walled valley.

intrusion. The process of emplacement of magma into preexisting rock. Also, the igneous rock mass formed.

island arc. A offshore, generally curved belt of volcanoes above a subduction zone.

joint. A break in rock without relative movement of rocks on either side of the fracture surface.

kame delta. A flat-topped, steep-sided hill of well-sorted sand and gravel deposited by a meltwater stream flowing into a proglacial or other ice-marginal lake; the proximal margin of the delta was built in contact with a glacier.

labradorite. A silicate (silicon + oxygen) mineral of the plagioclase group with the general formula $(Ca,Na)(Al,Si)_4O_8$.

lacustrine. Describes a process, feature, or organism pertaining to, produced by, or inhabiting a lake.

landslide. A collective term covering a wide variety of slope-movement landforms and processes that involve the downslope transport of soil and rock material en masse under the influence of gravity.

Laurasia. The late Paleozoic continent of the Northern Hemisphere and counterpart of Gonwana of the Southern Hemisphere; both were derived from the supercontinent Pangaea.

lava. Molten or solidified magma that has been extruded though a vent onto Earth's surface.

left-lateral fault. A strike-slip fault on which the side opposite the observer has been displaced to the left. Synonymous with "sinistral fault."

lens. A sedimentary deposit that resembles a convex lens and is characterized by converging surfaces, thick in the middle and thinning out toward the edges.

limestone. A carbonate sedimentary rock consisting of more than 95% calcite and less than 5% dolomite.

lithology. The physical description or classification of a rock or rock unit based on characteristics such as color, mineral composition, and grain size.

lithosphere. Earth's relatively rigid outer shell that consists of the entire crust plus the uppermost mantle. It is broken into about 20 plates, and according to the theory of plate tectonics, movement and interaction of these plates is responsible for most geologic activity.

loess. Windblown silt-sized sediment.

mafic. A mnemonic adjective derived from ***ma***gnesium + ***f***erric + ***ic*** that describes an igneous rock composed mostly of one or more ferromagnesian, dark-colored minerals; also, describes those minerals. Compare to "felsic."

magma. Molten rock beneath Earth's surface capable of intrusion and extrusion.

magmatic arc. An arcuate line of plutons, volcanic rocks, or active volcanoes formed at a convergent plate boundary.

mantle. The zone of the Earth below the crust and above the core.

matrix. The fine-grained material between coarse (larger) grains in an igneous rock or poorly sorted clastic sediment or rock. Also refers to rock or sediment in which a fossil is embedded.

meander. Sinuous lateral curve or bend in a stream channel; a meander's original pattern is preserved with little modification. An entrenched meander is incised (carved downward) into the surface of its valley.

mechanical weathering. The physical breakup of rocks without change in composition. Synonymous with physical weathering.

metamorphism. The mineralogical, chemical, and structural changes of solid rocks, generally imposed at depth below the surface zones of weathering and cementation.

mica. A group of abundant silicate (silicon + oxygen) minerals characterized by perfect cleavage, readily splitting into thin sheets. Examples include "biotite" and "muscovite."

monzonite. An intrusive (plutonic) igneous rock, intermediate in composition between syenite and diorite, containing approximately equal amounts of alkali feldspar and plagioclase and very little quartz. Monzonite contains less quartz and more plagioclase than granite.

moraine. A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of a glacier, in a variety of topographic landforms that are independent of control by the surface on which the drift lies.

mud crack. Crack formed in clay, silt, or mud by shrinkage during dehydration at Earth's surface.

muscovite. A light-colored silicate (silicon + oxygen) mineral of the mica group, $KAl_3Si_3O_{10}(OH)_2$, characterized by perfect cleavage in one direction and the ability to split into thin, clear sheets.

normal fault. A fault in which the hanging wall appears to have moved downward relative to the footwall; the angle of dip is usually 45°–90°.

oblique fault. A fault in which motion includes both dip-slip and strike-slip components.

oceanic crust. Earth's crust that underlies the ocean basins and is rich in iron and magnesium; ranges in thickness from about 5 to 10 km (3 to 6 mi).

olivine. A silicate (silicon + oxygen) mineral of magnesium and iron, $(Mg,Fe)_2SiO_4$; commonly olive-green and an essential mineral in basalt, gabbro, and peridotite.

orogeny. A mountain-building event.

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.

outwash. Glacial sediment transported and deposited by meltwater streams.

overbank deposit. Fine-grained sediment (silt and sand) deposited on a floodplain by floodwaters.

Pangaea. A supercontinent that existed from about 300 to about 200 million years ago and included most of the continental crust of the Earth, from which the present continents were derived by fragmentation and continental drift. During an intermediate stage of the fragmentation—between the existence of Pangaea and that of the present continents—Pangaea split into two large fragments, Laurasia on the north and Gondwana on the south.

passive margin. A continental plate boundary where no plate-scale tectonism is taking place; plates are not converging, diverging, or sliding past one another.

pegmatite. An intrusive (plutonic) 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.

permeability. A measure of the relative ease with which a fluid moves through the pore spaces of a rock or unconsolidated deposit.

perthite. A variety of alkali feldspar consisting of parallel or subparallel intergrowths in which the potassium-rich phase appears to be the host from which the sodium-rich phase exsolved; the exsolved areas are visible to the naked eye, and typically form strings, lamellae, blebs, films, or irregular small veins.

plagioclase. A silicate (silicon + oxygen) mineral of the feldspar group that contains both sodium and calcium ions that freely substitute for one another; characterized by striations (parallel lines) in hand specimens.

pluton. A deep-seated igneous intrusion.

potassium feldspar. A feldspar mineral rich in potassium such as orthoclase, microcline, and sanidine.

pseudomorph. A mineral whose outward crystal form resembles that of another mineral; described as being "after" the mineral whose outward form it has (e.g., quartz after fluorite).

pyroxene. A group of silicate (silicon + oxygen) minerals composed of magnesium and iron with the general formula $(Mg,Fe)SiO_3$; characterized by short, stout crystals in hand specimens.

quartzite. A medium-grained, nonfoliated metamorphic rock composed mostly of quartz; metamorphosed quartz sandstone.

quartz monzonite. An intrusive (plutonic) igneous rock of granitic composition but with about as much plagioclase as alkali feldspar.

regolith. The layer of unconsolidated rock material that forms the surface of the land and overlies or covers bedrock; includes rock debris of all kinds, volcanic ash, glacial drift, alluvium, loess, and aeolian deposits, vegetal accumulations, and soil. Etymology: Greek "rhegos" (blanket) + "lithos" (stone).

reverse fault. A contractional high-angle (greater than 45°) dip-slip fault in which the hanging wall moves up relative to the footwall.

rift. A region of Earth's crust where extension results in formation of many related normal faults, commonly associated with volcanic activity.

right-lateral fault. A strike-slip fault on which the side opposite the observer has been displaced to the right.

ripple marks. The undulating, approximately parallel and usually small-scale pattern of ridges formed in sediment by the flow of wind or water.

rock. A solid, cohesive aggregate of one or more minerals.

rock fall. The most rapid mass-wasting process, in which rocks are dislodged and move downslope rapidly.

roundness. The relative amount of curvature of the "corners" of a sediment grain.

sandstone. Clastic sedimentary rock of predominantly sand-sized grains.

saprolite. Soft, often clay-rich, decomposed rock formed in place by chemical weathering.

scarp. A steep cliff or topographic step resulting from displacement on a fault or by mass movement or erosion. Also called an "escarpment."

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.

sedimentary rock. A rock resulting from the consolidation of loose sediment that has accumulated in layers; it may be "clastic," consisting of mechanically formed fragments of older rock; "chemical," formed by precipitation from solution; or "organic," consisting of the remains of plants and animals. One of the three main classes of rock—igneous, metamorphic, and sedimentary.

shale. A clastic sedimentary rock made of clay-sized particles and characterized by fissility.

silicate. A mineral group composed of silicon (Si) and oxygen (O) plus an element or elements, for example, quartz, SiO_2; olivine, $(Mg, Fe)_2SiO_4$; and pyroxene, $(Mg,Fe)SiO_3$; as well as the amphiboles, micas, and feldspars.

slump. A generally large, coherent slope movement with a concave failure surface and subsequent backward rotation relative to the slope.

soil. The unconsolidated portion of the Earth's crust modified through physical, chemical, and biotic processes into a medium capable of supporting plant growth.

solifluction. The slow downslope movement of waterlogged soil, normally at rates of 0.5 to 5.0 cm (0.2 to 2 in) per year; especially, the flow occurring at high

elevations in regions underlain by frozen ground, which acts as a downward barrier to water percolation.

spring. A place where groundwater flows naturally from a rock or the soil onto the land surface or into a body of surface water. Its occurrence depends on the nature and relationship of rocks, especially permeable and impermeable strata; the position of the water table; and topography.

stream terrace. A planar surface along the sides of a stream valley representing the remnants of an abandoned floodplain, stream bed, or valley floor produced during a former stage of erosion or deposition.

strike. The compass direction of the line of intersection of an inclined surface with a horizontal plane.

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault. Described as left-lateral (sinistral) when relative motion of the block opposite the observer is to the left, and right-lateral (dextral) when relative motion is to the right.

structure. The attitudes and relative positions of the rock masses of an area resulting from such processes as faulting, folding, and igneous intrusion.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

syncline. A generally concave upward fold of which the core contains the stratigraphically younger rocks. Compare with "anticline."

talus. Rock fragments, usually coarse and angular, lying at the base of a cliff or steep slope from which they have fallen.

tectonic. Describes a feature or process related to large-scale movement and deformation of Earth's crust.

