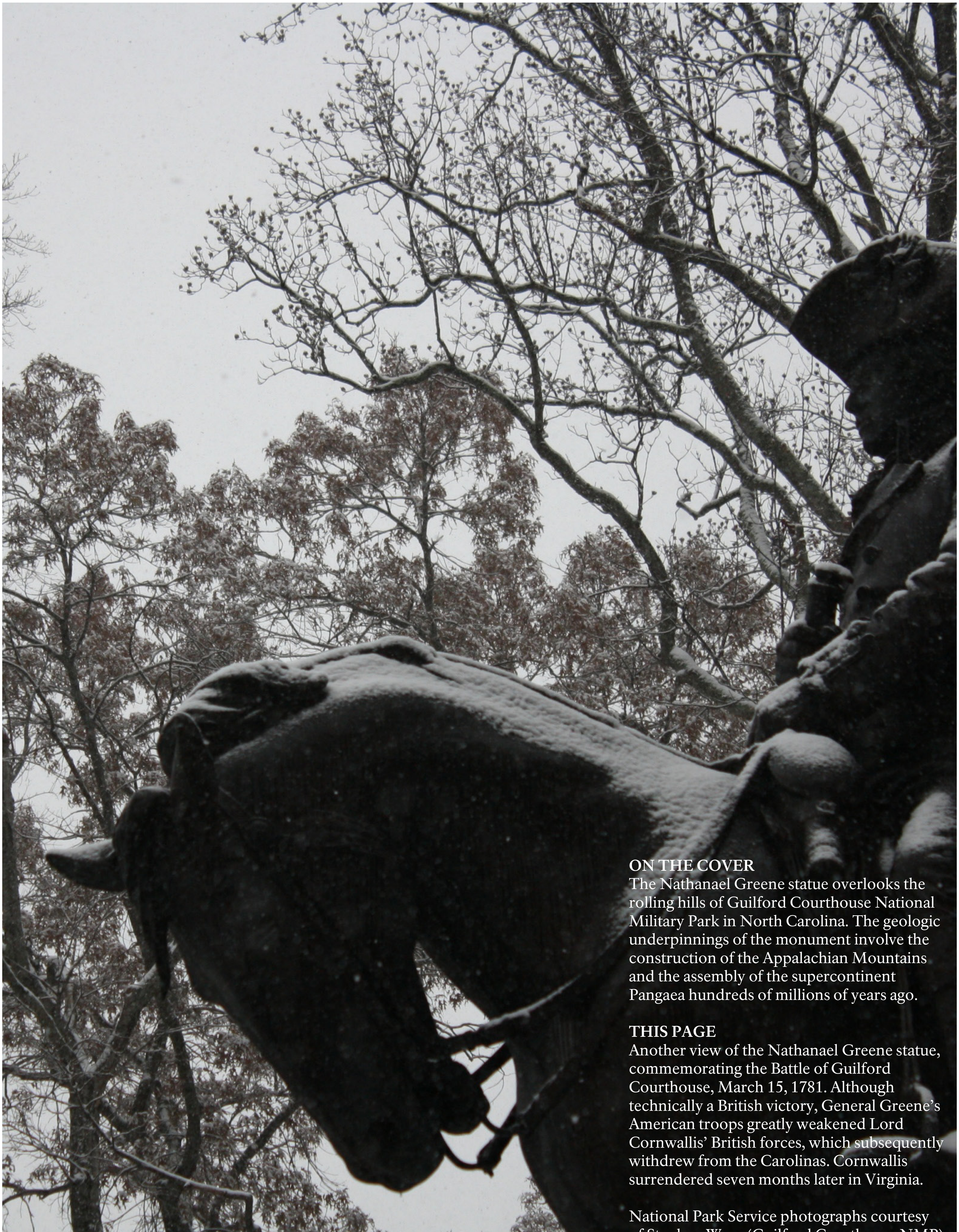
National Park Service
U.S. Department of the Interior

Natural Resource Program Center

# Guilford Courthouse National Military Park

## *Geologic Resources Inventory Report*

Natural Resource Report NPS/NRPC/GRD/NRR—2011/338



**ON THE COVER**
The Nathanael Greene statue overlooks the rolling hills of Guilford Courthouse National Military Park in North Carolina. The geologic underpinnings of the monument involve the construction of the Appalachian Mountains and the assembly of the supercontinent Pangaea hundreds of millions of years ago.

**THIS PAGE**
Another view of the Nathanael Greene statue, commemorating the Battle of Guilford Courthouse, March 15, 1781. Although technically a British victory, General Greene's American troops greatly weakened Lord Cornwallis' British forces, which subsequently withdrew from the Carolinas. Cornwallis surrendered seven months later in Virginia.

National Park Service photographs courtesy of Stephen Ware (Guilford Courthouse NMP)

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National Park Service
Geologic Resources Division
PO Box 25287
Denver, CO 80225

March 2011

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

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Please cite this publication as:

Thornberry-Ehrlich, T. 2011. Guilford Courthouse National Military Park: geologic resources inventory report. Natural Resource Report NPS/NRPC/GRD/NRR—2011/338. National Park Service, Ft. Collins, Colorado.

NPS 316/106984, March 2011

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# Executive Summary

*This report accompanies the digital geologic map data for Guilford Courthouse National Military Park in North Carolina, produced by the Geologic Resources Division in collaboration with its partners. It contains information relevant to resource management and scientific research. This document incorporates preexisting geologic information and does not include new data or additional fieldwork.*

The Battle of Guilford Courthouse was a key turning point for Americans seeking independence from England during the Revolutionary War. This largest and fiercest battle of the war's Southern Campaign severely crippled British military strength. Although the British claimed nominal victory, the battle foreshadowed the defeat of Lord Cornwallis months later at Yorktown, Virginia. The battle occurred near the tiny hamlet of Guilford Courthouse, North Carolina. Geology influenced its outcome; the heavily treed slopes caused extensive losses of British men organized in lines. Visitors' experience of the park could begin with consideration of the geologic processes underlying its environment, history, and scenery.

Geologic processes yield rock formations, mountains, slopes, valleys, springs, and streams. These processes develop a landscape that may facilitate or impede human use. The landscape of the battlefield at Guilford Courthouse National Military Park attracts visitors in search of a historical touchstone and recreational opportunities. The park's geologic resources merit emphasis to enhance visitors' experience. Humans continue to significantly modify the landscape surrounding Guilford Courthouse National Military Park. Geological processes also modify the landscape, creating challenges in preservation and park upkeep. Knowledge of the park's geologic resources may influence resource management decisions regarding potential geological issues, future scientific research projects, interpretive needs, and economic resources associated with the park.

During a Geologic Resources Inventory scoping meeting in 2000, the following issues, features, and processes were identified as having the most geological importance and highest level of management significance to the park:

- Landscape Preservation.
  The record of human impact is intimately tied to the history of Guilford Courthouse National Military Park. Given the past agricultural activities of American Indians, the clearing of fields in the colonial period, and modern urban development, preservation of the park is characterized by a struggle between anthropogenic features and historical context. Geologic processes such as erosion and weathering pose additional challenges to the goal of preservation.
- Erosional and Slope Processes.
  The relatively humid climate of the eastern U.S. and the slopes along the park's waterways create a setting that is susceptible to slumping, which may create new hazard areas. Such problems are often due to a local lack of stabilizing plant growth, combined with substantial seasonal runoff and frequent and intense seasonal rainstorms. Road and trail construction also impact slope stability and slopes may fail when saturated. Although resistant rock units underlie small hills and ridges, they are subject to slope failure when jointed, faulted, or fractured.
- Modern Anthropogenic Impacts.
  Visitors come to Guilford Courthouse National Military Park not only to experience its Revolutionary War history, but also to enjoy the scenic beauty of central North Carolina. Facilities catering to visitors include trails, tour routes, greenways, picnic areas, and visitor centers. Increasing recreational and infrastructural demands influence geologic resource management. Interpretation for visitors of the park's geology, especially in relation to the battle fought there in 1781, is also a resource management issue. High-use areas such as trails are at risk of erosion.

The rocks of central North Carolina record the ancient beginnings of the Appalachian Mountain belt. Accreted bodies of rocks (terranes), exotic to ancient North America and oriented in northeast-southwest parallel belts, characterize the Piedmont of North Carolina. The entire region underwent compression during subsequent mountain-building events (orogenies), culminating in the Alleghany Orogeny (240 million years ago) with the construction of the Appalachian Mountains and the assembly of the supercontinent Pangaea. Metamorphism and volcanic activity were associated with each event, and the processes of erosion and sedimentation were ongoing. After the Alleghany Orogeny and subsequent separation of North America from Europe and Africa (beginning approximately 180 million years ago and continuing to the present day), the erosion and transport of sediment to the east formed what is now the Atlantic Coastal Plain physiographic province. Its western boundary lies near Raleigh, North Carolina, located 130 km (80 mi) east of Guilford Courthouse National Military Park.

The glossary contains explanations of many technical terms used in this report, including terms used in the Map Unit Properties Table. A geologic time scale is provided as figure 10.

# Acknowledgements

*The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service Inventory and Monitoring Program. The GRI is administered by the Geologic Resources Division of the Natural Resource Program Center.*

The Geologic Resources Division relies heavily on partnerships with institutions such as the U.S. Geological Survey, Colorado State University, state geologic surveys, local museums, and universities in developing GRI products.

Special thanks to: Scott Howard (South Carolina Geological Survey) for his help with the Kings Mountain National Military Park GRI report that greatly aided this report. Stephen Ware (Guilford Courthouse NMP) contributed photos and other information to the report.

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# Introduction

*The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Guilford Courthouse National Military Park.*

### Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The GRI, administered by the Geologic Resources Division of the Natural Resource Program Center, is designed to provide and enhance baseline information available to park managers. The GRI team relies heavily on partnerships with institutions such as the U.S. Geological Survey, Colorado State University, state geologic surveys, local museums, and universities in developing GRI products.

The goals of the GRI are to increase understanding of the geologic processes at work in parks and to provide sound geologic information for use in park decision making. Sound park stewardship requires an understanding of the natural resources and their role in the ecosystem. Park ecosystems are fundamentally shaped by geology. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS-75, Natural Resources Inventory and Monitoring Guideline.

To realize these goals, the GRI team is systematically conducting a scoping meeting for each of the 270 identified natural area parks and providing a park-specific digital geologic map and geologic report. These products support the stewardship of park resources and are designed for non-geoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRI mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their Geographic Information Systems (GIS) Data Model. These digital data sets bring an interactive dimension to traditional paper maps. The digital data sets provide geologic data for use in park GIS and facilitate the incorporation of geologic considerations into a wide range of resource management applications. The newest maps contain interactive help files. This geologic report assists park managers in the use of the map and provides an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and current GRI contact information please refer to the Geologic Resources Inventory web site (http://www.nature.nps.gov/geology/inventory/).

### Park Setting

Guilford Courthouse National Military Park is located adjacent to U.S. 220 (Battleground Avenue) in a picturesque area that stretches along the eastern foothills of the southern Appalachian Mountains in North Carolina. The National Park Service strives to preserve the 92.6 ha (229 ac) of a historic Revolutionary War battleground landscape (approximately one-fourth of the area in which fighting occurred), the archaeological remains of the town of Martinsville (ca. 1785), and cultural remains associated with the commemorative period beginning in the mid-1880s (fig. 1) (Baker 1995; Hiatt 2003). The national military park is currently the centerpiece of a larger (130 ha, 320 ac) National Historic Landmark district consisting of battlefield land owned by federal, municipal, and private entities (Hiatt 2003). The park is surrounded by the town of Greensboro, North Carolina, in 1984 and urban sprawl has consumed nearly all unprotected portions of the battlefield (Hiatt 2003). The resources within the park are thus critical for the understanding of the area's history and the preservation of natural space within the now urban context.

The park is located in the southern Appalachian Mountains, northwest of Great Smoky Mountains National Park. Annual visitation to Guilford Courthouse National Military Park exceeded 285,000 visitors in 2010. The attraction of the park extends beyond the history of the famous battle; the area's topography and geology are complex and scenic.

### Geologic Setting

Guilford Courthouse National Military Park is located in the southern Appalachian Piedmont physiographic province. This province extends from the Blue Ridge Mountains to the "Fall Line" or "Fall Zone", which marks the inland termination of the Atlantic Coastal Plain (Harris et al. 1997). The Piedmont was formed by a combination of accretion, folding, faulting, uplift, and erosion. The present topography is the result of uplift, weathering, and erosion of an ancient Appalachian mountain system that rivaled today's Himalayas. The roots of that system are consequently exposed today.

The geology of the Carolina Piedmont is tied to the formation of the Appalachian Mountains and the assembly of the supercontinent Pangaea (see "Geologic History" below). It is characterized by a series of metamorphosed (altered by high temperature and pressure) northeast-trending terranes in the Carolinas. Terranes are bodies of rock that formed elsewhere and were subsequently accreted onto the continent during repeated Paleozoic collisional events. Ancient faults mark the boundaries of the terranes. These terranes have experienced low- (termed "greenschist–facies") to high-grade (termed "amphibolite–facies") metamorphism, and alternate in parallel bands that trend roughly northeast-southwest (fig. 2) (Horton 2008). This report uses the terrane definitions of Horton et al. (1994), wherein the Carolina terrane (a large component of the "Carolina Zone" of Hibbard et al. 2002) includes packages of rocks traditionally assigned to the Carolina Slate, Charlotte, Kiokee, and Belair belts, and the Kings Mountain sequence.

