National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Stones River National Battlefield

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2012/566

ON THE COVER
Cannons dot the landscape in front of Artillery Monument.

THIS PAGE
The treacherous karst landscape caused this now peaceful area to be termed the “slaughter pen” by Civil War soldiers.

National Park Service photographs by Jim Lewis (Stones River National Battlefield).

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

September 2012

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

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

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

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

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Contents

List of Figures

List of Tables

Executive Summary

This report accompanies the digital geologic map data for Stones River National Battlefield in Tennessee, produced by the Geologic Resources Division in collaboration with its partners. It contains information relevant to resource management and scientific research. This report was prepared using available published and unpublished geologic information. The Geologic Resources Division did not conduct any new fieldwork in association with this report.

Stones River National Battlefield comprises several units northwest of Murfreesboro along the West Fork Stones River in central Tennessee. There, in the winter of 1862–63, the Battle of Stones River—also known as the Battle of Murfreesboro—broke out between the Union and Confederate armies. The national battlefield memorializes the major human sacrifice that ultimately halted the Confederate advance in Tennessee and raised Union hopes for eventual victory west of the Appalachians. Stones River National Battlefield preserves and protects the historic and natural resources pertaining to the Battle of Stones River and provides visitors with a greater understanding of the battle as well as events leading to it and its effects on the eventual outcome of the American Civil War.

The national battlefield is separated into six areas covering a combined 263 ha (650 ac), from west to east, (1) General Rosecrans Headquarters Site, (2) the main battlefield and National Cemetery, (3) Artillery Monument and McFadden Ford, (4) General Bragg Headquarters Site, (5) Redoubt Brannan, and (6) Lunettes Palmer and Thomas, and Curtain Wall No. 2. Redoubt Brannan, the lunettes, and Curtain Wall No. 2 were part of the larger Fortress Rosecrans. Several local roads, including the historically significant Nashville Pike, connect the areas.

The bedrock beneath Stones River National Battlefield dates to the Middle Ordovician period (about 470–455 million years ago) and represents lime and mud sediments originally deposited in a marine basin that inundated the Mississippi River corridor of eastern North America. Surficial units consist of scant alluvium (gravel, sand, silt, and clay) along the West Fork Stones River corridor and some thin soils between bedrock outcrop exposures. These rocks and unconsolidated deposits gave rise to the landforms that influenced the actions taken during the Battle of Stones River.

This Geologic Resources Inventory (GRI) report was written for resource managers to assist in resource management and science-based decision making, but it may also be useful for interpretation. The report discusses geologic issues facing resource managers at the park, distinctive geologic features and processes within the park, and the geologic history leading to the park's present-day landscape. An overview graphic illustrates the geologic data and the Map Unit Properties Table summarizes the main features, characteristics, and potential management issues for all rocks and unconsolidated deposits on the digital geologic map for Stones River National Battlefield. This report also provides a glossary that contains explanations of technical, geologic terms, including terms appearing on the Map Unit Properties Table. Additionally, a geologic time scale shows the chronologic arrangement of major geologic events, with the oldest events and time units at the bottom and the youngest at the top (fig. 4).

Geologic issues of particular significance for resource management at Stones River National Battlefield were identified during a 2009 GRI scoping meeting and a 2012 follow-up conference call. They include the following:

- Disturbed Lands and Historic Landscape Restoration. The park was established in 1927, 64 years after the battle, and transferred from the War Department to the National Park Service in 1933. Much of the land area contained within the national battlefield was reclaimed from various land uses following the battle. Examples include concrete dumps and home sites. The park continues to remediate these areas, restoring the battle-era landscape. These efforts include slope regrading and native vegetation planting.
- Karst Challenges. Karst features on the landscape include caves, sinkholes, and karren. These types of feature posed great challenges for the Union and Confederate armies and continue to pose hazards to visitors today. Most locations of cave or sinkhole openings within the park are withheld from visitors. Sinkholes and low-lying areas within the park are also prone to flooding, which is controlled by runoff from precipitation, its connection to the underlying karst conduit system, and the morphology of these features. Some sinkholes within the park remain flooded for several days after a storm event.
- Fluvial Processes and Flooding. The West Fork Stones River is a prominent local feature within 0.8 km (0.5 mi) of all battlefield areas. Riprap has been installed along a stretch of the river near McFadden Ford to prevent bank erosion. The Tennessee Department of Environment and Conservation considers this waterway to be impaired due to the input of industrial and other waste. Fluvial flooding occurs infrequently along the waterway.

The historic and natural resources at Stones River National Battlefield are influenced by the following geologic features and processes:

- Karst Features. Landforms such as karren, sinkholes, and caves are typical in karst-dominated areas. Karst features result from the dissolution of carbonate bedrock by flowing water. Exposures of karren, consisting of trough-like "cutters" between limestone pinnacles, are well developed karst features in the park. Rebel Yell Cave is the only mapped cave within park boundaries. Several types of closed depression or sinkhole exist within park boundaries, ranging from steep-sided crevices to shallow basins.
- Cedar Glades. Open areas where weathered limestone gravel covers the ground surface with very little to no soil development occur throughout the southern portion of the park. These cedar glades appear to be devoid of appreciable flora, but are home to an uncommon assemblage of cedars and endemic, rare, and/or endangered species.
- Geologic Connections to Park Stories. Geologic features played a significant role in strategic battle planning and during the battle. Karren made travel through forested areas extremely challenging for wagons and cannon. Cedar glades provided much easier passage through the thick forests. The karren provided cover for troops and impeded their movements, leading one area to be termed the "Slaughter Pen." McFadden Ford was another focal point where Confederates on a small hill to the east were prevented from crossing the river due to the commanding presence of Union artillery on a ridge west of the river.
- Paleontological Resources. Fossils from the Middle Ordovician occur in the park within the Ridley Limestone (geologic map unit Ord) and the undivided Pierce and Murfreesboro limestones (Opm). In particular, marine invertebrate fossils such as cephalopods, bryozoans, brachiopods, ostracodes, and gastropods are visible in the bedrock and weathered limestone at cedar glades within the park. Pleistocene fossils may be present in caves within the park.
- Stones River Group. The excellent bedrock exposures in the greater park area were used to define the Stones River Group. This group, dominated by Ordovician-age limestone, is an important regional geologic feature.

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 Stewardship and Science Directorate.

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.

Additional thanks to: Dale Pate (NPS Geologic Resources Division) for his comments on the Karst Challenges and Karst Features sections of the report.

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Introduction

This section briefly describes the National Park Service Geologic Resources Inventory Program and the regional geologic and historic setting of Stones River National Battlefield.

Geologic Resources Inventory Program

The Geologic Resources Inventory (GRI) is one of 12 baseline natural resource inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI.

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

The objectives of the GRI are to provide geologic map data and pertinent geologic information to support resource management and science-based decision making in more than 270 natural resource parks throughout the National Park System. To realize these objectives, the GRI team undertakes three tasks for each natural resource park: (1) conduct a scoping meeting and provide a scoping summary, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report. These products are designed and written for nongeoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps, develop a geologic mapping plan, and discuss geologic issues, features, and processes that should be included in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan into digital geologic map data in accordance with their data model. Refer to the "Geologic Map Data" section for additional map information. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the geologic report. This geologic report assists park managers in the use of the map, and provides an overview of the park geology, including geologic resource management issues, geologic features and process, and the geologic history leading to the park's present-day landscape.

For additional information regarding the GRI, including contact information, please refer to the Geologic Resources Inventory website (http://www.nature.nps.gov/geology/inventory/). The current status and projected completion dates for GRI products are available on the GRI status website (http://www.nature.nps.gov/geology/GRI_DB/Scoping/Quick_Status.aspx).

Regional Information

Stones River National Battlefield encompasses 263 ha (650 ac) of Rutherford County in central Tennessee, near the town of Murfreesboro (fig. 1). The park's authorized boundary extends to 287 ha (709 ac), but the additional lands have not been acquired to date. The park was originally established as a national military park on March 3, 1927 and managed by the War Department until August 10, 1933, when it was transferred to the National Park Service. Stones River National Battlefield preserves the location and tells the stories of the Civil War Battle of Stones River, also known as the Battle of Murfreesboro, which took place over three days from December 31, 1862 to January 2, 1863. This battle was the culmination of the Stones River Campaign that began some days earlier when Union forces left Nashville to meet the Confederates at Murfreesboro. The battle resulted in extraordinarily high casualties—nearly one-third of the 81,000 men engaged. Though the losses were appalling, the battle represented a political success for the Union cause and provided support for the Emancipation Proclamation to take effect on January 1, 1863. The Confederates finally withdrew following a disastrous assault on the Union position atop a hill east of West Fork Stones River near McFadden Ford, and ultimately lost control of middle Tennessee. The Union Army of the Cumberland was led by Maj. Gen. William Rosecrans and the Confederate Army of Tennessee was led by Gen. Braxton Bragg. Today, Stones River National Battlefield includes several dispersed sites, including the General Bragg Headquarters, General Rosecrans Headquarters, Redoubt Brannan, and Curtain Wall No. 2 sites. Most infrastructure development at the park occurred in the 1960s. The tour road and waysides were reconstructed and revised in 2011.

The park is part of a relatively flat karst sinkhole plain within the Inner Basin of the Central Basin physiographic province (figs. 2 and 3). Gently rolling hills and valleys covered by pasture, glades, and forest characterize the terrain of the Central Basin. Outcrop exposures within the park are limited in area and deeply weathered. The bedrock formations mapped in the park area are primarily limestone of Middle Ordovician age (approximately 470 million years old, figs. 4 and 5), including the Lebanon Limestone (geologic map unit Olb), Ridley Limestone (Ord), and Pierce and Murfreesboro limestones (Opm; see "Geologic Map Data"). They were deposited within a large, shallow, open marine basin when the North American continent was situated near the equator. These limestones are among the oldest exposed sedimentary rocks in Tennessee. They are exposed in the Inner Basin (fig. 3) because erosion was accelerated by the local uplift of the Nashville Dome by the end of the Paleozoic Era (251 million years ago) (Stearns and Reesman 1986). Not included on the bedrock geologic map of the park are scant, shallow alluvial and soil deposits. These unconsolidated deposits are typically found in deeply weathered bedrock joints and fractures along the West Fork Stones River channel and flanking riparian zones.

Carbonate rocks, such as the limestones mapped in the park, are dissolved by surface and ground water. Such dissolution produces karst topography characterized by sinkholes, caves, and underground drainage. Typical for a karst plain landscape, little topographic variability is present in and around the park (fig. 6). Elevations range from 150 to 180 m (500 to 600 ft) above sea level. The karst area developed on flat-lying, thick layers of limestone bedrock with a thin layer of unconsolidated regolith. Erosion and dissolution into subsurface solution channels, in addition to subsurface collapse of caves, created numerous lowlands, sinkholes, and karst windows in the area (Law 2002). The larger streams flow in well-defined channels cut into the bedrock (Moore et al. 1969). Where the West Fork Stones River cuts through the northern area of the park, moderate slopes flank the waterway and adjacent riparian areas. Though large-scale landforms are not typical of the park, smaller-scale karst features influenced the battle fought there.

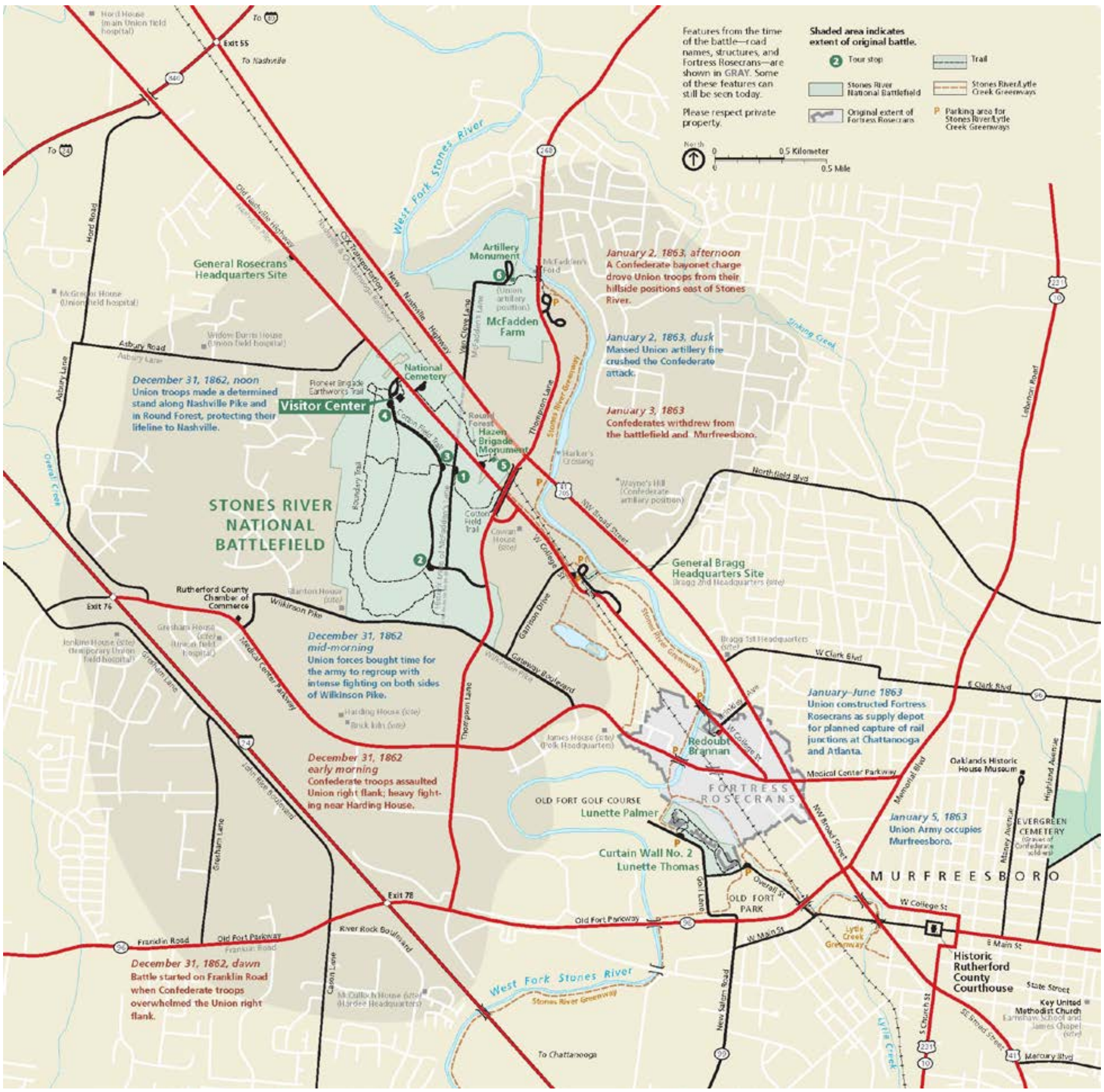

Figure 1. Map of Stones River National Battlefield. National Park Service map.

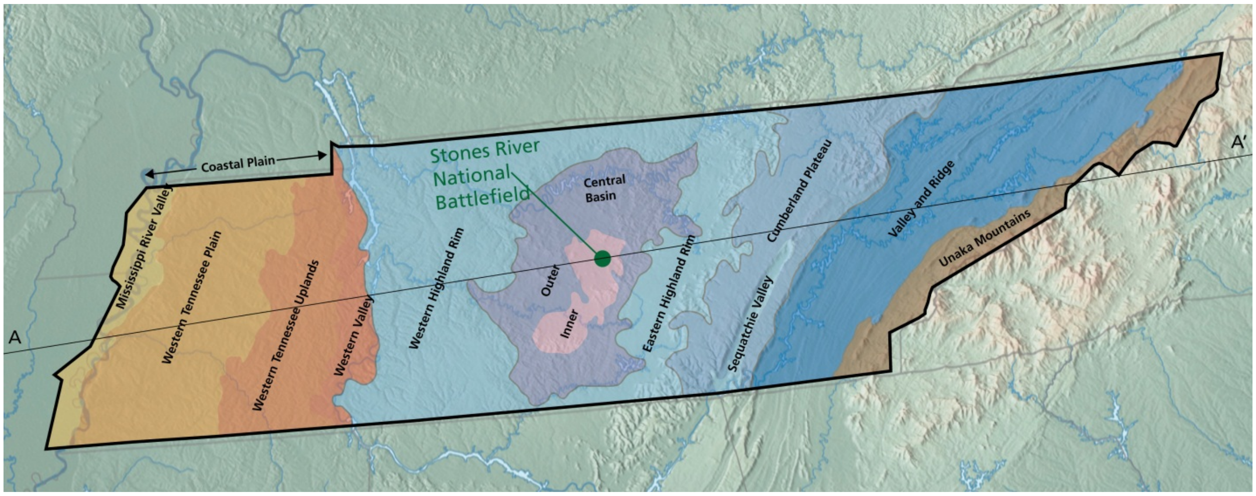

Figure 2. Physiographic provinces of Tennessee. A cross-sectional view through the state (line A-A') is presented in figure 3. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Harris (2012). Base map by Tom Patterson, available online: http://www.shadedrelief.com/physical/index.html (accessed 29 August 2012).

