National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

National Park Service Geologic Type Section Inventory

Cumberland Piedmont Inventory & Monitoring Network

Natural Resource Report NPS/CUPN/NRR—2022/2390

ON THE COVER

The towering cliffs known as White Rocks, as seen from Powell Valley. White Rocks, within Cumberland Gap National Historical Park, includes the type locality exposures of the Early Pennsylvanian White Rocks Sandstone Member of the Warren Point Sandstone (NPS/SCOTT TEODORSKI).

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Executive Summary

A fundamental responsibility of the National Park Service (NPS) is to ensure that the resources of the National Park Service are preserved, protected, and managed in consideration of the resources themselves and for the benefit and enjoyment by the public. Through the inventory, monitoring, and study of park resources, we gain a greater understanding of the scope, significance, distribution, and management issues associated with these resources and their use. This baseline of natural resource information is available to inform park managers, scientists, stakeholders, and the public about the conditions of these resources and the factors or activities that may threaten or influence their stability and preservation.

There are several different categories of geologic or stratigraphic units (supergroup, group, formation, member, bed) that form a hierarchical system of classification. The mapping of stratigraphic units involves the evaluation of lithologies (rock types), bedding properties, thickness, geographic distribution, and other factors. Mappable geologic units may be described and named through a rigorously defined process that is standardized and codified by the professional geologic community (North American Commission on Stratigraphic Nomenclature 2021). In most instances when a new geologic unit such as a formation is described and named in the scientific literature, a specific and well-exposed section or exposure area of the unit is designated as the stratotype (see "Definitions" below). The type section is an important reference exposure for a named geologic unit that presents a relatively complete and representative example for this unit. Geologic stratotypes are important both historically and scientifically, and should be available for other researchers to evaluate in the future.

The inventory of all geologic stratotypes throughout the 423 units of the NPS is an important effort in documenting these locations in order that NPS staff recognize and protect these areas for future studies. The focus adopted for completing the baseline inventories throughout the NPS is centered on the 32 inventory and monitoring networks (I&M) established during the late 1990s. The I&M networks are clusters of parks within a defined geographic area based on the ecoregions of North America (Fenneman 1946; Bailey 1976; Omernik 1987). These networks share similar physical resources (geology, hydrology, climate), biological resources (flora, fauna), and ecological characteristics. Specialists familiar with the resources and ecological parameters of the network, and associated parks, work with park staff to support network-level activities (inventory, monitoring, research, data management).

Adopting a network-based approach to inventories worked well when the NPS undertook paleontological resource inventories for the 32 I&M networks. The planning team from the NPS Geologic Resources Division who proposed and designed this inventory selected the Greater Yellowstone Inventory & Monitoring Network (GRYN) as the pilot network for initiating this project (Henderson et al. 2020). Through the research undertaken to identify the geologic stratotypes within the parks of the GRYN, methodologies for data mining and reporting on these resources were established. Methodologies and reporting adopted for the GRYN have been used in the development of this report for the Cumberland Piedmont Inventory & Monitoring Network (CUPN).

The goal of this project is to consolidate information pertaining to geologic type sections that occur within NPS-administered areas, in order that this information is available throughout the NPS to inform park managers and to promote the preservation and protection of these important geologic landmarks and geologic heritage resources. The review of stratotype occurrences for the CUPN shows there are currently no designated stratotypes for Abraham Lincoln Birthplace National Historical Park (ABLI), Chickamauga and Chattanooga National Military Park (CHCH), Cowpens National Battlefield (COWP), Fort Donelson National Battlefield (FODO), Guilford Courthouse National Military Park (GUCO), Little River Canyon National Preserve (LIRI), Mammoth Cave National Park (MACA), Ninety Six National Historic Site (NISI), Russell Cave National Monument (RUCA), Shiloh National Military Park (SHIL), and Stones River National Battlefield (STRI). Cark Sandburg Home National Historic Site (CARL) has one type area; Cumberland Gap National Historical Park (CUGA) has five type sections and two type localities; and Kings Mountain National Military Park (KIMO) has one type area (Table 1).

This report concludes with a recommendation section that addresses outstanding issues and future steps regarding park unit stratotypes. These recommendations will hopefully guide decision-making and help ensure that these geoheritage resources are properly protected and that proposed park activities or development will not adversely impact the stability and condition of these geologic exposures.

Table 1. List of CUPN stratotype units sorted by park unit and geologic age, with associated reference publications and locations.

Unit	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
CARL	Henderson Augen Gneiss (Chg)	Keith 1905; Horton and McConnell 1991	Type area: extensive exposures in Henderson Co., western NC.	Cambrian
CUGA	Mingo Formation (PNm)	Ashley and Glenn 1906; McDowell et al. 1985	Type section: Mingo Mountain in the Log Mountains area, Claiborne Co., TN.	Middle Pennsylvanian
CUGA	Hensley Member, Alvy Creek Formation (PNah)	Englund 1964	Type section: exposed along Skyland Road and U.S. Highway 25E [now along Pinnacle Road and Route 988, Old Wilderness Road] on northwest side of Cumberland Gap, [approximate latitude 36°36′40″ N., longitude 83°40′40″ W., Middlesboro South 7.5′ Quadrangle], Bell Co., KY.	Early Pennsylvanian
CUGA	Middlesboro Member, Lee Formation	Englund 1964	Type section: exposed on Skyland Road on the north side of the Cumberland Gap, Bell Co., KY.	Early Pennsylvanian
CUGA	Dark Ridge Shale Member, Bottom Creek Formation (PNbcd)	Englund 1964	Type locality: near the south end of Dark Ridge, a northward-trending ridge on the north side of Cumberland Gap, Bell Co., KY.	Early Pennsylvanian
CUGA	White Rocks Sandstone Member, Warren Point Sandstone (PNwpw)	Englund 1964	Type locality: White Rocks, a prominent south-facing cliff at crest of Cumberland Mountain [Ewing 7.5′ Quadrangle], Lee Co., VA.	Early Pennsylvanian
CUGA	Chadwell Member, Lee Formation	Englund 1964	Type section: at Chadwell Gap, a notch in Cumberland Mountain, approximately 16 km (10 mi) northeast of Cumberland Gap, Lee Co., VA.	Early Pennsylvanian
CUGA	Pinnacle Overlook Sandstone (Mpo)	Englund 1964	Type section: exposure at the Pinnacle, a scenic overlook on the northeast side of Cumberland Gap, Lee Co., VA.	Mississippian
KIMO	Battleground Formation (PCbs, PCbmp, PCbct, PCbdt, PCbmc, PCbmq, PCbd, PCbj, PCbc, PCbaq, PCkq, PCbms, PCbvc, PCbmps, PCbgs, PCbfs, PCbht)	Horton 1984	Type area: at the Kings Mountain battleground, the site of a Revolutionary War battle, Cherokee and York Cos., SC.	Neoproterozoic

Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic type sections for the national parks of the Cumberland Piedmont Inventory & Monitoring Network (CUPN). We first want to extend our sincere appreciation to Randy Orndorff, David Soller, and Nancy Stamm (United States Geological Survey, USGS) for their assistance with this geologic type section inventory and other important NPS projects. Randy, Dave, and Nancy manage the National Geologic Map Database (https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl?glx=1) and GEOLEX (https://ngmdb.usgs.gov/Geolex/search, the U.S. Geologic Names Lexicon, a national compilation of names and descriptions of geologic units), critical sources of geologic information for science, industry, and the American public.

We thank our colleagues and partners in the Geological Society of America (GSA) and Stewards Individual Placement Program for their continued support to the NPS with the placement of geologic interns and other ventures. Additionally, we are grateful to Rory O'Connor-Walston and Alvin Sellmer from the NPS Technical Information Center in Denver for their assistance with locating hard-to-find publications.

Thanks to our NPS colleagues in the CUPN and various network parks including: Steven Thomas, Johnathon Jernigan, and William Moore (CUPN), Irene Van Hoff (CARL), Jennifer Beeler (CUGA), Diana Bramble (KIMO), Rick Olson and Rick Toomey (MACA). Additional thanks to Linda York for continued support for this and other important geology projects in the former Southeast Region of the NPS (now DOI Unified Region 2 and parts of 1 and 4). Linda served as peer review coordinator for this report.

We extend our appreciation to Don Chestnut (retired Kentucky Geological Survey) and Rick Toomey (MACA) for reviewing this inventory report and providing feedback to improve this publication.

This project is possible through the support from research associates and staff in the National Park Service Geologic Resources Division and we extend our thanks to Stephanie Gaswirth, Hal Pranger, Julia Brunner, Jason Kenworthy, Rebecca Port, Jim Wood, and the Geologic Resource Inventory Team.

Dedication

This Cumberland Piedmont Inventory and Monitoring Network Geologic Type Section Inventory is dedicated to retired Kentucky Geological Survey (KGS) geologist Don Chesnut. Don earned his B.S., M.S., and Ph.D. at the University of Kentucky and served the KGS for 25 years. Throughout his career he has enjoyed participating in cooperative geologist networks both regionally and worldwide. Although he is now retired, Don continues to study geology and paleontology. Regarding the geology of Kentucky and the greater Appalachian region, Don appreciates the exposed countryside and largely undeveloped landscapes that tie together with the interesting tectonic history of the Appalachian Mountains and related mountain chains in other countries. Don considers himself lucky to have been raised in a family and school system that promoted an interest in science. He is thankful to have worked with inspirational teachers, professors, and colleagues from around the world. Don especially thanks his wife and family who have supported his field work and numerous travels over the years.

Thanks for your tremendous service Don!

Don Chesnut.

Introduction

The NPS Geologic Type Section Inventory Project ("Stratotype Inventory Project") is a continuation of and complements the work performed by the Geologic Resources Inventory (GRI). The GRI is funded by the NPS Inventory & Monitoring Program and administered by the Geologic Resources Division (GRD). The GRI is designed to compile and present baseline geologic resource information available to park managers, and advance science-informed management of natural resources in the national parks. The goals of the GRI are to increase understanding and appreciation of the geologic features and processes in parks and provide robust geologic information for use in park planning, decision making, public education, and resource stewardship. Additional GRI information and products can be accessed on IRMA or the GRI publication page (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm).

Documentation of stratotypes (i.e., type sections/type localities/type areas; see "Definitions" below) that occur within national park boundaries represents a significant component of a geologic resource inventory, as these designations serve as the standard for defining and recognizing geologic units (North American Commission on Stratigraphic Nomenclature 2021). The importance of stratotypes lies in the fact that they represent important comparative sites where past investigations can be built upon or re-examined, and can serve as teaching sites for the next generation of students (Brocx et al. 2019). The geoheritage significance of stratotypes is analogous to libraries and museums in that they are natural repositories of Earth history and record the physical and biological evolution of our planet.

The goals of this project are to (1) systematically report the assigned stratotypes that occur within national park boundaries, (2) provide detailed descriptions of the stratotype exposures and their locations, and (3) reference the stratotype assignments from published literature. It is important to note that this project cannot verify a stratotype for a geologic unit if one has not been formally assigned and/or published. Additionally, numerous stratotypes are located geographically outside of national park boundaries; those within 48 km (30 mi) of park boundaries are mentioned briefly in this report because of their proximity.

This geologic type section inventory for the parks of the Cumberland Piedmont Inventory & Monitoring Network (CUPN) follows standard practices, methodologies, and organization of information introduced in the Greater Yellowstone I&M Network stratotype inventory (Henderson et al. 2020). All network-specific reports are prepared, peer-reviewed, and submitted to the Natural Resources Stewardship and Science Publications Office for finalization. A small team of geologists and paleontologists from the NPS Geologic Resources Division and the NPS Paleontology Program have taken responsibility for this important inventory for the NPS.

This inventory fills a void in basic geologic information compiled by the NPS at most parks. Instances where geologic stratotypes occur within NPS areas were determined through research of published geologic literature and maps. Sometimes the lack of specific locality or other data limited determination of whether a particular stratotype was located within NPS administered boundaries. Below are the primary justifications that warrant this inventory of NPS geologic stratotypes.

- Geologic stratotypes are a part of our national geologic heritage and are a cornerstone of the scientific value used to define the societal significance of geoheritage sites (https://www.nps.gov/articles/scientific-value.htm);
- Geologic stratotypes are important geologic landmarks and reference locations that define important scientific information associated with geologic strata. Geologic formations are frequently named after topographic or geologic features and landmarks that are recognizable to park staff;
- Geologic stratotypes are both historically and scientifically important components of earth science investigations and mapping;
- Understanding and interpreting the geologic record depends on the stratigraphic occurrences of mappable lithologic units (formations, members, etc.). These geologic units are the foundational attributes of geologic maps;
- Geologic maps are important tools for science, resource management, land use planning, and other areas and disciplines;
- Geologic stratotypes are similar in nature to type specimens in biology and paleontology, serving as the primary reference for defining distinctive characteristics and establishing accurate comparisons;
- Geologic stratotypes within NPS areas have not been previously inventoried and there is a general absence of baseline information for this geologic resource category;
- NPS staff may not be aware of the concept of geologic stratotypes and therefore would not understand the significance or occurrence of these natural references in the parks;
- Given the importance of geologic stratotypes as geologic references and geologic heritage resources, these locations should be afforded some level of preservation or protection when they occur within NPS areas;
- If NPS staff are unaware of geologic stratotypes within parks, the NPS cannot proactively monitor the stability, condition, or potential impacts to these locations during normal park operations or planning. This lack of information also hinders the protection of these localities from activities which may involve ground disturbance or construction.
- This inventory can inform important conversations on whether geologic stratotypes rise to the level of national register documentation. The NPS should consider if any other legal authorities (e.g., National Historic Preservation Act), policy, or other safeguards currently in place can help protect geologic stratotypes that are established on NPS administered lands. Through this inventory, the associated report, and close communication with park and I&M Network staff, we hope there will be an increased awareness about these important geologic landmarks in parks. In turn, the awareness of these resources and their significance may be recognized in park planning and operations, to ensure that geologic stratotypes are preserved and available for future study.

Geology and Stratigraphy of the CUPN I&M Network Parks

The Cumberland Piedmont Inventory & Monitoring Network (CUPN) consists of 14 national park units in Alabama, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, and Virginia (Figure 1). These units are: Abraham Lincoln Birthplace National Historical Park (ABLI), Carl Sandburg Home National Historic Site (CARL), Chickamauga and Chattanooga National Military Park (CHCH), Cowpens National Battlefield (COWP), Cumberland Gap National Historical Park (CUGA), Fort Donelson National Battlefield (FODO), Guilford Courthouse National Military Park (GUCO), Kings Mountain National Military Park (KIMO), Little River Canyon National Preserve (LIRI), Mammoth Cave National Park (MACA), Ninety Six National Historic Site (NISI), Russell Cave National Monument (RUCA), Shiloh National Military Park (SHIL), and Stones River National Battlefield (STRI) (Figure 1). Although they occupy some of the same geographic area, parks such as Great Smoky Mountains National Park are part of the neighboring Appalachian Highland Inventory & Monitoring Network that is largely situated in the Blue Ridge and Valley and Ridge Provinces. The park units that comprise the Cumberland Piedmont Network protect a combined 47,534 hectares (117,461 acres) and vary in size from 101 hectares (251 acres) in GUCO to 21,379 hectares (52,830 acres) in MACA.

The Appalachian Mountains are among the oldest mountain ranges on Earth. The long stability of the Appalachian Mountains, combined with its great variation in geology, landforms, and climate, have supported the evolution of a rich diversity of fauna and flora, especially in the southern regions which were not directly impacted by glacial activity. Park units of the Cumberland Piedmont Network cover parts of five physiographic provinces of the Appalachian Mountains that include (from east to west): (1) Piedmont; (2) Blue Ridge; (3) Valley and Ridge; (4) Appalachian Plateau; and 5) Interior Low Plateaus.

The Piedmont province is characterized by rolling hills with gentle slopes underlain by ancient Neoproterozoic- to Cambrian-age metamorphic rocks that originated as offshore sediments, volcanic rocks, and small landmasses that were accreted to the eastern margin of North America (Clark 2008; see Appendix B for a geologic time scale). The Blue Ridge province is a mountainous area that rises abruptly above valleys and hills of the Piedmont to the east and forms the backbone of the Appalachian Mountains. Rocks of the Blue Ridge are predominantly Neoproterozoic-age metamorphic rocks that include fragments of the former supercontinent Rodinia, thick sequences of sedimentary basin fill, marine sedimentary and volcanic rocks, and fragments of oceanic crust (Clark 2008).

West of the Blue Ridge, the Valley and Ridge province marks a transition to folded and faulted, non-metamorphosed Paleozoic-age sedimentary rocks that include sandstones, conglomerate, limestone, dolomite, and shale (mudstone), with some Pennsylvanian-age coal beds. Many of these rocks were deposited on the floor of a shallow inland sea that inundated most of the ancestral North American continent from the Cambrian to the Permian Periods ~540 to 270 Ma (mega-annum, million years ago) (Clark 2008). These sedimentary units are underlain by large thrust faults generated by numerous orogenies (mountain building episodes) associated with the formation of the Appalachian

Mountains. The Appalachian Plateau (including the Cumberland Plateau) is a deeply dissected plateau comprised of relatively flat sedimentary strata that have been carved by water into a labyrinth of rocky ridges and deep gorges. Like the Valley and Ridge province, rocks of the Cumberland Plateau formed on the floor of an ancient inland sea. The Interior Low Plateaus province is similar to the Appalachian Plateaus but has gentler slopes (Clark 2008).

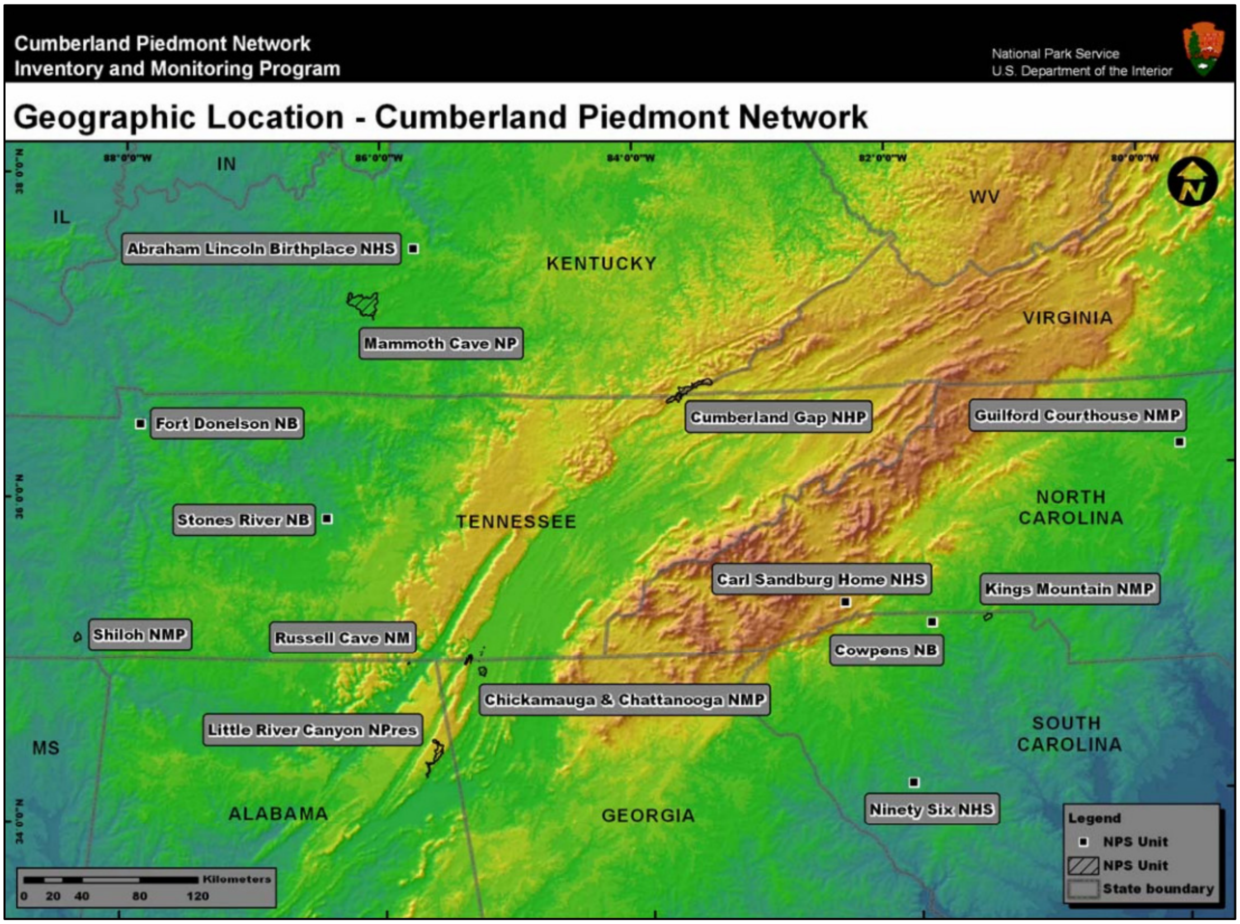


Figure 1. Map of Cumberland Piedmont I&M Network parks, including: Abraham Lincoln Birthplace National Historical Park (ABLI), Carl Sandburg Home National Historic Site (CARL), Chickamauga and Chattanooga National Military Park (CHCH), Cowpens National Battlefield (COWP), Cumberland Gap National Historical Park (CUGA), Fort Donelson National Battlefield (FODO), Guilford Courthouse National Military Park (GUCO), Kings Mountain National Military Park (KIMO), Little River Canyon National Preserve (LIRI), Mammoth Cave National Park (MACA), Ninety Six National Historic Site (NISI), Russell Cave National Monument (RUCA), Shiloh National Military Park (SHIL), and Stones River National Battlefield (STRI) (NPS).

Precambrian

Precambrian rocks are found only in a few park units of the CUPN and include unnamed Neoproterozoic-age igneous intrusive rocks in GUCO, unnamed Neoproterozoic-age metamorphic units in COWP and NISI, and rocks of the Neoproterozoic Kings Mountain Sequence (Battleground Formation and Blacksburg Formation) in KIMO.

Paleozoic

Paleozoic strata underlie 10 of the 14 park units of CUPN, with some of the oldest rocks represented by the Cambrian Henderson Augen Gneiss in CARL and Copper Ridge Dolomite in CHCH. Ordovician rocks are mapped in CHCH, CUGA, and STRI and represent thick carbonate sequences that include the Knox Group (Chepultepec Dolomite, Longview Dolomite, Kingsport Formation, and Mascot Dolomite), Chickamauga Group (Pond Spring Formation, Murfreesboro Limestone, Ridley Limestone, Lebanon Limestone, Carters Limestone, Hermitage Formation), as well as the Cannon, Ben Hur, Hardy Creek, Eggleston, Trenton, and Pierce Limestones. Siliciclastic units of Ordovician age include the Sequatchie Formation, Catheys Formation, and strata of the Nashville Group. Rocks of Silurian age are found in CUGA and consist of the Rockwood Formation, Clinton Shale, and Hancock Dolomite. Igneous rocks of the Silurian–Devonian Greenwood pluton are mapped in NISI. The Devonian–Mississippian Chattanooga Shale is found only in CUGA.