The rocks of the Inner Piedmont are primarily layered metamorphic rocks such as schist, gneiss, migmatite, and amphibolite. They contain numerous granite-like intrusions of previously molten material that now form layers, dikes, and small plutons (Goldsmith 1981). Many terranes underlie this region. Shear zones—areas where rock was deformed, and/or faulted in response to intense shearing forces—often separate the terranes. Geologic mapping in the vicinity of Guilford Courthouse has revealed that the park is located near an east-northeast–trending shear zone between the Carolina Slate (east) and Charlotte (west) belts of metamorphosed rocks, all part of the Carolina terrane (see Appendix A) (Carpenter 1982; Mininger and Nunnery 2001). Elsewhere in central North Carolina, the Gold Hill–Silver Hill fault zone forms the boundary (Butler and Secor 1991).

The landscape of Guilford Courthouse is characterized by low, irregular ridges, sinuous creeks, and narrow ravines; these features are typical of the Piedmont physiographic province (Hiatt 2003). The relative resistance and structure of the underlying metamorphic bedrock control the location of ridges, ravines, and other Piedmont features. Few bedrock outcrops are exposed within Guilford Courthouse National Military Park. Richland Creek flows through the middle of the park; it contains two impounded ponds south of the park's boundaries, in Greensboro Country Park. The highest elevations in the park are near the Greene Monument at 265 m (870 ft) above sea level. The lowest elevation [238 m (780 ft) above sea level] occurs at the confluence of Hunting Creek and its tributary in the northeastern section of the park.

### History of Guilford Courthouse

Guilford Courthouse National Military Park preserves the setting of a pivotal battle between American troops under General Nathanael Greene and British Redcoats under Lord Cornwallis during the Southern Campaign of the Revolutionary War. This campaign was an attempt by the British to revitalize the stalemate in the north by restoring normal relations with the southern colonies. They met with some initial success, capturing Savannah in 1778 and the rest of Georgia in 1779, devastating South Carolina in April 1779, and placing Charleston under siege in 1779. The Battle of Kings Mountain (now Kings Mountain National Military Park) in South Carolina on October 7, 1780 was a key American victory that effectively halted the British southern advance; Cornwallis' troops fell back. See Thornberry-Ehrlich (2009) for a Geologic Resources Inventory report for Kings Mountain NMP.

Though technically a British victory, the Battle of Guilford Courthouse on March 15, 1781 marked the beginning of the end of the Revolutionary War. The British were outmanned, but were vastly more organized, disciplined, trained, and experienced than their foes. The battle, however, proved very costly for the British. When it was over, they could not pursue the fleeing Americans and had to withdraw from North Carolina. They headed north and were defeated seven months later at Yorktown, Virginia, which forced Cornwallis to surrender. Today, Colonial National Historical Park interprets colonial life and culmination of the Revolutionary War.

The first local effort to commemorate the Battle of Guilford Courthouse was initiated in 1857 by the Greene Monument Association (Baker 1995; Hiatt 2003), but was derailed by the American Civil War in the 1860s. During a great frenzy of post–Civil War patriotism and reconciliation, Americans erected many monuments at battlefields such as Yorktown, Bennington, Newburg, Cowpens, Saratoga, Monmouth, Groton, and Oriskany. Although a similar monument was proposed by early commemoration proponents at Guilford Courthouse, preservationists largely ignored the site until Judge David Schenck took interest in the progress of Greensboro, North Carolina. Acres of land were purchased privately in 1886, helping to preserve at least a portion of the battlefield, and the Guilford Battle Ground Company was founded in March 1887 (fig. 3) (Baker 1995).

Guilford Courthouse National Military Park was established on March 2, 1917 by an act of Congress which provided: "That in order to preserve for historical and professional military study one of the most memorable battles of the Revolutionary War, the battlefield of Guilford Courthouse, in the State of North Carolina, is hereby declared to be a national military park." Guilford Courthouse was the first Revolutionary War battlefield site set aside for preservation as a national park. The War Department administered the unit until its transfer in 1933 to the National Park Service. For more information on the Battle of Guilford Courthouse, consult the park's web site: http://www.nps.gov/guco.

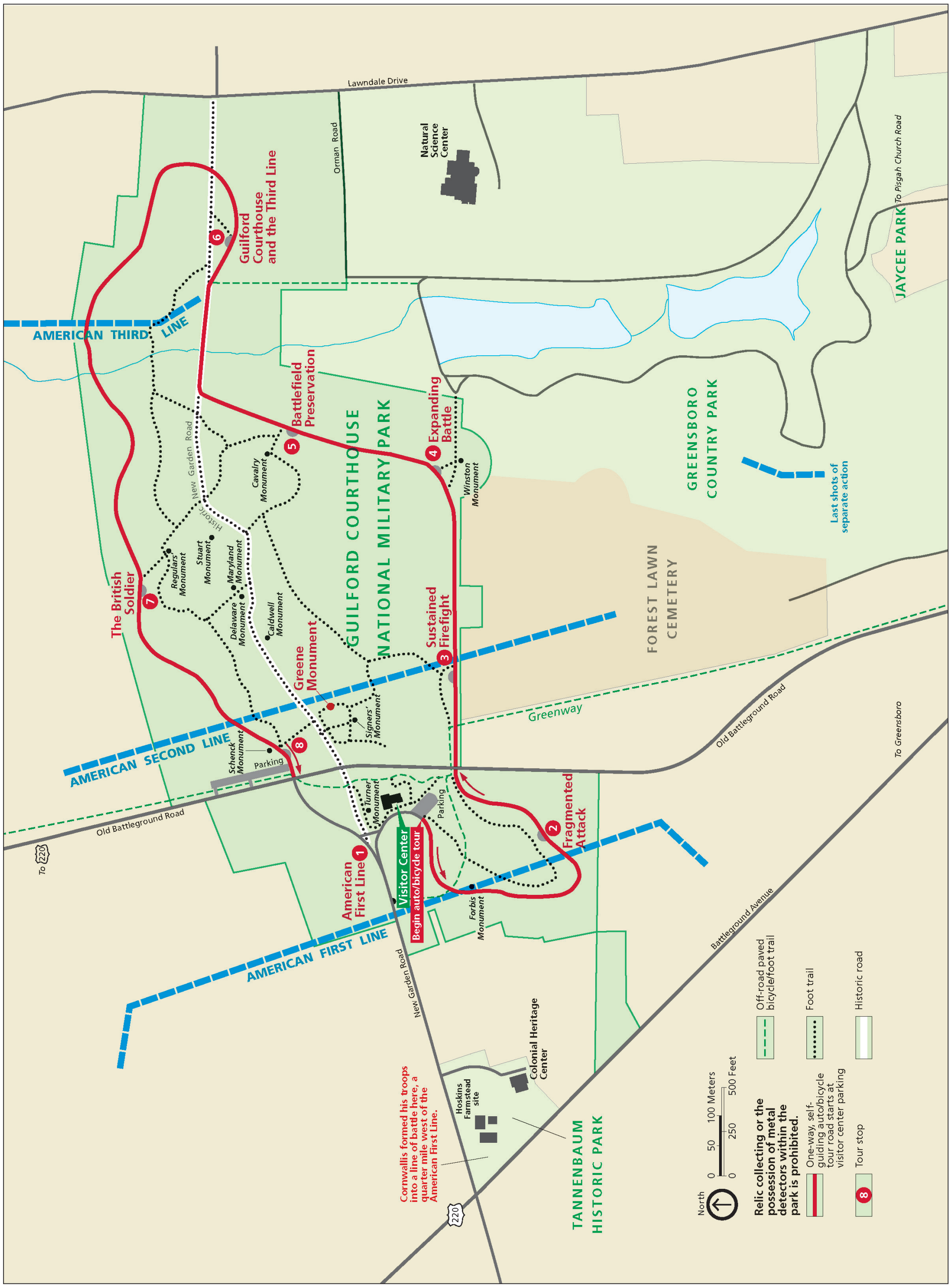


**Figure 1. Location of and features within Guilford Courthouse National Military Park. National Park Service graphic.**

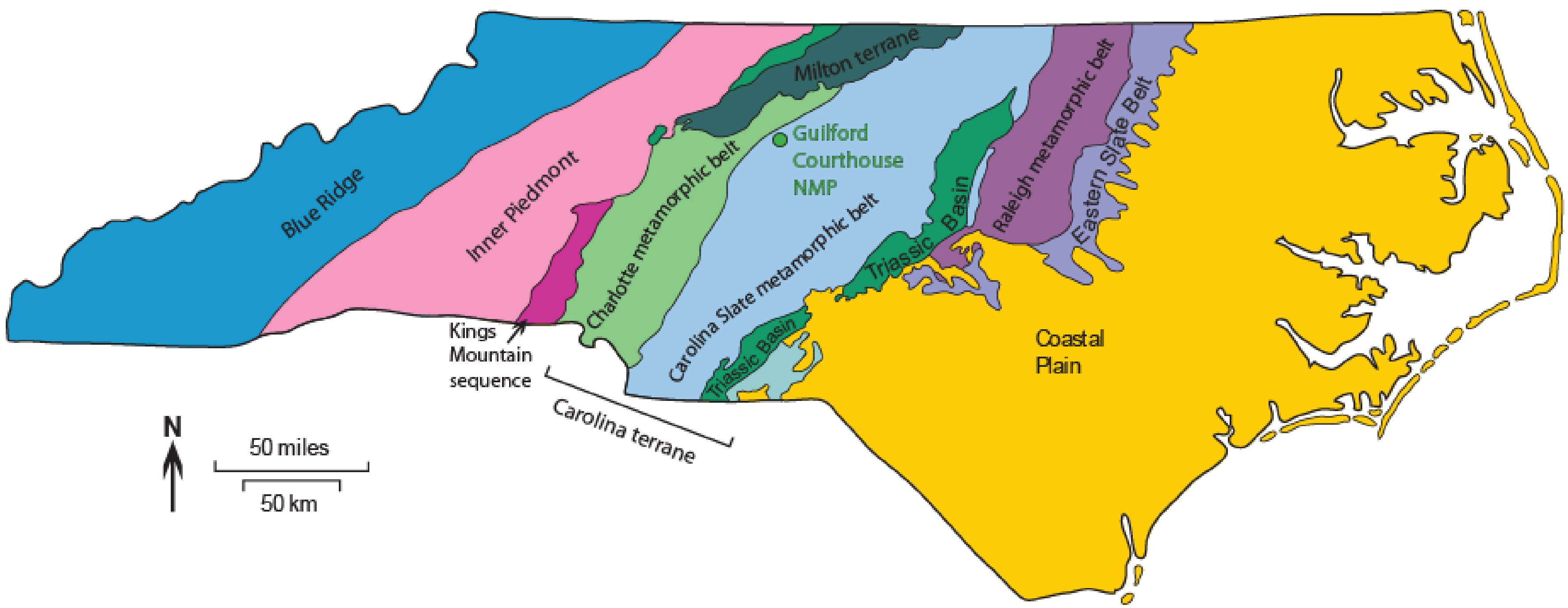


Figure 2. Map of the physiographic provinces and geologic sections in North Carolina. Note the location of Guilford Courthouse National Military Park (green circle). Figure 6 (below) also contains local terrane information. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), using information from the North Carolina Geological Survey Web site (http://www.geology.enr.state.nc.us/).

# Geologic Issues

*The Geologic Resources Division held a Geologic Resources Inventory scoping session for Guilford Courthouse National Military Park on September 20, 2000, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers. Contact the Geologic Resources Division for technical assistance.*

### Landscape Preservation

When the Guilford Battle Ground Company first took interest in the battlefield at Guilford Courthouse, it aimed not to restore the original rugged, largely wooded, wild battleground landscape, but rather to create a "pleasuring ground" with monuments commemorating lost heroes. In 1887, labor crews initiated this beautification project by reclaiming fields from vegetation succession and bringing them back into cultivation, filling in eroded areas and gullies, and removing understory vegetation (a significant feature for the battle) (Schenck 1893; Hiatt 2003). Later, the company cleared the vegetation around the springs at Spring Vale and placed a basin of granite rocks in the primary spring; they also constructed new roads, or "avenues", to the springs (Hiatt 2003). In 1892, a tributary of Hunting Creek was dammed to create Lake Wilfong between the former American second and third battle lines. This project involved grading, excavating, and mounding of earth (Hiatt 2003). Two springhouses and a restaurant were constructed nearby to accommodate visitors to the recreation grounds (Baker 1995). By the time Guilford Courthouse became a national park, it contained 29 monuments and graves on 50 ha (125 ac) of land that commemorated battlefield commanders and soldiers, including the Kerrenhappuch Turner, Nathanael Greene (see front cover), Delaware, Maryland, and Francisco monuments, as well as many other structural "improvements". The effect of these landscape changes at Guilford Courthouse counteracted the preservation of historical context and the battlefield's legacy. Visitors viewed the park more as a picnic area than as a military park (Hiatt 2003).

Following its transfer from the War Department to the Department of the Interior in 1933, the park's mission became one of historical restoration and preservation. Despite a long history of anthropogenic manipulation, the geological terrain remains largely intact today, bolstering the integrity of the setting (Hiatt 2003). The National Park Service is committed to restoring the original landscape at Guilford Courthouse to the greatest possible extent, while acknowledging the significance of the early commemorative period. Park leadership commissioned a report (Hiatt 2003) that has provided guidance on landscape management in relation to battle-era features (three battle lines and the historic New Garden Road). Such management includes natural and cultural resources (Hiatt 2003), and is challenged by the natural processes of flooding, erosion, and weathering, as well as the demands of increasing local population and urban development. The perspectives and proposed actions of cultural and natural resource management may also conflict. For example, the proposed restoration of an historic building may include the removal of surrounding natural resources or the installation of exotic plant species. In contrast to the historically more open pattern, approximately 90% of the park is currently forested (Hiatt 2003). Selective deforestation (e.g., wooded areas west of the first and third line positions) and reforestation (e.g., the former third line or "Schenck's field"—an unnatural clearing) would be necessary to recreate the open and wooded areas present at the time of the battle (Hiatt 2003). Some slope rehabilitation would also be necessary restore the primary battle lines of 1781. These efforts attempt to resist many natural geologic changes and processes that have been exacerbated by early commemoration efforts, such as the infilling of gullies and devegetation of understory growth. According to the park's 1936 master plan, this devegetation had caused the woodland floors to become bare red clay (visible in fig. 4) (Hiatt 2003). Additional removal of stabilizing vegetation may lead to increased erosion, resulting in subsequent sediment loading and changes to the channel morphologies of local streams.

