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Saratoga National Historical Park

Geologic Resources Inventory Report

Photograph of field artillery (howitzer) near the visitor center in the northern Battlefield Unit. View is facing east toward the Hudson River across rolling fields where the Battles of Saratoga were fought. The Hudson River landscape—featuring floodplains, bluffs, fields, hills, terraces, and ravines—played a major role in the strategy and outcome of the battles. The upland fields and bluffs flanking the river are underlain by a thick sequence of clay and sand deposits that accumulated in a series of glacial lakes during the last Ice Age. These ancient lakes occupied the Hudson River Valley thousands of years ago during the Pleistocene Epoch.
NPS

Saratoga National Historical Park: Geologic resources inventory report

Science Report NPS/SR—2024/203

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Abstract

Geologic Resources Inventory reports provide information and resources to help park managers make decisions for visitor safety, planning and protection of infrastructure, and preservation of natural and cultural resources. Information in this report may also be useful for interpretation. This report synthesizes discussions from a scoping meeting held in 2007 and a follow-up meeting in 2023. Chapters of this report discuss the geologic heritage, geologic features and processes, geologic history, and geologic resource management issues of Saratoga National Historical Park. Guidance for resource management and information about the previously completed GRI GIS data and poster (separate products) is also provided.

Acknowledgments

The GRI team thanks the participants of the 2007 scoping meeting and 2023 follow-up meeting for their assistance in this inventory. The lists of participants are in alphabetical order by last name and reflect the names and affiliations of these participants at the time of the meeting and call. Because the GRI team does not conduct original geologic mapping, we are particularly thankful for DeSimone Geoscience Investigations for its maps of the area. This report and accompanying GIS data could not have been completed without them. Thanks to Matt Harrington, Trista L. Thornberry-Ehrlich, Ron Karpilo, and Thom Curdts (Colorado State University) for providing some of the photographs and figures in this report. Additional thanks to Justin Tweet, Anthony Gallegos, Denny Capps (all NPS GRD), William Griswold (NPS Northeast Archeological Resources Program), Amanda Babson (NPS Interior Region 1), Dr. Robert Jacobi (University at Buffalo), Dr. Amy Frappier (Skidmore College), and Dr. Richard Allmendinger (Cornell University).

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Executive Summary

Comprehensive park management to fulfill the mission of the National Park Service (NPS) requires an accurate inventory of the geologic features of a park unit, but park managers may not have the necessary information, geologic expertise, or means to complete such an undertaking; therefore, the Geologic Resources Inventory (GRI) provides information and resources to help park managers make decisions for visitor safety, planning and protection of infrastructure, and preservation of natural and cultural resources. Information in the GRI report may also be useful for interpretation.

Saratoga National Historical Park (referred to as the "historical park" herein) is located along the upper Hudson River Valley of Saratoga County, east-central New York. Established on 1 June 1938, the historical park consists of five separate parcels (Battlefield Unit, Saratoga Monument, Saratoga Surrender Site, Schuyler Estate, and Victory Woods) that commemorate the Battles of Saratoga fought during the American Revolutionary War. Occurring on 19 September 1777 (Battle of Freeman's Farm) and 7 October 1777 (Battle of Bemus Heights), the Battles of Saratoga resulted in a decisive American victory and the first British surrender in world history. The surrender of British forces at the Battles of Saratoga boosted American morale and convinced France to enter the war on behalf of the United States. Geologic processes, features, and resources within the historical park are integral to its history and cultural identity. This report outlines these connections and is one of the most comprehensive, park-specific geologic reports known for the historical park.

This report contains the following chapters:

Introduction—This chapter provides background information about the GRI, highlights the GRI process and products, and recognizes GRI collaborators. This chapter highlights the GRI geographic information system (GIS) data, which are the principal deliverable of the GRI, as well as the geologic maps that served as the source maps used by the GRI team in compiling the GRI GIS data. The chapter also calls attention to the poster, which illustrates the GRI GIS data.

Geologic Heritage—This chapter summarizes the establishment of the historical park and its setting. In addition, this chapter highlights the significant geologic features, landforms, landscapes, and stories of the historical park preserved for their heritage values. It also draws connections between geologic resources and other park resources and stories such as the Taconic orogeny, the last Ice Age, and how the park's surficial geology impacted the Battles of Saratoga.

Geologic History—This chapter describes the chronology of geologic events that formed the present landscape. Rocks adjacent to and within the historical park record geologic processes that began over 1 billion years ago.

Geologic Features and Processes—This chapter describes the geologic features and processes of significance for the historical park and highlights them in the context of geologic time. The features and processes are discussed in order of geologic time, from oldest to youngest.

Geologic Resource Management Issues—This chapter discusses management issues related to the historical park's geologic resources (features and processes). Geologic hazard issues include (1) climate change; (2) disturbed lands; (3) flooding; (4) Hudson River contamination issues; (5) mass wasting events; (6) quicksand; (7) radon; (8) seismic activity; (9) shrink/swell clays; and (10) toxicological soils. Additional geologic resource monitoring and protection issues include future paleontological resource potential. Information regarding these issues was compiled from the historical park scoping summary report (Thornberry-Ehrlich 2008), the foundation document (National Park Service 2021a), the natural resource condition assessment report (Wagner et al. 2014), notes from the 2023 GRI follow-up meeting, research conducted in preparation of this report, and input from reviewers.

Guidance for Resource Management—This chapter follows and is a follow up to the "Geologic Resource Management Issues" chapter. It provides resource managers with a variety of ways to find and receive management assistance with geologic resources. A summary of laws, regulations, and policies which apply to geologic resources is also provided.

Additional References, Resources, and Websites—This chapter provides a thorough list of additional sources of information (e.g., websites, tools, publications, organizations) that may be useful to further explore the topics presented in this report.

In addition to these chapters, "Literature Cited" compiles all the references cited in this GRI report. It serves as a source of park-specific geologic information that is applicable to the protection, management, and interpretation of the historic site's geologic resources.

Introduction

The purpose of this report is to familiarize readers with Saratoga National Historical Park's geologic history, features, processes, and best practices for managing the historical park's geologic resources. The Geologic Resources Inventory (GRI), which is administered by the Geologic Resources Division (GRD) of the National Park Service (NPS) Natural Resource Stewardship and Science Directorate, provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. The GRI is funded by the NPS Inventory and Monitoring Program.

Park Background and Establishment

Saratoga National Historical Park (referred to as the "historical park" in this report) is composed of five non-contiguous parcels located along the west bank of the Hudson River in Saratoga County, New York: (1) the Battlefield Unit (Stillwater, NY); (2) Schuyler Estate (Schuylerville, NY); (3) Saratoga Monument (Victory, NY); (4) Victory Woods (Victory, NY); and (5) Saratoga Surrender Site (Saratoga, NY) (Figure 1). Established on 1 June 1938, the historical park commemorates the unprecedented British surrender and significant American military victory during the American Revolutionary War, and preserves sites associated with the military skirmishes, siege, and resignation of British forces during the Battles of Saratoga that took place on 19 September 1777 (Battle of Freeman's Farm) and 7 October 1777 (Battle of Bemus Heights; National Park Service 2021a, b). American forces under the command of Maj. Gen. Horatio Gates won a decisive victory over British Lt. Gen. John Burgoyne's army—the conflict marked the first time in history that a British army had ever surrendered. The American military success at Saratoga ended the British campaign to capture Albany and provided a major morale boost for supporters of the revolution. More importantly, the defeat of Burgoyne's forces convinced France to enter the war and provide critical military assistance on behalf of the United States.

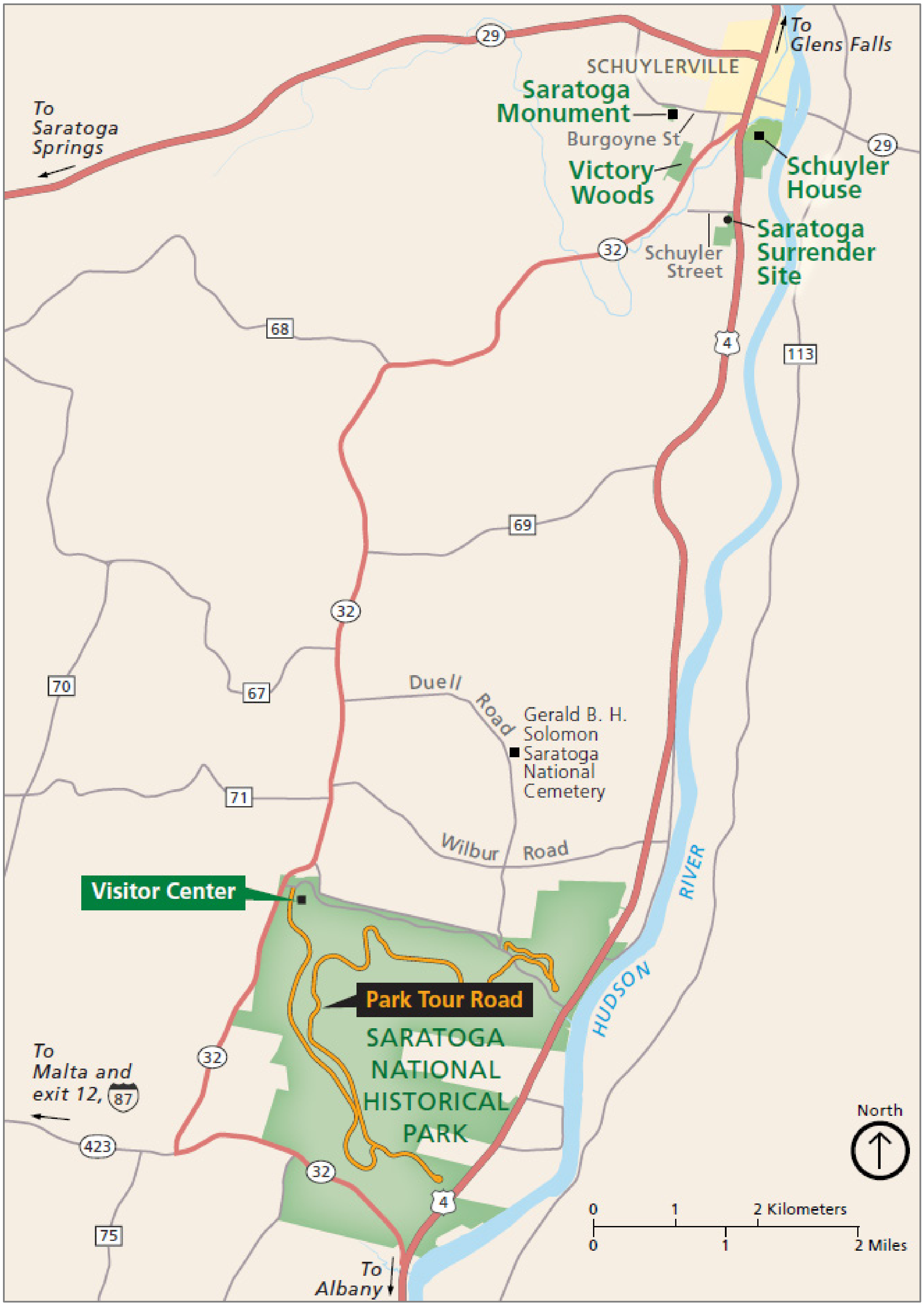

Figure 1. Map of Saratoga National Historical Park. The historical park consists of more than 1,375 ha (3,400 ac) distributed across five separate parcels. The primary access points to the main Battlefield Unit are along US Route 4 (eastern entrance) and New York State Route 32 (western entrance). Both US Route 4 and NY 32 link the Battlefield Unit north to the Saratoga Monument, Saratoga Surrender Site, Schuyler Estate, and Victory Woods parcels. NPS maps are available at www.nps.gov/carto.

The five separate parcels of the historical park account for approximately 1,378 ha (3,406 ac) and protect unique resources portraying different themes associated with the Battles of Saratoga. The main Battlefield Unit encompasses over 95% of the park and preserves the hallowed ground where the American and British armies fought prior to Burgoyne's retreat and surrender. A one-way tour road runs 14 km (9 mi) through the historical park and connects the visitor center to ten interpretive stops throughout the battlefield, including the redoubts (earthen and timber fortifications), military headquarters, strategic viewsheds, historical markers, and monument sites (Commisso and Foulds 2014). Located about 8 km (5 mi) north of the Battlefield Unit, the Schuyler Estate, Saratoga Monument, Victory Woods, and Saratoga Surrender Site form a group of small parcels collectively referred to as the "Old Saratoga Unit." The Schuyler Estate contains the restored and refurbished home of American Maj. Gen. Philip Schuyler; the original hamlet of Saratoga was incorporated as a village and renamed Schuylerville in his honor in 1831 (Killion et al. 2022; Eric Schnitzer, Saratoga National Historical Park, personal communication 5 June 2024). The Saratoga Monument is a conspicuous, 47 m (155 ft) tall granite obelisk that was erected on the 100th anniversary of the Battles of Saratoga to memorialize the American troops who fought, perished, and prevailed over the British (National Park Service 2004). Preserved at Victory Woods is a small portion of the final defensive positions, fortifications, and encampments held by Burgoyne's army in the days prior to surrender. Finally, the Saratoga Surrender Site marks the location where Lt. Gen. Burgoyne ceremoniously handed his sword to Maj. Gen. Gates in defeat. The surrender scene is famously depicted in John Trumbull's (1821) painting that hangs in the United States Capitol Rotunda (Figure 2).

The cultural landscape of the historical park features rolling hills, ravines, bluffs, terraces, agricultural fields, meadows, forests, and wetlands flanking the low-lying floodplain of the Hudson River. Many of these topographic and geologic features were instrumental in determining the location, strategy, and outcome of the Battles of Saratoga (see "Geology and the Battles of Saratoga").

Figure 2. An oil painting titled Surrender of General Burgoyne. This oil painting (Trumbull 1821) depicts the momentous surrender of British Lt. Gen. John Burgoyne (left of center) as he hands his sword in defeat to American Gen. Horatio Gates (center). A key to the famous figures depicted in the painting is provided by Weir (1901). The historic scene took place on land that now comprises the Saratoga Surrender Site—the view is facing north toward the confluence of Fish Creek and the Hudson River (Killion et al. 2022). Today, Trumbull's famous painting hangs in the US Capitol rotunda.

Introduction to the GRI

The GRI team is a collaboration between the NPS, GRD, Colorado State University Department of Geosciences, and University of Alaska Museum of the North. The GRI was established in 1998 by the GRD and the NPS Inventory and Monitoring Program [Division] to meet the NPS need for geologic mapping and related information. Geologic maps were identified as one of 12 natural resource data sets critical for long-term science-informed park management. From the beginning, the GRI has worked with long-time NPS partner Colorado State University to ensure products are scientifically accurate and use the latest in geographic information system (GIS) technology. Because Alaskan NPS units have unique scale and resource management challenges, the GRI partnered with the NPS Alaska Regional Office and, starting in 2021, the University of Alaska Museum of the North to develop GRI products.

GRI Products

The GRI team completed the following tasks as part of the reporting process for Saratoga National Historical Park: (1) conduct a scoping meeting and provide a scoping summary; (2) provide geologic map data in a GIS format; (3) create posters to display the GRI GIS data; and (4) provide a GRI report (this document). GRI products are available on the NPS DataStore through the Integrated Resource Management Applications (IRMA) portal (see "Access to GRI Products").

The information provided in GRI products is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based on the information provided in GRI products. Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features in the GRI GIS data or on the posters. Based on the source map scale (DeSimone 2015a, b; both are 1:62,500 scale) and *Map Accuracy Standards* (US Geological Survey 1999), geologic features represented in the GRI are horizontally within 32 m (104 ft) of their true locations.

Scoping Meeting

On 9 July 2007, the NPS held a scoping meeting for the historical park at the University of Massachusetts Amherst in Amherst, Massachusetts. The scoping meeting brought together historical park staff and geologic experts, who reviewed and assessed available geologic maps, developed a geologic mapping plan, and discussed geologic features, processes, and resource management issues to be included in the final GRI report (see "Acknowledgments"). A scoping summary (Thornberry-Ehrlich 2008) summarizes the findings of that meeting.

GRI GIS Data

The GRI team compiled the GRI GIS data in 2015 and updated it in 2022. The GRI GIS data may be updated again if new, more accurate geologic maps become available or if software advances require an update to the digital format. These data are the principal deliverable of the GRI. The GRI team did not conduct original geologic mapping but compiled existing geologic information (i.e., paper maps and/or digital data) into the GRI GIS data (Figure 3). Scoping participants and the GRI team identified the best available source maps based on coverage (area mapped), map scale, date of mapping, and compatibility of the mapping to the current geologic interpretation of an area.

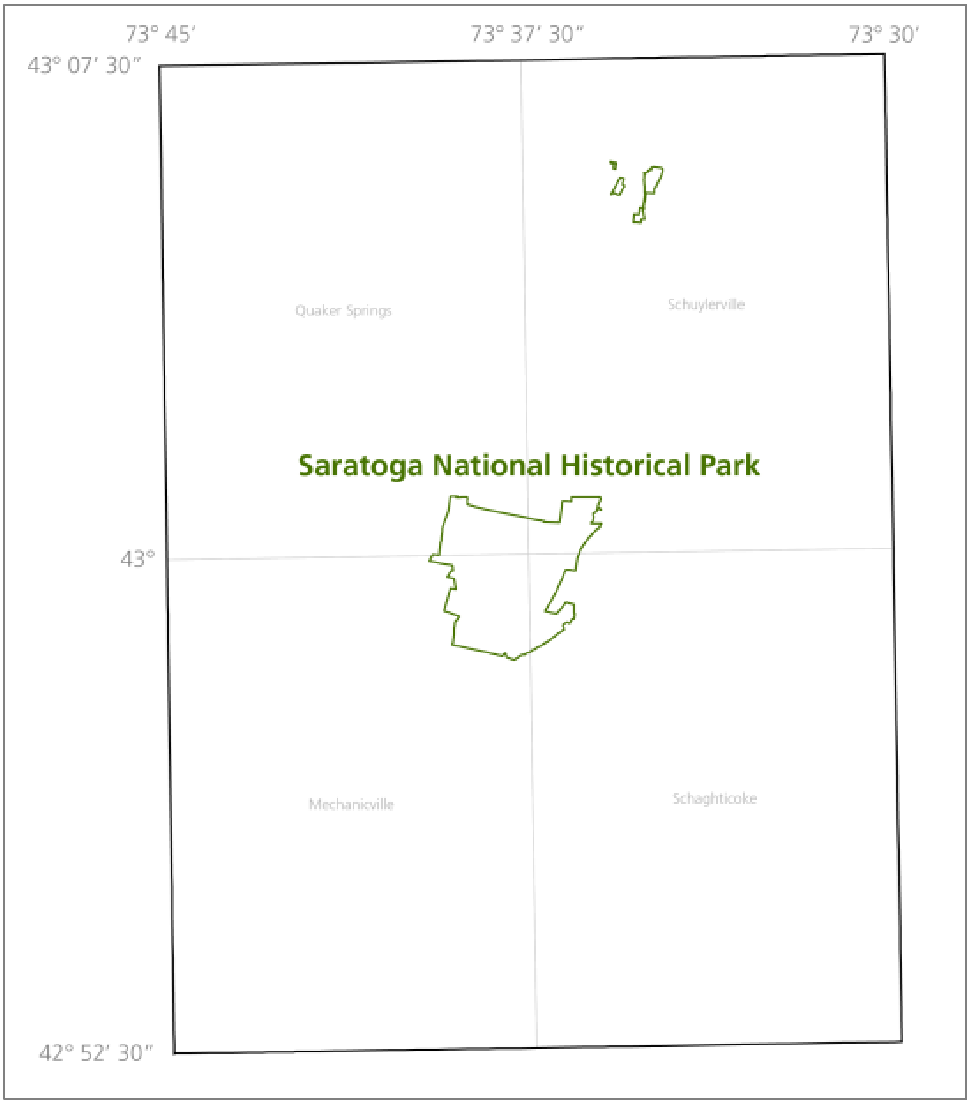

Figure 3. Index map of the GRI GIS data for Saratoga National Historical Park. The map displays the extent (that of the Mechanicville, Quaker Springs, Schaghticoke, and Schuylerville 7.5' quadrangles) of the GRI digital geologic-GIS map produced for the historical park. The boundary for the historical park (as of July 2022) is outlined in green, while the extent of the GRI Digital Geologic-GIS Map for the historical park and vicinity is outlined in black. GRI graphic by Ron Karpilo (Colorado State University).

More information about the GRI GIS data can be found in the files accompanying the data on IRMA. The “GIS readme file” explains the available file formats for the GRI GIS data, how to use the different file formats, and where to find more information about the GIS data model. The “ancillary map information document” lists the geologic maps or GIS data used to produce the GRI GIS data, the map units and map unit descriptions (including descriptions from all source maps), and additional information about the source maps.

The GRI GIS data for the historical park includes two individual source maps that account for the bedrock geology, including faults and paleo-channels, and the surficial geology, including known bedrock outcrop locations. The bedrock map of the historical park is divided into several structural "zones" in lieu of formal stratigraphic nomenclature (i.e., groups, formations, and members) to account for the complex deformational fabric observed in rocks along the upper Hudson River Valley. More detailed information about the bedrock and surficial geologic maps is found in the "Geologic Features and Processes" chapter.

The GRI GIS data for the historical park was compiled from the following two source maps:

- DeSimone, D. 2015a. Bedrock Geologic Map of Saratoga National Historical Park and Vicinity, New York: DeSimone Geoscience Investigations, unpublished bedrock geologic map, scale 1:62,500.
- DeSimone, D. 2015b. Surficial Geologic Map of Saratoga National Historical Park and Vicinity, New York: DeSimone Geoscience Investigations, unpublished surficial geologic map, scale 1:62,500.

GRI Poster

The poster of the historical park follows the surficial geologic map of DeSimone (2015b) and was selected for several reasons, including lack of exposed bedrock and park management considerations; the park's military history is also largely influenced by younger surficial deposits. The GRI GIS data draped over a shaded relief image of the historical park and surrounding area is the primary figure referenced throughout this GRI report. The poster is not a substitute for the GIS data but is supplied as a helpful tool for office and field use and for users without access to ArcGIS. All GIS feature classes are included on the poster, and selected park features have been added. Digital elevation data and added geographic information are not included in the GRI GIS data but are available online from a variety of sources.

GRI Report

On 23 October 2023, the GRI team hosted a follow-up meeting for historical park staff and interested geologic experts (see "Acknowledgments"). The call provided an opportunity to get back in touch with park staff, introduce "new" (since the 2007 scoping meeting) staff to the GRI process, and update the list of geologic features, processes, and resource management issues for inclusion in the final GRI report.

This report and the poster are the culmination of the GRI process. The report synthesizes discussions from the scoping meeting in 2007, the follow-up meeting in 2023, reviewers' comments in 2024, and additional geologic research. The selection of geologic features discussed in the report was guided by the previously completed GRI GIS data and discussions during the scoping and follow-up meetings. Notably, the writing reflects the geologic interpretation provided by the author of the source maps (see "GRI GIS Data"). Information from the historical park's foundation document (National Park Service 2021a) and natural resource condition assessment (Wagner et al. 2014) were also included as applicable to the historical park's geologic resources and resource management.

The GRI report links the GRI GIS data to the geologic features and processes discussed in the report using map unit symbols; for example, the Ordovician Stillwater Shale Zone mapped in the historical park has the map symbol **Ossz**. Capital letters indicate age, and the lowercase letters that follow symbolize the unit name. "**O**" represents the Ordovician Period (approximately 485.0 million to 444.0 million years ago), and "**ssz**" represents the Stillwater Shale Zone. See "Geologic History" for a geologic time scale that lists all the map units in the historical park.

The primary audience of GRI reports is park resource managers, but the GRI team hopes that these reports will appeal and be useful to other audiences, such as park interpreters and the public. To that end, the reports try to avoid technical terms and keep the writing accessible to readers without a background in geology. Nevertheless, like most sciences, geology is a science that is full of jargon and based on complex concepts that have changed over time with more information and greater understanding. Thus, GRI reports use geologic terminology, but terms are defined at their first instance, usually in parentheses following the term. Commonly, graphics are provided to illustrate unfamiliar concepts.

Geologic and geographic names used in this report reflect the formal nomenclature found in the US Geologic Names Lexicon ("Geolex") and the spellings recorded in the Geographic Names Information System (GNIS), respectively. Geolex is a national compilation of names and descriptions of geologic units maintained by the USGS (see "Additional References, Resources, and Websites"). GNIS contains geographic terms that the US Board on Geographic Names has formally accepted. In 1947, the Secretary of the Interior was given joint authority with the US Board on Geographic Names and has final approval of the board's actions. The online GNIS database is maintained by the USGS (see "Additional References, Resources, and Websites").

Geologic Heritage

This chapter highlights geologic features, landforms, landscapes, and stories of the historical park valued for their geologic heritage qualities, including aesthetic, artistic, cultural, economic, educational, recreational, and scientific values. It also draws connections between geologic resources and other historical park resources and stories.

Geologic Heritage Sites and Conservation

Geologic heritage (also called "geoheritage") evokes the idea that the geology of a place is part of its history and cultural identity. In 2015, in cooperation with the American Geosciences Institute (AGI), the GRD, which administers the GRI (see "Introduction to the GRI"), published *America's Geologic Heritage: An Invitation to Leadership* (National Park Service and American Geosciences Institute 2015). That booklet introduced the American experience of geologic heritage and outlined key principles and concepts, including the following five big ideas:

1. America's geologic landscape is an integral part of its history and cultural identity, and Americans have a proud tradition of exploring and preserving geologic heritage.
2. America's geologic heritage, as shaped by geologic processes over billions of years, is diverse and extensive.
3. America's geologic heritage holds abundant values—aesthetic, artistic, cultural, ecological, economic, educational, recreational, and scientific—for all Americans.
4. America's geologic heritage benefits from established conservation methods developed around the world and within the United States.
5. America's geologic heritage engages many communities, and involvement by individuals will ensure its conservation for future generations.

Geoheritage sites are conserved so that their lessons and beauty will remain as a legacy for future generations. Such areas generally have great potential for scientific studies, use as outdoor classrooms, and enhancing public enjoyment. Geoheritage sites are fundamental to understanding dynamic Earth systems, the succession and diversity of life, climatic changes over time, the evolution of landforms, and the origin of mineral deposits. Currently, the United States does not have a comprehensive national registry of geoheritage sites. Though park units have not been established specifically for geoheritage values, any geologic component of a park's enabling legislation or planning and management documents can be considered a part of America's geoheritage.

Geologic Connections to Park Resources

The Taconic Orogeny

While the setting of the park today is predominantly fluvial and glacial in origin, the rocks beneath the park tell the story of a shrinking ocean basin replaced by a massive mountain chain that slowly eroded to form the modern landscape. The bedrock underlying the historical park is made up of sedimentary and metasedimentary (metamorphosed sedimentary) strata (layers), which were originally deposited in an ancient ocean and subsequently compressed, faulted, and emplaced during a mountain-building event called the Taconic orogeny. The name “Taconic” is derived from the Taconic Ranges in eastern New York and western New England. Remnants of the orogeny are seen in the uplifted rocks that form Bald, Schuyler, Wheldon, and Willard Mountains, which rise to the east of the historical park opposite the Hudson River. The Taconic orogeny occurred during the Middle Ordovician to early Silurian Periods, approximately 475 million to 440 million years ago, and is interpreted as a collision between an ancient landmass known as Laurentia (ancestral North America) and a series of volcanic islands (Karabinos et al. 2003, 2017; Macdonald et al. 2017; Jacobi and Mitchell 2018; Hildebrand and Whalen 2021). Today, the orogeny is defined by an extensive, narrow belt (called the Taconic orogenic belt) of deformed Paleozoic rock that is approximately 100 km (60 mi) wide and more than 2,000 km (1,200 mi) long (Zen 1972). Located in parts of both Canada and the United States, the Taconic orogenic belt encompasses northwestern Newfoundland, eastern Quebec, western Vermont, eastern New York, and north-central New Jersey to southeastern Pennsylvania (Figure 4; Zen 1972). It is believed that the Taconic orogeny is the first of three successive orogenic episodes in the Appalachian Mountains.

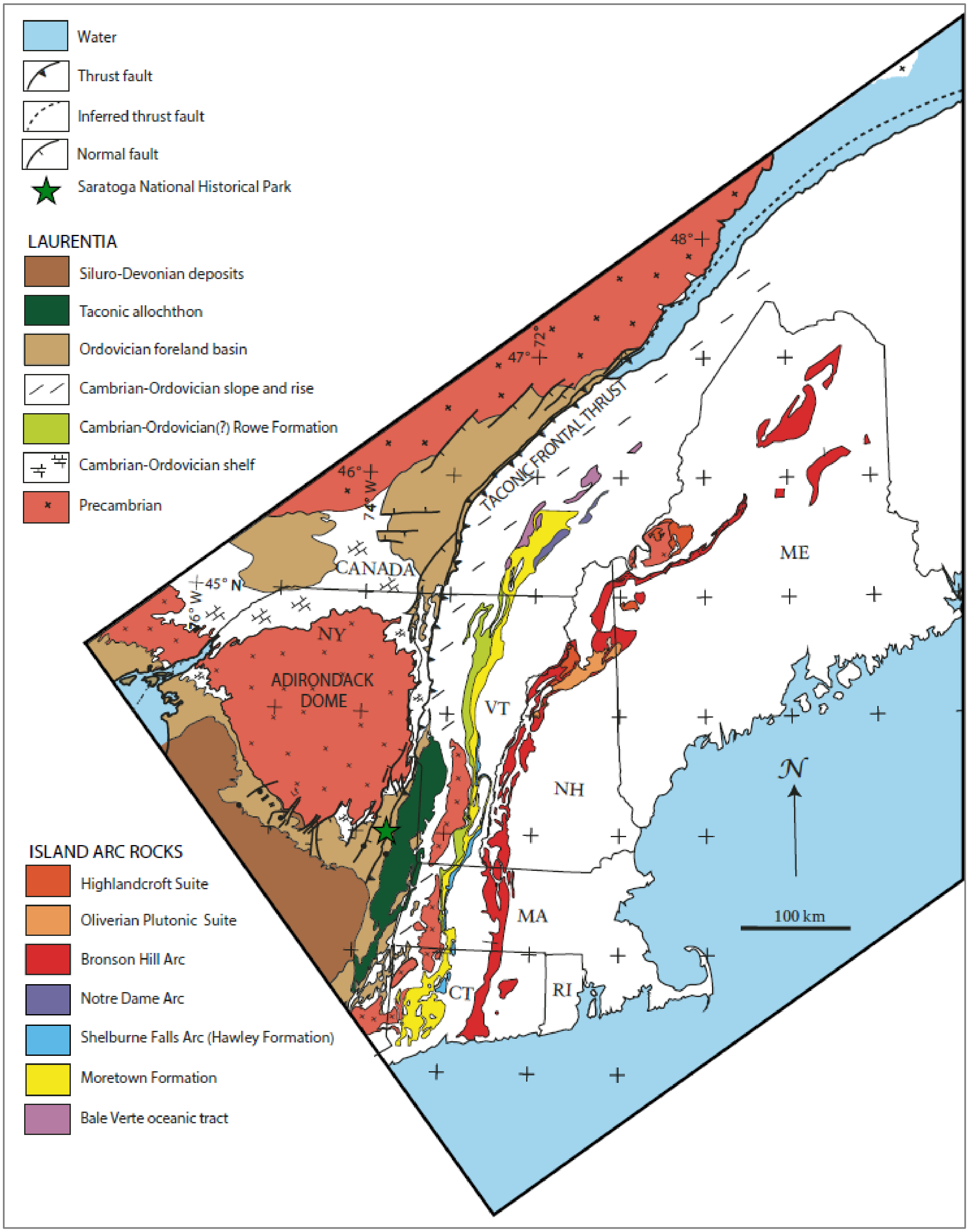

Figure 4. Simplified map of the Taconic orogenic belt. The geology is categorized into rocks of Laurentia and those of the volcanic island arc. The historical park is situated along the western edge of the Taconic Frontal Thrust. which runs along the New York-Vermont border and extends north into Canada. The thrust system folded, faulted, and emplaced Cambrian–Ordovician deep marine strata of the Taconic allochthon and continental slope or rise over similar-aged carbonates of the continental shelf. Map is Figure 1 from Jacobi and Mitchell (2018), modified by Tim C. Henderson (Colorado State University).