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

terrestrial. Describes a feature, process, or organism related to land, Earth, or its inhabitants.

thrust fault. A dip-slip fault with a shallowly dipping (less than 45°) fault surface where the hanging wall moves up and over relative to the footwall.

till. Unstratified drift deposited directly by a glacier without reworking by meltwater and consisting of a mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.

trace (structural geology). The intersection of a geological surface with another surface, for example, the trace of bedding on a fault surface, or the trace of a fault or outcrop on the ground.

trace fossil. A fossilized feature such as a track, trail, burrow, or coprolite (dung), that preserves evidence of an organism's life activities, rather than the organism itself.

transform fault. A strike-slip fault that links two other faults or plate boundaries such as two segments of a mid-ocean ridge.

trend. The direction or bearing of an outcrop of a geologic feature such as an ore body, fold, or orogenic belt.

undercutting. The removal of material at the base of a steep slope by the erosive action of water (such as a stream), sand-laden wind in a desert, or waves along the coast.

uplift. A structurally high area in Earth's crust produced by movement that raises the rocks.

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

volcanic. Pertaining to the activities, structures, or rock types of a volcano.

volcanic arc. A large-scale (hundreds of kilometers) generally curved belt of volcanoes above a subduction zone.

water table. The upper surface of the saturated zone; the zone of rock in an aquifer saturated with water.

weathering. The physical, chemical, and biological processes by which rock is broken down, particularly at the surface.

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Additional References

This section lists additional references, resources, and websites that may be of use to resource managers. Web addresses are valid as of August 2014. 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): http://nature.nps.gov/geology/

NPS Geologic Resources Inventory: http://www.nature.nps.gov/geology/inventory/index.cfm

NPS Geoscientist-In-the-Parks (GIP) internship and guest scientist program: http://www.nature.nps.gov/geology/gip/index.cfm

NPS Views program (geology-themed modules are available for Geologic Time, Paleontology, Glaciers, Caves and Karst, Coastal Geology, Volcanoes, and a variety of geologic parks): http://www.nature.nps.gov/views/

NPS Resource Management Guidance and Documents

1998 National parks omnibus management act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf

Management Policies 2006 (Chapter 4: Natural resource management): http://www.nps.gov/policy/mp/policies.html

NPS-75: Natural resource inventory and monitoring guideline: http://www.nature.nps.gov/nps75/nps75.pdf

NPS Natural resource management reference manual #77: http://www.nature.nps.gov/Rm77/

Geologic monitoring manual (Young, R., and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado): http://nature.nps.gov/geology/monitoring/index.cfm

NPS Technical Information Center (TIC; Denver, Colorado; repository for technical documents): http://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://globalchange.gov/home

Intergovernmental Panel on Climate Change: http://www.ipcc.ch/

Geological Surveys and Societies

New Jersey Geological and Water Survey http://www.state.nj.us/dep/njgs/

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.agiweb.org/

Association of American State Geologists: http://www.stategeologists.org/

US Geological Survey Reference Tools

National geologic map database (NGMDB): http://ngmdb.usgs.gov/

Geologic names lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

Geographic names information system (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/

GeoPDFs (download searchable 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://tapestry.usgs.gov/Default.html

Appendix A: Scoping Participants

The following people attended the GRI scoping meeting for Morristown National Historical Park, held on 10 July 2007, and/or the follow-up report writing conference call, held on 8 August 2013. 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.

2007 Scoping Meeting Participants

Name	Affiliation	Position
Tim Connors	NPS Geologic Resources Division	Geologist, GRI maps coordinator
Bruce Heise	NPS Geologic Resources Division	Geologist, GRI program coordinator
Bob Masson	NPS Morristown NHP	Biologist
Brian Mitchell	NPS Northeast Temperate Network	Network coordinator
Trista Thornberry-Ehrlich	Colorado State University	Geologist, report author
Suzanne Wall	Andover Geologic Consulting	Geologist
Don Wise	University of Massachusetts, Amherst	Geologist
Ron Witte	New Jersey Geological Survey	Geologist

2013 Conference Call Participants

Name	Affiliation	Position
Debbie Conway	NPS Morristown NHP	Acting superintendent
Jason Kenworthy	NPS Geologic Resources Division	Geologist, GRI reports coordinator
Don Monteverde	New Jersey Geological and Water Survey	Geologist
Scott Stanford	New Jersey Geological and Water Survey	Geologist
Trista Thornberry-Ehrlich	Colorado State University	Geologist, report author

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 National Park Service 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 July 2014. Contact the NPS Geologic Resources Division for detailed guidance.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Paleontology	**National Parks Omnibus Management Act of 1998, 16 USC § 5937** 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.	**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. Regulations in association with 2009 PRPA are being finalized (May 2014).	**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.
Rocks and Minerals	**NPS Organic Act**, **16 USC § 1 *et seq.*** directs the NPS to conserve all resources in parks (including 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 CFR § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units. **Exception: 36 CFR § 7.91** allows limited gold panning in Whiskeytown. **Exception: 36 CFR § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, or 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
Park Use of Sand and Gravel	**Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units. **Exception:** 16 USC §90c 1(b) the non-wilderness portion of Lake Chelan National Recreation Area, where sand, rock and gravel may be made available for sale to the residents of Stehekin for local use as long as such 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.
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
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.	**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. **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.

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 337/125984, August 2014

National Park Service
US Department of the Interior

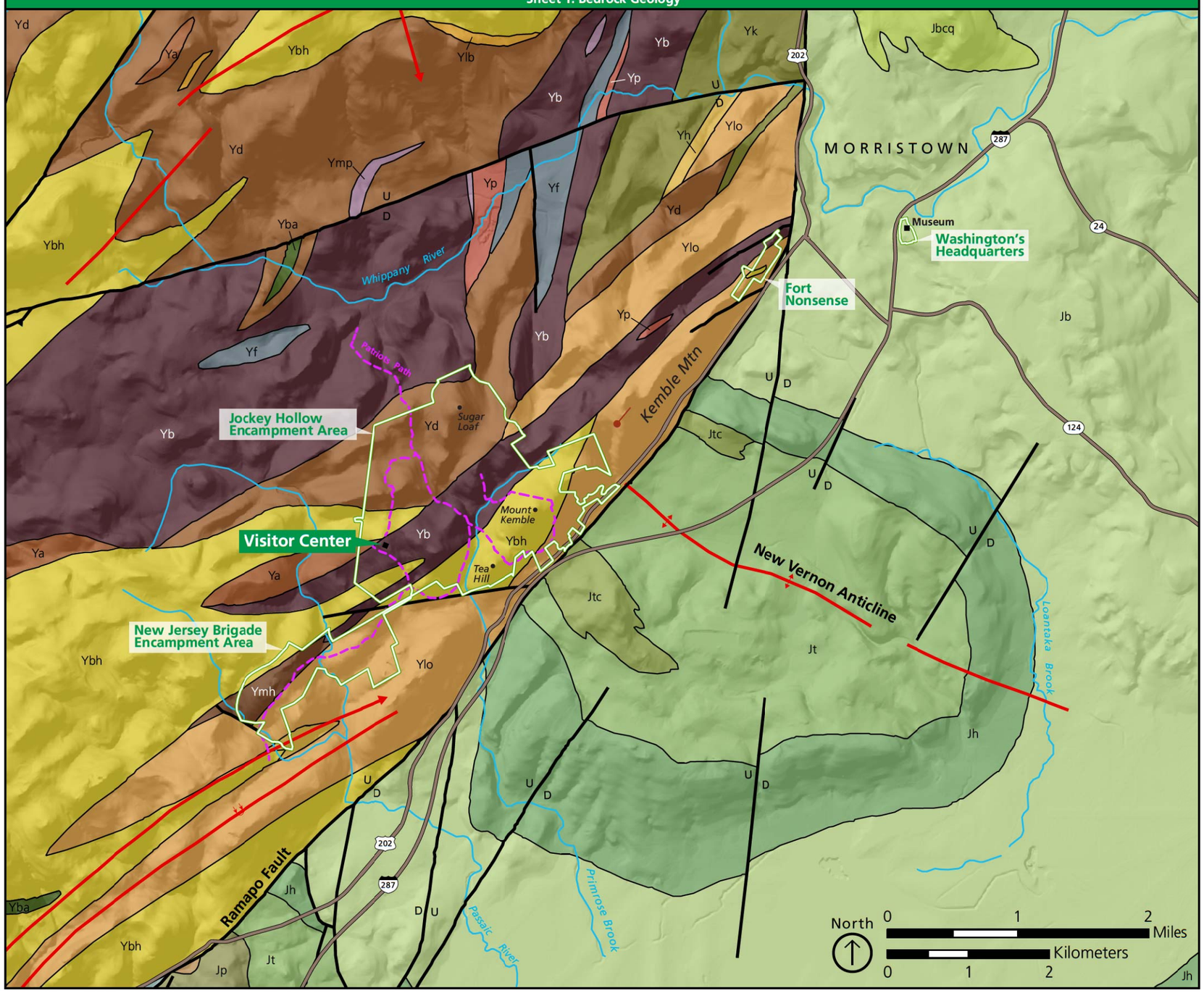
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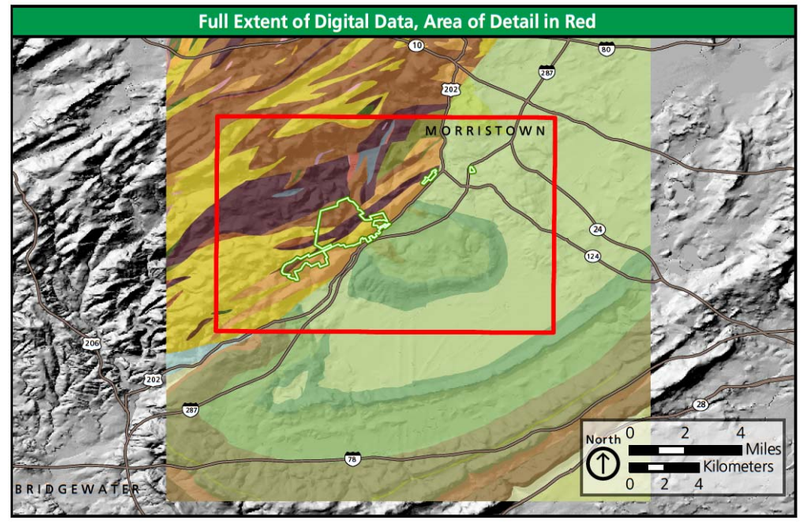
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Geologic Map of Morristown National Historical Park, New Jersey