In November 1935, the park's new mission was launched with a newly installed sewer system and two structures built as a museum and an administration building. Park resource management favored reforestation plans over formal gardens. The dam impounding the long-silted-up Lake Wilfong was eliminated and the circuitous roads leading to it were reseeded. Construction of an amphitheatre commenced in 1939 and was completed in 1941 (Baker 1995; Hiatt 2003). In the 1940s, the park management sought to expand the landholdings of the park in several small parcels, but expansion remained dormant until the late 1950s because of World War II (fig. 3). Meanwhile, surrounding suburban development accelerated. In the 1960s and 1970s, recent acquisitions were allowed to recover to their "natural condition" (Hiatt 2003). The park's restoration has occurred slowly; given the long history of human-induced landscape changes and the suburban encroachment of Greensboro, the reconstruction of the original battleground setting continues to the present day. The population of Greensboro exploded from 79,272 to 246,520 between 1920 and 1960. According to the U.S. Census Bureau 2009 population estimates, the population of Greensboro is more than 255,000; Guilford County now has more than 480,000 residents, an increase of 38% since 1990. Regional population continues to increase, particularly in the Guilford Courthouse area (Hiatt 2003). Resource management must balance the pressures of increasing population demands with the restoration and preservation of park resources.

This management includes the National Park Service's efforts to decrease through-going traffic in the park, for example by closing New Garden Road, the contemporary correlate of historic Salisbury Road. Hurricane Gracie breached the Lake Caldwell Dam in October 1959 and washed out the road. Although no repairs were planned to precede the construction of a bypass, local and governmental pressures mandated the construction of an aluminum bridge for New Garden Road (Baker 1995). The road proceeds over the top of former Lake Caldwell's earthen dam, now punctured by a culvert to allow the passage of Hunting Creek (Hiatt 2003). Some of the original roadbed is now a gravel surface. The public New Garden Road remains a primary access route through the battlefield and, following restoration in 1975, is an historic highway (Hiatt 2003). The park thus receives daily commuter traffic. Approximately 10,000 vehicles per day travel north through the park on Old Battleground Avenue. These cars distract visitors and generally compromise the scenic and historic setting of the park (Hiatt 2003). Fuel and salt contamination from roads and cars may also enter the hydrogeologic system at the park.

The park's cultural features and targets for historic preservation and restoration include: 1) the restored course of New Garden (Old Salisbury) Road, 2) archaeological remains of the Guilford Courthouse (later Martinsville) community, 3) the 19th-century commemorative landscape, 4) the central sections of the positions held by the first and second American lines, 5) the ground defended by the left wing of the third American line, 6) the bed of artificial Lake Wilfong (drained and reforested by the National Park Service in the 1930s), and 7) a terraced-earth amphitheatre, Colonial Revival superintendent's residence, and Colonial Revival utility facilities (Hiatt 2003). These features are contained within an area that represents approximately one-fourth of the original battlefield. They should be made available for visitation without compromising the natural resources or historical context of the park.

Maintenance of the battle landscape often involves the resistance of natural geologic changes, which presents several management challenges. Flooding along local streams, such as Hunting Creek, leaves sediment deposits on flanking floodplains and may damage park infrastructure. However, flooding does not appear to be a major resource management concern within the park (S. Ware, Guilford Courthouse NMP, personal communication, December 15, 2010). As throughout the North Carolina Piedmont, geologic slope processes such as mass wasting (slumping and slope creep) and chemical weathering shape the park's landscape. Such changes include the formation and modification of low, irregular ridgelines, sinuous creeks, and narrow gullies or ravines (Hiatt 2003). Runoff erodes sediments from open areas and carries them down streams and gullies. Erosion naturally diminishes higher areas and fills in lower areas, potentially distorting significant historical landscape features. These forces, in addition to anthropogenic features such as roads, dams, buildings, and trails, obscure the historic context of the landscape at Guilford Courthouse National Military Park. Weathering also affects the historic monuments at the park; this destruction should be periodically monitored to determine the degree of degradation and prioritize remediation efforts.

For further information on Guilford Courthouse National Military Park and its restoration-preservation projects, please consult Hiatt (2003).

#### Erosion and Slope Processes

Overall elevation changes by 27 m (90 ft) within park boundaries (Hiatt 2003). The steepest gradients rise from the banks of Hunting Creek, its tributary, and various ravines and gullies (fig. 4). The topographic differences within and surrounding the park may seem subtle, but there is some likelihood of slope failure. This likelihood increases with precipitation, natural erosion, and undercutting of slopes by roads, trails, and other development (North Carolina Geological Survey 2010). The relative risk of landslide occurrence could be determined by using a topographic map to calculate the steepness of a slope, a geologic map to identify the underlying rock type, vegetation patterns, and precipitation data. Deposits of unconsolidated alluvium, for instance, are vulnerable to failure when exposed on a slope, especially during the heavy rainstorms or flow events that are common in the eastern U.S. Wieczorek and Snyder (2009) suggested five methods and "vital signs" for monitoring slope movements: types of landslides, landslide triggers and causes, geologic materials in landslides, measurement of landslide movement and assessing landslide hazards and risks.

Resource Management Suggestions for Erosion and Slope Processes

- Monitor steep slopes for rock movement and manage undercut areas appropriately.
- Monitor hazards to staff and visitors from unstable slopes and mass wasting. Wieczorek and Snyder's (2009) chapter in the geologic monitoring manual listed in the "Additional References" section provides guidance for addressing mass-wasting problems. The North Carolina Geological Survey web site also contains links to useful geologic information and contacts (http://www.geology.enr.state.nc.us/Landslide_Info/Landslides_main.htm).
- Perform a comprehensive study of the active erosional/weathering processes at the park, taking into account differences in rock formations, slope aspects, location, and likelihood of instability.

- Inventory areas susceptible to runoff flooding, in relation to climate and confluence zones.

#### Modern Anthropogenic Impacts

The mission of the National Park Service is to protect park resources and to provide opportunities for visitors to enjoy those resources. Guilford Courthouse National Military Park provides numerous recreational opportunities, including hiking, bicycling, picnicking, and photography. In 2010, the park received over 285,000 visitors, with the heaviest visitation occurring during the summer months. In past years' visitation surpassed 800,000. These visitors place increasing demands on park resources; management concerns range from trail erosion to historic landscape and monument integrity. Human impacts continue with the construction of water, gas, and power lines, radio towers, industrial complexes, roads, and housing developments. Increasing use and surrounding development may threaten soil and water quality at the park through ground compaction and the increased area of impervious surfaces, such as parking lots and roadways. Impervious surfaces decrease the natural absorption of precipitation, funneling it as sheet flow directly into waterways.

Four dirt paths (unofficial, "social trails") enable residents from surrounding suburban developments to enter the park (Hiatt 2003). Several trails and bike paths, including the Bicentennial Greenway (the former railroad bed of the old Cape Fear and Yadkin Valley line), wind through potentially fragile ecosystems, especially near streams. Off-trail hiking and social trail use promotes devegetation, erosion, sediment loading, and changes to stream channel morphology. A tour route through the park features eight interpretive pullout stops. These areas are at risk of foot-traffic damage.

Resource Management Suggestions for Modern Anthropogenic Impacts

- Design wayside exhibits to encourage responsible use of park resources.
- Restore any degraded trails to prevent further slope erosion.
- Perform trail stability studies to identify the trails most at risk and in need of further stabilization.
- Monitor human impacts at picnic areas, official and social trails, fishing sites, and similar locations within the park.
- Assess the environmental impacts of any proposed construction sites near park boundaries using photo points or aerial photography.

#### Suggestions for Further Geologic Research

These suggestions arose from discussions with the park during the scoping meeting in 2000 and in subsequent discussions during the review process. Contact the Geologic Resources Division for assistance.

- Promote studies to connect the park's geology to the parent material of different soil types, vegetation patterns, habitats, and battlefield characteristics. Refer to work by the 2005 NPS Soil Resources Inventory (see "Additional Resources") and Daniels et al. (1984).
- Support research and development of a land use map showing the present and historical extent of farming and other intensive land use, and landscape changes since 1781.
- Incorporate any U.S. Geological Survey groundwater studies into the park GIS.
- Use sediment coring, tree ring studies, and historical data to develop chronologies of past floods and their impacts. Based thereon, document future frequency and extent of flood impacts, including changes to shoreline morphology and position, nature of the substrate, post-flood changes, and ecosystem recovery. When possible, data should also be collected during storm and flood events to monitor immediate effects.
- Use shallow geophysics, such as shallow seismic imaging, ground-penetrating radar, and electrical resistivity to determine the depths to the groundwater table and bedrock, and the location of contacts in bedrock.
- Encourage more detailed, larger-scale geologic mapping of the park area, especially between Guilford College and the park, possibly by college students. In particular, the major shear zone in the vicinity of (and probably running through) the park should be mapped at a larger scale; this zone dates to the collision of Africa and North America over 240 million years ago.
- Determine the 1781 stream locations and measure the degree to which their courses have since altered. Most changes have likely been due to anthropogenic geomorphic adjustments, such as the construction of dams within and just south of the park. Scoping participants did not believe that stream locations had changed substantially since 1781.
- Utilize the mineral collection in the neighboring Natural Science Center (Charles Almy, Guilford College, professor emeritus, written communication, 2009) for interpretation and education regarding the geologic history of the area and for assistance in detailed field mapping.

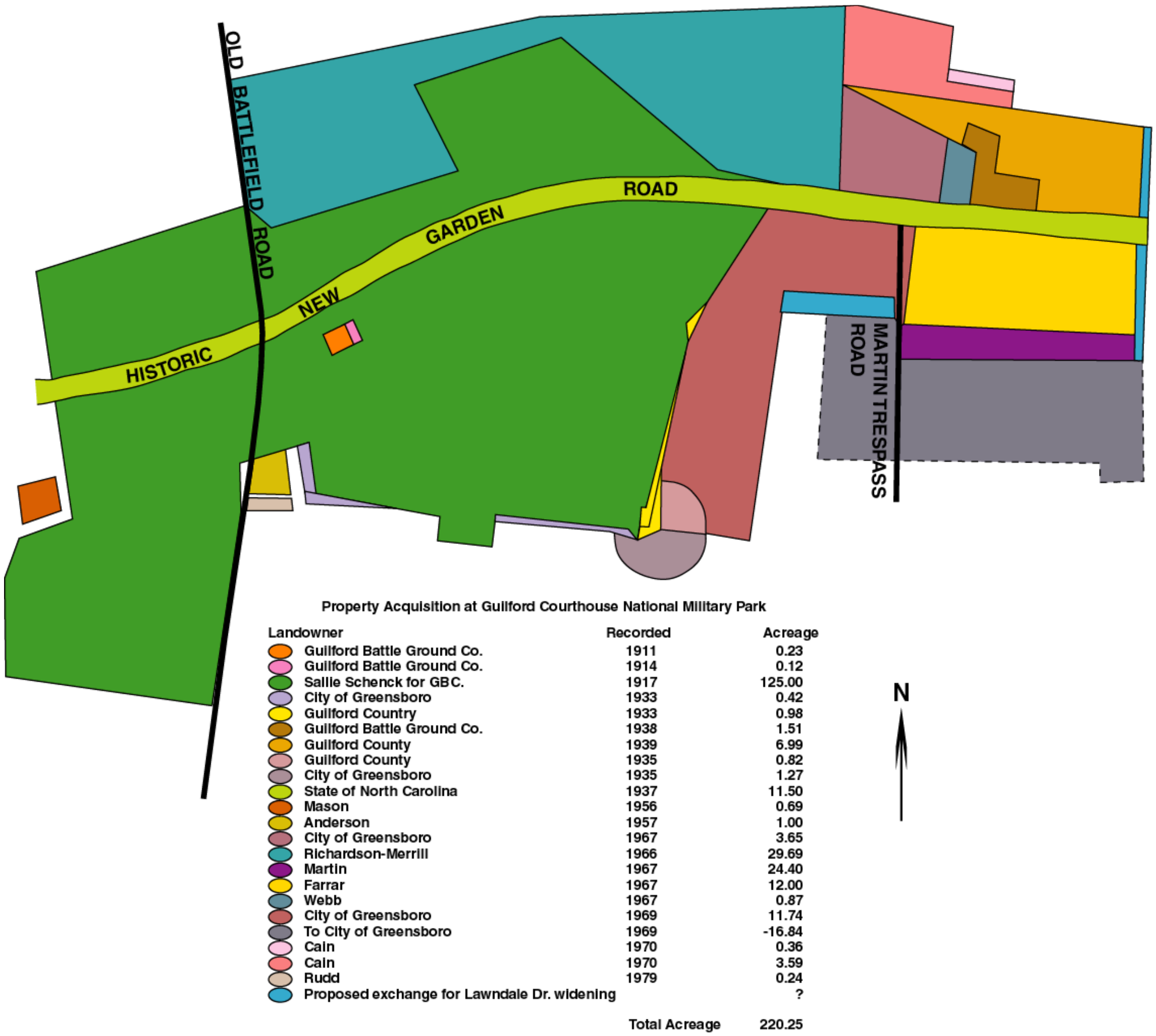


**Figure 3. Map showing land acquisition and management history at Guilford Courthouse National Military Park. This map illustrates the piecemeal approach to preserving the current park's acreage over more than seven decades. Adapted from Baker (1995).**