Extensive sequences of Mississippian-age strata are located throughout the Cumberland Piedmont Network. Several formations are distributed across multiple park units and include the St. Louis Limestone (ABLI, CHCH, FODO, MACA), Monteagle Limestone (CHCH, LIRI, RUCA), Bangor Limestone (CHCH, LIRI, RUCA), Warsaw Limestone (CHCH, FODO), Fort Payne Chert (CHCH, FODO), and Pennington Formation (CHCH, LIRI, and RUCA). Other Mississippian rocks include the Borden Formation, Harrodsburg Limestone, and Salem Limestone in ABLI; rocks of the Gizzard Group (Raccoon Mountain Formation, Warren Point Sandstone, Signal Point Shale), Crooked Fork Group (Sewanee Conglomerate, Whitwell Shale), and Hartselle Formation in CHCH; Grainger Formation, Newman Limestone, and Pinnacle Overlook Sandstone in CUGA; Tuscumbia Formation in LIRI; and the Ste. Genevieve Limestone, Girkin Formation, Haney Limestone, Glen Dean Limestone, Big Clifty Sandstone, Hardinsburg Formation, and Leitchfield Formation in MACA.

Rocks of Pennsylvanian age are predominantly located in CUGA and include the Alvy Creek Formation, Warrant Point Formation, Bottom Creek Formation, Sewanee Sandstone, Bee Rock Sandstone, Pikeville Formation, Grundy Formation, and Hyden Formation. Pennsylvanian strata also occur in LIRI and RUCA (Pottsville Formation) as well as MACA (Caseyville Formation).

Mesozoic

Mesozoic strata are limited to four formations in two park units: the Cretaceous Tuscaloosa Gravel and McNairy Formation in FODO, and the Cretaceous Eutaw Formation and Coffee Formation in SHIL.

Cenozoic

Cenozoic surficial deposits are mapped in several of the CUPN park units and consist of Quaternary-age alluvium (ABLI, FODO, MACA, RUCA, SHIL), colluvium (CUGA), terrace deposits (CUGA, RUCA), fluvial deposits (ABLI, SHIL), and loess (FODO).

National Park Service Geologic Resources Inventory

The Geologic Resources Inventory (GRI) provides digital geologic map data and pertinent geologic information on park-specific features, issues, and processes to support resource management and science-informed decision-making in more than 270 natural resource parks throughout the National Park System. The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division (GRD) of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. The GRI team consists of a partnership between the GRD and the Colorado State University Department of Geosciences to produce GRI products.

GRI Products

The GRI team undertakes four tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document; (2) provide digital geologic map data in a geographic information system (GIS) format; (3) create posters to display the GRI GIS data; and (4) provide a GRI report. These products are designed and written for non-geoscientists.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Scoping sessions were held on the following dates for the CUPN parks: CARL on May 10–12, 2000; KIMO on September 19, 2000; GUCO on September 20, 2000; COWP in April 2005; ABLI on June 15, 2006; MACA on June 15–16, 2006; CUGA on June 6, 2007; CHCH in March 2009; FODO, SHIL, and STRI on March 23, 2009; LIRI and RUCA on March 25, 2009; and NISI on March 23, 2012.

Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. As of 2022, GRI reports have been completed for ABLI, CARL, COWP, CUGA, FODO, GUCO, KIMO, MACA, RUCA, SHIL, and STRI. The GRI team conducts no new field work in association with their products.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). Additional information regarding the GRI, including contact information, is available at https://www.nps.gov/subjects/geology/gri.htm.

Geologic Map Data

A geologic map in GIS format is the principal deliverable of the GRI program. GRI GIS data produced for the CUPN parks follows the selected source maps and includes components such as: faults, mine area features, mine point features, geologic contacts, geologic units (bedrock, surficial, glacial), geologic line features, structure contours, and so forth. These are commonly acceptable geologic features to include in a geologic map.

Posters display the data over imagery of the park and surrounding area. Complete GIS data are available at the GRI publications website: https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at, or beneath the land surface (Evans 2016). Color and sometimes symbols on geologic maps are used to distinguish geologic map units. The unit labels consist of an uppercase letter (or symbol for some ages) indicating the geologic age and lowercase letters indicating the formation's name. Other symbols depict structures such as faults or folds, locations of past geologic hazards that may be susceptible to future activity, and other geologic features. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps. The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) and work by Bernknopf et al. (1993) provides more information about geologic maps and their uses.

Geologic maps are typically one of three types: surficial, bedrock, or a combination of both. Surficial geologic maps typically encompass deposits that are unconsolidated and which formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type, geologic processes, and/or depositional environment. The GRI team has produced various maps for the CUPN parks.

Source Maps

The GRI team does not conduct original geologic mapping. The team digitizes paper maps and compiles and converts digital data to conform to the GRI GIS data model. The GRI GIS dataset includes essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, cross sections, figures, and references. These items are typically included in an ancillary map information document (PDF) for a specific park. The GRI team uses a unique "GMAP ID" value for each geologic source map, and all sources to produce the GRI GIS datasets for the CUPN parks can be found in Appendix A.

GRI GIS Data

The GRI team standardizes map deliverables by using a data model. The most recent GRI GIS data for CHCH, FODO, GUCO, and LIRI were compiled using data model version 2.3, which is available at https://www.nps.gov/articles/gri-geodatabase-model.htm; the ABLI, CARL, COWP, CUGA, KIMO, MACA, NISI, RUCA, SHIL, and STRI data are based on older data models and need to be upgraded to the most recent version. The data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI website (https://www.nps.gov/subjects/geology/gri.htm) provides more information about the program's products.

GRI GIS data are available on the GRI publications website (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm) and through the NPS Integrated Resource Management Applications (IRMA) Data Store portal (https://irma.nps.gov/DataStore/Search/Quick). Enter "GRI" as the search text and select ABLI, CARL, CHCH, COWP, CUGA, FODO, GUCO, KIMO, LIRI, MACA, NISI, RUCA, SHIL, or STRI from the unit list.

The following components are part of the dataset:

- A GIS readme file that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information;
- Data in ESRI geodatabase GIS format;
- Layer files with feature symbology;
- Federal Geographic Data Committee (FGDC)-compliant metadata;
- An ancillary map information document that contains information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross-sections, and figures;
- ESRI map documents that display the GRI GIS data; and
- A version of the data viewable in Google Earth (.kml / .kmz file).

GRI Map Posters

Posters of the GRI GIS draped over shaded relief images of the park and surrounding area are included in GRI reports. Geographic information and selected park features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data, but are available online from a variety of sources. Contact GRI for assistance locating these data.

Use Constraints

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

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the posters. Based on the source map scales (1:100,000, 1:62,500, and 1:24,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are expected to be horizontally within 51 m (167 ft), 32 m (104 ft), and 12 m (40 ft), respectively, of their true locations.

Methods

Described here are the methods employed and definitions adopted during this inventory of geologic stratotypes located within the administrative boundaries of the parks in the CUPN. This report is part of an inventory of stratotypes throughout the National Park System. Therefore, the methods, definitions, and challenges identified here pertain not only to the parks of the CUPN, but also to other inventory and monitoring networks and parks.

There are several considerations for this inventory. The most up-to-date information available is necessary, either found online or in published articles and maps. Occasionally, there is a lack of specific information which limits the information contained within the final report. This inventory does not include any new field work and is dependent on the existing information related to individual park geology and stratigraphy. Additionally, this inventory does not attempt to resolve any unresolved or controversial stratigraphic interpretations, which is beyond the scope of the project.

Stratigraphic nomenclature may change over time with refined stratigraphic field assessments and discovery of information through the expansion of stratigraphic mapping and measured sections. One important observation regarding stratigraphic nomenclature relates to differences in use of geologic names for units that transcend state boundaries. Geologic formations and other units that cross state boundaries may be referenced with different names in each of the states the units are mapped. An example would be the Triassic Chugwater Formation in Wyoming, which is equivalent to the Spearfish Formation in the Black Hills of South Dakota.

The lack of a designated and formal type section, or inadequate and vague geospatial information associated with a type section, limits the ability to capture precise information for this inventory. The available information related to the geologic type sections is included in this report.

Finally, this inventory report is intended for a wide audience, including NPS staff who may not have a background in geology. Therefore, this document is developed as a reference document that supports science, resource management, and a historic framework for geologic information associated with NPS areas.

Methodology

The process of determining whether a specific stratotype occurs in an NPS area involves multiple steps. The process begins with an evaluation of the existing park-specific GRI map to prepare a full list of recognized map units (Figure 2).

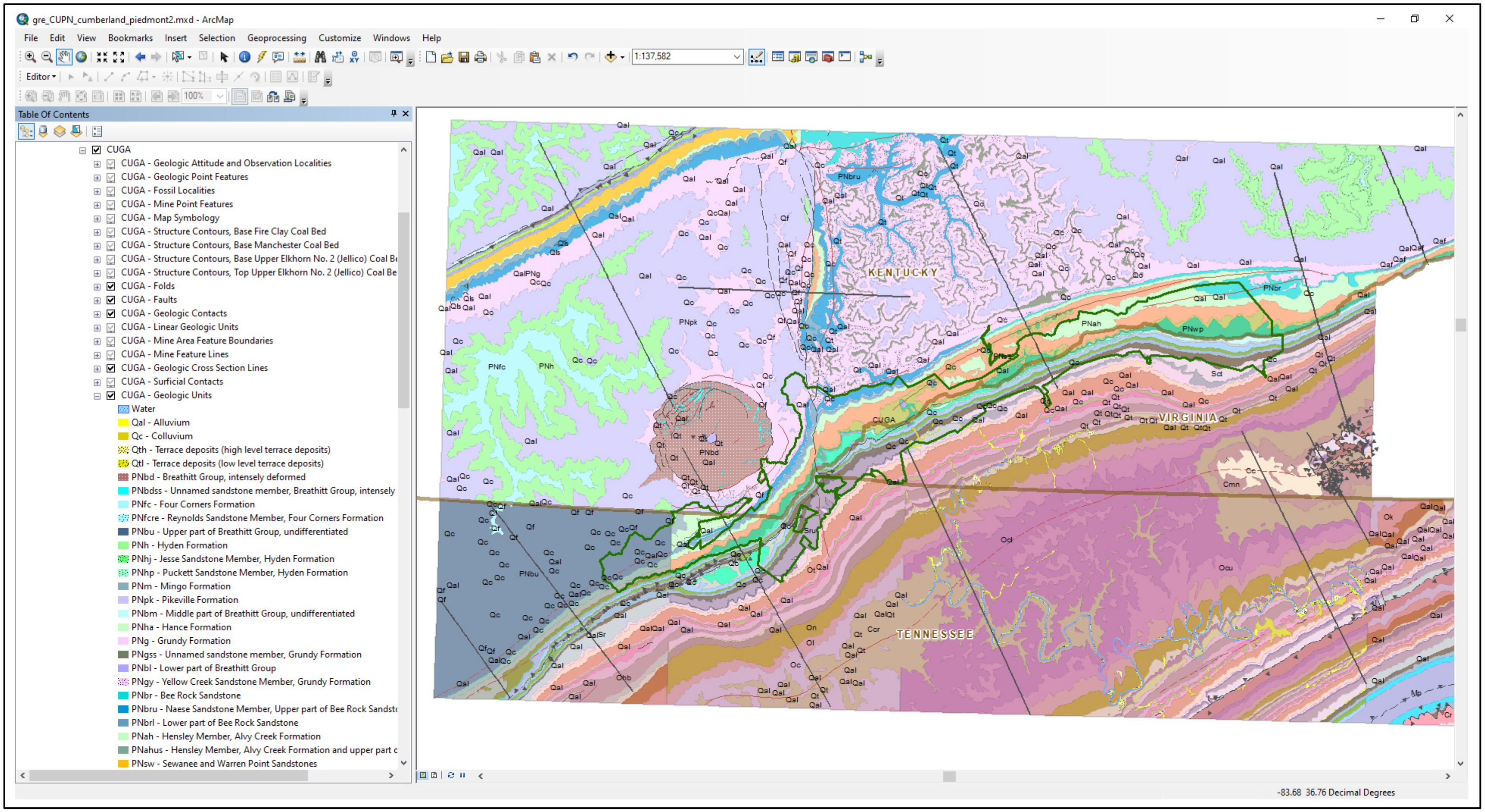


Figure 2. Screenshot of digital geologic map of Cumberland Gap National Historical Park showing mapped units. Note: circular feature represents the Middlesboro impact structure in Bell County, Kentucky. Data modified from CUGA GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047055.

Each map unit name is then queried in the USGS Geologic Names Lexicon online database ("GEOLEX", a national compilation of names and descriptions of geologic units) at https://ngmdb.usgs.gov/Geolex/search. Information provided by GEOLEX includes unit name, stratigraphic nomenclature usage, geologic age, and published stratotype location descriptions, and the database provides a link to significant publications as well as the USGS Geologic Names Committee Archives (Wilmarth 1938; Keroher et al. 1966). The "Significant Publications" link provides published references and additional information about nomenclature revisions for certain geologic units. Figure 3 below is taken from a search on the Middlesboro Member of the Lee Formation.

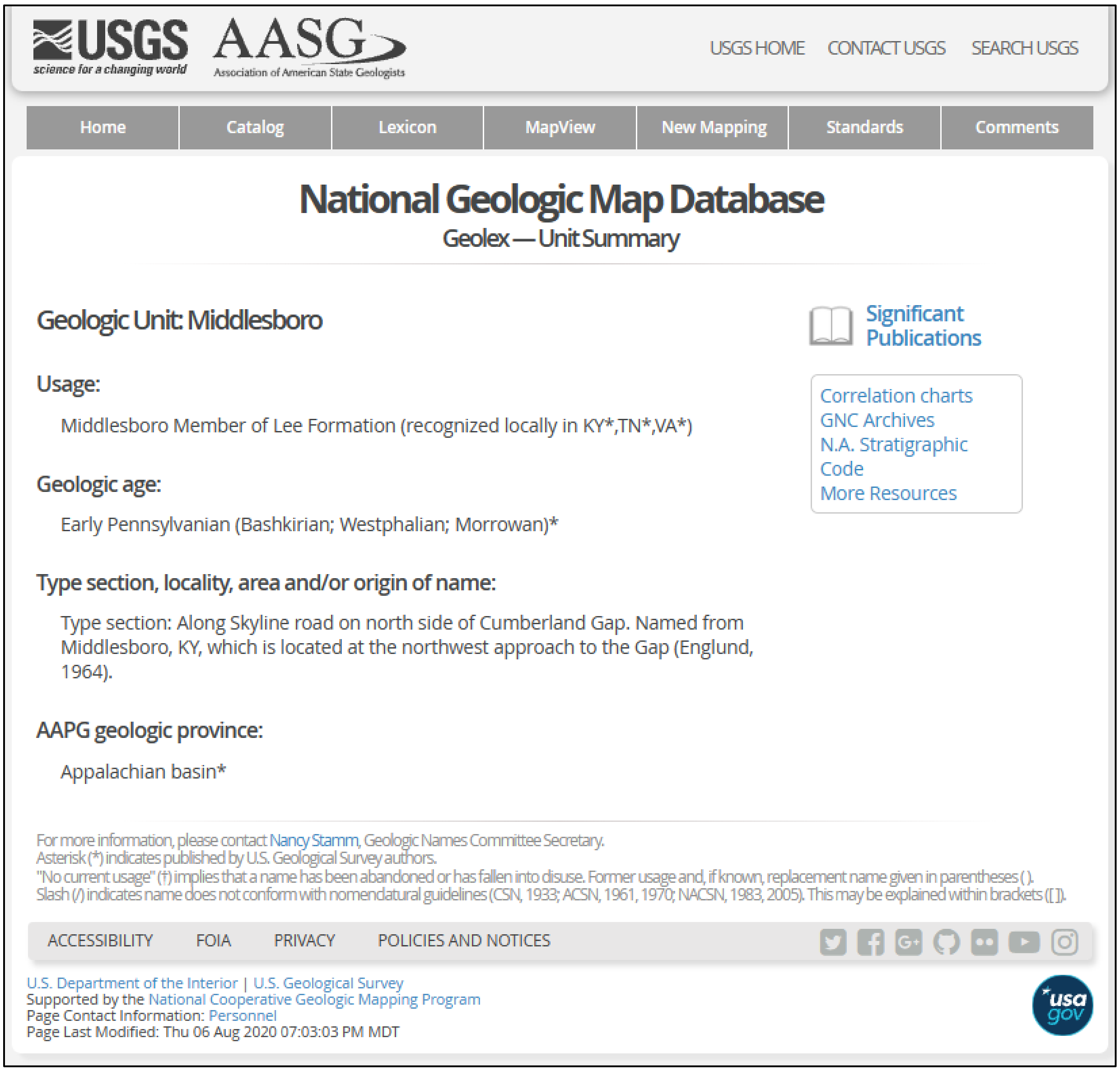
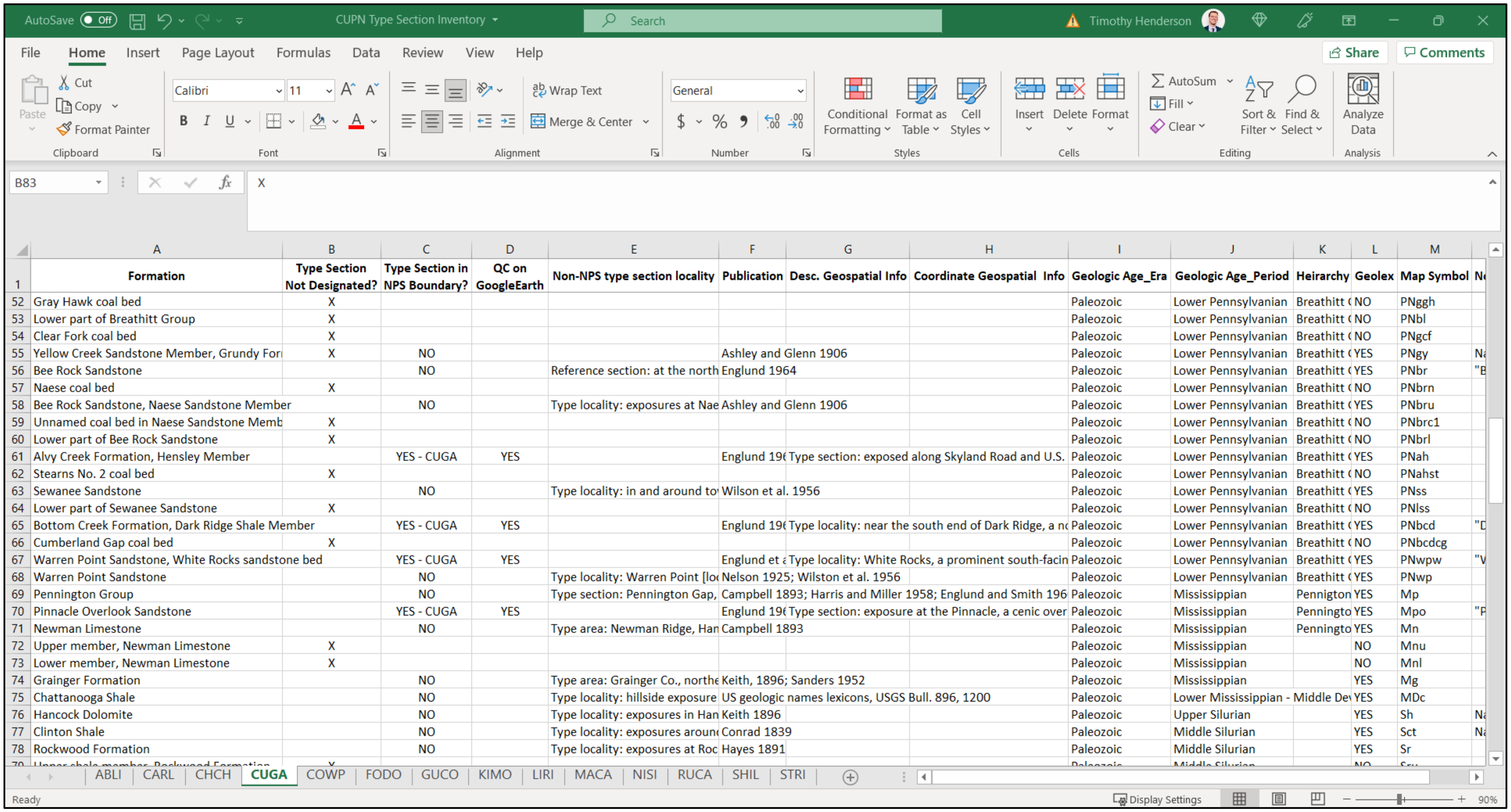


Figure 3. GEOLEX search result for Middlesboro Member unit of the Lee Formation.

Published GEOLEX stratotype spatial information is provided in three formats: (1) descriptive, using distance from nearby points of interest; (2) latitude and longitude coordinates; or (3) Township/Range/Section (TRS) coordinates. TRS coordinates are based upon subdivisions of a single 93.2 km^2 (36 mi^2) township into 36 individual 2.59 km^2 (1 mi^2) sections, and were converted into Google Earth (.kmz file) locations using Earth Point (https://www.earthpoint.us/TownshipsSearchByDescription.aspx). Coordinates are typically presented in an abbreviated format such as "sec. [#], T. [#] [N. or S.], R. [#] [E. or W.]". The most accurate GEOLEX descriptions using TRS coordinates can help locate features within 0.1618 km^2 (0.0625 mi^2). Once stratotype locality information provided for a given unit is geolocated using Google Earth, a GRI digital geologic map of the national park area is draped over it. This step serves two functions: to improve accuracy in locating the stratotype, and validating the geologic polygon for agreement with GEOLEX nomenclature. Geolocations in Google Earth are then converted into an ArcGIS format using a "KML to Layer" conversion tool in ArcMap.

Upon accurately identifying the stratotypes, a Microsoft Excel spreadsheet is populated with information pertinent to the geologic unit and its stratotype attributes. Attribute data recorded in this way include: (1) whether a stratotype is officially designated; (2) whether the stratotype is on NPS land; (3) whether the stratotype location has undergone a quality control check in Google Earth; (4) reference of the publication citing the stratotype; (5) description of geospatial information; (6) coordinates of geospatial information; (7) geologic age (era, period, epoch, etc.); (8) hierarchy of nomenclature (supergroup, group, formation, member, bed, etc.); (9) whether the geologic unit is listed in GEOLEX; and (10) a generic notes field (Figure 4).