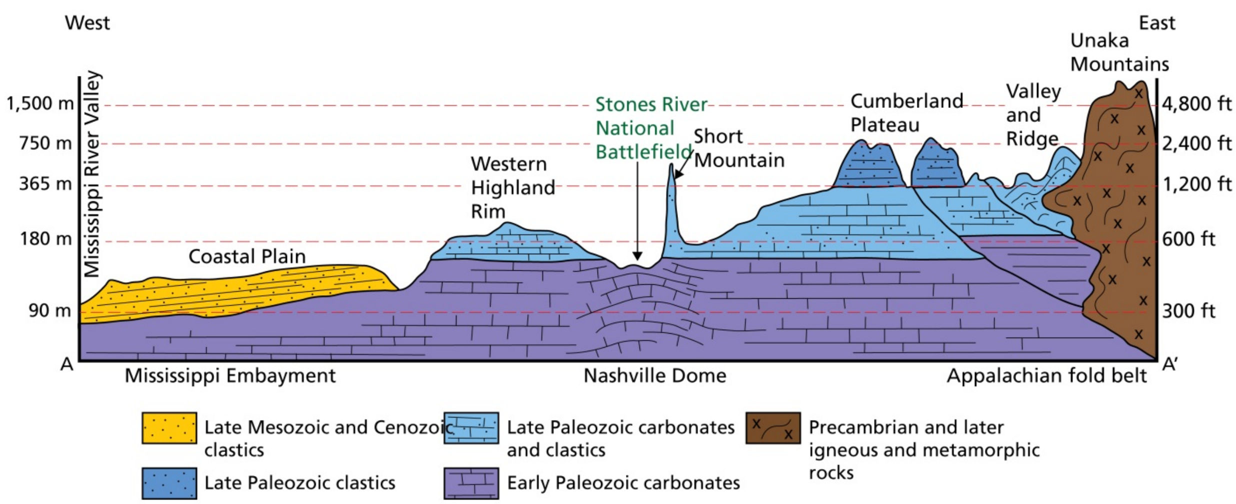

Figure 3. Schematic cross-sectional view through Tennessee. Carbonates are chemical sediments such as limestone and dolomite. Clastics are rocks composed of smaller fragments of other rocks, such as sandstone or siltstone. Graphic shows the classic inverted topography of the Central Basin (Nashville Dome), as described in the "Geologic History" section. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Harris (2012).

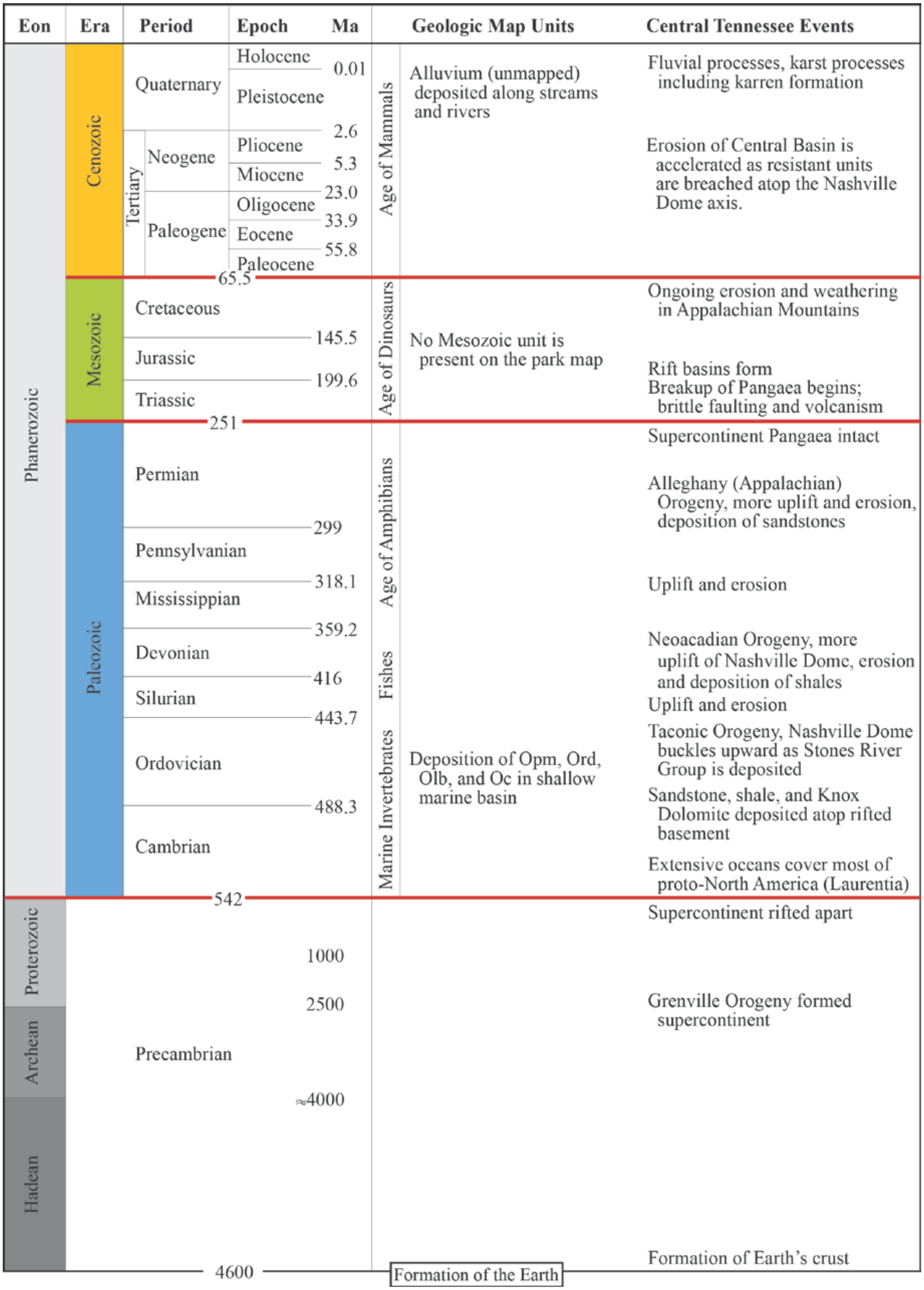

Figure 4. Geologic time scale. Included are geologic events occurring in central Tennessee, with an emphasis on units appearing within the park (see Map Unit Properties Table). Red lines indicate major unconformities between eras. Radiometric ages shown are in millions of years (Ma). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University). Adapted from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2010/3059/) and the International Commission on Stratigraphy (http://www.stratigraphy.org/column.php?id=Chart/Time%20Scale)

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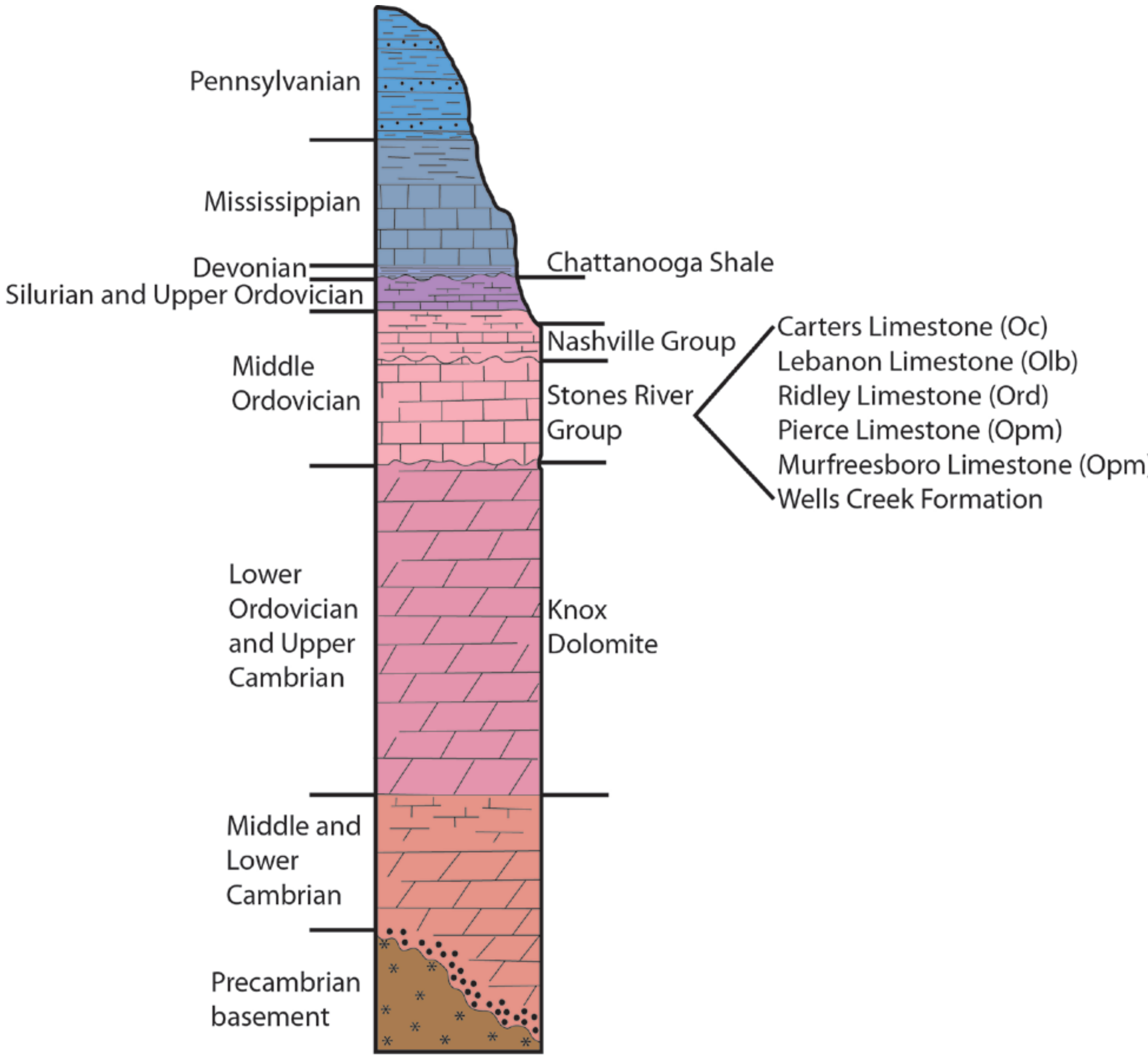

Figure 5. Stratigraphic column of the Nashville Dome in central Tennessee. Geologic map unit symbols included in parentheses correspond with GRI digital geologic map data. The Ridley, Pierce, Murfreesboro, and Lebanon limestones are mapped within Stones River National Battlefield. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after figure 2 in Stearns and Reesman (1986).

Figure 6. Typical, gently undulating terrain in a forested, bedrock-strewn area of Stones River National Battlefield. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

Geologic Issues

The Geologic Resources Division held a Geologic Resources Inventory scoping meeting for Stones River National Battlefield on March 23–24, 2009 and a follow-up conference call on December 28, 2011, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes those discussions and highlights particular issues that may require attention from resource managers. Contact the Geologic Resources Division for technical assistance.

During the 2009 scoping meeting and 2011 conference call, the following geologic resource management issues were identified:

- Disturbed lands and historic landscape restoration
- Karst challenges
- Flooding and fluvial processes
- Slope processes
- Seismicity

The NPS Geologic Resources Division initiated and funded the development of *Geological Monitoring* (Young and Norby 2009; http://nature.nps.gov/geology/monitoring/index.cfm) to provide guidance for resource managers seeking to establish the status and trends of geologic resources and processes within the National Park System, and to advance the understanding of how geologic processes impact ecosystem dynamics. The manual provides guidance for monitoring vital signs—measurable parameters of the overall condition of natural resources. Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, including expertise, personnel, and equipment needed; approximate cost; and labor intensity.

Disturbed Lands and Historic Landscape Restoration

After the Battle of Stones River and the end of the Civil War, the Stones River Battlefield area was subjected to a wide variety of uses that altered the landscape. The National Park Service is restoring the historic landscape and viewsheds important to the battle. Such actions have required new land-use practices and restoration of lands previously disturbed by agricultural use and invasive vegetation, debris dumping, road construction, and limestone quarrying. The Cultural Landscape Report prepared by Wiss, Janey, Elstner Associates and John Milner Associates (2007) provides a detailed description of historic conditions, landscape evolution, existing conditions, and suggestions for the restoration of historic battlefield landscapes and viewsheds that are beyond the scope of this report. A brief summary is presented here.

When established in the 1920s, Stones River National Battlefield covered 141 ha (350 ac), much of which was cultivated with cotton. To better represent the cultural landscape of the battlefield, park staff continues to convert many of these former cotton fields to native grasses. The staff is also reducing mowing, planting trees, and removing exotic species such as privet (*Lingstrum* spp.) from floodplain areas along West Fork Stones River (G. Backlund and T. Morris, Chief of Operations and Resource Manager, respectively, Stones River NB, conference call, 28 December 2011). Park managers occasionally permit hay cutting on 15 ha (38 ac) of pasture. Special use permits are granted for crops covering 5–6 fields of more than 14 ha (35 ac) total. The current areal extent of native grass fields cut varies, but could reach 49–57 ha (120–140 ac) when the park staff has restored all fields (G. Backlund, written communication, 20 July 2012). Several anthropogenic ponds, originally constructed to provide water for livestock, also exist within the current park boundaries, including one near the Artillery Monument (Thornberry-Ehrlich 2009). Park managers currently have no plan to remediate these small ponds (G. Backlund and T. Morris, conference call, 28 December 2011).

Since the park's establishment in 1927 and transfer to the National Park Service in 1933, boundary changes and land acquisition have included within the park several areas that were previously used as dump sites or sources of fill material. Restoration of some sites has been completed, and that of others is underway. For example, a concrete truck washout pit was filled and the concrete debris removed in the mid-1990s, following the 1991 boundary expansion. In 2006–2007, the NPS Geologic Resources Division provided assistance to the park to design a restoration plan for additional tracts of land incorporated into the park (D. Steensen, chief, NPS Geologic Resources Division, personal communication, 20 March 2012). Artificial fill, concrete and other construction debris obscured the land surface at those sites. The park lacked the resources to remove the fill, but instead removed a dump of construction debris and revegetated the site to restore a natural appearance (fig. 7; G. Backlund and T. Morris, conference call, 28 December 2011). Another area now incorporated within the park was previously mined for topsoil and subsequently used as a dump. As of March 2012, the park is trying to obtain funding to mitigate this area, as a significant amount of fill is needed to remediate the soil mine areas. The city of Murfreesboro used the Redoubt Brannan site and adjacent city land as a dumpsite. The dump was removed and refuse (no hazardous materials) was transferred to a landfill in the late 1990s. An old oil and gas well, converted to a water well, is within the park boundary. This may be the well contained in the wellhouse of the maintenance area (G. Backlund, written communication, 20 July 2012).

Figure 7. This former concrete and construction debris dump is now located within the park near the Artillery Monument. Reclamation and revegetation of the site occurred in the mid-1990s. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

In the mid-2000s, the park ecologist noticed that the original 1920s–1930s-era tour road in the park was altering surface water runoff and in turn impacting cedar glade areas (G. Backlund, written communication, 20 July 2012). The tour road was already slated for reonstruction. As part of the cultural landscape restoration plan contained in the park's General Management Plan and Environmental Impact Statement, record of decision 1999, a new route for the tour road was proposed, along with a variety of other transportation infrastructure improvements (Wiss et al. 2007). The new tour road opened on November 15, 2011. The former western portion of the road is now open only to pedestrians, cyclists, and park vehicles (G. Backlund, written communication, 20 July 2012). Construction of the new road included an asphalt overlay on the eastern portion of the existing tour road and on Van Cleve Lane (G. Backlund and T. Morris, conference call, 28 December 2011). This work also included bridging a sinkhole on Van Cleve Lane that posed problems when the road was used as a county road (G. Backlund, written communication, 20 July 2012). A portion of the new tour road located along Historic McFadden Lane/Van Cleve Lane south of Old Nashville Pike may be vulnerable to impacts by sinkholes, as described in the "Karst Challenges" section. The bridging of the sinkhole should minimize collapse potential; park staff will continue to monitor the area for any other sinkhole formation (G. Backlund, written communication, 20 July 2012).

The Lebanon (geologic map unit Olb) and Ridley limestones (Ord) have been mined for aggregate and building stone for decades. Two large, water-filled quarries (identified in the geologic GIS data for the park) adjacent to the Old Nashville Highway near General Rosecrans Headquarters are just outside the park boundary. Although quarrying can impact the hydrogeologic system, hydrologists have seen no alteration in groundwater flow associated with local quarrying to date (J. Meiman, hydrologist, NPS Gulf Coast and Cumberland Piedmont networks, written communication, 9 January 2012). Impacts to the park associated with the quarries include trespassing, damage to fences, and the creation of social trails by people seeking to access the quarries for swimming (G. Backlund and T. Morris, conference call, 28 December 2011). A quarry southwest of the Old Nashville Highway remains active in association with an asphalt plant and limestone milling operation (G. Backlund and T. Morris, conference call, 28 December 2011). According to current Tennessee regulations, no reclamation is likely to be performed at any abandoned limestone quarry (M. Hoyal and R. Zurawski, geologists, Tennessee Division of Geology, written communication, 28 December 2011).