Sheet 1: Bedrock Geology



Full Extent of Digital Data, Area of Detail in Red



NPS Boundary

Infrastructure
- buildings
- park trails
- highways

Water Features
- rivers

Faults
- U upthrown side
- D downthrown side
- reverse fault, known or certain
- normal fault, known or certain

Linear Dikes
- Zd - Diabase dike, known or certain

Folds
- anticline, known or certain
- plunging antiform, known or certain
- overturned antiform, known or certain
- overturned synform, known or certain
- plunging synform, known or certain

Bedrock Geologic Contacts
- known or certain

Bedrock Geologic Units

Jb	Boonton Formation
Jbcq	Quartz-pebble conglomerate
Jh	Hook Mountain Basalt
Jt	Towaco Formation
Jtc	Towaco Formation, conglomerate and sandstone facies
Ya	Amphibolite
Yb	Biotite-quartz-feldspar gneiss
Yba	Microperthite Alaskite
Ybh	Hornblende granite
Yd	Diorite
Yf	Franklin Marble
Yh	Hypersthene-quartz-oligoclase gneiss
Yk	Potassic feldspar gneiss
Ylb	Biotite-quartz-oligoclase gneiss
Ylo	Quartz-oligoclase gneiss
Ymh	Hornblende-quartz-feldspar gneiss
Ymp	Clinopyroxene-quartz-feldspar gneiss
Yp	Pyroxene gneiss

This figure was prepared as part of the NPS Geologic Resources Division's Geologic Resources Inventory. It is an overview of compiled digital geologic data, and not a substitute for site-specific investigations.

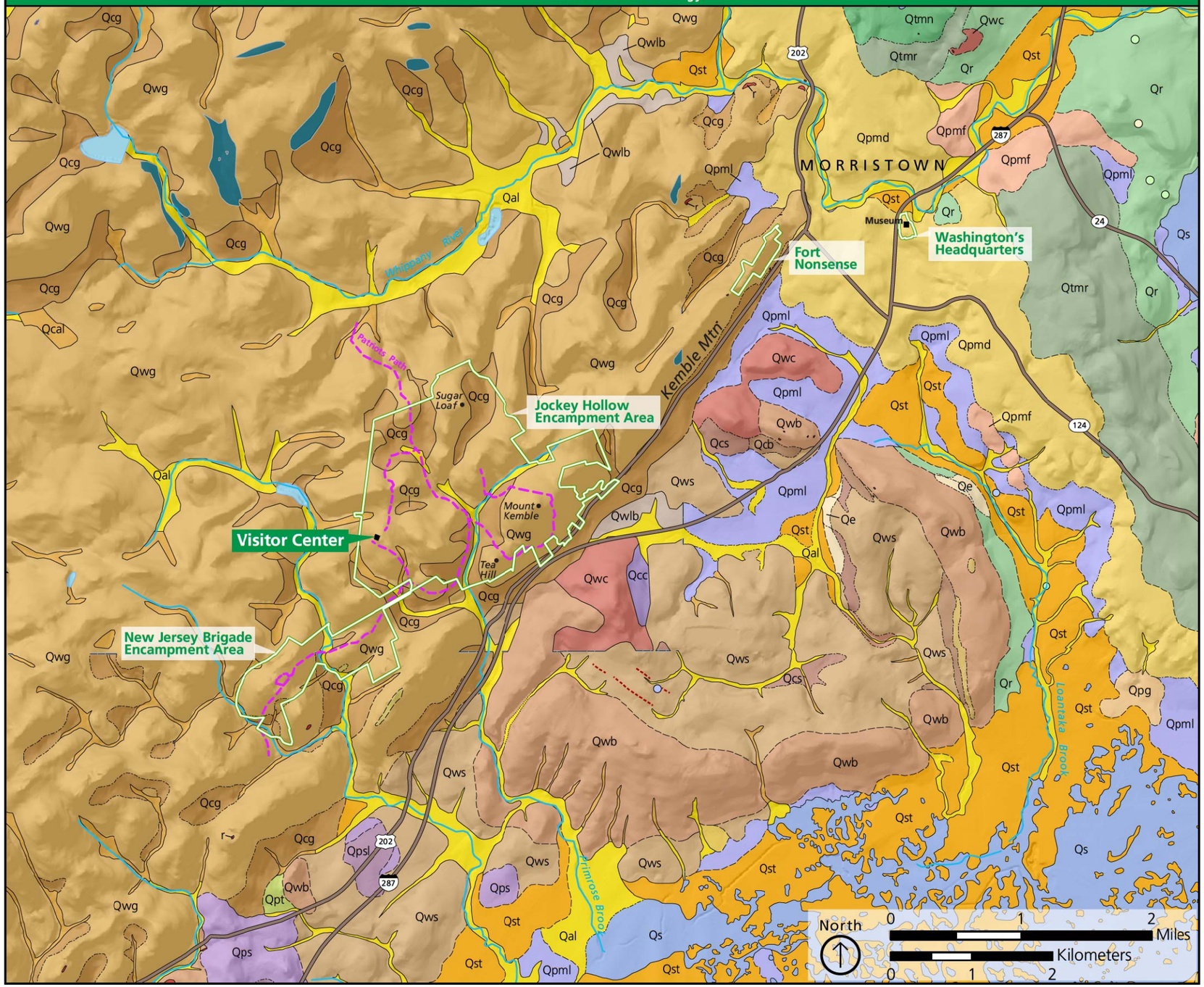
Minor inaccuracies may exist regarding the location of geologic features relative to other geologic or geographic features on the figure. Based on the source map scales (1:24,000 and 1:100,000) and U.S. National Map Accuracy Standards, geologic features represented here are within 12 meters / 40 feet (24k), 50 meters / 166 feet (100k) (horizontally) of their true location.

The source maps used in creation of the digital geologic data product include paper and digital New Jersey Geological Survey publications and paper U.S. Geological Survey Publications (see Geologic Map Data section for specific sources).

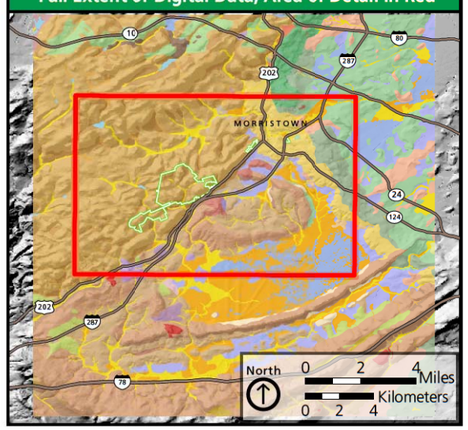
All digital geologic data and publications prepared as part of the Geologic Resources Inventory are available at the NPS Integrated Resource Management Applications Portal (IRMA): https://irma.nps.gov/App/Reference/Search. Enter "GRI" as the search text and select a park from the unit list.

Geologic Map of Morristown National Historical Park, New Jersey

Sheet 2: Surficial Geology



Full Extent of Digital Data, Area of Detail in Red



NPS Boundary

Infrastructure
- buildings
- park trails
- highways

Water Features
- rivers

Ridge Crest Line Features
- ridge crest, known or certain

Bedrock Outcrop Boundaries
- known or certain

Point Geologic Units
- Qpml - Glacial Lake Passaic, lake-bottom deposits
- Qr - Rahway Till
- Qpmb - Moggy Hollow Stage of Lake Passaic, beach deposits
- Qpmf - Glacial Lake Passaic, lacustrine-fan deposits
- Qpc - Glacial Lake Passaic, deltaic and lacustrine-fan deposits
- Qwc - Weathered conglomerate
- Qb - Bergen Till

Bedrock Outcrops
- extensive outcrops
- scattered outcrops

Surficial Geologic Contacts
- contact - dashed where approximate; dotted where concealed
- water or shoreline

Surficial Geologic Units selection
- water
- Qal Alluvium
- Qs Swamp and marsh deposits
- Qaf Alluvial fan deposits
- Qcal Alluvium and colluvium, undivided
- Qe Eolian deposits
- Qst Stream terrace deposits
- Qpg Great Notch Stage deposits
- Qcc Conglomerate colluvium
- Qpml Glacial Lake Passaic, lake-bottom deposits
- Qcs Shale and sandstone colluvium
- Qcg Gneiss colluvium
- Qcb Basalt colluvium, blocky phase
- Qcbl Basalt colluvium, silty phase
- Qr Rahway Till
- Qtmr Rahway Till, terminal moraine
- Qtmn Netcong Till, terminal moraine
- Qpmd Glacial Lake Passaic, deltaic deposits
- Qpmf Glacial Lake Passaic, lacustrine-fan deposits
- Qwlb Late Wisconsinan glacial lake-bottom deposits
- Qwde Late Wisconsinan glacial delta deposits
- Qwc Weathered conglomerate
- Qwg Weathered gneiss
- Qwgt Weathered gneiss, thin or absent and fractured outcrops abundant
- Qwb Weathered basalt
- Qwbt Weathered basalt, thin or absent and fractured rock rubble abundant
- Qws Weathered shale and sandstone
- Qwst Weathered shale and sandstone, thin or absent and outcrops or shale-chip rubble abundant
- Qps Deltaic and lacustrine-fan deposits
- Qpsl Lake-bottom deposits
- Qpt Pre-Illinoian till
- r Bedrock

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Bedrock Map Unit Properties Table: Morristown National Historical Park