**Figure 4. Erosion within Guilford Courthouse NMP forms gullies, such as this one along a creek bed north of the historic New Garden Parkway. The exposed soil areas in both images show where active erosion is taking place. The lower image is a close-up where exposed roots and erosional cutbank are particularly evident. Note typical, although uncommon, exposure of metamorphosed rock in the upper image (arrow). Surficial deposits and soil, particularly visible in the lower image, obscure much of the bedrock in the area. National Park Service photographs courtesy Stephen Ware (Guilford Courthouse NMP).**

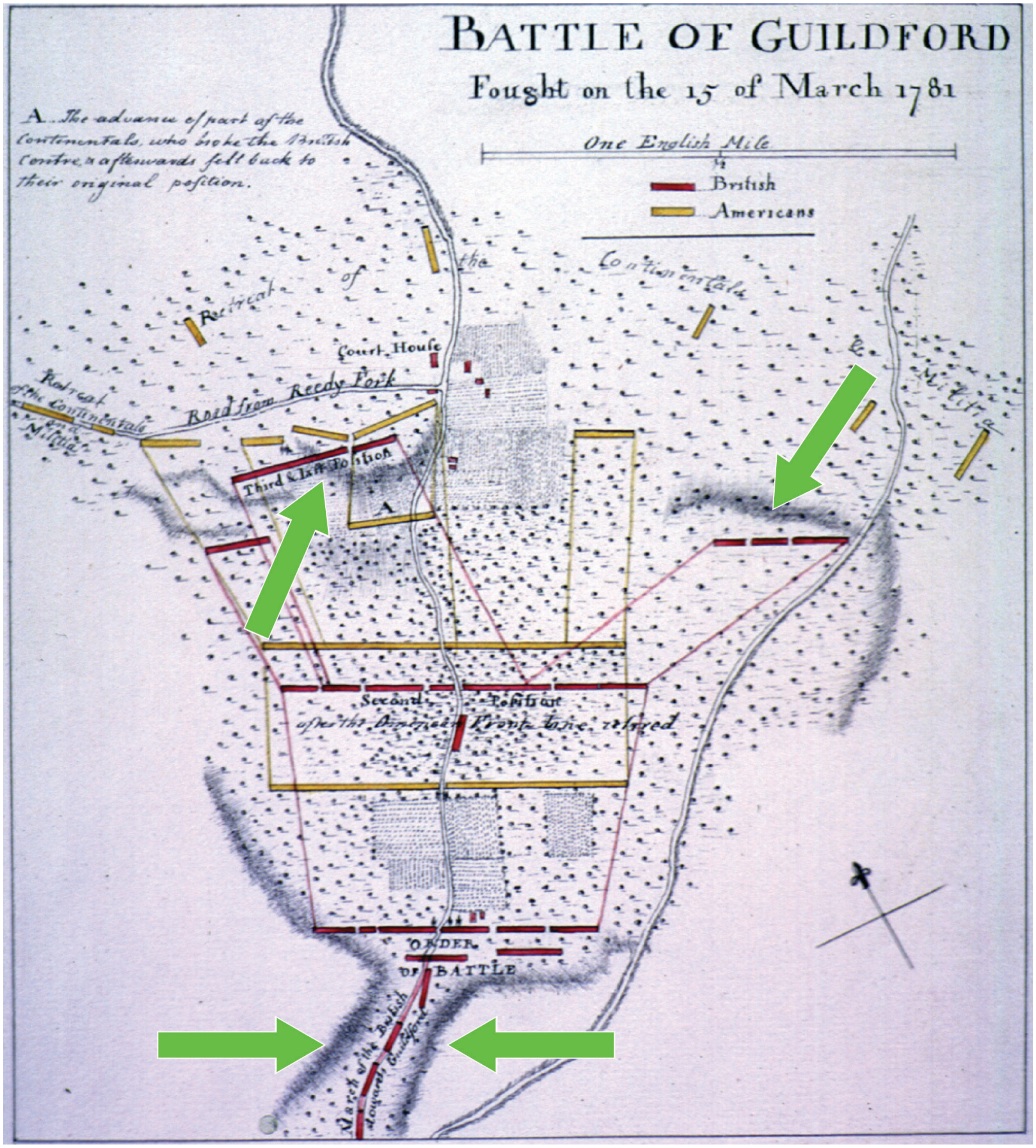


**Figure 5. British plan of the Battle of Guilford Courthouse originally attributed to Lieutenant Colonel Banastre Tarleton (A History of the Campaigns of 1780 and 1781. In the Southern Provinces of North America. 1787). Note how troop positions relate to ridges and hills (green arrows) indicated on the map. The map was created from an earlier version drawn shortly after the battle by a British engineer officer and submitted with Cornwallis' reports to his commander. Map courtesy of Stephen Ware (Guilford Courthouse NHP), annotated by Jason Kenworthy (NPS Geologic Resources Division).**

# Geologic Features and Processes

*This section describes the most prominent and distinctive geologic features and processes in Guilford Courthouse National Military Park.*

### Geologic and Historic Connections at Guilford Courthouse National Military Park

In addition to preserving and commemorating an event in Revolutionary War history, Guilford Courthouse National Military Park evidences a long regional history that includes early settlement and land use since the 1781 battle. Nomadic groups of forager-hunters likely traveled through the area as early as 8,000 years B.C.E. (Before Common Era) (Ward and Davis 1999; Hiatt 2003). Evidence of American Indian use has been found 6 km (4 mi) southwest of the park, where open tracts of land noticed by a group of Pennsylvania Quakers in the mid-1700s were likely formed through periodic burning by American Indians for hunting and agricultural purposes (Arnett 1955; Hiatt 2003). Periodic flooding of the Haw and Deep rivers formed fertile floodplain deposits derived from weathered metamorphic rocks in the area, attracting early colonial settlers and fostering nearly continuous urban growth to the present day (Hiatt 2003). Settlers usually occupied land along rivers and streams to take advantage of the fertile soil and waterpower potential (Hiatt 2003). Humans created the pastoral setting of the future battlefield by clearing fields and founding the tiny hamlet of Guilford Courthouse in 1774. Rivers and streams likely influenced the selection of the hamlet's location, described as "lying on both sides of Hunting Creek[,] a fork of Rich Land Creek waters of the Reedy Fork of Haw River and on both Sides [of] the Main Buffalo Road" (Cateret 1762; Hiatt 2003). The area's inhabitants fled after the 1781 battle due to the destruction caused by the fighting, superstitions about spirits, and the lingering odors of decay (Baker 1995); this was the last time that the population of the area declined. According to 2009 U.S. Census Bureau projections, more than 480,000 people now live in Guilford County, North Carolina.

Early settlements in North Carolina often centered on mineral wealth, which is tied to the underling geology. The complex geologic history of mountain building and metamorphism yielded a rich variety of mineral deposits in the area, including gold. Lode (veins or mineralized zones) and placer (stream-sediment or residual) deposits of gold were early mining targets in the state. Most early production was in the Carolina Slate belt of the Central Piedmont, including Guilford County. The slate belt includes the Gold Hill and Silver Hill districts, located southwest of Guilford Courthouse. Between 1803 and 1828, North Carolina was the only gold-producing state in the U.S. (North Carolina Geological Survey 2000). Mineral development continues to support the local population. According to the North Carolina Geological Survey's web site (http://www.geology.enr.state.nc.us/Permitted_mines_20041130/Permitted_mines_North_Carolina_Geological_Survey.htm), Guilford County contains active and inactive sand and gravel mines, as well as mines for brick clay and crushed stone although none are within the park.

Geology influenced the Battle of Guilford Courthouse. Although less publicized than battlefields such as Manassas or Gettysburg, the battlefield at Guilford Courthouse National Military Park offers the opportunity to investigate the influence of geology on military strategy and battle outcomes. Battles may be affected by features such as high ground, slopes, ridges, ravines and other low points, bodies of water, open fields, and bedrock crests. Local patterns of erosion left high and low areas utilized by troops as illustrated on battlefield maps (fig. 5). Surrounding the park, knowledgeable troops may have taken advantage of the higher areas underlain by rocks resistant to erosion such as diabase (geologic map unit JTRd; see Map Unit Properties Table and Appendix A), granite (PZpgr), and felsic intrusive rocks (PZPCicf). Less resistant rocks such as schist (PZPCms and PZPCmgs) are preferentially worn away by weathering and erosion, creating low points.

Streams and rivers cut through the underlying rocks to create low points and strategic crossings. Noting the importance of river crossings, both sides in the Battle of Guilford Courthouse raced to claim fords and protect potential boat crossings before fighting began. Such features were present on the Catawba, Yadkin, Dan, and Deep Rivers. Hunting Creek affected troop dispositions and the tactical progression of the battle (Hiatt 2003). American commander General Nathanael Greene set up battle stations at Guilford Courthouse on March 13$^{th}$ and 14$^{th}$, where he hoped to derive tactical advantages from the landscape's characteristic patchwork of fields and forest (Hiatt 2003). Lord Cornwallis marched from his camp on Deep River to engage the patriots.

The local geology affected the location of battle lines (fig. 5). On March 15, 1781, General Greene deployed his troops on the higher ground west of Guilford Courthouse. Greene's forces stood in three north-south lines, approximately 370 m (400 yards) apart, facing west. The first line was along the crest of a hill that sloped steadily down to a small stream about 0.8 km (0.5 mi) in front of the lines. The first two lines of men (primarily untrained militia) were positioned in a low point at the rear of small clearings across New Garden Road, and the third line (of better-trained Continental troops) followed the linear crest of a low hill north of the road (Mininger and Nunnery 2001; Hiatt 2003).

Geology and climate also interact with biological factors to produce soils that favor the growth of particular flora.

The deeply weathered bedrock underlying the region's slopes supports dense hardwood forests. Cecil series soils are the most widespread class of soil in Guilford County. They form from the decomposed residuum of underlying rock. Before colonization and subsequent agricultural development, these well-drained, loamy soils supported oak-hickory-pine forests (Orr and Stuart 2000; Hiatt 2003). At Guilford Courthouse in 1781, the heavily timbered slopes rendered cavalry and artillery ineffective and protected the flanks of the American lines. Although the colonists outnumbered the British, the much better-organized, disciplined, and experienced British forces were a formidable enemy. About 2,000 British troops formed a single line at Guilford Courthouse, with small reserves of artillery in the woods and cavalry on the road. The British attacked each of the Americans' three battle lines in turn, across open ground and through a seemingly impenetrable forest (Hiatt 2003). They suffered heavy losses but were able to break through at several points. Following the first breakthrough, fighting ensued along the topographically low road (fig. 5). The British gained costly ground and the battle reached the third American line. General Greene ultimately elected to retreat, giving the British the "victory" to avoid suffering heavy losses. The Americans incurred fewer than half of the nearly 600 British casualties in only two and a half hours of battle.

Interpretation and identification of the battlefield features at Guilford Courthouse is ongoing. The sites of the first Guilford Court House and the Reedy Fork "Retreat" Road have yet to be conclusively located (Hiatt 2003). Based on reexamination of primary battle sources and consideration of topography and underlying geology, historians recently determined that the location of the third American line had been misidentified. They maintain that the third line actually stood within the monument-laden field located between tour stops 5 and 7, about 400 m (1,300 ft) east of the position designated by Judge David Schenck and unchallenged since the 1880s (Durham 1987; Hiatt 2003). This new position is just east of Hunting Creek on the ridgeline that extends northwest from tour stop 6 (Durham 1987; Mininger and Nunnery 2001; Hiatt 2003). Such re-interpretations emphasize the usefulness of comprehensive study of the underlying landforms, biological resources (past and present), and geologic controls on the progression of the Battle of Guildford Courthouse.

### Regional Geologic Structures

The subdued topography of the park and surrounding area belie the large scale deformation experienced by the rocks in the area (fig. 6). Several mappable zones of deformation are located near Guilford Courthouse National Military Park (Carpenter 1982). Bedrock exposures are typically limited to creek beds in this area, recent mapping revealed a sheared area between rocks assigned to the Charlotte metamorphic belt (granites of the Churchland Pluton in the immediate park area) and the Carolina Slate metamorphic belt (epidote amphibolite in the immediate park area) (figs. 7 and 8) (Mininger and Nunnery 2001). Shear zones are bands of rock that have been intensely deformed and in some cases may represent major boundaries between blocks of rock accreted onto the North American continent during the formation of the Appalachian Mountains. The sheared zone at the park is composed of deformed ("mylonitic") material from both metamorphic rock belts, and large slabs of each rock type appear within the other. The shear zone trends generally east-northeast in the area, conforming to the overall trend of parallel, northeast-trending structures in the Central Piedmont of the Southern Appalachians. This shear zone may have been reactivated several times during Appalachian mountain-building processes (Mininger and Nunnery 2001).

The larger Gold Hill–Silver Hill fault (shear) zone is located southwest of Guilford Courthouse (fig. 9). This northeast-trending zone was named after famous 19$^{th}$-century mining districts in this part of North Carolina (North Carolina Geological Survey 2000). It extends for 120 km (75 mi) and distinctly separates the Carolina Slate and Charlotte metamorphic belt rocks. The shear zone near Guilford Courthouse (described above) may be an extension of this zone.

Rocks of the shear zones display features that suggest deformation stresses from more than one direction. Therefore it is likely that the rocks experienced multiple episodes of metamorphism and deformation (Butler and Secor 1991). Such features include schistosity, a platy or flaky texture (usually imparting a "sheen" to the rock), and foliation, a strong alignment of minerals within a rock, form in response to stress focused in a primary direction can be used to help determine the tectonic history of an area. The rocks within the Carolina Slate metamorphic belt in the Guilford Courthouse area are mildly deformed and metamorphosed. The dominant structures are southwest-plunging open folds (Butler and Secor 1991); northeast-plunging folds are present further south in the belt. Many of the original textures and stratigraphic relationships are evident in the rocks throughout this area, making it a valuable study site (Butler and Secor 1991).