The Taconic orogeny has a long history of study dating back to the early 19th century and was once a source of geologic debate involving criminal accusations, libel litigation, and resignations (Seward 2021). Geologists continue to debate specific structural and tectonic elements of the event, with different models involving the collision of one or multiple volcanic island arcs (chains of active volcanoes), the incorporation of one or multiple subduction zones (regions where one lithospheric plate descends beneath another), and differing subduction directions (Karabinos et al. 2003, 2017; Jacobi and Mitchell 2018; Hildebrand and Whalen 2021).

One of the simplest models for the Taconic orogeny involves an east-dipping subduction zone below a single volcanic island arc (Figure 5; Jacobi 1981; Rowley and Kidd 1981; Stanley and Ratcliffe 1985; Bradley and Kidd 1991). According to this model, the subduction of Laurentia's distal oceanic crust beneath the volcanic island arc facilitated the closure of the ancient Iapetus Ocean (precursor to the modern Atlantic Ocean) and enabled melting that fueled the volcanic origin of the islands. At the subduction zone trench, sediments of the descending oceanic slab were scraped off and incorporated into the overriding plate to form an accretionary wedge (steeply inclined, fault-bounded accumulations of rock material) in front of the advancing island arc (Figure 5).

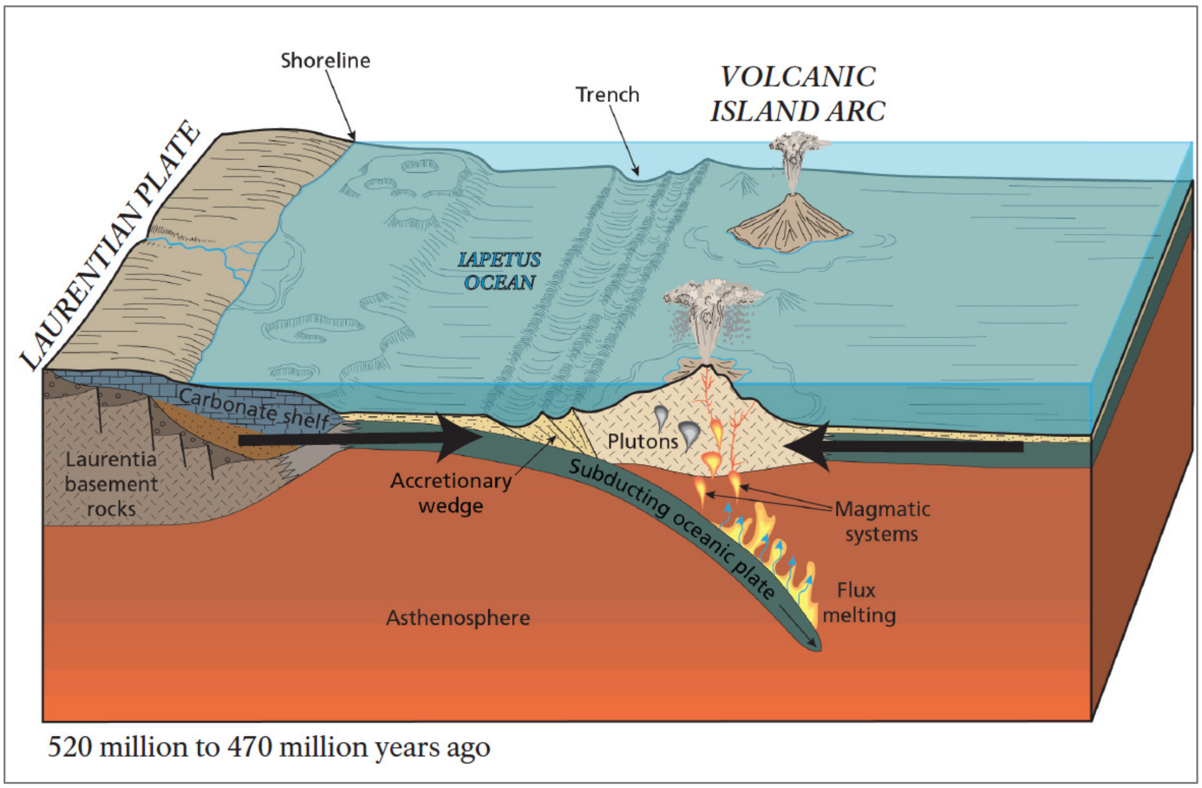

Figure 5. A simplified block model of the subduction zone prior to the Taconic orogeny. In this model, the Laurentian plate is converging with and subducting below volcanic island arc fragments about 520 million to 470 million years ago (Cambrian–Ordovician Periods). The bedrock underlying the historical park was originally deposited as an accretionary wedge along the trench between the colliding land masses. As the orogeny progressed, the marine sediments of the accretionary wedge were compressed, faulted, and thrust hundreds of kilometers west to their current position. Graphic created by Trista L. Thornberry-Ehrlich (Colorado State University).

As the orogeny progressed, the collision of Laurentia with the volcanic island arc thrust deep marine sediments of the accretionary wedge, continental slope, and continental rise to the west, where they now overlie shallow marine rocks of the Laurentian continental shelf (Rowley and Kidd 1981; Bosworth and Kidd 1985; Isachsen et al. 2000). Referred to as the Taconic allochthon (**OCta**), this sequence of thrusted rocks is located a short distance (about 4.0 km [2.5 mi]) east of the historical park, opposite the Hudson River (Figure 6; DeSimone 2015a). The terms “allochthon” or “allochthonous” are used to describe blocks of rock that have been tectonically transported from their original depositional setting. Regionally, the allochthon is mapped across eastern New York and the western portions of Vermont, Massachusetts, and Connecticut (see Figure 4). The allochthon is a complex area of broken, folded, and sheared rocks that form a series of roughly north–northeast-trending thrust faults (low-angle reverse faults that uplift older rock on top of younger rock) and slices (Figure 7; Zen 1967; Rowley and Kidd 1981; Stanley and Ratcliffe 1985; Landing 1988, 2007; Vollmer and Walker 2009; Hildebrand and Whalen 2021). Estimates of thrust displacement for the Taconic allochthon range from 200 km (120 mi) to nearly 1,000 km (620 mi; Stanley and Ratcliffe 1985; Hurowitz and McLennan 2005).

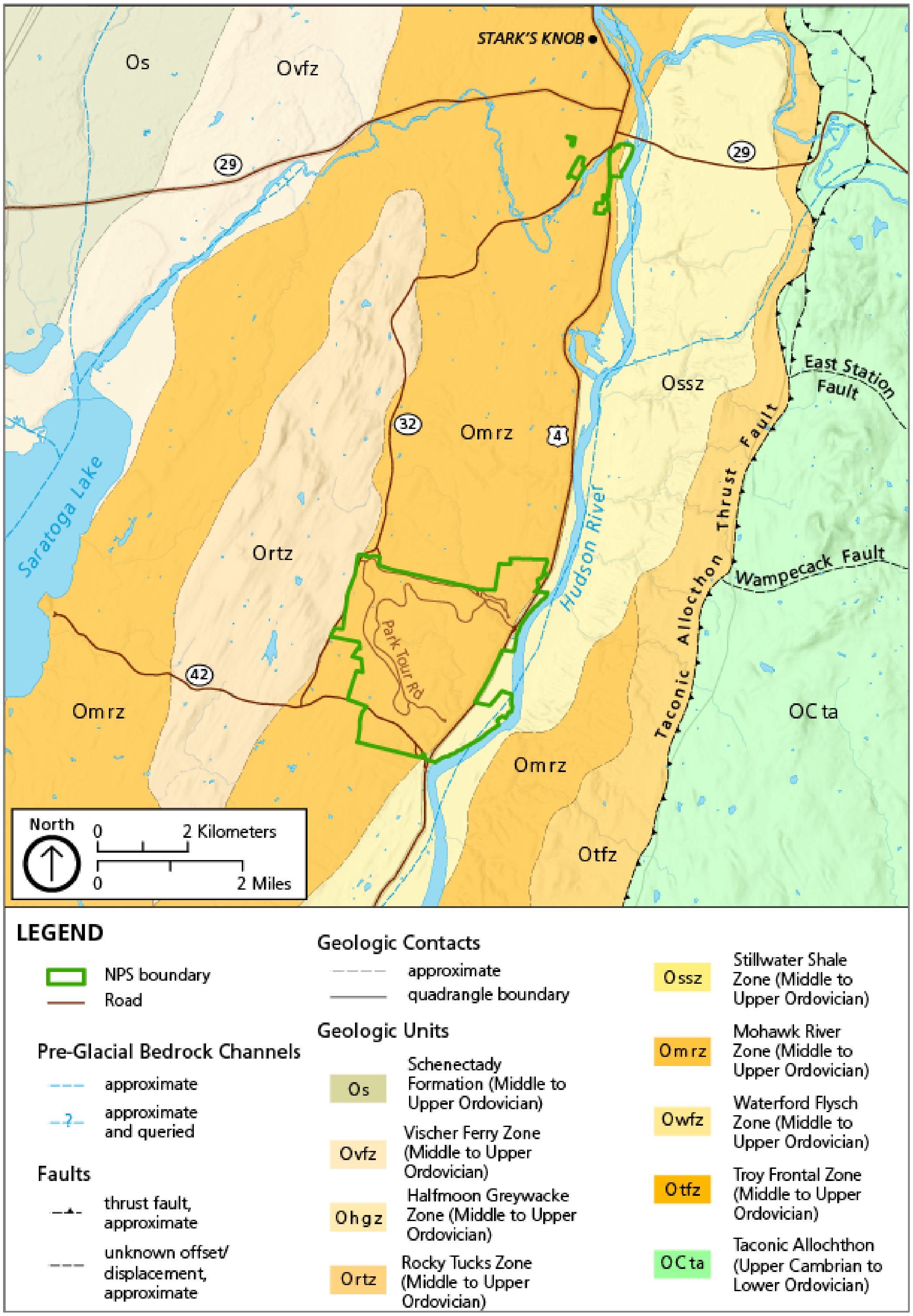

Figure 6. Bedrock geologic map of Saratoga historical park and surrounding area. The upper Hudson River Valley consists of Cambrian and Ordovician sedimentary rocks that have been compressed, folded, and faulted. To the east of the historical park, the Taconic allochthon is a sequence of marine strata that has been tectonically uplifted along the Taconic Allochthon Thrust Fault. The path of the Hudson River follows the general trend of the weaker, shale-rich Stillwater Shale Zone. Map figure created by Thom Curdts (Colorado State University) using the bedrock GRI GIS data (source map of DeSimone 2015a).

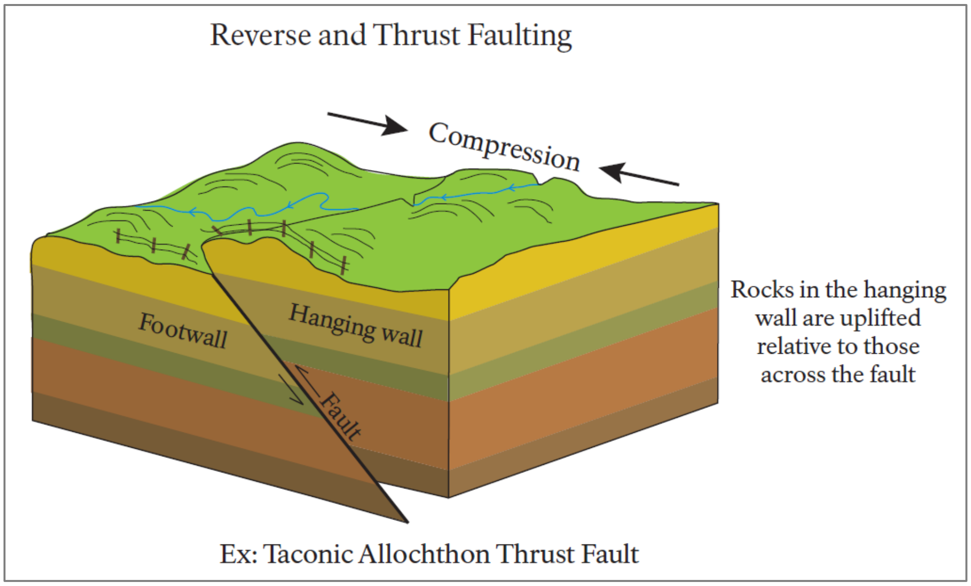

Figure 7. Simplified block model of reverse and thrust fault motion. A reverse fault occurs as rocks are compressed and strata within the hanging wall are uplifted relative to the footwall. A thrust fault is a reverse fault with a low angle fault plane (45° or less). To the east of the historical park, rocks of the Taconic allochthon have been uplifted along the regional Taconic Frontal Thrust. Today, uplifted remnants of the Taconic orogeny are seen in the rocks that form Bald, Schuyler, Wheldon, and Willard Mountains. Figure created by Trista L. Thornberry-Ehrlich (Colorado State University).

Ordovician strata mapped within and surrounding the historical park are classified as flysch deposits associated with the Taconic orogeny. The term "flysch" is applied to rock sequences that record a transition from deep marine to shallower marine sedimentation. In the case of the Taconic orogeny, flysch strata consist of shales, siltstones, and turbidites (submarine gravity-flows consisting of interbedded sandstone, siltstone, and shale) that record the closure of the Iapetus Ocean between Laurentia and the converging island arc terrane. As collision progressed, the Taconic allochthon was thrust west onto the Laurentian carbonate shelf, forming an elongate flexural depression (foreland basin) within the continental interior. Flysch sedimentation accumulated within the foreland basin along the western front of the Taconic allochthon throughout the orogenic event. The flysch deposits were derived from, progressively deformed by, and, in some places, structurally overridden or incorporated into the allochthon as it was emplaced (Vollmer and Bosworth 1984; Kidd et al. 1995). In the upper Hudson River Valley region, flysch deposits were faulted, folded, and sheared to form chaotic belts of tectonic mélange. The term "mélange" refers to a mappable, internally fragmented, and mixed body of rock containing a variety of blocks that are commonly set in a pervasively deformed matrix (Bosworth and Vollmer 1981).

More information about the bedrock geologic units within the historical park can be found in the "Geologic Features and Processes" section of this report.

Pleistocene Glaciation of the Hudson River Valley

The historical park is marked by geologic features that record an interval in Earth's history in which thick, extensive ice sheets advanced and retreated across North America approximately 23,000 to

11,000 years ago. The recent geologic history of the historical park is defined by multiple Pleistocene glacial episodes ("Ice Ages") that sculpted the landscape of the Hudson River Valley. Continental glaciers associated with the Laurentide Ice Sheet advanced south across Canada and the northern United States, beveling, gouging, scratching, and polishing the underlying bedrock. The direction of the ice flow paralleled the Hudson River Valley and was responsible for widening and deepening the ancestral valley floor (Johnsen 1976). When the glacial ice melted and retreated north, enormous quantities of meltwater and unconsolidated rock debris were released. Today, the surficial geology of the historical park predominantly consists of glacial deposits that partially blanket or obscure older, underlying bedrock in the form of drift or till (unconsolidated, poorly sorted rock material of different sizes; **Qtv**), drumlins (elongate mounds of till), glacial lake sediments (clays and silts [**Qlc**] or sands [**Qls**]), and erratics (large masses of ice transported bedrock) (Figure 8; see poster).

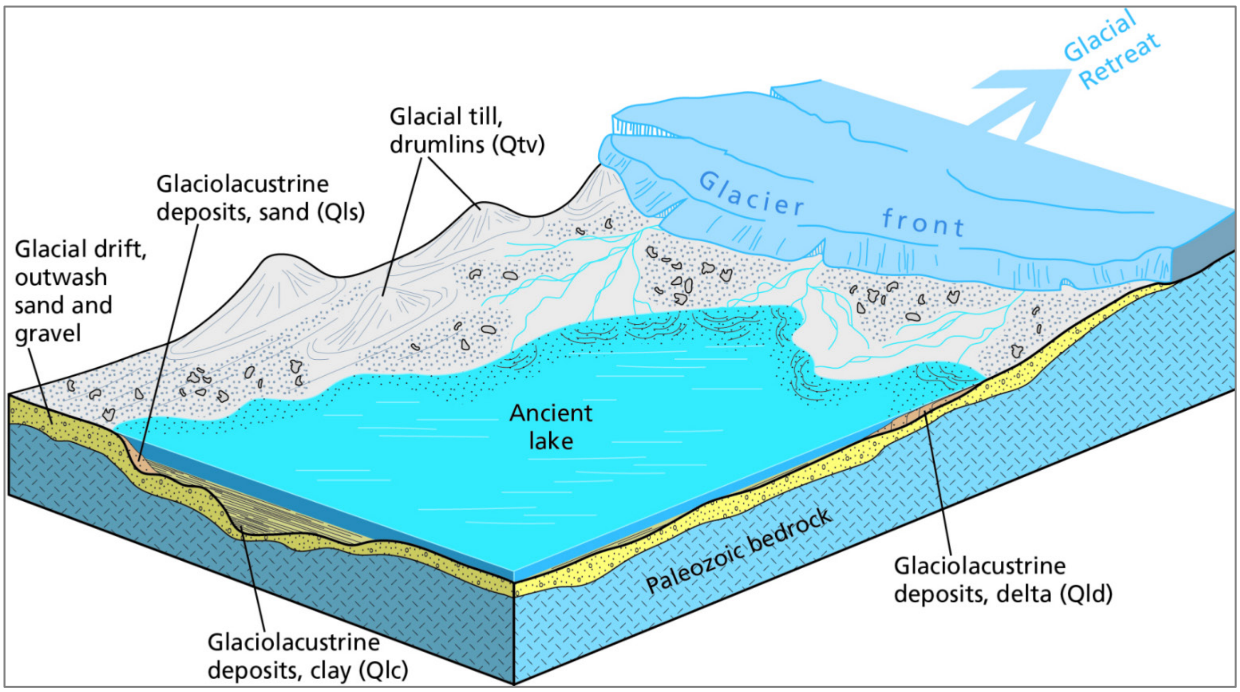

Figure 8. Block diagram illustrating the late Pleistocene glacial setting of the historical park. As the Laurentide Ice Sheet retreated north, large amounts of glacial till were deposited across the landscape and later sculpted into drumlins (Qtv). Receding glaciers released an immense amount of meltwater that formed a series of ancient lakes within the Hudson River Valley. Fine-grained clays and silts (Qlc) accumulated on the deep lake bottom, while coarser sands (Qls) and gravels were deposited along shorelines and deltas (Qld) near the shallow margins of the lake. Graphic created by Trista L. Thornberry-Ehrlich (Colorado State University).

Although glaciers have repeatedly covered the Hudson River Valley, evidence of previous glaciations has been widely destroyed or buried by subsequent glacial events (Cadwell et al. 2003). The region encompassing the historical park contains physical evidence of the most recent glacial episode in North America, the Wisconsinan (or Wisconsin) glaciation. This glaciation began approximately 75,000 years ago, reached its maximum southern ice extent (the "Last Glacial Maximum") roughly 23,000 years ago, and ended about 11,000 years ago (Stone et al. 2005; Gibbard and Cohen 2008; Franzi et al. 2016). In the state of New York, the southernmost ice extended along Long Island and is recorded in extensive till and moraine (linear ridges of till that accumulate along glacial margins) deposits (see GRI report for Sagamore Hill National Historic Site by Henderson 2024). Following the Last Glacial Maximum, the Laurentide Ice Sheet slowly melted and receded north across New York (Figure 9). Glacial meltwater released by the ice sheet was impounded along the retreating ice front to form a series of ancient glacial lakes that inundated the Hudson River Valley, Champlain Lowlands, and present-day Lake Ontario Basin (Johnsen 1976; Connally and Sirkin 1986; Connally and Cadwell 2002; Cadwell et al. 2003; Donnelly et al. 2005).

Figure 9. Deglacial chronology of New York during the late Pleistocene Epoch. Ice margin positions include calibrated U-Th radiocarbon dates (in thousands of years before present) that record the northerly retreat of the Laurentide Ice Sheet. After reaching its southernmost extent about 28,000 to 23,000 years ago along the area of Long Island, the ice sheet receded north (into Canada) until the end of the Ice Age, approximately 11,000 years ago. The green star is the approximate location of the historical park. Map is Figure 2 from Franzi et al. (2016), courtesy of the Adirondack Journal of Environmental Sciences, and modified by Trista L. Thornberry-Ehrlich (Colorado State University).

In the upper Hudson River Valley, several glacial lakes occupied the lowland area for thousands of years, including (from oldest to youngest): Glacial Lake Albany (14,000 to 11,900 ^{14}C years before present [BP]); Glacial Lake Quaker Springs (11,900 to 11,500 ^{14}C years BP); and Glacial Lake Coveville (11,500 to 11,100 ^{14}C years BP) (Figure 10; Dineen and Miller 2006). It is important to acknowledge that radiocarbon dates are not equivalent to calendar dates and that radiocarbon years require calibration to yield calendar years. Each successive lake became progressively shallower and narrower as these lake systems breached their glacial dams and catastrophically flooded south through the river valley into the Atlantic Ocean (DeSimone and LaFleur 1985, 2008). These lacustrine (lake) environments accumulated thick layers of clay and silt (**Qlc**) along the deep lake bottoms, with coarser sand (**Qls**) deposited in shallower lake margin settings (De Simone 2015b). At the historical park, the clay-rich river bluffs at the Battlefield Unit represent deep-water sedimentation in Glacial Lake Albany; these deposits are overlain by lake sands that record a drop in water level associated with Glacial Lake Coveville (DeSimone 2016; Rayburn et al. 2018).

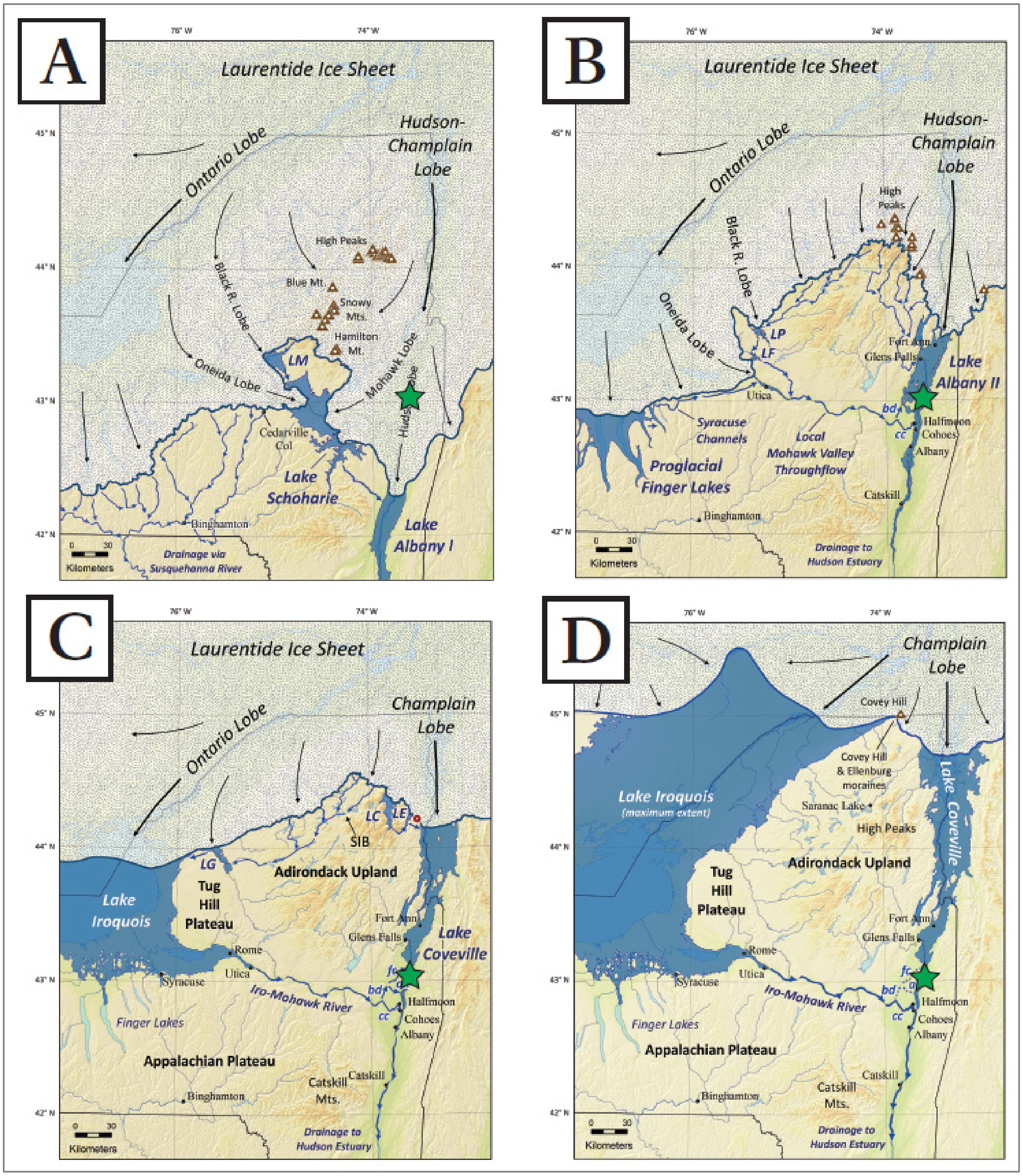

Figure 10. Paleogeographic maps of late Pleistocene glacial lakes and ice lobes in northeastern New York. The Hudson River Valley was home to a number of glacial lakes during the late Pleistocene (in order from oldest to youngest): (A) Lake Albany **I**, approximately 16,000 14C years before present; (B) Lake Albany **II**, approximately 14,000 to 11,900 14C years before present; and (C–D) Lake Coveville, approximately 11,500 to 11,100 14C years before present. The green star represents the approximate location of the historical park. The red circle in (C) is a fossil locality of Franzi et al. (2016). Maps are Figures 4–7 from Franzi et al. (2016), courtesy of the Adirondack Journal of Environmental Sciences, and modified by Tim C. Henderson (Colorado State University).

Surrounding the historical park are additional glacial features, some of which played a role in the Battles of Saratoga (see "Geology and the Battles of Saratoga"). As the Laurentide Ice Sheet receded north during the Pleistocene, meltwater tributaries emptied into the glacial lakes, depositing sand and gravel along the shorelines to form lacustrine deltas (**Qld**). One such feature is the Batten Kill delta, located east of the Hudson River across from the Saratoga Monument and Saratoga Surrender Site (see poster; Cushing and Ruedemann 1914; DeSimone 2016; Rayburn et al. 2018). Several small delta features are mapped south of the historical park along the Hoosic River. As the glacial lakes drained, sand-rich sediments from former lake shores and lake bottoms were exposed (Dineen and Rogers 1979). With little to no stabilizing vegetation, the prevailing winds eroded sand from **Qls** and **Qld** deposits to form dunes (**Qds**) that surround modern-day Saratoga Lake and Fish Creek (see poster).

More information about the surficial geologic units within the historical park can be found in the "Geologic Features and Processes" section of this report.

Geology and the Battles of Saratoga

> *Any one [sic] who studies this region with an interest both for its fascinating history and its geology, can not [sic] fail to be impressed by the close relationship between the course of the historic events and the geology of the region. (Cushing and Ruedemann 1914, p. 168)*

Overall Military Strategy and Prelude to Saratoga

The geology of the Hudson River Valley played a key role in the Battles of Saratoga, as the historic river corridor predetermined the location of combat and influenced military strategy (both American and British) as well as the resulting surrender of Lt. Gen. John Burgoyne's forces. As King George III attempted to suppress the dissonance of the American colonies, Burgoyne drafted a military proposal to stage a majority of the Canada Army at Albany, New York, by capturing the city. The "Saratoga Campaign" or "Burgoyne Campaign" consisted of a two-pronged attack. The northern prong, commanded by Burgoyne, advanced south across the Lake Champlain and Lake George watersheds, traversed the St. Lawrence River Divide via the Great Carrying Place, and continued down the Hudson River to Albany. The second prong, a smaller diversionary force commanded by Lt. Col. St. Leger, advanced from Lake Ontario down the Oswego River, traversed the St. Lawrence River Divide via the Oneida Carry, and continued east along the Mohawk River. Once both prongs convened at Albany, Burgoyne would receive further operational directions from his commander-in-chief, Gen. Sir William Howe. Depending on the difficulties facing Burgoyne at that time, he would be positioned to either move on other strongpoints in upstate New York or even strike into New England (Eric Schnitzer, Saratoga National Historical Park, personal communication 5 June 2024). The northern prong and its association with the historical park are the focus of this report.

Burgoyne's army departed St. Johns, Canada, in June of 1777 and journeyed south along Lake Champlain toward the Hudson River. After a string of early victories, British troops followed a path that crossed downfaulted Ordovician rocks at the eastern base of the Adirondack Mountains near the town of Whitehall, NY (Cushing and Ruedemann 1914). As the British descended into the low-lying valley near Wood Creek, they encountered a fluvial landscape consisting of ancient glacial lake sediments that was riddled with wetlands and swamps (Cushing and Ruedemann 1914; Johnson and Reichart 2002). Burgoyne and his army wasted valuable time, energy, and provisions navigating these swamps; the situation was made more cumbersome by retreating American forces, who purposely destroyed bridges and littered trails and roads with downed trees (Nowak and Commisso 2011). Additionally, Burgoyne's advance was delayed by one month (mid-August through mid-September) during which time his army barely moved at all; these actions were the result of the British loss at the Battle of Bennington which took place on 16 August 1777 (Eric Schnitzer, Saratoga National Historical Park, personal communication 5 June 2024). Upon reaching the Hudson River, the British army continued south until it was faced with the superior defensive positions held by the Americans at Bemis Heights. It was there that Burgoyne's military ambitions collided against the formidable geologic terrain that was better understood by the Americans.