Karst Challenges

The karst features that form the landscape of Stones River National Battlefield are described in the "Geologic Features and Processes" chapter. This section focuses on the resource management challenges associated with a karst landscape. The Ordovician limestone units (geologic map units Opm, Ord, Olb, and Oc) are conducive to karst formation on the highland rim and in the Central Basin in Tennessee. The Ridley Limestone (geologic map unit Ord) is particularly prone to cave and spring development in the pure limestone reaches of the unit (Ogden et al. 2006). Shale layers within the Ridley Limestone and underlying Pierce Limestone (geologic map unit Omp) tend to restrict the formation of conduits and may act as aquitards or restrict connectivity between zones within the groundwater system (Bradley and Hileman 2006).

Because of the nature of their formation, karst landscapes pose several hazards of which park resource managers should be aware, including cave opening and collapse, sinkhole formation, and sinkhole flooding. Rebel Yell Cave is the only known cave opening in the park. This opening is unmarked and surrounded by a steep, unstable, rubble-covered sinkhole (fig. 8). Although the cave opening has been partially reinforced with rebar, the entrance could pose a safety hazard to visitors walking off trail. The park currently does not advertise the location of the cave. This practice should continue to minimize visitor access.

Sinkhole Development

Sinkholes form where dissolution creates a funnel-shaped depression that drains into underground conduits. Excepting areas immediately adjacent to the West Fork Stones River, nearly the entire park is considered to be a sinkhole watershed, meaning that surface water drains into sinkholes (Bradley and Hileman 2006). This process creates flooding issues, as described in the "Sinkhole Flooding" section. Sinkholes impact infrastructure within the park. One sinkhole along a trail in the western portion of the park was filled with gravel. A grate was installed over another sinkhole, expressed as a surface crack in the bedrock along a trail, to promote visitor safety. As such, it poses no immediate resource management concerns (G. Backlund and T. Morris, conference call, 28 December 2011).

Figure 8. Rubble-strewn slopes surround the narrow, rocky opening to Rebel Yell Cave. The exposed limestone blocks are of the Ridley Formation (geologic map unit Ord). Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

South of Old Nashville Highway, historic Van Cleve Lane has been damaged by sinkhole formation. The road was originally gravel, but was "asphaltized" by repeated oil applications. The park staff has since filled the sinkhole and repaved the road. Periodic collapse of the sinkhole requires monitoring and occasional maintenance (G. Backlund and T. Morris, conference call, 28 December 2011).

Sinkhole filling provides only a temporary "fix" to a problem. The same natural dissolution processes that form sinkholes will continue to enlarge them, as illustrated by the need for continued monitoring and upkeep along Van Cleve Lane. To minimize impacts to natural sinkhole features and karst processes, the NPS Geologic Resources Division recommends that managers avoid filling sinkholes and instead consider alternatives such as signs and fences, or rerouting roads and trails away from karst features. When primary cultural resources are potentially impacted by sinkhole formation, park managers face a challenge to balance historic preservation and natural processes.

Sinkhole Flooding

Off-river flooding in sinkholes and low-lying areas in the flood plain of the West Fork Stones River is an acute problem, particularly west of Murfreesboro (Law 2002). Bradley and Hileman (2006) performed an extensive study of sinkhole flooding in three areas of Murfreesboro, including Stones River National Battlefield (therein referred to as part of the Manson Pike focus area), using terrain analysis, aerial photography, and hydrologic measurements such as stream flow, groundwater levels, and flood levels before, during, and after storm events. Within and surrounding the park, they observed sinkholes that never flood, some that flood and then drain quickly, and others that remain flooded for long periods. These behaviors are controlled by water inflow, water outflow, and connectivity to the groundwater conduit system dissolved in the underlying limestones. The authors described three types of sinkhole: pan sinkholes with low connectivity, deep sinkholes with high connectivity, and deep sinkholes with low connectivity to the groundwater conduit system (fig. 9). Such classification of sinkholes based on an understanding of their flood characteristics can guide land-use planning and minimize future damage or potential hazards. Bradley and Hileman's (2006) scheme is presented here:

- "Pan sinkholes with low connectivity—Land-surface modifications that direct more water into a pan sinkhole can result in higher flood-level altitudes and longer flood durations. Land-surface modifications that increase the outflow by overland drainage could decrease the flood-level altitudes. Road construction or alterations that reduce flow within or between pan sinkholes could result in increased flooding duration."
- "Deep sinkholes with high connectivity—These sinkholes store the initial flooding and then rapidly transmit water to the ground-water conduit system (high outflow). Land-surface modifications that direct more water into the sinkhole may increase the flood-peak altitudes, but may not have a substantial effect on flood durations."
- "Deep sinkholes with low connectivity—Outflow from these sinkholes is limited or restricted by a low connectivity to the ground-water conduit system. Land-surface changes that increase the inflow to the sinkholes could result in higher peak-flood levels or longer flood durations."

The authors observed that the West Fork Stones River had a short-lived response to intense precipitation, in contrast to the sinkholes, many of which showed prolonged retention of stormwater. Two low-lying sinkholes located northeast and east of the park's tour road held water for more than 10 days (fig. 10) (Bradley and Hileman 2006). These features may be classified as deep sinkholes with low connectivity. Low-lying areas west of the tour road tend to drain faster and contain deep sinkholes with high connectivity (Law 2002; Bradley and Hileman 2006). Most sinkholes within and surrounding the park area, particularly near the intersection of Manson Pike and Thompson Lane (constructed in 1994), are shallow pan sinkholes with prolonged flood durations, indicating poor connectivity to drains (Bradley and Hileman 2006).

At Rebel Yell well (located at Rebel Yell Cave) in Stones River National Battlefield, a crest-stage monitor measures peak stage (water level). The land surface elevation surrounding the cave is 173 m (568 ft), whereas the bottom of the cave lies at 167 m (547 ft) (Law 2002). Between 1998 and 2000, several measurements at Rebel Yell Cave were dry and detectable water levels peaked at 172.5 m (566 ft), just below the land surface (Law 2002). However, crest-stage gauges at the National Cemetery

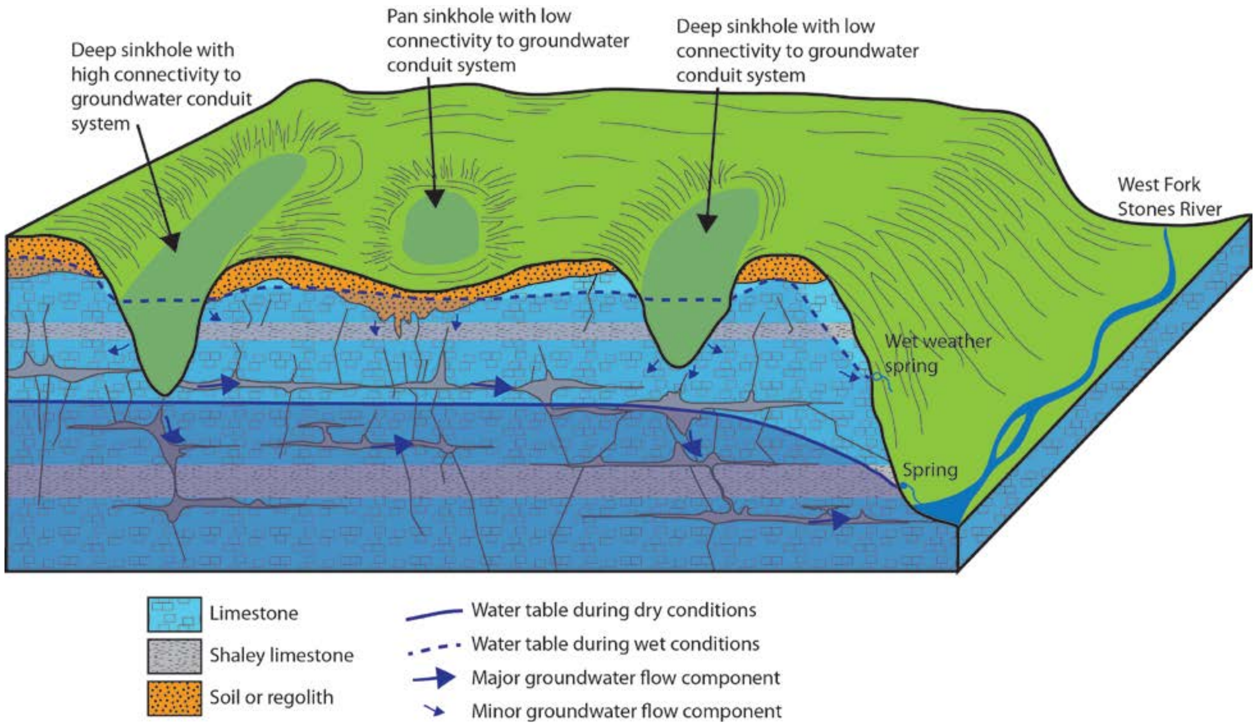

Figure 9. Schematic graphic illustrating the three types of sinkhole and their relationships to a conceptual model of the groundwater system and groundwater flow zones in the Murfreesboro area. Knowing the nature of a particular sinkhole and its relationship to the groundwater system is crucial to predict flood response to heavy runoff. All three types of sinkhole exist within park boundaries. The sinkhole west of the park's tour road is a deep sinkhole with high connectivity. Sinkholes near the intersection of Manson Pike and Thompson Lane are pan sinkholes with low connectivity. North and east of the tour road are deep sinkholes with low connectivity. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after figure 3 in Bradley and Hileman (2006).

frequently recorded water levels higher than the land surface elevation of 167 m (549 ft) that peaked at nearly 169 m (553 ft) during the same period of time, indicating frequent inundation (Law 2002). In the 1970s, soil was excavated from the other side of the highway to fill low spots within the cemetery. These low spots still catch rain and runoff, but are now revegetated with native flood-tolerant species (G. Backlund and T. Morris, conference call, 28 December 2011). The "Fluvial Processes and River Flooding" section contains additional information about flooding in and around the park.

Monitoring Karst Vital Signs

In the chapter in *Geological Monitoring* about caves and associated landscapes, Toomey (2009) described methods for inventorying and monitoring cave-related vital signs, including the following: (1) cave meteorology, such as microclimate and air composition; (2) airborne sedimentation, including dust and lint; (3) direct visitor impacts, such as breakage of cave formations, trail use in caves, graffiti, and artificial cave lighting; (4) permanent or seasonal ice; (5) cave drip and pool water, including drip locations, drip rate, drip volume, drip water chemistry, pool microbiology, and temperature; (6) cave microbiology; (7) stability associated with breakdown, rockfall, and partings; (8) mineral growth of speleothems, such as stalagmites and stalactites; (9) surface expressions and processes that link the surface and the cave environment, including springs, sinkholes, and cracks; (10) regional groundwater levels and quantity; and (11) fluvial processes, including underground streams and rivers.

Fluvial Processes and Flooding

West Fork Stones River is the primary fluvial feature at Stones River National Battlefield. Certain reaches of the river are bedrock incised and relatively stable, whereas natural fluvial processes in other portions cause the river to meander and migrate, which may impact park resources. In the 1970s, the park installed rock riprap to stabilize the riverbank along 90 m (300 ft) of the shoreline downstream from McFadden Ford. Near tour route stop 6, the riprap blends in well with nearby limestone outcrops of the Ridley Formation (fig. 11) (Thornberry-Ehrlich 2009). As of 2011, park staff is considering removing the riprap to allow the river to return to its natural configuration and processes. This plan reflects an overall change in the resource management approach at the battlefield toward the restoration of the landscape to a more natural and historically accurate appearance with native vegetation, as opposed to a heavily manicured setting (G. Backlund and T. Morris, conference call, 28 December 2011).

Karst areas are particularly vulnerable to issues of water quantity (flooding) and quality (contaminant transport). A rapid response to precipitation in lowlands, sinkholes, and local waterways is typical in karst landscapes. At Stones River National Battlefield, this characteristic is due to a high degree of hydraulic connectivity through dissolved conduits in the underlying limestone units on

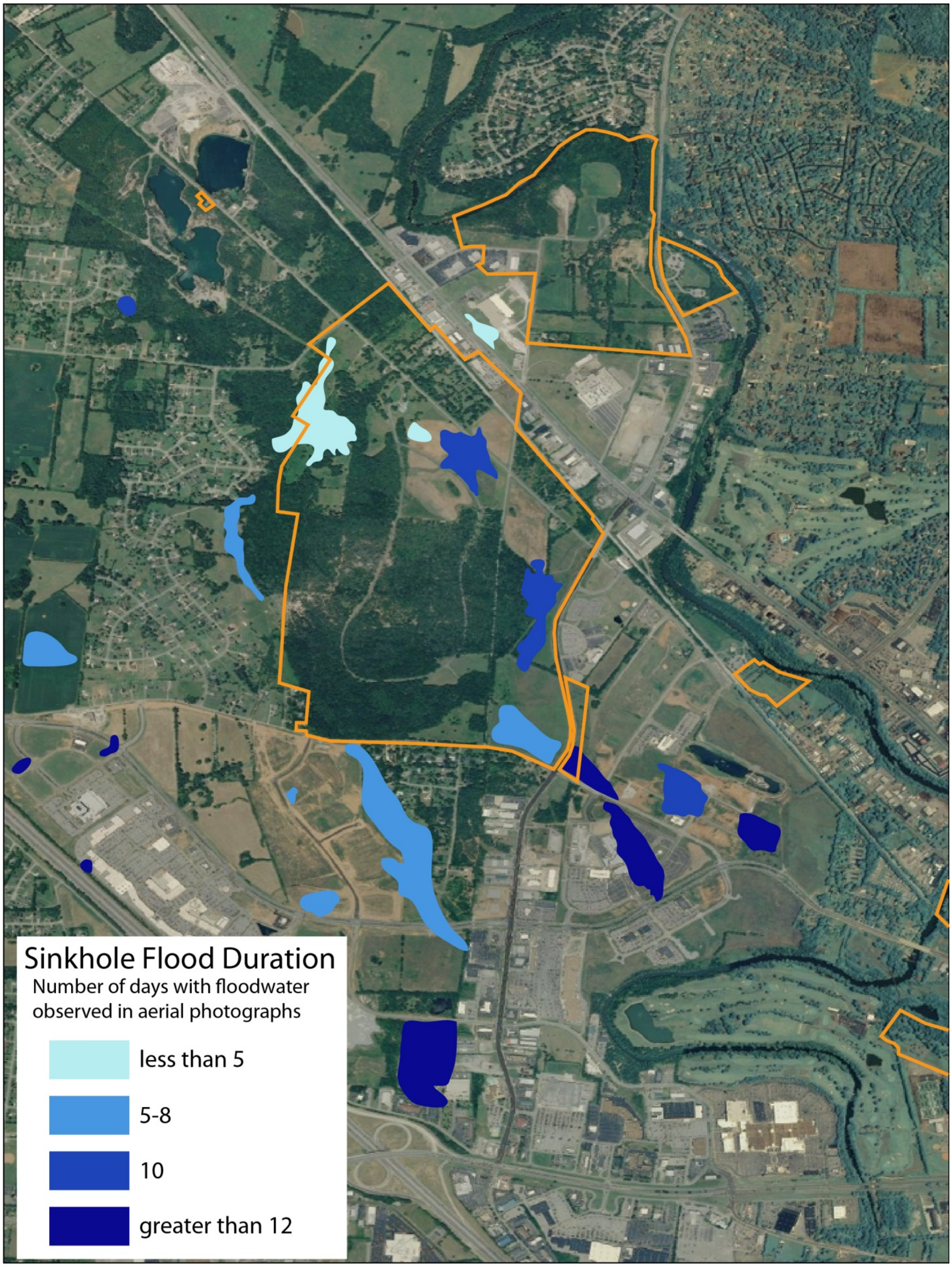

Figure 10. Flood durations of sinkholes in the Manson Pike focus area following a March 2002 storm. Floodwater retention is directly related to the connectivity of a sinkhole with an underground conduit system. Sinkholes with low connectivity retain water longer than those with high connectivity. Note the location of the tour road loop in proximity to sinkholes within Stones River National Battlefield (orange lines are National Park Service boundaries). Graphic by Trista L. Thornberry-Ehrlich and Rebecca Port (Colorado State University) after figure 10 in Bradley and Hileman (2006).

the sinkhole plain and hydraulic connections to the West Fork Stones River. The local sinkholes are relatively shallow and wide (Guebert et al. 1997). According to Law (2002), periodic flooding occurs at lowlands and sinkholes in, and adjacent to, the floodplain of the West Fork Stones River (fig. 12). Sinkhole flooding is described in greater detail in the “Karst Challenges” section. Flooding typically peaks during December through March. Three basic mechanisms cause lowland flooding in the park area: direct storm runoff, rising groundwater levels, and overflow from the West Fork Stones River. The elevation of land surrounding a particular lowland site or overflow outlet controls the maximum floodwater level. Lowlands and sinkholes reach maximum water levels (independent of overflow from the river) every 1–4 years. Minor overflow (less than 0.3 m [1 ft]) from the West Fork Stones River is expected to occur every 10–20 years, moderate overflow of 0.3–0.6 m (1–2 ft) every 20–50 years, and major river overflow (greater than 0.6 m [2 ft]) can be expected every 50 years (Law 2002).