Northeast of Guilford Courthouse National Military Park, the Carolina Slate belt is primarily characterized by a large, regional fold that is concave-up ("U"-shaped) called the Virgilina synclinorium. Left-lateral faults offset this synclinorium and its related folds more than 16 km (10 mi) during a mountain-building period in the late Precambrian (Glover and Sinha 1973; Wilkins et al. 1995). This deformation was characterized by the production of tight folding without regionally pervasive high-grade metamorphism. It occurred about 575 million years ago, before the Taconic Orogeny. The Taconic Orogeny may have included a second phase of folding and metamorphism (Glover and Sinha 1973; Butler and Secor 1991). These types of deformation events created the substrate for the rolling hills of the current park setting. The "Geologic History" section contains additional details regarding the formation of geologic structures that underlie the park and surrounding area.

**Figure 6. The gently rolling hills of the park and surrounding area belie the intense history of deformation experienced by the rocks beneath the park and once grand mountains that rose above the area. The Cavalry Monument is in the foreground. National Park Service photograph courtesy Stephen Ware (Guilford Courthouse NMP).**

**Figure 7. Typical bedrock outcrop at Guilford Courthouse National Military Park along Hunting Creek. The metamorphosed bedrock here is likely amphibolite (Geologist's leg for scale). National Park Service photograph by Tim Connors (NPS Geologic Resources Division).**

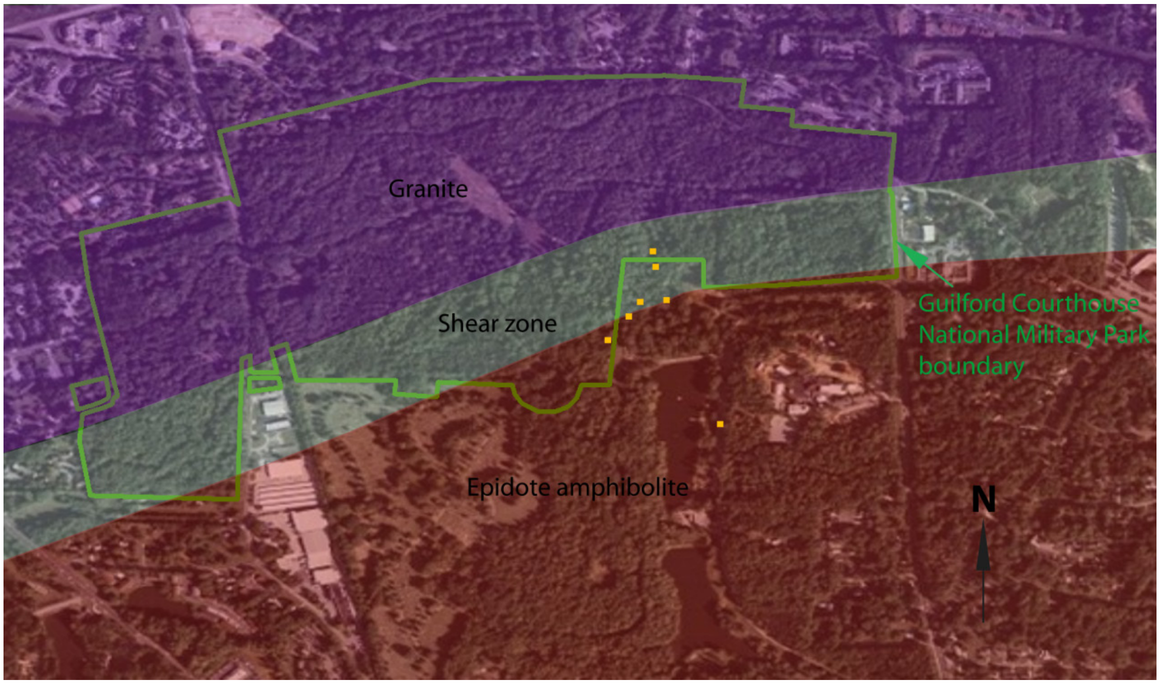


**Figure 8. Aerial view of Guilford Courthouse National Military Park with recent geologic mapping superimposed. Shear zone between granitic rocks typical of the Charlotte belt and amphibolite rocks typical of the Carolina Slate belt runs directly through the park. Note the location of bedrock outcrops (yellow squares) within the park area. Mapping by Mininger and Nunnery (2001). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University). Base map compiled by Jason Kenworthy (NPS Geologic Resources Division) from ESRI ArcImage Server, USA Prime Imagery.**

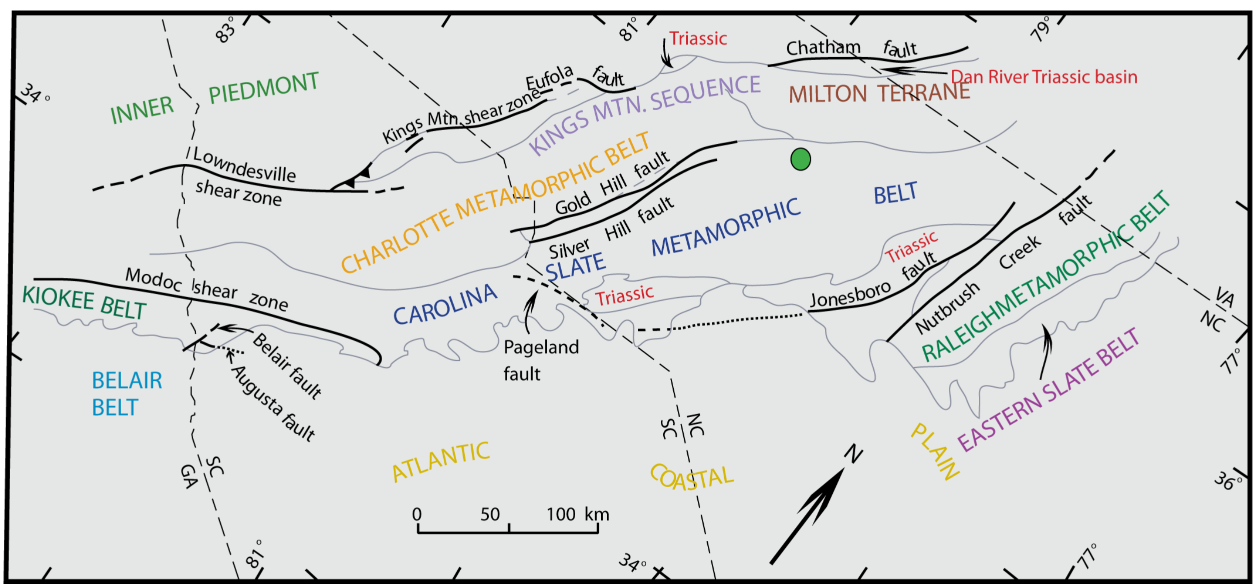


**Figure 9. Structural relationships within the Carolina terrane of the Piedmont in the Carolinas. Green dot indicates the location of Guilford Courthouse National Military Park. The belts of metamorphosed rocks, faults, and shear zones resulted from intense deformation associated with the building of the Appalachians. See the Geologic History section for additional information. Note orientation of north on map. Map by Trista L. Thornberry-Ehrlich (Colorado State University), adapted from Butler and Secor (1991).**

# Map Unit Properties

*This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Guilford Courthouse National Military Park. The accompanying table is highly generalized and for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table.*

Geologic maps facilitate an understanding of Earth, its processes, and the geologic history responsible for its formation. Hence, the geologic map for Guilford Courthouse National Military Park provided information for the "Geologic Issues," "Geologic Features and Processes," and "Geologic History" sections of this report. Geologic maps are two-dimensional representations of complex three-dimensional relationships; their color coding illustrates the distribution of rocks and unconsolidated deposits. Bold lines that cross or separate the color patterns mark structures such as faults and folds. Point symbols indicate features such as dipping strata, sample localities, mines, wells, and cave openings.

Incorporation of geologic data into a Geographic Information System (GIS) increases the usefulness of geologic maps by revealing the spatial relationships among geologic features, other natural resources, and anthropogenic features. Geologic maps are indicators of water resources because they show which rock units are potential aquifers and are useful for finding seeps and springs. Geologic maps are not soil maps, and do not show soil types, but they do show parent material—a key factor in soil formation. Furthermore, resource managers have used geologic maps to make connections between geology and biology; for instance, geologic maps have served as tools for locating sensitive, threatened, and endangered plant species, which may prefer a particular rock unit.

Although geologic maps do not show where earthquakes will occur, the presence of a fault indicates past movement and possible future seismic activity. Similarly, map units show areas that have been susceptible to hazards such as landslides, rockfalls, and volcanic eruptions. Geologic maps do not show archaeological or cultural resources, but past peoples may have inhabited or been influenced by depicted geomorphic features. For example, alluvial terraces may have been preferred use areas and formerly inhabited alcoves may occur at the contact between two rock units.

The geologic units listed in the following table correspond to the accompanying digital geologic data. Map units are listed in the table from youngest to oldest. Please refer to the geologic timescale (fig. 10) for the age associated with each time period. The table highlights characteristics of map units such as: susceptibility to erosion and hazards; the occurrence of paleontological resources (fossils), cultural resources, mineral resources, and caves or karst; and suitability as habitat or for recreational use. Some information on the table is conjectural and meant to serve as suggestions for further investigation.

The GRI digital geologic maps reproduce essential elements of the source maps including the unit descriptions, legend, map notes, graphics, and report. The following reference is the source for the GRI digital geologic data for Guilford Courthouse National Military Park:

Carpenter, P. A. 1982. Geologic Map of Region G, North Carolina (scale 1:125,000). Regional Geology Series (discontinued) 1201. North Carolina Geological Survey, Raleigh, North Carolina, USA.

The GRI team implements a geology-GIS data model that standardizes map deliverables. This data model dictates GIS data structure including data layer architecture, feature attribution, and data relationships within ESRI ArcGIS software, and increases the overall utility of the data. GRI digital geologic map products include data in ESRI personal geodatabase, shapefile, and coverage GIS formats, layer files with feature symbology, Federal Geographic Data Committee (FGDC)-compliant metadata, a Windows help file that contains all of the ancillary map information and graphics, and an ESRI ArcMap map document file that easily displays the map. GRI digital geologic data are included on the attached CD and are available through the NPS Natural Resource Information Portal (http://nrinfo.nps.gov/Reference.mvc/Search). Select the park from the drag and drop list and type "GRI" in the *Search Text* field.

#### Rocks at Guilford Courthouse National Military Park

The Carolina terrane forms a large portion of the southern Appalachian Piedmont in the vicinity of Guilford Courthouse National Military Park. The southern Appalachian area is associated with a great variety of rock units, ranging from ridgetop Precambrian and Paleozoic gneisses, schists, slates, mylonites, quartzites, and other metamorphic rocks to unconsolidated, recent Quaternary sediments that line valleys.

The Carolina Slate metamorphic belt of the Carolina terrane contains a suite of metamorphosed volcanic and sedimentary rocks of Late Proterozoic to Cambrian age. These rocks are lower greenschist facies, such as quartzite, metagranite, and gneiss. The rare metavolcanic rocks are predominantly pyroclastics and lava flows. Exposed within park boundaries, a felsic intrusive complex (geologic map unit **PZPCicf**) metamorphosed into biotite schist dominates the belt (Carpenter 1982). This complex contains mafic tuffs and layered beds of reworked volcanic material interrupted by lava flows, lava domes, and volcanic plugs. Locally, it may be approximately 11,000 m (36,000 ft) thick. General rock types include granite, granodiorite, quartz diorite, and quartz monzonite (Carpenter 1982; Butler and Secor 1991). Porphyritic granite (unit **PZpgr**) also crops out within park boundaries. This unit is correlative with the Churchland Pluton (Carpenter 1982).

Other units present in the park area include:
1) metagabbro intrusions, 2) an intermediate intrusive complex (unit **PZPCdi**), 3) muscovite and biotite schist (unit **PZPCms**), 4) mica gneiss and schist (unit **PZPCmgs**), and 5) Triassic-Jurassic diabase (unit **JTRd**) (Carpenter 1982; Butler and Secor 1991). The Carolina Slate metamorphic belt is juxtaposed against the Charlotte metamorphic belt to the west by a pervasive shear zone in the vicinity of Guilford Courthouse and by the Gold Hill–Silver Hill fault zone elsewhere in North Carolina (Mininger and Nunnery 2001). The Charlotte metamorphic belt of the Carolina terrane is predominantly composed of plutonic rocks of Silurian-Devonian age. Locally, it consists of metamorphosed porphyritic granite of the Churchland Pluton. The percentage of plutons in the Charlotte belt decreases markedly near Greensboro (Butler and Secor 1991).

Unconsolidated sands, silts, and other Quaternary deposits line the open areas, river valleys, and small basins (unit **Qal**) throughout the park. Well-rounded pebbles and cobbles are locally present in isolated layers (Carpenter 1982).