The American military strategy relied on a critical understanding of the Hudson River's role in the success of the Burgoyne Campaign. The British army—including its soldiers, heavy munitions, and supplies—were confined to the river or the adjacent riverbank road ("Road to Albany") for navigation and transportation. The decision to build fortifications at Bemis Heights along the western bank of the Hudson River exploited a natural chokepoint along the river corridor that offered a commanding and defensible high ground position. As the Hudson River flows south, it meanders to the west against the bluffs at Bemis Heights, which rise approximately 60 m (200 ft) above the floodplain (Johnson and Reichart 2002). At Bemis Heights, the river had scoured the cut bank (outside curve or bend in a river channel) and steepened the clay-rich bluffs (**Qlc**), while also having deposited mud and silt in the point bar (inner curve or bend in a river channel) immediately to the north. For Burgoyne's army moving south, this swampy ground impeded momentum just before the road dangerously funneled into a constrained gap below the heights (Johnson and Reichart 2002). The American army encamped on and fortified not only the narrow floodplain valley and the key terrain along the bluffs, but also the forested hills that formed the uplands around Neilson Farm. For the British to reach Albany, they either had to risk a frontal assault between the bluffs and the river or attempt to flank the Americans from the west on higher ground. Ultimately, Burgoyne chose the latter of the two options.

The Battle of Freeman's Farm and the Battle of Bemus Heights

Geological landforms located within and surrounding the historical park played key roles in the battles. High ridges and hills throughout the battlefield were vantage points, and nearby mountains such as Willard, Beadle, and Schuyler Mountains helped scouts survey military positions from across the Hudson River (Figure 11; Cushing and Ruedemann 1914; Oudemool et al. 2002). The mountains east of the historical park are composed of the Taconic allochthon (**OCta**) and represent the eroded remnants of continental collision and tectonic uplift associated with the Taconic orogeny (see "The Taconic Orogeny").

Figure 11. Photograph of a cannon emplacement at the Great Redoubt in the northern Battlefield Unit. View is facing east across the Hudson River toward the Willard (right) and Wheldon (left) Mountains. The Hudson River landscape—featuring floodplains, bluffs, fields, hills, terraces, and ravines—played a major role in the strategy and outcome of the Battles of Saratoga. The strategic bluffs overlooking the river are underlain by a thick sequence of lacustrine clay and sand deposits that accumulated in a series of ancient glacial lakes during the late Pleistocene. NPS photograph.

As Burgoyne's army left the Road to Albany on 19 September 1777 in their attempt to confront the Americans from the west, they first had to navigate a series of deep ravines and steep escarpments along the western bank of the Hudson River. The ravine networks punctuating the battlefield landscape were formed from stream incision following the last Ice Age (Dalton 2004). The major ravine networks in the Battlefield Unit—the Great Ravine (of the Kroma Kill) and Middle Ravine (of Mill Creek)—extend in a general northwest–southeast direction and have variable depths that increase downstream (see poster; Figure 12). At its lowest elevation near the Great Redoubt, the Great Ravine is flanked by slopes rising about 65 m (220 ft) above the floodplain. Navigating the ravine networks slowed the approach of the British forces, hindered their ability to internally command and control their advancing columns, and reduced their ability to detect American forces (Dalton 2004). In contrast, the ravines and stream networks were favorably exploited by the American military. Gates' army used these erosional valleys for defensive positions, to conceal troop movements, and to purposely slow the British. As part of their defensive strategy, the Americans destroyed almost every bridge structure north of Bemis Heights to slow the momentum of Burgoyne's soldiers and heavy artillery.

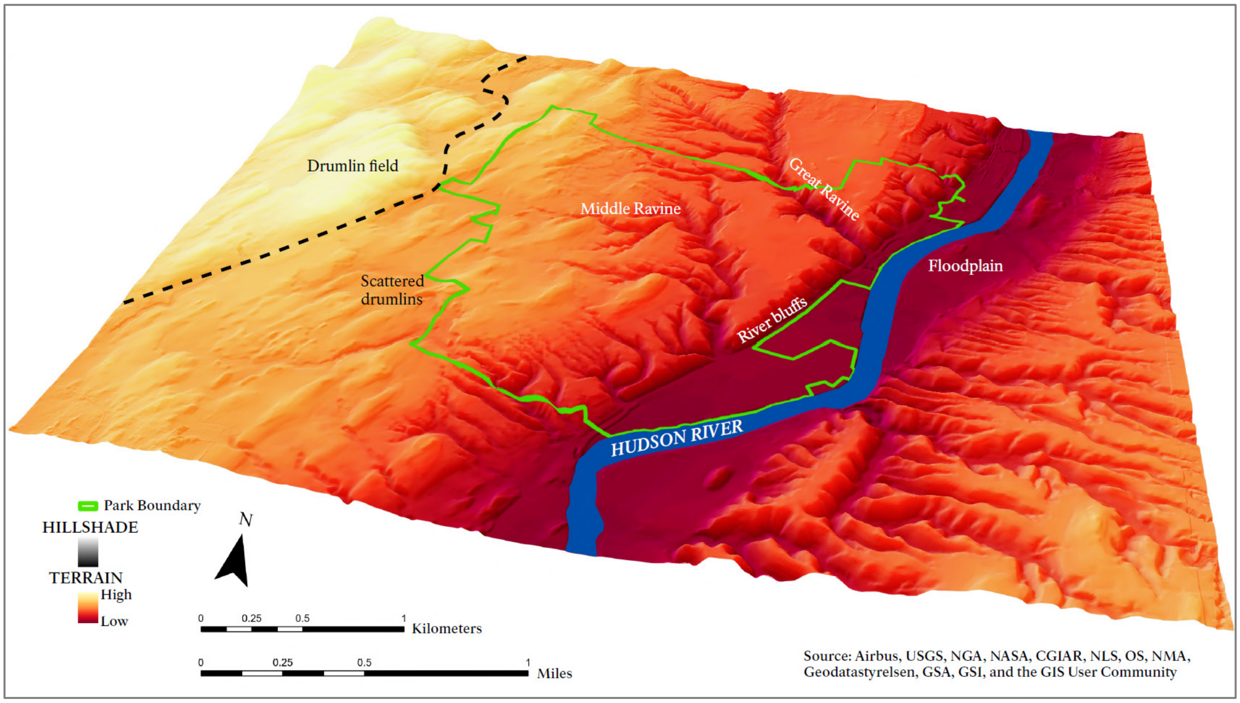

Figure 12. A three-dimensional digital elevation model of the Battlefield Unit. The Battlefield Unit (outlined in green) occupies the dissected floodplain and uplands adjacent to the Hudson River. A drumlin field forms the elevated topography west of the historical park, and its eastern limit is denoted by the dashed line. The battlefield contains scattered drumlins that were elevated vantage points during the Battles of Saratoga. The ravine networks cut through the rolling hills and fields flanking the river and provided defensive military positioning. One significant limitation of the British invasion strategy was that its forces, heavy artillery, and supplies could only advance along the river and floodplain. Figure created by Tim C. Henderson (Colorado State University).

During the Battle of Freeman's Farm, fighting pitched back and forth across the clearing of Freeman Farm and deep into the surrounding woods. American troops occupied the high ground west of the clearing in an area of two large, forested hills underlain by glacial till (**Qtv**) (Figure 13; Oudemool et al. 2002; Commisso and Foulds 2011). The Americans used the wooded hillsides for cover, while riflemen under the command of Col. Daniel Morgan (elite sharpshooters referred to as "Morgan's Corps") held key positions along the Middle Ravine along the southern end of the clearing. The ravine served as a natural trench, as it not only shielded Morgan's Corps from being reached by the enemy but also allowed them ample time to reload their weapons (Oudemool et al. 2002). Although the Battle of Freeman's Farm resulted in nearly twice as many casualties for the British, the Americans were forced to retreat but still held the strategic stronghold at Bemis Heights (Dalton 2004). Following the battle, Burgoyne's army dug in, constructing a series of redoubts stretching west from the Great Ravine to the Freeman Farm. The British fortifications were constructed based on geologic features offering favorable defense and sustenance; the Great Redoubt and Burgoyne's headquarters were centered around the Great Ravine. The steep, eroded walls of the ravine, combined with the Hudson River bluffs, protected the British flank and may have contained natural springs that provided a valuable source of water (Thornberry-Ehrlich 2008). The Great Ravine exposes porous glacial sand deposits (**Qls**) overlying more impermeable, clay-rich lake deposits (**Qlc**)—a configuration suitable for spring development (see "Springs and Seeps").

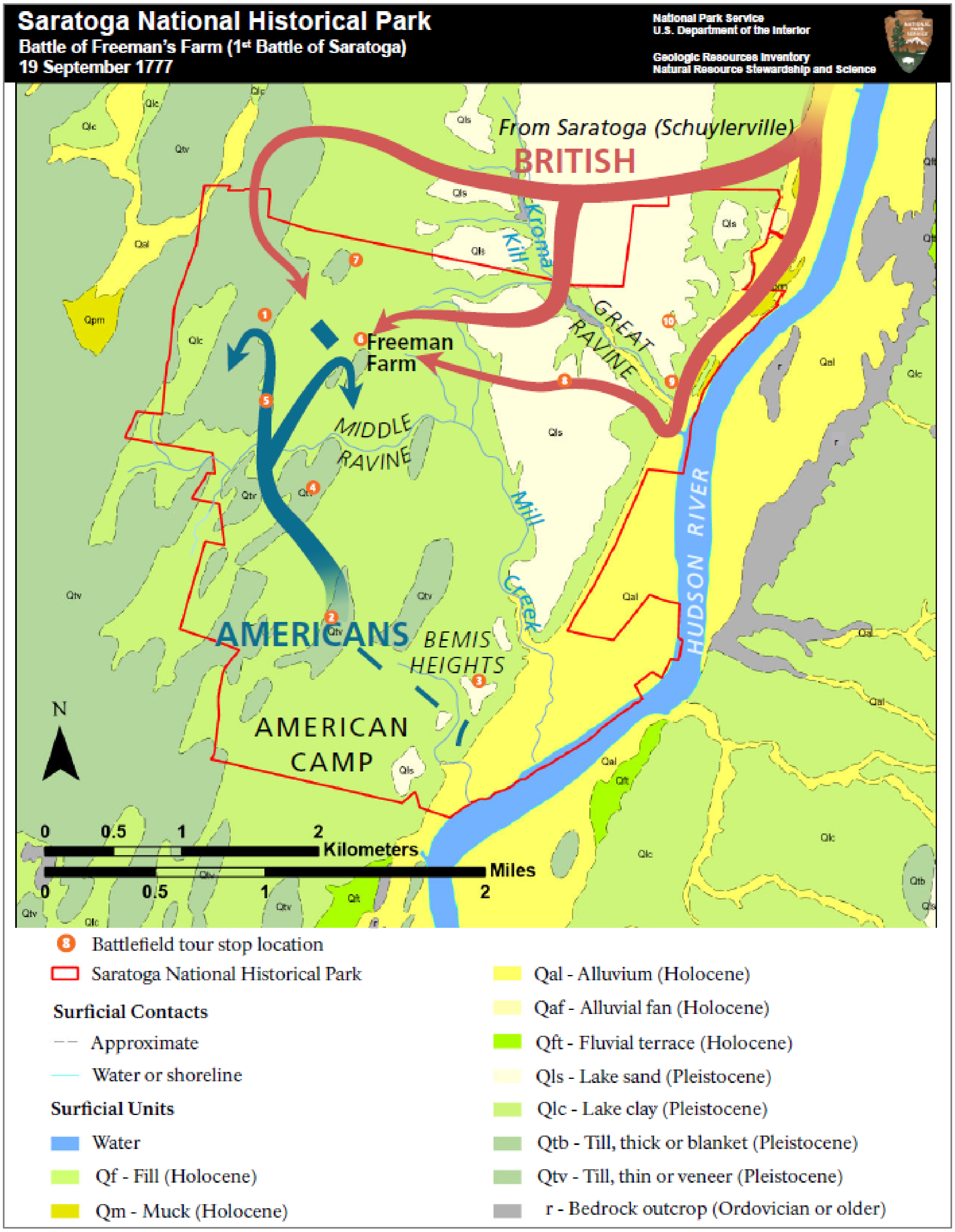

Figure 13. Surficial geologic map showing troop movements during the Battle of Freeman's Farm. Orange markers indicate tour road stop locations within the Battlefield Unit. American troops (blue arrows) confronted the British (red arrows) in the clearing of Freeman Farm but occupied forested hills to the west and south of the battlefield. The forested hills were commanding territory underlain by glacial till deposits (Qtv). American sharpshooters also strategically used the Middle Ravine for defensive cover. Figure created by Tim C. Henderson (Colorado State University).

Following an eighteen-day stalemate in which Burgoyne's entrenched army waited for reinforcements, the prospects of assistance dwindled. On 7 October 1777, the British sent out a reconnaissance force of approximately 1,500 men to assess the location and strength of American positions; Burgoyne's intent was to follow up with a full-scale attack the following day (Dalton 2004). As the reconnaissance unit explored the area of the Barber Farm, their positions were compromised by the concealed vantage points provided by the forested uplands of Bemis Heights. Many of these vantage points are glacial drumlins aligned roughly parallel to the Hudson River Valley (Figure 12 and Figure 14; DeSimone 2016; Rayburn et al. 2018). The ensuing Battle of Bemus Heights resulted in a decisive British defeat that convinced Burgoyne to withdraw north to Saratoga (present-day Schuylerville) on 8 October 1777. Under the cover of nightfall, the demoralizing British retreat followed a road underlain by clay-rich, Pleistocene lake deposits (**Qlc**) that were turned into a quagmire by heavy rains (Johnson and Reichert 2002; Dalton 2004; National Park Service 2021b; Schnitzer 2023).

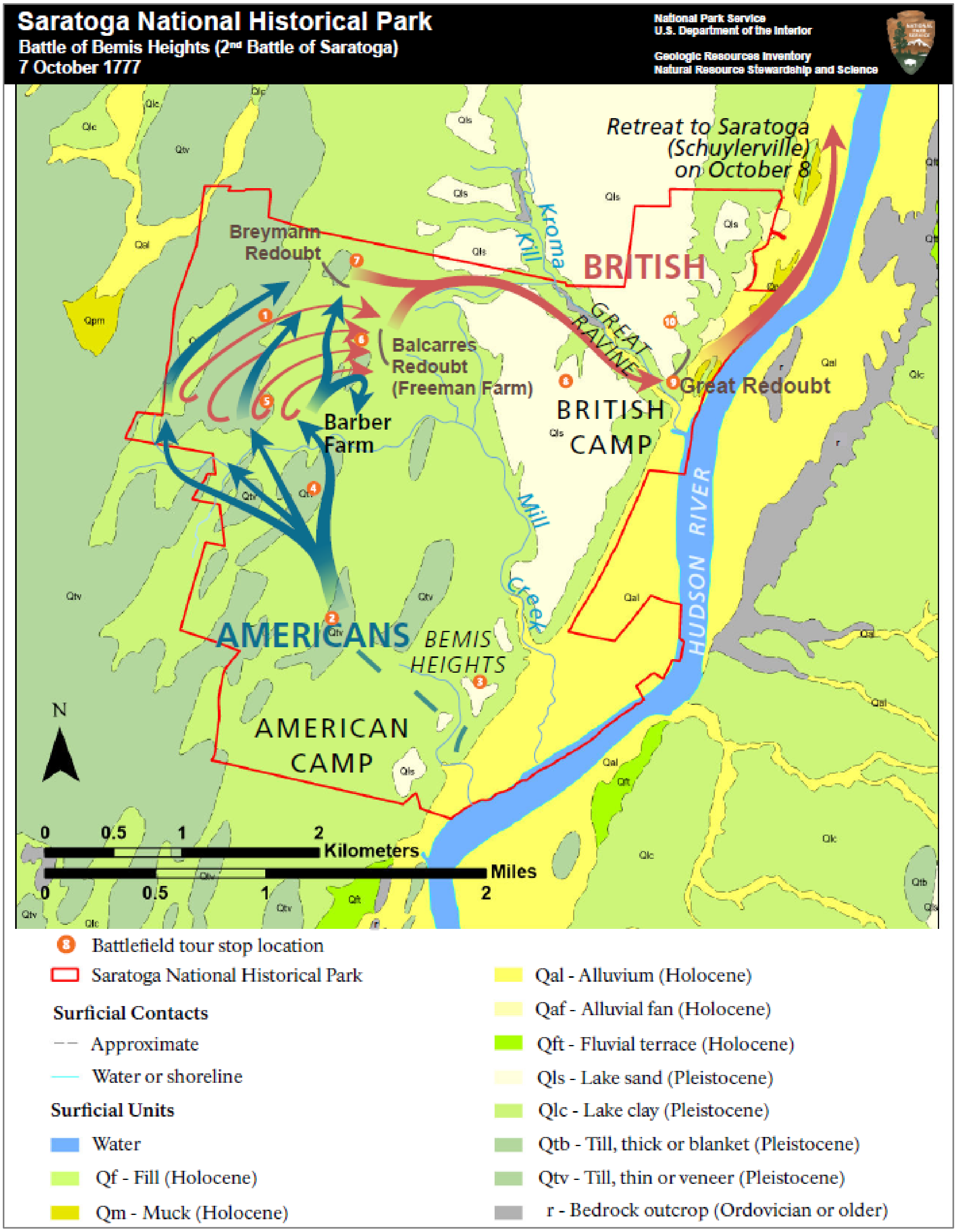

Figure 14. Surficial geologic map showing troop movements during the Battle of Bemus Heights. Orange markers represent tour road stop locations within the Battlefield Unit. Forested hillsides underlain by glacial till provided Americans (blue lines) the ability to catch the British (red lines) off-guard in the Barber Farm. Following a decisive American victory, the British retreated north along the swampy Hudson River floodplain. Map created by Tim C. Henderson (Colorado State University).

Table 1 and Figures 12–14 provide geologic guide companions to the Battles of Saratoga and the Battlefield Unit tour road. The table and figures outline the topography, surficial geology, and geologic features located at each stop along the tour and explain how they influenced the strategy and outcomes of the battles.

Table 1. Geologic guide to the tour road in the Battlefield Unit of Saratoga National Historical Park. Original site descriptions modified after table 8.1 of Oudemool et al. (2002).

Stop #	Battlefield Event and Geologic Connection
1	Freeman Farm Overlook. The major fighting of the Battle of Freeman's Farm took place here on 19 September 1777. The Freeman Farm consists of rolling fields underlain by clay-rich Pleistocene lake deposits (**Qlc**) that have been dissected by stream erosion to form ravines, including the Middle Ravine and Great Ravine. The rolling fields are surrounded by elevated hills consisting of Pleistocene glacial till (**Qtv**) to the west and south. The till deposits provided strategic high ground during the battles and form the highest topographic point in the historical park—the Battlefield Unit visitor center.
2	Neilson Farm (Bemis Heights). The Neilson Farm was used as headquarters for the Northern Army's left wing, commanded by Maj. Gen. Benedict Arnold, and occupies the strategic upland of Bemis Heights. The Neilson Farm is situated on one of several glacial drumlins composed of till (**Qtv**) that are oriented roughly parallel to the Hudson River Valley.
3	American River Fortifications. Fortifications along the bluffs at Bemis Heights exploited a natural chokepoint where the Hudson River meanders dangerously close to the upland riverbank. The bluffs consist of thick, clay-rich Pleistocene lake deposits (**Qlc**) nearly 60 m (200 ft) thick that are capped by Pleistocene lake sands (**Qls**).
4	Chatfield Farm. The elevated ridge at Chatfield Farm was an American outpost that spotted the British reconnaissance force at Barber Farm on 7 October 1777. Similar to stop #2, the high ground is a drumlin feature composed of Pleistocene glacial till (**Qtv**) that gently rises above Barber and Freeman Farms. Beyond the ridge is the Middle Ravine, an erosional feature of Mill Creek that was used by American forces for defensive cover during the battles.
5	Barber Wheatfield. Here and in the adjacent field farther west, the American Continental Army intercepted the British reconnaissance force on 7 October 1777 and successfully forced Burgoyne's troops to withdraw to their fortifications near Freeman Farm. The Barber wheatfield is an area of gently undulating topography underlain by Pleistocene lake deposits consisting of clay and silt (**Qlc**). The wheatfield is nestled against hills composed of Pleistocene glacial till (**Qtv**) that were used as vantage points by the American military.
6	Balcarres Redoubt (Freeman Farm). Following the Battle of Freeman's Farm, the British constructed the Light Infantry Redoubt. The redoubt is situated in an upland region of Pleistocene glacial till (**Qtv**), and is surrounded by dissected, rolling fields that are underlain by clay-rich Pleistocene lake deposits (**Qlc**). During the Battle of Bemus Heights, the British were driven back from the Barber wheatfield and withdrew to the redoubt under heavy American gunfire.
7	Breymann Redoubt. Breymann's fortified camp was constructed following the Battle of Freeman's Farm and guarded the British right flank. Similar to stop #6, Breymann's fortified camp occupied an upland region underlain by Pleistocene glacial till (**Qtv**). During the Battle of Bemus Heights, the American army was able to overwhelm the British forces and capture the fortification.

Table 1 (continued). Geologic guide to the tour road in the Battlefield Unit of Saratoga National Historical Park. Original site descriptions modified after table 8.1 of Oudemool et al. (2002).

Stop #	Battlefield Event and Geologic Connection
8	Burgoyne's Headquarters. The site of Burgoyne's headquarters was the center of British command and camp life during the interlude between the Battle of Freeman's Farm and the Battle of Bemus Heights. Located along a tributary valley of the Great Ravine, the headquarters are situated on Pleistocene lake sands (**Qls**) that cap older, clay-rich lake deposits (**Qlc**). The geologic configuration of porous sand overlying impermeable clay creates conditions suitable for spring development and may have provided a valuable water source that persuaded Burgoyne to choose the location as his central command (National Park Service 1989; Vana-Miller et al. 2001).
9	The Great Redoubt. Situated at the mouth of the Great Ravine (of the Kroma Kill) along the steep bluffs of the Hudson River, the Great Redoubt was a system of heavily guarded British defenses. The redoubt is perched on late Pleistocene lake sands (**Qls**) that overlie lake clays (**Qlc**) steepened by fluvial incision. British forces camped along the floodplain beneath the fortified bluff during the interlude between the two battles. Following their defeat at the Battle of Bemus Heights, British forces withdrew behind the Great Redoubt prior to their retreat north to Schuylerville. Although stop #10 includes the traditional gravesite of British Brig. Gen. Simon Fraser, he was actually buried in the Great Redoubt following mortal wounds suffered during the Battles of Bemis Heights.
10	Fraser Burial Site and Trail. A 1.6 km (1.0 mi) loop trail passes the traditional gravesite of British Brigadier General Simon Fraser, who was mortally wounded during the Battle of Bemus Heights. The original burial site is believed to be located within the Great Redoubt, underlain by Pleistocene lake sands (**Qls**) that cap the bluffs flanking the Hudson River.

Burgoyne's Surrender

As Burgoyne's forces retreated north to Saratoga (present-day Schuylerville), the American Northern Army followed in pursuit and effectively used the geologic landscape to surround the British and prevent their escape. Although Burgoyne favored the defensible high ground north of Fish Creek, he soon realized his army was flanked in every direction. American forces under the command of Gen. Gates were stationed south of Fish Creek; Gates established his new headquarters near what is now the Saratoga Surrender Site. North of Saratoga, American forces under the command of Gen. John Stark occupied an anomalous hill of pillow basalt (Stark's Knob) that strategically faced the Hudson River and blocked any further retreat north (Cushing and Ruedemann 1914; Piper 1985; Stevens et al. 2007). However, some of the history regarding Stark's Knob has been revised since scholars now believe Stark placed his artillery on another nearby hill that was mixed up in the mapmaking process. More information about Stark's Knob is in the "Geologic Features and Processes" chapter.

East of the Hudson River, opposite Saratoga, an American militia brigade commanded by Brig. Gen. John Fellows held favorable high ground positions underlain by glacial deltaic deposits consisting of unconsolidated gravel and sand (**Qld**). These deltaic sediments mark the western edge of the Batten Kill delta, a large Ice Age depositional feature created by meltwater tributaries as they emptied into Glacial Lake Quaker Springs over 11,000 years ago (Cushing and Ruedemann 1914; Johnson and Reichert 2002; DeSimone 2006; DeSimone et al. 2008; Rayburn et al. 2018). Directly west of Burgoyne's forces, Col. Daniel Morgan's riflemen were positioned in a heavily wooded area north of Fish Creek consisting of stabilized Pleistocene sand dunes (**Qls**; Johnson and Reichert 2002; National Park Service 2004). Pinned down in the heights north of Fish Creek, with limited supplies and no escape, Burgoyne's forces conceded on 17 October 1777—a momentous day in American history shaped by the geologic history of the Hudson River Valley.

Geologic History

This chapter describes the geologic events that formed the present landscape. Events are discussed more-or-less in order of geologic age (oldest to youngest). A geologic time scale shows the chronology of geologic events (bottom to top) that led to the historical park's present-day landscape; this story covers more than 1 billion years and encompasses glacial events that occurred less than 20,000 years ago.

Geologic Time Scale

The following geologic map units table (Table 2) and geologic time scale (Table 3) put the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Likewise, rocks and unconsolidated deposits are listed stratigraphically. The oldest (Ordovician) rocks form the bedrock within and immediately surrounding the historical park. The youngest (Quaternary) rocks are surficial glacial and fluvial units that partially mantle or obscure the underlying bedrock.

Table 2. Geologic units mapped within the historical park.

Geologic Time Unit [A]	Age [B]	Geologic Map Units [C]	Geologic Events	Locations
Quaternary Period (Q): Pleistocene Epoch (PE) and Holocene Epoch (H)	2.6 million to less than 11,700 years ago	Alluvium (Qal) Alluvial fan (Qaf) Muck (Qm) Fluvial terraces (Qft) Lake clay (Qlc) Lake sand (Qls) Till, thin or veneer (Qtv)	The deposition of glacial till is associated with the recessional stages of the Laurentide Ice Sheet during the late Wisconsinan glaciation, approximately 14,000 14C years before present (Dineen and Miller 2006). Deglaciation of the upper Hudson River Valley produced several glacial lakes that accumulated thick sedimentary deposits approximately 14,000 to 11,000 14C years before present (Dineen and Miller 2006). As the lakes drained and disappeared, exposed lake deposits, till, and bedrock were reworked by fluvial and aeolian processes to form alluvial fans, floodplains, terraces, and dunes.	Till deposits are mapped along the upland regions adjacent to the Hudson River and Fish Creek in the Battlefield Unit, Saratoga Surrender Site, Schuyler Estate, and Victory Woods. Lake clays and sands underlie the bluffs and upland regions adjacent to the Hudson River and Fish Creek at the Battlefield Unit, Saratoga Monument, and Victory Woods. Alluvium, alluvial fan, muck, and fluvial terrace deposits are mapped along the low-lying Hudson River floodplain at the Battlefield Unit and Schuyler Estate. Terrace deposits are restricted to the Schuyler Estate, where they underlie the western half of the property. Several alluvial fans are located in the Battlefield Unit to the north of the entrance road (US Route 4) near the Great Redoubt.
Ordovician Period (O)	485.4 million to 443.8 million years ago	Mohawk River Zone (Omrz) Rocky Tucks Zone (Ortz) Stillwater Shale Zone (Ossz)	Rocks of the Mohawk River Zone, Rocky Tucks Zone, and Stillwater Shale Zone represent flysch and mélange deposits associated with the Taconic Orogeny. Deep marine shales and greywackes that comprise these zones were compressed, faulted, and thrust westward during the orogenic event approximately 475 million to 440 million years ago (Kidd et al. 1995; Karabinos et al. 2017; Macdonald et al. 2017).	A major portion of the historical park (all five parcels) is underlain by the Mohawk River Zone. The Stillwater Shale Zone is mapped along the low-lying Hudson River floodplain in the Battlefield Unit and Schuyler Estate. The Rocky Tucks Zone is restricted to the westernmost Battlefield Unit near the visitor center. Within the historical park, the occurrence of bedrock exposures (r) is limited to ravines, creek beds, and low-elevation regions flanking the Hudson River (see poster).

[A] Colors correspond to USGS suggested colors for geologic maps. Letters in parentheses are abbreviations for each time division. The Quaternary Period is part of the Cenozoic Era. The Ordovician Period is part of the Paleozoic Era. See Table 3 for a geologic time scale.

[B] Boundary ages follow the International Commission on Stratigraphy (2023).

[C] Only geologic units mapped within the historical park are included. Letters in parentheses correspond to GRI map unit symbols (see “GRI Products”).

Table 3. Geologic time scale. The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Colors correspond to USGS suggested colors for geologic maps. Letters in parentheses are abbreviations for geologic time units. Where no geologic time subdivision exists, "n/a" indicates not applicable.

Eon	Era(s)	Period(s)	Epoch(s)	MYA [A]
Phanerozoic	Cenozoic	Quaternary (Q)	Holocene (H)	0.0117–today
	Cenozoic	Quaternary (Q)	Pleistocene (PE)	2.6–0.0117
	Cenozoic	Neogene (N)	Pliocene (PL)	5.3–2.6
	Cenozoic	Neogene (N)	Miocene (MI)	23.0–5.3
	Cenozoic	Paleogene (PG)	Oligocene (OL)	33.9–23.0
	Cenozoic	Paleogene (PG)	Eocene (E)	56.0–33.9
	Cenozoic	Paleogene (PG)	Paleocene (EP)	66.0–56.0
	Mesozoic	Cretaceous (K)	Upper, Lower	145.0–66.0
	Mesozoic	Jurassic (J)	Upper, Middle, Lower	201.4–145.0
	Mesozoic	Triassic (TR)	Upper, Middle, Lower	251.9–201.4
	Paleozoic	Permian (P)	Lopingian, Guadalupian, Cisuralian	298.9–251.9
	Paleozoic	Pennsylvanian (PN)	Upper, Middle, Lower	323.2–298.9
	Paleozoic	Mississippian (M)	Upper, Middle, Lower	358.9–323.2
	Paleozoic	Devonian (D)	Upper, Middle, Lower	419.2–358.9
	Paleozoic	Silurian (S)	Pridoli, Ludlow, Wenlock, Llandovery	443.8–419.2
	Paleozoic	Ordovician (O)	Upper, Middle, Lower	485.4–443.8
	Paleozoic	Cambrian (C)	Furongian, Miaolingian, Series 2, Terreneuvian	538.8–485.4
Proterozoic	Neoproterozoic (Z)	Ediacaran, Cryogenian, Tonian	n/a	1,000–538.8
	Mesoproterozoic (Y)	Stenian, Ectasian, Calymmian	n/a	1,600–1,000
	Paleoproterozoic (X)	Statherian, Orosirian, Rhyacian, Siderian	n/a	2,500–1,600
Archean	Neo-, Meso-, Paleo-, Eo-archean	n/a	n/a	4,000–2,500
Hadean	n/a	n/a	n/a	4,600–4,000

[A] Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2022).

Items in parentheses in the geologic map units table and geologic time scale include GRI map abbreviations for geologic time units (see "Geologic Map Units" column in Table 2; see "Period" or "Epoch" columns in Table 3). For example, "**O**" in a map unit symbol means that a map unit was deposited during the Ordovician Period (approximately 485.0 million to 444.0 million years ago).

Accompanying lowercase letters of a map unit symbol indicate the name of a map unit, such as "**rtz**" for Rocky Tucks Zone (**Ortz**).