	Formation	Type Section Not Designated?	Type Section in NPS Boundary?	QC on GoogleEarth	Non-NPS type section locality	Publication	Desc. Geospatial Info	Coordinate Geospatial Info	Geologic Age_Era	Geologic Age_Period	Heirarchy	Geolex	Map Symbol	N
52	Gray Hawk coal bed	X							Paleozoic	Lower Pennsylvanian	Breathitt (	NO	PNggh	
53	Lower part of Breathitt Group	X							Paleozoic	Lower Pennsylvanian	Breathitt (	NO	PNbl	
54	Clear Fork coal bed	X							Paleozoic	Lower Pennsylvanian	Breathitt (	NO	PNgcf	
55	Yellow Creek Sandstone Member, Grundy Fori	X	NO			Ashley and Glenn 1906			Paleozoic	Lower Pennsylvanian	Breathitt (	YES	PNgy	Na
56	Bee Rock Sandstone		NO		Reference section: at the north	Englund 1964			Paleozoic	Lower Pennsylvanian	Breathitt (	YES	PNbr	"B
57	Naese coal bed	X							Paleozoic	Lower Pennsylvanian	Breathitt (	NO	PNbrn	
58	Bee Rock Sandstone, Naese Sandstone Member		NO		Type locality: exposures at Nae	Ashley and Glenn 1906			Paleozoic	Lower Pennsylvanian	Breathitt (	YES	PNbru	
59	Unnamed coal bed in Naese Sandstone Memb	X							Paleozoic	Lower Pennsylvanian	Breathitt (	NO	PNbrc1	
60	Lower part of Bee Rock Sandstone	X							Paleozoic	Lower Pennsylvanian	Breathitt (	NO	PNbrl	
61	Alvy Creek Formation, Hensley Member		YES - CUGA	YES		Englund 19(	Type section: exposed along Skyland Road and U.S.		Paleozoic	Lower Pennsylvanian	Breathitt (	YES	PNah	
62	Stearns No. 2 coal bed	X							Paleozoic	Lower Pennsylvanian	Breathitt (	NO	PNahst	
63	Sewanee Sandstone		NO		Type locality: in and around to	Wilson et al. 1956			Paleozoic	Lower Pennsylvanian	Breathitt (	YES	PNss	
64	Lower part of Sewanee Sandstone	X							Paleozoic	Lower Pennsylvanian	Breathitt (	NO	PNlss	
65	Bottom Creek Formation, Dark Ridge Shale Member		YES - CUGA	YES		Englund 19(	Type locality: near the south end of Dark Ridge, a nc		Paleozoic	Lower Pennsylvanian	Breathitt (	YES	PNbcd	"D
66	Cumberland Gap coal bed	X							Paleozoic	Lower Pennsylvanian	Breathitt (	NO	PNbcdcg	
67	Warren Point Sandstone, White Rocks sandstone bed		YES - CUGA	YES		Englund et a	Type locality: White Rocks, a prominent south-facin		Paleozoic	Lower Pennsylvanian	Breathitt (	YES	PNwpw	"V
68	Warren Point Sandstone		NO		Type locality: Warren Point [loc	Nelson 1925; Wilston et al. 1956			Paleozoic	Lower Pennsylvanian	Breathitt (	YES	PNwp	
69	Pennington Group		NO		Type section: Pennington Gap,	Campbell 1893; Harris and Miller 1958; Englund and Smith 196			Paleozoic	Mississippian	Pennigton	YES	Mp	
70	Pinnacle Overlook Sandstone		YES - CUGA	YES		Englund 19(	Type section: exposure at the Pinnacle, a cenic over		Paleozoic	Mississippian	Penningto	YES	Mpo	"P
71	Newman Limestone		NO		Type area: Newman Ridge, Han	Campbell 1893			Paleozoic	Mississippian	Penningto	YES	Mn	
72	Upper member, Newman Limestone	X							Paleozoic	Mississippian		NO	Mnu	
73	Lower member, Newman Limestone	X							Paleozoic	Mississippian		NO	Mnl	
74	Grainger Formation		NO		Type area: Grainger Co., northe	Keith, 1896; Sanders 1952			Paleozoic	Mississippian		YES	Mg	
75	Chattanooga Shale		NO		Type locality: hillside exposure	US geologic names lexicons, USGS Bull. 896, 1200			Paleozoic	Lower Mississippian - Middle Dev		YES	MDc	
76	Hancock Dolomite		NO		Type locality: exposures in Han	Keith 1896			Paleozoic	Upper Silurian		YES	Sh	Na
77	Clinton Shale		NO		Type locality: exposures aroun	Conrad 1839			Paleozoic	Middle Silurian		YES	Sct	Na
78	Rockwood Formation		NO		Type locality: exposures at Roc	Hayes 1891			Paleozoic	Middle Silurian		YES	Sr	

Figure 4. Stratotype inventory spreadsheet of the CUPN displaying attributes appropriate for geolocation assessment.

Definitions

In order to clarify, standardize, and consistently reference stratigraphic concepts, principles, and definitions, the North American Stratigraphic Code is recognized and adopted for this inventory. This code seeks to describe explicit practices for classifying and naming all formally defined geologic units. An important designation for a geologic unit is known as a ***stratotype***—the standard exposure (original or subsequently designated) for a named geologic unit or boundary and constitutes the basis for definition or recognition of that unit or boundary (North American Commission on Stratigraphic Nomenclature 2021). There are several variations of stratotype referred to in the literature and this report, and they are defined as follows:

1) **Unit stratotype**: the **type section** for a stratified deposit or the **type area** for a non-stratified body that serves as the standard for recognition and definition of a geologic unit (North American Commission on Stratigraphic Nomenclature 2021). Once a unit stratotype is assigned, it is never changed. The term "unit stratotype" is commonly referred to as "type section" and "type area" in this report.

2) **Type locality**: the specific geographic locality encompassing the unit stratotype of a formally recognized and defined unit. On a broader scale, a type area is the geographic territory encompassing the type locality. Before development of the stratotype concept, only type localities and type areas were designated for many geologic units that are now long- and well-established (North American Commission on Stratigraphic Nomenclature 2021).

3) **Reference sections**: for well-established geologic units for which a type section was never assigned, a reference section may serve as an invaluable standard in definitions or revisions. A principal reference section may also be designated for units whose stratotypes have been destroyed, covered, or are otherwise inaccessible (North American Commission on Stratigraphic Nomenclature 2021). Multiple reference sections can be designated for a single unit to help illustrate heterogeneity or some critical feature not found in the stratotype. Reference sections can help supplement unit stratotypes in the case where the stratotype proves inadequate (North American Commission on Stratigraphic Nomenclature 2021).

4) **Lithodeme**: the term "lithodeme" is defined as a mappable unit of plutonic (igneous rock that solidified at great depth) or highly metamorphosed and pervasively deformed rock and is a term equivalent in rank to "formation" among stratified rocks (North American Commission on Stratigraphic Nomenclature 2021). The formal name of a lithodeme consists of a geographic name followed by a descriptive term that denotes the average modal composition of the rock (example: Cathedral Peak Granodiorite). Lithodemes are commonly assigned type localities, type areas, and reference localities.

Abraham Lincoln Birthplace National Historical Park (ABLI)

Abraham Lincoln Birthplace National Historical Park (ABLI) is located 5 km (3 mi) south of Hodgenville and about 80 km (50 mi) south of Louisville in LaRue County, Kentucky (Figure 5). Originally established as Abraham Lincoln National Park on July 17, 1916, the park unit was then re-designated a national historical park (1933), national historical site (1959), and most recently again a national historical park on March 30, 2009 (National Park Service 2016a). Encompassing approximately 139 hectares (345 acres), ABLI was among the first park units in the National Park System set aside to protect and preserve cultural resources associated with the 16th president of the United States. The historical park consists of two units (Birthplace and Boyhood Home units) that contain the Sinking Spring Farm and Knob Creek Farm, Lincoln's birthplace and early boyhood home (Thornberry-Ehrlich 2010). A symbolic cabin similar to the one in which Lincoln was born is preserved in a memorial building at the site of his birth. Lincoln's boyhood home at Knob Creek was the site of his formative years and earliest memories, influencing his beliefs and choices throughout his life and presidency (National Park Service 2015).

ABLI is situated atop the Pennyroyal Plateau, a region characterized by karst topography that includes rolling hills, sinking streams, sinkholes, springs, and caves. The karst landscape of ABLI strongly influenced the Lincoln family to settle in the area, where as farmers they were positioned to take full advantage of the available water supply. Bedrock within ABLI consists entirely of Mississippian-age carbonate rocks that include the Borden Formation, Harrodsburg Limestone, Salem Limestone, and St. Louis Limestone (Figures 6 and 7). The karst topography of ABLI is the result of chemical erosion and dissolution of these underlying carbonate rocks to form cavities that grow to form conduits and interconnected cave systems. The youngest geologic units mapped in ABLI are Quaternary-age unconsolidated deposits associated with local rivers and slope processes. The age gap between the lithified bedrock and the unconsolidated surficial deposits is more than 300 million years (Thornberry-Ehrlich 2010).

There are no designated stratotypes identified within the boundaries of ABLI. There are three identified stratotypes located within 48 km (30 mi) of ABLI boundaries, for the Mississippian Horse Cave Member of the Ste. Genevieve Limestone (type locality), Muldraugh Member of the Borden Limestone (type section), and Leitchfield Formation (type area).

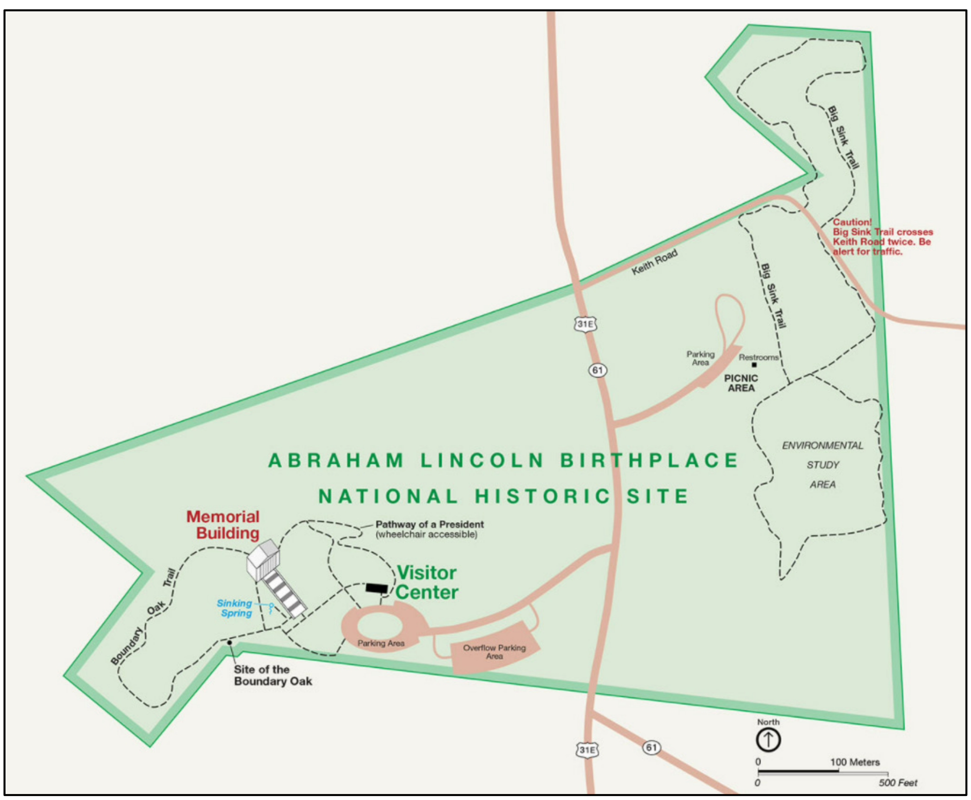


Figure 5. Park maps of ABLI (top, Birthplace Unit; bottom, Boyhood Home Unit), Kentucky (NPS).

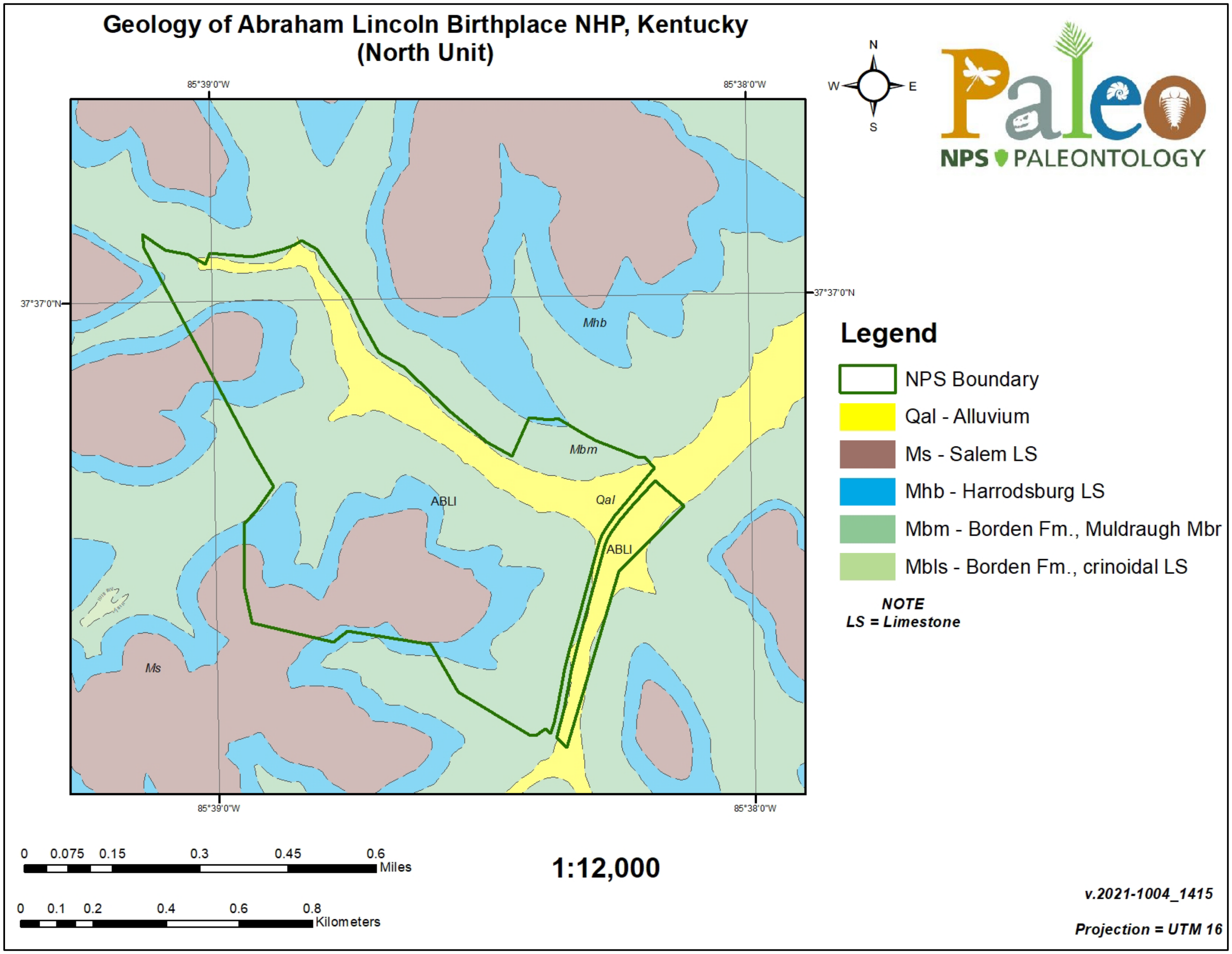


Figure 6. Geologic map of ABLI (Birthplace Unit), Kentucky. Data modified from ABLI GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1040610.

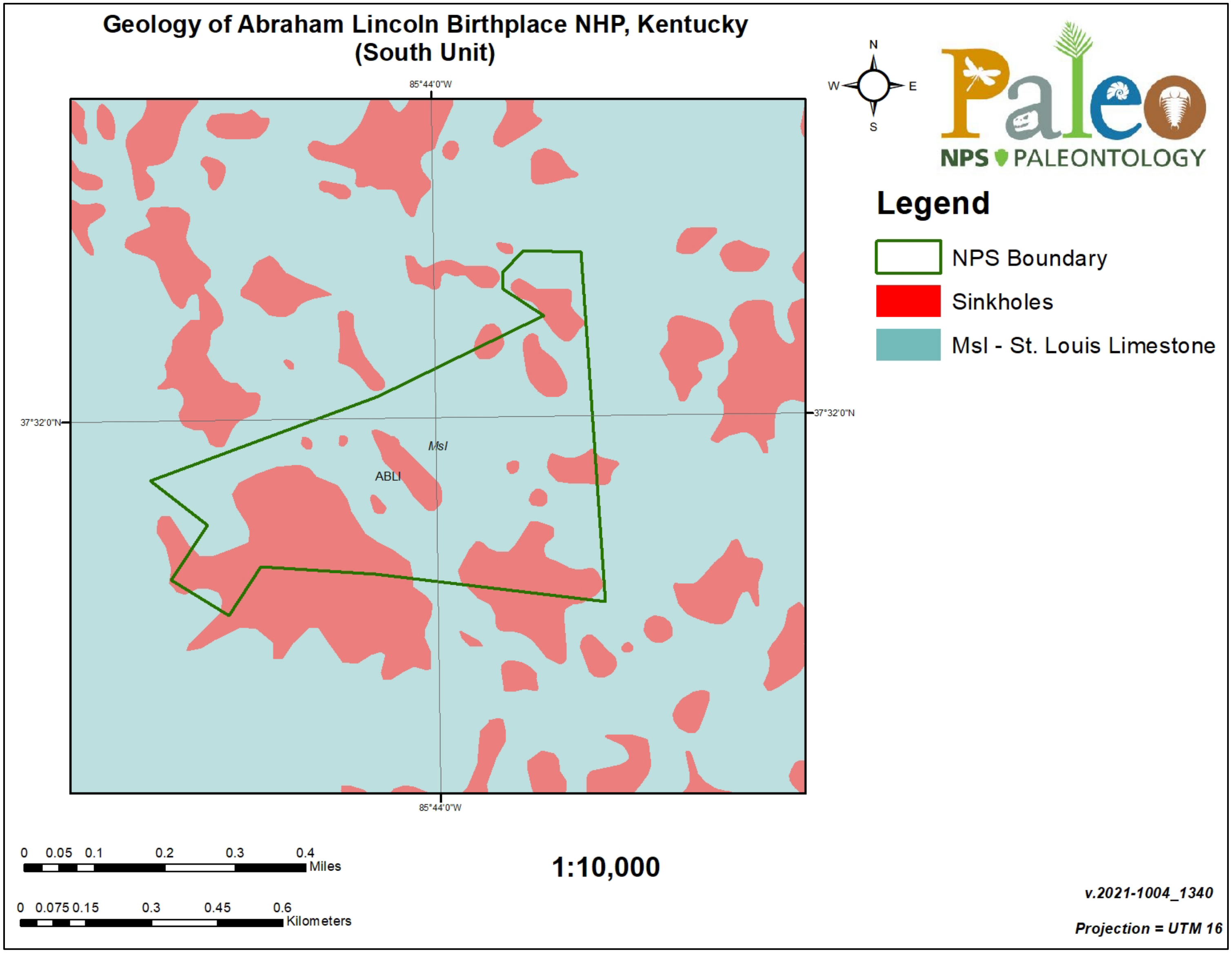


Figure 7. Geologic map of ABLI (Boyhood Home Unit), Kentucky. Data modified from ABLI GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1040610.

Carl Sandburg Home National Historic Site (CARL)

Carl Sandburg Home National Historic Site (CARL) is located in the southern Appalachian Mountains, about 64 km (40 mi) southeast of Great Smoky Mountains National Park and 32 km (20 mi) south of Asheville in Henderson County, North Carolina (Figure 8). Established on October 27, 1972, CARL contains approximately 106 hectares (264 acres) and commemorates the legacy of Carl Sandburg: the stories of his works, life, and importance as an American poet, writer, and social activist (National Park Service 2016a). Regarded as the "poet of the people", Sandburg's literary career captured and recorded America's traditions, struggles, and dreams in his poetry, journalism, biographies, novels, and a collection of folk songs. The historic site preserves Connemara, the farm in Flat Rock, North Carolina, where Sandburg and his family lived for the last 22 years of his life (1945–1967). The Sandburgs' personal belongings, furnishings, farm equipment, library, and papers are preserved at CARL and offer a unique perspective into the American author's lifestyle, philosophy, and intellectual pursuits.

The bedrock of CARL consists entirely of Cambrian-age metamorphic rock of the Henderson Augen Gneiss (Figure 9). The Henderson Augen Gneiss was metamorphosed by heat and pressure generated during the numerous collisions that uplifted the Appalachian Mountains, and characteristically forms "domes" and other areas of high relief within CARL (Thornberry-Ehrlich 2012a). The vista observed from the trail to Glassy Mountain (named for light reflecting off the exposed bedrock) offers a panoramic view of nearby Mount Pisgah and the neighboring peaks of the Balsam Mountains. Bedrock outcrops within CARL inspired the previous owner Ellison Smyth to name the estate "Connemara" after the rugged landscape of quartzite and schist on Ireland's western coast (Thornberry-Ehrlich 2012a).

CARL contains one identified stratotype, for the Cambrian Henderson Augen Gneiss (Table 2; Figure 10). There are no additional identified stratotypes located within 48 km (30 mi) of CARL boundaries.

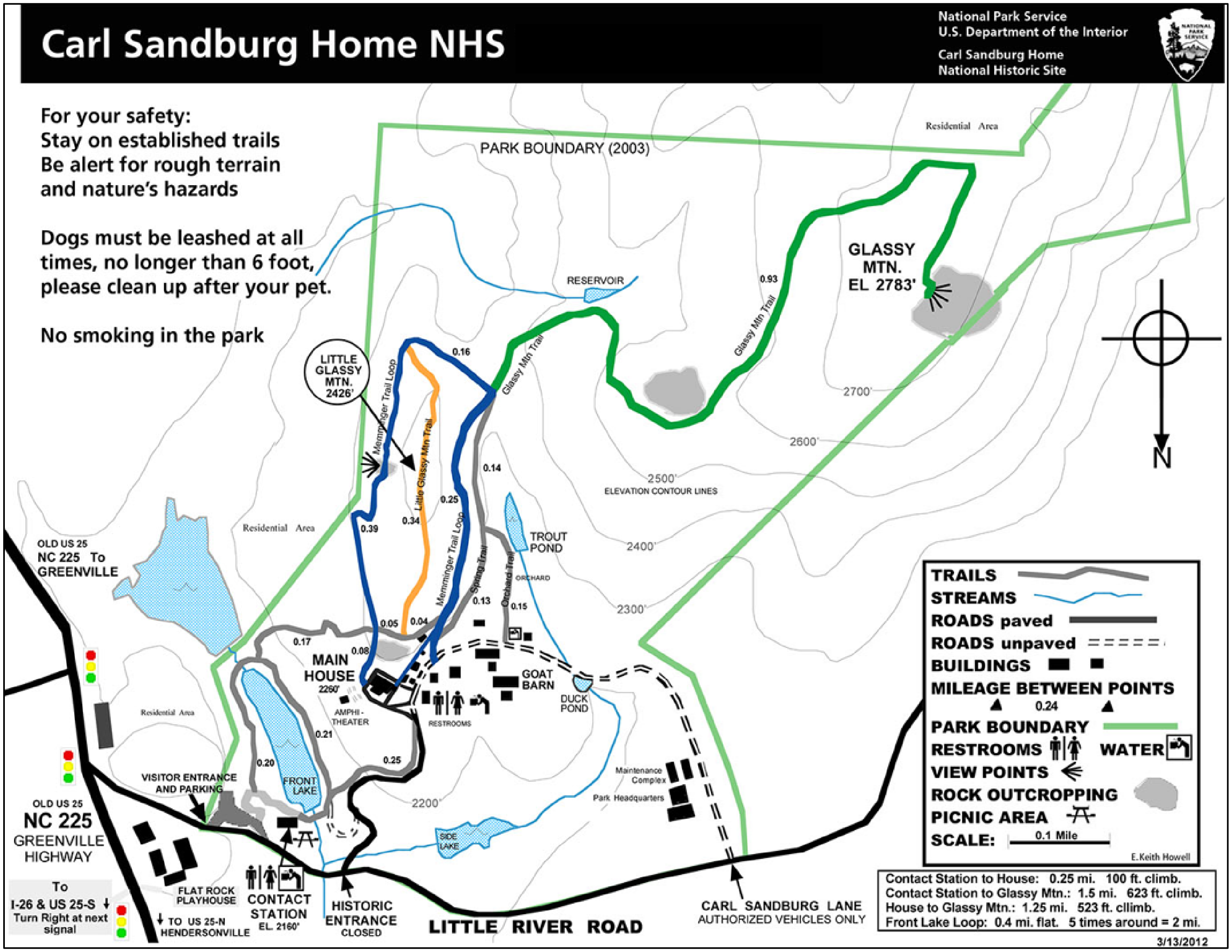


Figure 8. Park map of CARL, North Carolina (NPS).