Colored map units are mapped within Morristown National Historical Park. Bold text refers to sections in report.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
JURASSIC (Lower)	Boonton Formation (Jb) Boonton Formation, quartz-pebble conglomerate (Jbcq)	**Jb** contains interlayered, reddish-brown to purple, fine-grained sandstone, siltstone, and mudstone. Sandstone commonly contains mica flakes. Siltstone and mudstone occur in sequences, with grain size fining upward in each layer. The lower beds of the unit contain partly dolomitic siltstone and shale. **Jbcq** is distinctive quartz-pebble conglomerate present as interlayers with sandstone, siltstone, and shale of **Jb** near Morristown. Individual conglomeratic beds are about 0.5 m (1.6 ft) thick. **Jb** is up to 500 m (1,640 ft) thick. **Jb** is mapped within park boundaries at the Washington's Headquarters unit.	**Bedrock Features**—**Jb** and **Jbcq** contain upward-fining sequences, mudcracks, symmetrical ripple marks, burrows, and pseudomorphs of halite (salt), gypsum, and glauberite. **Paleontological Resources**—Sandstone layers near the middle and upper parts of the unit may contain carbonized plant remains and reptile footprints.	None reported.	**Breakup of Pangaea, Crustal Extension, and Volcanism**—**Jb** and **Jbcq** were deposited in a long narrow graben (fault-bounded valley) that opened as the supercontinent Pangaea broke apart during the Early Mesozoic. **Jb** is the youngest unit of the Newark Supergroup in New Jersey.
	Hook Mountain Basalt (Jh)	**Jh** is light– to dark–greenish-gray basalt. The primary mineral constituents are plagioclase, clinopyroxene, and iron-titanium oxides, such as magnetite and ilmenite. Two major flows compose **Jh**, with a maximum thickness of 110 m (360 ft). **Jh** is relatively resistant to erosion and underlies some low, strategic ridges southeast of Morristown.	**Bedrock Features**—**Jh** is amygdaloidal (contains mineral-filled bubbles or vesicles). Small spherical to tubular cavities represent gas-escape vesicles that formed while lava was molten. They are commonly filled with zeolite minerals or calcite.		**Breakup of Pangaea, Crustal Extension, and Volcanism**—**Jh** is one of a series of basaltic lava flows that accompanied crustal extension during the breakup of Pangaea. Thinning of Earth's crust allowed molten material to reach the surface.
	Towaco Formation (Jt) Towaco Formation, conglomerate and sandstone facies (Jtc)	**Jt** consists of reddish-brown to purple, fine- to medium-grained micaceous sandstone, siltstone, and silty mudstone. The rocks occur in 1–3-m (3–10-ft) sequences, with grain size fining upward in each layer. **Jtc** is conglomerate and conglomeratic sandstone containing quartzite and quartz clasts in light-red to brown silt. **Jtc** interfingers with **Jt** locally. Maximum thickness of units is about 380 m (1,250 ft).	**Bedrock Features**—**Jt** and **Jtc** contain upward-fining sequences, cross laminations, and bioturbated beds. Layers of **Jc** in contact with **Jh** flows were thermally metamorphosed into hornfels. **Paleontological Resources**—Calcareous siltstone and mudstone interlayers contain pollen, fish, and dinosaur tracks.		**Breakup of Pangaea, Crustal Extension, and Volcanism**—**Jt** and **Jtc** were deposited in a long narrow graben (fault-bounded valley) that opened as the supercontinent Pangaea broke apart during the Early Mesozoic.
	Preakness Basalt (Jp) Preakness Basalt, sandstone and siltstone (Jps)	**Jp** contains dark–greenish-gray to black, very fine-grained, dense, hard basalt. The primary mineral constituents are intergrown plagioclase and clinopyroxene. Three major flows compose **Jp**, with thickness ranging from 250 to 320 m (820–1,050 ft). A thin (2–8-m [7–26-ft]) bed of siltstone, **Jps**, separates the lower two flows of **Jp**. **Jp** and **Jps** are relatively resistant to erosion and underlie Second Watchung Mountain, southeast of Morristown.	**Bedrock Features**—**Jp** is amygdaloidal (contains mineral-filled bubbles or vesicles). Small spherical to tubular cavities represent gas-escape vesicles that formed while lava was molten. They are commonly filled with zeolite minerals or calcite. Abundance of amygdules increases near contacts between flows. Radiating slender columns, formed by overall shrinkage while cooling, are abundant in the highest flow.		**Breakup of Pangaea, Crustal Extension, and Volcanism**—**Jp** is one of a series of basaltic lava flows that accompanied crustal extension during the breakup of Pangaea. Thinning of Earth's crust allowed molten material to reach the surface. **Jps** represents a temporary cessation of volcanism when deposition of siltstone took place.
	Feltville Formation (Jf)	**Jf** consists of interlayered brownish-red to gray, fine- to coarse-grained sandstone; gray and black, coarse siltstone; and silty mudstone. Two 3-m- (10-ft-) thick layers of thin, black carbonaceous (carbon-bearing) limestone and gray, calcareous (calcium carbonate-bearing) siltstone occur near the base of **Jf**. Some thin gray to black siltstone and mudstone sequences occur near the top of **Jf**. Maximum thickness of this unit is 155 m (510 ft).	**Bedrock Features**—**Jf** contains upward-fining sequences, cross laminations, and bioturbated beds. Layers of **Jf** in contact with **Jp** flows were thermally metamorphosed into hornfels. **Paleontological Resources**—Carbonaceous limestone and calcareous siltstone interlayers contain abundant fish, reptile, arthropod, and diagnostic plant fossils.		**Breakup of Pangaea, Crustal Extension, and Volcanism**—**Jf** was deposited in a long narrow graben (fault-bounded valley) that opened as the supercontinent Pangaea broke apart during the Early Mesozoic.
	Orange Mountain Basalt (Jo)	**Jo** is dark–greenish-gray to black, fine-grained basalt. The primary mineral constituents are calcic plagioclase and clinopyroxene. Three major flows, separated by weathered zones or minor siltstone or mixed volcanic/sediment rocks, compose **Jo**, with a maximum thickness of 182 m (597 ft). **Jo** is relatively resistant to erosion and underlies First Watchung Mountain, southeast of Morristown.	**Bedrock Features**—**Jo** is amygdaloidal (contains mineral-filled bubbles or vesicles). Small spherical to tubular cavities represent gas-escape vesicles that formed while lava was molten. They are commonly filled with zeolite minerals or calcite. Abundance of amygdules increases near contacts between flows. Curvilinear and columnar joints, formed by overall shrinkage while cooling, are abundant in the lowest and middle flows. The uppermost flow has pillow structures at its base and pahoehoe (ribbony) flow structures near the top.		**Breakup of Pangaea, Crustal Extension, and Volcanism**—**Jo** is one of a series of basaltic lava flows that accompanied crustal extension during the breakup of Pangaea. Thinning of Earth's crust allowed molten material to reach the surface.

Colored map units are mapped within Morristown National Historical Park. Bold text refers to sections in report.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
Lower JURASSIC and Upper TRIASSIC	Passaic Formation (JTRp) Passaic Formation, sandy mudstone (JTRpms) Passaic Formation, conglomerate and sandstone facies (JTRpsc)	**JTRp** is reddish-brown to purple to grayish-red siltstone and shale with a maximum thickness of 3,600 m (11,810 ft). **JTRp** has several members, including: (1) reddish-brown to red, massive, silty to sandy mudstone and siltstone (**JTRpms**) and (2) brownish-red pebble conglomerate and medium- to coarse-grained, feldspathic sandstone and micaceous siltstone (**JTRpsc**). **JTRpsc** is up to 1,100 m (3,610 ft) thick.	**Bedrock Features**—**JTRpms** contains ripple marks, cross laminations, desiccation features, mudcracks, burrows, root casts, and bioturbated beds. Layers of **JTRpms** in contact with **Jo** flows were thermally metamorphosed into hornfels. **JTRpsc** contains 0.5–2.5- (2–8-ft-) thick upward-fining sequences, ripple marks, pebble layers, desiccation cracks, and root casts. **Paleontological Resources**—**JTRpms** and **JTRpsc** contain some fossils, burrows, and root casts.	None reported.	**Breakup of Pangaea, Crustal Extension, and Volcanism**—**JTRp**, **JTRpms**, and **JTRpsc** were deposited in a long narrow graben (fault-bounded valley) that opened as the supercontinent Pangaea broke apart during the Early Mesozoic.
ORDOVICIAN (Middle)	Jutlan Klippe Sequence unit B (Ojtb)	**Ojtb** is a heterogeneous mix of red, green, tan, and gray shale; interlayered dolomite and shale; interlayered fine-grained greywacke siltstone with beds or lenses of sandstone; light-gray to pale pinkish-gray quartzite; and interlayered fine-grained, thin-bedded limestone and red and green shale. Thickness ranges from 460 to 500 m (1,500–1,800 ft).	**Bedrock Features**—Limestone beds resemble conglomerates because they are disrupted, broken into rounded blocks (boudinage) in situ, and surrounded by shale beds. Graywacke is a sedimentary rock characterized by hardness, dark color, and poorly sorted angular grains of quartz and feldspar mixed with small rock or lithic fragments set in a compact, clay-fine matrix. Graywackes may form in submarine landslides where mixtures of dissimilar sediment sizes occur—immature sedimentary rocks. **Paleontological Resources**—Graptolites, conodonts, brachiopods.		**Appalachian Mountain Building**—Unit was highly deformed and transported along a thrust fault during the Paleozoic orogenies along the eastern margin of North America.
CAMBRIAN (Middle and Lower)	Leithsville Formation (Cl)	**Cl** consists of light- to dark- and olive-gray, fine- to medium-grained, thin- to medium-bedded dolomite in the upper layers. These layers grade downward into medium-gray to yellow to pink dolomite and dolomitic sandstone, siltstone, and shale. The lower layers of the unit are gray, medium-grained, medium-bedded dolomite with quartz sand stringers and lenses near the base. This unit is eroded and thickness ranges from 0 to 56 m (0–185 ft).	None reported.		**Longstanding Marine Margin**—**Cl** has a gradational contact with underlying **Ch**, indicating more or less continuous deposition.
CAMBRIAN (Lower)	Hardyston Quartzite (Ch)	**Ch** consists of light- to medium-gray and bluish conglomeratic sandstone. Some layers are pebble conglomerates, whereas others are finer-grained quartzite, arkosic, or dolomitic sandstone. Unit thickness ranges from about 0 to 9 m (1–30 ft).	**Bedrock Features**—Quartz pebbles in **Ch** are white and up to 2.5 cm (1 in) in diameter.		**Longstanding Marine Margin**—**Ch** has a gradational contact with overlying **Cl**, indicating more or less continuous deposition. The lower contact of **Ch** is unconformable, indicating a period of erosion or nondeposition.
LATE PROTEROZOIC ERA	Diabase dike (Zd)	Diorite is a gray to dark-gray to greenish intrusive igneous rock with moderate silica content. Primary minerals include plagioclase feldspar, biotite, hornblende, and/or pyroxene. Diorites may also contain small amounts of quartz, microcline, and olivine. **Zd** was mapped as linear dikes or intrusive bodies that cut across pre-existing bedrock structures, but no description of the unit is available.	None reported.		**Rifting of Rodinia and Opening of the Iapetus Ocean**—Discrete intrusions of igneous rocks, such as **Zd**, accompanied the rifting of Rodinia during crustal extension.