The names of map units used in this table and throughout the report reflect the nomenclature used in the NPS GRI source maps (DeSimone 2015a, b), in addition to Kidd et al. (1995). In geologic terminology, a formation is the fundamental rock-stratigraphic unit, meaning it is mappable (at a particular scale), lithologically distinct (with respect to rock type and other characteristics such as color, mineral composition, and grain size) from adjoining strata, and has a definable upper and lower contact (surface between two types or ages of rock). A formation can be divided into "members" or combined into a "group." In the historical park area, the underlying geology has been intensely deformed, faulted, and sheared to a degree that the usage of rock-stratigraphic units is disregarded in favor of structural "zone" mapping (see "Bedrock and Surficial Geology Background"). Although the individual zones are not formally recognized by the USGS Geologic Names Lexicon ("Geolex," a compilation of names and geologic unit descriptions), the zonation names are capitalized; for example, the Mohawk River Zone (**Omrz**) and Troy Frontal Zone (**Otfz**) units of the Ordovician Cohoes Mélange. Table 2 contains a column for "Age," which provides geologic age ranges that follow the International Commission on Stratigraphy (2023).

Additionally, Table 2 has a column for "Geologic Events." By reading the "Geologic Events" column from bottom to top, a geologic history is provided. Detailed descriptions of geologic events and associated geologic features are provided in sections of this chapter. The "Location" column of the table lists examples of where a geologic event is represented in the historical park. Information in the geologic time scale, including timing of geologic events, is primarily from the geologic source maps (DeSimone 2015a, b), but also from Kidd et al. (1995), Dineen and Miller (2006), Karabinos et al. (2017), Macdonald et al. (2017), and Rayburn et al. (2018).

The historical park is in the Hudson Lowlands of the Valley and Ridge physiographic province, a low-relief region of eastern New York defined by the glaciated Hudson River Valley (Figure 15). Situated along the floodplains, bluffs, and uplands flanking the Hudson River, the historical park is surrounded by the Adirondack Mountains to the northwest, the Catskill Mountains to the southwest, and the Taconic Mountains to the east. The geologic history of the Hudson Lowlands encompasses events that date back to the Proterozoic Eon, over 541 million years ago (Isachsen et al. 2000). The bedrock underlying the region forms a series of faulted, northeast–southwest-trending ridges and valleys predominantly composed of early Paleozoic sedimentary rocks (Vigil et al. 2000; Cadwell et al. 2003). The Ordovician strata that underlie the historical park record several large-scale tectonic processes associated with the Taconic orogeny. The surficial geology is largely a product of more recent Pleistocene glaciations (the "Ice Age") combined with fluvial activity.

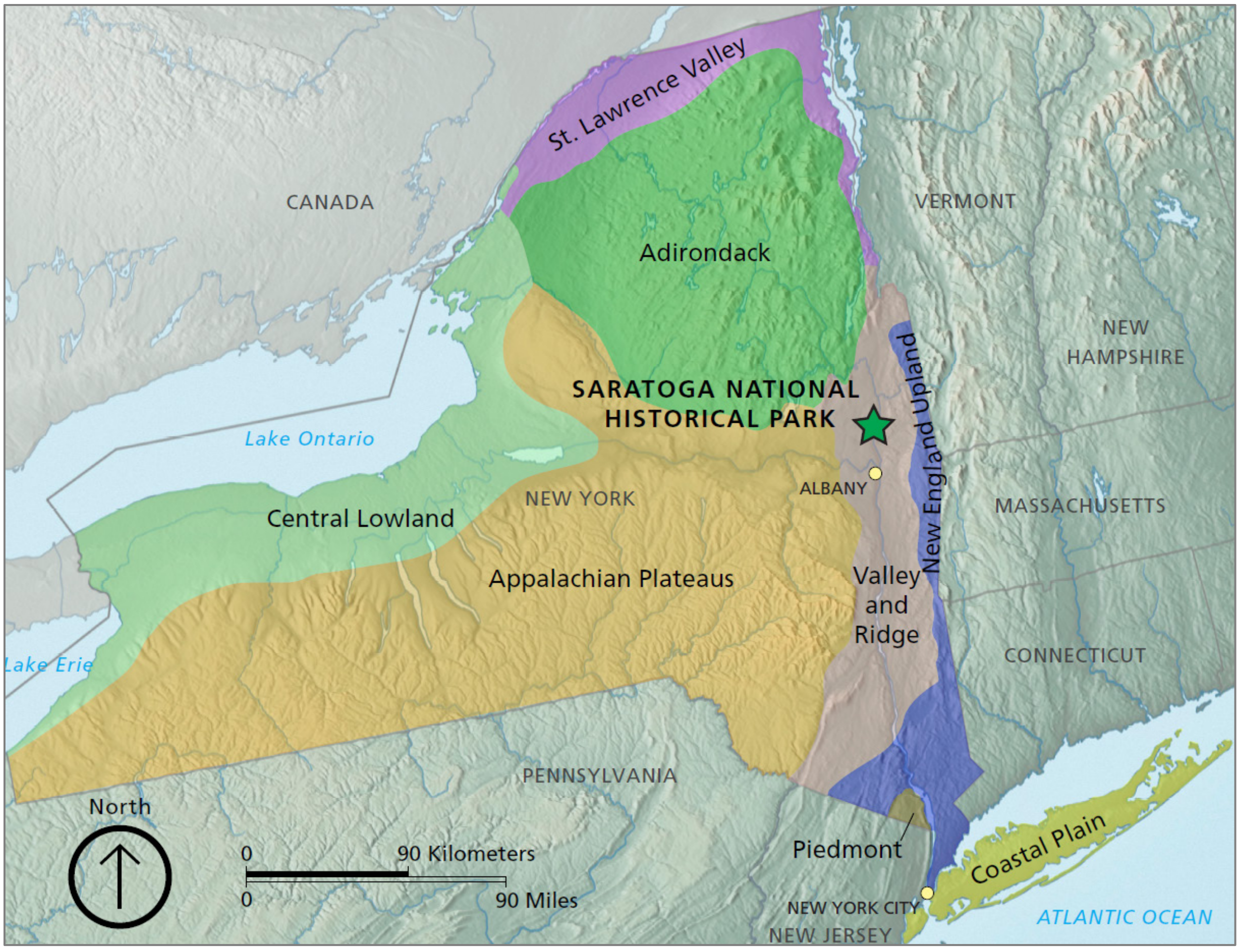

Figure 15. Physiographic province map of New York. The historical park is situated in the Hudson Lowlands of the Valley and Ridge physiographic province, a low-relief region defined by the glaciated Hudson River Valley. The approximate location of the historical park is denoted by the green star. Graphic created by Trista L. Thornberry-Ehrlich (Colorado State University) and modified from Fenneman and Johnson (1946).

Proterozoic Eon

Beginning in the Proterozoic Eon over 1 billion years ago, the ancient continent Laurentia (ancestral North America) existed in the southern hemisphere. The area of present-day New York was occupied by a tropical, shallow sea, and multi-celled organisms did not exist yet. Approximately 1.1 billion years ago, Laurentia collided with another continental landmass, resulting in a major mountain-building episode referred to as the Grenville orogeny (Isachsen et al. 2000; Karabinos et al. 2003). Compression during the Grenville orogeny deformed and thickened the crust, producing a mountain chain similar in scale to the modern Himalayan Mountains. The orogeny was one of several collisional events that led to the assembly of the ancient supercontinent Rodinia (the large single landmass that preceded Pangea; Isachsen et al. 2000; Li et al. 2008). Marine sedimentary, volcanic, and plutonic rocks that formed prior to and during the Grenville orogeny were buried about 30 km (19 mi) deep and were metamorphosed under increased temperature and pressure conditions. It took several hundred million years for erosion to slowly bring them to the surface (Isachsen et al. 2000).

Today, the highly deformed metamorphic rocks and igneous intrusions that are records of the Grenville orogeny underlie the eastern seaboard of North America. In New York, Grenville-age rocks form the Adirondack Mountains and Hudson Highlands, some of the oldest bedrock exposures in the state.

Continental-scale extension rifted the supercontinent Rodinia apart in the late Proterozoic, opening the ancient Iapetus Ocean and creating a passive continental margin along eastern Laurentia (Hurowitz and McLennan 2005; Li et al. 2008). A passive margin is characterized by a lack of activity such as collision, subduction, seismicity, or volcanism; present-day examples include the Atlantic and Gulf coasts of North America. During the late Proterozoic and early Paleozoic, the location of the Iapetus Ocean shoreline was further inland and closer to the historical park than the modern Atlantic coast (Figure 16a).

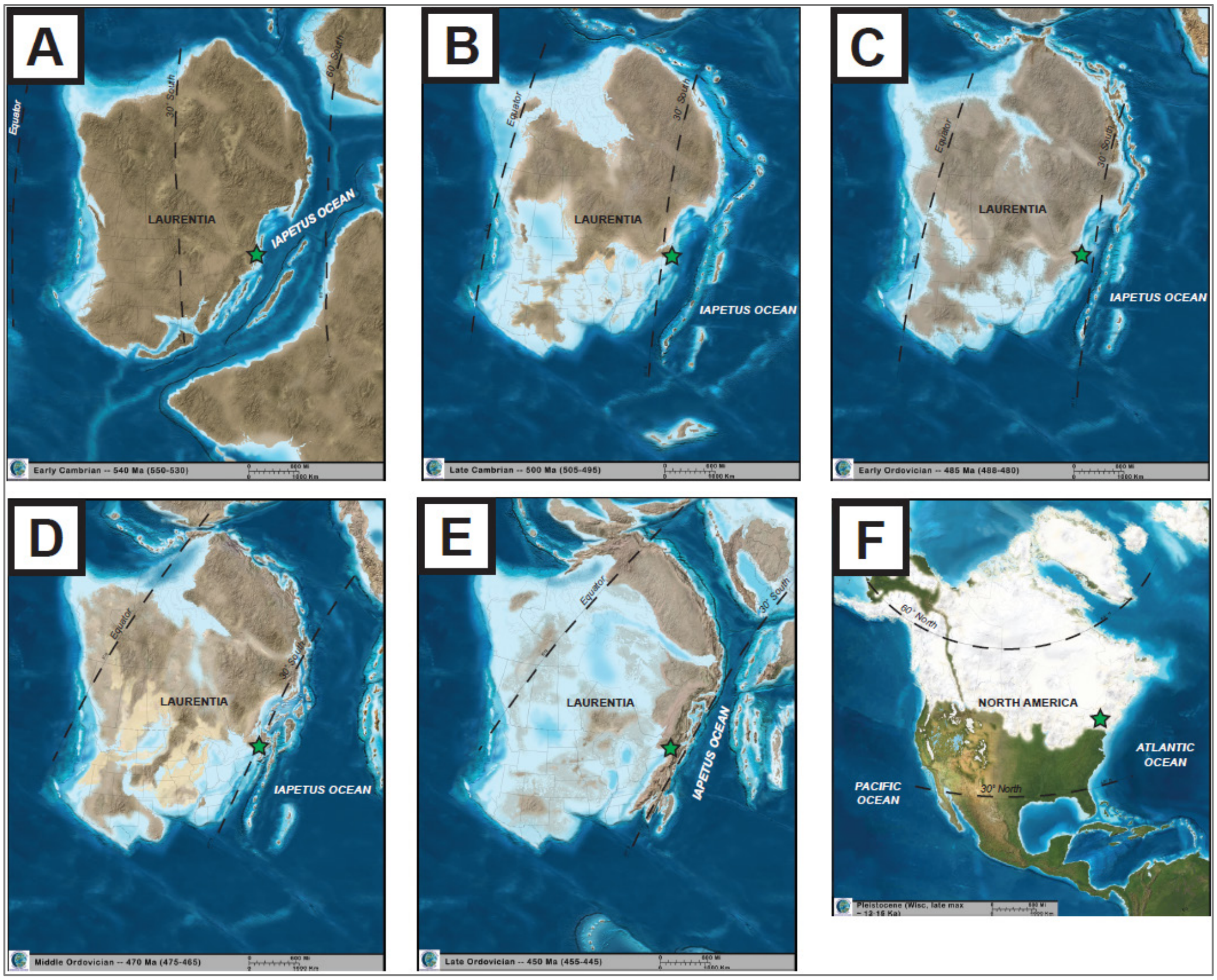

Figure 16. Paleogeographic reconstructions of North America emphasizing the tectonic events that shaped the historical park. The approximate location of the historical park is denoted by the green stars. (A) Early Cambrian (540 million years ago) passive margin development and the formation of the Iapetus Ocean following the break-up of the supercontinent Rodinia; (B) Late Cambrian (500 million years ago) extensive shallow marine carbonate shelf deposition and active margin development associated with the initial closing stages of the Iapetus Ocean; (C) Early Ordovician (485 million years ago) continued closure of the Iapetus Ocean and growth of an extensive volcanic island arc complex; (D) Middle Ordovician (470 million years ago) early collisional stages of the Taconic orogeny; (E) Late Ordovician (450 million years ago) deformation and thrust emplacement of the Taconic allochthon; and (F) Pleistocene late Wisconsinan glaciation (15,000 to 12,000 years ago) that scoured the landscape of Canada and the northern United States. North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc., modified by Tim C. Henderson (Colorado State University).

Paleozoic Era

In the Cambrian and Early Ordovician Periods (approximately 541 million to 475 million years ago), an active plate margin (a boundary characterized by abundant tectonic activity such as subduction, seismicity, volcanism, or collision) formed off the coast of Laurentia, which marked the initial closing stages of the Iapetus Ocean (Figure 16b and Figure 16c). During the early Paleozoic Era, carbonate deposition occurred across the shallow continental shelf of Laurentia, with coeval deep-water siliciclastic (sediments composed of rock fragments rich in silicate minerals) deposition further offshore on the continental slope and rise (Hurowitz and McLennan 2005). These shallow marine carbonates and sandstones are referred to as the Beekmantown Group, named after geologic exposures near the city of Beekmantown in northeastern New York (Clarke and Schuchert 1899). Carbonate rocks of the group's Cambrian Hoyt Limestone Member of the Little Falls Formation host the spectacular stromatolite reef fossils found at Petrified Sea Gardens, located about 18 km (11 mi) northwest of the Battlefield Unit (Landing et al. 2011). Correlative deep marine siliciclastic rocks deposited on the continental slope and rise are composed of shale, siltstone, sandstone, and limestone conglomerate of the Hatch Hill and Poultney formations (Landing et al. 1992; Isachsen et al. 2000; Macdonald et al. 2017).

By the Middle Ordovician, closure of the Iapetus Ocean led to the collision of Laurentia with a chain of volcanic islands, an event referred to as the Taconic orogeny (see "The Taconic Orogeny"; Rowley and Kidd 1981; Landing et al. 1992; Isachsen et al. 2000; Landing 2007). Oceanic and volcanic sedimentation occurred in the collisional zone, depositing what are now the greywackes (dark, poorly sorted sandstone with angular grains), shales, cherts, and minor ash beds of the Normanskill Group (Austin Glen, Mount Merino, and Indian River Formations) (Figure 16d; Rowling and Kidd 1981; Landing et al. 1992; Landing 2007). Prior to collision, accretionary wedge deposits that accumulated in front of the island arc were scraped up and structurally incorporated rocks of the continental slope and rise of Laurentia; today, this combined sequence of rock is known as the Taconic allochthon (**Octa**) (see Figure 6).

As the orogeny progressed, continental-scale compression thrust the Taconic allochthon onto the margin of Laurentia. Strata of the allochthon were compressed, faulted, and transported hundreds of kilometers west to their present location, where they now overlie shallow marine carbonate rocks of the Laurentian shelf (Figure 16e; Stanley and Ratcliffe 1985; Isachsen et al. 2000; Hurowitz and McLennan 2005). The addition of the allochthon caused the continental margin and shelf sediments to subside, forming an elongate foreland basin (structural depression) along the eastern edge of Laurentia. By the Late Ordovician, underthrusting (reverse faulting that displaces rocks of the footwall below a relatively passive hanging wall) of the continental margin beneath the accretionary prism produced a series of mountains that include the present-day Taconic Mountains. Weathering and erosion of these uplifted rocks shed sediments westward, infilling the trench and foreland basin with shales, siltstones, and turbidites now known as the Utica Shale, Schenectady Formation (**Os**), and Normanskill Group (Isachsen et al. 2000). According to previous maps of the historical park area, strata of the Normanskill Group and Utica Shale are considered the undeformed equivalents of the chaotic flysch and mélange structural zones underlying the historical park (see "Bedrock and Surficial Geology Background"). Further west of the historical park, the shale, siltstone, and greywacke of the Schenectady Formation are relatively undeformed and mark the western edge of the Taconic deformational belt (Kidd et al. 1995).

Cenozoic Era

The surficial geology within and surrounding the historical park consists of unconsolidated Quaternary (approximately 2.58 million years ago to present) deposits that partially bury or obscure older Paleozoic bedrock. During the Pleistocene Wisconsinan glaciation (about 75,000 to 11,000 years ago), continental glaciers associated with the Laurentide Ice Sheet advanced south across North America and regionally sculpted portions of Canada and the northern United States (see "Pleistocene Glaciation of the Hudson River Valley"). In New York, glaciers extended as far south as Long Island (Figure 16f; Stone et al. 2005). As the ice sheets migrated south, they scoured the landscape, eroding mountainous regions while widening and deepening lowland valleys. As the glaciers melted and retreated north, vast amounts of meltwater and glacial till (**Qtb** and **Qtv**) were released. The receding ice front created a series of glacial lakes that occupied the Hudson River Valley. Thick deposits of clay and silt (**Qlc**) accumulated along the deep lake bottoms, while tributary streams emptying into shallow lake margins constructed sand-dominated shorelines (**Qls**) and deltas consisting of gravel and sand (**Qld**). As the glacial lakes drained south through the Hudson River Valley, aeolian processes reworked the exposed lake sand and delta deposits to form dunes (**Qds**). During the late Pleistocene and Holocene Periods, fluvial incision incised and reworked the glacial, glaciolacustrine (glacial lake), and bedrock deposits to form ravine networks, river terraces (**Qft**), alluvial fans (**Qaf**), alluvium (**Qal**), and wetland muck (**Qm**).

Geologic Features and Processes

This chapter highlights geologic features and processes significant to the landscape and history of the historical park. Selection of these features and processes was based on input from the scoping and follow-up meeting participants, analysis of the GRI GIS data, and research of the scientific literature and NPS reports. These features and processes are discussed more-or-less in order of geologic age (oldest to youngest).

At the beginning of each of the following sections, surficial map units, which can be seen on the poster, are listed; these indicate which map units are discussed in each section. Although the GRI poster of Saratoga National Historical Park follows the surficial map of DeSimone (2015b), bedrock geologic units are also discussed here and shown in Figure 6. Map units are referenced directly in the text as well. Some sections may not be directly related to a map unit on the poster, in which case no unit is listed at the start of the section. The map units can also be viewed in the GRI GIS data.

Bedrock and Surficial Geology Background

The bedrock underlying the historical park consists of Ordovician sedimentary and metasedimentary rocks that are considered flysch and mélange deposits associated with the Taconic orogeny (see "The Taconic Orogeny"). Mapped along the western margin of the Taconic allochthon (**OCta**) is a major thrust fault system known as the Taconic Allochthon Thrust Fault (see Figure 6; see "Faults and Folds"). Adjacent to and west of the thrust system, flysch and mélange form a 16–20 km (10–12 mi) wide belt of deformed rock (Lim et al. 2005). Due to structural complications and a lack of properly defined stratigraphy, the deformational belt is subdivided into unique "zones" based on lithology, structure, and assemblages of incorporated fragmented blocks (Bosworth and Vollmer 1981; Bosworth 1982; Kidd et al. 1995; Lim et al. 2005). It has been speculated that each zone is bounded by thrust faults and highly likely to contain internal fault structures (Plesch 1994; Kidd et al. 1995; Landing et al. 2003; English et al. 2006). The westernmost extent of the highly deformed rocks is referred to as Ruedemann's Line, which lies east of Saratoga and west of the Mohawk River Zone (**Omrz**; Jacobi and Mitchell 2018). A progressive west-to-east increase in deformational style is recorded across the belt, with the highest degree of faulting, folding, shearing, mélange formation, and foliation (repetitive layering in metamorphic rocks) occurring in rocks immediately adjacent to the Taconic Allochthon Thrust Fault (Cushing and Ruedemann 1914; Bosworth and Vollmer 1981; Vollmer and Bosworth 1984; Lim et al. 2005).

According to the bedrock GRI GIS data (DeSimone 2015a), the geologic units mapped within and surrounding the historical park that are considered flysch deposits include the Rocky Tucks Zone (**Ortz**), the Stillwater Shale Zone (**Ossz**), the Vischer Ferry Zone (**Ovfz**), and the Halfmoon Greywacke Zone (**Ohgz**). Bedrock layers interpreted to be mélange deposits include the Mohawk River Zone (**Omrz**), the Troy Frontal Zone (**Otfz**), and the Waterford Flysch Zone (**Owfz**; see Figure 6; DeSimone 2015a). Interestingly, although named "Flysch Zone," the **Owfz** is considered a flysch-dominated mélange (Plesch 1994; Kidd et al. 1995). Geologic units mapped within the administrative boundaries of the historical park are discussed in detail in the remaining sections of this chapter.

The geology surrounding the Taconic orogenic belt is complex and has been interpreted in many ways since the early 20th century. Prior to flysch and mélange zone mapping of the upper Hudson River Valley (Vollmer and Bosworth 1984; Plesch 1994; Kidd et al. 1995; DeSimone 2015a), previous geologic maps of the region (Cushing and Ruedemann 1914; Ruedemann and Cook 1930; Fisher et al. 1970) applied stratigraphic formation names to the bedrock underlying the historical park. However, stratigraphic names and ages within the deformed flysch-mélange belt of the upper Hudson River Valley are misinterpreted for several reasons: (1) difficulty in deciphering the ages of blocks and matrices in a recycled, tectonic sedimentary unit; (2) structural complexities (i.e., folds, faults, exotic blocks) associated with the Taconic orogeny; (3) the application of biostratigraphic names to inadequately defined lithic units; and (4) a veneer of Pleistocene surficial deposits (Bosworth and Vollmer 1981; Bosworth 1982; Plesch 1994; Kidd et al. 1995).

According to Fisher et al. (1970) and Kidd et al. (1995), most of the historical park underlain by the Mohawk River Zone (**Omrz**) was previously interpreted as marine sedimentary rocks (shale, slate, and chert) of the Ordovician Mount Merino and Indian River Formations. Similarly, the Rocky Tucks Zone (**Ortz**) flysch that forms the upland regions along the western boundary of the battlefield was regarded as greywacke and turbidite deposits of the Ordovician Austin Glen Formation. Together, the Mount Merino, Indian River, and Austin Glen Formations comprise the Normanskill Group, a sequence of strata that record and corroborate the gradual approach and collision of a volcanic arc terrane with the margin of Laurentia (Rowley and Kidd 1981; Landing 1988, 2007; Landing et al. 1992). Along the Hudson River, the floodplain and river corridor underlain by the Stillwater Shale Zone (**Ossz**) were previously interpreted as the Ordovician Utica Shale.

According to the surficial GRI GIS data, the surficial geology of the historical park consists of Quaternary glacial, glaciolacustrine, and fluvial (river) deposits that predominantly overlie and obscure any older bedrock. Glacial and glaciolacustrine deposits were formed throughout the ancestral Hudson River Valley during the Wisconsinan glaciation, the most recent Ice Age event of the Pleistocene (see "Pleistocene Glaciation of the Hudson River Valley"). As the climate warmed and the ice sheets retreated north, an immense amount of glacial till (**Qtv**) was released that blanketed the landscape. Meltwater produced by the receding ice produced several ancient lake basins that accumulated thick, unconsolidated sedimentary deposits, including lake sands (**Qls**) and clays (**Qlc**). During the late Pleistocene and Holocene Periods, fluvial erosion associated with the Hudson River and its tributaries incised river terraces (**Qft**) and reworked older sedimentary deposits to form alluvial fan (**Qaf**), alluvium (**Qal**), and wetland muck (**Qm**) deposits.

Flysch Deposits

Rocky Tucks Zone (bedrock map unit Ortz)

The Rocky Tucks Zone (**Ortz**) is a greywacke-rich flysch (a term used to describe a thick succession of reworked, redeposited marine strata formed during an orogenic event) that contains significantly less shale compared to the adjacent Mohawk River and Stillwater Shale Zones. The zone is an elongate, narrow lens of resistant rock that forms the uplands along the western boundary of the Battlefield Unit. The Rocky Tucks Zone is comparable to the Halfmoon Greywacke Zone (**Ohgz**), as both are lens-shaped, greywacke-dominated flysch zones that form prominent upland ridges adjacent to the mélange (a mappable, internally fragmented, and mixed body of rock containing a variety of blocks commonly set in a pervasively deformed matrix) of the larger Mohawk River Zone (**Omrz**). Ridges within the Rocky Tucks and Halfmoon Greywacke Zones are typically oriented in a north–northeastern direction that mimics the general structural trend of the surrounding rocks.

The phrase "rocky tucks" has historically been applied to a region of extremely rough topography surrounding the town of Stillwater, northwest of the visitor center (Cushing and Ruedemann 1914). The Rocky Tucks Zone encompasses this rugged area and consists of folded, broken greywacke flysch beds that form closed synclines (basins) and closed anticlines (domes). Some of these beds were previously quarried for building stone north of the Battlefield Unit near Quaker Springs. A comparison of bedrock and hillshade data reveals a strong spatial relationship between the Rocky Tucks Zone and the drumlin field (**Otv**) located west of the Battlefield Unit (see Figure 6).

To explain the occurrence of bedded flysch (e.g., Rocky Tucks and Halfmoon Greywacke Zones) within mélange, Plesch (1994) proposed four possible mechanisms to identify flysch zones, such as **Ortz** and **Ohgz**: (1) they are outliers of the Taconic allochthon; (2) they are blocks of flysch in mélange; (3) they are thrust slices within mélange; or (4) they are deformed lower slope basin deposits (see Plesch 1994 for more details). However, it is possible that the Rocky Tucks and Halfmoon Greywacke Zones represent large-scale, greywacke-rich boudinage structures. The term "boudinage" refers to the weakening and fracturing of a sedimentary rock sequence due to deformation, shearing, and ductility (the ability of a rock to deform without breaking). In the process of forming mélange (e.g., the Mohawk River Zone), progressive thrust faulting and shearing of less ductile greywacke and siltstone beds can lead to isolated blocks of flysch enclosed within mélange (Bosworth 1982; Vollmer and Bosworth 1984; Kidd et al. 1995; Lim et al. 2005).

Stillwater Shale Zone (bedrock map unit Ossz)

The Stillwater Shale Zone (**Ossz**) is a shale-rich flysch that contains only minor amounts of greywacke. Within the historical park, the zone underlies the low-lying Hudson River floodplain at the Battlefield Unit and Schuyler Estate. In the Hudson Lowlands region of New York, the present course of the Hudson River is governed by the underlying bedrock and generally flows along weak belts of shale-rich strata west of the Taconic Mountains (Johnsen 1976). According to the source map by De Simone (2015a), the deeper portion of the Hudson River pre-glacial valley follows the trend of the Stillwater Shale Zone and is referred to as the Battenkill-Hudson Channel. The weaker, shale-rich flysch of **Ossz** underlies a 26 km (16 mi) section of the pre-glacial Battenkill-Hudson Channel in addition to the modern Hudson River (see Figure 6).

Although bedrock exposures of the Stillwater Shale Zone are not located within the historical park, notable outcrops exist along the eastern side of the Hudson River, directly across from the Battlefield Unit. Extending along County Road 113, these exposures form dissected ravines and terraces that can be viewed from the river bluffs near the Great Redoubt (surficial map unit "**r**"; see poster).

Mélange Deposits

Cohoes Mélange (bedrock map units Omrz, Otfz, and Owfz)

The Cohoes Mélange was proposed by Kidd et al. (1995) and named after distinct rock exposures along the cliffs and riverbank of the Mohawk River near Cohoes Falls, approximately 24 km (15 mi) south of the historical park. The mélange is a chaotic sequence of recycled sedimentary rock derived from thrusted flysch and strata of the Taconic allochthon. Primarily composed of deformed dark gray shale or siltstone, the mélange also contains fragmented blocks of greywacke and less common "exotic" blocks of carbonate rock, chert, and mudstone (Lim et al. 2005). Several major linear zones of mélange are associated with the Cohoes Mélange, including the Mohawk River Zone (**Omrz**), the Troy Frontal Zone (**Otfz**), and the Waterford Flysch Zone (**Owfz**; see Figure 2 of Kidd et al. 1995). Of these, only the Mohawk River Zone is within the historical park.

Mohawk River Zone (bedrock map unit Omrz)

The Mohawk River Zone (**Omrz**; formerly the "Mohawk River Central Zone" of Kidd et al. 1995) underlies a majority of the historical park and consists of mélange dominated by shale with some minor greywacke. This mélange zone forms the bedrock in all four parcels of the Old Saratoga Unit and is mapped along the uplands west of the Hudson River at the Battlefield Unit (see Figure 6). The greywacke-rich intervals of the Mohawk River Zone are of intermediate resistance to erosion and form elevated ridges commonly obscured by a surficial veneer of Pleistocene glacial deposits. Within the historical park, bedrock exposures of the Mohawk River Zone are in the following areas: (1) in the Great Ravine of the Kroma Kill in the northern Battlefield Unit; (2) in the northwest corner of the Schuyler Estate along Fish Creek; and (3) along the eastern Saratoga Surrender Site. These exposures are denoted by the map unit "**r**" in the surficial GRI GIS data (see poster). Additional, unmapped bedrock exposures occur along portions of Mill Creek and the Middle Ravine.

The Mohawk River Zone occupies the middle of the deformed Taconic flysch-mélange belt and contains several notable structural features. According to the bedrock GRI GIS data (DeSimone 2015a), the Mohawk River Zone encompasses two narrow flysch zones along the western Battlefield Unit (Rocky Tucks Zone [**Ortz**]), as well as south of the historical park near Mechanicsville (Halfmoon Greywacke Zone [**Ohgz**]). The contacts between these zones are likely thrust faults (Kidd et al. 1995). Additional structural features within the Mohawk River Zone include a significant occurrence of rock fragments or blocks; those blocks were distributed throughout the mélange as Taconic thrusting fragmented and mixed several lithologies together. Except for Stark's Knob, all known blocks are sedimentary rocks tectonically derived from formations of the Taconic allochthon sequence (Kidd et al. 1995).

<u>Stark's Knob</u>

Immediately north of the Old Saratoga Unit parcels, the mélange of the Mohawk River Zone contains a notable and unique geologic feature referred to as Stark's Knob. Named after American Gen. John Stark, Stark's Knob is a conspicuous hill composed of pillow basalt (submarine volcanic rock) and lava tubes that overlooks the Hudson River (see Figure 6 and Figure 17). Measuring approximately 125 m (400 ft) long and 39 m (130 ft) high, Stark's Knob stands out topographically and lithologically against the surrounding bedrock, which is comprised of pervasively deformed shale

(Vollmer and Bosworth 1984; Landing et al. 2003). During the American Revolution, Stark's Knob was strategically occupied by Stark and his men to prevent the northward retreat of Lt. Gen. Burgoyne's forces following the Battles of Saratoga (see "Burgoyne's Surrender"; Cushing and Ruedemann 1914; Piper 1985; Stevens et al. 2007). After the war, Stark's Knob was quarried for building stone, which removed the eastern portion of the knob and exposed a section through the basalt (Cushing and Ruedemann 1914; Landing et al. 2003).