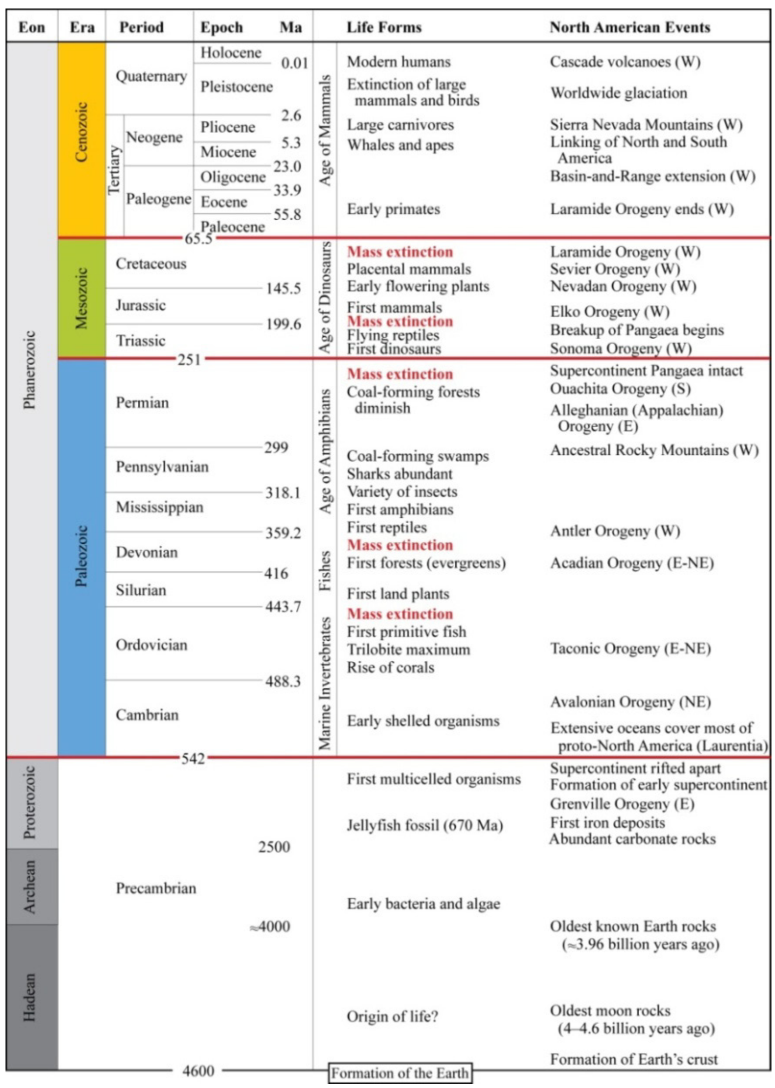


**Figure 10. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Isotopic ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events. Adapted from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2007/3015/) with additional information from the International Commission on Stratigraphy (http://www.stratigraphy.org/view.php?id=25).**

# Geologic History

*This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Guilford Courthouse National Military Park, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.*

This section summarizes the tectonic and depositional history recorded in the strata within and surrounding Guilford Courthouse National Military Park. The tectonic history includes several major mountain building events (orogenies), culminating in the formation of the Appalachian Mountains and the assembly of supercontinent Pangaea. The rocks in the Guilford Courthouse area represent a wide variety of depositional environments and dynamic processes that shaped today's landscape. Refer to figure 10 for a geologic time scale.

#### Precambrian (prior to 542 million years ago): Forming the Foundation

Over one billion years ago, the Grenville Orogeny deformed and metamorphosed Laurentia, the continental mass ancestral to North America. Following their uplift, the basement rocks were exposed to erosion before the deposition of subsequent rock units (Moore 1988). Fragments of the billion-year-old supercontinent are visible at Blowing Rock in northern North Carolina and Red Top Mountain in northern Georgia (Clark 2001). Beginning about 750 to 700 million years ago, rifting of Laurentia led to the opening of the Iapetus Ocean and formed a new eastern continental margin. The Iapetus was one of several proto-Atlantic ocean basins (the Theic and Rheic are two others) that closed episodically during the Paleozoic; these closures were often accompanied by the accretion of terranes (Horton and Zullo 1991; Nance and Linnemann 2008). A subsequent episode of deformation, between about 620 and 575 million years ago, formed the north-trending, broadly "U"-shaped feature called the Virgilina synclinorium.

Uranium-lead (U-Pb) isotopic analysis of felsic (high concentrations of silica-rich minerals) volcanic and plutonic rocks in the Carolina terrane of North Carolina's Central Piedmont has identified two episodes of magmatism at 560 to 590 million years ago and 620 to 640 million years ago (Goldberg et al. 1995). The muscovite and biotite schist (map unit **PZPCms**; see Appendix A and Map Unit Properties Table) and felsic intrusive complex (**PZPCicf**) at Guilford Courthouse are Late Proterozoic to Cambrian in age (Carpenter 1982; Butler and Secor 1991). The intermediate intrusive complex (**PZPCdi**) is typically present in narrow dikes within the felsic intrusive complex, and the muscovite and biotite schist contains pegmatite dikes (Carpenter 1982). These complex relationships imply that extensional rifting (pulling apart) and regional volcanism, intrusion of molten material, and metamorphism occurred in the Piedmont area during these periods (Dennis and Wright 1993). They may also be associated with an intrusive center of a magmatic arc (Faggart and Basu 1987; Butler and Secor 1991). The rocks comprising the majority of the Carolina Slate metamorphic belt originated in a magmatic arc or adjacent basin in a volcanic island-arc, perhaps similar to Alaska's Aleutian Islands, or continental-margin environment (Butler and Secor 1991).

#### Paleozoic Era (542 to 251 million years ago): Building Mountains and Assembling a Supercontinent

Throughout the Paleozoic, fragments of oceanic crust, basin sediments, volcanic island arcs, and continental landmasses collided with the eastern margin of the North American continent (fig. 11). Many of these myriad fragments accreted to Laurentia in several episodes of compression with related metamorphism and magmatism. These compressional orogenic events of varying duration and intensity affected overlapping portions of the eastern edge of North America (Horton and Zullo 1991).

Within the Carolina terrane, high-grade metamorphosed rocks, which had been deeply buried, were juxtaposed against shallow, lower-grade metamorphosed rocks along major shear zones (Secor et al. 1998). Several phases of deformation occurred within the Carolina terrane before it collided with North America (Butler and Secor 1991).

Many terranes accreted, deformed, and metamorphosed during the Taconic Orogeny about 470 to 440 million years ago during the Ordovician Period (Horton et al. 1988; Horton et al. 1989a, 1989b; Horton and Zullo 1991). These terranes are now located northwest of the Carolina terrane. During the Taconic Orogeny, oceanic crust and a chain of volcanic islands (called a "volcanic arc") converged with the eastern edge of the North American continent. Major thrust faults indicate where these rocks were moved next to each other. The Iapetus Ocean closed during this time (Moore 1988; Connelly and Woodward 1990; Nance and Linnemann 2008). Approximately 415 to 385 million years ago, a major amount of molten material (plutons) intruded the Carolina terrane (Butler and Secor 1991). Mountain-building activity in the southern Appalachian region also occurred approximately 380 to 340 million years ago; this activity appears to be younger than events associated with the Acadian Orogeny that primarily affected New England (Horton et al. 1989a).

As parts of Gondwana (a composite continent consisting of South America, Africa, Madagascar, Antarctica, India, other parts of South Asia, and Australia) pulled apart, or rifted, during the Early Ordovician, a new ocean basin formed called the Rheic Ocean (Nance and Linnemann 2008). It widened at the expense of the Iapetus Ocean as the Carolina terrane drifted toward Laurentia (Nance and Linnemann 2008) (fig. 11). The Gold Hill–Silver Hill shear zone has deformed intrusions of molten material associated with this activity; suggesting the molten material was emplaced before the Late Ordovician (Butler and Secor 1991).

During the Alleghany Orogeny about 330 to 270 million years ago, the continental collision of Laurentia and Gondwana formed the supercontinent Pangaea and the Rheic Ocean closed (fig. 11) (Horton and Zullo 1991; Nance and Linnemann 2008). By this time the Appalachian Mountains had achieved their maximum size, rivaling today's Himalayas.

The deformation associated with the Alleghany Orogeny overprints many previous structures in the Southern Appalachians (Schaeffer 1982; Scott Howard, Geologist, South Carolina Geological Survey, written communication, 2009). In the Carolinas, major effects of this collision included: 1) widespread emplacement of molten material such as the Churchland granite and other similar plutons such as the porphyritic granite in the Guilford Courthouse area (geologic map unit **PCpgr**); 2) westward transport of terranes as part of a large "thrust sheet"; 3) regional metamorphism and deformation; and 4) predominantly right-lateral strike-slip faulting along shear zones that sliced and shifted accreting terranes (Carpenter 1982; Horton et al. 1989a, 1989b; Horton and Zullo 1991; Butler and Secor 1991; Nance and Linnemann 2008).

The timing of the accretion of the Carolina terrane to Laurentia remains unresolved (Hibbard 2000). The magnetic signature (used to interpret ancient location of continents) suggests that the terrane had sutured to the continent by approximately 300 million years ago (Butler and Secor 1991). The Kings Mountain shear zone, which underlies Kings Mountain National Military Park (Thornberry-Ehrlich 2009), coincides with outcrops of pegmatites and is responsible for the deformation of the Cherryville Granite and other Inner Piedmont plutons to the west, about 340 to 285 million years ago. Some local deformation and plutonism along the Kings Mountain shear zone may thus date to the Alleghany Orogeny and be associated with the collision of North America and Gondwana (LeHuray 1986; Butler and Secor 1991). Other geologists favor Late Ordovician to Silurian age for the accretion, based on the presence of a Silurian unconformity on the Laurentian margin, extensive magma emplacement in the Piedmont at that time. Ages based on argon isotopes ($^{40}Ar/^{39}Ar$) found in mica minerals indicate a Middle to Late Ordovician and Silurian uplift event (Hibbard 2000; Hibbard et al. 2002). Hibbard et al. (2002) have compiled the details of this debate within the context of a comprehensive history of the Carolina zone.

#### Mesozoic Era (251 to 65.5 million years ago): Formation of the Atlantic Ocean

During the Mesozoic, extensional tectonic forces rifted (pulled apart) Pangaea, forming roughly the same continental masses and Atlantic Ocean that persist today (fig. 11). Along the eastern margin of North America, normal faulting opened rift basins that rapidly filled with sediment eroded from the Alleghany highlands. Brittle faults, joints, and shear zones developed across the Inner Piedmont and Carolina terranes as the continent was pulled apart and the Atlantic Ocean basin formed (Garihan et al. 1993). Widespread igneous activity was associated with the extension, locally including Triassic-Jurassic dolerite diabase dikes (map unit **JTRd**); hydrothermal activity occurred throughout the Piedmont in the Carolinas (Carpenter 1982; Schaeffer 1982; Horton and Zullo 1991; Nystrom 2003; Howard 2004; Horton 2006). Hydrothermal fluids containing economically valuable minerals such as gold can transport and precipitate them in surrounding rocks.

Following the intrusion of these molten igneous rocks into the surrounding metamorphic and plutonic rocks in the Jurassic, the region underwent a period of slow uplift and erosion approximately 200 million years ago. So called "isostatic adjustments" in the buoyancy of the crust forced the continental crust upward, exposing it to erosion (Harris et al. 1997). Since the breakup of Pangaea and the uplift of the Appalachian Mountains, the North American plate has continued to move westward, widening the Atlantic Ocean.

#### Cenozoic Era (65.5 million years ago to present day): Shaping the Modern Landscape

Running water and wind transported thick deposits of unconsolidated gravel, sand, and silt from the eroding Appalachian Mountains. These materials were deposited in alluvial fans at the base of the mountains east of Guilford Courthouse National Military Park, and further east on the Atlantic Coastal Plain. With fluctuating relative sea level and tectonic processes throughout the Cenozoic, sediments were regionally deposited and eroded in alternating events (fig. 11). The sinuous "Fall Line" defines the modern extent of the Atlantic Coastal Plain deposits (Horton and Zullo 1991). Today waterfalls and rapids mark the location of the "Fall Line" where the softer, sedimentary rocks of the Coastal Plain contact the harder metamorphosed rocks of the Piedmont. The former western extent of the Coastal Plain remains undefined; the Blue Ridge escarpment is one proposed western boundary (Scott Howard, Geologist, South Carolina Geological Survey, written communication, 2009). Exposed metamorphic rocks throughout the Piedmont and Blue Ridge represent an immense amount of eroded material. Many rocks exposed at the surface must have been at least 20 km (~10 mi) below the surface before regional uplift and erosion.

Throughout the Cenozoic, erosion and weathering were the primary geologic processes occurring in the Southern Appalachians. Erosion continues today along regional drainage patterns developed during the early Cenozoic

Era; large rivers and tributaries strip sediments, diminish mountains, and deposit alluvial terraces and alluvium (map unit **Qal**) along the rivers to create the present landscape (Moore 1988; Nystrom 2003; Howard 2004; Horton 2006). Rain, frost, rooted plants, rivers and streams, chemical dissolution, and mass wasting wear away the once-craggy peaks. Layers of resistant rocks, such as sandstones and metamorphic rocks, top ridges and mountains and create ledges commonly associated with waterfalls near Guilford Courthouse National Military Park (Schultz and Seal 1997).