Figure 11. Riprap installed adjacent to bedrock outcrops along the West Fork Stones River. Visitors frequently recreate in this area, using the riprap surfaces as fishing perches. Note the location of bedrock outcrops in the magnified view along the river edge. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

The potential for flooding in the park area is related to rainfall amount and intensity, groundwater levels, and flow in the West Fork Stones River. Other than a few areas of high ground (significant during the battle), most of the park area lies within the West Fork Stones River’s 100-year floodplain. In 2009, long-term drought in the southeastern United States was an ongoing problem affecting central Tennessee. Park resource managers were unsure how the hydrogeologic system and park ecosystem would change in response to less precipitation (Thornberry-Ehrlich 2009). Then, in 2010, heavy spring rains triggered regional flooding that caused severe damage, particularly in Nashville, about 50 km (30 mi) northwest of Murfreesboro. In other parts of Tennessee, heavy precipitation and flooding triggered slope failures and caused sinkholes and caves to open. Some erosion occurred in the floodplain adjacent to the West Fork Stones River, but overall, the park’s infrastructure was unaffected (G. Backlund and T. Morris, conference call, 28 December 2011). Climate forecasts continue to predict relatively wet local conditions compared with pre-2009 droughts. Climate models predict increasing temperatures (average temperatures will rise by about 4.5°F by the 2080s) and more frequent heavy storms (Karl et al. 2009). As climate continues to change, more severe weather events could alter runoff and erosion, thereby impacting fluvial processes and sediment loads in park streams and rivers.

Flood effects are exacerbated by surrounding urbanization, which will continue to expand with the increasing local population (Guebert et al. 1997). Central Tennessee is experiencing the fastest population growth in the state. U.S. Census data estimated more than 111,000 residents in Murfreesboro in 2011, compared with 45,000 in 1992. Impervious surfaces are a major factor affecting water runoff (quantity) and contaminant introduction (quality). During heavy rains, West Fork Stones River rises rapidly due to increased runoff caused by large and expanding areas of impervious surfaces, such as buildings, roads, and parking lots (Thornberry-Ehrlich 2009). Most major roads and railroads are elevated, causing rapid flow of runoff down adjacent slopes. The city of Murfreesboro imposed a stormwater fee as part of a mandate of the Clean Water Act because of the Stones River’s impaired status (G. Backlund, written communication, 20 July 2012).

Areas adjacent to the Nashville Highway and near the National Cemetery receive increased runoff from roadways. Drain and fill work near the cemetery was undertaken in an attempt to mitigate flooding and standing water in the low-lying areas. In general, the use of crushed rock and soil to fill in part of the available floodplain and lowland areas disrupts the natural structure of the karst hydrologic system (Law 2002). The construction of a large drain from a local development known as the Gateway and the Avenues outdoor mall south of the park may prevent some major flooding at the park by channeling runoff away from low-lying areas within the park (Thornberry-Ehrlich 2009). Because the city of Murfreesboro assesses a stormwater runoff tax based on a property’s impervious surface area, minimizing impervious surfaces and rainwater runoff is an important issue for all landowners (G. Backlund and T. Morris, conference call, 28 December 2011).

Water Quality and Karst Geology

This section of the report focuses on the geologic influences of karst on contaminant transport through ground and surface water. For technical assistance regarding water quality issues and monitoring, please contact the NPS Water Resources Division (www.nature.nps.gov/water). The West Fork Stones River is an impaired waterway, due in large part to its location in an urban setting (Tennessee Department of Environment and Conservation 2000; Ogden et al. 2006). The low assimilative capacity (measure of the ability of a body of water to cleanse itself) of the subsurface karst aquifer and the surface karst drainage system is a constant source of concern for developers (Guebert et al. 1997). Runoff and infiltration from external development impact water quality within and around the park (Thornberry-Ehrlich 2009). The characteristically high infiltration rates and permeability of karst landscapes result in little to no adsorption of contaminants, while the rapid runoff rate allows for rapid introduction of surface contaminants. The U.S. Geological Survey performed water quality testing in the late 1990s and found elevated concentrations of volatile organic compounds at park locations such as Battlefield Spring, and dye tracing has revealed direct conduits from local industrial sites to areas beneath the park (Thornberry-Ehrlich 2009). According to Joe Meiman (hydrologist, NPS Gulf Coast and Cumberland Piedmont networks, e-mail communication, 9 January 2012), the NPS Inventory and Monitoring Program considers Stones River National Battlefield a tier (category) 1 water quality park, as defined by the following criteria:

- Water resources are central to park establishment or mission.
- Park visitation includes a high amount of recreational use.
- The park contains federal- or state-listed threatened, endangered, or rare aquatic or dependent species.
- The park's waterways have known exceedances of key water quality standards or are 303d-listed waters. The 303d is an Environmental Protection Agency–mandated list of impaired waters for which the Clean Water Act requires a submittal of approval from states every two years.
- There is a high probability of water resource damage with little or no information of fundamental elements of hydrogeology or water quality.

Because Stones River National Battlefield is a tier 1 park, water quality measurements are conducted regularly at five locations within the park as part of the NPS Inventory and Monitoring Program. The current schedule includes sampling on a fixed monthly date for two years followed by five "off years" before the cycle starts again.

Monitoring Fluvial Processes

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

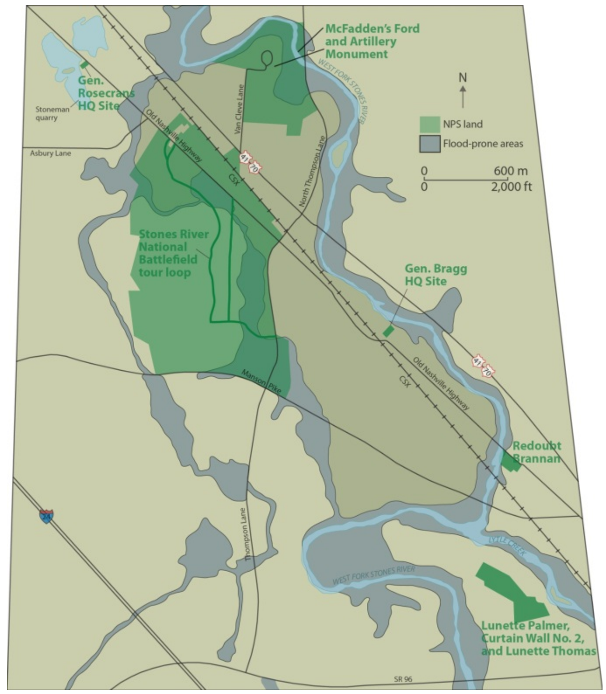

Figure 12. Map of lowland and sinkhole flood-prone areas within and around Stones River National Battlefield. Large fluvial floods with recurrence intervals of more than 10 years flank the river course, but can also overflow into sinkholes and lowlands. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after figure 10 in Law (2002).

Slope Failure and Erosion

According to geologists with the Tennessee Division of Geology, landslide hazards exist within Rutherford County, but the low slopes at the national battlefield preclude risks for major slope failure (fig. 13). Most existing or potential landslide areas are in the southern portion of the county. Tree roots and freeze-and-thaw cycles may dislodge bedrock blocks, which could then tumble down short slopes, such as that near Artillery Monument. Unvegetated areas are more prone to slope failures, such as landslides or slumping. Alternating wet and dry seasons cause normal erosion and slumping, which can be exacerbated by a prolonged drought followed by a sudden saturation event.

The abutment slopes constructed where Thompson Lane crosses the Old Nashville Highway and railroad slump regularly. New trees are beginning to grow there and may eventually stabilize the slope. The city of Murfreesboro has regraded the slope, but it continues to slump after most heavy rains. Although the slumping does not significantly affect park resources at this time, park managers will need to grant a permit to the city for any future work on the slope (G. Backlund and T. Morris, conference call, 28 December 2011). The only other areas of particular risk for slope failure are the slopes along the banks of the West Fork Stones River that occasionally slump.

Figure 13. Artillery Monument atop a bedrock slope flanking the West Fork Stones River (behind the photographer). This area features the steepest topography within the park and is considered stable. Freeze-and-thaw cycles may dislodge blocks of limestone. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

Over time, erosion will continue to subdue and diminish some cultural landforms at the battlefield, including the earthworks. Park staff planted native warm-season grasses in an attempt to stabilize the earthworks. Trees and other vegetation were uprooted from a field in the northern reaches of the park during a spring 2009 tornado. This tornado cut a swath of approximately 24–28 ha (60–70 ac) through the middle of the main body of the park and the Round Forest near tour stop 5. Veering north, the tornado cleared much land along the Stones River to the east of the park boundary in the McFadden Farm area (G. Backlund, written communication, 20 July 2012). Park staff replanted vegetation to help restore the landscape, but heavy rains in 2010 washed away the new vegetation. Park staff plan to continue revegetating the area with native species to stabilize the land surface and reduce runoff (G. Backlund and T. Morris, conference call, 28 December 2011).

In the chapter in *Geological Monitoring* about mass wasting, Wieczorek and Snyder (2009) described five vital signs useful for understanding and monitoring slope movements: (1) types of landslide, (2) landslide causes and triggers, (3) geologic materials in landslides, (4) measurement of landslide movement, and (5) assessing landslide hazards and risks.

Seismicity

Stones River National Battlefield is within an area of relatively low seismic risk (M. Hoyal and R. Zurawski, conference call, 28 December 2011). However, low-magnitude seismic events occur frequently in the area. Though not likely, potential hazards associated with seismicity that could threaten park resources include liquefaction within water-saturated, unconsolidated floodplain deposits. Soil development in the area is relatively thin and only places with significant soils could experience liquefaction (M. Hoyal and R. Zurawski, conference call, 28 December 2011). Strong seismic shaking could damage park infrastructure, including buildings, roads, trails, monuments, and bridges (Thornberry-Ehrlich 2009). Although uncommon, large earthquakes have occurred in the area. The most notable were the New Madrid earthquakes of 1811–1812. Strong shaking from those quakes was felt in Nashville. The August 2011 magnitude-5.8 earthquake in Virginia was not widely felt in central Tennessee, but serves as a recent reminder that not all large earthquakes occur in the western United States.

Seismic monitoring data can be used for many purposes, such as determining the frequency of earthquake activity, evaluating earthquake risk, interpreting the geologic and tectonic activity of an area, and providing an effective vehicle for public information and education (Braile 2009). In the chapter in *Geological Monitoring* about earthquakes and seismic activity, Braile (2009) described the following methods and vital signs useful for understanding earthquakes and monitoring seismic activity: (1) monitoring earthquakes, (2) analysis and statistics of earthquake activity, (3) analysis of historical and prehistoric earthquake activity, (4) earthquake risk estimation, (5) geodetic monitoring and ground deformation, and (6) geomorphic and geologic indications of active tectonics.

Geologic Features and Processes

Geologic resources underlie park ecosystems and geologic processes shape the landscape of every park. This section describes the most prominent and distinctive geologic features and processes in Stones River National Battlefield.

Stones River National Battlefield is underlain by Middle Ordovician limestones. Consequently, karst features are well developed on the park landscape, and indeed throughout central Tennessee. The cedar glades in the park are a globally rare habitat developed on limestone bedrock. The karst features of the landscape played an important role in tactics and maneuverability during the Battle of Stones River. Paleontological resources (fossils) are found throughout the limestones, and the area around Murfreesboro is the place of original description for the group of rocks mapped within the park, the Stones River Group.

Karst Features

The term "karst" comes from a Slavic word that means "barren, stony ground." Karst is a distinctive topography of sinkholes, caves, underground drainage, and other features that develops by dissolution of soluble rocks. Dissolution occurs when acidic water reacts with carbonate rock surfaces along cracks and fractures. Most meteoric water is of relatively low pH ("acidic") due to the reaction between atmospheric carbon dioxide (CO_2) and water (H_2O). The product of this reaction is carbonic acid (H_2CO_3). Groundwater may become even more acidic as it flows through decaying plant debris and soils. The acid reacts with calcium carbonate ($CaCO_3$) in the rocks to produce soluble calcium (Ca^{2+}) and bicarbonate (HCO_3^-); that is, "rocks in solution" or "dissolved rocks." Over hundreds of thousands of years, dissolution has occurred between the intergranular pores and along fractures, creating larger and larger voids.

As carbonate rocks, limestones are soluble in the humid, temperate climate of the Southeast. Three Ordovician limestone units are mapped within the park—the Pierce and Murfreesboro limestones (mapped together as geologic map unit Opm), the Ridley Limestone (Ord), and the Lebanon Limestone (Olb)—as illustrated in the Geologic Map Overview Graphics. The main battlefield and nearly all of the Fortress Rosecrans areas of the park are underlain by the Ridley Limestone, which is widespread throughout Rutherford County. Park areas closer to the West Fork Stones River are underlain by the Pierce and Murfreesboro limestones. Within the park, the Lebanon Limestone is mapped only at the General Rosecrans Headquarters Site.

Nearly all of Rutherford County is underlain by limestone and karst topography (fig. 14) is well developed, particularly in the widespread Ridley Limestone (Ord) (Ogden et al. 2006). Within the park, the deeply weathered limestones display characteristic karst features, including karren, closed depressions (including sinkholes), a cave, and springs (fig. 11).

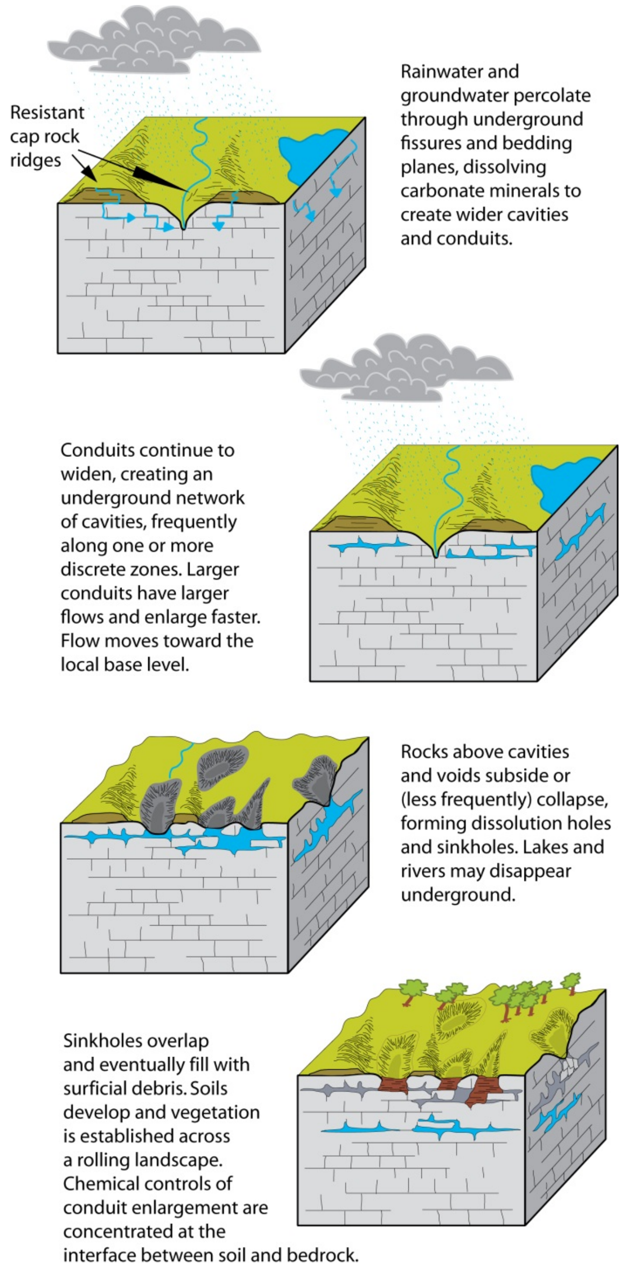

Figure 14. Cross-sectional view of the development of a karstic landscape analogous to that of central Tennessee. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Among the more significant and interesting karst features at the national battlefield are karren ("cutters") on limestone pavements. Karren are "furrows" dissolved into flat bedrock exposures of limestone (pavements; fig. 15). In the park area, karren formed along wide,-weathered fractures or cracks in bedrock called joints (figs. 16 and 17). Joints permit water flow that dissolves bedrock along fractures, widening them. By channeling runoff and entraining organic debris, joints serve as areas of soil development, typically much deeper than on other karst features. Due to soil availability, trees and other vegetation tend to grow within the joint pattern (fig. 18) (Moore et al. 1969). The vegetation and soil contribute to the expansion of karren, and tree roots mechanically weather them. Microbes within the soil release CO_2 into water, thereby creating an acidic solution that dissolves limestone more readily. Between the karren are limestone "pinnacles," or bedrock projections (fig. 19). Joints within the park meet at right angles along two primary orientations: N45°E and N45°W (Moore et al. 1969).

A sinkhole is any closed depression in soil or bedrock formed by the erosion and transport of earth material from below the land surface, which is circumscribed by a closed topographic contour and drains to the subsurface. Most sinkholes form through the slow subsidence of material into an underlying karst conduit dissolved into limestone, rather than a sudden bedrock collapse into an underlying cavern. Several of the park's sinkholes are broad, shallow basins; however, a narrow, crevasse-like sinkhole is located near the western edge of Lunette Palmer. The sinkhole is covered with a metal grate and surrounded by wooden worm fencing to protect visitors from falling into the opening (Wiss et al. 2007). As mentioned in the "Geologic Issues" section, several active sinkholes exist within the battlefield. They are primarily blocked and/or filled to enhance visitor safety.