Figure 17. Photograph of Stark's Knob. Stark's Knob is a volcanic feature consisting of pillow basalt and lava tubes that occurs within the Mohawk River Zone (Omrz) about 2.5 km (1.5 mi) north of the Schuyler Estate. The conspicuous knob stands nearly 39 m (130 ft) tall and is named after American Gen. John Stark. Following the Battles of Saratoga, Gen. Stark and his men occupied the strategic high ground of the knob to prevent the northerly retreat of British forces. Note the flagpole at the top left of the photo. Photograph courtesy of Dr. Richard Allmendinger (Cornell University).

Although Stark's Knob has been discussed in numerous publications (Cushing and Ruedemann 1914; Bosworth and Vollmer 1981; Vollmer and Bosworth 1984; Piper 1985; Kidd et al. 1995; Landing et al. 2003; Landing 2022), its origin and relationship to the surrounding sedimentary rocks have been a matter of debate. One interpretation explains Stark's Knob as an exotic block that was structurally incorporated into the Taconic flysch-mélange belt during westward thrusting (Bosworth 1982; Vollmer and Bosworth 1984; Kidd et al. 1995). Mapping of several thrust faults in the vicinity of Stark's Knob—including the Stark's Knob Thrust of Bosworth and Kidd (1985)—supports the exotic block model. However, geochemical and petrographic analyses by Landing et al. (2003) indicate that Stark's Knob is a normal mid-ocean ridge basalt that formed during the Taconic orogeny as molten rock was extruded along fractures in the seafloor. According to this model, the subduction of Laurentian oceanic crust along the outer trench slope created flexural extension that facilitated volcanism. In contrast to the exotic block model, Landing et al. (2003) and Landing (2022) conclude that Stark's Knob is part of a small volcanic edifice (a seamount) that formed relatively *in situ* (in the original position) and was later overprinted (tectonically obscured) by Taconic thrusting.

Glacial Features and Processes

The surficial geology of the historical park predominantly consists of glacial deposits and features including till (**Qtv**), drumlins, striations (linear grooves carved into rock surfaces by mobile ice sheets), and thick sequences of glacial lake sediments (Thornberry-Ehrlich 2008). During the Pleistocene, the Hudson River Valley was covered by vast sheets of ice that carved the underlying bedrock to widen and deepen the ancestral river corridor. The upper Hudson River Valley region of the historical park once hosted a series of ancient glacial lakes that formed along the receding front of the Laurentide Ice Sheet. These lakes were named after nearby cities and include (from oldest to youngest): Glacial Lake Albany, Glacial Lake Quaker Springs, and Glacial Lake Coveville (see "Pleistocene Glaciation of the Hudson River Valley").

Till, thin or veneer (surficial map unit Qtv)

Till (**Qtv**) refers to an unsorted and unstratified deposit of glacial origin consisting of a range of clast sizes, including clay, silt, sand, and gravel. Akin to frozen sandpaper, the advance and retreat of continental glaciers across New York during the last Ice Age beveled the geologic landscape and eroded an immense amount of underlying bedrock. Abraded rock material was entrained, transported, and later deposited by glaciers as they melted. Till deposits (**Qtv**) are less than 3 m (10 ft) thick and are commonly eroded to reveal the underlying Ordovician bedrock; this is especially true along Fish Creek near the Schuyler Estate and Victory Woods (DeSimone 2015b; see poster).

Within and surrounding the historical park, glacial till is widely distributed along both sides of the Hudson River and typically forms the upland regions adjacent to the low-lying floodplain. Till is mapped across the western half of the Battlefield Unit, where it forms drumlins and hills, including those that underlie the visitor center, Freeman Farm Overlook, Barber Wheatfield Overlook, Chatfield Farm, Freeman Farm, Neilson Farm, Breymann Redoubt, and Balcarres Redoubt (see poster; see Table 1; DeSimone 2016; Rayburn et al. 2018). The visitor center was constructed on the crest of a till mound that provides scenic battlefield views and forms the highest topographic point in the historical park (Oudemool et al. 2002). At the Old Saratoga Unit, glacial till deposits form the steep slopes flanking Fish Creek along the eastern boundary of Victory Woods. High angle slopes consisting of till are considered unstable, and mass wasting events such as slides are common (De Simone 2015b; see "Geologic Resource Management Issues"). Till deposits also form part of the gently undulating topography underlying the western Saratoga Surrender Site, immediately south of the Fish Creek-Hudson River confluence.

Lake Clay (surficial map unit Qlc)

Fine-grained, thinly laminated or varved (seasonally deposited sedimentary layers in a still body of water) lake clay and silt sediments (**Qlc**) are widely distributed along the Hudson River and represent exposed Pleistocene lake deposits of ancient Glacial Lake Albany, Glacial Lake Quaker Springs, and Glacial Lake Coveville. Lacustrine clays and silts were deposited along the deep bottom plain of the former glacial lake basins. According to the GRI source map (De Simone 2015b), these lake sediments are the thickest, most widely mapped surficial deposit in the area, and acquire a thickness exceeding 30 m (100 ft) along the axis of the low-lying Hudson River Valley. Borehole data from within the historical park corroborate this thickness, with one well penetrating approximately 31 m (101 ft) of clay before encountering bedrock (Figure 18; Heath and Tannenbaum 1963). Lake silts and clays overlie and obscure older till deposits (**Qtb, Qtv**) and bedrock (**r**), except in areas where these units are positioned above a former lake bottom (see poster).

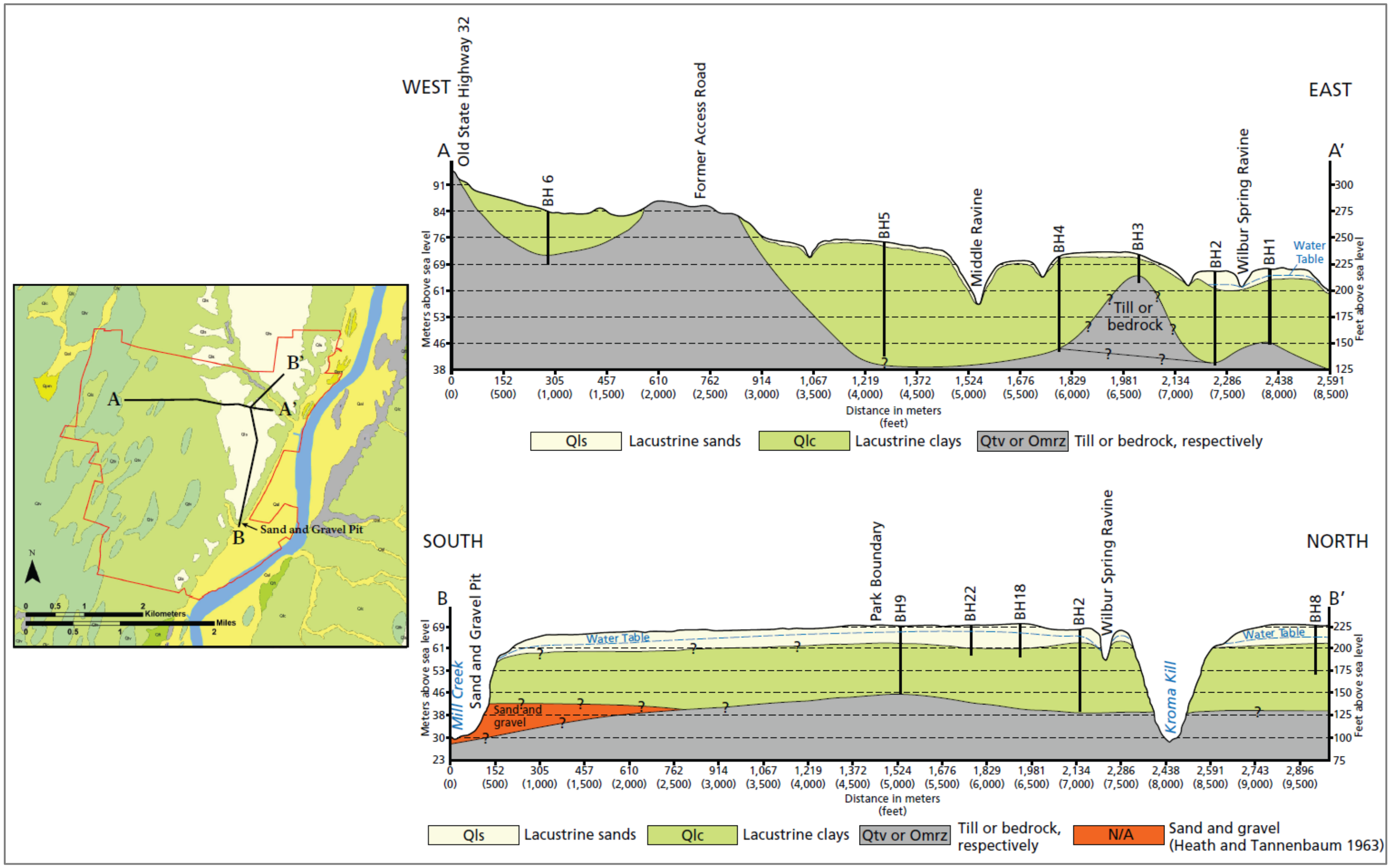

Figure 18. Geologic cross sections in the Battlefield Unit. Cross sections were constructed using borehole data (e.g., "BH5" is borehole #5) and outcrop observations. Question marks indicate areas of inferred stratigraphy based on limited data. Profile A–A′ shows the irregular, undulating contact between till or bedrock and overlying lacustrine clay deposits. When Glacial Lake Albany occupied the Hudson River Valley, these clays were draped on top of pre-existing glacial topography and capped by lacustrine sands as lake levels receded. In profile B–B′, lacustrine clays underlie a significant portion of the bluffs along the Hudson River and serve as an impermeable hydrologic barrier that influences the local water table, including springs and seeps. Incision along the Kroma Kill and Mill Creek reveals some of the few bedrock exposures in the park. According to Heath and Tannenbaum (1963), an isolated outcrop of cross-bedded sand containing lenses of gravel (not in the GRI GIS data) is located at a pit exposure near the intersection of US Route 4 and Mill Creek. Figure created by Tim C. Henderson and Trista L. Thornberry-Ehrlich (Colorado State University) using figures III-1 and III-6 from Heath and Tannenbaum (1963).

Within the historical park, clay and silt sediments form the steep river bluffs that rise above the adjacent floodplain in the Battlefield Unit. During the Battles of Saratoga, these fine-grained deposits were instrumental to the American strategy and defensive positions at Bemis Heights (see "The Battle of Freeman's Farm and the Battle of Bemus Heights"). Across the battlefield landscape, lacustrine clays and silts have been heavily dissected by Mill Creek and the Kroma Kill to form a network of steep-sided ravines, including the Great Ravine and Middle Ravine (Figure 19). The presence of these fine-grained sediments plays a major role in the occurrence of groundwater or runoff, as these deposits impede the downward percolation of water (see "Springs and Seeps"). The clay-rich nature of these deposits makes them susceptible to erosion, gullying, and mass wasting events such as landslides, especially in areas of high-angle topography (see "Mass Wasting along the Hudson River").

Figure 19. Photograph of the Middle Ravine of Mill Creek within the Battlefield Unit. Since the end of the last Ice Age, Mill Creek has been carving out lake clay deposits (Qlc), which form the upper slopes of the ravine. The creek bed and lower portions of the ravine contain scattered outcrops of Ordovician bedrock (r). During the Battles of Saratoga, ravine networks were strategically used for defensive positions, to conceal troop movements, and to slow enemy advances. Photograph taken by Matt Harrington (Colorado State University).

Lake Sand (surficial map unit Qls)

Pleistocene lake sand deposits (**Qls**) consist of laminated, well-sorted, fine- to medium-grained sand that accumulated in shallower portions of the glacial lake basins. At the Battlefield Unit, lacustrine sand overlies and caps sections of the clay-rich river bluffs (**Qlc**) stretching from Bemis Heights to the Great Redoubt. According to borehole data, the thickness of these sand deposits varies from 0.3–0.6 m (1–2 ft) at its western margin to over 7 m (25 ft) near the head of the Wilbur Spring ravine east of Burgoyne's headquarters (see Figure 18; Heath and Tannenbaum 1963). The geologic configuration of porous sand overlying impermeable clay and silt has created several spring horizons that may have been used during the Battles of Saratoga (see "Geology and the Battles of Saratoga" and "Springs and Seeps"; Heath and Tannenbaum 1963; Vana-Miller et al. 2001). In the Old Saratoga Unit, lake sand underlies the Saratoga Monument and overlies the steep slopes of the Victory Woods parcel (see poster). Some of these sandy deposits include minor, stabilized sand dunes that were utilized by Morgan's Corps during the siege of Burgoyne's forces (Johnson and Reichert 2002; National Park Service 2004). The relatively unconsolidated nature of the lacustrine sand deposits makes them prone to gullying and headward erosion (see "Mass Wasting along the Hudson River").

Historically, the presence of lake sand helped determine the locations of cemeteries and burial sites within and surrounding the historical park. Several burial sites occur in sandy areas at the top of the bluffs and along the uplands flanking the Hudson River. South of the Battlefield Unit, the former Bemis Heights cemetery was where many historic settlers (including the John Neilson family) were buried. The location of the cemetery was close to the intersection of NY Route 32 and US Route 4 in an area where lake clays transitioned into sand-dominated deposits (Linda White, Saratoga National Historical Park, personal communication 23 October 2023). North of the Battlefield Unit are several additional cemeteries underlain by lake sand, including the Gerald B. H. Solomon Saratoga National Cemetery.

In the northern portion of the Battlefield Unit, lake sand deposits were mined in the 19th and early 20th centuries. These mining operations have impacted the historical park's topography, drainage, and resources (see "Disturbed Lands").

Sand and Gravel (surficial map unit N/A)

In the Battlefield Unit, there is a documented occurrence of unique sand and gravel deposits that are not included in the GRI GIS data. According to a groundwater resources report by Heath and Tannenbaum (1963), a pit exposure located a few hundred feet north of where US Route 4 crosses Mill Creek consists of sand and gravel overlain by lacustrine clay (**Qlc**) and sand (**Qls**) deposits (see Figure 18). The thickness of the sand and gravel unit is unknown, as the bottom of the deposit is not exposed. The complete pit exposure consists of three layers (in ascending order): (1) fine- and medium-grained, cross-bedded sand with lenses of gravel, 11+ m (36+ ft thick); (2) thin-bedded, brown to gray clay, 14 m (47 ft) thick; and (3) fine-grained, orange sand, 1.2 m (4 ft) thick (Heath and Tannenbaum 1963). Unlike the other unconsolidated surficial deposits, the sand and gravel deposits appear to be restricted to this outcrop and have not been encountered in any of the boreholes drilled throughout the historical park. Further investigation of this unit is merited, as it may represent the oldest stratified deposit to overlie till or bedrock within the park and could shed additional insight into the glacial history of the area.

Erratics (surficial map unit N/A)
Although not depicted as part of the GRI GIS data, large boulders of glacial origin, referred to as erratics, occur in association with Pleistocene glacial till deposits (**Qtv**). Erratics are large blocks of underlying bedrock that were plucked, transported, and deposited far away (sometimes hundreds to thousands of miles) from their point of origin by glaciers.

Fluvial/Colluvial Features and Processes

The Hudson River and its Tributaries
The predominant natural feature of the historical park's landscape is the Hudson River, an integral water resource that has long nurtured human settlement by providing sustenance, transportation, and a means for conducting trade (Johnsen 1976). In addition, the Hudson River played a fundamental role in the British strategy to divide and conquer the American colonies during the American Revolutionary War. From a geologic perspective, the Hudson River is the most dynamic geomorphologic feature of the historical park, as it drains the landscape, transports sediments and vital nutrients, and slowly reshapes the region through erosion and deposition. The configuration of the modern Hudson River fluvial system is a result of previous Pleistocene glaciations that scoured, widened, and deepened the ancestral river valley, combined with erosional processes that continue to carve steep slopes, terraces, and bluffs. In the low-lying valley, the present course of the river is governed by the underlying geology and generally flows along weak belts of shale located between the Catskill and Taconic Mountains (Johnsen 1976).

Occasional flooding events pose a significant risk to the resources of the historical park situated in the low-elevation floodplain adjacent to the Hudson River. Approximately 12% of the total park acreage is floodplain, some of which resides within the 100-year flood zone of the Hudson River, a designation that predicts a given area will experience at least one major flood recurrence every century (or a 1% annual chance) (see "Flooding along the Hudson River"; Wagner et al. 2014). Additionally, polluted water and fluvial sediments within the Hudson River expose historical park resources to polychlorinated biphenyls (PCB) contamination, especially along floodplain and wetland environments periodically exposed to floodwaters (see "Hudson River Contamination Issues").

In the historical park, approximately 13 km (8 mi) of perennial streams flow toward the Hudson River (Gawley and Dieffenbach 2016). Since the last Ice Age, these tributaries have dissected thick sequences of Pleistocene lake deposits to form a network of ravines and gullies while redistributing sediments into the floodplain. These erosional features helped define the battlefield landscape and played a major role in the Battles of Saratoga as well as in the final days leading to the surrender of Lt. Gen. Burgoyne's forces. At the Battlefield Unit, the Great Ravine (of the Kroma Kill) and the Middle Ravine (of Mill Creek) were utilized for defensive positions, to conceal troop movements, and to purposely slow the advance of the British. Along the southern portion of the battlefield, Devil's Hollow (historically referred to as S. Ravine or Great Fall Creek) and American's Creek are two locally recognized perennial streams that drain the uplands of Bemis Heights (Starbuck 1988; Gawley and Dieffenbach 2016). Devil's Hollow is a deeply eroded gorge that reaches a maximum depth of approximately 25 m (80 ft) and features hemlock-laden waterfalls (Vana-Miller et al. 2001; Wagner et al. 2014). Stream incision that formed the ravine networks of the Battlefield Unit has revealed several groundwater spring horizons where porous sand deposits (**Qls**) overlie impermeable clays and silts (**Qlc**); some of these springs are potentially historic and may have provided valuable sources of water during the battles (Heath and Tannenbaum 1963; Vana-Miller et al. 2001).

North of the Battlefield Unit, Fish Creek drains Saratoga Lake and flows east between the four non-contiguous parcels of the Old Saratoga Unit. The Victory Woods site is situated along the northern embankment of Fish Creek and preserves a portion of the final defensive positions held by the British. Following a hasty retreat north after their defeat at the Battle of Bemus Heights, Burgoyne's army fortified the ground above Fish Creek, a high plateau later referred to as the "Heights of Saratoga" (Stevens et al. 2007). The British encampment sat approximately 75 m (250 ft) above the confluence of Fish Creek and the Hudson River and had a commanding view of the adjacent floodplain. Although the high ground flanking Fish Creek provided reasonable defense for the British, they lacked supplies and were significantly outnumbered, surrounded, and trapped by the American Continental Army (Oudemool et al. 2002).

Pre-glacial Bedrock Channels

According to the GRI bedrock source map (DeSimone 2015a), several pre-glacial bedrock channels (buried, glacially scoured valleys) are located along the upper Hudson River Valley. These older channel features existed prior to the modern fluvial landscape and are evidence of ancient drainage networks that experienced multiple stages of fluvial and glacial erosion (Dineen and Hanson 1983). One of these channels, the Battenkill-Hudson Channel, is mapped along the eastern boundary of the Battlefield Unit and follows the course of the modern Hudson River (DeSimone 2015a). Glacial Lake Fort Ann, one of the glacial lakes that occupied the Champlain Valley north of the historical park about 11,700 years ago, exhumed the channel (Connally and Cadwell 2002; Rayburn et al. 2018). The excavation of the pre-glacial channel by Fort Ann flood waters was first recognized by Woodworth (1905). North of the main battleground, the Battenkill-Hudson Channel splits into two separate tributaries: (1) the Fort Ann Branch that flowed south and adjacent to the Old Saratoga Unit; and (2) the Battenkill Branch that flowed west from Greenwich (DeSimone 2015a). West of the historical park are additional pre-glacial bedrock channels associated with Saratoga Lake (Colonie Channel, Kayderosseras Branch, Lake George Branch, and Fish Creek Branch) and Round Lake (East Line or Anthony Kill Branch) (see Figure 6; DeSimone 2015a).

Fluvial Terraces (surficial map unit Qft)

Fluvial terraces (**Qft**) consist of the silt, fine sand, and gravel of older floodplains left stranded above the current river corridor. Terraces generally form flat to gently sloping deposits less than 5 m (16 ft) thick that overlie alluvium (**Qal**), lacustrine clay (**Qlc**), lake delta (**Qld**), lake sand (**Qls**), and bedrock (**r**) units (De Simone 2015b). According to the surficial GRI GIS data (DeSimone 2015b), fluvial terraces are mapped within and surrounding the historical park along the Hudson River, Fish Creek, Batten Kill, and the Hoosic River. At the Schuyler Estate, terraces occur near the Fish Creek-Hudson River confluence and underlie the Schuyler house (see poster).

Alluvial Fan (surficial map unit Qaf)
Alluvial fan deposits (**Qaf**) consist of poorly sorted silt, sand, and gravel that were originally deposited along tributary streams and at the base of steep slopes. A combination of weathering, erosion, and gravity reworked the previously deposited material into an apron of unconsolidated rock material. Within the historical park, several alluvial fans are located in the Battlefield Unit along the Hudson River bluffs adjacent to the Great Redoubt (see poster).

Alluvium (surficial map unit Qal)
Alluvium deposits (**Qal**) consist of unconsolidated sediments (clay, silt, sand, gravel) along the floodplains of the Hudson River, Hoosic River, and their tributaries (see poster). These low-lying stream valleys and floodplain environments are susceptible to flooding, which presents several hazards. Additionally, the occurrence of quicksand has been reported along floodplain areas mapped as alluvium deposits (see "Geologic Hazards").

Wetland Features and Processes
Forty-nine wetlands cover about 70 ha (175 ac) of the historical park, all of which are dominated by persistent vegetation and considered critical to the health and success of the park's biological communities (Tiner et al. 2000; Oudemool et al. 2002; Wagner et al. 2014; National Park Service 2021a). These hydrodynamic environments are diverse and include forested wetlands, marshes, wet meadows, ponds, mixed stands of forest-shrub wetlands, and a small, farmed wetland (National Park Service 2004). According to Tiner et al. (2000), 15 of the 49 wetlands were considered significantly impacted by human activities such as excavation, impoundment, partial drainage, or road fragmentation.

Muck (surficial map unit Qm)
Muck deposits (**Qm**) consist of organic silt and clay sediments that accumulate in wetland and swamp environments. Surrounding the historical park are large, continuous wetland and swamp deposits mapped along the low-lying floodplains flanking the Hudson River, Fish Creek, and Saratoga Lake; these environments are susceptible to flooding events that pose several hazards (see "Flooding along the Hudson River"). Some smaller, isolated wetland and swamp areas are hosted within closed depressions along upland regions flanking the valley. In the historical park, muck deposits associated with wetland features are mapped along the Hudson River floodplain in the northern Battlefield Unit as well as in the southern Schuyler Estate (see poster). Although not depicted in the NPS GRI data, the Victory Woods site contains a few identified wetlands in the heights along its western boundary (Stevens et al. 2007).

Springs and Seeps
Several significant springs and seeps are preserved in the historical park. These features serve as valuable groundwater aquifers, affect natural processes such as slope stability and flooding, and possibly trace back to the American Revolution. The stratigraphy of the park's glacial deposits has created conditions favorable for spring development where porous lake sand deposits (**Qls**) overlie impermeable lake clay deposits (**Qlc**). Precipitation infiltrates downward through the sand and encounters the underlying impermeable clay, which acts as a barrier that forces water to travel

laterally along the sand-clay contact. This lateral subsurface flow contributes to differential erosion, slope instability, and mass wasting events (see "Mass Wasting along the Hudson River").

In the northern Battlefield Unit, two tributary ravines—locally referred to as the Wilbur Spring ravine and Dakota Spring ravine—contain several spring horizons that feed into the Kroma Kill east of Burgoyne's headquarters (tour road stop #8 in Figure 13 and Figure 14) near the entrance road overpass. Located south of the Kroma Kill, the Wilbur Spring ravine contains three distinct springheads and a relatively continuous seepage line that have developed along the sand-clay contact (Heath and Tannenbaum 1963). To the north of the Kroma Kill, the Dakota (DeCoteau) Spring ravine discharges from at least four major springheads similar in manner to the Wilbur Spring ravine (Heath and Tannenbaum 1963). In the past, nearby residents were known for drawing water from the Dakota Spring ravine during dry periods (Heath and Tannenbaum 1963). However, these spring horizons are believed to date back to the Battles of Saratoga and may have served as a valuable water source to the British camp that occupied the area (Heath and Tannenbaum 1963; Vana-Miller et al. 2001). According to Vana-Miller et al. (2001), additional springs are located in the southern end of the Battlefield Unit near the Neilson Farm.

Seasonal variations in precipitation regulate groundwater flow from the Wilbur and Dakota Spring ravines and affect the likelihood of flooding within the historical park. According to measurements by Heath and Tannenbaum (1963), the combined discharge from the Wilbur Spring ravine was fairly consistent throughout the year at approximately 25–30 gallons per minute, but increased to a maximum of about 50 gallons per minute in response to heavy spring rains that recharged the sand aquifer. Total groundwater flow at the Dakota Spring ravine peaked during the winter and spring months at nearly 70 gallons per minute and tapered to a low of about 35 gallons per minute throughout the summer and fall (Heath and Tannenbaum 1963). Since the Wilbur and Dakota Spring ravines are tributaries of the Kroma Kill, seasonal fluctuations in snowfall and rainfall have impacted the local watershed and stressed the drainage infrastructure designed to bypass US Route 4 (see "Flooding along the Hudson River").

Faults and Folds

The bedrock underlying the upper Hudson River Valley area has been faulted, folded, and metamorphosed due to intense tectonic forces associated with the Taconic orogeny (see "The Taconic Orogeny"). East of the Hudson River, opposite the historical park, is a regional fault structure referred to as the Taconic Allochthon Thrust Fault (see Figure 6; DeSimone 2015a); the thrust fault has also been called the "Taconic Frontal Thrust" by several authors (Bosworth and Kidd 1985; Kidd et al. 1995; Landing 2007; Rayburn et al. 2018). The Taconic Allochthon Thrust Fault is an imbricate thrust fault system that trends north-northeast–south-southwest, roughly parallel to the course of the Hudson River, and separates Cambrian–Ordovician rocks of the Taconic allochthon (**OCta**) from Ordovician flysch and mélange deposits that formed along the western leading edge of the allochthon (Bosworth and Kidd 1985; Bosworth et al. 1988; Kidd et al. 1995; Lim et al. 2005; Landing 2007). According to the bedrock GRI GIS data (DeSimone 2015a), the thrust system contains several internal cross-faults that include the Wampecack Fault near the Battlefield Unit, the East Station Fault near Coveville, and the Tomhannock Fault near the city of Schaghticoke. The

Wampecack and East Station Faults straddle Willard Mountain and are possibly synonymous with the "Willard Mountain Thrust" of Bosworth and Vollmer (1981) (see Figure 6). South of the historical park, the Tomhannock Fault forms the southern boundary of the Troy Frontal Zone (**Otfz**) and extends across the Taconic allochthon into the Waterford Flysch Zone (**Owfz**).

The flysch and mélange deposits within and surrounding the historical park are divided into unique structural zones that record a progressive increase in deformation from west to east (Cushing and Ruedemann 1914; Bosworth and Vollmer 1981; Bosworth 1982; Kidd et al. 1995). Zones with the highest intensity of deformation (folding, foliation, faulting, and shearing) are situated proximal to the Taconic Allochthon Thrust Fault. Although not depicted in the GRI GIS data, it has been speculated that the geologic contacts between individual zones are thrust faults, and each zone likely contains a significant number of internal faults (Plesch 1994; Kidd et al. 1995). Southwest of the historical park, an unnamed fault cuts across the Mohawk River Zone (**Omrz**) and connects rocks of the Rocky Tucks Zone (**Ortz**) with similar lithologies of the Halfmoon Greywacke Zone (**Ohgz**) to the south (DeSimone 2015a). According to Bosworth and Kidd (1985), the area encompassing the Battlefield Unit is underlain by the "Hudson River Thrust," which juxtaposes mélange deposits west of the fault against flysch sequences to the east. The north-northeast–south-southwest-oriented fault follows the trend of the Taconic Allochthon Thrust Fault and extends east across the Hudson River near the Old Saratoga Unit (Bosworth and Kidd 1985).

Folded strata are mapped across a 16–20 km (10–12 mi) wide portion of the Hudson River Valley west of the Taconic Allochthon Thrust Fault. Folded greywacke beds of the Mohawk River Zone mélange are exposed along the Kroma Kill in the Battlefield Unit (Figure 20). These beds are enclosed within a heavily sheared shale-rich matrix; this is typical for most outcrops of the Taconic mélange (Bosworth and Vollmer 1981). Further west of the Vischer Ferry Zone (**Ovfz**) and Ruedemann's Line, rocks transition from gently folded to flat-lying over a distance of several tens of kilometers (Bosworth and Vollmer 1981; Jacobi and Mitchell 2018).

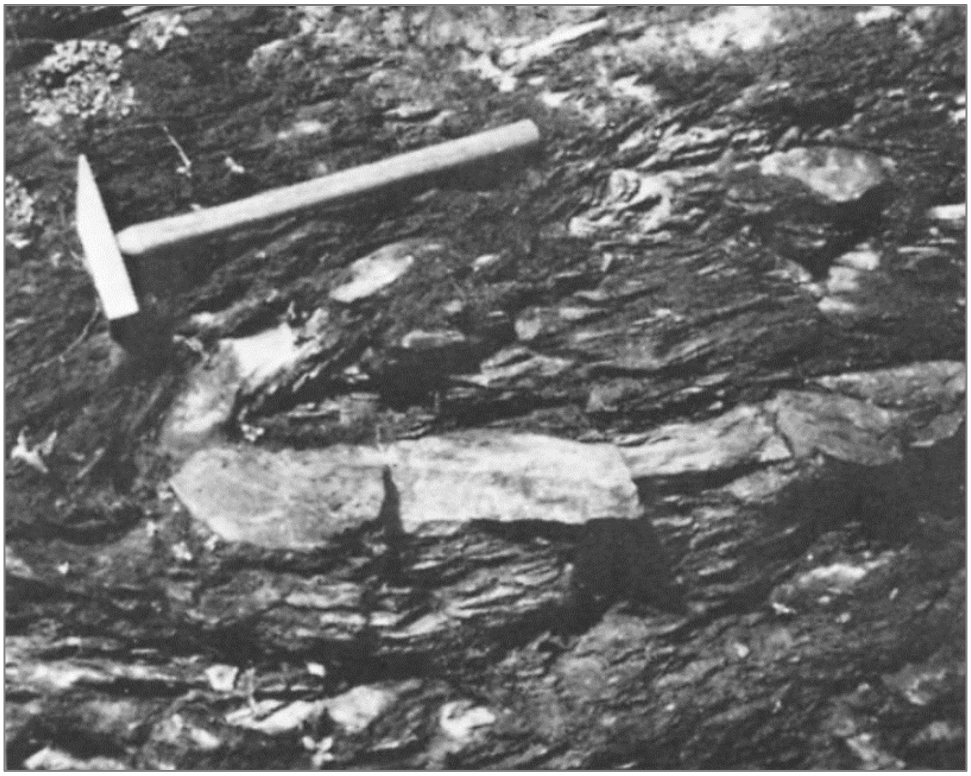

Figure 20. Photograph of an isolated fold in mélange exposures within the Battlefield Unit. Viewed along the Kroma Kill above US Route 4, the fold occurs in a discontinuous greywacke bed that is encompassed by darker, shale-rich layers. The hammer handle length is 0.5 m (1.6 ft). Figure 4 from Bosworth and Vollmer (1981), used with permission from the Journal of Geology.