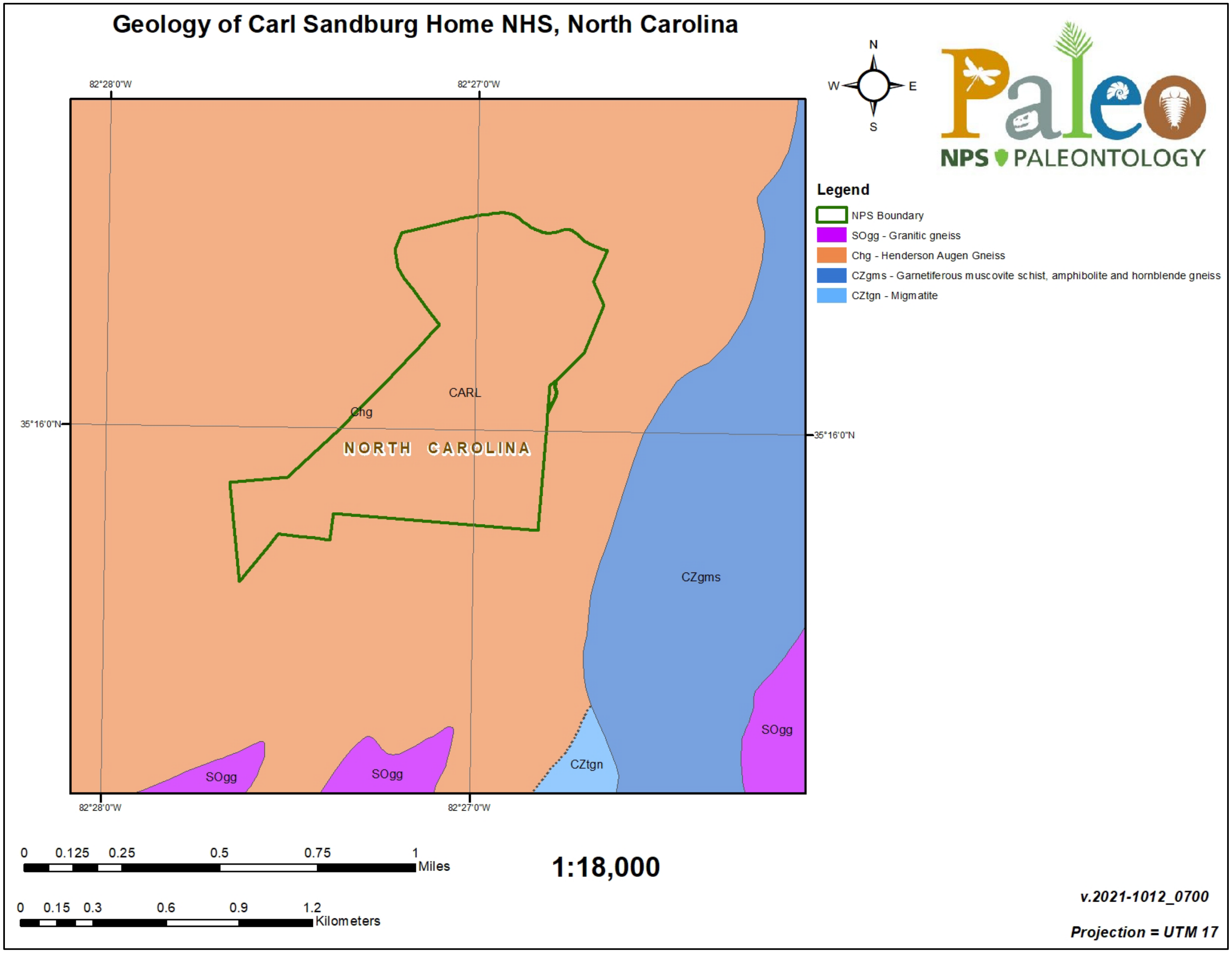


Figure 9. Geologic map of CARL, North Carolina. Data modified from CARL GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048434.

Table 2. List of CARL stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Henderson Augen Gneiss (Chg)	Keith 1905; Horton and McConnell 1991	Type area: extensive exposures in Henderson Co., western NC.	Cambrian

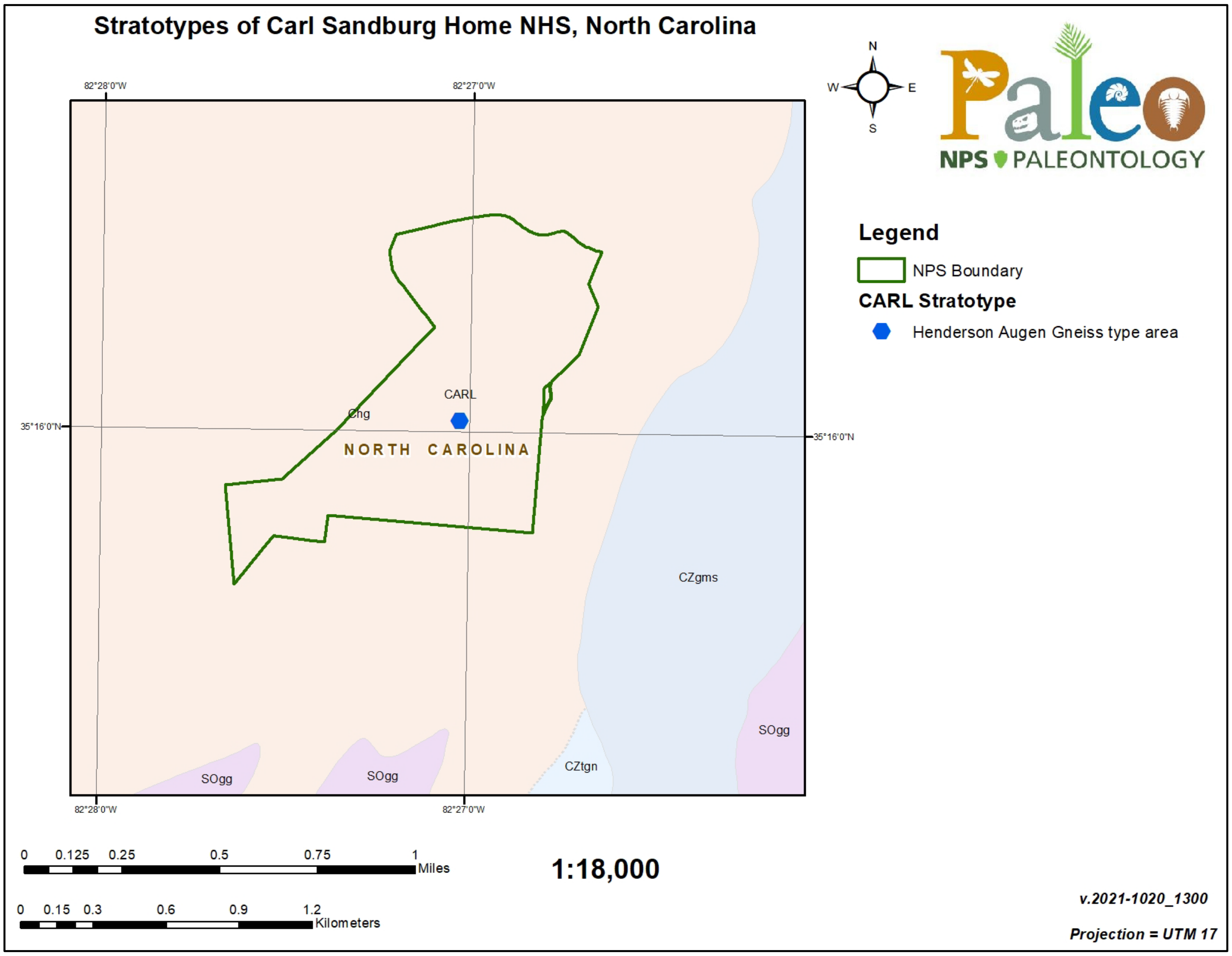


Figure 10. Modified geologic map of CARL showing stratotype locations. The transparency of the geologic units layer has been increased.

Henderson Augen Gneiss

The Cambrian Henderson Augen Gneiss was proposed by Keith (1905) in the Mount Mitchell Quadrangle, North Carolina–Tennessee. The unit is named after its extensive type area exposures in Henderson County, western North Carolina (Table 2; Figures 10–13; Keith 1905; Horton and McConnell 1991). In the type area, the gneiss occurs in a large, irregular mass with smaller tongues that project from the main body (Keith 1905). The Henderson Augen Gneiss is a medium-gray, biotite granite augen gneiss predominantly composed of microcline, oligoclase, quartz, biotite, and minor amounts of muscovite, epidote, and titanite (Keith 1905; Horton and McConnell 1991). Zircon morphology studies indicate an igneous origin for the gneiss in its type area, where the unit is intrusive of all older Archean-age rocks in contact (Keith 1905; Lemmon 1981). Phenocrysts (large mineral crystals) of orthoclase feldspar are a prominent characteristic of the rock and many are drawn out into lenses (or augen) more than 5 cm (2 in) in length (Keith 1905). At numerous localities the gneiss shows flow banding or wavy flow bands where minerals in the rock have aligned in roughly parallel layers due to metamorphism. Light-colored bands consist of quartz and feldspar while dark-colored bands are composed of biotite and hornblende (Figure 11; Keith 1905).

Figure 11. Type area exposures of the Henderson Augen Gneiss showing banding and foliation. Light colored bands contain coarse-grained feldspar crystals, whereas the darker bands contain flaky biotite crystals and other opaque minerals (NPS/TIM CONNORS).

Figure 12. Panoramic view from the top of Glassy Mountain at type area exposures of the Henderson Augen Gneiss (NPS).

Figure 13. Sandburg's Rock, consisting entirely of Henderson Augen Gneiss. Sandburg's Rock is located on the side of the Main house and was a peaceful place where Carl Sandburg would sit and write poetry (NPS).

Chickamauga and Chattanooga National Military Park (CHCH)

Chickamauga and Chattanooga National Military Park (CHCH) encompasses 18 separate units along the Georgia–Tennessee border in Catoosa, Dade, and Walker Counties, Georgia, as well as Georgia and Hamilton Counties, Tennessee (Figure 14). Established as the first national military park on August 19, 1890, CHCH encompasses about 3,673 hectares (9,078 acres) and preserves nationally significant resources associated with the Civil War campaign for Chattanooga, including the battles of Chickamauga and Chattanooga and the 12,000 years of human habitation of the Moccasin Bend Peninsula (National Park Service 2016b). The Chattanooga campaign was one of the deciding campaigns of the Civil War, where Union victories assured access through the "Gateway to the Deep South," ultimately hastening the end of fighting and the reunification of the United States. Resources preserved in CHCH offer exceptional opportunities for study of some of the most remarkable maneuvers and brilliant fight strategies of the Civil War. Moccasin Bend National Archeological District provides an outstanding opportunity for education and research of American Indian habitation, including those of transitional Paleo-Indian/Archaic, Archaic, Woodland, Mississippian, and historic periods (National Park Service 2016b).

Situated in the southern Appalachian Mountains in the Valley and Ridge physiographic province, the bedrock geology of CHCH predominantly consists of Paleozoic sedimentary rocks (Figures 15–17; Clark 2008). Formations within CHCH occur as elongate northeast–southwest trending belts that mimic the orientation of the Valley and Ridge province. Mapped units that underlie Chickamauga Battlefield are predominantly Ordovician-age carbonates and include rocks of the Knox Group (Chepultepec Dolomite, Longview Dolomite, Kingsport Formation, and Mascot Dolomite) and Chickamauga Group (Pond Spring Formation, Murfreesboro Limestone, Ridley Limestone, Lebanon Limestone, Carters Limestone, and Hermitage Formation). The Lookout Mountain Battlefield region is underlain by a rich assemblage of strata spanning the Ordovician through the Pennsylvanian. At Lookout Mountain, these units form a broad syncline and include the Ordovician Sequatchie Formation; Silurian Rockwood Formation; Mississippian Fort Payne Chert, Warsaw Limestone, St. Louis Limestone, Monteagle Limestone, Hartselle Formation, Bangor Limestone, and Pennington Formation; and formations of the Pennsylvanian Gizzard Group (Raccoon Mountain Formation, Warren Point Sandstone, Signal Point Shale) and Crooked Fork Group (Sewanee Conglomerate, Whitwell Shale) (Cramer 1986). The Lookout Valley fault is a major structural feature that cuts across most of Lookout Mountain Battlefield and Moccasin Bend National Archeological District.

There are no designated stratotypes identified within the boundaries of CHCH. There are 14 identified stratotypes located within 48 km (30 mi) of CHCH, for the Cambrian Conasauga Formation (type locality); Ordovician Chickamauga Supergroup (type area), Pond Spring Formation (type section), Sequatchie Formation (type area), and Shellmound Member of the Sequatchie Formation (type section); Devonian–Mississippian Chattanooga Shale (type locality); Mississippian Monteagle Limestone (type section); and Pennsylvanian Gizzard Group (type section), Signal Point Shale (type locality), Whitwell Shale (type area), Warren Point Sandstone (type locality), Raccoon Mountain Formation (type section), Flat Rock Member of the Raccoon Mountain Formation (type section), and Norwood Cove Member of the Raccoon Mountain Formation (type section).

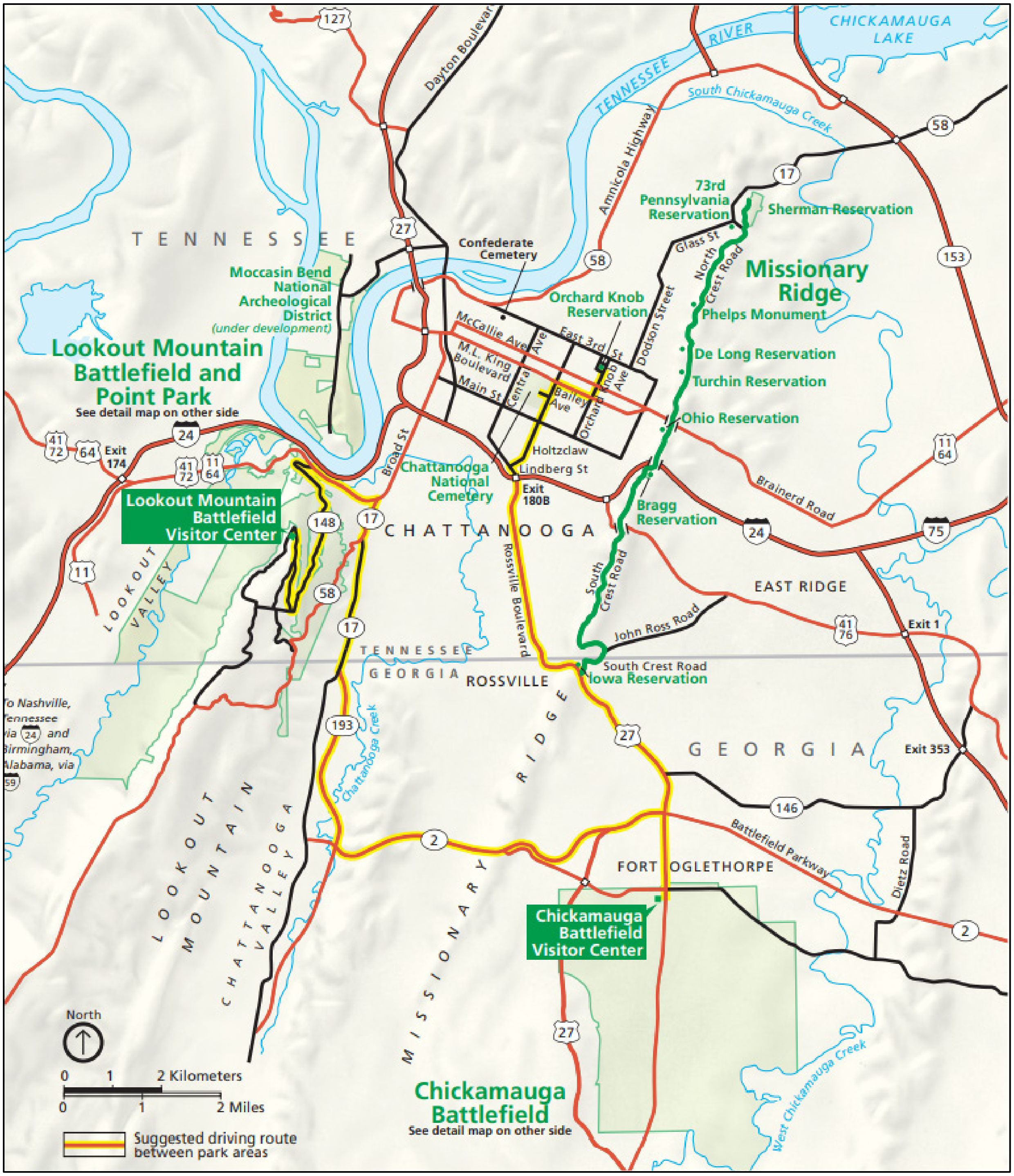


Figure 14. Park map of CHCH, Georgia–Tennessee (NPS).

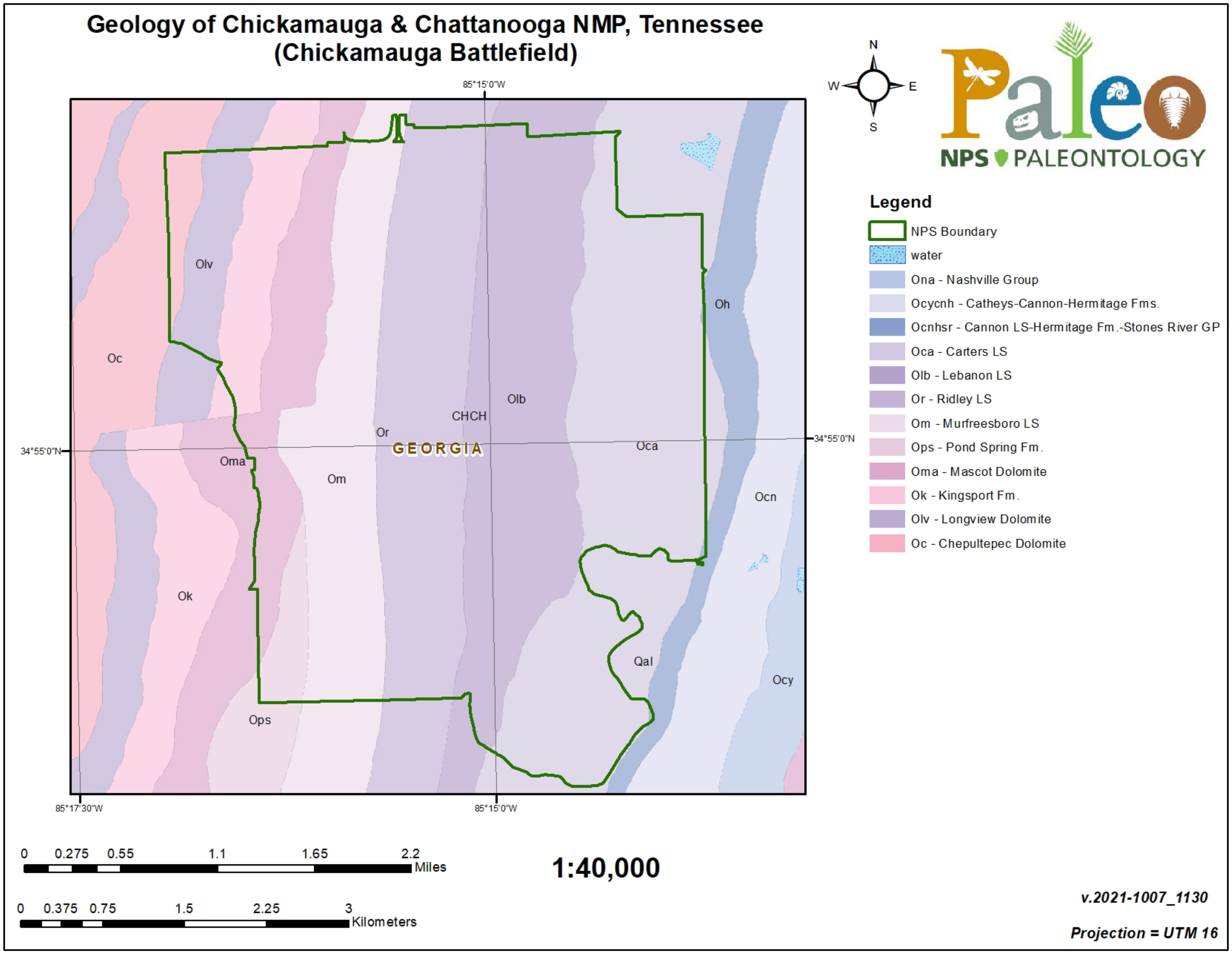


Figure 15. Geologic map of CHCH (Chickamauga Battlefield Unit), Georgia. Data modified from CHCH GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2240764.