Colored map units are mapped within Morristown National Historical Park. Bold text refers to sections in report.

Age	Map Unit (Symbol)		Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
MIDDLE PROTEROZOIC ERA	Lake Hopatcong Intrusive Suite	Pyroxene granite (Ypg)	**Ypg** is greenish-gray, medium- to coarse-grained, massive, gneissic to scantly foliated granite with some monzonite, quartz monzodiorite, or granodiorite phases locally (for brief explanation, see http://en.wikipedia.org/wiki/QAPF_diagram [accessed 19 August 2014]). **Ypg** weathers to gray, buff, or white. Primary mineral constituents are microcline, quartz, oligoclase, and clinopyroxene. Secondary minerals include titanite, magnetite, apatite, and some pyrite. **Ypg** contains thin amphibolite bodies (see **Ya**).	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Ypg** include foliation.	None reported.	**Grenville Orogeny and the Supercontinent Rodinia**—**Ypg**, **Yba**, and **Ybh** were part of a series of igneous intrusions during the Grenville Orogeny, just prior to its peak metamorphic intensity in the area of present-day New Jersey. They are among the youngest basement rocks exposed in the New Jersey Highlands.
	Byram Intrusive Suite	Microperthite allanite (Yba)	Alaskite is a type of igneous (and/or metamorphic) rock, typically light colored, composed mainly of quartz and feldspar, with little or no dark-colored minerals. **Yba** was metamorphosed from granite to gneiss with scant foliation textures. In fresh exposures, **Yba** is pinkish gray to white, medium to coarse grained, and appears pink to buff on weathered outcrops. Primary mineral constituents are microcline (microperthite, a potassium feldspar), quartz, and oligoclase.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Yba** include scant foliation.		
		Hornblende granite (Ybh)	**Ybh** is pinkish-white to gray, medium- to coarse-grained, somewhat foliated granite and granitic gneiss. Primary mineral constituents include microcline, microperthite, quartz, oligoclase, and hornblende. Small bodies of pegmatite and amphibolite (see **Ya**) are present locally within **Ybh**. **Ybh** is mapped within park boundaries at the Fort Nonsense, New Jersey Brigade Encampment Area, and Jockey Hollow Encampment Area units.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Ybh** include foliation. **Ybh** has a U-Pb age of approximately 1,090 million years.	**Disturbed Lands**—Minerals in Mesoproterozoic units were targets of local mining. Several abandoned mine land sites occur in the park.	
	Potassic feldspar gneiss (Yk)		**Yk** is pinkish-white to gray, fine- to medium-grained, moderately foliated gneiss with lesser amounts of granofels (a coarse-grained, non-foliated metamorphic rock). Primary mineral constituents include quartz, microcline, microperthite, and some biotite, garnet, sillimanite, and opaque (dark) minerals. Weathered outcrops of **Yk** appear light gray to pinkish to buff.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Yk** include foliation.	None reported.	**Grenville Orogeny and the Supercontinent Rodinia**—**Yk**, **Yb**, **Ymh**, **Ymp**, **Yp**, and **Yf** (also some **Ya** units) are part of a series of metasedimentary (supracrustal) rocks deposited in a basin between compressive episodes of the Grenville Orogeny. **Yf** was metamorphosed limestone, perhaps originally part of a carbonate platform in a shallow marine setting.
	Biotite-quartz-feldspar gneiss (Yb)		Gneiss is a metamorphic rock in which minerals are segregated into bands of alternating composition—commonly marked by bands of flaky or elongate minerals. **Yb** consists of gray to tan or greenish-gray, fine- to medium–coarse-grained gneiss with variable foliation textures and compositions. **Yb** weathers to gray or rusty color. Primary mineral constituents are oligoclase, microcline, quartz, and biotite. Secondary minerals include garnet, graphite, sillimanite, and opaque (dark) minerals. **Yb** is mapped within park boundaries at the Fort Nonsense, New Jersey Brigade Encampment Area, and Jockey Hollow Encampment Area units.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Yb** include layering and foliation. **Paleontological Resources**—Graphite deposits in **Yb** may represent the remains of algal mats or other metamorphosed organic material.	**Disturbed Lands**—Minerals in Mesoproterozoic units were targets of local mining. Several abandoned mine land sites occur in the park.	

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
MIDDLE PROTEROZOIC ERA	Hornblende-quartz-feldspar gneiss (Ymh)	**Ymh** is pinkish-white to gray, fine- to medium-grained, massive to moderately well-layered gneiss. Primary mineral constituents include microcline, quartz, oligoclase, hornblende, and magnetite, with some garnet and biotite locally. **Ymh** weathers to pinkish gray to buff. **Ymh** is mapped within park boundaries at the New Jersey Brigade Encampment Area unit.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Ymh** include foliation and layering.	**Disturbed Lands**—Minerals in Mesoproterozoic units were targets of local mining. Several abandoned mine land sites occur in the park.	**Grenville Orogeny and the Supercontinent Rodinia**—**Yk**, **Yb**, **Ymh**, **Ymp**, **Yp**, and **Yf** (also some **Ya** units) are part of a series of metasedimentary (supracrustal) rocks deposited in a basin between compressive episodes of the Grenville Orogeny. **Yf** was metamorphosed limestone, perhaps originally part of a carbonate platform in a shallow marine setting.
	Clinopyroxene-quartz-feldspar gneiss (Ymp)	**Ymp** is white to pink to gray, fine- to medium-grained, massive to moderately well-layered gneiss. Primary mineral constituents include microcline, quartz, oligoclase, and clinopyroxene, with some epidote, biotite, titanite, and opaque (dark) minerals locally. **Ymp** is commonly interlayered with amphibolite (see **Ya**) or pyroxene amphibolite. **Ymp** weathers to pink or buff.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Ymp** include foliation and layering.	None reported.	
	Pyroxene gneiss (Yp)	**Yp** is greenish-gray, fine- to medium-grained, well-layered gneiss. Primary mineral constituents include oligoclase, clinopyroxene, some quartz, and scant opaque (dark) minerals and titanite. **Yp** is commonly interlayered with pyroxene amphibolite or marble (see **Yf**). **Yp** weathers to white or tan.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Yp** include foliation and layering.		
	Franklin Marble (Yf)	Marble is a non-foliated (non-banded) metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite. Marble is commonly metamorphosed limestone. **Yf** is white to gray to pinkish-orange, coarse- to fine-crystalline calcite marble. Accessory minerals include graphite, phlogopite, chondrodite, clinopyroxene, and serpentinite. Pods and layers of metaquartzite and clinopyroxene- and hornblende-rich rock occur locally. Talc and asbestos mines near Easton, Pennsylvania, are within **Yf**.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. **Yf** contains the Franklin and Sterling Hill zinc ore bodies. **Paleontological Resources**—Graphite deposits in **Yf** may represent the remains of algal mats or other metamorphosed organic material.		
	Losee Metamorphic Suite (basement rocks) — Amphibolite (Ya)	Amphibolite is a type of metamorphic rock composed mainly of amphibole (dark) and plagioclase feldspar (light), with little or no quartz. Amphibolite is typically dark and heavy, with a weakly foliated (banded appearance) or schistose (flaky) texture. Small black and white crystals give the rock a salt-and-pepper appearance. **Ya** is gray to grayish-black, medium-grained amphibolite. Biotite and clinopyroxene are minor mineral constituents. **Ya** is mapped within park boundaries at the Jockey Hollow Encampment Area unit.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia.	**Disturbed Lands**—Minerals in Mesoproterozoic units were targets of local mining. Several abandoned mine land sites occur in the park.	**Grenville Orogeny and the Supercontinent Rodinia**—**Ya**, **Yd**, **Yh**, **Ylb**, and **Ylo** are part of a series of metamorphic rocks that were part of the early eastern margin of North America. Initial metamorphism and deformation of these rocks occurred during the Grenville Orogeny, more than 1 billion years ago, during the formation of the supercontinent Rodinia. **Ya** stems from the metamorphism of a variety of sources in the park area, including volcanic rocks, sediments, and gabbros (low-silica igneous rocks).
	Losee Metamorphic Suite (basement rocks) — Hypersthene-quartz-oligoclase gneiss (Yh)	**Yh** consists of greenish-gray to brown, medium-grained gneiss with strong foliation textures and layering. **Yh** weathers to gray or tan and has a greasy sheen. Primary mineral constituents are andesine or oligoclase, quartz, clinopyroxene, hornblende, hypersthene, and scant biotite. **Yh** is commonly layered with amphibolite (see **Ya**) and plagioclase-quartz gneiss. **Yh** is mapped within park boundaries at the Fort Nonsense unit.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Yh** include strong foliation and layering.		