Paleontological Resources

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (any remains of the actual organism such as bones, teeth, shells, or leaves) or trace fossils (evidence of an organism's activity such as nests, burrows, tracks, or coprolites [fossil feces]). All fossils are nonrenewable. Fossils in NPS areas occur in situ in rocks or unconsolidated deposits, in museum collections, and in cultural contexts such as building stones or archeological resources. As of March 2023, 286 NPS areas had documented paleontological resources in at least one of these contexts (Vince Santucci, NPS Geologic Resources Division, paleontologist, email communication to Rebecca Port, NPS Geologic Resources Division, geologist, 15 March 2023).

According to Tweet et al. (2010), the historical park fossil collections contain two cataloged specimens derived from Quaternary surficial deposits in the Battlefield Unit. These two fossils include a horn coral (cataloged as an animal tooth) found in proximity to the Neilson House, and a bivalve shell recovered during an archeological investigation of the American headquarters site (Woodworth Farm) (Tweet et al. 2010). The horn coral, a fossil known only from the Paleozoic, presumably eroded from older bedrock, and the same may be true of the bivalve (Justin Tweet, NPS Geologic Resources Division, paleontologist, personal observation, 2 May 2024).

Although documented fossil resources are currently limited to younger surficial deposits, the Ordovician bedrock underlying the historical park contains several known fossil localities that merit additional research (see “Paleontological Resource Potential”). In the region of the historical park, there are two notable fossil discovery sites. Located about 18 km (11 mi) northwest of the Battlefield Unit, the famous Petrified Sea Gardens preserve Cambrian stromatolites (fossilized mounds of bacteria) that were first correctly identified and understood as organic structures by James Hall in 1883 (Tweet et al. 2010). The fossil site is part of the NPS-administered National Natural Landmarks Program and has also been designated a National Historic Landmark. The other fossil locality within proximity to the historical park is the 1866 Cohoes mastodon site. It is approximately 24 km (15 mi) south of the Battlefield Unit in the city of Cohoes. This site yielded a remarkably complete mastodon specimen from Pleistocene deposits (Miller 2008; Tweet et al. 2010; Lewis and Anderson 2020).

Archeological Resources

Regarding both historical and Indigenous archeological resources, natural resource managers could monitor areas that experience high levels of erosion (e.g., gullies, springs, unstable slopes, flood zones) or storm damage that may reveal or even disturb potential new archeological discoveries. In May 2018, a microburst (a localized pattern of intense winds that descend vertically and radiate outward along the ground surface) that occurred at the historical park brought down approximately 1,000 trees throughout the central and northern sections of the Battlefield Unit (Gregory and Kirk 2019). Windthrown and uprooted trees had a detrimental effect on the preservation of archeological resources, revealing the presence of battle-related items in the ripped-up root structures (Figure 21). Gregory and Kirk (2019) suggest that any future windthrown or downed trees within the core battlefield area be metal detected shortly after their fall to ensure archeological resources are not lost. Looting is also a possible threat, as instances of archeological theft have been documented in the past.

Figure 21. Photograph of a tree that was uprooted during the May 2018 microburst event. Intense winds downed approximately 1,000 trees in the historical park, exposing archeological resources contained within the root structures of the fallen trees. Note the shovel in the left foreground for scale. Figure 27 from Gregory and Kirk (2019).

Historical Resources

The historical park museum collection contains over 110,000 archeological objects excavated from within the park's boundaries, a majority of which were recovered from the Battlefield Unit, Schuyler Estate, and Victory Woods (National Park Service 2021a). Historical resources related to the Battles of Saratoga include battlefield structures (fortification lines, cannon emplacements, gunpowder magazines, and encampment sites), building foundations, burial sites, artillery pieces, ballistics (musket balls, rifle shot, bird/buck shot, mortar shell fragments, and iron canister shot), tools (cutlery), weaponry (knives and gun parts), personal items (camp furniture, ceramics, coins, buttons, and buckles), and the John Neilson house—the only surviving building from the time of the battles (Starbuck 1988; National Park Service 2004, 2007; Stevens et al. 2007; Commisso and Foulds 2014; Kirk et al. 2019). Preserved battlefield features have helped piece together the historical park's American Revolutionary War history and corroborated the accuracy of military maps drafted at the time of the battles (Commisso and Foulds 2014).

Indigenous Resources

Prior to European contact, the Hudson River Valley was home to Native American cultures that have had a profound influence on the region. Indigenous contributions remain in customs, oral histories, resource awareness, and namesakes; the term “Saratoga” is of Indigenous origin and was applied to bountiful hunting grounds extending along both sides of the Hudson River (Stevens et al. 2007).

Even though the historical park is better known for its American Revolutionary War history, it also preserves Indigenous resources that record human cultures dating back nearly 8,000 years (Stevens et al. 2007; National Park Service 2021a). Excavations within the Battlefield Unit and the Schuyler Estate have discovered approximately 1,000 artifacts, the bulk of which consist of projectile points or fragments, stone tools, fire-cracked quartzite, and chert (National Park Service 2007; Penney and Luhman 2012; Kirk et al. 2019). An archeological study at Victory Woods discovered several Indigenous resources that indicate the site was sporadically occupied by Native Americans during the Middle Archaic Period (8,000–5,000 years before present [BP]), as well as the Middle (1,600–1,000 BP) to Late (1,000–340 BP) Woodland periods (Stevens et al. 2007; National Park Service 2021a). These resources include a roasting platform, projectile points, and hundreds of debitage flakes (waste flakes formed during stone tool production and sharpening) associated with a lithic processing station (Stevens et al. 2007). Other known Indigenous archeological sites exist along Fish Creek, near Victory Woods and the Schuyler Estate. Based on this evidence, Stevens et al. (2007) argued that the region around the Schuyler Estate may have been an area of prolonged prehistoric occupation.

Geologic Resource Management Issues

This chapter highlights issues (geologic features, geologic processes, and human activities affecting or affected by geology) that may require management for human safety, protection of infrastructure, or preservation of natural and cultural resources. The issues are categorized based on whether geology poses a hazard ("Geologic Hazards" section) or whether the geologic feature or process requires resource protection ("Geologic Resource Monitoring and Protection" section). Within each section, the issues are ordered alphabetically. The GRD provides technical and policy assistance for these issues (see "Guidance for Resource Management" chapter).

Geologic Hazards

Park resources are not only visitor attractions but may also be potentially hazardous. The dynamic landscapes preserved at many national park units present a variety of natural hazards that threaten NPS facilities, staff, and visitors. Many of these natural hazards are geologic. Geologic hazards are naturally occurring, dynamic geologic processes that have the potential to cause damage, loss of property, and/or injury and loss of life. Schaller et al. (2014) summarized and categorized the geologic hazards of the National Park System. Appendix A in Schaller et al. (2014) is a table of hazards at each of the 83 parks in the study. Geologic hazard categories include avalanches, cave and karst incidents, coastal and shoreline hazards, flooding, geothermal risks, glacial activity, mass wasting events, rockfalls, seismic activity, and volcanic hazards.

The primary geologic hazards identified at the historical park are flood-related impacts associated with the Hudson River and its tributaries, particularly the Kroma Kill. Furthermore, floodplain and wetland environments along the Hudson River have likely been exposed to PCB contamination resulting from flooding events. Additional potential geologic hazards include mass wasting events, climate change impacts, disturbed lands, quicksand, and seismic activity. These hazards are discussed in the remaining sections of this chapter. Table 4 summarizes the geologic hazards at the historical park.

Table 4. Geologic hazards checklist. This summary table is a synthesis of existing GRI-compiled map data and information, as well as published US Geological Survey or state geological survey information. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or National Environmental Policy Act (NEPA) analysis. Ground-disturbing activities should neither be approved nor denied based upon the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2023 and Jarvis 2015). It is meant to provide general information to identify the full range of geologic hazard-based risks for the historical park.

Potential Hazard	Best Professional Judgement	Risk or Secondary Hazard	Information Source(s) Used
Sea level change	Not applicable	Not applicable	Not applicable
Coastal storm surge	Not applicable	Not applicable	Not applicable
Coastal erosion	Not applicable	Not applicable	Not applicable
Flash flood	**Known Hazard**	• Destruction of infrastructure (e.g., roads, trails, culverts) through impact or saturation • Breaching of Old Champlain Canal walls • Reduced or precluded visitation • Human injury or casualty	• NPS Water Resources Division report (Martin 2003)
Riverine flood	**Known Hazard (extreme)**	• Inundation • Destruction of infrastructure (e.g., roads, trails, culverts) through impact or saturation • River channel migration and riverbank erosion • Water quality effects • Water supply diminished • Contamination through Hudson River PCB's • Reduced or precluded visitation	• Federal Emergency Management Agency (FEMA) National Flood Hazard Layer • US Department of Interior (DOI) Strategic Hazard Identification and Risk Assessment (SHIRA) risk mapper (Department of the Interior 2023) • NPS GRI Scoping Summary (Thornberry-Ehrlich 2008) • NPS Natural Resource Condition Assessment report (Wagner et al. 2014)
Lake and Reservoir Level Change	Not applicable	Not applicable	Not applicable

Table 4 (continued). Geologic hazards checklist. This summary table is a synthesis of existing GRI-compiled map data and information, as well as published US Geological Survey or state geological survey information. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or National Environmental Policy Act (NEPA) analysis. Ground-disturbing activities should neither be approved nor denied based upon the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2023 and Jarvis 2015). It is meant to provide general information to identify the full range of geologic hazard-based risks for the historical park.

Potential Hazard	Best Professional Judgement	Risk or Secondary Hazard	Information Source(s) Used
Earthquake	**Potential Hazard (very low)**	• Falling objects • Collapsing structures • Inoperability of major building systems (e.g., power, sewer, water) • Liquefaction; loss of strength to foundations, silt deposition, standing water • Trigger to other hazards (e.g., landslides, slumping, slope creep)	• DOI SHIRA risk mapper (Department of the Interior 2023) • New York City Area Consortium for Earthquake Loss Mitigation report (Tantala et al. 2005) • NPS GRI Scoping Summary (Thornberry-Ehrlich 2008) • USGS Earthquake Hazards Program, Information by Region – New York • USGS National Seismic Hazard Model • Wheeler et al. (2000) • Jacobi and Ebel (2019)
Slope movements (e.g., landslide, slumping, slope creep)	**Known Hazard (susceptible to landslides)**	• Rockfall • Slides or flows onto structures • Slides or flows from under structures • Damage or destruction of park infrastructure, including roadways, drainage systems, or buildings • Damage to or loss of archeological, cultural, or paleontological resource sites or features • Human injury or casualty	• GRI GIS hazard layers or slope movement deposits (e.g., “alluvial fan”) • DOI SHIRA risk mapper (Department of the Interior 2023) • FEMA National Risk Index: Landslide • NPS GRI Scoping Summary (Thornberry-Ehrlich 2008) • NPS Natural Resource Condition Assessment report (Wagner et al. 2014) • Unstable Slope Monitoring Program • USGS Landslide Inventory
Permafrost	Not applicable	Not applicable	Not applicable
Cave/karst	Not applicable	Not applicable	Not applicable

Table 4 (continued). Geologic hazards checklist. This summary table is a synthesis of existing GRI-compiled map data and information, as well as published US Geological Survey or state geological survey information. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or National Environmental Policy Act (NEPA) analysis. Ground-disturbing activities should neither be approved nor denied based upon the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2023 and Jarvis 2015). It is meant to provide general information to identify the full range of geologic hazard-based risks for the historical park.

Potential Hazard	Best Professional Judgement	Risk or Secondary Hazard	Information Source(s) Used
Shrink/swell soils	**Known Hazard (moderate to low)**	• “Heaving” of ground beneath structures • Increased mass wasting susceptibility • Damage or destruction of park infrastructure, including roadways, drainage systems, or buildings • Damage to or loss of archeological, cultural, or paleontological sites or features	• NPS Natural Resource Condition Assessment report (Wagner et al. 2014) • NRCS Web Soil Survey
Tsunami	Not applicable	Not applicable	Not applicable
Volcanic eruption	Not applicable	Not applicable	Not applicable
Hydrothermal activity	Not applicable	Not applicable	Not applicable
Quicksand	**Known Hazard**	• Damage or destruction of park infrastructure • Damage or loss of wildlife • Human injury or casualty	• Personal communication (Linda White, NPS Saratoga National Historical Park, 23 October 2023)
Radon	**Potential Hazard (moderate)**	Health hazard	• DOI SHIRA risk mapper (Department of the Interior 2023) • EPA Map of Radon Zones • New York State Department of Health Radon Result Tracker website: Saratoga County
Toxicological soil (arsenic[2], *Baccillus anthracis* [causes anthrax][1], cadmium[2], lead[3], selenium[2])	[1] **Potential Hazard (low)** [2] **Potential Hazard (moderate)** [3] **Potential Hazard (very high)**	Health hazard	• DOI SHIRA risk mapper (Department of the Interior 2023)

Table 4 (continued). Geologic hazards checklist. This summary table is a synthesis of existing GRI-compiled map data and information, as well as published US Geological Survey or state geological survey information. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or National Environmental Policy Act (NEPA) analysis. Ground-disturbing activities should neither be approved nor denied based upon the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2023 and Jarvis 2015). It is meant to provide general information to identify the full range of geologic hazard-based risks for the historical park.

Potential Hazard	Best Professional Judgement	Risk or Secondary Hazard	Information Source(s) Used
Fluvial contamination (Hudson River)	**Known Hazard**	Health hazard	• NPS GRI Scoping Summary (Thornberry-Ehrlich 2008) • NPS Natural Resource Condition Assessment report (Wagner et al. 2014) • US Environmental Protection Agency (2002) Hudson River PCBs Site Record of Decision • US Environmental Protection Agency (2019, 2023) Hudson River PCBs Superfund site fact sheets • US Environmental Protection Agency Hudson River PCBs Superfund website

According to NPS Management Policies (2006), although the magnitude and timing of future geologic hazards are difficult to forecast, the NPS strives to understand hazards and, subsequently, minimize their potential impact on visitors, staff, and developed areas. NPS Policy Memorandum 15-01 (Jarvis 2015) directs NPS managers and their teams to proactively identify and document facility vulnerabilities to climate change and other natural hazards. The saving of human life will take precedence over all other management actions. Activities to mitigate risks associated with geologic hazards are carried out within the constraints of the 1916 Organic Act, primarily that discretionary activities may not impair park resources and values and must be consistent with management policies. The NPS cannot totally control these risks; therefore, park visitors must assume a substantial degree of risk and responsibility for their own safety when visiting areas that are managed and maintained as natural, cultural, or recreational environments (National Park Service 2006).

Management policies (National Park Service 2006) do not impose specific visitor safety prescriptions. This GRI report presents recommendations for reducing risks related to geologic hazards; however, it is up to the discretion of decision-makers at the park level on whether, how, and when to implement these recommendations and will be subject to the availability of funding and staffing as well as legal and policy considerations.

At the main Battlefield Unit, the steep hillslopes and ravines that flank the Hudson River are prone to mass wasting events and present a considerable hazard. Numerous occurrences of slumps, landslides, and roadway slippage have necessitated several reconstruction and slope stabilization projects. It is recommended that any future development, maintenance, or rehabilitation projects that disturb the ground, redirect drainage, or remove vegetation in these areas be avoided until the potential destabilization impact has been evaluated.

It is recommended that historical park management and staff consider avoiding the placement of new facilities in geologically hazardous areas such as the low-lying Hudson River floodplain (see “Flooding along the Hudson River”). Low-elevation regions along the river and its tributaries are susceptible to flooding events and river contaminants. The exposure to PCB-contaminated floodwaters and floodplain sediments along the Hudson River presents a potential health hazard (see “Hudson River Contamination Issues”). Historical park managers could examine the feasibility of phasing out, relocating, or providing alternative facilities for park developments subject to hazardous processes. When it is determined that facilities must be placed in areas with dynamic natural processes, their design and siting should be based on a thorough understanding of the nature of the physical processes to avoid or mitigate risks to human life and property, as well as the effect of the facility on natural physical processes.

Climate Change

Although climate change planning is beyond the scope of this GRI report, a discussion of climate change is included because of the potential disruption it may cause to the geologic features, processes, and resources of the historical park. Additionally, NPS Policy Memorandum 15-01 (Jarvis 2015) directs NPS managers and their teams to proactively identify and document facility vulnerabilities to climate change and other natural hazards. Park managers are directed to the NPS

Climate Change Response Program (see "Additional References, Resources, and Websites") to address climate change planning. This program helps park managers develop plausible science-based scenarios that can be used to guide strategies and adaptive management activities that can help reduce the effects of climate change or adapt to them.

Climate change manifestations that may intensify geologic hazards within the historical park include the following:

- More frequent and intense storm events
- More frequent and intense flooding
- Increased erosion
- Increased threat of mass wasting events

According to National Park Service (2021a) and Climate Change Response Program (2024), climate model forecasts project an increase in average temperatures, precipitation, and extreme events such as drought and storm frequency or intensity. Projected climate change scenarios may adversely affect the landscape and viewshed of the historical park by increasing the susceptibility to flooding (including flash flooding), erosion, and invasive species, while potentially shifting species phenology (cyclical and seasonal biotic cycles) and driving northward shifts in species ranges. Additionally, factors such as soil stability, vegetation, species composition, forest types, and habitat diversity may be impacted. The climate has already changed at the historical park, and recent temperature conditions have already shifted beyond the historical average (1979–2012) and show a progressive warming trend of approximately 3.6°C (6.5°F) per century since 1970 (Climate Change Response Program 2024).

Rising global temperatures present a clear and present risk now and in the coming decades as they facilitate increases in sea level, storm frequency and intensity, wave effects, coastal flooding, river flows, and rainfall (Sweet et al. 2022). Increased storm frequency and intensity can bring extreme costs through loss of visitor access, impacts to neighboring communities and local economies, investments in recovery, irrevocable damage to unique resources, and permanent loss of land space (Caffrey et al. 2018; Sweet et al. 2022). For example, a May 2018 microburst event downed approximately 1,000 trees throughout the central and northern portion of the Battlefield Unit, exposing battle-related archeological resources and jeopardizing their preservation (see "Archeological Resources"; Gregory and Kirk 2019). In addition to damaging winds, enhanced rain and snowfall have the potential to impact the Hudson River and its tributaries (Kroma Kill, Mill Creek, American's Creek, Devil's Hollow or Great Fall Creek, and Fish Creek), increasing the threat and vulnerability posed by flooding hazards (National Park Service 2021a). Low-lying floodplains and wetlands along the river corridor are particularly vulnerable to storm-induced flood events. Currently, segments of the Old Champlain Canal in the historical park are periodically flooded, which has impacted transportation along US Route 4 and damaged historical park resources; these issues are likely to be exacerbated by the effects of climate change (National Park Service 2021a).

Projected increases in temperature, precipitation, and storm activity have both direct and indirect consequences on slope stability and erosion. Excessive amounts of rainfall or snowfall will contribute to the threat of mass wasting events, as additional water will increase ground mass and subsurface pore-water pressures, leading to slope destabilization and failure (Coates 1985; Jäger and Wieczorek 1994). The bluffs and steep ravines flanking the Hudson River are underlain by unconsolidated glacial sediments that are susceptible to erosion, slope creep, slumping, and landslides (see "Mass Wasting along the Hudson River"; National Park Service 2004; Thornberry-Ehrlich 2008; Wagner et al. 2014). Rising global temperatures may exacerbate these issues. Projected temperature increases may drive a shift in tree species tolerance while introducing invasive biota. For example, beech trees at the historical park are at risk of beech bark disease (BBD), an illness caused by invasive insect and fungal species that attack the bark of the tree. The spread of BBD is destructive, resulting in a tree mortality rate of nearly 50% after five years of infection (Wagner et al. 2014). Additionally, hemlock trees located along the streams and ravines of the historical park are susceptible to the invasive hemlock wooly adelgid. Reduction or loss of slope vegetation will increase soil instability, erosion, and mass wasting.

Disturbed Lands

Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by development, including facilities, mining, roads, dams, and abandoned campgrounds; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; overuse; or inappropriate use. Restoration returns a site, watershed, or landscape to some previous condition, commonly some desirable historic baseline. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities. Lands disturbed by human activity often cause unwanted and long-lasting problems that affect other resources. Many of these disturbances obliterate soil profiles, exacerbate the invasion of exotic plants, result in contamination of water and soil, and/or cause erosion and sedimentation. These damages, in turn, frequently impair the quality of habitats, disrupt ecosystem functions, and cause problems for parks managing areas as wildlands.

Following the Battles of Saratoga, the landscape and viewshed of the historical park underwent significant changes resulting from human activities such as cultivation, mining, milling, road and trail construction or maintenance, urban development, and the construction of the Old Champlain Canal. Since the American Revolution, the land encompassing the historical park and the Hudson River has been used for farming and mills, while small stone quarries and mining operations excavated the surficial deposits along the riverbanks for manufacturing (Russell 1991; Thornberry-Ehrlich 2008; Commisso and Foulds 2014).

Mining

Historic sand mining operations of the 19th and early 20th centuries occurred in portions of the Battlefield Unit and have altered the historical park's topography, hydrology, and resources. From 1917 through the late 1920s, commercial operations extracted surficial deposits along the bluffs of the Great Redoubt (Oudemool et al. 2002). Lacustrine sand deposits (**Qls**) that cap the Hudson River bluffs contain a high amount of weathered, feldspar-rich clay that was ideal for making cohesive, durable molding sand considered valuable in the metal casting process (Cushing and Ruedemann 1914; Nowak and Commisso 2011). The molding sand (dubbed the "Albany molding sands" by Newland [1916] and Nevin [1925]) was extracted from beneath the topsoil to a depth of roughly 1–2 m (3–6 ft; Oudemool et al. 2002). Operators would commonly dig around large trees to extract the sand, which was then transported down the bluff to the river for shipment. These surface mining operations have altered the area surrounding Burgoyne's headquarters, disturbed valuable archeological resources, modified drainage patterns, and left discernible scars on the landscape (Oudemool et al. 2002; Nowak and Commisso 2011). Additionally, mining operations along the riverbank may have resulted in the destruction of Brig. Gen. Simon Fraser's grave site (Thornberry-Ehrlich 2008). Abandoned mining infrastructure still exists within the historical park in the form of mine cart tracks and former river dock structures (Linda White, Saratoga National Historical Park, personal communication 23 October 2023).

<u>Old Champlain Canal</u>

The Old Champlain Canal is a relic of the historic 19^{th}-century transportation corridor that once extended between the cities of Whitehall and Waterford, New York. At its southern terminus, the Old Champlain Canal connected to the Erie Canal and was once part of an extensive network of artificial waterways. Considered a technological advancement of the Hudson River corridor, the Old Champlain Canal provided an efficient means of transporting goods, materials, and people from Canada, Vermont, northern New York, and western Massachusetts to markets in New York City (Stevens et al. 2007; Commisso and Foulds 2011). Portions of the canal located within Saratoga County were constructed from 1821 to 1823 (Commisso and Foulds 2011; National Park Service 2021). Shortly after its development, the Old Champlain Canal transformed commerce and industry as small hamlets, farms, mills (i.e., saw, grist, plaster, and salt), mining operations, general stores, shops, and lodges sprung up along the canal.

Although the Old Champlain Canal heralded a new economic era for the upper Hudson River Valley, its construction and subsequent abandonment have negatively impacted the historical park's landscape and resources. Excavation of the canal structure modified the natural drainage of the upland regions west of the Hudson River, presenting issues related to flooding, sedimentation, and debris accumulation. Additionally, the construction of the canal has disturbed much of the archeological remains located along the basal Hudson River bluffs in the Battlefield Unit (Oudemool et al. 2002). During the historic operation of the canal, excessive runoff was discharged through a series of spillways or waste weirs, and the waterway was periodically dredged to remove excessive accumulations of sediment.

Since disuse, the Old Champlain Canal has been a hydrologically inefficient structure due to sediment infilling from natural hillslope processes as well as the presence of natural (e.g., beaver activity) and anthropogenic (e.g., roadway) constrictions (Martin 2003). As the historic waterway now sits abandoned, additional safety concerns have arisen that include cracking and spalling of the canal walls (Thornberry-Ehrlich 2008). Portions of the canal adjacent to US Route 4 have periodically flooded, resulting in road and trail closures, the destruction of infrastructure, and damaged park resources (Thornberry-Ehrlich 2008; National Park Service 2021a). Since 2007, the

New York Department of Transportation (NYDOT) has completed multiple restoration efforts to establish a new drainage pattern that directs precipitation and runoff around the canal. In 2022, work performed by the NYDOT included dredging the canal and constructing drainage ditches on both sides of US Route 4. The newly constructed drainage network extends along portions of the roadway and continues eastward through the lower floodplain, where it empties into the Hudson River.

Active Land Disturbance

Urbanization within and adjacent to the historical park provides potential concern for disturbance, including threats to the battlefield viewshed and resources. Housing, commercial development, and population growth have negatively impacted the integrity of natural resources through habitat fragmentation, land cover conversion, and pollution. The development of roads and buildings reduces the size and connectivity of natural ecosystems, which threatens wildlife populations while promoting an overall loss in biodiversity. Additionally, roadways provide transportation corridors that aid in the dispersal of invasive plant species. Roads and parking lots are impervious surfaces that facilitate increases in surface water runoff, erosion, and sedimentation while also introducing contaminants that leach into nearby environments (Wagner et al. 2014). Increased land conversion to impervious surfaces within a watershed may result in higher storm-related flows, which can modify stream channel morphology and stability (Wagner et al. 2014).

The viewshed to and from the historical park is considered an essential part of the battlefield setting as it significantly contributes to visitor appreciation and understanding of the Battles of Saratoga (National Park Service 2021a). In the 1930s, NPS historian Roy Edgar Appleman submitted the first survey and report, providing detailed recommendations to restore the historic battlefield to what it was during the American Revolution (Russell 1991). In 1941, the Civilian Conservation Corps followed through on Appleman's recommendations by removing stone fences, old wire fence lines, and tree orchards not considered part of the historical scene; some former agricultural areas were naturally reclaimed (Russell 1991; Thornberry-Ehrlich 2008). Although the viewshed of the historical park has been moderately preserved due to proactive efforts by the NPS and affiliated conservation groups, it remains highly vulnerable to urbanization projects (Wagner et al. 2014).

Flooding along the Hudson River

One of the primary management concerns for the historical park is the flooding associated with the Hudson River and its tributaries. In the Hudson Lowlands, flooding is a common occurrence that helps rejuvenate soil fertility, but it also routinely damages and threatens buildings, roads, trails, and ecosystems situated in and along the floodplain. Within the historical park, flooding not only contributes to slope instability and mass wasting events but also exposes visitors, staff, and wildlife to chemical pollutants that have contaminated the Hudson River since the 1940s (see "Mass Wasting along the Hudson River" and "Hudson River Contamination Issues"). Park managers are directed to the NPS Water Resources Division (see "Additional References, Resources, and Websites") to address water resources planning.

Historically, floods along the Hudson River have been responsible for dam failures and the destruction of Old Champlain Canal infrastructure (Whitford 1906). At the historical park, there have been at least four major flooding events in the last 30 years (Linda White, Saratoga National Historical Park, personal communication 23 October 2023). Portions of the Battlefield Unit and Schuyler Estate are located within the 100-year floodplain of the Hudson River, a designation that predicts a given area will experience at least one major flooding event every century (or a 1% annual chance) (Wagner et al. 2014). Currently, the 100-year floodplain zone extends approximately 0.32–0.80 km (0.2–0.5 mi) west from the river channel and encompasses low-elevation regions east of US Route 4 (Figure 22; Federal Emergency Management Agency 1995; National Park Service 2004; Wagner et al. 2014).

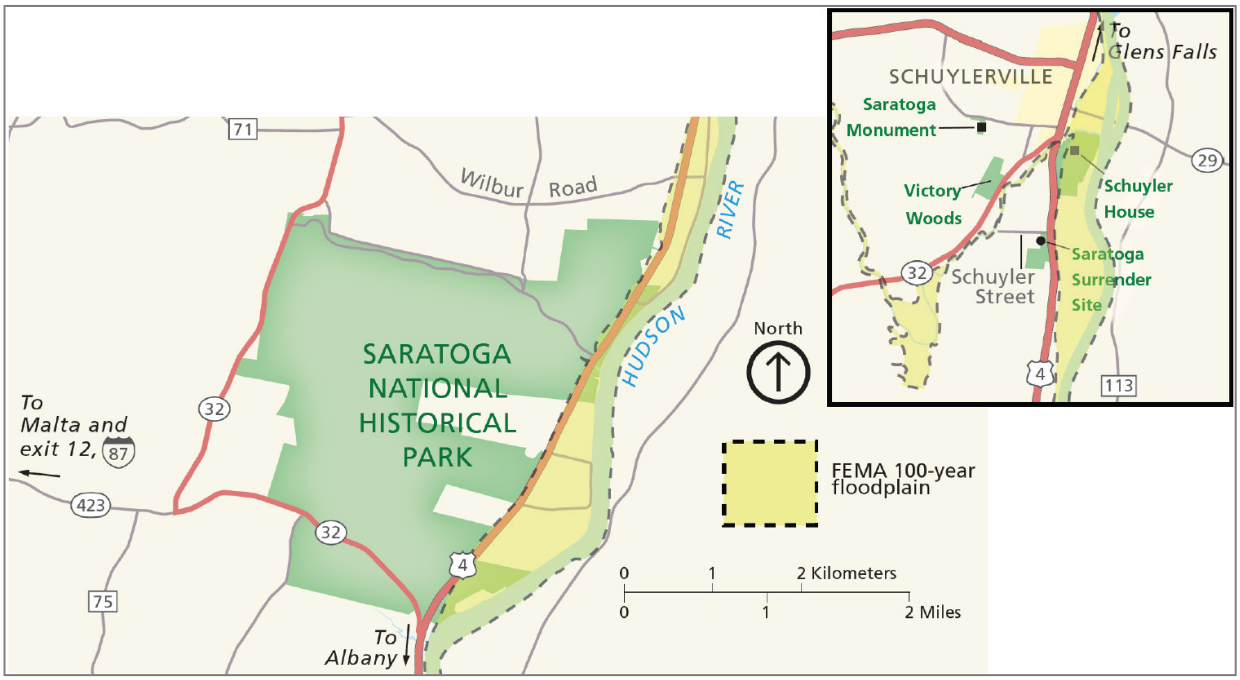

Figure 22. Map of the historical park showing the FEMA 100-year floodplain west of the Hudson River. Inset map shows the parcels of the Old Saratoga Unit. Low-elevation regions of the Battlefield Unit and Schuyler House east of US Route 4 are highly susceptible to flooding events. Figure created by Tim C. Henderson (Colorado State University).