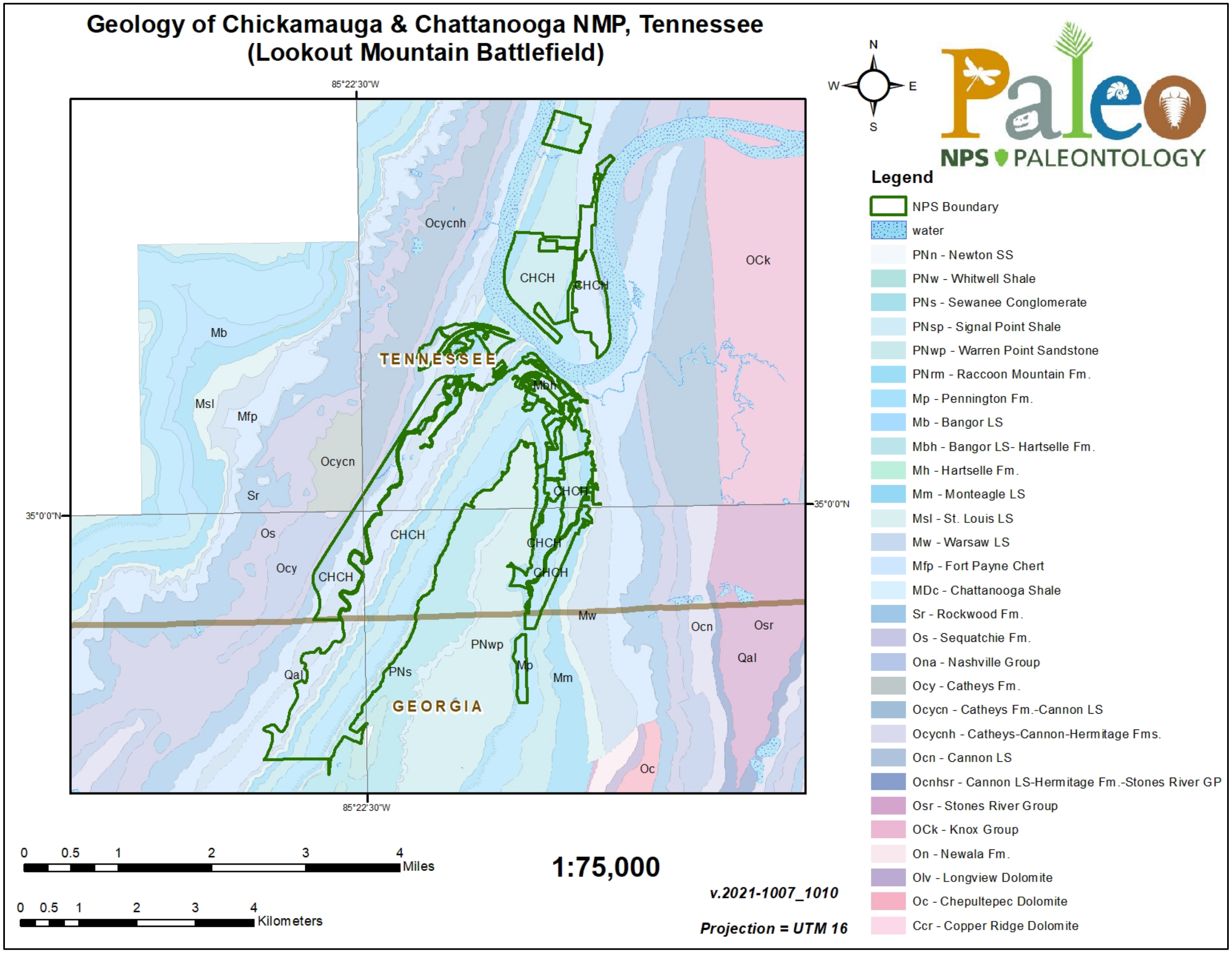


Figure 16. Geologic map of CHCH (Lookout Mountain Battlefield Unit), Georgia–Tennessee. Data modified from CHCH GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2240764.

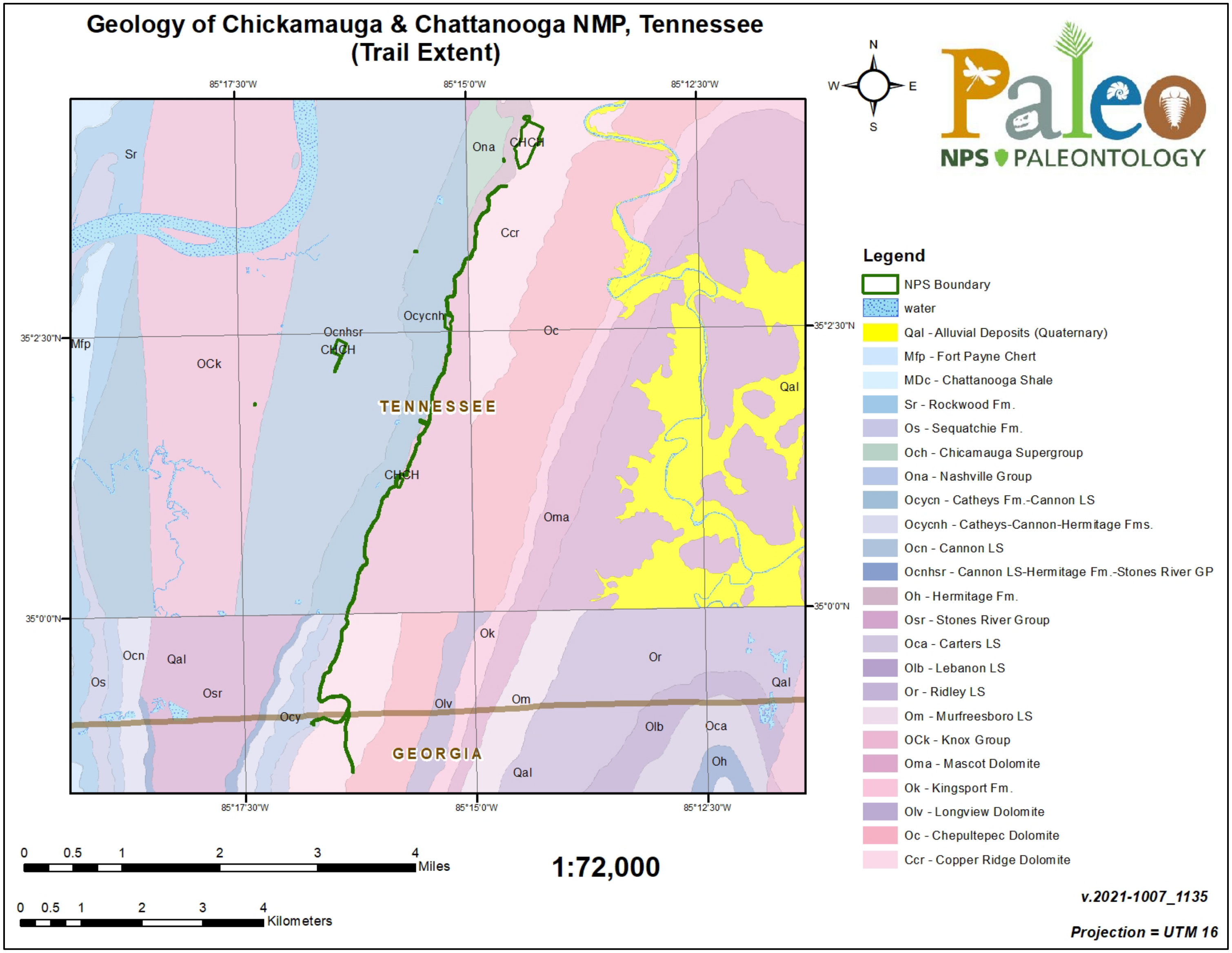


Figure 17. Geologic map of CHCH (Missionary Ridge Trail Extent), Georgia–Tennessee. Data modified from CHCH GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2240764.

Cowpens National Battlefield (COWP)

Cowpens National Battlefield (COWP) is located between the towns of Gaffney and Chesnee at the intersection of U. S. Highway 221-A and South Carolina Highways 11 and 110 in Cherokee County, South Carolina (Figure 18). Originally established as a national battlefield site on March 4, 1929, the park unit was re-designated a national battlefield on April 11, 1972 (National Park Service 2016a). Encompassing about 370 hectares (842 acres), COWP commemorates the decisive American victory at the Battle of Cowpens during the Southern Campaign of the American Revolutionary War on January 17, 1781. On that day, Brigadier General Daniel Morgan's militia soldiers defeated British Lieutenant Colonel Banastre Tarleton's troops, boosting American morale and ultimately leading to the British surrender at Yorktown, Virginia, in October 1781. COWP contains traces of Colonial-period roads associated with routes marched by troops, two historic monuments (the 1856 Washington Light Infantry Monument and the 1932 U.S. Monument), historic structures, a battlefield trail, a nature trail, a battlefield-perimeter auto route, and other visitor use facilities (National Park Service 2014a).

The bedrock of COWP reflects a long geologic history of deposition, metamorphism, mountain building, and erosion. Rocks that underlie COWP represent ocean sediments that were lithified, buried, metamorphosed, pushed up as part of the Six Mile thrust sheet, and folded and faulted during the formation of the Appalachian Mountains (Thornberry-Ehrlich 2020a). Only two geologic units are mapped in COWP and consist of late Proterozoic to early Cambrian-age quartz-rich mica schist and biotite gneiss (Figure 19). Weathered mica schist is mapped as part of an east–west trending ridge composed of a series of tight double-plunging folds that includes Thicketty Mountain. Biotite gneiss is predominantly mapped in southeastern COWP and underlies the lower valleys and occurs in stream bed exposures. These metamorphic units alternate in northeast–southwest trending bands oriented perpendicular to the compressive tectonic forces that occurred during the formation of the Appalachian Mountains (Thornberry-Ehrlich 2020a).

There are no designated stratotypes identified within the boundaries of COWP. There are six identified stratotypes located within 48 km (30 mi) of COWP, for the Neoproterozoic Gaffney Marble Member of the Blacksburg Formation (type area), Marble Member of Dixon Branch of the Blacksburg Formation (type area), Crowders Creek Metaconglomerate Member of the Battleground Formation (type locality), Drayton Metaconglomerate Member of the Battleground Formation (type locality), Dixon Gap Metaconglomerate Member of the Battle Ground Formation (type locality), and Jumping Branch Manganiferous Member of the Battleground Formation (type locality).

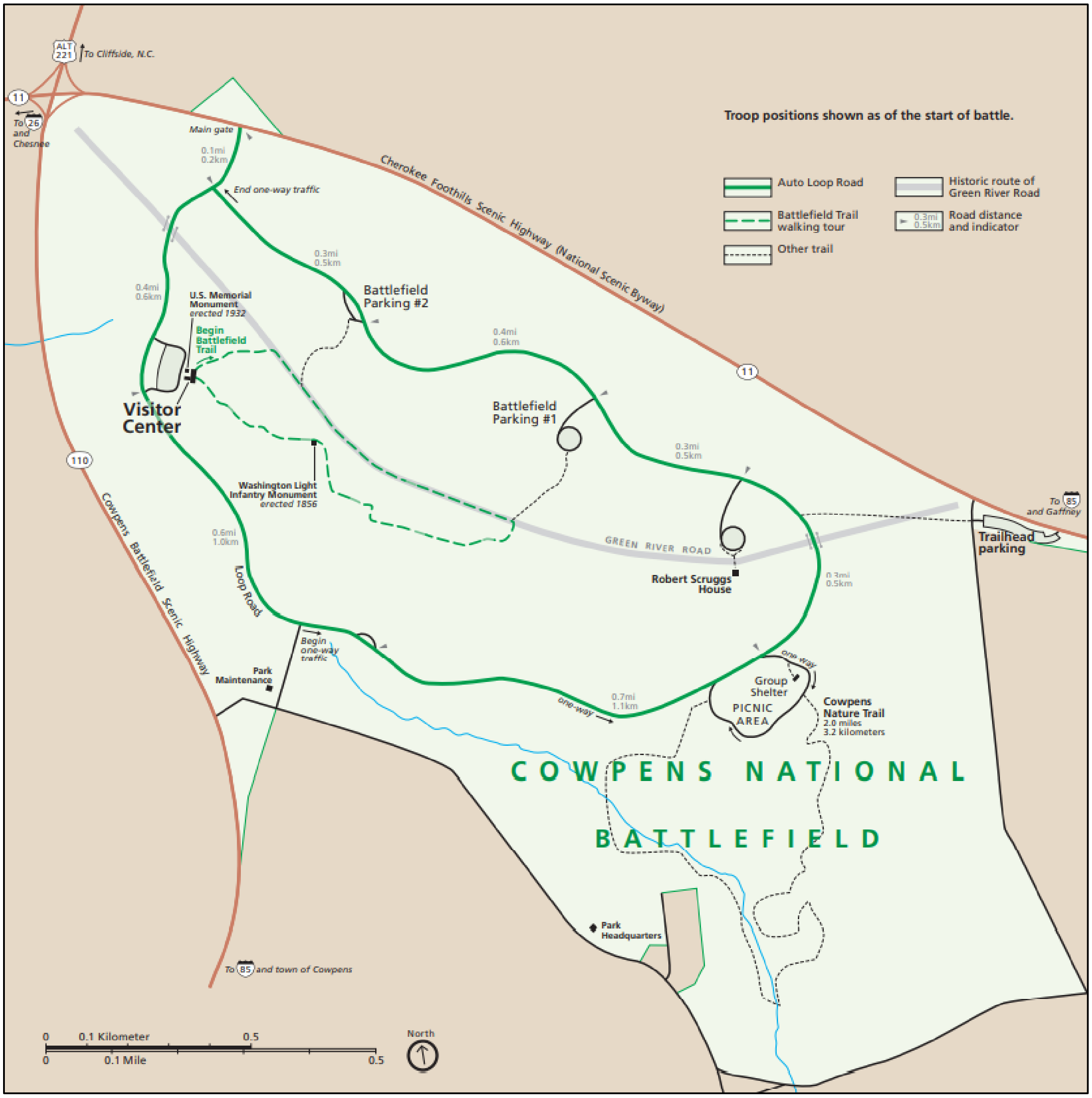


Figure 18. Park map of COWP, South Carolina (NPS).

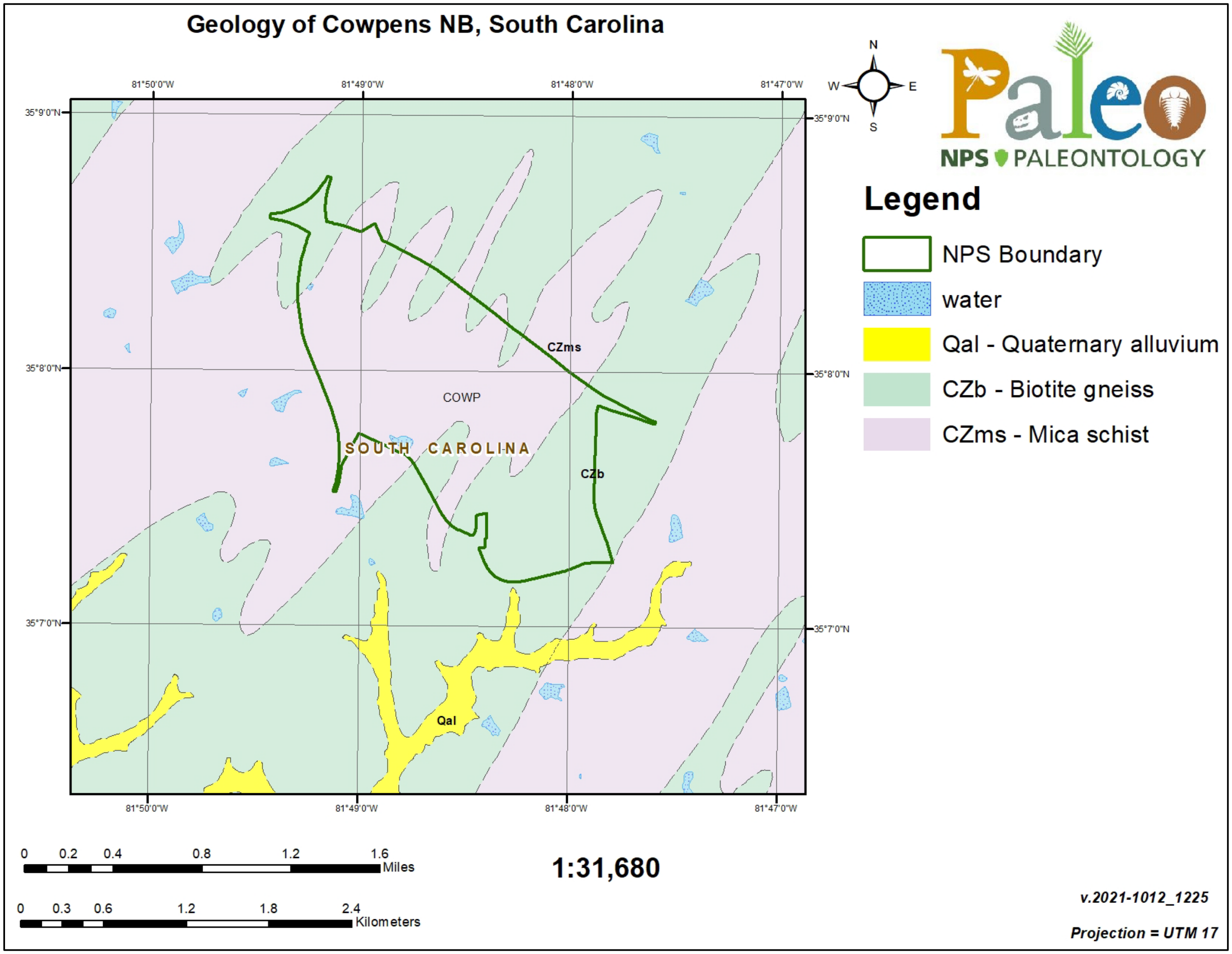


Figure 19. Geologic map of COWP, South Carolina. Data modified from COWP GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2167826.

Cumberland Gap National Historical Park (CUGA)

Cumberland Gap National Historical Park (CUGA) stretches for 32 km (20 mi) astride the forested Cumberland and Brush Mountains in Bell and Harlan Counties, Kentucky, Claiborne County, Tennessee, and Lee County, Virginia (Figure 20). The park extends southwestward from White Rocks overlook along Cumberland Mountain across the gap and into the Little Yellow Creek watershed beyond Fern Lake Reservoir (Thornberry-Ehrlich 2011a). Authorized on June 11, 1940, CUGA contains approximately 9,933 hectares (24,547 acres) and protects the geologic "doorway to the west"—the Cumberland Gap of the southern Appalachian Mountains. Famously explored by frontiersman Daniel Boone in 1775, the Cumberland Gap forms a prominent break in the otherwise formidable mountains that developed into a main corridor of western expansion into the interior of the nation and was an important military objective during the Civil War (National Park Service 2016a). Boone's Trace evolved into the Wilderness Road, which was later utilized during the Civil War to transport supplies, troops, and ordnance. Another key historic resource in CUGA is the Hensley Settlement, a community of scattered farmsteads located on Brush Mountain that was originally established by Sherman Hensley circa 1903. The settlement consists of more than 40 historic structures, several log cabin homes, split rail fences, a one-room log cabin schoolhouse, pastures, and woodlands with scenic mountain views (National Park Service 2016c).

The rugged landscape of CUGA comes from Paleozoic-age sedimentary rocks originally deposited in or near shallow seas millions of years ago that were subsequently folded, faulted, and thrusted up and westward along the Pine Mountain thrust fault (Figures 21 and 22; Thornberry-Ehrlich 2011a). The sedimentary rock record of CUGA dates back more than 400 Ma to the Silurian Period, represented by the Rockwood Formation and Clinton Shale mapped along the southeastern park boundary. The Devonian–Mississippian Chattanooga Shale occurs in the lowermost valleys of CUGA, overlain by mixed shales, cherts, limestones, and sandstones of the Mississippian Grainger Formation, Fort Payne Chert, and rocks of the Pennington Group (Newman Limestone and Pinnacle Overlook Sandstone). Chemical erosion and dissolution of the Mississippian carbonate rocks formed caves such as Gap, Skylight, and Big Salt caves (Thornberry-Ehrlich 2011a). Formations of the Pennsylvanian-age Breathitt Group form the majority of rock exposures within the park and include the Warren Point Sandstone, Bottom Creek Formation, Sewanee Sandstone, Alvy Creek Formation, Bee Rock Sandstone, Pikeville Formation, Grundy Formation, and Hyden Formation. Erosion-resistant sandstones of the Breathitt Group underlie ridgetops and form steep cliffs along Cumberland and Pine mountains. The youngest units within the historical park include Quaternary-age terrace gravels, landslide deposits, colluvium, and alluvial deposits that mantle some of the bedrock exposures within the park. A notable concentration of caves and karst formations, cliffs, pinnacles, and other geologic features are preserved in CUGA that provide a valuable window into the dynamic nature and impact of geology on human migration and culture (Thornberry-Ehrlich 2011a).

CUGA contains seven identified stratotypes that are subdivided into five type sections and two type localities (Table 3; Figure 23). In addition to the designated stratotype located within CUGA, stratotypes located within 48 km (30 mi) of the park boundaries include: the Cambrian Rutledge Limestone (type locality), Copper Ridge Dolomite (type section), Maynardville Limestone (type section), and Rogersville Shale (type locality); Ordovician Eidson Member of the Lincolnshire Formation (type section), Hogskin Member of the Lincolnshire Formation (type locality), Rob Camp Limestone (type section), Martin Creek Limestone (type section), Dot Formation (type section), Poteet Limestone (type locality), Hardy Creek Limestone (type section), Ben Hur Limestone (type section), Hurricane Bridge Limestone (type section), and Woodway Limestone (type section); Silurian Hancock Dolomite (type locality); Mississippian Grainger Formation (type area), Newman Limestone (type area), and Pennington Formation (type locality); and Pennsylvanian Bryson Formation (type area), Hignite Formation (type area), Bee Rock Sandstone (reference section), Naese Sandstone Member of the Bee Rock Sandstone (type locality), Catron Formation (type section), Wallins Creek Coal of the Catron Formation (type locality), Betsie Shale Member of the Pikeville Formation (type section), Crummies Member of the Pikeville Formation (type section), Hance Formation (type area), Puckett Coal of the Hance Formation (type locality), Reynolds Sandstone Member of the Four Corners Formation (type locality), Stoney Fork Member of the Princess Formation (type section), Jesse Sandstone Member of the Hyden Formation (type locality), Cawood Sandstone (type locality), Slater Sandstone (type locality), and Harlan Coal of the Mingo Formation (type locality).