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Age	Map Unit (Symbol)		Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
MIDDLE PROTEROZOIC ERA	Losee Metamorphic Suite (basement rocks)	Diorite (Yd)	**Yd** is greenish-gray to brown, medium- to coarse-grained, massive diorite. Some amphibolite layers (**Ya**) occur throughout the unit. Outcrop appearance is gray to tan with a greasy sheen. Primary minerals include andesine or oligoclase (plagioclase feldspars), clinopyroxene, and hypersthene, with some biotite and magnetite. **Yd** is mapped within park boundaries at the Jockey Hollow Encampment Area unit.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia.	**Disturbed Lands**—Minerals in Mesoproterozoic units were targets of local mining. Several abandoned mine land sites occur in the park.	**Grenville Orogeny and the Supercontinent Rodinia**—**Ya**, **Yd**, **Yh**, **Ylb**, and **Ylo** are part of a series of metamorphic rocks that were part of the early eastern margin of North America. Initial metamorphism and deformation of these rocks occurred during the Grenville Orogeny, more than 1 billion years ago, during the formation of the supercontinent Rodinia. **Ya** stems from the metamorphism of a variety of sources in the park area, including volcanic rocks, sediments, and gabbros (low-silica igneous rocks).
		Quartz-oligoclase gneiss (Ylo)	**Ylo** is greenish-gray, medium- to coarse-grained, moderately layered to somewhat foliated gneiss and some granofels. **Ylo** weathers to white. Primary mineral constituents are quartz, andesine or oligoclase, and locally biotite, clinopyroxene or hornblende. **Ylo** contains thin amphibolite layers (see **Ya**). **Ylo** is mapped within park boundaries at the Fort Nonsense, New Jersey Brigade Encampment Area, and Jockey Hollow Encampment Area units.	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Ylo** include foliation and layering.		
		Biotite-quartz-oligoclase gneiss (Ylb)	**Ylb** consists of gray to greenish-gray, fine- to coarse-grained, massive to moderately layered and foliated gneiss. **Ylb** weathers to white or light gray. Primary mineral constituents are andesine or oligoclase, quartz, biotite, and some local garnet. **Ylb** is commonly interlayered with amphibolite (see **Ya**).	**Bedrock Features**—Old metamorphic rocks are from a variety of original sources that were deformed, fragmented, and transported over millennia. Metamorphic textures of **Ylb** include foliation and layering.		