Rebel Yell Cave is the only identified cave on Stones River National Battlefield property. The cave was named by park employees following a mapping effort by the Nashville Grotto in the 1970s (M. Hoyal and R. Zurawski, conference call, 28 December 2011). When not inundated by water, the cave is at least 6–9 m (20–30 ft) deep and is basically a vertical, narrow rocky shaft. Dye traces link Rebel Yell Cave with Snail Shell Cave,

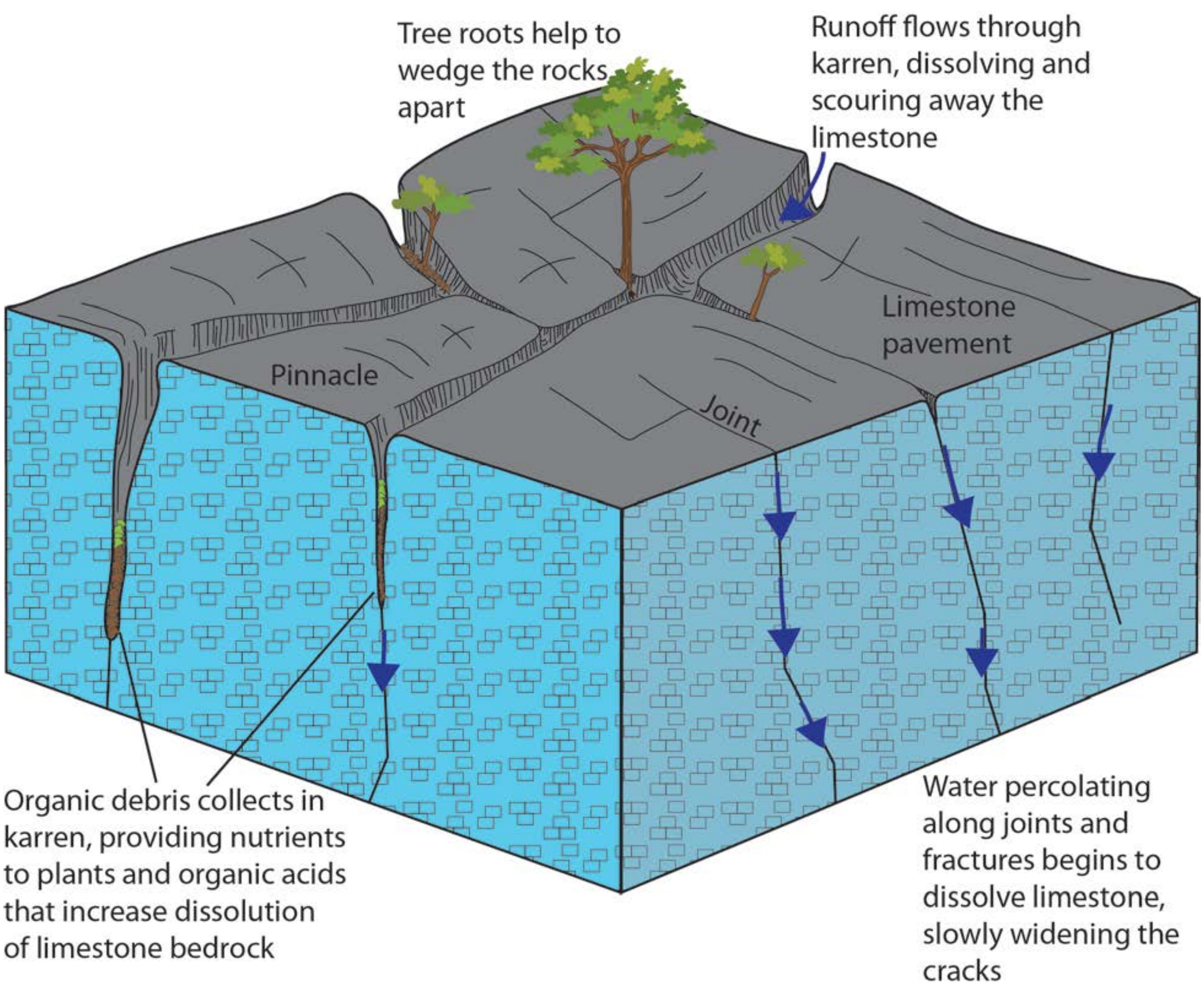

Figure 15. Development of karren in jointed limestone analogous to that at Stones River National Battlefield. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

which is one of the most biologically significant cave sites in the southeastern United States and, with more than 14 km (9 mi) of surveyed passages, the longest continuous cave in the Central Basin of Tennessee (Thornberry-Ehrlich 2009; Southeastern Cave Conservancy n.d.). Snail Shell Cave is located approximately 7.5 km (4.7 mi) southwest of Rebel Yell Cave, outside of park boundaries.

Generally, springs develop where the ground surface intercepts the water table. In karst systems, almost all groundwater emerges at discrete springs in entrenched river valleys or karst windows (Palmer 1990). Springs may also develop in karst systems on slopes that intersect relatively impermeable layers, such as those of shale or sandstone, that form small, locally perched aquifers. The Ridley Limestone (geologic map unit Ord, exposed within the park) contains several springs that emerge at the Ridley Limestone contact with the relatively impermeable underlying Pierce Limestone (Ogden et al. 2006). The karst plain is internally drained, with springs emerging and draining almost immediately. At least two springs occur within the park. Battlefield (McFadden) Spring is surrounded by a stone wall (fig. 20) that was installed at the same time that riprap was placed to armor a section of the West Fork Stones River (G. Backlund and T. Morris, conference call, 28 December 2011). Another spring feeds King Pond. Five or six small, ephemeral wetlands overlie aquitard layers within the park and may also be associated with springs.

Figure 16. Deciduous trees growing within karren at Stones River National Battlefield. Karren entrap organic debris and act as water conduits; this combination creates relatively deep soil that supports plant life. Soil formation and plant growth mechanically and chemically weather and widen the karren. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

These karst features, particularly the karren, hindered troop and artillery movements during the Civil War battle, but also provided soldiers with shelter from enemy fire, so-called shelters of convenience. Joints at the Slaughter Pen are more than 1 m (3 ft) deep, and were thus capable of sheltering a soldier or trapping a wagon wheel. For more information, refer to the “Geologic Connections to Park Stories” section.

Figure 17. Ninety-degree angles in karren at Stones River National Battlefield. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

Cedar Glades

Approximately 17 ha (43 ac) of globally rare cedar glade habitats exist in the southern part of Stones River National Battlefield (fig. 18), where weathered limestone gravel covers the ground surface with very little to no soil development (0.64 cm [0.25 in.] maximum soil depth; fig. 21). These glades tend to develop atop thin-bedded limestone bedrock (Moore et al. 1969). The Gladesville soil type, characterized by a thin veneer of weathered soil and rocks (regolith), was named after the cedar glades. Refer to the Soil Resources Inventory map and database (National Park Service 2009) for additional soil information.

These open areas appear devoid of appreciable flora, but in fact host an uncommon assemblage of species. Cedars and endemic, rare, and/or endangered species, such as the Tennessee purple coneflower and Pyne’s ground-plum, have adapted to the high light/heat reflectivity of the exposed bedrock and the alkaline properties of the scant regolith (Moore et al. 1969; Wiss et al. 2007; Thornberry-Ehrlich 2009). In July 2011, the cone flower was removed from the endangered species list (G. Backlund and T. Morris, conference call, 28 December 2011). Red cedar trees preferentially grow in areas with little to no soil development and can form nearly impenetrable thickets. The cedars are not found in areas with thicker soil, where they would be out-competed by faster-growing hardwoods (Moore et al. 1969). The tour road of the national battlefield currently passes through several cedar glades. Signs are posted in an attempt to

Figure 18. Aerial photograph of the cedar glade areas in the southern region of the park. Note areas devoid of trees (cedar glades). Aerial imagery from ESRI Arc Image Service, Bing Maps layer.

keep visitors from trampling and degrading the glades, but it remains unclear whether the roads themselves have any impact on these fragile ecosystems.

To better understand the conditions of the cedar glades and to predict future response to environmental changes, the NPS is participating in an interagency project with the U.S. Geological Survey to explore the hydrology of the limestone glades within Stones River National Battlefield. Within the park, the goals of the project are four-fold: (1) develop an annotated bibliographic review of previously published hydrologic observations in limestone glades; (2) collect seasonal measurements of soil moisture, depth, slope, and runoff in and around at least five selected sites containing glades; (3) develop a conceptual model of the karst hydrology of limestone glades; and (4) design a study plan to develop, calibrate and apply a predictive model of limestone-glade hydrology. The model seeks to illuminate the interactions among the underlying geologic structure, karst processes, soil conditions, and surface runoff as they relate to plant distribution and ecological health (National Park Service unpublished).

The cedar glades played an important role in tactics and maneuvers during the Battle of Stones River, as described in the "Geologic Connections to Park Stories" section.

Figure 19. A pinnacle amid karren or "cutters" at Stones River National Battlefield. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

Figure 20. Battlefield Spring near West Fork Stones River in the Artillery Monument and McFadden Ford unit of the park. Springs such as this are characteristic of karst terrains. The stonework and steps were added in the 1970s, accompanying the installment of riprap along the nearby riverbank. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

Figure 21. Cedar glade along the tour road at Stones River National Battlefield. These areas seem nearly devoid of plant life, but harbor a unique collection of species. These open areas influenced the battle fought there. In stark contrast to the forested thickets or cumbersome karren, these glades were easily crossed by cannon, artillery, wagons, and soldiers. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

Geologic Connections to Park Stories

The agricultural landscape of central Tennessee, combined with the transportation corridors near Murfreesboro, made the area strategically important during the Civil War (Cozzens 1990; Wiss et al. 2007). Underlying geology contributed to the landscape and transportation access in the area. Geologic features also greatly influenced the Battle of Stones River.

Historically, any arable land (i.e., not rocky, with significant and uniform soil development and appropriate slope and drainage) in Rutherford County was used as field or pasture. This use contrasted with uncultivated forested areas, which generally have limestone rock outcrops and thin soils (Moore et al. 1969).

Local rock supplied the material for the original Nashville, Murfreesboro, and Shelbyville Turnpike (Nashville Pike), a 9-m (30-ft)-wide toll road with a convex surface constructed with crushed stone and stone dust compacted with water. This road, in addition to local railroads, played a major role in military campaigns in the area during the Civil War. The Nashville and Chattanooga Railroad played a strategic role in the battles fought there. The raised rail beds (underlain by the same material used for elevated roads) provided high ground for Union cannon. These arms repulsed a Confederate advance before it reached the Nashville Pike. After the battle, the railroad continued to serve as a supply route for Union forces advancing southward (National Park Service 2010).

Confederate General Bragg recognized the strategic importance of the central Tennessee farms that provided food to Confederate army troops, as well as the transportation hub of Murfreesboro. He aimed to block any Federal advance on Chattanooga. The Union army desperately wanted a victory to boost morale after their defeat at Fredericksburg and strengthen the nation's resolve to continue the struggle to retain the union. The gently undulating landscape around Murfreesboro offered "no particular advantages for the defense" according to General Bragg. However the cedar glades and karren played significant roles in the battle. The park's website contains detailed descriptions and maps of the battle, which are beyond the scope of this report (National Park Service 2010).

While positioning Confederate troops around the city, small but dense cedar forests were noted near the intersection of the Nashville Pike and the Nashville and Chattanooga Railroad, in places more impenetrable to infantry than the infamous Wilderness of Spotsylvania Courthouse in Virginia (now part of Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park; Thornberry-Ehrlich 2010). Rocky ground and cedar forests somewhat impeded initial Confederate attacks (Wiss et al. 2007). One rocky 2-ha (4-ac) cedar forest, locally named "Round Forest," became known as "Hell's Half-Acre" after intense fighting occurred there. Hazen's brigade erected the nation's oldest intact Civil War monument in this location in 1863. The cedar glades were open areas that allowed easy passage of troops during the battle, compared with the karren described below. Soldiers present at the battle wrote in journals and letters about "empty fields" (Thornberry-Ehrlich 2009).

The “Slaughter Pen,” an area of well-developed karren and pinnacles, is the most popular tour stop at the park and is considered a signature natural and cultural feature of the park (G. Backlund and T. Morris, conference call, 28 December 2011). The karren and pinnacles, described by soldiers as “rows of teeth,” provided “shelters of convenience” for soldiers trying to avoid enemy fire. They also impeded the movement of wagons, artillery, and troops (fig. 22), and hampered communication and coordination between units. Following hours of fighting, the Union troops were nearly out of ammunition and almost completely surrounded, forcing their retreat through the cedars. The difficult terrain slowed the progress of the battle and retreat, leading to extraordinary numbers of casualties. Union troops compared the carnage to the slaughter pens in Chicago stockyards. The Nashville Pike was used as a commanding Union artillery position while the Confederates struggled through the cedars and karren (Wiss et al. 2007).

As is typical of karst landscapes, soil cover was very thin, making construction of fortifying earthworks difficult except in areas such as those parallel to the Nashville Pike, where the Union Pioneer Brigade dug in (Wiss et al. 2007). Earthworks were also used to construct Fortress Rosecrans, a critical link in the supply chain for the Union army and a fortified position to protect the Nashville Pike and railroad crossings (Wiss et al. 2007). The placement of the fort and its redoubts took advantage of natural topographic highs underlain by Ordovician bedrock. After a second local military engagement known as the Battle of the Cedars (December 7,1864) and the end of the Civil War in 1865, the earthworks of Fortress Rosecrans were left to erode away or be used as construction fill (Wiss et al. 2007).

Because much of the West Fork Stones River flows through a bedrock channel, geology controlled the location of the shallow McFadden Ford that was a turning point in the battle—a feature now largely obscured by 1970s-era riprap along the river (Moore et al. 1969; Wiss et al. 2007; Thornberry-Ehrlich 2009). At the ford, Confederates who had just gained high ground on the east side of the river were stalled trying to cross by heavy fire from Union artillery positioned on a low ridge on the other side (fig. 23). The Confederates suffered more than 1,800 casualties in less than an hour and were pushed back to Wayne’s Hill (Wiss et al. 2007).

After the Civil War and prior to the park establishment in 1927, much of the woodlands were cleared, as described in the “Disturbed Lands” section. Many of the stones used for fences, building foundations, and possibly memorials are locally sourced limestone bedrock. After the Civil War and prior to 1926, at a central section of the former battlefield, west of the Nashville Pike and the Hazen Monument, an African-American community was established. Rebel Yell Cave was likely used as a water source (Wiss et al. 2007; G. Backlund and T. Morris, conference call, 28 December 2011). Park staff is currently developing an interpretive program about this community to educate visitors about the post-battle history of the area.

Figure 22. Scene from the “Slaughter Pen.” The limestone karren proved tremendously challenging to traverse during the Battle of Stones River. As described in an exhibit at the Slaughter Pen, the karren formed a “limestone labyrinth.” The labyrinth changed from a “stone stronghold” to an “ankle-twisting deathtrap” when Union Brig. Gen. James Negley called for a retreat. Retreat was necessary after nearby Gen. Philip Sheridan’s troops ran out of ammunition and Confederate troops threatened to overrun the Union positions. National Park Service wayside exhibit graphic.

Figure 23. Confederate viewpoint near the McFadden Ford across the West Fork Stones River. National Park Service photograph by Jim Lewis (Stones River National Battlefield).

Paleontological Resources

Paleontological resources (fossils), primarily marine invertebrates, are known from limestones in Stones River National Battlefield and attest to the abundance of life in shallow seas during the Ordovician period. As part of a paleontological resource summary for all parks in the NPS Cumberland Piedmont Network, Hunt-Foster et al. (2009) presented an overview of fossils within the park and provided recommendations for paleontological resource management.

The Middle Ordovician Ridley Limestone (Ord), underlying most of the park, contains coiled-shell cephalopods as well as sponges, bryozoans, brachiopods, and gastropods (Galloway 1919; Hunt-Foster et al. 2009). Fossils of squid-like cephalopods (possibly *Gonioceras occidentale* or *G. anceps*) are known from the park and are visible in cross section along trails, particularly in areas near the Artillery Monument (fig. 24). Fossil corals are present in limestone "float" (most likely of the Ridley Formation) that occurs on the surfaces of cedar glades within the park. Although fossils have not yet been documented from them within the park, the Pierce and Murfreesboro limestones (Opm) contain marine invertebrate fossils of bryozoans, brachiopods, ostracodes, and gastropods (Galloway 1919; Hunt-Foster et al. 2009). The Lebanon Limestone (Olb) is also richly fossiliferous, although no fossils are yet known from the formation within the park.

Fossils tend to be secure within the bedrock and are not weathering out in abundance (M. Hoyal and R. Zurawski, conference call, 28 December 2011). The park staff is not aware of any illegal collecting (G. Backlund and T. Morris, conference call, 28 December 2011). Some caves in Tennessee contain Pleistocene or Holocene (ice age or younger) fossil remains, but such remains are not likely to be present in Rebel Yell Cave (Thornberry-Ehrlich 2009).