Between about 2.6 million years ago and about 11,000 years ago, advances of ice sheets during the "Ice Ages" resulted in significant changes to Earth's landscape. Although glaciers never reached the Southern Appalachians, colder ice-age climates affected the mountains' geomorphology when a wetter climate, sparse vegetation, and freezing winter temperatures caused increased precipitation to run into ancestral rivers. These conditions enhanced downcutting and erosion (Schultz and Seal 1997). Many of the concentrations of boulders, block fields, and fine-textured colluvium on the forested mountainsides of the Southern Appalachians record the process of frost-wedging. Subsequent erosion continues to carve the land so that isolated differences in rock material created areas of higher and lower topography, which would influence the placement of battle lines at Guilford Courthouse

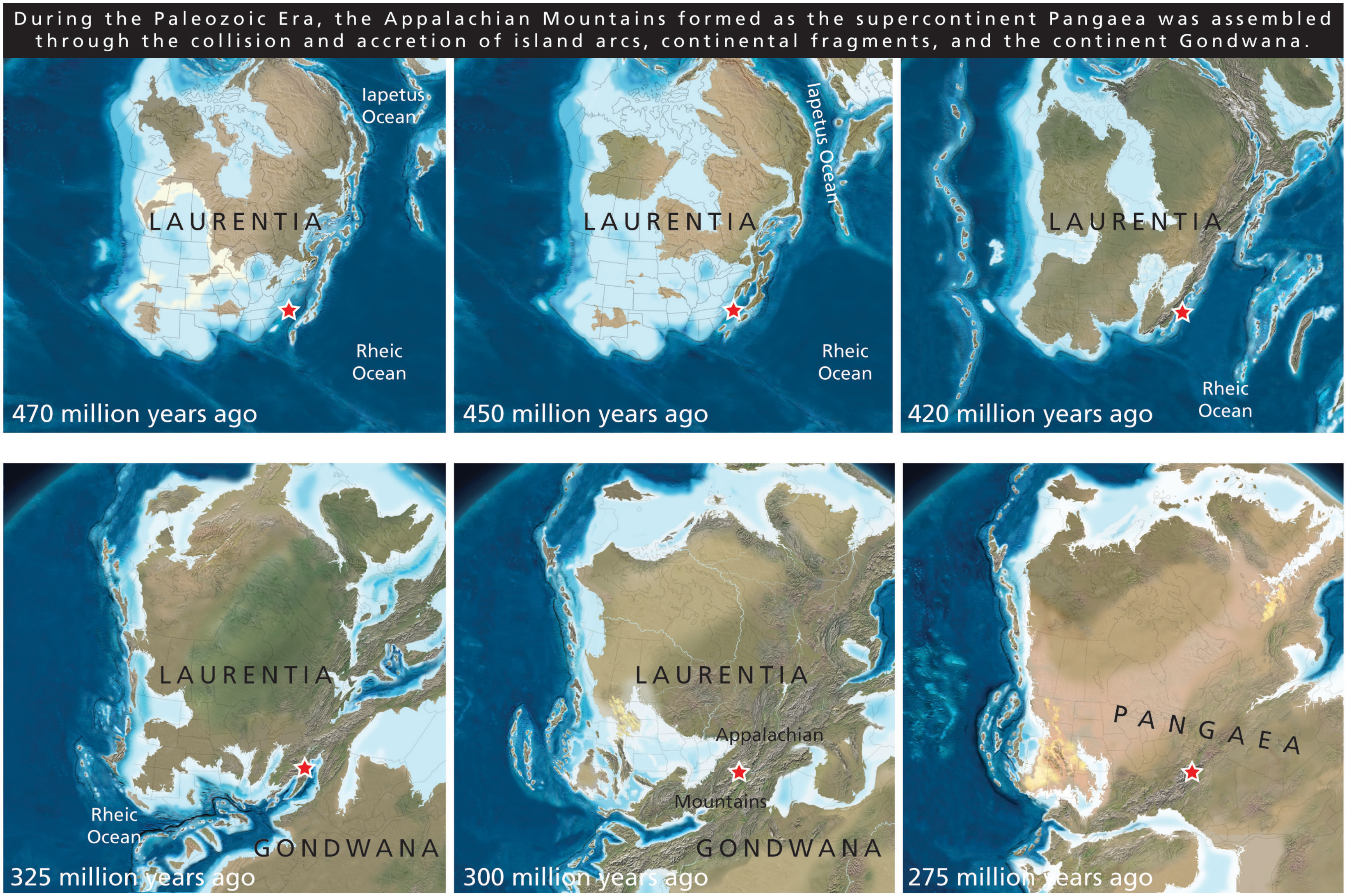


**Figure 11. The geologic units of Guilford Courthouse National Military Park are tied to the intense deformation and intrusion of molten material during the formation of the Appalachian Mountains that culminated with the assembly of Pangaea. Red stars indicate approximate location of Guilford Courthouse National Military Park. Graphic compiled by Jason Kenworthy (NPS-Geologic Resources Division). Base paleogeographic maps by Ron Blakey (Northern Arizona University Department of Geology) and available online: http://jan.ucc.nau.edu/~rcb7/index.html.**

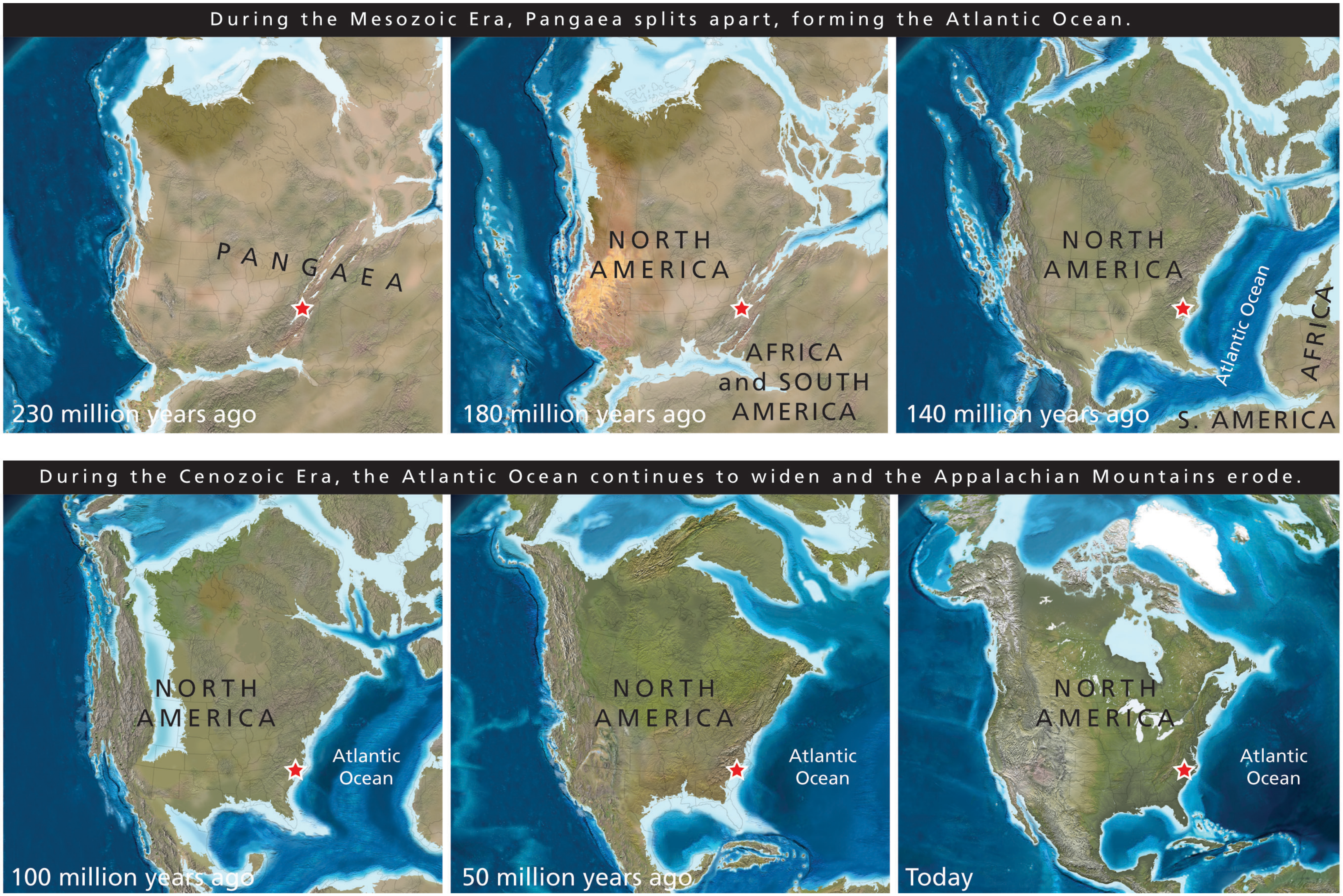


**Figure 11 (continued). Pangaea began to split apart during the Mesozoic and the Appalachian Mountains began to erode. Today, the Atlantic Ocean continues to widen and erosion has exposed the core of the Appalachian Mountains. Red stars indicate approximate location of Guilford Courthouse National Military Park. Graphic compiled by Jason Kenworthy (NPS Geologic Resources Division). Base paleogeographic maps by Ron Blakey (Northern Arizona University Department of Geology) and available online: http://jan.ucc.nau.edu/~rcb7/index.html.**

# Glossary

*This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://geomaps.wr.usgs.gov/parks/misc/glossarya.html. Definitions are based on those in the American Geological Institute Glossary of Geology (fifth edition; 2005).*

**absolute age.** The geologic age of a fossil, rock, feature, or event in years; commonly refers to radiometrically determined ages.

**abyssal plain.** A flat region of the deep ocean floor, usually at the base of the continental rise.

**accretion.** The gradual addition of new land to old by the deposition of sediment or emplacement of landmasses onto the edge of a continent at a convergent margin.

**accretionary prism.** A wedge-shaped body of deformed rock consisting of material scraped off of subducting oceanic crust at a subduction zone. Accretionary prisms form in the same manner as a pile of snow in front of a snowplow.

**active margin.** A tectonically active margin where lithospheric plates come together (convergent boundary), pull apart (divergent boundary) or slide past one another (transform boundary). Typically associated with earthquakes and, in the case of convergent and divergent boundaries, volcanism. Compare to "passive margin."

**allochthon.** A mass of rock or fault block that has been moved from its place of origin by tectonic processes; commonly underlain by décollements.

**allochthonous.** Describes rocks or materials formed elsewhere and subsequently transported to their present location. Accreted terranes are one example.

**alluvial fan.** A fan-shaped deposit of sediment that accumulates where a hydraulically confined stream flows to a hydraulically unconfined area. Commonly out of a mountainous area into an area such as a valley or plain.

**alluvium.** Stream-deposited sediment.

**amphibole.** A common group of rock-forming silicate minerals. Hornblende is the most abundant type.

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

**anticline.** A convex-upward ("A" shaped) fold. Older rocks are found in the center.

**anticlinorium.** A large, regional feature with an overall shape of an anticline. Composed of many smaller folds.

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

**ash (volcanic).** Fine material ejected from a volcano (also see "tuff").

**asthenosphere.** Earth's relatively weak layer or shell below the rigid lithosphere.

**augen.** Describes large lenticular mineral grains or mineral aggregates that have the shape of an eye in cross-section. Found in metamorphic rocks such as schists and gneisses.

**autochthon.** A body of rocks in the footwall (underlying side) of a fault that has not moved substantially from its site of origin. Although not moved, the rocks may be mildly to considerably deformed.

**axis (fold).** A straight line approximation of the trend of a fold which divides the two limbs of the fold. "Hinge line" is a preferred term.

**barrier island.** A long, low, narrow island formed by a ridge of sand that parallels the coast.

**basement.** The undifferentiated rocks, commonly igneous and metamorphic, that underlie rocks exposed at the surface.

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

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

**batholith.** A massive, discordant pluton, larger than 100 $km^2$ (40 $mi^2$), and often formed from multiple intrusions of magma.

**bed.** The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two and distinguishable from beds above and below.

**bedding.** Depositional layering or stratification of sediments.

**bedrock.** A general term for the rock that underlies soil or other unconsolidated, surficial material.

**block (fault).** A crustal unit bounded by faults, either completely or in part.

**calcareous.** Describes rock or sediment that contains the mineral calcium carbonate ($CaCO_3$).

**carbonate.** A mineral that has $CO_3^{-2}$ as its essential component (e.g., calcite and aragonite).

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

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

**clast.** An individual grain or rock fragment in a sedimentary rock, produced by the physical disintegration of a larger rock mass.

**clastic.** Describes rock or sediment made of fragments of pre-existing rocks (clasts).

**clastic dike.** A tabular mass of sedimentary material that cuts across the structure or bedding of pre-existing rock in a manner of an igneous dike; formed by filling cracks or fissures from below, above, or laterally.

**clay.** Can be used to refer to clay minerals or as a sedimentary fragment size classification (less than 1/256 mm [0.00015 in]).

**claystone.** Lithified clay having the texture and composition of shale but lacking shale's fine layering and fissility (characteristic splitting into thin layers).

**cleavage (mineral).** The tendency of a mineral to break preferentially in certain directions along planes of weaknesses in the crystal structure.

**cleavage.** The tendency of a rock to split along parallel, closely spaced planar surfaces. It is independent of bedding.

**colluvium.** A general term applied to any loose, heterogeneous, and incoherent mass of rock fragments deposited by unconcentrated surface runoff or slow continuous downslope creep, usually collecting at the base of gentle slopes or hillsides.

**concordant.** Strata with contacts parallel to the orientation of adjacent strata.

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

**continental crust.** Crustal rocks rich in silica and alumina that underlie the continents; ranging in thickness from 35 km (22 mi) to 60 km (37 mi) under mountain ranges.

**continental rise.** Gently sloping region from the foot of the continental slope to the deep ocean abyssal plain; it generally has smooth topography but may have submarine canyons.

**continental shelf.** The shallowly submerged part of a continental margin extending from the shoreline to the continental slope with water depths less than 200 m (660 ft).

**continental shield.** A continental block of Earth's crust that has remained relatively stable over a long period of time and has undergone minor warping compared to the intense deformation of bordering crust.

**continental slope.** The relatively steep slope from the outer edge of the continental shelf down to the more gently sloping ocean depths of the continental rise or abyssal plain.

**convergent boundary.** A plate boundary where two tectonic plates are colliding.

**core.** The central part of Earth, beginning at a depth of about 2,900 km (1,800 mi), probably consisting of iron-nickel alloy.

**country rock**. The rock surrounding an igneous intrusion or pluton. Also, the rock enclosing or traversed by a mineral deposit.

**craton.** The relatively old and geologically stable interior of a continent (also see "continental shield").

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

**cross section.** A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in a vertically oriented plane.

**crust.** Earth's outermost compositional shell, 10 to 40 km (6 to 25 mi) thick, consisting predominantly of relatively low-density silicate minerals (also see "oceanic crust" and "continental crust").

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

**debris flow**. A moving mass of rock fragments, soil, and mud, in which more than half the particles of which are larger than sand size.

**deformation**. A general term for the process of faulting, folding, and shearing of rocks as a result of various Earth forces such as compression (pushing together) and extension (pulling apart).