Surficial Map Unit Properties Table: Morristown National Historical Park

Colored map units are mapped within Morristown National Historical Park. Bold text refers to sections in report.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Holocene)	Artificial fill (Qf) Trash fill (Qaft)	These units are anthropogenic. **Qf** consists of sand, gravel, silt, clay, and rock fragments, as well as anthropogenic materials, such as cinders, ash, brick, concrete, wood, slag, asphalt, metal, glass, and trash (**Qaft**). **Qaft** occurs as solid-waste landfills. Trash is mixed and covered with sand, silt, clay, and gravel. Units are 6–9 m (20–30 ft) thick. **Qf** and **Qaft** reflect the long anthropogenic influence on the landscape surrounding the park.	None reported.	**Disturbed Lands**—Landfills occur in the park area, but are too small to appear in the map data.	**Postglacial Modification of the Landscape and Modern Geomorphological Development**—Units record episodes in the human history of landscape change.
	Alluvium (Qal)	**Qal** is sorted sand, silt, clay, pebble gravel, and some cobbles deposited by rivers and streams. Some deposits of **Qal** are massive, whereas others are layered. The coarser components (sand and gravel) are deposited in stream channels. Finer silt and clay are deposited on levees and overbank areas as part of the floodplain adjacent to streams. Unit may contain organic matter or demolition debris and trash downstream of urban areas. **Qal** is up to 9 m (30 ft) thick. **Qal** is mapped within park boundaries at the New Jersey Brigade and Jockey Hollow encampment area units.	**Postglacial Deposits**—**Qal** covers some glacial deposits. **Paleontological Resources**—This unit may contain Pleistocene fossils.	**Slope Movement Hazards and Risks**—Local streams simultaneously deposit and erode local alluvium during channel meandering. **Flooding**— Flooding undercuts and erodes trails, alters river-channel morphology and sedimentation patterns, and can damage infrastructure.	**Postglacial Modification of the Landscape and Modern Geomorphological Development**—Following the last glaciation, local streams and rivers began to incise thick glacial deposits, establishing modern drainages.
	Swamp and marsh deposits (Qs)	**Qs** collects in stagnant-water swamps and marshes, where fine-grained material slowly settles and abundant organic material is interlayered. **Qs** consists of peat, organic silt, clay, and minor sand. Unit is black, brown, and gray. Unit is up to 6 m (20 ft) thick.	**Paleontological Resources**—**Qs** contains a pollen record including pollen from pine, spruce, and birch documenting accumulation dating to at least 9,000 years before present.	None reported.	**Postglacial Modification of the Landscape and Modern Geomorphological Development**—**Qs** deposits collect in areas underlain by glaciolacustrine deposits of Lake Passaic. Such deposits contain paleoclimatic markers.
	Alluvium and colluvium, undivided (Qcal)	Interbedded and poorly sorted colluvium (**Qcg**, **Qcb**, **Qcbl**, **Qcs**, and **Qcsl**) and alluvium (**Qal**). Colluvium is a slope deposit, forming as blocks are weathered from an exposure and tumble downslope under the force of gravity. **Qcal** consists of up to 5 m (15 ft) silty sand, sandy to clayey silt, and some pebbles and cobbles, with scant organic matter. It appears yellowish or reddish brown. **Qcal** locally includes lag accumulations (areas where wind has blown away finer material) on eroded surfaces or local bedrock. **Qcal** is mapped within park boundaries at the New Jersey Brigade and Jockey Hollow encampment area units	**Postglacial Deposits**—**Qcal** covers some glacial deposits. **Paleontological Resources**—This unit may (but is not likely to) contain Pleistocene fossils.	**Slope Movement Hazards and Risks**—Talus and colluvium are associated with slope processes. **Flooding**— Flooding undercuts and erodes trails, alters river-channel morphology and sedimentation patterns, and can damage infrastructure.	**Postglacial Modification of the Landscape and Modern Geomorphological Development**—Following the last glaciation, local streams and rivers began to incise thick glacial deposits, establishing modern drainages. Colluvium collected as a result of slope processes.
QUATERNARY (Holocene and late Pleistocene)	Alluvial fan deposits (Qaf)	**Qaf** consists of sorted and stratified (layered) sand, silt, pebbles, and cobbles. It is up to 12 m (40 ft) thick. Organic material may be present locally. Unit may be reddish or yellowish brown. **Qaf** may be dissected by modern streams depositing **Qal**.	None reported.	**Flooding**— Flooding undercuts and erodes trails, alters river-channel morphology and sedimentation patterns, and can damage infrastructure.	**Postglacial Modification of the Landscape and Modern Geomorphological Development**—**Qaf** collects at the bases of scarps, such as the Highland scarp, where drainages suddenly deposit sediment loads in fan-shaped deposits.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Holocene and Late Pleistocene)	Talus (Qta)	**Qta** is angular to subangular (i.e., not rounded by flowing water) cobbles and small boulders of basalt. Deposits of **Qta** are up to 5 m (15 ft) thick. **Qta** collects as an apron at the bases of cliffs along Green Brook south of Seelys Pond.	None reported.	**Slope Movement Hazards and Risks**—Talus and colluvium are associated with slope processes.	**Postglacial Modification of the Landscape and Modern Geomorphological Development**—**Qta** formation accelerated during colder climates of the ice ages, and deposits collected at the bases of local slopes.
	Eolian deposits (Qe)	**Qe** consists of very fine to fine sand, silty fine sand, and minor fine to medium sand. Some deposits of **Qe** are massive, whereas others are layered. **Qe** is up 5 m (15 ft) thick and appears pale brown to yellowish brown.	**Postglacial Deposits**—**Qe** formed as glacial Lake Passaic drained away from the area, leaving broad expanses of lake deposits available for aeolian transport as sheets and small dunes.	None reported.	**Postglacial Modification of the Landscape and Modern Geomorphological Development**—Wind-transported **Qe** sediments were deposited on adjacent uplands and slopes shortly after draining of the Moggy Hollow stage of Lake Passaic.
QUATERNARY (Late Pleistocene)	Stream terrace deposits (Qst) High stream terrace deposits (Qstu)	**Qst** consists of silt, fine to coarse sand, and pebbles in well-sorted, stratified to massive exposures. Some coarser deposits, including cobbles to boulders (**Qstu**), occur along larger rivers, such as the Passaic River. Most outcrops are pale brown, yellowish to reddish brown, or light gray. **Qst** is up to 5 m (15 ft) thick and is perched 2–5 m (5–15 ft) above modern floodplains. **Qst** is mapped within park boundaries at the Washington's Headquarters unit. **Qstu** is weakly stratified, moderately sorted, pebble to cobble gravel and fine to medium sand perched 6–8 m (20–25 ft) above the modern Passaic River floodplain in Summit. **Qstu** is up to 2 m (6 ft) thick and appears brown to reddish brown in outcrop.	**Postglacial Deposits**—**Qst** was, in part, deposited in shallow postglacial lakes (including the Stanley and Millington stages of Lake Passaic), forming a sequence of abandoned and incised meanders as the lakes lowered and drained away following the end of the Pleistocene ice ages. **Qstu** may mark the initial spillway level for the Stanley stage of Lake Passaic. **Paleontological Resources**—This unit may (but is not likely to) contain Pleistocene fossils.	None reported.	**Postglacial Modification of the Landscape and Modern Geomorphological Development**—Portions of **Qst** were incised between about 14,000 and 10,000 years before present. Organic layers in **Qst** date to 13,975 ± 340 years before present. The Passaic River deposited **Qtsu** during early downcutting through the glacial moraine at Stanley.
	Great Notch stage deposits (Qpg)	**Qpg** is fine to medium sand, pebbly sand, and pebble to cobble gravel that appears yellowish brown, brown, and reddish brown in outcrop. Deposits are up to 5 m (15 ft) thick.	**Glacial Features**—**Qpg** was deposited as alluvial fans in the Great Notch stage of Lake Passaic. Some areas of **Qpg** were deposited at the mouths of streams eroding material from adjacent Moggy Hollow–stage deltas.		**Pleistocene Ice Ages**—Portions of **Qst** were deposited as alluvial fans during several stages of Lake Passaic.
	Conglomerate colluvium (Qcc)	**Qcc** contains subrounded, fractured pebbles and cobbles derived from weathered conglomeratic bedrock and some weathered-rock surface rubble. Some minor sand and silt layers occur within **Qcc**. Thickness of **Qcc** ranges from 3 to 9 m (10–30 ft).	None reported.	**Slope Movement Hazards and Risks**—Layers of **Qcc** have been subjected to creep or possibly solifluction. Colluvium is associated with slope processes.	**Pleistocene Ice Ages**—**Qcc** formation accelerated during glaciations.
	Lake bottom deposits (Qpml)	**Qpml** consists of silt, clay, and minor fine sand in laminated outcrops that appear gray to light-reddish brown. **Qpml** is up to 36 m (120 ft) thick.		None reported.	**Pleistocene Ice Ages**—Portions of **Qpml** were deposited in the Chatham, Moggy Hollow (majority), Great Notch, Stanley, Millington, and Totowa stages of Lake Passaic.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Late Pleistocene)	Beach deposits, lower stages (Qpgb)	**Qpgb** contains medium to coarse sand and pebbly sand that appears in reddish-brown to gray, unstratified (layered) to weakly stratified outcrops. Individual clasts are primarily weathered shales with some quartz and quartzite pieces. Estimated thickness of **Qpgb** is 5 m (15 ft).	**Glacial Features**—**Qpgb** formed by wave-action erosion of shale bedrock along the shores of Lake Passaic.	None reported.	**Pleistocene Ice Ages**—**Qpgb** formed along the shoreline of Lake Passaic during the Great Notch and Millington stages.
	Shale colluvium, silty phase (Qcsl)	**Qcsl** consists of reddish- to yellowish-brown to gray, silty clay with shale chips and sparse basalt pebbles. It is up to 3 m (10 ft) thick.	None reported.	**Slope Movement Hazards and Risks**—Colluvium is associated with slope processes.	**Pleistocene Ice Ages**—**Qcsl** formation accelerated during glaciations.
	Rahway Till (Qr) Rahway Till, yellow phase (Qry) Rahway Till, terminal moraine (Qtmr) Rahway Till, less than 10 feet thick over bedrock (Qrt)	Glacial till generally consists of unsorted mixtures of directly deposited glacial sediments. **Qr** consists of reddish- to yellowish-brown silty sand to clayey sandy silt and locally clayey silt with pebbles, cobbles, and (rarely) boulders. All larger clasts are somewhat rounded, with compositions ranging from red and gray sandstone and siltstone, gray gneiss, and white quartz to purple conglomerate, quartzite, and basalt. Matrix between clasts is generally compact with sticky (clay-rich) areas. Lenses and blocks of deformed laminated silt, clay, and sand also occur locally. **Qr** is up to 33 m (110 ft) thick, but **Qrt** denotes areas where **Qr** is present in thin (less than 3-m- [10-ft-] thick) deposits over bedrock. **Qry** is glacial till as in **Qr**, but the dominant color is yellowish brown and the matrix is mostly sandy clayey silt. **Qry** is about 12 m (40 ft) thick. **Qtmr** has the same composition as **Qr** and marks the greatest extent of that particular glacial advance.	**Glacial Features**—**Qtmr** formed as the glacier dumped till at its terminus before retreating up the valley. Deformed lenses and blocks of layered deposits represent glacial erosion of glaciolacustrine deposits.		**Pleistocene Ice Ages**—**Qtmr** formed during the maximum extent of an ice lobe, followed by glacial retreat. **Qr** formed atop previous glaciolacustrine deposits in repeated glaciations.
	Netcong Till (Qn) Netcong Till, terminal moraine (Qtmn)	Glacial till generally consists of unsorted mixtures of directly deposited glacial sediments. **Qn** is yellowish-brown to brown to grayish-brown silty sand to sandy silt, with many pebbles and cobbles and sparse boulders. Fine-grained matrix around larger clasts is generally compact, with some subhorizontal fissility (tendency to break into shards). Deposits of **Qn** may reach 24 m (80 ft) thick. **Qtmn** has the same composition as **Qn** and marks the greatest extent of that particular glacial advance.	**Glacial Features**—**Qn** and **Qtmn** formed as local glaciers melted, leaving their assorted sediments in an unsorted deposit.	None reported.	**Pleistocene Ice Ages**—**Qtmn** formed during the maximum extent of an ice lobe, followed by glacial retreat.
	Beach deposits, Moggy Hollow stage (Qpmb)	**Qpmb** consists of pebble gravel, pebbly sand, and silt in reddish-brown, weakly layered deposits. Most pebbles are red and gray shale, basalt, quartzite, sandstone, and gneiss. **Qpmb** is up to 3 m (10 ft) thick.	**Glacial Features**—**Qpmb** includes scant ice-rafted glacial erratics.		**Pleistocene Ice Ages**—**Qpmb** formed as wave action eroded shale bedrock adjacent to the Lake Passaic shoreline during the Moggy Hollow stage.
	Deltaic deposits (Qpmd)	**Qpmd** contains fine to coarse sand and pebble to cobble gravel with some minor silt and very fine sand. Deposits are up to 21 m (70 ft) thick. **Qpmd** is mapped within park boundaries at the Washington's Headquarters unit.	**Glacial Features**—**Qpmd** formed as fluvial deltas deposited in Lake Passaic. Many areas of **Qpmd** formed along the front of the terminal moraine during glacial retreat. **Paleontological Resources**—This unit may contain Pleistocene fossils.		**Pleistocene Ice Ages**—**Qpmd** formed in Lake Passaic during the Moggy Hollow stage.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Late Pleistocene)	Lacustrine fan deposits (Qpmf)	**Qpmf** consists of fine to coarse sand and pebble to cobble gravel with minor silt and very fine sand. **Qpmf** is up to 24 m (80 ft) thick.	None reported.	None reported.	**Pleistocene Ice Ages**—**Qpmf** formed in Lake Passaic during the Moggy Hollow stage.
	Plainfield glaciofluvial deposit (Qpf)	**Qpf** contains pebble to cobble gravel and fine to coarse sand in deposits up to 24 m (80 ft) thick.			**Pleistocene Ice Ages**—**Qcs** formation accelerated during glaciations.
	Deltaic and lacustrine fan deposits (Qpc)	**Qpc** consists of fine to coarse sand, pebble gravel, minor cobble gravel, silt, and clay deposits. **Qpc** is up to 36 m (120 ft) thick. Unit also contains some beach or spit gravel and a few ice-rafted glacial erratics.	**Glacial Features**—**Qpc** formed as deltas and lacustrine fans in Lake Passaic. Unit includes some ice-rafted erratics.		**Pleistocene Ice Ages**—**Qpc** was deposited in Lake Passaic during the Chatham stage; some lower reaches of the unit may have been deposited during the Great Notch stage.
	Late Wisconsinan glacial lake-bottom deposits (Qwlb) Late Wisconsinan glacial delta deposits (Qwde) Late Wisconsinan glaciofluvial terrace deposits (Qwft)	**Qwlb** includes a fluviodelta, lake bottom silt, sand, clay, and some alluvium. Deltaic deposits are at an altitude of 116 m (380 ft) and are about 46 m (150 ft) thick. **Qwde** consists of two ice-marginal deltas and one fluviodelta with glaciolacustrine fans and lake-bottom fine sand, silt, and minor clay. Unit is approximately 46 m (150 ft) thick. **Qwft** contains coarse gravel, sand and gravel, and pebbly sand in terraces perched above the Rockaway River Valley and local tributary valleys. Deposits are up to 15 m (50 ft) thick.	**Glacial Features**—**Qwlb** contains glaciofluvial deposits and glaciolacustrine deposits from Lake Whippany. The spillway from Lake Whippany (over deposits of **Qrpm**) into Lake Passaic was at 113 m (372 ft) elevation. **Qwde** contains glaciofluvial and glaciodeltaic deposits. The spillway from Lake Succasumma is over bedrock near Milltown.		**Pleistocene Ice Ages**—Lake Whippany was dammed by **Qrpm** of Lake Passaic (Moggy Hollow–stage deposits). When the ice margin had retreated to the Cedar Knolls area, Lake Whippany lowered to the level of the Moggy Hollow stage of Lake Passaic. **Qwde** formed in Lake Succasumma in preglacial, north-draining tributary valleys of the Rockaway River. **Qn** deposits overlay **Qwde** locally, indicating a temporal relationship. **Qwft** formed as fluvial terraces after the draining of lakes Dover and Denville. **Postglacial Modification of the Landscape and Modern Geomorphological Development**—Many local, north-flowing drainage basins filled with sediment and the drainages reversed to flow southward.
	Uncorrelated lacustrine deposits (Qsu)	**Qsu** deposits were not correlated with any specific glaciolacustrine event. Unit consists of fine to coarse sand and pebble to cobble gravel in deposits up to 6 m (20 ft) thick.	None reported.		**Pleistocene Ice Ages**—**Qsu** was deposited in Lake Passaic in uncorrelated stages.
	Meltwater terrace deposits (Qmt)	**Qmt** contains gravel, pebbles, and cobbles, with some fine to coarse sand in deposits up to 6 m (20 ft) thick.			**Pleistocene Ice Ages**—**Qmt** was deposited along meltwater streams during the last major glaciation.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Middle to Late Pleistocene)	Shale colluvium (Qcs)	**Qcs** consists of reddish- to yellowish-brown, clayey to sandy silt with shale chips and scant sandstone cobbles. The unit is poorly sorted, compact, and has a firm consistency. It is up to 9 m (30 ft) thick. Some surfaces of **Qcs** include rock rubble.	None reported.	**Slope Movement Hazards and Risks**—Layers of **Qcs** have been subjected to creep or possibly solifluction. Colluvium is associated with slope processes.	**Pleistocene Ice Ages**—**Qcs** formation accelerated during glaciations.
	Gneiss colluvium (Qcg)	**Qcg** contains sandy silt, silty sand, sandy-clayey silt, and pebbles and cobbles of variably weathered gneiss. Pebbles of red shale and siltstone occur where the unit is adjacent to **Qws**. **Qcg** is up to 21 m (70 ft) thick. Outcrops are yellowish or reddish brown to brown and typically poorly sorted, with some layering. **Qcg** is mapped within park boundaries at the New Jersey Brigade and Jockey Hollow encampment area units.	**Periglacial Bedrock Weathering and Thermokarst Topography**—**Qcg** formation was likely accelerated during the periglacial climates of the Pleistocene Epoch. **Paleontological Resources**—This unit may (but is not likely to) contain Pleistocene fossils.	**Slope Movement Hazards and Risks**—Layers of **Qcg** have been subjected to creep or possibly solifluction. Colluvium is associated with slope processes.	**Pleistocene Ice Ages**—**Qcg** formed atop deposits left by the Illinoian glaciation.
	Basalt colluvium, blocky phase (Qcb) Basalt colluvium, silty phase (Qcbl)	**Qcb** contains reddish- to yellowish-brown to brown clayey silt, silty clay, and some minor sandy silt with subangular (not entirely rounded edges) pebbles to cobbles of basalt. Red shale and mudstone chips occur locally. Deposits of **Qcb** are up to 18 m (60 ft) thick. **Qcbl** contains reddish-yellow to brown to gray clayey silt to silty clay with minor sandy silt and scant basalt pebbles. **Qcbl** tends to occur as less than 3-m- (10-ft-) thick distal edges of **Qcb** deposits and is mapped only where more than 1 m (3 ft) thick.	**Periglacial Bedrock Weathering and Thermokarst Topography**—Weathered basalt clasts are common in some thicker deposits of **Qcb**, whereas unweathered basalt clasts dominate more surficial colluvium. These characteristics indicate periods of repeated deposition of colluvium during the extreme climates of glacial periods (as frost weathering was accelerated), and slope stability (outcrop weathering) during interglacial periods.	**Slope Movement Hazards and Risks**—Groundwater seepage may be responsible for some **Qcbl** deposition.	**Pleistocene Ice Ages**—**Qcb** contains deposits that were (1) originally glacial erratics from pre-Illinoian glacial till, (2) late Wisconsinan till, and (3) erratics deposited by icebergs on Lake Passaic.
	Weathered conglomerate (Qwc) Weathered gneiss (Qwg) Weathered gneiss, thin or absent (Qwgt) Weathered basalt (Qwb) Weathered basalt, thin or absent (Qwbt) Weathered shale (Qws) Weathered shale and sandstone, thin or absent and outcrop or shale-chip rubble abundant (Qwst)	**Qwc** contains unsorted, reddish-brown, fine to coarse sand and silty sand with abundant white to purple quartz and conglomerate pebbles and subangular (less rounded) red sandstone pebbles and cobbles. Layers of **Qwc** are up to 61 m (200 ft) thick. **Qwg** consists of yellowish-brown to reddish-yellow silty sand and mixtures of sand, clay and silt, with some subangular (not completely rounded) pebbles and cobbles of gneiss. Most clasts are highly weathered. Exposures of **Qwg** are up to 30 m (100 ft) thick; however, **Qwgt** is mapped where fractured, less-weathered outcrop appears in lieu of weathered material. **Qwb** appears reddish yellow to brownish to gray in outcrop exposures and contains mixtures of clay, silt, and sand, with some to many angular pebbles and cobbles of basalt. Locally, gabbro (very-low-silica basalt) clasts occur. Most clasts have distinct weathering rinds. Exposures of **Qwb** are up to 15 m (50 ft) thick; however, **Qwbt** is mapped where fractured, less-weathered outcrop appears in lieu of weathered material. **Qws** consists of reddish- to yellowish-brown mixtures of clay and silt with many shale chips or angular pebbles and cobbles of mudstone. **Qws** is up to 5 m (15 ft) thick; however, **Qwst** is mapped where fractured, less-weathered outcrop appears in lieu of weathered material. In areas where **Qws** is combined with quartzite and conglomerate saprolite and rock rubble, the thickness can reach 46 m (150 ft). **Qwg** is mapped within the park boundaries at the Fort Nonsense, New Jersey Brigade Encampment Area, and Jockey Hollow Encampment Area units. **Qwgt** is mapped in the New Jersey Brigade Encampment Area unit.	**Periglacial Bedrock Weathering and Thermokarst Topography**—**Qwc**, **Qwg**, **Qwgt**, **Qwb**, **Qwbt**, **Qws**, and **Qwst** weather unevenly to produce thick layers of saprolite or unconsolidated, but compact, material as a mixture of clays and weathered clasts of different grain sizes. Some units contain up to 60% weathered, but distinct, pebbles and/or cobbles. These units vary based on the source or parent material's composition (fractured bedrock in most cases). As the rocks weather in situ, the original bedrock fabrics or structures are preserved in the saprolite. **Paleontological Resources**—This unit may (but is not likely to) contain Pleistocene fossils.	**Slope Movement Hazards and Risks**—Thick, weathered deposits (saprolite) may be prone to fail on slopes, particularly when water saturated. **Qbw** may be present as weathered rock rubble with boulders.	**Pleistocene Ice Ages**—These units formed during the long-standing, accelerated weathering climates of the Pleistocene.