In addition to the Hudson River, the Kroma Kill is prone to flooding which has damaged park resources, including roads and infrastructure. During severe weather events and high flood stages, the discharge of the Kroma Kill is often strong enough to overwhelm engineered drainage structures and scour the roadway surface of US Route 4. In May 2004, flooding damaged a drainage system at and around a culvert that passes under US Route 4 in the southern portion of the Battlefield Unit. Near the culvert, the highway sustained shoulder damage, and silt and debris were deposited on the roadway surface (Martin 2003). For planning, protection, and management purposes, historical park staff are monitoring the flow conditions of the Hudson River and its tributaries, as well as performing post-flood damage assessments. Efforts are being made to develop drainage maps that will allow staff to analyze which archeological resources along the floodplain are most susceptible to flood-related impacts (Margaret Wilkes, NPS Northeast Archeological Resources Program, personal communication 23 October 2023).

The construction of the Old Champlain Canal in the early 19th century artificially modified the natural drainage pattern of the upland regions toward the Hudson River, resulting in flooding issues within the historical park along US Route 4 (see "Disturbed Lands"). Since abandonment, the canal in its present state is a hydrologically inefficient structure that infills with sediment derived from upland slopes. The originally engineered drainage to the remaining segments of the canal has been destroyed, creating a mix of isolated sections that are either drained or impound water and are flood-prone (Martin 2003). Historic maintenance helped reduce the frequency of flooding events, but the canal is still likely to be overtopped during extreme rainfall events. Under its present abandoned condition, the canal may be expected to flood on a more frequent basis. Over the years, segments of the Old Champlain Canal adjacent to the Battlefield Unit have become further restricted due to beaver activity and roadway construction. In the southern half of the Battlefield Unit, portions of the canal towpath near Wrights Loop Road have experienced multiple breaches, many of which are associated with short (lasting less than 24 hours) but heavy rainfall (Martin 2003). Additionally, sections of the historical park entrance road near US Route 4 have become inundated due to storm-related breaches of the canal. As recently as July 2023, flash flooding damage has occurred near the eastern entrance park road, resulting in substantial roadway damage that closed the road and several hiking trails (Figure 23).

Figure 23. Flash flooding damage along the US Route 4 park entrance. Torrential rainfall that occurred 16 July 2023 resulted in substantial flood damage that washed out portions of the roadway and closed the entrance road and hiking trails. NPS photograph.

Hudson River Contamination Issues

Although water resource issues are beyond the scope of this GRI report, a discussion of river contamination is included because of the potential disruption it may cause to the geologic features, processes, and resources of the historical park. Park managers are directed to the NPS Water Resources Division (see “Additional References, Resources, and Websites”) to address water resources planning.

According to the Natural Resource Condition Assessment report by Wagner et al. (2014), the Hudson River corridor adjacent to the historical park is a federally designated Superfund site (uncontrolled or controlled sites containing hazardous waste). For several decades, the Hudson River has been contaminated by industrial chemical pollutants that now directly impact the natural resources of the historical park. From the 1940s through the 1970s, manufacturing plants discharged an estimated 590,000 kg (1.3 million pounds) of PCBs into the river, contaminating the lower 322 km (200 mi) stretch extending from Hudson Falls to the Battery in New York City (National Park Service 2004; Wagner et al. 2014; US Environmental Protection Agency 2023). The US Environmental Protection Agency (EPA) has banned the production of PCBs because these substances accumulate inside living things, gradually increasing in concentration as they move up the food chain. Although PCBs originated upriver, the pollutants contaminated the water and river bottom and adhered to mobile river sediments; these negatively impacted downstream ecosystems. Several New York fisheries were closed, and public advisory notifications were issued when certain species of fish tested above the acceptable level of PCBs for human consumption (US Environmental Protection Agency 2002).

Contamination along the Hudson River Superfund site is not confined to the river channel itself, as floodplains and other low-elevation regions have been exposed to PCBs due to flooding events (Oudemool et al. 2002; Thornberry-Ehrlich 2008; Wagner et al. 2014). Over time, PCBs can be continuously released from bedrock and floodplain sediments, presenting a long-term safety hazard for surface water and local wildlife, including natural resources and wildlife communities within the historical park (Wagner et al. 2014). As part of the remediation process, the EPA coordinated a multi-year sediment removal project north of the historical park near the sources of PCB contamination. Initial restoration efforts began in 2009 when the EPA required GE to dredge PCB-contaminated river sediment "hot spots" along a 64 km (40 mi) interval of the upper Hudson River from Fort Edward to Troy, New York (US Environmental Protection Agency 2002, 2023). Continued dredging and habitat restoration activities were completed over an additional 6-year period; in all, approximately 2.1 million cubic meters (2.75 million cubic yards) of PBC-contaminated sediment were removed from the river bottom (US Environmental Protection Agency 2019). As of 2024, the EPA and the New York State Department of Environmental Conservation are monitoring floodplain soils at multiple testing sites.

As a result of the river contamination, historical park staff have discouraged visitors from certain activities such as fishing for consumption and recreating along the Hudson River floodplain or shoreline (Figure 24; Wagner et al. 2014). Furthermore, the presence of contaminants has altered vegetative management techniques to address staff health and safety concerns while working along the floodplain (Wagner et al. 2014).

Figure 24. Catch and release fishing signs posted along the Hudson River at the historical park. These postings by the New York State Department of Environmental Conservation warn against the presence of PCB contamination in fish that may cause reproductive and developmental effects and cancer. For several decades, the river has been contaminated by industrial chemical pollutants that now directly impact the natural resources of the historical park, including aquatic and floodplain environments. Photograph from Wagner et al. (2014).

Mass Wasting along the Hudson River

The term "mass wasting" is used to describe downhill movements of rock or soil and includes events such as landslides, slumping, and slope creep. Mass wasting events are driven by natural processes such as erosion, precipitation, flooding, and seismicity (earthquakes), but they can also be artificially induced by construction, mining, undercutting, vegetative clearing, and other projects that destabilize the ground. At the historical park, the Hudson River fluvial system is a significant and dynamic landscape component that incises bluffs, terraces, and ravines while simultaneously modifying hillslope stability conditions. As rocks are weathered and eroded, unstable material is transported downgradient by water, wind, and gravity, where it accumulates as unconsolidated alluvium (**Qal**) or alluvial fan (**Qaf**) deposits along the basal slopes and lowlands of the Hudson River Valley.

According to the NPS scoping summary (Thornberry-Ehrlich 2008), slope instability and mass wasting are known management concerns within the historical park that are primarily driven by frost/root wedging and differential erosion. Within the Battlefield Unit, steep-sided till deposits

(**Qtv**), lake clays (**Qlc**), lake sands (**Qls**), and clay-rich soil horizons are subject to gullying, slumping, and landslide issues that pose a constraint on visitor access and facility development (National Park Service 2004; Wagner et al. 2014; DeSimone 2015b). More importantly, these types of mass wasting events are a considerable risk, as the historical park's roads, bridges, trails, historic structures, and archeological sites are at risk of being damaged or destroyed (Thornberry-Ehrlich 2008).

In the Battlefield Unit, the geologic configuration of porous lake sands (**Qls**) overlying impermeable lake clays (**Qlc**) creates an unconfined aquifer that directs groundwater flow, feeding springs and seeps (see "Springs and Seeps"). As precipitation infiltrates downward through the sand and encounters the underlying clay, the decrease in hydraulic conductivity (the ease with which groundwater can move) acts as a vertical barrier that forces water to travel laterally along the sand-clay contact. Lateral subsurface flow along these layers contributes to differential erosion, slope instability, and mass wasting events. Restricted groundwater flow along the contact promotes subsurface drainage pattern development that enlarges pores and voids within the overlying rock or soil. Referred to as piping, this erosional process preferentially removes loose or unconsolidated material and dissolves mineral cements, promoting slope instability and driving headward incision along gullies. Spring horizons (stratigraphic intervals where spring waters emerge) could be a mechanism of slope failure and mass wasting along the steep bluffs and ravines. A detailed, geospatial location map of all the spring horizons within the historical park could assist in determining the configuration of the lacustrine sand-clay contact. Knowledge of the sand-clay boundary configuration may help predict groundwater flow patterns and serve as an erosion management tool (David DeSimone, DeSimone Geoscience Investigations, personal communication 23 October 2023).

Regionally, lacustrine clay deposits and clay-rich soil horizons underlie a large portion of the Hudson River Valley and are notorious for causing mass wasting events along slopes and artificially steepened embankments (Titus and Titus 2012). Several incident reports documented in the late 1980s and early 1990s include small landslide events (up to ¾ acre) that occurred throughout drainages within the Battlefield Unit (Vana-Miller et al. 2001). Additionally, clay-based soils within the historical park can retain large amounts of water and occasionally shift 1.5–3.0 m (5.0–10 ft) downslope (Vana-Miller et al. 2001). Wagner et al. (2014) calculated potential soil loss through erosion across the historical park and generated a soil hazard rating map with categorized zones of slight, moderate, or severe/very severe hazard potential. Regions associated with the highest soil erosion are located along the tributary streams, ravine networks, and Hudson River bluffs at the Battlefield Unit, in addition to the steep embankment of Fish Creek at the Victory Woods site (Figure 25; Wagner et al. 2014).

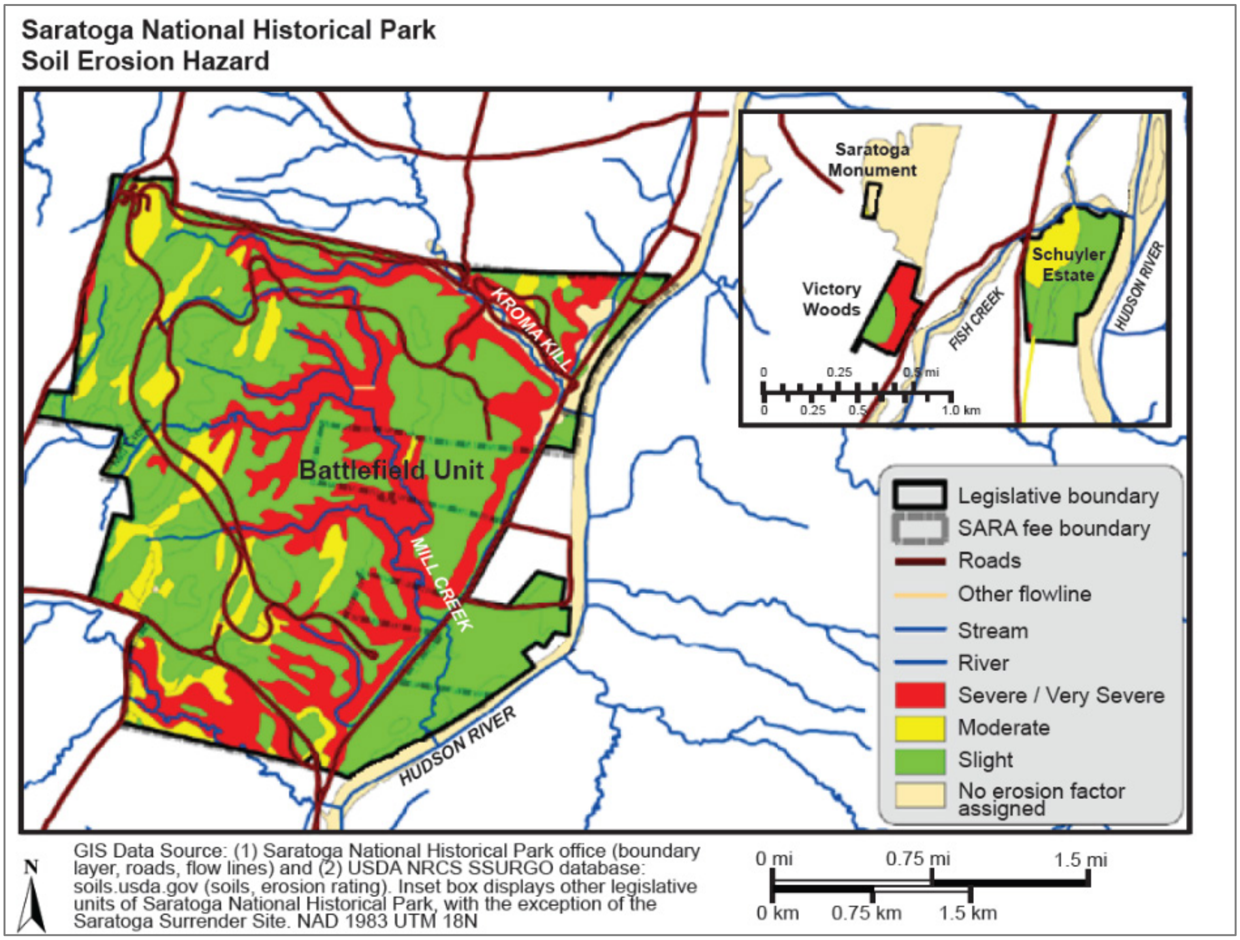

Figure 25. Soil erosion hazard ratings map for the historical park. Regions of severe or very severe soil erosion generally occur along tributary valleys and bluffs flanking the Hudson River where fluvial incision has created steepened embankments. Hazard ratings for the Battlefield Unit are based on a 2004 USDA NRCS soil survey in Saratoga County, New York, in relation to streams and roads. Inset box shows ratings for the small parcels of the historical park, except for the Saratoga Surrender Site. Map is Figure 2.9 from Wagner et al. (2014), modified by Tim C. Henderson (Colorado State University).

Incidents of mass wasting have impacted historical park resources and infrastructure along the battlefield tour road, near the US Route 4 entrance road, and along the ravines and river bluffs stretching from Bemis Heights to the Great Redoubt. Over several decades, a portion of the entrance road located approximately 305 m (1,000 ft) west of the US Route 4 intersection has been impacted by incidents of slope instability, including landslides and slope creep (Table 5; McGuffey and Moore 1979; Federal Highway Administration 2001). On several occasions, the steep cliffs above and below the entrance road have slowly migrated downward, dragging the road along with them. During a 1979 landslide investigation, approximately 90 m (300 ft) of roadway was found to have shifted, with cracks traversing the westernmost 30 m (100 ft) of the slide (McGuffey and Moore 1979). Additional cracks were observed at different locations upslope from the landslide, including some that were reported about 5 m (15 ft) away from the sidewalk around the Great Redoubt parking lot (Table 5). Another landslide event in 1984 destroyed part of the same portion of the entrance road (Federal

Highway Administration 2001). Although repairs in the form of a rock buttress were completed in 1987, the instability problem remained unresolved (Table 5).

Table 5. Summary of mass wasting events along the Battlefield tour road and entrance park road since the late 1970s. Information provided from McGuffey and Moore (1979), Federal Highway Administration (2001), Griswold (2012), and Terracon Consultants, Inc. (2017).

Year	Mass Wasting Event
1979	A small, 15 m (200 ft) landslide north of the bridge overpass along the entrance park roadway. The slide ruptured a drainage pipe beneath the roadway, causing drainage incision and gully development.
1979	Landslide event along the park entrance road below the Great Redoubt. The slide area shifted approximately 90 m (300 ft) of roadway, with cracks traversing the westernmost 30 m (100 ft) of the slide. Additional cracks were observed at different locations upslope from the landslide, including some about 5 m (15 ft) away from the sidewalk around the Great Redoubt parking lot.
1984	Landslide event along the park entrance road below the Great Redoubt. Rehabilitation work in the form of rock buttress installation was completed in 1987.
2001	Landslide event along the park entrance road below the Great Redoubt. The slide area was measured to be 300 m (985 ft) long and extended approximately 60 m (180 ft) upslope to the Great Redoubt Overlook. The landslide event occurred approximately one week after construction crews completed a new drainage system and ditch line adjacent to the roadway; most of the substantial movement took place after periods of heavy rain. Investigators noted several landslide features, including transverse cracks and scarps, a toe bulge, and old head scarps.
2011	Slumping along the tour road near Burgoyne's headquarters required rehabilitation in the form of swale installation (2007), excavation and backhoe testing (2011, 2012), and geotechnical instrumentation installation (2017).

A more recent 2001 landslide investigation of the entrance road reported the slide area to be 300 m (985 ft) long and extending approximately 60 m (180 ft) upslope to the Great Redoubt Overlook (Federal Highway Administration 2001). The 2001 landslide event occurred approximately one week after construction crews completed a new drainage system and ditch line adjacent to the roadway; most of the substantial movement took place after the historical park experienced periods of heavy rain. Investigators noted several landslide features, including (1) transverse cracks and scarps toward the bottom of the slope; (2) a toe bulge adjacent to a newly constructed ditch line; and (3) the appearance of head scarps in the upper portion of the slope (Figure 26; Table 5; Federal Highway Administration 2001). According to the Federal Highway Administration (2001) report, water was observed collecting in areas near the toe bulge, and maintenance personnel reported that groundwater seepage occurs year-round, regardless of the amount of precipitation. The presence of continuous seepage in proximity to the toe bulge could indicate that water is helping to lubricate subsurface slippage planes. Previous remediation projects that sampled cores of the road substrate revealed a clay-rich layer overlain by coarse sand—a geologic configuration that served as a natural slip surface. When saturated, the clay horizon acquires a texture like oatmeal and is prone to failure along hillslopes (Thornberry-Ehrlich 2008).

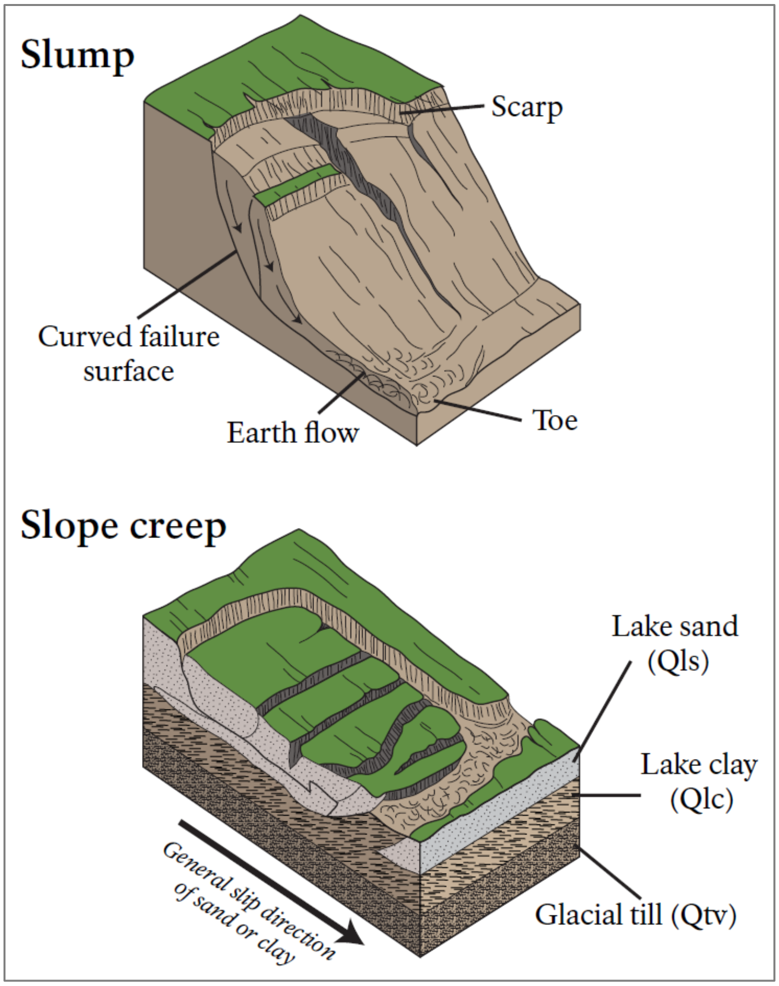

Figure 26. Illustrations of slope movements. Slumping and slope creep are prevalent mass wasting issues at the historical park and occur within unconsolidated materials such as soils and surficial deposits. During saturated conditions, lake clays (Qlc) are prone to failure along steep slopes and develop a slippage plane along which lake sands (Qls) can mobilize. Mass wasting poses a considerable threat to historical park infrastructure and resources. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), redrafted after a graphic and information in Varnes (1978) and Cruden and Varnes (1996).

According to the Federal Highway Administration (2001) report, hillslope stabilization options along the entrance road are limited by the active nature of the landslide, subsurface conditions, and a limited work area. Several mitigation techniques were used to address the slide: (1) unloading or flattening of the slope; (2) buttressing; (3) stone column reinforcement; (4) retaining walls; and (5) drainage installation.

Similar to the entrance road, portions of the battlefield tour road have experienced mass wasting issues dating back several decades. In 1979, a small landslide event was investigated approximately 61 m (200 ft) uphill (north) of the bridge overpassing the entrance road (McGuffey and Moore 1979). Measuring about 15 m (50 ft) long, the hillslope failure severed a 0.3 m (1 ft) diameter drainage pipe that ran underneath the roadway. Water discharging from the broken pipe outlet scoured a 1.2–1.8 m

(4–6 ft) deep erosional gully in the underlying clay slope (Table 5; McGuffey and Moore 1979). In 2011, a section of the tour road near Burgoyne's headquarters experienced slumping attributed to unstable clay deposits and required rehabilitation. To address these issues, several slope stabilization measures were completed, including a new drainage system and swale installation (2008), excavation and backhoe testing (2011 and 2012), and the installation of geotechnical instrumentation (2017) such as inclinometers (which measure slope angles and elevation) and piezometers (which measure fluid pressure) (Table 5; Griswold 2012; Terracon Consultants, Inc. 2017). Older incidents of slumping reported near stop #8 are responsible for covering or obscuring local spring horizons, some of which may have dated to the American Revolution (Linda White, Saratoga National Historical Park, personal communication 23 October 2023).

Anthropogenic modifications to the ravine slopes or bluffs are some of the most common triggers of mass wasting events. Even engineering projects designed with the purpose of redirecting water and stabilizing hillslopes have resulted in enhanced ground instability and the reactivation of old slide surfaces (Thornberry-Ehrlich 2008; McGuffey and Moore 1979; Federal Highway Administration 2001). Any slope stabilization design requires a detailed investigative procedure that includes subsurface analyses (i.e., strength characteristics, pore pressures, depth to bedrock) and topographic surveys to establish reference points to monitor slope movement (Federal Highway Administration 2001). To better maintain the integrity and safety of trail segments near gully damage, steep slopes, or areas of high visitor traffic, the NPS has constructed retaining structures such as checks (logs or rows of stone) to prevent erosion and rehabilitate trail surfaces (Stevens et al. 2007).

The GRD employs three slope management strategies: (1) an Unstable Slope Management Program (USMP) for transportation corridor risk reduction; (2) quantitative risk estimation for specific landslide hazards; and (3) monitoring of potential mass wasting areas. Historical park managers can contact the GRD to discuss these options and determine if submitting a technical request is appropriate. Further information about slope movements and requesting assistance with these issues is provided in "Guidance for Resource Management." The National Landslide Preparedness Act was signed into law on 5 January 2021. The act authorized the establishment of the National Landslide Hazards Reduction Program and requires the US Geological Survey and other federal agencies to identify, map, assess, and research landslide hazards.

Quicksand

Quicksand, also referred to as "sinking sand," consists of very fine- and fine-grained sediment (sand, silt, or clay) suspended in water. Although quicksand commonly looks solid in appearance, it behaves as a non-Newtonian fluid (has variable viscosity depending on stress) and loses cohesive strength as it is disturbed or agitated. People and wildlife who are accidentally caught in quicksand often find it hard to move or escape. Within the historical park, the occurrence of "quicksand" has been reported along areas of the Hudson River floodplain mapped as alluvium deposits (**Qal**). In the southern portion of the Battlefield Unit, park staff unexpectedly encountered quicksand at a water monitoring site near the Mill Creek-Hudson River confluence (see poster). One staff member discovered the quicksand to be roughly waist deep and was retrieved from the sticky matrix with a great deal of assistance. Another occurrence of quicksand was reported in 2001 near the entrance road along the steep slopes below the Great Redoubt (see poster). While performing a slope re-stabilization project, an excavator became caught in a deep pocket of quicksand and was almost completely engulfed (Linda White, Saratoga National Historical Park, personal communication 8 November 2023).

Radon

Radon is a naturally occurring gas created by the radioactive decay of the element radium. Although radon is usually ubiquitous (present in small amounts) in soil and rocks, some types of rock (i.e., volcanic rocks, granites, dark shales, phosphate-rich rocks, and metamorphic rocks) have the potential to produce above average amounts of radon gas that can pose a known health risk (Otton 1992). According to the EPA map of radon zones, Saratoga County is identified as a zone of moderate potential (zone 2) for elevated indoor radon levels.

Seismic Activity

The eastern continental margin of North America is considered passive, meaning that it lacks high levels of earthquake, volcanic, or mountain-building activity associated with tectonic plate motion. However, seismic events still occur along the eastern seaboard of the United States as geologic structures (e.g., faults and fractures) accommodate stress within the deep subsurface of the Earth’s crust. In general, east-central New York experiences only minor seismicity, which largely goes unnoticed. Data from the USGS Earthquake Hazards Program show approximately 500 recorded lower magnitude seismic events in New York since 1900, with many additional earthquakes along the Connecticut-New Jersey-New York boundary (Figure 27). The nearest seismic monitoring station (station “TRY” in Troy, New York) is located about 30 km (19 mi) south of the historical park and is part of the New England Seismic Network.

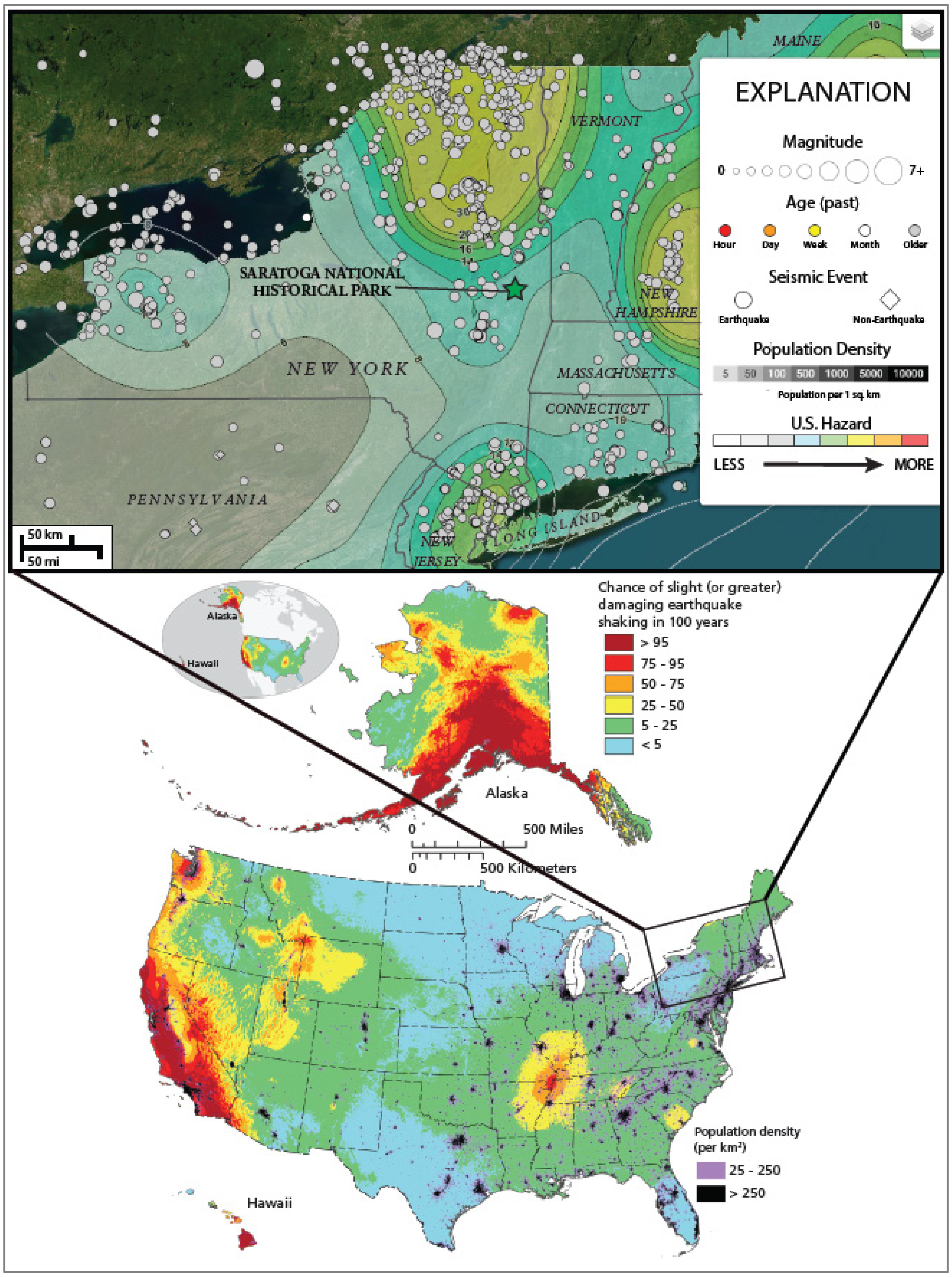

Figure 27. National seismic hazard map of the United States, with a detailed seismic map of the New York area. The national map shows predicted earthquake hazards across the United States for the next 100 years based on National Seismic Hazard Models (US 50-state National Seismic Hazard Model by Petersen et al. 2023). The detailed New York seismic map depicts historic earthquake activity since 1900. Numerous low magnitude earthquakes have been recorded surrounding the historical park, but these events only pose a low potential seismic hazard. Contour labels in the detailed New York seismic map represent the expected number of damaging earthquake occurrences per 10,000 years. Based on both maps, the historical park is situated in an area of low seismic hazard, relative to the rest of the country. USGS map modified by Tim C. Henderson (Colorado State University) using data from the USGS Earthquake Hazards Program (https://www.usgs.gov/programs/earthquake-hazards/science/information-region-new-york; accessed April 2024).

Historically, there have been only six earthquake events registering greater than a magnitude 5.0 on the Richter scale within the state of New York (Wheeler et al. 2000; Tantala et al. 2005). The most recent of these larger seismic events was a magnitude 5.1 earthquake that occurred in 1983 near the city of Plattsburg, approximately 175 km (110 mi) north of Schuylerville (Tantala et al. 2005; Thornberry-Ehrlich 2008). The seismic event was felt at the historical park, but it was not strong enough to threaten park infrastructure. Although unlikely to occur, a large earthquake could trigger mass wasting events and be a threat to historical park resources (Thornberry-Ehrlich 2008). Interestingly, a swarm of seismic events occurred over a four-year span near Albany; the epicenters are aligned with the Saratoga-McGregor fault that passes through Saratoga Springs, west of the historical park (Jacobi and Ebel 2019).

Shrink/swell Clays

The bedrock and surficial deposits within the historical park have been glacially and fluvially eroded to form shrink-and-swell clays (minerals that swell when water-saturated and shrink upon drying) that are a known hazard. As these clay minerals expand and contract, the constant change in volume undermines the integrity of the soil and can increase the susceptibility to mass wasting events. Data from the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Web Soil Survey indicates that several soils within the historical park are rated moderate in linear extensibility (a determination of shrink-swell potential of soils), meaning they can cause damage to buildings, roads, and other structures. These soils are widely mapped across the Battlefield Unit, including the steep river bluffs and tributary valleys.