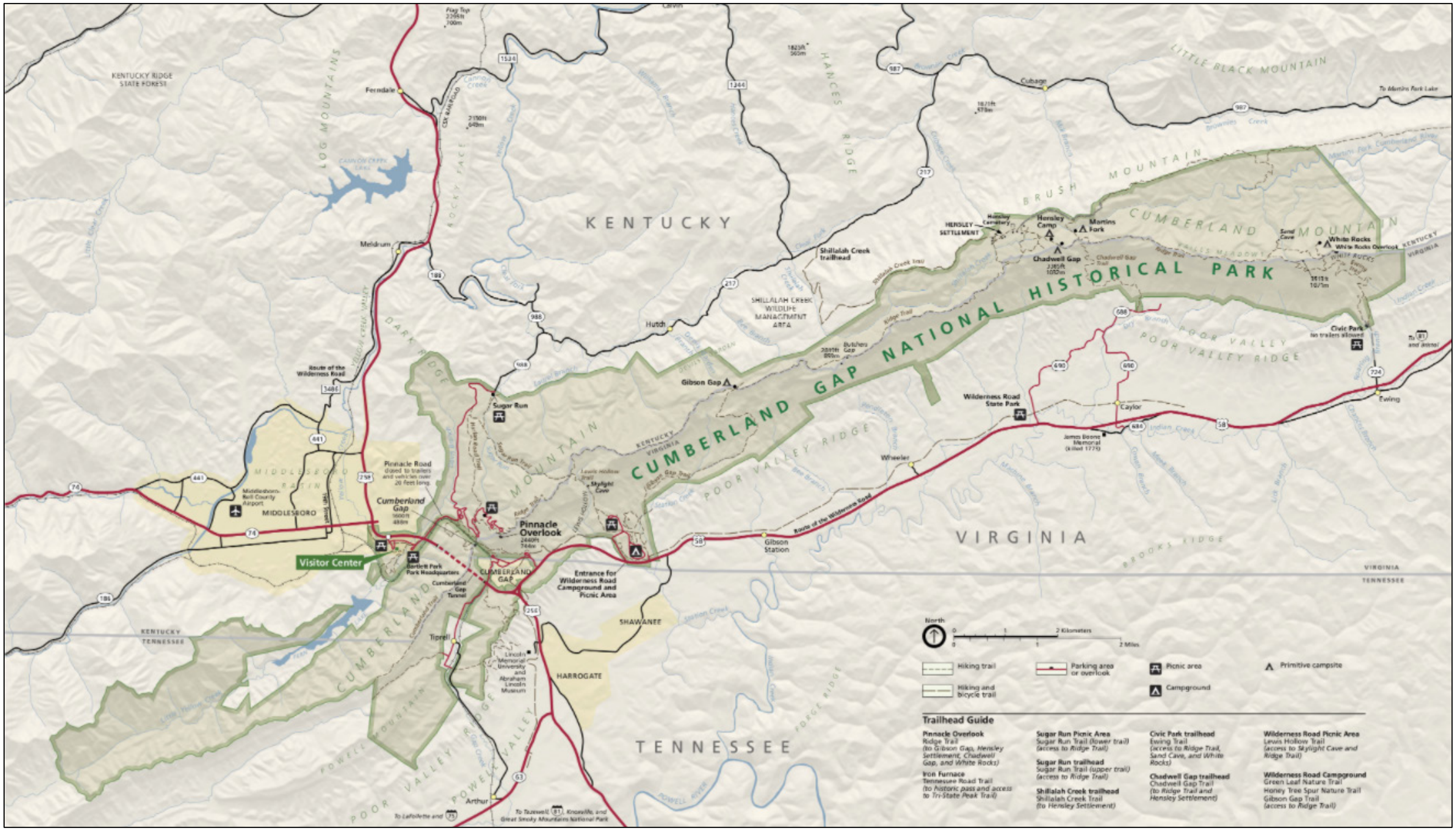


Figure 20. Park map of CUGA, Kentucky–Tennessee–Virginia (NPS).

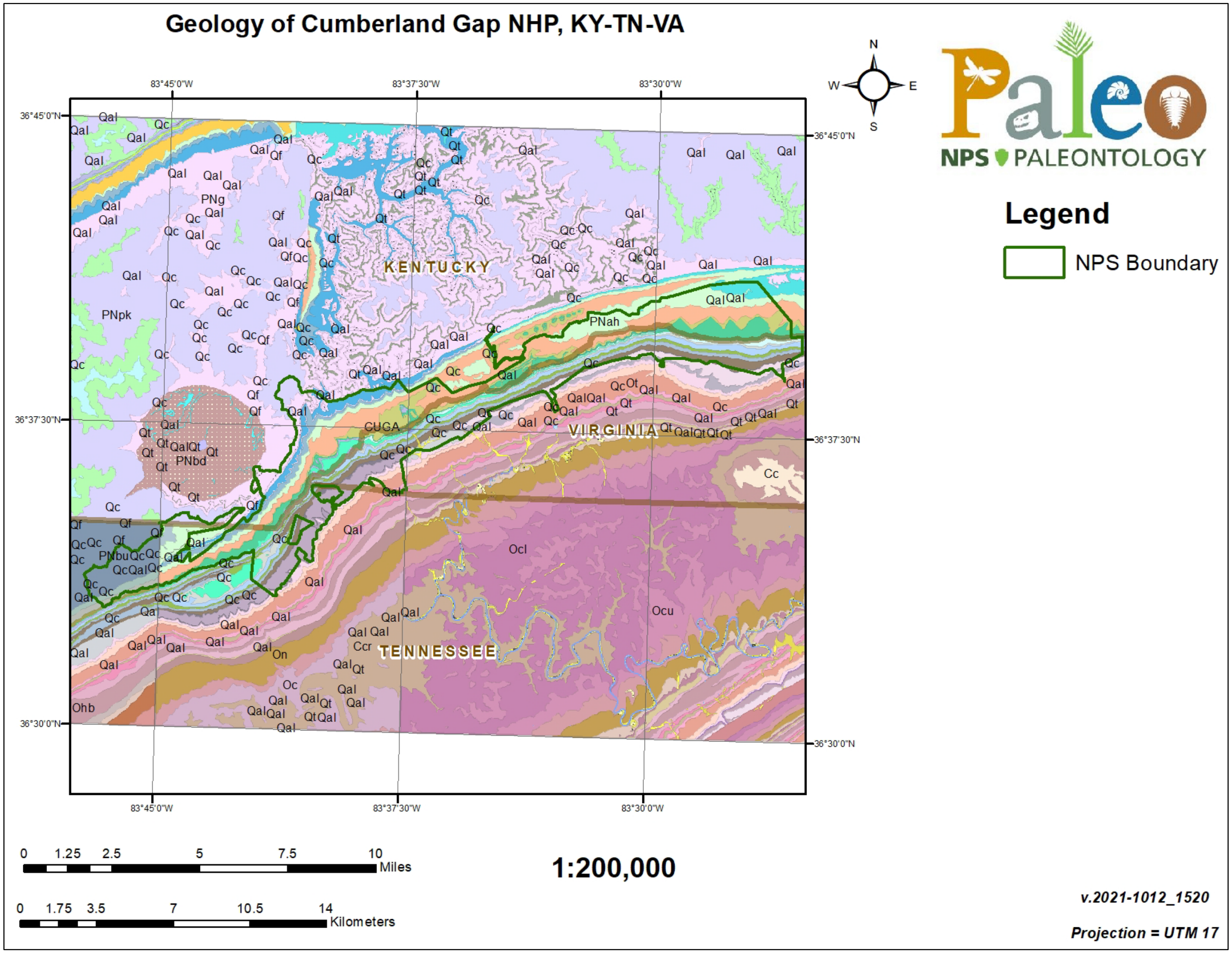


Figure 21. Geologic map of CUGA, Kentucky–Tennessee–Virginia; see Figure 22 for legend. Data modified from CUGA GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047055.

Figure 22. Geologic map legend of CUGA, Kentucky–Tennessee–Virginia.

Table 3. List of CUGA stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Mingo Formation (PNm)	Ashley and Glenn 1906; McDowell et al. 1985	Type section: Mingo Mountain in the Log Mountains area, Claiborne Co., TN.	Middle Pennsylvanian
Hensley Member, Alvy Creek Formation (PNah)	Englund 1964	Type section: exposed along Skyland Road and U.S. Highway 25E [now along Pinnacle Road and Route 988, Old Wilderness Road] on northwest side of Cumberland Gap, [approximate latitude 36°36′40″ N., longitude 83°40′40″ W., Middlesboro South 7.5′ Quadrangle], Bell Co., KY.	Early Pennsylvanian
Middlesboro Member, Lee Formation	Englund 1964	Type section: exposed on Skyland Road on the north side of the Cumberland Gap, Bell Co., KY.	Early Pennsylvanian
Dark Ridge Shale Member, Bottom Creek Formation (PNbcd)	Englund 1964	Type locality: near the south end of Dark Ridge, a northward-trending ridge on the north side of Cumberland Gap, Bell Co., KY.	Early Pennsylvanian
White Rocks Sandstone Member, Warren Point Sandstone (PNwpw)	Englund 1964	Type locality: White Rocks, a prominent south-facing cliff at crest of Cumberland Mountain, Ewing 7.5′ Quadrangle, Lee Co., VA.	Early Pennsylvanian
Chadwell Member, Lee Formation	Englund 1964	Type section: at Chadwell Gap, a notch in Cumberland Mountain, approximately 16 km (10 mi) northeast of Cumberland Gap, Lee Co., VA.	Early Pennsylvanian
Pinnacle Overlook Sandstone (Mpo)	Englund 1964	Type section: exposure at the Pinnacle, a scenic overlook on the northeast side of Cumberland Gap, Lee Co., VA.	Mississippian

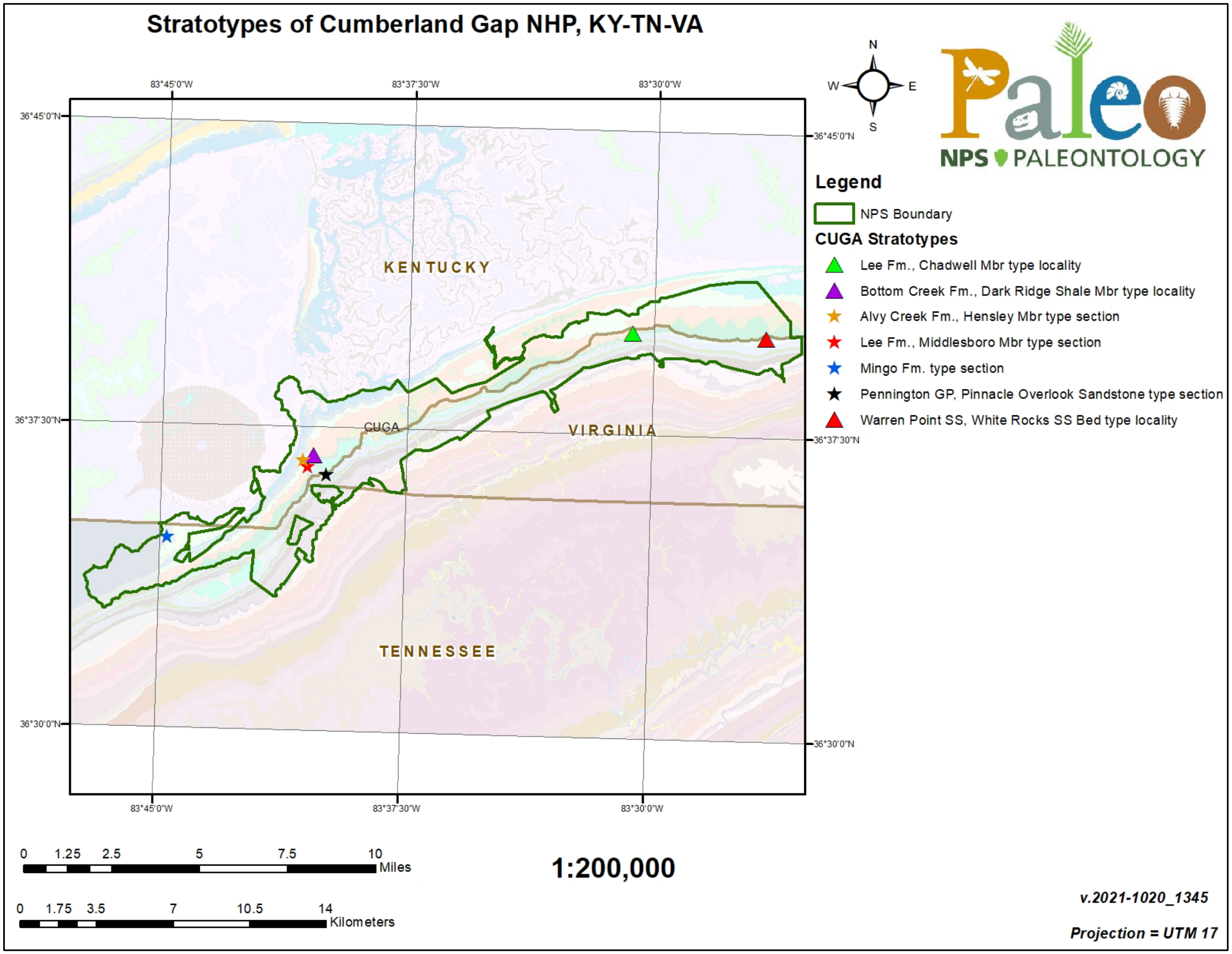


Figure 23. Modified geologic map of CUGA showing stratotype locations. The transparency of the geologic units layer has been increased.

Pinnacle Overlook Sandstone

The Mississippian Pinnacle Overlook Sandstone was originally named as the lowest member of the Lee Formation by Englund (1964) and formally assigned as a formation of the Pennington Group by Chesnut (1992). The formation is named after its type section exposure at the Pinnacle, a scenic overlook on the northeast side of Cumberland Gap, Virginia (Table 3; Figures 23 and 24; Englund 1964). The type section measures 70 m (230 ft) thick and consists of white- to light gray, fine- to medium-grained, thick-bedded sandstone that displays conspicuous crossbedding and ripple laminations (Englund 1964). In the Cumberland Mountains region, the Pinnacle Overlook Sandstone overlies the Little Stone Gap Member of the Pennington Formation and underlies the Chadwell Member of the Lee Formation.

Figure 24. View from the Pinnacle looking south across Cumberland Gap. The type section of the Pinnacle Overlook Sandstone is located at the Pinnacle and consists of cross-bedded sandstone approximately 70 m (230 ft) thick (NPS).

Chadwell Member, Lee Formation

The Early Pennsylvanian Chadwell Member of the Lee Formation was proposed by Englund (1964) and named after its type section exposure at Chadwell Gap, a notch in Cumberland Mountain approximately 16 km (10 mi) northeast of Cumberland Gap, Virginia (Table 3; Figure 23). The type section of the member is exposed 137 m (450 ft) below the southeast side of the Chadwell Gap and measures about 56 m (183 ft) thick (Englund 1964). The unit predominantly consists of white- to light-gray, fine- to medium-grained, massive sandstone that displays crossbedding and commonly forms two resistant ledges (Englund 1964). At the type section the Chadwell Member overlies the Pennington Formation and underlies the White Rocks Sandstone Member of the Warren Point Sandstone.

White Rocks Sandstone Member, Warren Point Sandstone

The Early Pennsylvanian White Rocks Sandstone Member of the Warren Point Sandstone was originally proposed by Englund et al. (1961) as a member of the Lee Formation and revised by Chesnut (1992). The unit is named after its type locality exposures at White Rocks, a prominent south-facing cliff at the crest of Cumberland Mountain, Virginia (Table 3; Figure 23; Englund 1964). Type locality exposures measure approximately 91 m (300 ft) thick and form a precipitous cliff consisting of fine- to coarse-grained, light-gray, massive, cross-bedded sandstone with well-rounded quartz pebbles (Figure 25; Englund et al. 1961, 1963; Englund 1964). The White Rocks Sandstone Member overlies the Chadwell Member of the Lee Formation and underlies the Dark Ridge Shale Member of the Bottom Creek Formation.

Figure 25. View of the towering cliffs known as White Rocks from Powell Valley. White Rocks includes the type locality exposures of the White Rocks Sandstone Member of the Warren Point Sandstone. White Rocks was a key landmark to early pioneers who were traveling through the valley to Cumberland Gap and into Kentucky (NPS/SCOTT TEODORSKI).

Dark Ridge Shale Member, Bottom Creek Formation

The Early Pennsylvanian Dark Ridge Shale Member of the Bottom Creek Formation was originally proposed as a member of the Lee Formation by Englund (1964) and re-assigned by Chesnut (1991, 1992). The member is named after its type locality exposures near the south end of Dark Ridge, a northward-trending ridge on the north side of Cumberland Gap, Kentucky (Table 3; Figure 23; Englund 1964). Type locality exposures measure 18 m (60 ft) thick and consist of medium-dark-gray shale with a few thin beds of very fine- to fine-grained sandstone (Englund 1964). Upper exposures of the unit contain the Cumberland Gap coal bed that ranges from 0.9–1.2 m (3–4 ft) thick and is a persistent coal bed interval in the type locality (Englund 1964). The Dark Ridge Shale Member overlies the White Rocks Sandstone Member of the Warren Point Sandstone and underlies the Middlesboro Member of the Lee Formation.

Middlesboro Member, Lee Formation

The Early Pennsylvanian Middlesboro Member of the Lee Formation was named by Englund (1964) after the city of Middlesboro, situated immediately northwest of CUGA. Englund (1964) designated the type section on Skyland Road on the north side of Cumberland Gap in Bell County, Kentucky (Table 3; Figure 23). The type section measures about 143 m (470 ft) thick and consists of white- to light gray, massive, cross-bedded, conglomeratic sandstone (Englund 1964). The unit is the principal ridge- and cliff-forming unit along Cumberland Mountain and Pine Mountain on the northwest limb of the Middlesboro syncline (Englund 1964). At the type section the Middlesboro Member overlies the Dark Ridge Shale Member of the Bottom Creek Formation and underlies the Hensley Member of the Alvy Creek Formation.

Hensley Member, Alvy Creek Formation

The Early Pennsylvanian Hensley Member of the Alvy Creek Formation was originally proposed as a member of the Lee Formation by Englund (1964) and formally reassigned to the Alvy Creek Formation by Chesnut (1992). The unit is named from Hensley Flats, an upland area underlain by the member located between the crest of Brush Mountain and Cumberland Mountain. The type section of the member is located along Skyland Road and U.S. Highway 25E (now along Pinnacle Road and Route 988, Old Wilderness Road) on the northwest side of Cumberland Gap in Bell County, Kentucky (Table 3; Figure 23; Englund 1964). The type section exposure measures approximately 97 m (320 ft) thick and is predominantly composed of dark gray shale in the lower, middle, and upper parts with two very fine- to medium-grained, light gray sandstone intervals in between (Englund 1964). At the type section the Hensley Member overlies the Middlesboro Member of the Lee Formation and underlies the Bee Rock Sandstone.

Mingo Formation

The Middle Pennsylvanian Mingo Formation was defined by Ashley and Glenn (1906) to describe exposures in the Log Mountains area that consist predominantly of medium gray shale interbedded with fine-grained sandstone, siltstone, coal, and clay. The unit is named after its type section exposure at Mingo Mountain in Claiborne County, Tennessee (Table 3; Figure 23; McDowell et al. 1985 citing Ashley and Glenn 1906). The type section extends from the bottom of the Bennetts Fork coal bed upward to the base of the Poplar Lick coal bed, a measured thickness of about 290 m (950 ft) thick (McDowell et al. 1985). The Mingo Formation overlies the Hance Formation and underlies the Catron Formation.

Fort Donelson National Battlefield (FODO)

Ford Donelson National Battlefield (FODO) is located on the western bank of Kentucky Lake and in the high bluffs overlooking the Cumberland River in Calloway County, Kentucky, and Henry and Stewart Counties, Tennessee (Figure 26). Established on March 26, 1928, FODO contains approximately 529 hectares (1,309 acres) and protects well-preserved archeological, cultural, and natural resources associated with the 1862 Civil War campaign for Forts Henry, Heiman, and Donelson and the control of the Cumberland and Tennessee Rivers (National Park Service 2016a). The campaign for Forts Henry, Heiman, and Donelson resulted in the first major strategic Union victory in the Civil War under the leadership of General Ulysses S. Grant and thwarted a key Confederate strategy for the defense of the western theater. Grant's capture of the three forts resulted in the Union Army gaining control of important resources such as the area's iron industry, railroads, rivers, and the Tennessee Valley's agricultural wealth (National Park Service 2020). The primary areas of FODO are the main park unit; Ford Donelson National Cemetery, located within the main park unit; the Dover Hotel, located about 3.2 km (2 mi) east of the main park unit; and the Fort Heiman Unit, located approximately 35 km (22 mi) west of the main park unit.

The bedrock geology at FODO dates back to the Mississippian Period, more than 320 million years ago. Rock units mapped in FODO can be separated into three distinct groups by age and type (from oldest to youngest): (1) Mississippian carbonate bedrock of the Fort Payne Formation, Warsaw Limestone, and St. Louis Limestone; (2) Cretaceous siliciclastic bedrock of the Tuscaloosa Gravel and McNairy Formation; and (3) geologically young, unconsolidated surficial deposits from the Cenozoic Era (Figures 27 and 28; Thornberry-Ehrlich 2020b). Mississippian-age carbonates and chert in FODO were originally deposited at a time when North America was located near the equator and was partially covered by a shallow sea. During the Cretaceous Period (143–66 Ma) and into the Cenozoic Era, ancient river systems were incising channels and depositing reworked sediments on top of the weathered Mississippian rocks (Thornberry-Ehrlich 2020b). The oldest mapped unit in FODO is the Fort Payne Formation, which crops out in the deepest stream valleys within the southern portion of the Fort Heiman Unit. The fossiliferous Warsaw Limestone is widely mapped in FODO and occurs in both the Fort Donelson and Fort Heiman park units. The St. Louis Limestone occurs only in the highest reaches of the Fort Donelson Unit. Cretaceous-age strata and younger Cenozoic-age surficial deposits are restricted to the Fort Heiman Unit.

There are no designated stratotypes identified within the boundaries of FODO. There are also no identified stratotypes located within 48 km (30 mi) of FODO boundaries.

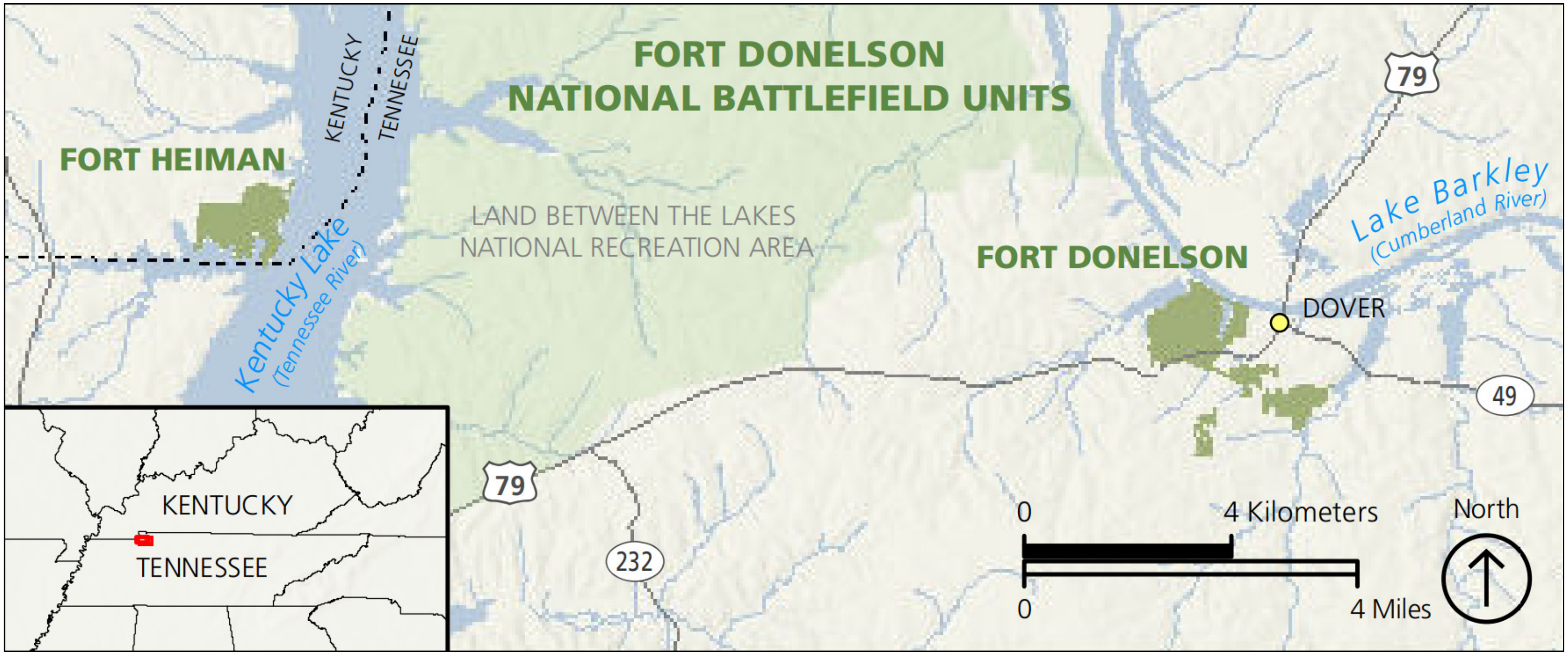


Figure 26. Regional map of FODO, Kentucky–Tennessee (NPS).