Santucci et al. (2009) outlined potential threats to *in situ* paleontological resources and suggested vital signs monitoring to qualitatively and quantitatively assess the potential impacts of these threats. Paleontological vital signs include: (1) erosion (geologic factors), (2) erosion (climatic factors), (3) catastrophic geohazards, (4) hydrology/bathymetry, and (5) human access/public use. The authors also presented detailed methodologies for monitoring each vital sign.

Figure 24. Fossil cephalopod shell (note growth chambers) in bedrock along a visitor trail in Stones River National Battlefield. Such fossils are probably not prone to theft because they weather at more or less the same pace as the surrounding bedrock. Fossil is approximately 15 cm (6 in.) in length. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University) in March 2009.

Stones River Group

The Middle Ordovician Stones River Group (referred to in other states as the Black River Group) consists of seven subunits, listed from oldest to youngest: Pond Spring Formation, Jewell Bluff Formation (these two formations are sometimes mapped as the Wells Creek Formation), Murfreesboro Limestone (geologic map unit Opm), Pierce Limestone (Opm), Ridley Limestone (Ord), Lebanon Limestone (Olb), and Carters Limestone (Oc). This group was originally described by Safford (1851) and named for the Stones River, where the most complete exposures of the group are found. Stones River National Battlefield and General Rosecrans Headquarters Site are located on the Ridley Limestone, whereas the Artillery Monument, Redoubt Brannan, Curtain Wall No. 2, Lunette Thomas, Lunette Palmer, and General Bragg Headquarters Site are all mapped on Pierce and Murfreesboro limestones (see "Geologic Map Data" for detailed descriptions) (Wilson 1964, 1965). No type section occurs within park boundaries. The Carters Limestone type section occurs on Carters Creek in Maury County. The Lebanon Limestone type section occurs at Readyville, northeast of where the Murfreesboro-Woodbury Highway crosses the East Fork Stones River. The Ridley Limestone type locality is at a river bluff downstream from Davis Mill in Rutherford County. The Murfreesboro Limestone type section occurs north of the city. The Pierce Limestone type locality is at Pierce's Mill, where the Murfreesboro and Lebanon Turnpike crosses Stones River in Rutherford County (U.S. Geological Survey 2011; M. Hoyal and R. Zurawski, conference call, 28 December 2011).

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Stones River National Battlefield, the environment in which those units were deposited, and the timing of geologic events that formed the present landscape.

The geologic history of the bedrock in Stones River National Battlefield is dominated by the presence of a long-standing marine basin during the Paleozoic Era. This basin collected vast amounts of carbonate sediments that are now called the Stones River Group (named for excellent exposures in and around Murfreesboro, although not within the park). Concurrent with several Paleozoic mountain-building events (orogenies) that ultimately formed the Appalachian Mountains was the buckling or uplift of the Nashville Dome, centered on what is now Murfreesboro. Younger sedimentary rocks were thinly deposited atop this dome. Hundreds of millions of years of erosion have revealed the limestone on the landscape today at the core of the Nashville Dome. As is typical in karst landscapes, limited to no soil development or unconsolidated surficial deposits occur within the park (fig. 4).

Early Paleozoic Era (542–416 million years ago)—Longstanding Marine Deposition

At the dawn of the Paleozoic Era 542 million years ago, the area that would become central Tennessee was a marine basin. At this time, in the Early Cambrian, tectonic forces were stretching Earth's crust apart. This extension, called "rifting", created deep grabens (basins) separated by horsts (ranges or ridges). These deep-seated basement structures were active throughout the Paleozoic, creating low-lying depositional basins separated by uplifted arches and domes. One such basement structure, the Nashville Dome, is part of the Cincinnati Arch, a prominent regional uplift that extends north from the Nashville area in central Tennessee to northwestern Ohio (fig. 25). The Cincinnati Arch separates the Illinois Basin to the north and west from the Appalachian Basin to the east.

The arch and adjacent depositional basins were present throughout most of the Paleozoic. Stratigraphic data show that individual units thicken toward the centers of the depositional basins and thin towards the axis of the arch, suggesting that the arch was present as early as the Ordovician (about 487–444 million years ago) (McDowell 2001). At this time, central Tennessee was centered roughly on the equator.

Deposition, Exposure, and Erosion of the Knox Dolomite

The grabens formed by extensional events at the beginning of the Cambrian collected vast amounts of mixed sediments and subsided further. Marine deposition continued with the deposition of the Upper Cambrian–Lower Ordovician Knox Dolomite. Abrupt changes in the thickness of the Knox Dolomite indicate the presence of basement structures (grabens) that collected more sediment relative to higher areas (Stearns and Reesman 1986). The Knox Dolomite does not appear to thicken toward the Appalachian Basin or Illinois Basin, but instead thickens southward, possibly as part of a Late Cambrian or Early Ordovician shelf structure (Stearns and Reesman 1986). This feature could indicate that the Nashville Dome was actively uplifting after deposition of the Knox Dolomite.

A regional unconformity (period of erosion or nondeposition) marks the boundary between the Knox Dolomite and the limestones of the Middle Ordovician Stones River Group (fig. 5). Erosion of the Knox Dolomite surface included karst formation that extends downward at least 150 m (500 ft) into the dolomite. Karst tends to form above a local base level, often manifested as a major stream, river, or even sea level. This tendency suggests that the entire formation was at least 150 m (500 ft) above sea level at some point following its deposition. In central Tennessee, the crystalline basement structure domes upward, but the main high point is not centered on the Nashville Dome; it lies to the northeast under the Cumberland Plateau. At this location, the Upper Cambrian and Lower Ordovician Knox Dolomite, upon which the Stones River Group was deposited, was most deeply eroded (Fischer 1977).

The Stones River Group—A Return to Marine Deposition

Following the exposure and erosion of the Knox Dolomite, relative sea levels rose and shallow, calm marine conditions returned during the deposition of the Middle Ordovician Stones River Group. This deposition began with the Wells Creek Formation atop the weathered, karstic surface of the Knox Dolomite (Stearns and Reesman 1986; Evenick and Hatcher 2006a). At this time, the axis of the Nashville Dome was level and oriented to the southwest (Stearns and Reesman 1986). Marine life thrived in the shallow environment, resulting in a fossil record rich in corals, snails, brachiopods, crinoids, and many other species (Wilson 1949).

In the middle of the Ordovician Period, the first of three major Appalachian orogenies began to change the eastern United States. During the Taconic Orogeny, about 470–440 million years ago, a volcanic arc collided with the eastern edge of proto–North America (a landmass referred to as Laurentia). The resulting highlands were located east of central Tennessee, but local basement structures such as the Nashville Dome were buckled gently upward and deposition of units exposed within the park was contemporaneous with the Taconic Orogeny (Holland and Patzkowsky 1997). The lack of significant deformation of the Ordovician bedrock, excepting some low-angle folds (Moore et al.

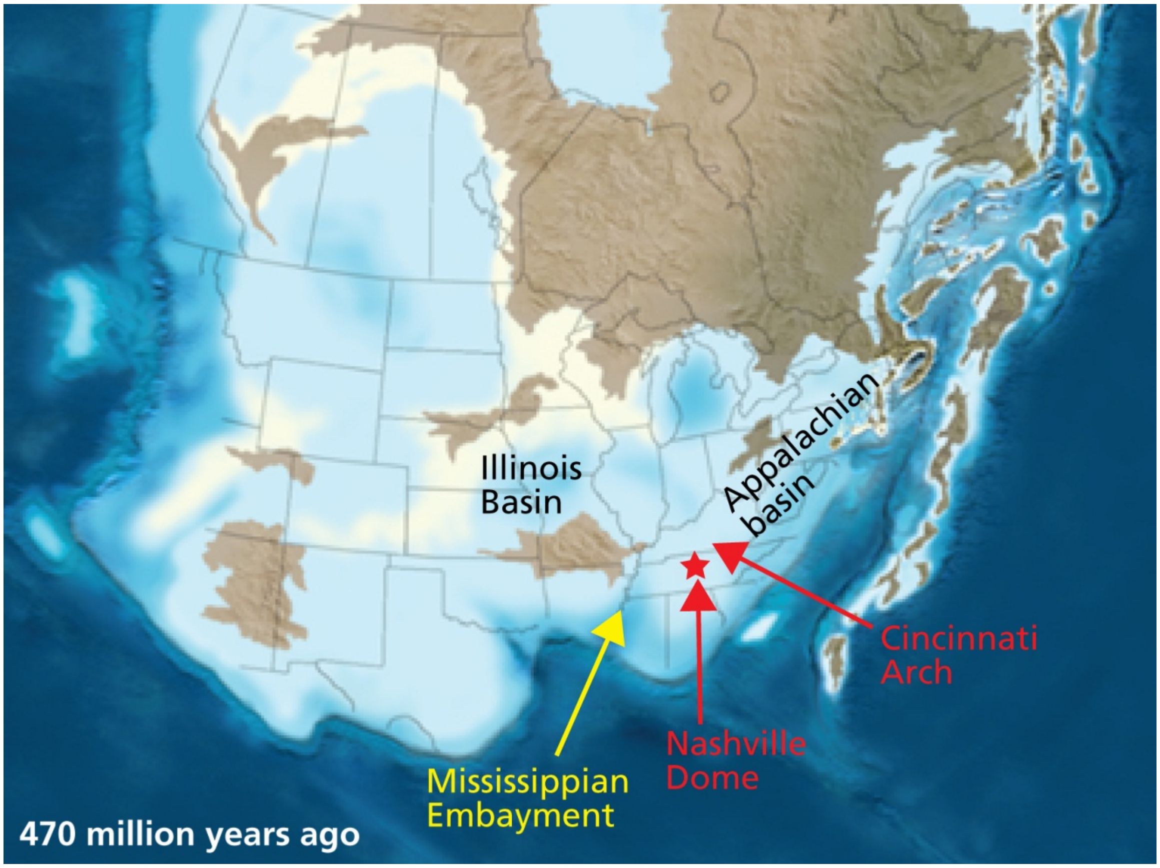

Figure 25. Marine inundation and local structures present during the Middle Ordovician (approximately 470 million years ago) in central Tennessee. At this time, limestone units (geologic map units Ord and Opm) exposed within Stones River National Battlefield were collecting in a shallow marine basin. Basins are downwarped geologic structures typically characterized by thick sedimentary deposition, whereas arches are geologic structural flexures, often located between basins. Arch erosion exposes rocks at the surface that are older than those in adjacent basins. Red star indicates approximate location of Stones River National Battlefield. Graphic compiled by Trista L. Thornberry-Ehrlich (Colorado State University). Base paleogeographic map by Ron Blakey (Colorado Plateau Geosystems, Inc.), available at http://cpgeosystems.com/paleomaps.html.

1969; Burchett and Moore 1971), indicates that inland deformation was not pervasive in central Tennessee. As the mountains rose, they immediately began to erode, shedding sediments to the east and west.

The lowermost units of the Stones River Group (Wells Creek Formation up into Murfreesboro and Pierce limestones [geologic map unit Opm]) contain substantial amounts of shale (Evenick and Hatcher 2006a), indicating significant sediment input from the eroding mountains. The Wells Creek Formation is predominantly shaly limestone and dolomite (Stagg 1972; Evenick and Hatcher 2006a). The Murfreesboro Limestone (Opm) consists of limestone and shaly limestone (Wilson 1964, 1965; Milici 1969; Evenick and Hatcher 2006a). The Pierce Limestone (grouped with the Murfreesboro Limestone as Opm) is a thin-bedded shaly limestone with a characteristic layer of clean, pure limestone in the middle (Wilson 1964, 1965; Evenick and Hatcher 2006a, b). Chemical sedimentation was predominant in the deposition of the Ridley Limestone (Ord), which tends to be massive with very little shaly or dolomitic interlayering (Wilson 1964, 1965; Milici 1969; Evenick and Hatcher 2006a). Because of its purity, the Ridley Limestone is the most karstic of the locally exposed units (Farmer and Hollyday 1999; Bradley and Hileman 2006). The Lebanon Limestone (Olb) contains significantly more shale layers than does the massive underlying Ridley Limestone (Ord) or the overlying Carters Limestone (Oc) (Wilson 1964, 1965; Milici 1969; Evenick and Hatcher 2006a). The Carters Limestone (Oc) has several distinguishable bentonite (altered volcanic ash) layers that are useful markers for dating and regional correlation (Milici 1969; Kunk and Sutter 1982; Evenick and Hatcher 2006a). Minimum age dates for these bentonites tend to cluster around approximately 455 million years ago, during the tectonic unrest associated with the Taconic Orogeny (Kunk and Sutter 1982).

An unconformity dating to the Middle Ordovician is present between the Carters Limestone (Oc) and the lowermost units of the Nashville Group (Stearns and Reesman 1986; Evenick and Hatcher 2006a, 2006b). This unconformity resulted from a local drop in relative sea level and exposure of the Stones River Group rocks to erosion. The Nashville Group (from oldest to youngest: Hermitage Formation, Bigby-Cannon Limestone, and Catheys Formation) documents continued deposition of mixed limestone and shale in a marine setting (Evenick 2006).

Later Paleozoic Era (416–251 million years ago)—Erosion, Uplift, and Deposition

Throughout the Devonian (about 416–359 million years ago), marine conditions prevailed locally. The collision of additional landmasses with Laurentia during the Devonian Period signaled the onset of another mountain-building pulse—the Neoacadian Orogeny. This episode occurred as the African continent (part of a landmass known as Gondwanaland) slowly approached between 410 and 360 million years ago. As with the earlier orogeny, the Nashville Dome buckled upward, causing the units deposited over its crest to be thinner relative to their thickness in adjacent basins.

Following an erosional event, the Chattanooga Shale was deposited atop the Nashville Group (known elsewhere as the Trenton Group) during the Middle–Upper Devonian. Prior to its deposition, the axis of the Nashville Dome plunged northeast (Stearns and Reesman 1986). Though not exposed within the park, the Chattanooga Shale records a regional resurgence of clastic sediments shed into the area by rivers and streams from nearby highland sources (Livesay 1953). Intermittent sandstone beds, or “bone beds,” within the Devonian sequence likely reflect widespread erosional periods during the Devonian (Conkin and Conkin 1969; Kepferle 2001).

Devonian and younger rocks in Tennessee, including the cherty Fort Payne Formation and other sandstones, thicken gradually away from the crest of the Nashville Dome (Stearns and Reesman 1986). Deposits were preferentially shed into the adjacent basins and eroded from the dome.

The Pennsylvanian–Permian Alleghany Orogeny (about 330–270 million years ago) involved continental collision between Laurentia and Gondwanaland, which formed a supercontinent called Pangaea and lifted the Appalachian Mountains to their maximum height. According to Stearns and Reesman (1986), the Nashville Dome was buried during the Mississippian, perhaps through the Permian. This deep burial was not necessarily due to subsidence of the dome; the rise of the Appalachian highlands to the east during the Paleozoic orogenies would have provided mass mantles of eroded sediment that could have buried the dome at this time. The end of this burial is not recorded because erosion prevailed on the Nashville Dome throughout the latest Paleozoic and early Mesozoic, which constitutes a “lost interval” (Stearns and Reesman 1986).

Mesozoic and Cenozoic Eras (251 million years ago–present)—Weathering and Shaping the Landscape

Since the end of the Paleozoic, the geologic history of the Stones River National Battlefield area has been characterized primarily by intermittent, uneven uplift of the Nashville Dome (Stearns and Reesman 1986), erosion, and weathering that have removed Pennsylvanian and older strata from structurally higher areas, such as the Nashville Dome. Since the end of the Paleozoic Era, the dome has been uplifted a total of about 1,940 m (6,350 ft) and the trend of the dome’s axis has become nearly east–west (Stearns and Reesman 1986).

During the end of the Mesozoic and the dawn of the Cenozoic, the Nashville Dome continued to rise. The west side of the dome experienced more than 300 m (1,000 ft) of post-Cretaceous uplift (Stearns and Reesman 1986). Throughout this time, erosion continued to remove layers of rock from the Nashville Dome. Due to its arch-like morphology, bedrock units were thinner at its crest than along its flanks; thus, subsequent erosion could more easily breach resistant bedrock units, such as sandstones. Pennsylvanian sandstones were entirely eroded from central Tennessee. By approximately 6 million years ago, the resistant Fort Payne Formation eroded through where it was thinnest, at the crest of the Nashville Dome in the present-day Murfreesboro area. This removal exposed less-resistant shales and more-soluble limestone rocks to erosion. These rocks eroded relatively quickly, leading to the formation of the Central Basin at the crest of the Nashville Dome—a classic geologic example of inverted topography (fig. 26) (Reesman and Godfrey 1981).

Throughout the Pleistocene and Holocene epochs, streams continued to erode into the Central Basin (inverted Nashville Dome) of central Tennessee. Major river valleys incised the upland margins of the basin by as much as 140 m (450 ft). Chemical weathering of the carbonate terrain of the Central Basin resulted in an estimated 43 m (140 ft)/million years of overall landscape denudation. Thus, the difference in relief along the major streams was probably achieved in less than 2 million years (Stearns and Reesman 1986).