Toxicological Soils

According to the DOI SHIRA Risk Mapper report, the soils of the historical park include potentially hazardous elemental abundances of arsenic, cadmium, lead, and selenium, in addition to *Bacillus anthracis*, a naturally occurring soil pathogen known to cause anthrax. Soil maps show that potentially hazardous elements occur within the top 5 cm (2 in) of soil based on 2010 sampling (DOI SHIRA). For more information on naturally occurring arsenic, cadmium, lead, and selenium and their potential health impacts, visit the US Department of Health and Human Services Agency for Toxic Substances and Disease Registry (see https://www.atsdr.cdc.gov/; accessed 26 June 2024). For more information on the public health risks associated with naturally occurring anthrax, visit the US Centers for Disease Control and Prevention's anthrax website (see https://www.cdc.gov/anthrax/about/index.html; accessed 26 June 2024).

Geologic Resource Monitoring and Protection

Paleontological Resource Potential

Although the historical park's fossil collections are currently limited to younger Quaternary deposits, outcrop exposures of Ordovician bedrock (**r**) have been reported as fossil localities that merit additional research (see poster). According to the bedrock GRI GIS data, these exposures represent the Ordovician Mohawk River Zone (**Omrz**). Further scientific investigation may yield new discoveries; a comprehensive inventory would be a valuable dataset for resource management and potential interpretive programs (Thornberry-Ehrlich 2008; Tweet et al. 2010).

The reported fossil sites within the historical park are restricted to the Mohawk River Zone (**Omrz**): (1) a site located along the northern escarpment of the Great Ravine in the Battlefield Unit (Cushing and Ruedemann 1914); (2) a locality along Mill Creek east of the Neilson Farm in the Battlefield Unit (Ruedemann and Cook 1930); (3) a cut bank exposure along Fish Creek in the Schuyler Estate (Cushing and Ruedemann 1914); and (4) a location at what is now the Saratoga Surrender Site (Figure 28; Cushing and Ruedemann 1914). Fossil specimens from sites (3) and (4) are identified as graptolites (worm-like colonial animals useful for relative dating), but more specific taxonomic information is needed on the other site locations (Vollmer and Bosworth 1984).

Figure 28. Photograph of bedrock exposures along the eastern boundary of the Saratoga Surrender Site. Located along the west side of US Route 4, these marine sedimentary rocks are mélange deposits assigned to the Ordovician Mohawk River Zone (Omrz). Outcrops in this area include a vaguely described fossil locality reported by Cushing and Ruedemann (1914) and merit additional investigation. Photograph taken by Matt Harrington (Colorado State University).

Guidance for Resource Management

This chapter provides information to assist resource managers in addressing geologic resource management issues and applying NPS policy. The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), NPS 2006 Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75).

Access to GRI Products

- GRI products (scoping summaries, GIS data, posters, and reports): https://go.nps.gov/gripubs
- GRI products are also available through the NPS Integrated Resource Management Applications (IRMA) DataStore portal: https://irma.nps.gov/DataStore/Search/Quick. Enter "GRI" as the search text and select a park from the unit list.
- GRI GIS data model: https://go.nps.gov/gridatamodel
- Additional information regarding the GRI, including contact information: https://www.nps.gov/subjects/geology/gri.htm

Three Ways to Receive Geologic Resource Management Assistance

- Contact the GRD (https://www.nps.gov/orgs/1088/contactus.htm). GRD staff members provide coordination, support, and guidance for geologic resource management issues in three emphasis areas: (1) geologic heritage, (2) active processes and hazards, and (3) energy and minerals management. GRD staff can provide technical assistance with resource inventories, assessments, and monitoring; impact mitigation, restoration, and adaptation; hazards risk management; laws, regulations, and compliance; resource management planning; and data and information management.
- Formally request assistance at the Solution for Technical Assistance Requests (STAR) webpage: https://irma.nps.gov/Star/ (available on the Department of the Interior [DOI] network only). NPS employees (from a park, region, or any other office outside of the Natural Resource Stewardship and Science [NRSS] Directorate) can submit a request for technical assistance from NRSS divisions and programs.
- Submit a proposal to receive geologic expertise through the Scientists in Parks program (SIP; see https://www.nps.gov/subjects/science/scientists-in-parks.htm). Formerly the Geoscientists-in-the-Parks program, the SIP program places scientists (typically undergraduate students) in parks to complete science-related projects that may address resource management issues. Proposals may be for assistance with research, interpretation and public education, inventory, and/or monitoring. The GRD can provide guidance and assistance with submitting a proposal. The Geological Society of America and Environmental Stewards are partners of the SIP program. Visit the internal SIP website to submit a proposal at https://doimspp.sharepoint.com/sites/nps-scientistsinparks (only available on DOI network computers).

Geological Monitoring

Geological Monitoring (Young and Norby 2009) provides guidance for monitoring vital signs (measurable parameters of the overall condition of natural resources). Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies. Chapters are available online at https://www.nps.gov/subjects/geology/geological-monitoring.htm

Assistance with River Pollution-Related Issues

Contamination of the Hudson River corridor introduces additional management considerations that are beyond the scope of this report. Agencies such as the EPA are best equipped to handle issues related to fluvial contamination or pollution. For issues related to the PCB contamination of the Hudson River, the reader is directed to the EPA Hudson River PCBs Superfund Site (https://www.epa.gov/hudsonriverpcbs). The EPA website contains fact sheets, remediation project documents, remediation updates, and long-term river monitoring operations. Additionally, park managers are directed to the NPS Water Resources Division (see "Additional References, Resources, and Websites") for more information regarding water resources guidance and planning.

Park-Specific Documents

Primary sources of information for resource management within the historical park include the NPS foundation document (National Park Service 2021a), Natural Resource Condition Assessment report (Wagner et al. 2014), GRI scoping summary report (Thornberry-Ehrlich 2008), and groundwater resources report (Heath and Tannenbaum 1963). These documents guided the writing of this GRI report.

NPS Natural Resource Management Guidance and Documents

- National Parks Omnibus Management Act of 1998: https://www.congress.gov/bill/105th-congress/senate-bill/1693
- NPS-75: Natural Resources Inventory and Monitoring guideline: https://irma.nps.gov/DataStore/Reference/Profile/622933
- NPS Management Policies 2006 (Chapter 4: Natural Resource Management): https://www.nps.gov/subjects/policy/management-policies.htm
- NPS Natural Resource Management Reference Manual #77: https://irma.nps.gov/DataStore/Reference/Profile/572379
- Resist-Accept-Direct (RAD)—A Framework for the 21st-century Natural Resource Manager: https://irma.nps.gov/DataStore/Reference/Profile/2283597

Geologic Resource Laws, Regulations, and Policies

The following sections, which were developed by the GRD, summarize laws, regulations, and policies that specifically apply to NPS geologic resources, geologic processes, energy, and minerals. The first section summarizes law and policy for geoheritage resources, which includes caves, paleontological resources, and geothermal resources. The energy and minerals section includes abandoned mineral lands, mining, rock and mineral collection, and oil and gas operations. Active processes include geologic hazards (e.g., landslides), coastal processes, soils, and upland and fluvial processes (e.g., erosion). Laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, NEPA, or the National Historic Preservation Act) are not included, but the NPS Organic Act is listed when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available.

Geoheritage Resource Laws, Regulations, and Policies

Caves and Karst Systems

Resource-specific laws:

- **Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309** requires Interior/Agriculture to identify "significant caves" on Federal lands, regulate/restrict use of those caves as appropriate, and include significant caves in land management planning efforts. Imposes civil and criminal penalties for harming a cave or cave resources. Authorizes Secretaries to withhold information about specific location of a significant cave from a Freedom of Information Act (FOIA) requester.
- **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of cave and karst resources.
- **Lechuguilla Cave Protection Act of 1993, Public Law 103-169** created a cave protection zone (CPZ) around Lechuguilla Cave in Carlsbad Caverns National Park. Within the CPZ, access and the removal of cave resources may be limited or prohibited; existing leases may be cancelled with appropriate compensation; and lands are withdrawn from mineral entry.

Resource-specific regulations:

- **36 CFR § 2.1** prohibits possessing/destroying/disturbing…cave resources…in park units.
- **43 CFR Part 37** states that all NPS caves are "significant" and sets forth procedures for determining/releasing confidential information about specific cave locations to a FOIA requester.

NPS Management Policies 2006:

- **Section 4.8.1.2** requires NPS to maintain karst integrity, minimize impacts.
- **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
- **Section 4.8.2.2** requires NPS to protect caves, allow new development in or on caves if it will not impact the cave environment, and to remove existing developments if they impair caves.
- **Section 6.3.11.2** explains how to manage caves in/adjacent to wilderness.

Geothermal

Resource-specific laws:

- **Geothermal Steam Act of 1970, 30 USC. § 1001** et seq. as amended in 1988, states:

    - No geothermal leasing is allowed in parks.
    - "Significant" thermal features exist in 16 park units (the features listed by the NPS at 52 Fed. Reg. 28793-28800 (August 3, 1987), plus the thermal features in Crater Lake, Big Bend, and Lake Mead).
    - NPS is required to monitor those features.
    - Based on scientific evidence, Secretary of Interior must protect significant NPS thermal features from leasing effects.
- **Geothermal Steam Act Amendments of 1988, Public Law 100--443** prohibits geothermal leasing in the Island Park known geothermal resource area near Yellowstone and outside 16 designated NPS units if subsequent geothermal development would significantly adversely affect identified thermal features.

Resource-specific regulations:

- **43 CFR Part 3200** requires BLM to include stipulations when issuing, extending, renewing, or modifying leases or permits to protect significant thermal features in NPS-administered areas (see 43 CFR §3201.10), prohibit the bureau from issuing leases in areas where geothermal operations are reasonably likely to result in significant adverse effects on significant thermal features in NPS-administered areas (see 43 CFR §3201.11 and §3206.11), and prohibit BLM from issuing leases in park units.

NPS Management Policies 2006:

- **Section 4.8.2.3** requires NPS to:
    - Preserve/maintain integrity of all thermal resources in parks.
    - Work closely with outside agencies.
    - Monitor significant thermal features.

Paleontological Resources

Resource-specific laws:

- **Archaeological Resources Protection Act of 1979, 16 USC §§ 470aa – mm Section 3 (1)** Archaeological Resource—nonfossilized and fossilized paleontological specimens, or any portion or piece thereof, shall not be considered archaeological resources, under the regulations of this paragraph, unless found in an archaeological context. Therefore, fossils in an archaeological context are covered under this law.
- **Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309 Section 3 (5)** Cave Resource—the term "cave resource" includes any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems. Therefore, every reference to cave resource in the law applies to paleontological resources.

- **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of paleontological resources and objects.
- **Paleontological Resources Preservation Act of 2009, 16 USC § 470aaa** et seq. provides for the management and protection of paleontological resources on federal lands.

Resource-specific regulations:

- **36 CFR § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof.
- **Prohibition in 36 CFR § 13.35** applies even in Alaska parks, where the surface collection of other geologic resources is permitted.
- **43 CFR Part 49** contains the DOI regulations implementing the Paleontological Resources Preservation Act, which apply to the NPS.

NPS Management Policies 2006:

- **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.

Energy and Minerals Laws, Regulations, and Policies

<u>Abandoned Mineral Lands and Orphaned Oil and Gas Wells</u>

Resource-specific laws:

- **The Bipartisan Infrastructure Law**, **Inflation Reduction Act**, and **NPS Line Item Construction** program all provide funding for the reclamation of abandoned mineral lands and the plugging of orphaned oil and gas wells.

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- None applicable.

<u>Coal</u>

Resource-specific laws:

- **Surface Mining Control and Reclamation Act (SMCRA) of 1977, 30 USC § 1201** et. seq. prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.

Resource-specific regulations:

- **SMCRA Regulations at 30 CFR Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation, and employee protection. Part 7 of the regulations states that National Park System lands are unsuitable for surface mining.

NPS Management Policies 2006:

- None applicable.

<u>Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)</u>

Resource-specific laws:

- **Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units.
- **Reclamation Act of 1939, 43 USC §387**, authorizes removal of common variety mineral materials from federal lands in federal reclamation projects. This act is cited in the enabling statutes for Glen Canyon and Whiskeytown National Recreation Areas, which provide that the Secretary of the Interior may permit the removal of federally owned nonleasable minerals such as sand, gravel, and building materials from the NRAs under appropriate regulations. Because regulations have not yet been promulgated, the National Park Service may not permit removal of these materials from these National Recreation Areas.
- **16 USC §90c-1(b)** authorizes sand, rock, and gravel to be available for sale to the residents of Stehekin from the non-wilderness portion of Lake Chelan National Recreation Area for local use as long as the sale and disposal does not have significant adverse effects on the administration of the national recreation area.

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- **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 the 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.

<u>Federal Mineral Leasing (Oil, Gas, and Solid Minerals)</u>

Resource-specific laws:

- **The Mineral Leasing Act, 30 USC § 181** et seq., and the Mineral Leasing Act for Acquired Lands, 30 USC § 351 et seq. do not authorize the BLM to lease federally owned minerals in NPS units.
- **Combined Hydrocarbon Leasing Act, 30 USC §181**, allowed owners of oil and gas leases or placer oil claims in Special Tar Sand Areas (STSA) to convert those leases or claims to combined hydrocarbon leases, and allowed for competitive tar sands leasing. This act did not modify the general prohibition on leasing in park units but did allow for lease conversion in Glen Canyon National Recreation Area, which is the only park unit that contains a STSA.
- **Exceptions:** Glen Canyon National Recreation Area (NRA) (16 USC § 460dd et seq.), Lake Mead NRA (16 USC § 460n et seq.), and Whiskeytown-Shasta-Trinity NRA (16 USC § 460q et seq.) authorize the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration.
- **American Indian Lands** Within NPS Boundaries Under the Indian Allottee Leasing Act of 1909, 25 USC §396, and the Indian Leasing Act of 1938, 25 USC §396a, §398 and §399, and Indian Mineral Development Act of 1982, 25 USCS §§2101-2108, all minerals on American Indian trust lands within NPS units are subject to leasing.
- **Federal Coal Leasing Amendments Act of 1975, 30 USC § 201** prohibits coal leasing in National Park System units.

Resource-specific regulations:

- **36 CFR § 5.14** states prospecting, mining, and…leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law.
- **BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing.
- Regulations re: Native American Lands within NPS Units:
    - **25 CFR Part 211** governs leasing of tribal lands for mineral development.
    - **25 CFR Part 212** governs leasing of allotted lands for mineral development.
    - **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development.
    - **25 CFR Part 224** governs tribal energy resource agreements.
    - **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938 (codified at 25 USC §§ 2101-2108).

- **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases.
- **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases.
- **30 CFR §§ 1206.50-1206.62 and §§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases.
- **30 CFR § 1206.450** governs the valuation of coal from Indian Tribal and Allotted leases.
- **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.

NPS Management Policies 2006:

- **Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs.

<u>Mining Claims (Locatable Minerals)</u>

Resource-specific laws:

- **Mining in the Parks Act of 1976, 54 USC § 100731** et seq. authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas.
- **General Mining Law of 1872, 30 USC § 21** et seq. allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA.
- **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.

Resource-specific regulations:

- **36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law.
- **36 CFR Part 6** regulates solid waste disposal sites in park units.
- **36 CFR Part 9**, Subpart A requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability.
- **43 CFR Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.

NPS Management Policies 2006:

- **Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at 36 CFR Parts 6 and 9A.
- **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.

<u>Nonfederal Minerals other than Oil and Gas</u>

Resource-specific laws:

- NPS Organic Act, 54 USC §§ 100101 and 100751

Resource-specific regulations:

- **NPS regulations at 36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a business operation (§ 5.3) or for construction of buildings or other facilities (§ 5.7), and to comply with the solid waste regulations at Part 6.

NPS Management Policies 2006:

- **Section 8.7.3** states that operators exercising rights in a park unit must comply with 36 CFR Parts 1 and 5.

<u>Nonfederal Oil and Gas</u>

Resource-specific laws:

- **NPS Organic Act, 54 USC § 100751** et seq. authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights).
- Individual Park Enabling Statutes:
    - 16 USC § 230a (Jean Lafitte NHP & Pres.)
    - 16 USC § 450kk (Fort Union NM)
    - 16 USC § 459d-3 (Padre Island NS)
    - 16 USC § 459h-3 (Gulf Islands NS)
    - 16 USC § 460ee (Big South Fork NRRA)
    - 16 USC § 460cc-2(i) (Gateway NRA)
    - 16 USC § 460m (Ozark NSR)
    - 16 USC § 698c (Big Thicket N Pres.)
    - 16 USC § 698f (Big Cypress N Pres.)

Resource-specific regulations:

- **36 CFR Part 6** regulates solid waste disposal sites in park units.
- **36 CFR Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights in parks outside of Alaska to:
    - Demonstrate valid right to develop mineral rights;
    - Submit an Operations Permit Application to NPS describing where, when, and how they intend to conduct operations;
    - Prepare/submit a reclamation plan; and
    - Submit financial assurance to cover reclamation and potential liability.
- **43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska.

NPS Management Policies 2006:

- **Section 8.7.3** requires operators to comply with 9B regulations.

<u>Recreational Collection of Rocks and Minerals</u>

Resource-specific laws:

- **NPS Organic Act, 54 USC. § 100101** et seq. directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law.
- **Exception: 16 USC. § 445c (c)** – Pipestone National Monument enabling statute. Authorizes American Indian collection of catlinite (red pipestone).

Resource-specific regulations:

- **36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources…in park units.
- **Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown National Recreation Area.
- **Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.

NPS Management Policies 2006:

- **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.

Transpark Petroleum Product Pipelines

Resource-specific laws:

- The **Mineral Leasing Act, 30 USC § 181** et seq., and the **Mineral Leasing Act for Acquired Lands, 30 USC § 351** et seq. authorize new rights of way across some federal lands for pipelines, excluding NPS areas.
- The only parks with the legal authority to grant new rights of way for petroleum product pipelines are:
    - Natchez Trace Parkway (16 USC §460a)
    - Blue Ridge Parkway (16 USC §460a-8)
    - Great Smoky Mountains National Park (P.L. 107-223 – 16 U.S.C. §403 notes)
    - Klondike Gold Rush National Historical Park (16 USC §410bb(c) (limited authority for the White Pass Trail unit)
    - Gulf Islands National Seashore—enabling act authorizes rights-of-way for pipelines for oil and gas transported across the seashore from outside the unit (16 USC §459h-3)
    - Gateway National Recreation Area—enabling act authorizes rights-of-way for gas pipelines in connection with the development of methane gas owned by the City of New York within the unit (16 USC §460cc-2(i))
    - Denali National Park—2013 legislation allows for issuance of right-of-way permits for a natural gas pipeline within, along, or near the approximately 7-mile segment of the George Parks Highway that runs through the park (Public Law 113–33)

Resource-specific regulations:

- NPS regulations at **36 CFR Part 14 Rights of Way**

NPS Management Policies 2006:

- **Section 8.6.4** states that new rights of way through, under, and across NPS units may be issued only if there is specific statutory authority and there is no practicable alternative.

Uranium

Resource-specific laws:

- **Atomic Energy Act of 1954** allows Secretary of Energy to issue leases or permits for uranium on BLM lands; may issue leases or permits in NPS areas only if president declares a national emergency.

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- None applicable.

Active Processes and Geohazards Laws, Regulations, and Policies

<u>Coastal Features and Processes</u>

Resource-specific laws:

- **NPS Organic Act, 54 USC § 100751** et. seq. authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights).
- **Coastal Zone Management Act, 16 USC § 1451** et. seq. requires Federal agencies to prepare a consistency determination for every Federal agency activity in or outside of the coastal zone that affects land or water use of the coastal zone.
- **Clean Water Act, 33 USC § 1342/Rivers and Harbors Act, 33 USC 403** require that dredge and fill actions comply with a Corps of Engineers Section 404 permit.
- **Executive Order 13089** (coral reefs) (1998) calls for reduction of impacts to coral reefs.
- **Executive Order 13158** (marine protected areas) (2000) requires every federal agency, to the extent permitted by law and the maximum extent practicable, to avoid harming marine protected areas.

Resource-specific regulations:

- **36 CFR § 1.2(a)(3)** applies NPS regulations to activities occurring within waters subject to the jurisdiction of the US located within the boundaries of a unit, including navigable water and areas within their ordinary reach, below the mean high water mark (or OHW line) without regard to ownership of submerged lands, tidelands, or lowlands.
- **36 CFR § 5.7** requires NPS authorization prior to constructing a building or other structure (including boat docks) upon, across, over, through, or under any park area.

NPS Management Policies 2006:

- **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress.
- **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety.
- **Section 4.8.1** requires NPS to allow natural geologic processes to proceed unimpeded. NPS can intervene in these processes only when required by Congress, when necessary for saving human lives, or when there is no other feasible way to protect other natural resources/park facilities/historic properties.
- **Section 4.8.1.1** requires NPS to:
    - Allow natural processes to continue without interference,
    - Investigate alternatives for mitigating the effects of human alterations of natural processes and restoring natural conditions,

- Study impacts of cultural resource protection proposals on natural resources,
- Use the most effective and natural-looking erosion control methods available, and
- Avoid putting new developments in areas subject to natural shoreline processes unless certain factors are present.

Geologic Hazards

Resource-specific laws:

- **National Landslide Preparedness Act, 43 USC §§ 3101–3104** strengthens the mandate to identify landslide hazards and reduce losses from landslides. Established the National Landslide Hazards Reduction Program. "…the United States Geological Survey and other Federal agencies, shall – identify, map, assess, and research landslide hazards;" Reduce landslide losses, respond to landslide events.

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- **Section 4.8.1.3**, Geologic Hazards
- **Section 9.1.1.5**, Siting Facilities to Avoid Natural Hazards
- **Section 8.2.5.1**, Visitor Safety
- **Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks.

Soils

Resource-specific laws:

- **Soil and Water Resources Conservation Act, 16 USC §§ 2001–2009** 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 ensure 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).

Resource-specific regulations:

- **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.

NPS Management Policies 2006:

- **Section 4.8.2.4** requires NPS to (1) prevent unnatural erosion, removal, and contamination; (2) conduct soil surveys; (3) minimize unavoidable excavation; and (4) develop/follow written prescriptions (instructions).

Upland and Fluvial Processes

Resource-specific laws:

- **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**).

Resource-specific regulations:

- None applicable.

NPS Management Policies 2006:

- **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.

Additional References, Resources, and Websites

Climate Change Resources

- Intergovernmental Panel on Climate Change: https://www.ipcc.ch/
- *Global and regional sea level rise scenarios for the Unites States* (Sweet et al. 2022): https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html
- NPS Climate Change Response Strategy (2023 Update): https://www.nps.gov/subjects/climatechange/response-strategy.htm
- NPS Green Parks Plan: https://www.nps.gov/subjects/sustainability/green-parks.htm
- NPS National Climate Change Interpretation and Education Strategy: https://www.nps.gov/subjects/climatechange/nccies.htm
- NPS Policy Memorandum 12-02—Applying NPS Management Policies in the Context of Climate Change: https://npspolicy.nps.gov/PolMemos/policymemoranda.htm
- NPS Policy Memorandum 15-01—Addressing Climate Change and Natural Hazards for Facilities: https://npspolicy.nps.gov/PolMemos/policymemoranda.htm
- NPS Sea Level Change website: https://www.nps.gov/subjects/climatechange/sealevelchange.htm/index.htm
- *Sea level rise and storm surge projections for the National Park Service* (Caffrey et al. 2018): https://irma.nps.gov/DataStore/Reference/Profile/2253283
- U.S. Global Change Research Program: https://www.globalchange.gov/

Days to Celebrate Geology

- Geologist Day—the first Sunday in April (marks the end of the winter and beginning of preparation for summer field work; formally celebrated in Ukraine, Kazakhstan, Belarus, Kyrgyzstan, and Russia)
- National Cave and Karst Day—6 June, also known as International Day of Caves and Subterranean World
- International Geodiversity Day—6 October: https://www.geodiversityday.org/
- Earth Science Week—typically the second full week of October: https://www.earthsciweek.org/
- National Fossil Day—the Wednesday of Earth Science Week: https://www.nps.gov/subjects/fossilday/index.htm

Disturbed Lands Restoration

Geoconservation—Disturbed Lands Restoration: https://www.nps.gov/articles/geoconservation-disturbed-land-restoration.htm

Earthquakes

- USGS Did You Feel It? reporting system: https://earthquake.usgs.gov/data/dyfi/
- USGS Earthquake Hazards Program unified hazard tool: https://earthquake.usgs.gov/hazards/interactive/
- USGS Earthquake Hazards Program, Information by Region – New York: https://www.usgs.gov/programs/earthquake-hazards/science/information-region-new-york
- USGS National Seismic Hazard Model: https://www.usgs.gov/programs/earthquake-hazards/science/national-seismic-hazard-model
- USGS ShakeMap: https://earthquake.usgs.gov/data/shakemap/

Flooding

- FEMA National Flood Hazard Layer: https://www.fema.gov/flood-maps/national-flood-hazard-layer
- NPS Water Resources Division report (Martin 2003)

Geologic Heritage

- NPS America's Geologic Heritage: https://www.nps.gov/subjects/geology/americas-geoheritage.htm
- NPS Geoheritage Sites—Examples on Public Lands, Natural Landmarks, Heritage Areas, and The National Register of Historic Places: https://www.nps.gov/subjects/geology/geoheritage-sites-listing-element.htm
- NPS Museum Collection (searchable online database): https://museum.nps.gov/ParkPList.aspx
- NPS National Natural Landmarks Program: https://www.nps.gov/subjects/nnlandmarks/index.htm
- NPS National Register of Historic Places: https://www.nps.gov/subjects/nationalregister/index.htm
- NPS Stratotype Inventory: https://www.nps.gov/subjects/geology/nps-stratotype-inventory.htm
- UNESCO Global Geoparks: https://en.unesco.org/global-geoparks

Geologic Maps

- American Geosciences Institute (provides information about geologic maps and their uses): https://www.americangeosciences.org/environment/publications/mapping
- *General Standards for Geologic Maps* (Evans 2016)
- USGS MapView by National Geologic Map Database: https://ngmdb.usgs.gov/mapview
- USGS National Geologic Map Database: https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

Geological Surveys and Societies

- American Geophysical Union: https://sites.agu.org/
- American Geosciences Institute: https://www.americangeosciences.org/
- Association of American State Geologists: https://www.stategeologists.org/
- Geological Society of America: https://www.geosociety.org/
- New York State Museum: https://www.nysm.nysed.gov/research-collections/geology
- US Geological Survey: https://www.usgs.gov/

Hudson River PCBs

- NPS Water Resources Division: https://www.nps.gov/orgs/1439/index.htm
- US Environmental Protection Agency Hudson River PCBs Superfund Site: https://www.epa.gov/hudsonriverpcbs

Landslides and Slope Movements

- FEMA National Risk Index—Landslide: https://hazards.fema.gov/nri/landslide
- *Geological Monitoring* chapter about slope movements (Wieczorek and Snyder 2009): https://go.nps.gov/geomonitoring
- *The Landslide Handbook—A Guide to Understanding Landslides* (Highland and Bobrowsky 2008): https://pubs.usgs.gov/circ/1325/
- Unstable Slope Management Program for transportation corridor risk reduction: https://usmp.info/client/credits.php
- USGS Landslide Inventory: https://www.usgs.gov/tools/us-landslide-inventory

New York State Geology

- *Geology of New York: A Simplified Account (2nd Edition)* (Isachsen et al. 2000): https://www.nysm.nysed.gov/publications/education-leaflets
- New York State Department of Health Radon Tracker: https://apps.health.ny.gov/statistics/environmental/public_health_tracking/tracker/index.html#/radonStatebyYear
- New York State Geological Association—Field Guidebooks: https://www.nysga-online.org/guidebooks/
- New York State Museum—Archeology: https://www.nysm.nysed.gov/research-collections/archaeology
- New York State Museum—Geology: https://www.nysm.nysed.gov/research-collections/geology
- New York State Museum—GIS Data: https://www.nysm.nysed.gov/research-collections/geology/gis

- New York State Museum—Paleontology: https://www.nysm.nysed.gov/research-collections/paleontology
- New York State Museum—Publications: https://www.nysm.nysed.gov/publications

NPS Geology

- NPS America's Geologic Legacy: https://go.nps.gov/geology. This primary site for information about NPS geology includes a geologic tour, news, and other information about geology in the NPS, and resources for educators and park interpreters.
- NPS Geodiversity Atlas: https://www.nps.gov/articles/geodiversity-atlas-map.htm. The NPS Geodiversity Atlas is a collection of park-specific webpages containing information about the park's geology and links to additional resources.
- NPS Geologic Resources Inventory: https://go.nps.gov/gri

NPS Reference Tools

- NPS Technical Information Center (TIC; repository for technical documents and means to receive interlibrary loans): https://www.nps.gov/orgs/1804/dsctic.htm
- GeoRef. The GRI team collaborates with TIC to maintain an NPS subscription to GeoRef (the premier online geologic citation database) via the Denver Service Center Library interagency agreement with the Library of Congress. Multiple portals are available for NPS staff to access these records. Park staff can contact the GRI team or GRD for access.
- NPS Integrated Resource Management Applications (IRMA) DataStore portal: https://irma.nps.gov/DataStore/Search/Quick. *Note*: The GRI team uploads scoping summaries, maps, and reports to IRMA. Enter "GRI" as the search text and select a park from the unit list.

Relevancy, Diversity, and Inclusion

- NPS Office of Relevancy, Diversity, and Inclusion: https://www.nps.gov/orgs/1244/index.htm
- Changing the narrative in science & conservation: an interview with Sergio Avila (Sierra Club, Outdoor Program coordinator). Science Moab radio show/podcast: https://sciencemoab.org/changing-the-narrative/

Soils

- US Centers for Disease Control and Prevention's anthrax website: https://www.cdc.gov/anthrax/about/index.html
- US Department of Health and Human Services Agency for Toxic Substances and Disease Registry (ATSDR): https://www.atsdr.cdc.gov/
- Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. It is operated by the USDA Natural Resources Conservation Service (NRCS): https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

- WSS_four_steps (PDF/guide for how to use WSS): https://irma.nps.gov/DataStore/Reference/Profile/2305342

USGS Reference Tools

- Geographic Names Information System (GNIS; official listing of place names and geographic features): https://gnis.usgs.gov/
- Geologic Names Lexicon (Geolex; geologic unit nomenclature and summary): https://ngmdb.usgs.gov/Geolex
- National Geologic Map Database (NGMDB): https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- NGMDB Geochron Downloader: https://ngmdb.usgs.gov/geochron/
- Publications Warehouse: https://pubs.er.usgs.gov/
- A Tapestry of Time and Terrain (descriptions of physiographic regions; Vigil et al. 2000): https://pubs.usgs.gov/imap/i2720/
- USGS Store (find maps by location or by purpose): https://store.usgs.gov/

Literature Cited

These references are cited in this report. Contact the GRD for assistance in obtaining them.

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