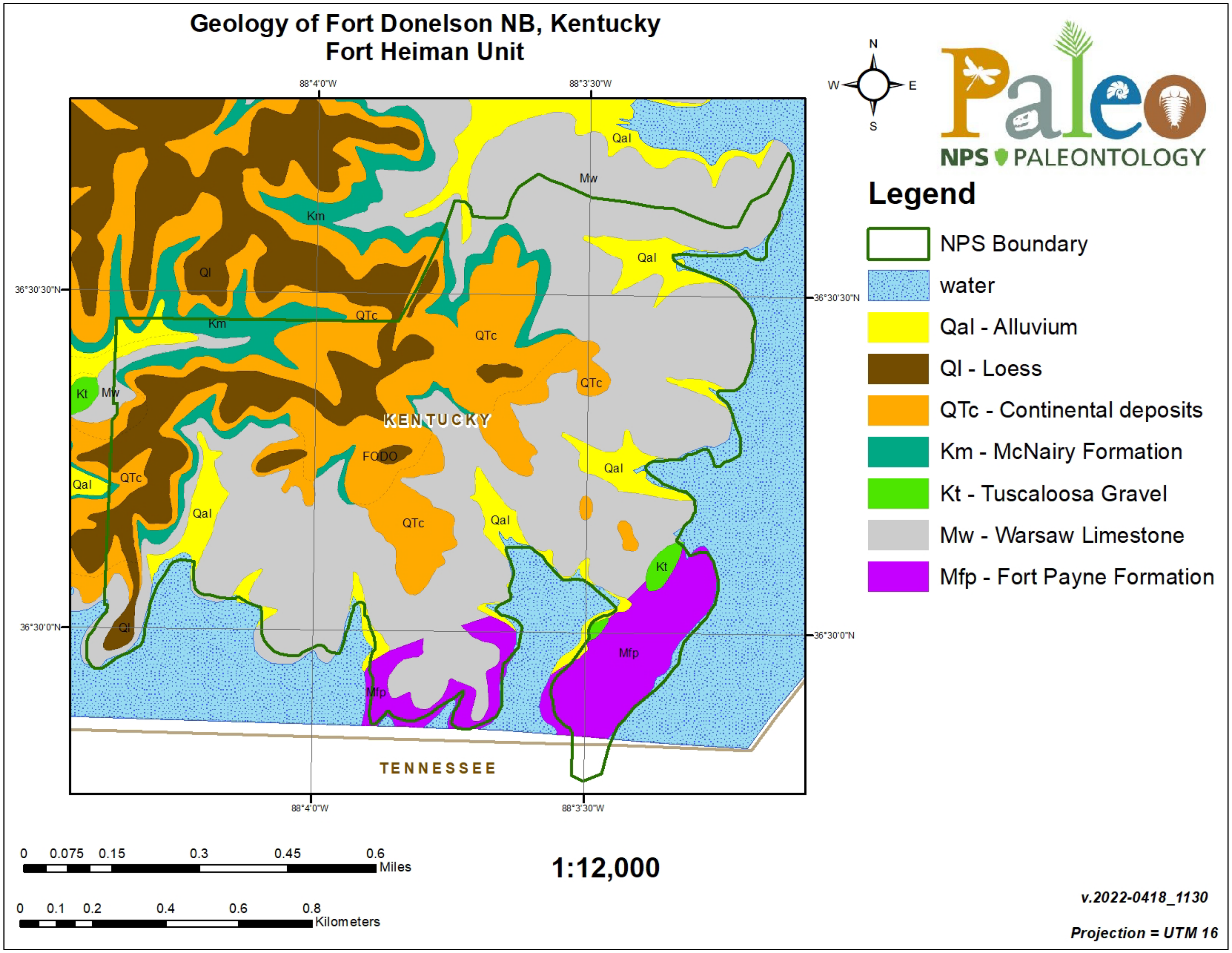


Figure 27. Geologic map of FODO (Fort Heiman Unit), Kentucky. Data modified from FODO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048342.

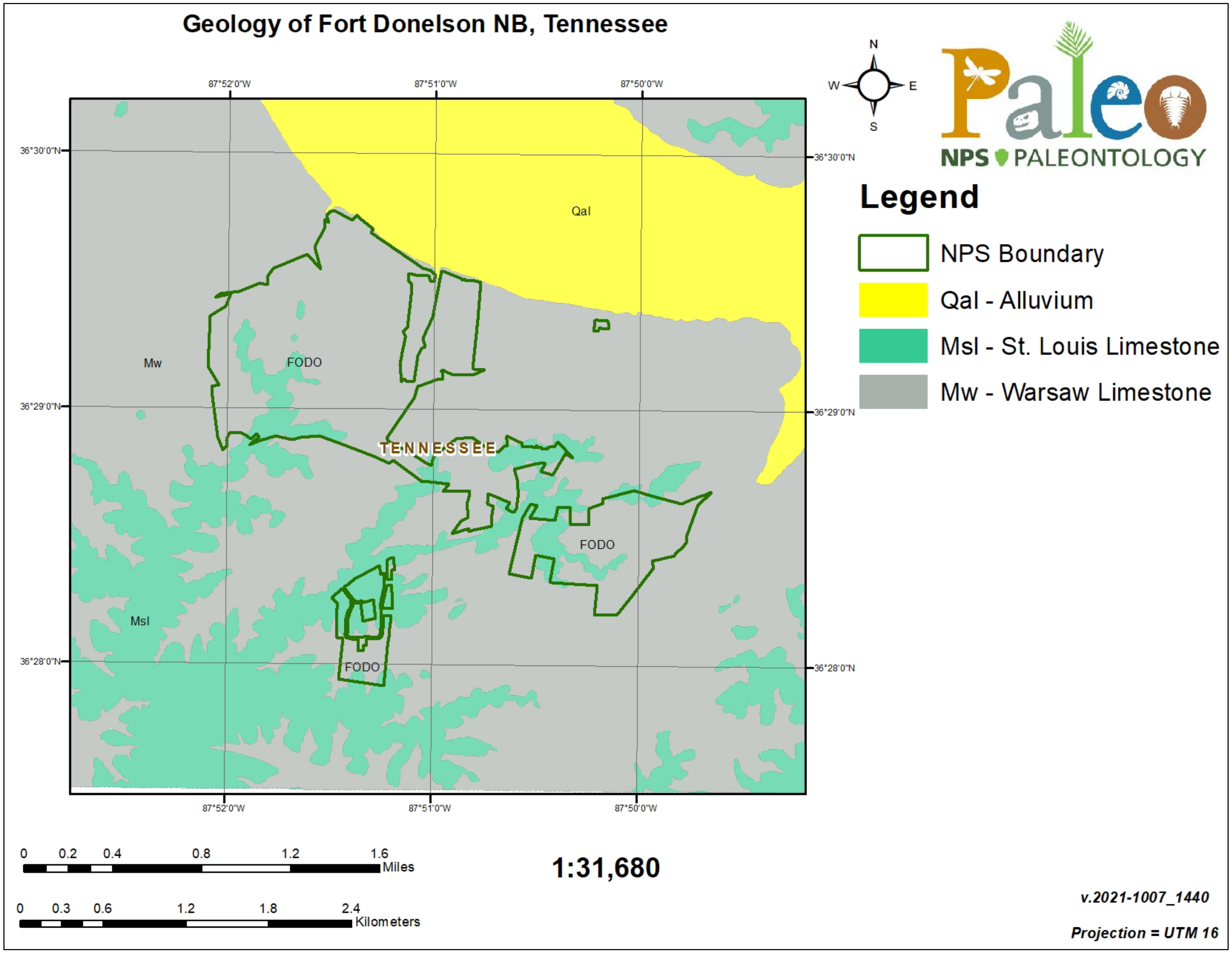


Figure 28. Geologic map of FODO (Fort Donelson Unit), Tennessee. Data modified from FODO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048342.

Guilford Courthouse National Military Park (GUCO)

Guilford Courthouse National Military Park (GUCO) is located about 8 km (5 mi) northwest of downtown Greensboro adjacent to U.S. 220 (Battleground Avenue) in a picturesque area that stretches along the eastern foothills of the southern Appalachian Mountains in Guilford County, North Carolina (Figure 29). Established on March 2, 1917, GUCO contains approximately 101 hectares (251 acres) and preserves the battlefield and the accounts of the Battle of Guilford Courthouse during the Southern Campaign of the American Revolution (National Park Service 2014b, 2016a). In March of 1781 Major General Nathanael Greene and his army of almost 4,500 American militia were defeated by a smaller British army of about 1,900 veteran soldiers and German allies commanded by General Lord Charles Cornwallis. Although Greene and his army lost the Battle of Guilford Courthouse, the losses suffered by the British were so costly that Cornwallis ultimately changed his southern strategy and retreated to Virginia, allowing Greene to turn southward and retake control of the South. The Battle of Guilford Courthouse constitutes one in a series of events that led to ultimate American victory in the Revolutionary War (National Park Service 2014b).

GUCO is located in the southern Appalachian Piedmont physiographic province, a region characterized by elongate, parallel belts of rock that were compressed, uplifted, and eroded as a result of numerous orogenies (mountain building episodes) that formed the Appalachian Mountains. Rocks of the Inner Piedmont are primarily layered metamorphic rocks such as schist, gneiss, amphibolite, or migmatite and contain numerous igneous intrusions in the form of layers, dikes, and small granite plutons. Geologic mapping in the vicinity of GUCO has revealed that the park is situated near an east–northeast trending shear zone between the Carolina Slate (east) and Charlotte (west) belts of metamorphosed rocks, all of which are part of the Carolina terrane (a crustal fragment that originated elsewhere and was transported to its current location) (Thornberry-Ehrlich 2011b). The oldest and most widely mapped unit in GUCO is a Precambrian–Paleozoic felsic intrusive complex with younger Paleozoic-age porphyritic granite underlying the northernmost portion of the park (Figure 30). Although relatively few surface exposures occur in GUCO, the relative resistance and structure of the underlying bedrock control the surficial landscape expression and determine the location of ridges, ravines, and other features.

There are no designated stratotypes identified within the boundaries of GUCO There are two identified stratotypes located within 48 km (30 mi) of GUCO boundaries, for the Triassic Cow Branch Formation (type section) and Cascade Station Member of the Leakesville Formation (type section).

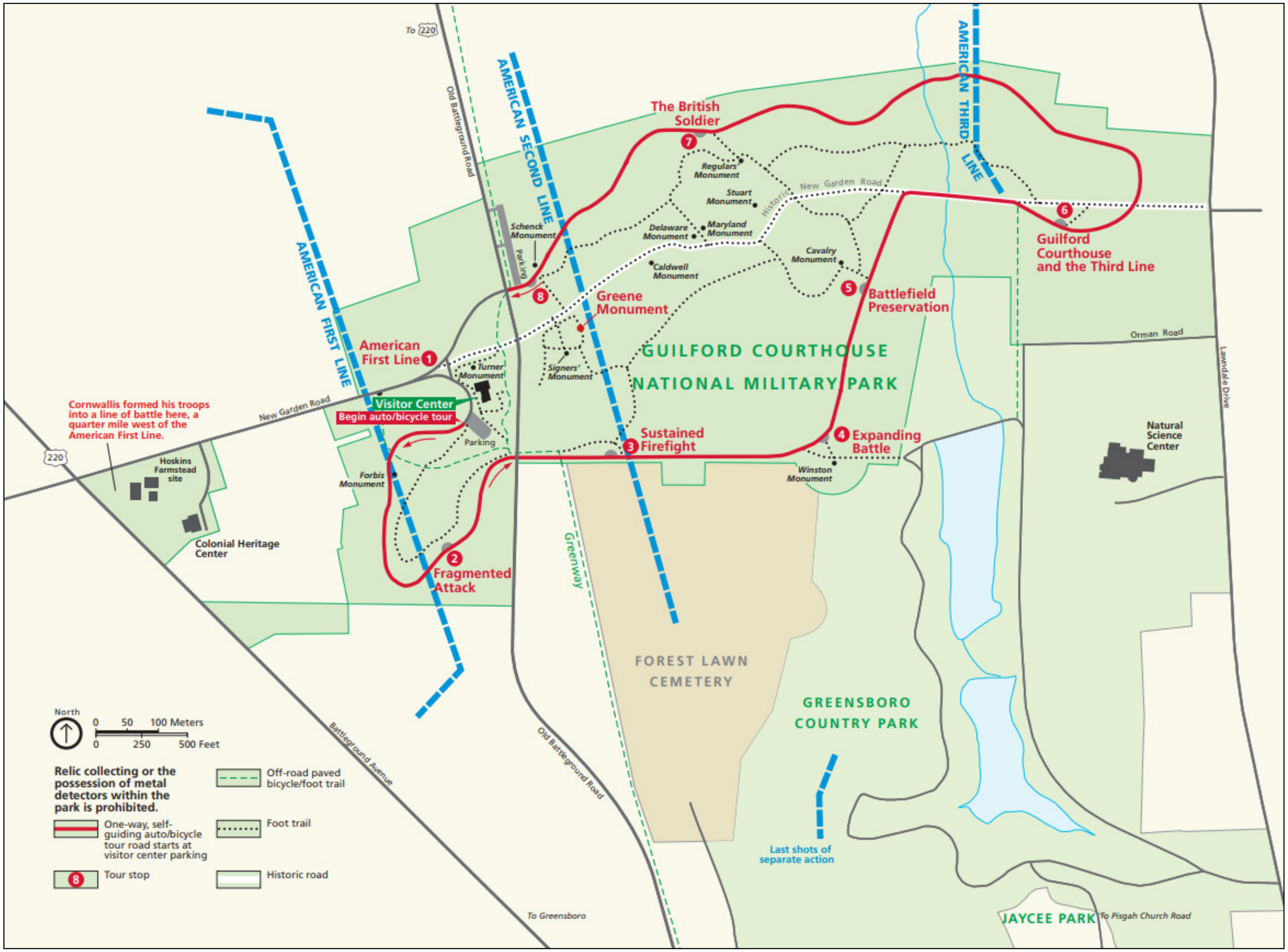


Figure 29. Park map of GUCO, North Carolina (NPS).

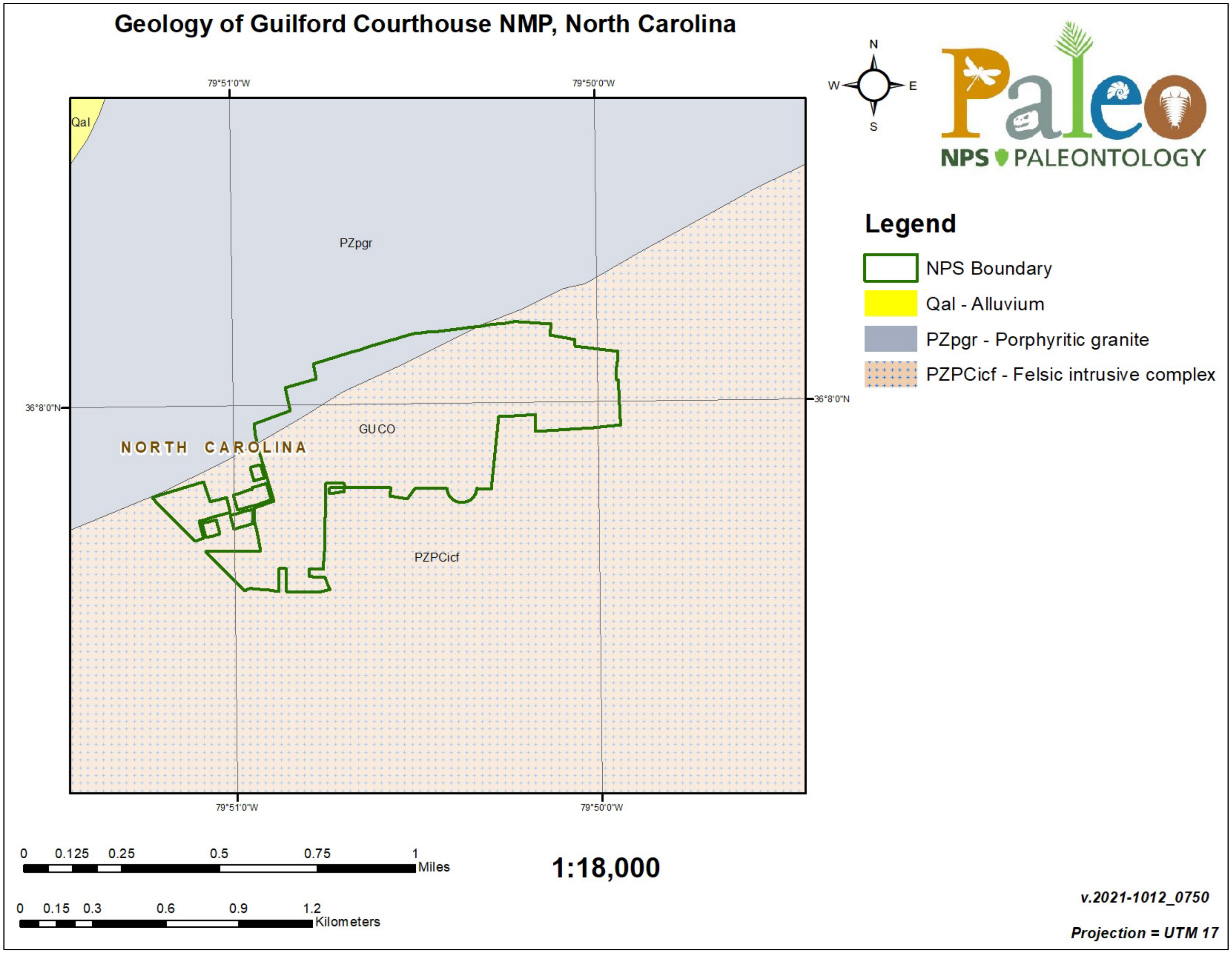


Figure 30. Geologic map of GUCO, North Carolina. Data modified from GUCO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1041103.

Kings Mountain National Military Park (KIMO)

Kings Mountain National Military Park (KIMO) is located just south of the North Carolina–South Carolina border, approximately 26 km (16 mi) northeast of Gaffney in Cherokee and York Counties, South Carolina (Figure 31). Established on March 3, 1931, KIMO contains 1,596 hectares (3,945 acres) and commemorates the Battle of Kings Mountain, the first major Patriot victory of the Southern Campaign of the American Revolution on October 7, 1780 (National Park Service 2016a). The battle is regarded as a major turning point in the war, effectively destroying the left wing of Lord Cornwallis' army and ending loyalist ascendance in the Carolinas (Thornberry-Ehrlich 2009). Thomas Jefferson referred to the decisive Patriot victory as "*The turn of the tide of success*." The park preserves the entire battlefield site and contains some of the best-preserved remnants of Colonial-era roads and trails that are associated with the route traveled by the troops in the Kings Mountain campaign.

KIMO is situated in the Piedmont physiographic province, a unique geographic region formed by a combination of accretion, folding, faulting, uplift, and erosion associated with the formation of the Appalachian Mountains. Located within the Kings Mountain sequence of the Carolina terrane, the KIMO area has a complex geologic framework and includes structures such as shear zones, normal faults, folds, and areas of varying metamorphic grade (Thornberry-Ehrlich 2009). The setting of the Kings Mountain sequence along the boundary between the Carolina and Inner Piedmont terranes makes understanding the geology vital to interpreting the geologic history of the region. Geologic units mapped within KIMO are Neoproterozoic-age metasedimentary and metaigneous rocks of the Battleground Formation and Blacksburg Formation that record several phases of deformation and pulses of metamorphism (Figure 32).

KIMO contains one identified stratotype, for the Neoproterozoic Battleground Formation (Table 4; Figure 33). In addition to the designated stratotype located within KIMO, stratotypes located within 48 km (30 mi) of KIMO boundaries include: the Neoproterozoic Gaffney Marble Member of the Blacksburg Formation (type area), Marble Member of Dixon Branch of the Blacksburg Formation (type area), Crowders Creek Metaconglomerate Member of the Battleground Formation (type locality), Drayton Metaconglomerate Member of the Battleground Formation (type locality), Dixon Gap Metaconglomerate Member of the Battle Ground Formation (type locality), and Jumping Branch Manganiferous Member of the Battleground Formation (type locality); and the Pennsylvanian High Shoals Granite (type locality).

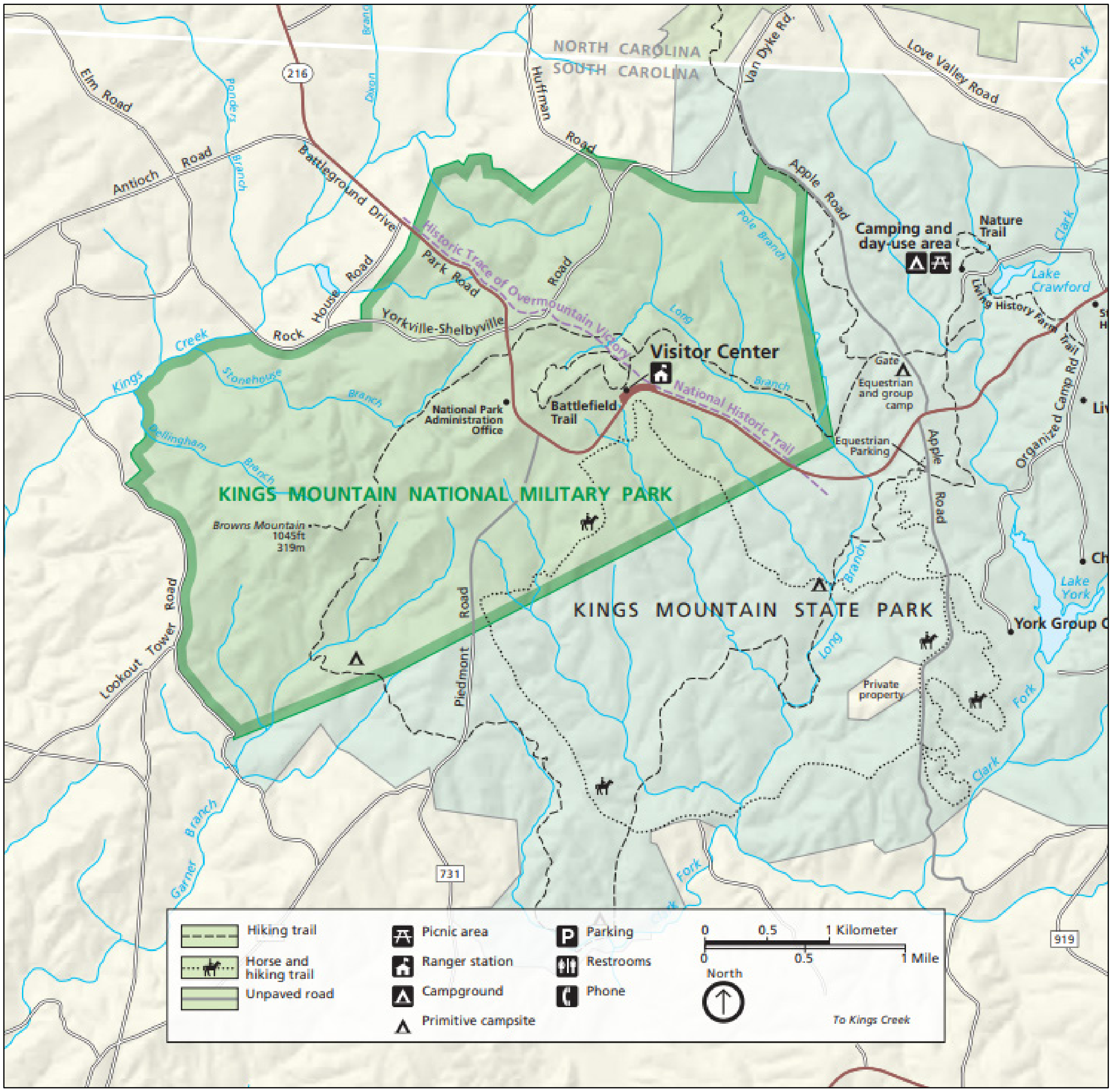


Figure 31. Park map of KIMO, South Carolina (NPS).