The geologic units within the park weather and erode to form distinctive landforms. Karren form along preexisting joints and fractures as they channel runoff and groundwater through soluble limestones. Limestone ledges appear atop low ridges and hills throughout the park. Sinkholes and caves form through karst dissolution and surficial subsidence and/or collapse. These processes of weathering and erosion continue to shape the landscape today. The alluvial processes of channel migration, flooding, and deposition will continue to change the West Fork Stones River corridor and will require attention from resource managers to balance the natural system with the goal of preserving a battleground landscape for visitor interpretation.

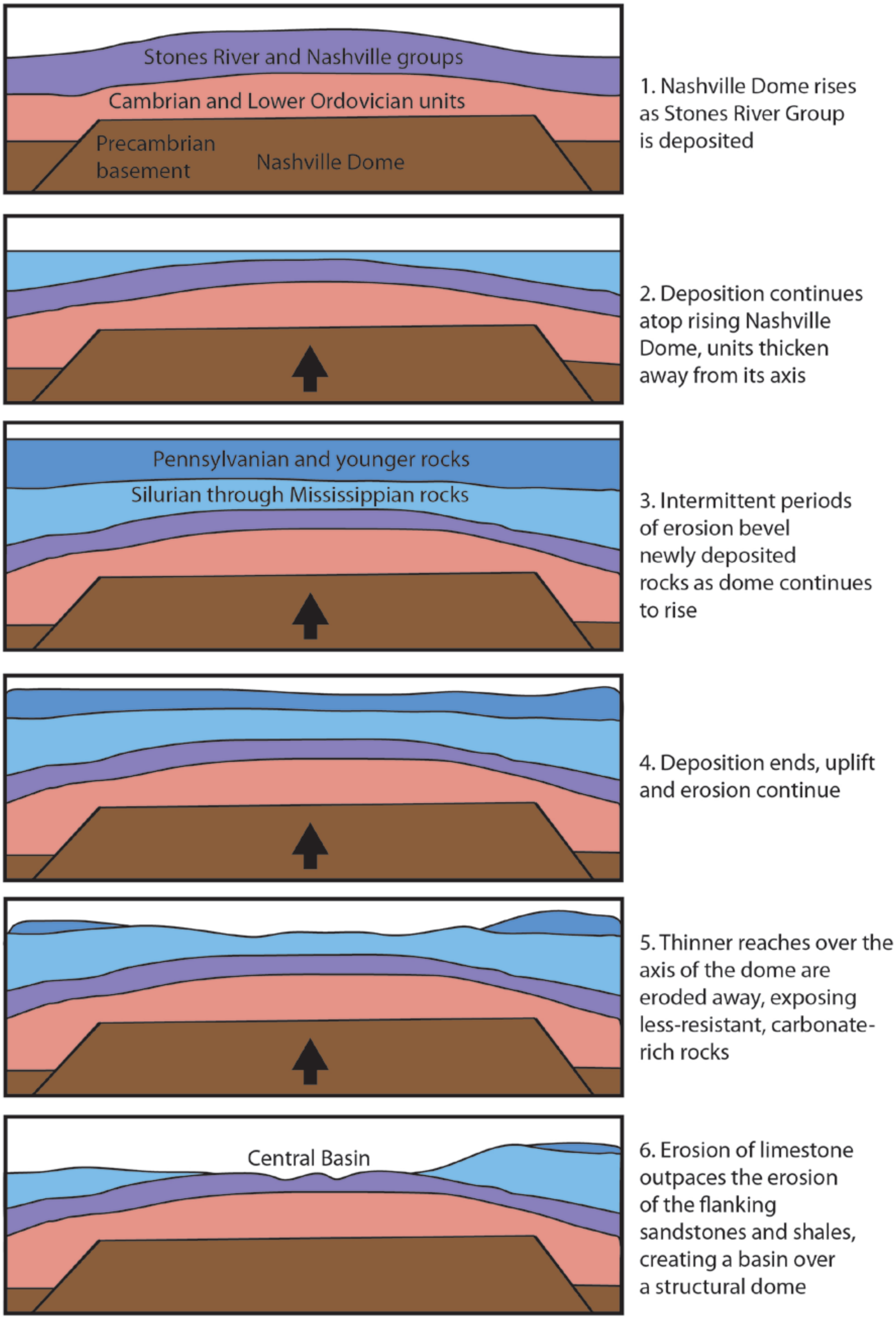

Figure 26. Formation of inverted topography. The Central Basin developed atop the Nashville Dome through uplift and preferential erosion. Diagrams are not to scale. Schematic graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Map Data

This section summarizes the geologic map data available for Stones River National Battlefield. The Geologic Map Overview Graphic displays the geologic map data draped over a shaded relief image of the park and surrounding area. The foldout Map Unit Properties Table summarizes this report's content for each geologic map unit. Complete GIS data are included on the accompanying CD and are also available at the GRI publications website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

Geologic Maps

Geologic maps facilitate an understanding of an area's geologic framework and the evolution of its present landscape. Using designated colors and symbols, geologic maps portray the spatial distribution and relationships of rocks and unconsolidated deposits. There are two primary types of geologic maps: surficial and bedrock. Surficial geologic maps encompass deposits that are frequently unconsolidated and formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, generally more consolidated, sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type. For reference, a geologic time scale is included as figure 4. Bedrock geologic map data are provided for Stones River National Battlefield.

Geologic maps also may show geomorphic features, structural interpretations, and locations of past geologic hazards that may be prone to future activity. Additionally, anthropogenic features such as mines and quarries may be indicated on geologic maps.

Source Maps

The Geologic Resources Inventory (GRI) team converts digital and/or paper source maps into GIS formats that conform to the GRI GIS data model. The GRI digital geologic map product also includes essential elements of the source maps, including unit descriptions, map legend, map notes, references, and figures. The GRI team used the following source maps to produce the digital geologic data for Stones River National Battlefield. These source maps provided information for the "Geologic Issues," "Geologic Features and Processes," and "Geologic History" sections of this report.

Wilson, C. W., Jr. 1965. Geologic map and mineral resources summary of the Murfreesboro Quadrangle (scale 1:24,000). Geologic Quadrangle Map 315 SW. Tennessee Division of Geology, Nashville, Tennessee, USA.

Wilson, C. W., Jr. 1964. Geologic map and mineral resources summary of the Walterhill Quadrangle (scale 1:24,000). Geologic Quadrangle Map 315 NW. Tennessee Division of Geology, Nashville, Tennessee, USA.

Geologic GIS Data

The GRI team implements a GIS data model that standardizes map deliverables. The data model is included on the enclosed CD and is also available online (http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm). This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI team digitized the data for Stones River National Battlefield using data model version 2.1.

GRI digital geologic data are included on the attached CD and are available through the NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/App/Reference/Search?SearchType=Q). Enter "GRI" as the search text and select Stones River National Battlefield from the unit list.

The following components and geology data layers are part of the data set:

- Data in ESRI geodatabase and shapefile GIS formats
- Layer files with feature symbology (table 1)
- Federal Geographic Data Committee (FGDC)–compliant metadata
- A help file (.pdf) document that contains all ancillary map information and graphics, including geologic unit correlation tables and map unit descriptions, legends, and other information captured from source maps
- An ESRI map document file (.mxd) that displays the digital geologic data

Table 1. Geology data layers in the Stones River National Battlefield GIS data.

Data Layer	Code	On Geologic Map Overview?
Geologic Attitude and Observation Localities	ATD	No
Geologic Contacts	GLGA	Yes
Geologic Units	GLG	Yes
Folds	FLD	No
Faults	FLT	No
Mine Area Features	MAF	Yes
Mine Area Feature Boundaries	MAFA	Yes
Mine Point Features	MIN	No

Note: All data layers may not be visible on the geologic map overview graphic.

Geologic Map Overview Graphic

The Geologic Map Overview Graphic (in pocket) displays the GRI digital geologic data draped over an aerial image of the park and surrounding area. For graphic clarity and legibility, not all GIS feature classes may be visible on the overview, as indicated in table 1. Cartographic elements and basic geographic information have been added to the overview. Digital elevation data and geographic information, which are part of the overview graphic, are not included with the GRI digital geologic GIS data for the park, but are available online from a variety of sources.

Map Unit Properties Table

The geologic units listed in the fold-out Map Unit Properties Table (in pocket) correspond to the accompanying digital geologic data. Following the structure of the report, the table summarizes the geologic issues, features, and processes, and geologic history associated with each map unit. The table also lists the geologic time period, map unit symbol, and a simplified geologic description of the unit. Connections between geologic units and park stories are also summarized.

Use Constraints

Graphic and written information provided in this section is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided here. Minor inaccuracies may exist regarding the location of geologic features relative to other geologic or geographic features on the overview graphic. Based on the source map scale (1:24,000) and U.S. National Map Accuracy Standards, geologic features represented in the geologic map data are horizontally within 12 m (40 ft) of their true location.

Please contact GRI with any questions.

Glossary

This glossary contains brief definitions of geologic terms used in this report. Not all geologic terms used are listed. Definitions are based on those in the American Geological Institute Glossary of Geology *(fifth edition; 2005). Additional definitions and terms are available at: http://geomaps.wr.usgs.gov/parks/misc/glossarya.html.*

alluvium. Stream-deposited sediment.
anticline. A convex-upward ("A" shaped) fold. Older rocks are found in the center.
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").
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.
base flow. Stream flow supported by groundwater; flow not attributed to direct runoff from precipitation or snow melt.
base level. The lowest level to which a stream can erode its channel. The ultimate base level for the land surface is sea level, but temporary base levels may exist locally.
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.
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.
bentonite. A soft clay or greasy claystone composed largely of smectite. Formed by the chemical alteration of glassy volcanic ash in contact with water.
bioturbation. The reworking of sediment by organisms.
breccia. A coarse-grained, generally unsorted sedimentary rock consisting of cemented angular clasts greater than 2 mm (0.08 in).
calcareous. Describes rock or sediment that contains the mineral calcium carbonate ($CaCO_3$).
calcite. A common rock-forming mineral: $CaCO_3$ (calcium carbonate).
carbonate. A mineral that has CO_3^{-2} as its essential component (e.g., calcite and aragonite).
carbonate rock. A rock consisting chiefly of carbonate minerals (e.g., limestone, dolomite, or carbonatite).
cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.
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.
chert. A extremely hard sedimentary rock with conchoidal (smooth curved surface) fracturing. It consists chiefly of interlocking crystals of quartz Also called "flint."
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).
clay. Can be used to refer to clay minerals or as a sedimentary fragment size classification (less than 1/256 mm [0.00015 in]).
concordant. Strata with contacts parallel to the orientation of adjacent strata.
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 rifting. Process by which a region of crust undergoes extension (pulling apart), resulting in the formation of many related normal faults, and often associated with volcanic activity.
convergent boundary. A plate boundary where two tectonic plates are colliding.
creep. The slow, imperceptible downslope movement of mineral, rock, and soil particles under gravity.
crinoid. A marine invertebrate (echinoderm) that uses a stalk to attach itself to a substrate. "Arms" are used to capture food. Rare today, they were very common in the Paleozoic. Crinoids are also called "sea lilies."
cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate flow conditions such as water flow direction and depth.
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.
deformation. A general term for the processes of faulting, folding, and shearing of rocks as a result of various

Earth forces such as compression (pushing together) and extension (pulling apart).

depocenter. An area or site of maximum deposition; the thickest part of any specified stratigraphic unit in a depositional basin.

differential erosion. Erosion that occurs at irregular or varying rates, caused by differences in the resistance and hardness of surface material.

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

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

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

dolomite. A carbonate sedimentary rock of which more than 50% by weight or by areal percentages under the microscope consists of the mineral dolomite (calcium-magnesium carbonate).

dolomitic. Describes a dolomite-bearing rock, or a rock containing dolomite.

doline. A type of sinkhole, or a karst collapse feature.

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.

downcutting. Stream erosion process in which the cutting is directed in primarily downward, as opposed to lateral erosion.

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

ephemeral stream. A stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

extension. A type of strain resulting from forces "pulling apart." Opposite of compression.

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.

floodplain. The surface or strip of relatively smooth land adjacent to a river channel and formed by the river. Covered with water when the river overflows its banks.

fold. A curve or bend of an originally flat or planar structure such as rock strata, bedding planes, or foliation that is usually a product of deformation.

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. Any break in a rock (e.g., crack, joint, 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.

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

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").

hydraulic conductivity. Measure of permeability coefficient.

hydrogeologic. Refers to the geologic influences on groundwater and surface water composition, movement and distribution.

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

incision. The process whereby a downward-eroding stream deepens its channel or produces a narrow, steep-walled valley.

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

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

karren. Channels or furrows caused by solution on massive bare limestone surfaces.

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

karst valley. A closed depression formed by the coalescence of several sinkholes.

karst window. A collapse sinkhole opening into a cave.

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

limb. Either side of a structural fold.

limestone. A sedimentary rock consisting chiefly of calcium carbonate, primarily in the form of the mineral calcite.

lineament. Any relatively straight surface feature that can be identified via observation, mapping, or remote sensing, often reflects crustal structure.

liquefaction. The transformation of loosely packed sediment into a more tightly packed fluid mass.

marker bed. A distinctive layer used to trace a geologic unit from one geographic location to another.

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

meander. Sinuous lateral curve or bend in a stream channel. An entrenched meander is incised, or carved downward into the surface of the valley in which a meander originally formed. The meander preserves its original pattern with little modification.

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

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

meteoric water. Pertaining to water of recent atmospheric origin.

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

nonconformity. An erosional surface preserved in strata in which crystalline igneous or metamorphic rocks underlie sedimentary rocks.

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

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.

ostracode. Any aquatic crustacean belonging to the subclass Ostracoda, characterized by a two-valved (shelled), generally calcified carapace with a hinge along the dorsal margin. Most ostracodes are of microscopic size.

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

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

parent material. The unconsolidated organic and mineral material in which soil forms.

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

perched aquifer. An aquifer containing unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.

permeability. A measure of the relative ease with which fluids move through the pore spaces of rocks or sediments.

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

porosity. The proportion of void space (e.g., pores or voids) in a volume of rock or sediment deposit.

pull-apart basin. A topographic depression created by an extensional bend or extensional overstep along a strike-slip fault.

radioactivity. The spontaneous decay or breakdown of unstable atomic nuclei.

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.

regolith. General term for the layer of rock debris, organic matter, and soil that commonly forms the land surface and overlies most bedrock.

relative dating. Determining the chronological placement of rocks, events, or fossils with respect to the geologic time scale and without reference to their numerical age.

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").

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

riprap. A layer of large, durable, broken rock fragments irregularly thrown together in an attempt to prevent erosion by waves or currents and thereby preserve the shape of a surface, slope, or underlying structure.

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.

sand. A clastic particle smaller than a granule and larger than a silt grain, having a diameter in the range of 1/16 mm (0.0025 in) to 2 mm (0.08 in).

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

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

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

silicate. A compound whose crystal structure contains the SiO_4 tetrahedra.

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.

sinkhole. A circular depression in a karst area with subterranean drainage and is commonly funnel-shaped.

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.

soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and often overlying the parent material from which it formed.

spreading center. A divergent boundary where two lithospheric plates are spreading apart. It is a source of new crustal material.

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

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

stratification. The accumulation, or layering of sedimentary rocks in strata. Tabular, or planar, stratification refers to essentially parallel surfaces. Cross-stratification refers to strata inclined at an angle to the main stratification.

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.

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.

syncline. A downward curving (concave-up) fold with layers that dip inward; the core of the syncline contains the stratigraphically-younger rocks.

synorogenic. Describes a geologic process or event occurring during a period of orogenic activity; also describes a rock or feature formed by those processes or event.

tectonic. Relating to large-scale movement and deformation of Earth's crust.

terrigenous. Derived from the land or a continent.

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 fossil. Tracks, trails, burrows, coprolites (dung), etc., that preserve evidence of organisms' life activities, rather than the organisms themselves.

trend. The direction or azimuth of elongation of a linear geologic feature.

type locality. The geographic location where a stratigraphic unit (or fossil) is well displayed, formally defined, and derives its name. The place of original description.

unconfined groundwater. Groundwater that has a water table; i.e., water not confined under pressure beneath a confining bed.

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 websites that may be of use to resource managers. Web addresses are current as of August 2012.