Colored map units are mapped within Morristown National Historical Park. Bold text refers to sections in report.

Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
QUATERNARY (Middle Pleistocene)	Flanders Till (Qitf)	Glacial till generally consists of unsorted mixtures of directly deposited glacial sediments. **Qitf** is brown to yellowish-brown silty sand to sandy clayey silt, with many pebbles and cobbles and sparse boulders. Larger clasts are typically weathered gneiss, mudstone, sandstone, conglomerate, and quartzite. Fine-grained matrix around larger clasts is generally compact, with some subhorizontal fissility (tendency to break into shards). Deposits of **Qitf** are generally up to 12 m (40 ft) thick (up to 66 m [215 ft] thick in thickest till).	**Glacial Features**—**Qitf** formed as local glaciers melted, leaving their assorted sediments in an unsorted deposit. **Qitf** forms drumlins in the thickest deposits.	None reported.	**Pleistocene Ice Ages**—**Qitf** is locally truncated by **Qn** deposits and is part of the Jerseyan drift.
	Illinoian glaciolacustrine sand and gravel deposits (Qide)	**Qide** contains six ice-margin deltas (up to 46 m [150 ft] thick) and lake-bottom silt and fine sand (up to 24 m [80 ft] thick) from different glacial lake stages.	**Glacial Features**—**Qide** contains glaciofluvial deposits and glaciolacustrine deposits from Lake Shongum. The highest spillway from Lake Shongum was at 259 m (850 ft) elevation at the Rockaway River–Whippany River drainage divide.		**Pleistocene Ice Ages**—Lake Shongum was dammed by glacial ice, occupying the Mill Brook Valley and an adjacent valley to the east. **Qide** collected in the impounded basin. When the Illinoian ice margin retreated north of Rockaway, the lake drained.
	Illinoian terminal moraine deposits (Qimt)	**Qimt** likely resembles **Qide** or **Qitf** in composition, but no description is available.	None reported.		**Pleistocene Ice Ages**—**Qimt** formed during the maximum extent of an Illinoian ice lobe, followed by glacial retreat.
	Bergen Till (Qb)	Glacial till generally consists of unsorted mixtures of directly deposited glacial sediments. **Qb** is reddish-brown or yellow mixtures of sand and clay. Composition of **Qb** is similar to that of **Qr,** with a compact matrix and slightly sticky behavior when saturated with water. Larger clasts include weathered gneiss, sandstone, and mudstone. **Qb** is up to 15 m (50 ft) thick.	**Glacial Features**—**Qb** formed as local glaciers melted, leaving their assorted sediments in an unsorted deposit. **Qb** tends to be deposited immediately atop bedrock and not on other glacial deposits.		**Pleistocene Ice Ages**—**Qb** predates late Wisconsinan till.
NEOGENE–QUATERNARY (Late Pliocene to Early Pleistocene)	Deltaic and lacustrine fan deposits (Qps)	**Qps** consists of reddish-yellow to pale-brown, fine to coarse sand, pebbles, cobbles, and some fine sand, clay, and silt layers. Larger clasts are weathered gneiss, quartzite, basalt, sandstone, and siltstone. Many clasts are almost entirely altered to clay. Deposits of **Qps** are up to 30 m (100 ft) thick.	**Glacial Features**—**Qps** contains some ice-rafted erratics.		**Pleistocene Ice Ages**—**Qps** was deposited in the Chatham stage; lower reaches of the unit may have been deposited in the Great Notch stage.
	Lake bottom deposits (Qpsl)	**Qpsl** contains reddish-yellow to brown clay, silt, very fine to fine sand, and scant coarser sand in unsorted, but thinly bedded, exposures. **Qpsl** is up to 5 m (15 ft) thick.	**Glacial Features**—**Qpsl** collected in glaciolacustrine settings.		**Pleistocene Ice Ages**—**Qpsl** was deposited in an early glacial lake, perhaps prior to the Illinoian glaciation.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Issues	Geologic History
NEOGENE–QUATERNARY (Late Pliocene to Early Pleistocene)	Pre-Illinoian till (Qpt)	Glacial till generally consists of unsorted mixtures of directly deposited glacial sediments. **Qpt** consists of reddish-brown to yellow clay, sand, and silt mixtures with some slightly rounded pebbles, cobbles, and scant boulders. Larger clasts include weathered red and gray mudstone, sandstone, basalt, purple quartzite conglomerate, gray quartzite, chert, quartz from **Tp**, and gneiss. **Qpt** is up to 15 m (50 ft) thick.	**Glacial Features**—**Qpt** formed as local glaciers melted, leaving their assorted sediments in an unsorted deposit.	None reported.	**Pleistocene Ice Ages**—**Qpt** predates the Illinoian glaciation.
NEOGENE (Late Pliocene)	Pensauken Formation (Tp)	**Tp** is reddish-yellow to brown, clay-rich, medium to coarse sand with some finer sand and pebbles. The sand is weathered feldspar; its weathered composition is almost entirely clay. Pebbles and gravel are primarily quartzite and dark-gray chert, with some weathered shale, sandstone, and gneiss. **Tp** is up to 3 m (10 ft) thick.	None reported.		**Continual Weathering and Erosion**—**Tp** formed as a weathering product of quartzofeldspathic bedrock.
	Large bedrock outcrop (r)	Bedrock outcrops occur throughout the area where glacial deposits have eroded away or were never deposited.	See Bedrock Geologic Map Unit Properties Table.		