**delta.** A sediment wedge deposited where a stream flows into a lake or sea.

**detachment fault.** Synonym for décollement. Widely used for a regionally extensive, gently dipping normal fault that is commonly associated with extension in a metamorphic core complex.

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

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

**discordant.** Describes contacts between strata that cut across or are set at an angle to the orientation of adjacent rocks.

**divergent boundary.** An active boundary where tectonic plates are moving apart (e.g., a spreading ridge or continental rift zone).

**dome.** General term for any smoothly rounded landform or rock mass. More specifically refers to an elliptical uplift in which rocks dip gently away in all directions.

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

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

**extrusive.** Describes molten (igneous) material that has erupted onto Earth's surface.

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

**facies (sedimentary).** The depositional or environmental conditions reflected in the sedimentary structures, textures, mineralogy, fossils, etc. of a sedimentary rock.

**fault.** A break in rock along which relative movement has occurred between the two sides.

**felsic.** Describes an igneous rock having abundant light-colored minerals such as quartz, feldspars, or muscovite. Compare to "mafic".

**footwall**. The mass of rock beneath a fault surface (also see "hanging wall").

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

**fracture.** Irregular breakage of a mineral; also any break in a rock (e.g., crack, joint, or fault).

**frost wedging.** The breakup of rock due to the expansion of water freezing in fractures.

**geology.** The study of Earth including its origin, history, physical processes, components, and morphology.

**gneiss.** A foliated rock formed by regional metamorphism with alternating bands of dark and light minerals.

**granite.** An intrusive igneous (plutonic) rock composed primarily of quartz and feldspar. Mica and amphibole minerals are also common. Intrusive equivalent of rhyolite.

**graben.** A down-dropped structural block bounded by steeply dipping, normal faults (also see "horst").

**greenschist.** A metamorphic rock, whose green color is due to the presence of the minerals chlorite, epidote, or actinolite, corresponds with metamorphism at temperatures in the 300–500°C (570–930°F) range.

**hanging wall.** The mass of rock above a fault surface (also see "footwall").

**hinge line.** A line or boundary between a stable region and one undergoing upward or downward movement.

**hornblende.** The most common mineral of the amphibole group. Hornblende is commonly black and occurs in distinct crystals or in columnar, fibrous, or granular forms.

**horst.** Areas of relative "up" between grabens, representing the geologic surface left behind as grabens drop. The best example is the Basin-and-Range province of Nevada. The basins are grabens and the ranges are weathered horsts. Grabens become a locus for sedimentary deposition (also see "graben").

**igneous.** Refers to a rock or mineral that originated from molten material; one of the three main classes of rocks—igneous, metamorphic, and sedimentary.

**intrusion.** A body of igneous rock that invades (pushes into) older rock. The invading rock may be a plastic solid or magma.

**island arc.** A line or arc of volcanic islands formed over and parallel to a subduction zone.

**isostacy.** The condition of equilibrium, comparable to floating, of the units of the lithosphere above the asthenosphere. Crustal loading (commonly by large ice sheets) leads to isostatic depression or downwarping; removal of the load leads to isostatic uplift or upwarping.

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

**karst topography.** Topography characterized by abundant sinkholes and caverns formed by the dissolution of calcareous rocks.

**landslide.** Any process or landform resulting from rapid, gravity-driven mass movement.

**lava.** Still-molten or solidified magma that has been extruded onto Earth's surface though a volcano or fissure.

**lithification.** The conversion of sediment into solid rock.

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

**lithosphere.** The relatively rigid outmost shell of Earth's structure, 50 to 100 km (31 to 62 miles) thick, that encompasses the crust and uppermost mantle.

**mafic.** Describes dark-colored rock, magma, or minerals rich in magnesium and iron. Compare to "felsic."

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

**mantle.** The zone of Earth's interior between the crust and core.

**mass wasting.** A general term for the downslope movement of soil and rock material under the direct influence of gravity.

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

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

**mélange.** A mappable body of jumbled rock that includes fragments and blocks of all sizes, both formed in place and those formed elsewhere, embedded in a fragmented and generally sheared matrix.

**member.** A lithostratigraphic unit with definable contacts; a member subdivides a formation.

**metamorphic.** Describes the process of metamorphism or its results. One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

**metamorphism.** Literally, a change in form. Metamorphism occurs in rocks through mineral alteration, formation, and/or recrystallization from increased heat and/or pressure.

**mid-ocean ridge.** The continuous, generally submarine and volcanically active mountain range that marks the divergent tectonic margin(s) in Earth's oceans.

**migmatite.** Literally, "mixed rock" with both igneous and metamorphic characteristics due to partial melting during metamorphism.

**mineral.** A naturally occurring, inorganic crystalline solid with a definite chemical composition or compositional range.

**normal fault.** A dip-slip fault in which the hanging wall moves down relative to the footwall.

**obduction.** The process by which the crust is thickened by thrust faulting at a convergent margin.

**oceanic crust.** Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6 to 7 km (3 to 4 miles) thick and generally of basaltic composition.

**orogeny.** A mountain-building event.

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

**paleogeography.** The study, description, and reconstruction of the physical landscape from past geologic periods.

**paleontology.** The study of the life and chronology of Earth's geologic past based on the fossil record.

**Pangaea.** A theoretical, single supercontinent that existed during the Permian and Triassic periods.

**parent material.** Geologic material from which soils form.

**parent rock.** Rock from which soil, sediments, or other rocks are derived.

**passive margin.** A margin where no plate-scale tectonism is taking place; plates are not converging, diverging, or sliding past one another. An example is the east coast of North America. (also see "active margin").

**pebble.** Generally, small rounded rock particles from 4 to 64 mm (0.16 to 2.52 in) in diameter.

**phenocryst.** A coarse (large) crystal in a porphyritic igneous rock.

**phyllite.** A metamorphosed rock, intermediate in grade between slate and mica schist, with minute crystals of graphite, sericite, or chlorite that impart a silky sheen to the surfaces ("schistosity").

**plastic.** Capable of being deformed permanently without rupture.

**plate tectonics.** The concept that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid asthenosphere.

**plateau.** A broad, flat-topped topographic high (terrestrial or marine) of great extent and elevation above the surrounding plains, canyons, or valleys.

**pluton (plutonic).** A body of intrusive igneous rock that crystallized at some depth beneath Earth's surface.

**progradation.** The seaward building of land area due to sedimentary deposition.

**protolith.** The parent or unweathered and/or unmetamorphosed rock from which regolith or metamorphosed rock is formed.

**provenance.** A place of origin. The area from which the constituent materials of a sedimentary rock were derived.

**pyroclastic.** Describes clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent; also pertaining to rock texture of explosive origin. In the plural, the term is used as a noun.

**radiometric age.** An age expressed in years and calculated from the quantitative determination of radioactive elements and their decay products.

**recharge.** Infiltration processes that replenish groundwater.

**regression.** A long-term seaward retreat of the shoreline or relative fall of sea level.

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

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

**rock fall.** Mass wasting process where rocks are dislodged and move downslope rapidly; it is the fastest mass wasting process.

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

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

**schist.** A strongly foliated metamorphic rock that can be readily be split into thick flakes or slabs. Micas are arranged in parallel, imparting a distinctive sheen, or "schistosity" to the rock.

**schistose.** A rock displaying schistosity, or foliation.

**seafloor spreading.** The process by which tectonic plates pull apart and new lithosphere is created at oceanic ridges.

**sediment**. An eroded and deposited, unconsolidated accumulation of rock and mineral fragments.

**sedimentary rock.** A consolidated and lithified rock consisting of clastic and/or chemical sediment(s). One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

**sequence.** A major informal rock-stratigraphic unit that is traceable over large areas and defined by a sediments associated with a major sea level transgression-regression.

**shale.** A clastic sedimentary rock made of clay-sized particles that exhibit parallel splitting properties.

**shear zone.** A zone of rock that has been crushed and brecciated by many parallel fractures due to shear strain.

**sheetwash (sheet erosion).** The removal of thin layers of surface material more or less evenly from an extensive area of gently sloping land by broad continuous sheets of running water rather than by streams flowing in well-defined channels.

**sill.** An igneous intrusion that is of the same orientation as the surrounding rock.

**silt.** Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256 to 1/16 mm [0.00015 to 0.002 in]).

**siltstone.** A variably lithified sedimentary rock composed of silt-sized grains.

**slope.** The inclined surface of any geomorphic feature or measurement thereof. Synonymous with "gradient."

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

**spring.** A site where water issues from the surface due to the intersection of the water table with the ground surface.

**stock.** An igneous intrusion exposed at the surface; less than 100 $km^2$ (40 $mi^2$) in size. Compare to "pluton."

**strata.** Tabular or sheet-like masses or distinct layers of rock.

**stratigraphy.** The geologic study of the origin, occurrence, distribution, classification, correlation, and age of rock layers, especially sedimentary rocks.

**stream.** Any body of water moving under gravity flow in a clearly confined channel.

**stream channel.** A long, narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

**stream terrace.** Step-like benches surrounding the present floodplain of a stream due to dissection of previous flood plain(s), stream bed(s), and/or valley floor(s).

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

**strike-slip fault.** A fault with measurable offset where the relative movement is parallel to the strike of the fault. Said to be "sinistral" (left-lateral) if relative motion of the block opposite the observer appears to be to the left. "Dextral" (right-lateral) describes relative motion to the right.

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

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

**subsidence.** The gradual sinking or depression of part of Earth's surface.

**suture.** The linear zone where two continental landmasses become joined via obduction.

**syncline.** A downward curving (concave up) fold with layers that dip inward; the core of the syncline contains the stratigraphically-younger rocks.
**system (stratigraphy).** The group of rocks formed during a period of geologic time.
**talus.** Rock fragments, usually coarse and angular, lying at the base of a cliff or steep slope from which they have been derived.
**tectonic.** Relating to large-scale movement and deformation of Earth's crust.
**terrace.** A relatively level bench or step-like surface breaking the continuity of a slope (see "marine terrace" and "stream terrace").
**terrane.** A large region or group of rocks with similar geology, age, or structural style.
**terrestrial.** Relating to land, Earth, or its inhabitants.
**thrust fault.** A contractional dip-slip fault with a shallowly dipping fault surface (less than 45°) where the hanging wall moves up and over relative to the footwall.
**topography.** The general morphology of Earth's surface, including relief and locations of natural and anthropogenic features.
**trace (fault).** The exposed intersection of a fault with Earth's surface.
**transgression.** Landward migration of the sea as a result of a relative rise in sea level.
**trend.** The direction or azimuth of elongation of a linear geologic feature.
**tuff.** Generally fine-grained, igneous rock formed of consolidated volcanic ash.
**unconformity.** An erosional or non-depositional surface bounded on one or both sides by sedimentary strata. An unconformity marks a period of missing time.
**uplift.** A structurally high area in the crust, produced by movement that raises the rocks.
**volcanic.** Describes anything related to volcanoes. Can refer to igneous rock crystallized at or near Earth's surface (e.g., lava).
**volcanic arc.** A commonly curved, linear, zone of volcanoes above a subduction zone.
**water table.** The upper surface of the saturated zone; the zone of rock in an aquifer saturated with water.
**weathering.** The physical, chemical, and biological processes by which rock is broken down.

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# Additional References

*This section lists additional references, resources, and web sites that may be of use to resource managers. Web addresses are current as of October 2010*

**Geology of National Park Service Areas**

NPS Geologic Resources Division (Lakewood, Colorado): http://nature.nps.gov/geology/

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

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

U.S. Geological Survey Geology of National Parks (includes 3D photographs): http://3dparks.wr.usgs.gov/


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Lillie, R. J. 2005. Parks and plates: the geology of our national parks, monuments, and seashores. W.W. Norton and Co., New York, New York, USA.


**Resource Management/Legislation Documents**

NPS 2006 Management Policies (Chapter 4—Natural Resource Management): http://www.nps.gov/policy/mp/policies.html#_Toc157232681

NPS-75: Natural Resource Inventory and Monitoring Guideline: http://www.nature.nps.gov/nps75/nps75.pdf

NPS Natural Resource Management Reference Manual #77: http://www.nature.nps.gov/Rm77/

Geologic Monitoring Manual: Young, R., and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado, USA. [Web site under development]. Contact the Geologic Resources Division to obtain a copy.

NPS Technical Information Center (Denver; repository for technical (TIC) documents): http://etic.nps.gov/

**Geological Survey Web sites**

North Carolina Geological Survey: http://www.geology.enr.state.nc.us/

U.S. Geological Survey: http://www.usgs.gov/

Geological Society of America: http://www.geosociety.org/

American Geological Institute: http://www.agiweb.org/

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

**Other Geology/Resource Management Tools**

U.S. Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/

U.S. Geological Survey Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features, and plot them on topographic maps or aerial photos): http://gnis.usgs.gov/

U.S. Geological Survey GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator")

U.S. Geological Survey Publications Warehouse (many USGS publications are available online): http://pubs.usgs.gov

U.S. Geological Survey, Tapestry of Time (description of physiographic provinces): http://tapestry.usgs.gov/Default.html


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**Detailed Geology of Greensboro Area**


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# Appendix A: Overview of Digital Geologic Data

*The following page is an overview of the digital geologic data for Guilford Courthouse National Military Park. For a PDF of this overview and complete digital data, please see the included CD or visit the Geologic Resources Inventory publications web site (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).*

# Appendix B: Scoping Session Participants

*The following is a list of participants from the GRI scoping session for Guilford Courthouse National Military Park, held on September 20, 2000. The contact information and email addresses in this appendix may be outdated; please contact the Geologic Resources Division for current information. The scoping meeting summary was used as the foundation for this GRI report. The original scoping summary document is available on the GRI web site: http://www.nature.nps.gov/geology/inventory/gre_publications.cfm.*

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NPS 316/106984, March 2011

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