Geology of National Park Service Areas

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

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

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

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

NPS Resource Management Guidance and Documents

1998 National Parks Omnibus Management Act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf

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. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado, USA. http://nature.nps.gov/geology/monitoring/index.cfm

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

Geological Surveys and Societies

Tennessee Division of Geology: http://www.tn.gov/environment/tdg/

Kentucky Geological Survey (karst website): http://www.uky.edu/KGS/water/general/karst/index.htm

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/

U.S. Geological Survey Reference 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; official listing of place names and geographic features): 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 (USGS publications, many available online): http://pubs.er.usgs.gov

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

Appendix: Scoping Meeting Participants

The following people attended the GRI scoping meeting for Stones River National Battlefield, held on March 23–24, 2009, or the follow-up report writing conference call, held on December 28, 2011. Discussions during these meetings supplied a foundation for this GRI report. The scoping summary document is available on the GRI publications website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

2009 Scoping Meeting Participants

Name	Affiliation	Position
Stacy Allen	NPS Shiloh NMP	Chief of Interpretation & Resource Management
Vince Antonacci	Tennessee Division of Geology	Geologist
Gib Backlund	NPS Stones River NB	Chief of Operations
Ron Clendening	Tennessee Division of Geology	Geologist
Tim Connors	NPS Geologic Resources Division	Geologist
Elaine Foust	Tennessee Division of Geology	Geologist
Terri Hogan	NPS Stones River NB	Ecologist
Albert Horton	Tennessee Division of Geology	Geologist
Mike Hoyal	Tennessee Division of Geology	Geologist
Mike Manning	NPS Fort Donelson NB	Chief Ranger
Joe Meiman	NPS Gulf Coast and Cumberland-Piedmont networks	Hydrologist
Lisa Norby	NPS Geologic Resources Division	Geologist
Trista Thornberry-Ehrlich	Colorado State University	Geologist
Ron Zurawski	Tennessee Division of Geology	State Geologist

2011 Conference Call Participants

Name	Affiliation	Position
Gib Backlund	NPS-Stones River NB	Chief of Operations
Tim Connors	NPS-Geologic Resources Division	Geologist
Mike Hoyal	Tennessee Division of Geology	Geologist
Jason Kenworthy	NPS Geologic Resources Division	Geologist
Troy Morris	NPS Stones River NBI	Resource Manager
Trista Thornberry-Ehrlich	Colorado State University	Geologist
Ron Zurawski	Tennessee Division of Geology	State Geologist

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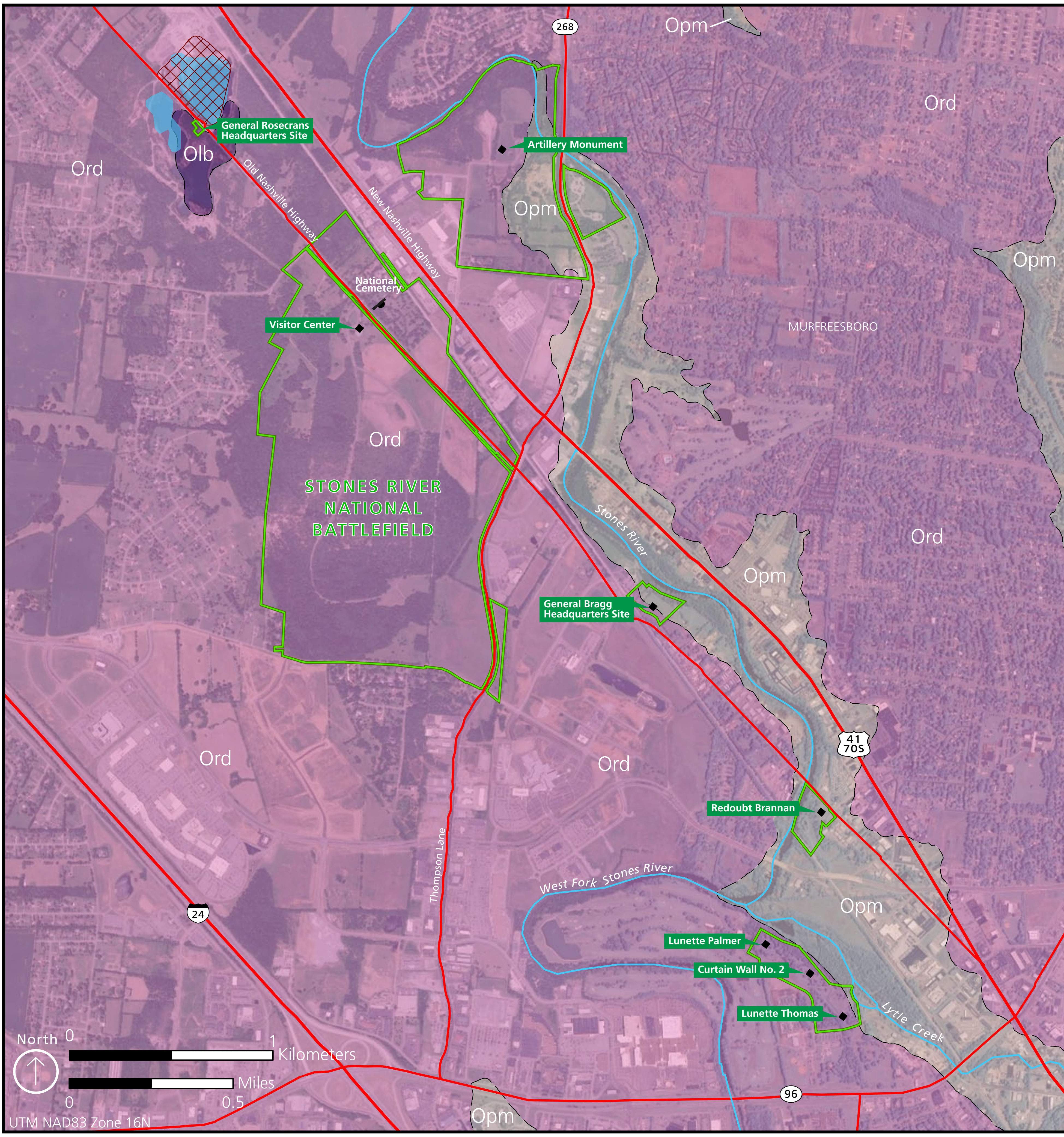
Overview of Digital Geologic Data for Stones River National Battlefield



This figure is an overview of compiled digital geologic data. It is not a substitute for site-specific investigations.

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

This figure was prepared as part of the NPS Geologic Resources Division's Geologic Resources Inventory. The source maps used in creation of the digital geologic data product were:

Wilson, C.W., Jr. 1965. Geologic Map and Mineral Resources Summary of the Murfreesboro Quadrangle, Tennessee (scale 1:24,000). Geologic Quadrangle Map 315 SW. Tennessee Division of Geology.

Wilson, C.W., Jr. 1964. Geologic Map and Mineral Resources Summary of the Walterhill Quadrangle, Tennessee (scale 1:24,000). Geologic Quadrangle Map 315 NW. Tennessee Division of Geology.

Digital geologic data and cross sections for Stones River National Battlefield, and all other digital geologic data prepared as part of the Geologic Resources Inventory, are available online at the NPS Integrated Resource Management Applications Portal (IRMA): https://irma.nps.gov/App/Reference/Search. (Enter "GRI" as the search text and select Stones River National Battlefield from the unit list.)

NPS Boundary

Infrastructure
- park structures
- highways

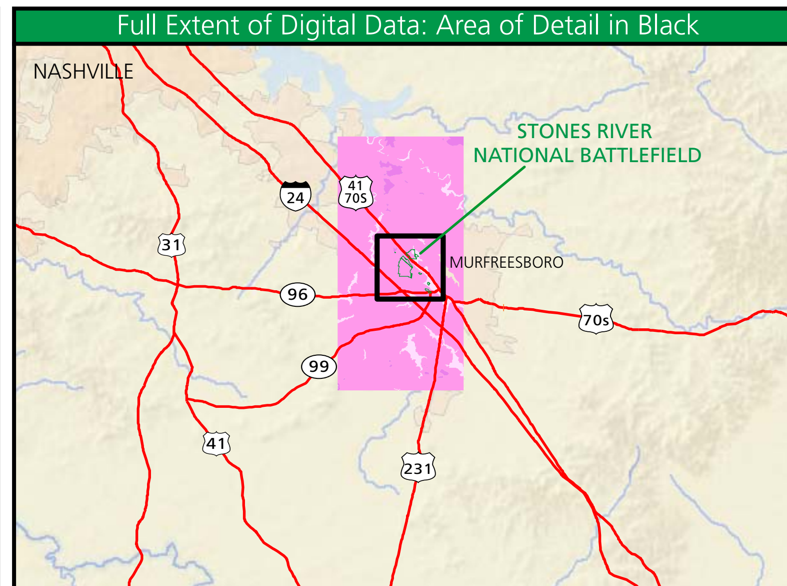
Mine Area Feature Boundaries
- known or certain

Mine Area Features
- quarry

Geologic Contacts
- known or certain
- approximate
- quadrangle boundary

Geologic Units
- Olb - Lebanon Limestone
- Ord - Ridley Limestone
- Opm - Pierce and Murfreesboro Limestones
- Water

Full Extent of Digital Data: Area of Detail in Black



Map Unit Properties Table: Stones River National Battlefield

Gray-shaded rows indicate geologic units not mapped within Stones River National Battlefield.

Age	Map Unit (Symbol)	Geologic Description	Geologic Issues	Geologic Features and Processes	Geologic History
ORDOVICIAN	Carters Limestone (Oc)	**Oc** is roughly divisible into three parts: an upper member, an altered volcanic ash (bentonite clay) layer, and a lower member. The upper member is approximately 3 m (10 ft) of very fine-grained to cryptocrystalline (individual grains are indiscernible with the naked eye), medium light-gray to brownish-gray and yellowish-brown limestone. The limestone is present in thin beds and breaks apart in layers, similar to shale or slate. The bentonite is green in fresh exposures, but weathers to white and yellow sticky clay. It is seldom visible in outcrop exposures and is 15–30 cm (6–12 in.) thick. The lower member is approximately 12 m (40 ft) of cryptocrystalline to very fine-grained, medium light-gray to brownish-gray and yellowish-brown limestone. Unlike the upper member, some beds may be coarse-grained and the bedding is medium to thick. Thin lenses of chert are present in the lower member. Erosion resistance is moderate. Mapped only in two very small areas in extreme southwestern corner of map area.	Disturbed lands and landscape restoration—no quarry indicated within **Oc** in mapped area. Karst challenges—unknown, likely similar to those within the park: sinkhole development and flooding, cave development and collapse. Fluvial processes and flooding—unknown, not mapped along waterways in map area. Slope failure and erosion—unknown. Seismicity—low seismic risk.	Karst features—karren, sinkholes, closed depressions, caves, springs possible. Cedar glades—occur on karst terrain throughout central Tennessee. Paleontological resources—marine invertebrates likely. Stones River Group—**Oc** is part of the Stones River Group.	Bentonite (altered volcanic ash) beds in **Oc** reveal that the unit is approximately 455 million years old. Volcanic ash was likely a product of the tectonic unrest associated with the Taconic Orogeny—one of three major mountain-building events that culminated in the Appalachian Mountains. **Oc** was deposited in a long-standing open marine basin present in this area of Tennessee throughout the Ordovician. The depth and extent of this basin fluctuated, particularly due to tectonic unrest to the east and uplift of the Nashville Dome.
	Lebanon Limestone (Olb)	**Olb** is 23–30 m (75–100 ft) of cryptocrystalline to very fine-grained, medium light-gray to brownish-gray and yellowish-brown limestone. Some individual beds of **Olb** may be coarse-grained. The limestone is present in thin beds and breaks apart in a shaly habit; approximately 14 m (45 ft) above the base of the formation is a zone of medium- to thick-bedded limestone. Erosion resistance is moderate. **Olb** is mapped within the Rosecrans Headquarters site.	Disturbed lands and landscape restoration—**Olb** is mapped immediately adjacent to a large quarry operation surrounding the Rosecrans Headquarters site. Karst challenges—sinkhole development and flooding, potential for cave formation and collapse, although no cave is documented from this unit within the park. Potential visitor safety issues associated with karst features. Fluvial processes and flooding—unknown, typically mapped at elevations above major waterways. Rapid runoff typical of karst areas facilitates flooding and water quality issues. Slope failure and erosion—non-karst erosion and slumping primarily an issue on constructed slopes (e.g., bridge abutments). Seismicity—low seismic risk.	Karst features—karren, sinkholes, closed depressions, springs. Cedar glades—occur on karst terrain throughout central Tennessee. Connections to park stories—karst terrain and features greatly impacted troop movement and battlefield tactics. Paleontological resources—marine invertebrates, although none have yet been documented in the park. Stones River Group—**Olb** is part of the Stones River Group. Type section is not located within the park.	Shale beds in this unit were derived from sediments eroding from the uplifting highlands to the east during the Taconic Orogeny. **Olb** was deposited in a long-standing open marine basin present in this area of Tennessee throughout the Ordovician. The depth and extent of this basin fluctuated, particularly due to tectonic unrest to the east and uplift of the Nashville Dome.

Gray-shaded rows indicate units not mapped within Stones River National Battlefield.

Age	Map Unit (Symbol)	Geologic Description	Geologic Issues	Geologic Features and Processes	Geologic History
ORDOVICIAN	Ridley Limestone (Ord)	**Ord** is 30–45 m (100–150 ft) of cryptocrystalline to very fine-grained, brownish-gray and yellowish-brown limestone. Some individual beds of **Ord** may be coarse-grained. Bedding within this unit tends to be medium to thick. Thin bands and irregular bands of magnesian limestone are present locally, along with lenses of chert. A conspicuous zone of thin-bedded limestone that breaks in a shaly habit occurs 6–11 m (20–35 ft) above the base of the unit. Erosion resistance is moderate. **Ord** is mapped within the main battlefield, Artillery Monument unit, a portion of General Bragg Headquarters site, and nearly all of Fortress Rosecrans.	Disturbed lands and landscape restoration—major quarry operation just outside Rosecrans Headquarters site mapped in **Ord**. Additional quarries throughout mapped area. Disturbed lands from previous debris dumps and other industrial uses within what is now parkland are being restored. Karst challenges—sinkhole development (particularly along tour road and McFadden Lane), sinkhole flooding, collapse and flooding of Rebel Yell Cave. Potential visitor safety issues associated with karst features. Fluvial processes and flooding—erosion and flooding potential where mapped along West Fork Stones River. Mapped areas in park generally not near the river. Rapid runoff typical of karst areas facilitates flooding and water quality issues. Slope failure and erosion—non-karst erosion and slumping primarily an issue on constructed slopes (e.g., bridge abutments). Seismicity—low seismic risk.	Karst features—well-developed karren, Rebel Yell Cave, sinkholes, closed depressions, springs (particularly at contact with **Opm**). Cedar glades—particularly well developed in southern portion of main battlefield unit, underlain by **Ord**. Connections to park stories—karren and cedar glades greatly impacted troop movement and tactics during the battle. The “Slaughter Pen” is one particularly well-described example. Rebel Yell Cave likely provided water for post-war African American settlement. Paleontological resources—marine invertebrates, including coral, cephalopods, gastropods, brachiopods, sponges, bryozoans. Some have been documented within the park. Stones River Group—**Ord** is part of the Stones River Group. Type section is not mapped within park, although the unit is extensively mapped in the main battlefield area.	Sediments from continental sources were less prevalent in the deposition of **Ord** than in that of **Opm**. **Ord** was deposited in a long-standing open marine basin present in this area of Tennessee throughout the Ordovician. The depth and extent of this basin fluctuated, particularly due to tectonic unrest to the east and uplift of the Nashville Dome. The Ridley Limestone represents a transgressive (sea level rise) period in the Middle Ordovician. Water depths were likely less than 60 m (200 ft).
ORDOVICIAN	Pierce and Murfreesboro limestones, undivided (Opm)	The Pierce Limestone is about 8 m (25 ft) of cryptocrystalline to very fine-grained, brownish-gray and yellowish-brown limestone. Some individual beds may be thicker and granular (coarse-grained). The limestone is present in thin beds and breaks apart in a shaly habit. The upper 3–21 m (10–70 ft) exposed of the Murfreesboro Limestone is cryptocrystalline to very fine-grained, medium-gray to medium dark-gray and brownish-black limestone. Unit is medium- to thick-bedded. Thin bands and irregular bands of magnesian limestone are present locally, along with lenses of dark-gray to brownish-black chert. Erosion resistance is moderate. **Opm** is mapped within eastern portion of the Artillery Monument, Redoubt Brannan, and a small area of Fortress Rosecrans.	Disturbed lands and landscape restoration—disturbed lands from previous debris dumps and other industrial uses within what is now parkland are being restored. Karst challenges—sinkhole development and flooding, potential for cave formation and collapse, although no cave is documented from this unit within the park. Potential visitor safety issues associated with karst features. Fluvial processes and flooding—erosion and flooding potential, particularly where mapped along West Fork Stones River. Riprap installed in 1970s to stabilize river banks at Artillery Monument site. Rapid runoff typical of karst areas facilitates flooding and water quality issues. Slope failure and erosion—non-karst erosion and slumping primarily an issue on constructed slopes (e.g., bridge abutments). Seismicity—low seismic risk.	Karst features—karren, sinkholes, closed depressions, springs (particularly at contact with **Ord**). Cedar glades—occur on karst terrain throughout central Tennessee. Paleontological resources—marine invertebrates include bryozoans, brachiopods, ostracodes, and gastropods, although none have yet been documented within the park. Stones River Group—Pierce and Murfreesboro limestones are part of the Stones River Group. Type section for Murfreesboro limestone located north of Murfreesboro, outside of park.	Shale beds in these units were derived from sediments eroding from the uplifting highlands to the east during the Taconic Orogeny. **Opm** was deposited in a long-standing open marine basin present in this area of Tennessee throughout the Ordovician. The depth and extent of this basin fluctuated, particularly due to tectonic unrest to the east and uplift of the Nashville Dome. The Murfreesboro Limestone is exposed along the East Fork Stones River in the park area. Its depositional setting was similar to **Ord**, whereas the Pierce Limestone was deposited in shallower water conditions.