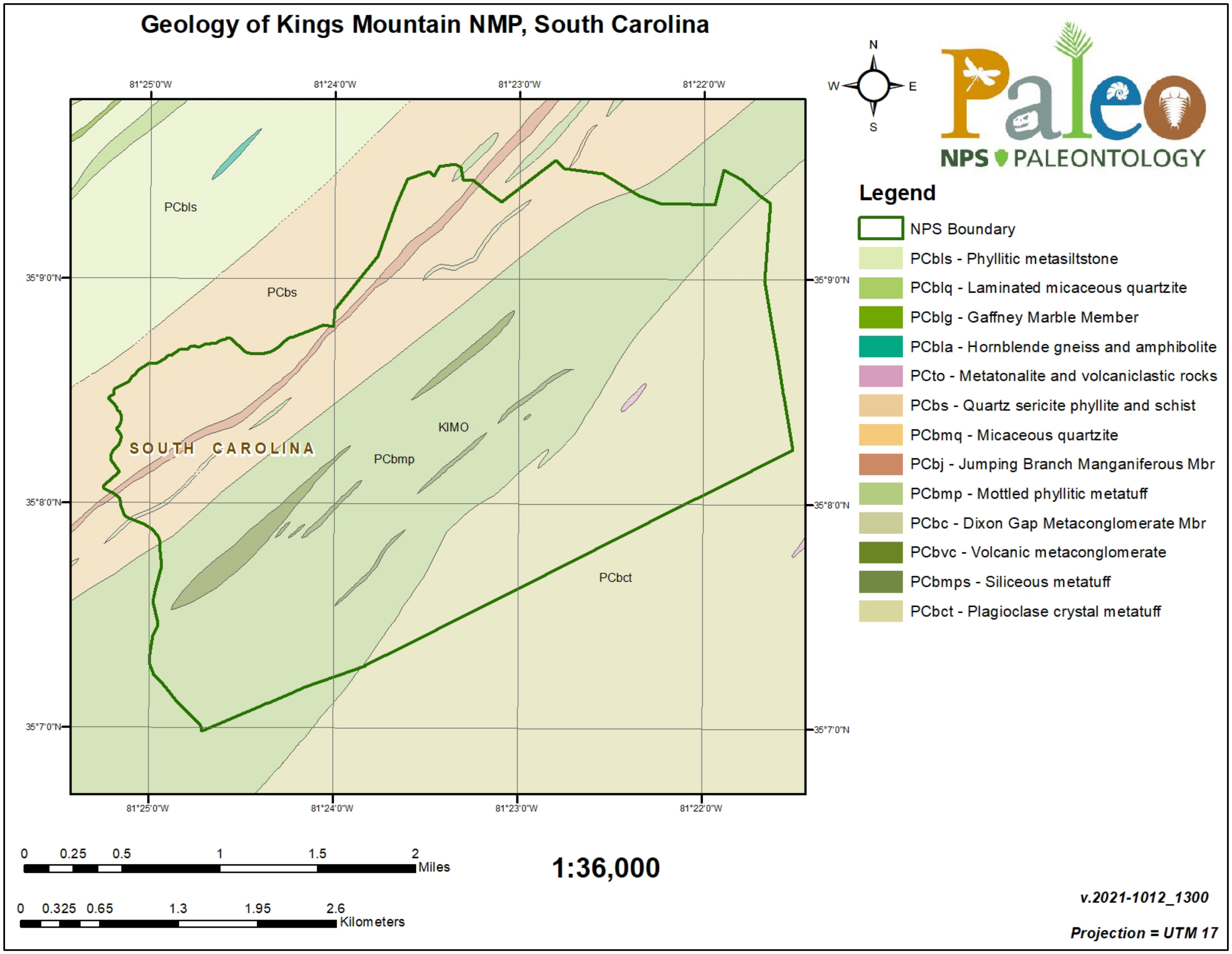


Figure 32. Geologic map of KIMO, South Carolina. Data modified from KIMO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2221910.

Table 4. List of KIMO stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Battleground Formation (PCbs, PCbmp, PCbct, PCbdt, PCbmc, PCbmq, PCbd, PCbj, PCbc, PCbaq, PCkq, PCbms, PCbvc, PCbmps, PCbgs, PCbfs, PCbht)	Horton 1984	Type area: at the Kings Mountain battleground, the site of a Revolutionary War battle, Cherokee and York Cos., SC.	Neoproterozoic

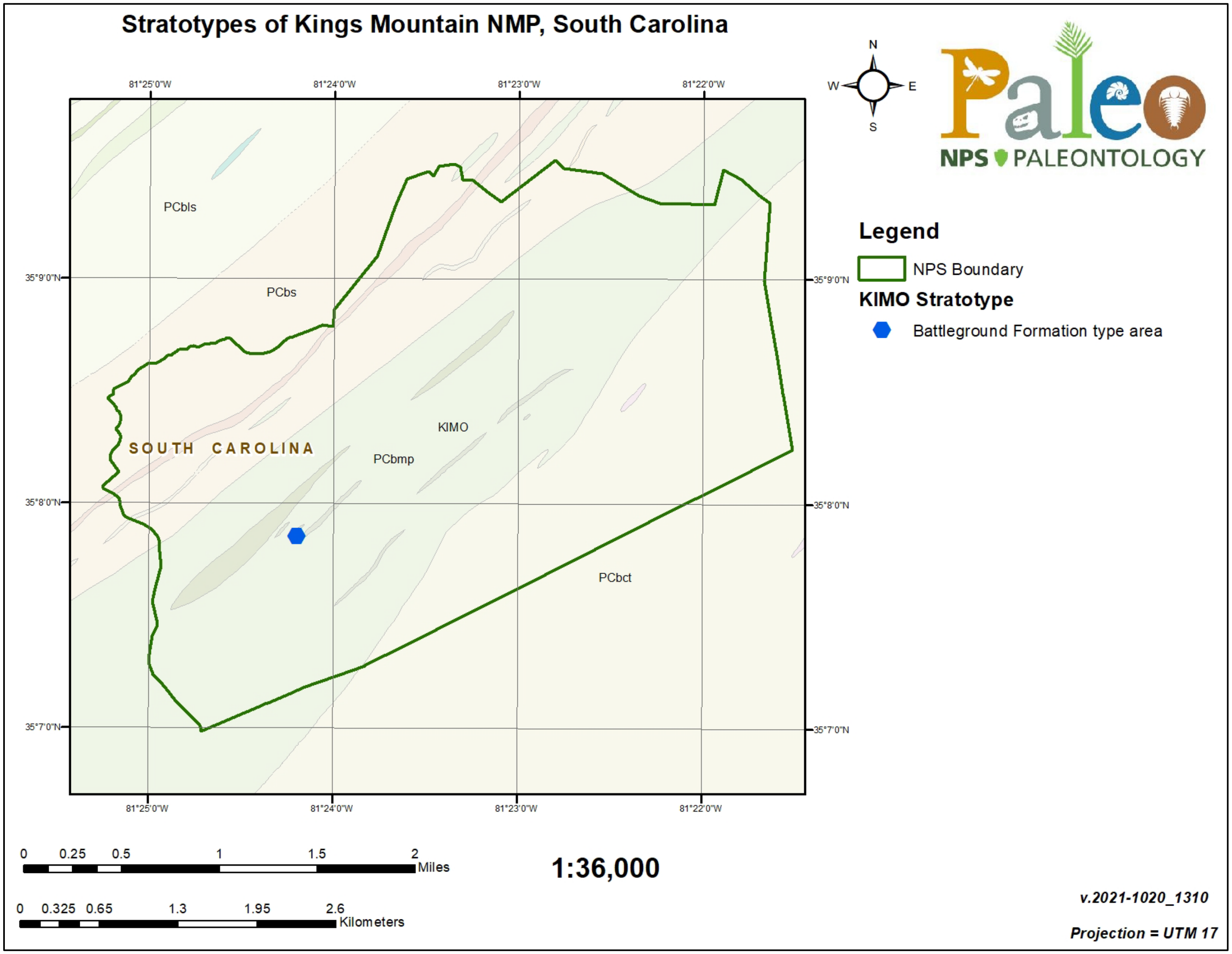


Figure 33. Modified geologic map of KIMO showing stratotype locations. The transparency of the geologic units layer has been increased.

Battleground Formation

The Neoproterozoic Battleground Formation was originally named the "Battleground schist" by Keith and Sterrett (1931) and redefined by Horton (1984). The type area is designated at the Kings Mountain battleground, the site of a Revolutionary War battle, in Cherokee and York Counties, South Carolina (Table 4; Figures 33 and 34; Horton 1984). Lithologically, the Battleground Formation consists of metavolcanic and metasedimentary rocks that include hornblende gneiss, feldspathic biotite gneiss, quartz-sericite schist, quartzite, and metaconglomerate (Horton 1984). On the west flank of the South Fork antiform the unit is about 7,000 m (23,000 ft) thick, but an undetermined amount of thickness results from stratigraphic repetition due to folding and faulting (Horton 1984). The lower and upper contacts of the Battleground Formation are not known to be exposed (Horton 1984).

Figure 34. Type area exposures of the Battleground Formation seen along the Battlefield Trail (NPS).

Little River Canyon National Preserve (LIRI)

Little River Canyon National Preserve (LIRI) is located approximately 138 km (85 mi) northeast of Birmingham on the boundary of De Kalb and Cherokee Counties, in the rugged yet verdant landscape of northeast Alabama (Figure 35). The preserve was authorized on October 24, 1992, and protects about 6,186 hectares (15,288 acres) of the Little River Canyon, one of the Southeast's deepest canyons carved by the nation's longest mountain-top river (National Park Service 2016d). The Little River flows along Lookout Mountain from its headwaters in northwestern Georgia to Weiss Lake and has eroded through sandstone and other sedimentary rocks over millions of years to create a landscape of ridges, outcroppings, and gorges reaching depths in excess of 183 m (600 ft). The variety of rock expanses, benches, and bluffs create a unique environment for several threatened and endangered species and for recreational pursuits, including kayaking and rock climbing (National Park Service 2016a).

LIRI is situated at the southern edge of the Cumberland Plateau, a distinct physiographic region west of the main Appalachian Mountain uplift (National Park Service 2016d). Underlying LIRI is a diverse assemblage of Carboniferous-age sedimentary rocks (~360 to 300 million years old) that have been slowly carved by the Little River over millions of years to form the dissected plateau landscape and its regional landforms (Figure 36). The oldest units mapped within LIRI are Mississippian-age carbonates of the Bangor Limestone, Monteagle Limestone, and Tuscumbia Limestone located in the southern portion of the reserve. Exposures that make up most of Little River Canyon and Lookout Mountain consist of younger Pennsylvanian-age strata of the Pottsville Formation, Parkwood Formation, and Pennington Formation. Little River Canyon is one of the deepest canyon systems east of the Mississippi River and the deepest in the state of Alabama. Incision and broadening of the Little River Canyon occurs in southern LIRI where the best exposures of the Parkwood and Pennington Formations are found in the canyon walls.

There are no designated stratotypes identified within the boundaries of LIRI. There are six identified stratotypes located within 48 km (30 mi) of LIRI boundaries, for the Cambrian Rome Formation (type locality); Ordovician Chickamauga Supergroup (type area) and Pond Spring Formation (type section); Mississippian Lavender Shale Member of the Fort Payne Formation (type locality); and Pennsylvanian Flat Rock Member of the Raccoon Mountain Formation (type section), and Norwood Cove Member of the Raccoon Mountain Formation (type section).

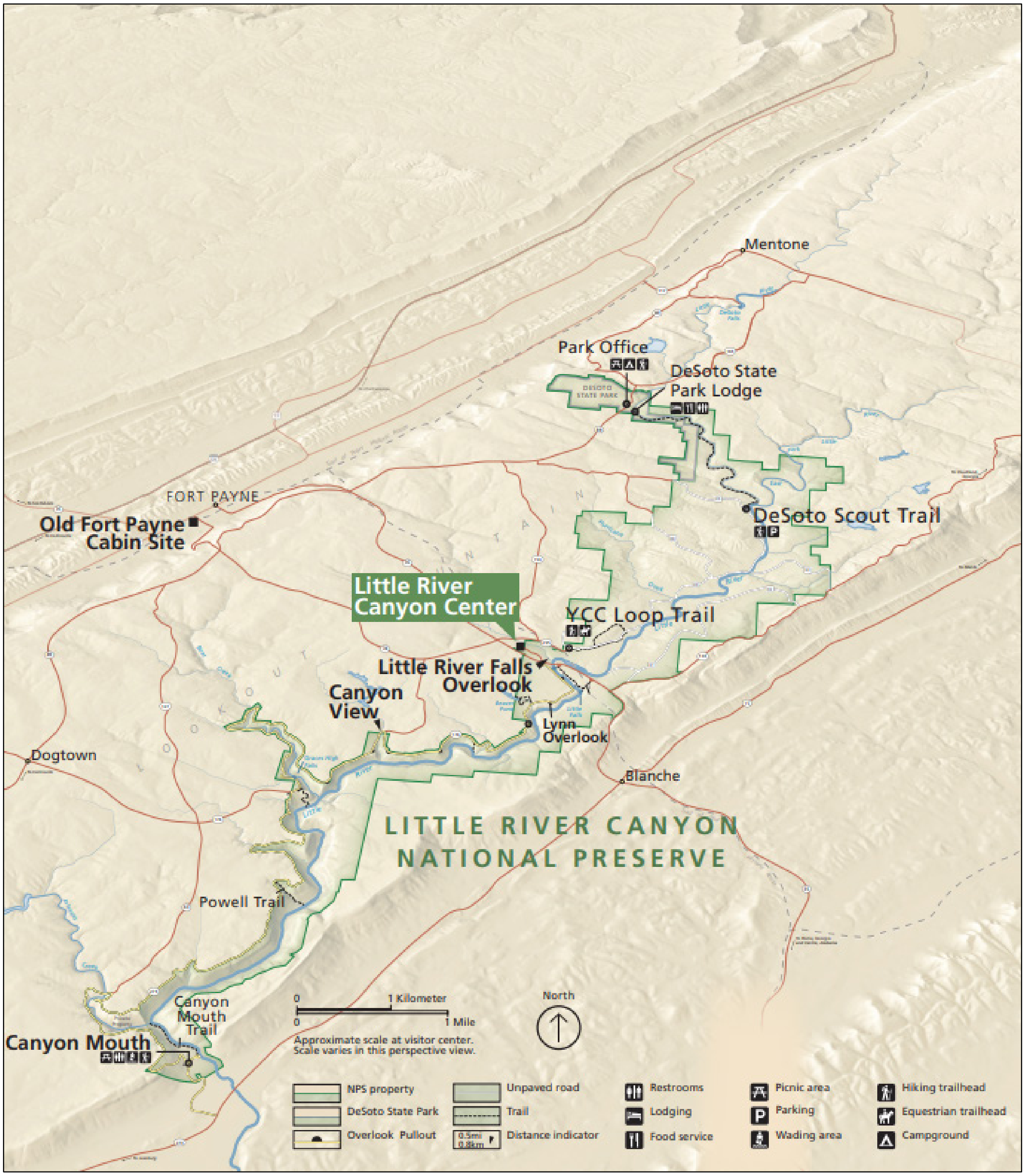


Figure 35. Park map of LIRI, Alabama (NPS).

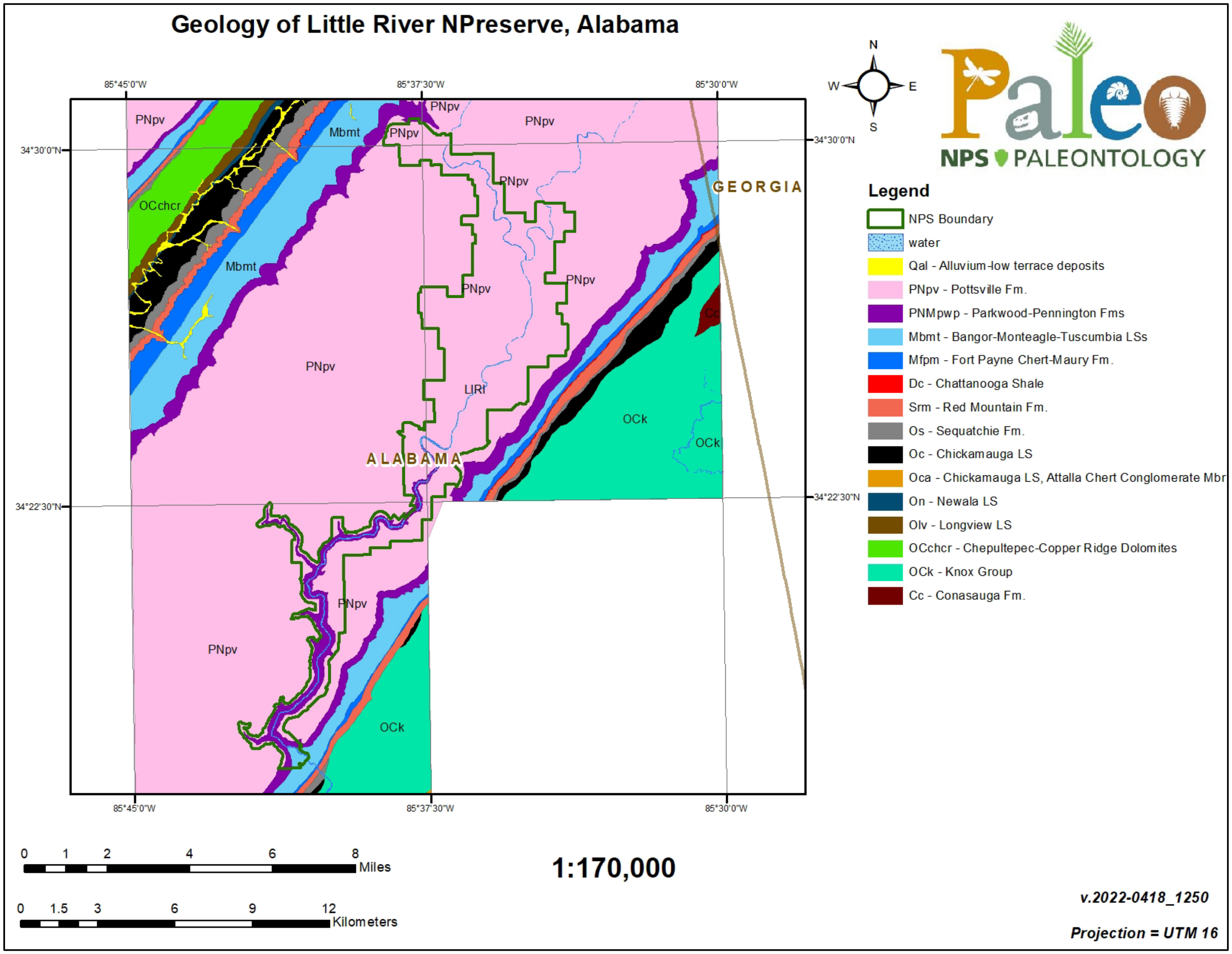


Figure 36. Geologic map of LIRI, Alabama. Data modified from LIRI GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2253584.

Mammoth Cave National Park (MACA)

Mammoth Cave National Park (MACA) is located approximately 140 km (90 mi) south of Louisville and 30 km (20 mi) northeast of Bowling Green in Barren, Edmonson, and Hart Counties, Kentucky (Figure 37). Established on July 1, 1941, MACA encompasses about 21,379 hectares (52,830 acres) and protects internationally recognized biological and geological resources associated with Mammoth Cave, the Green and Nolin River valleys, and extensive evidence of human history spanning the last 12,000 years (National Park Service 2016a). Mammoth Cave is the longest known cave system on earth with 676 km (420 mi) surveyed to date; underground rivers at the water table are still carving new passages today. Over millions of years, water has infiltrated its way deeper into the landscape, forming a variety of karst features including sinking streams, sinkholes, speleothems, and a vast interconnected cave network. The cultural and natural resources protected within MACA have received international recognition, first dedicated as a World Heritage Site in 1981 and as an International Biosphere Reserve in 1990.

The bedrock at MACA defines the regional surface expression and hosts the world-renowned geologic resources that helped define the park. Sedimentary rocks in MACA date back to the Carboniferous (~360–300 Ma) and were deposited at a time when North America was located near the equator and the Mammoth Cave area was partially inundated by a shallow sea (Figure 38; Thornberry-Ehrlich 2011c). The passages of the extensive Mammoth Cave system (consisting of the interconnected Mammoth Cave, Flint Ridge, and Roppel Cave systems) formed by dissolution and chemical erosion from percolating groundwater and flowing underground streams within the Mississippian-aged St. Louis Limestone, Ste. Genevieve Limestone, and Girkin Formation. The overlying Mississippian Haney and Glen Dean Limestones contain perched karst systems with smaller sporadic caves up to several hundred meters or feet in length (Thornberry-Ehrlich 2011c). A resistant cap of relatively insoluble sandstone and shale of the Mississippian Big Clifty Sandstone, Hardinsburg Sandstone, Leitchfield Formation, and Pennsylvanian Caseyville Formation promoted the regional-scale development and preservation of the caves. Young surficial units mapped within the park include unconsolidated, Quaternary-age alluvium deposits that occur along rivers and streams.

There are no designated stratotypes identified within the boundaries of MACA. Although the Mississippian “Mammoth Cave Limestone Series” (now Mammoth Cave Group) was named by Miller (1919) after Mammoth Cave in Edmonson County, Kentucky, no formal stratotype was assigned (see “Recommendations” below). There are two identified stratotypes located within 48 km (30 mi) of MACA boundaries, for the Mississippian Horse Cave Limestone Member of the Ste. Genevieve Limestone (type locality) and the Leitchfield Formation (type area).

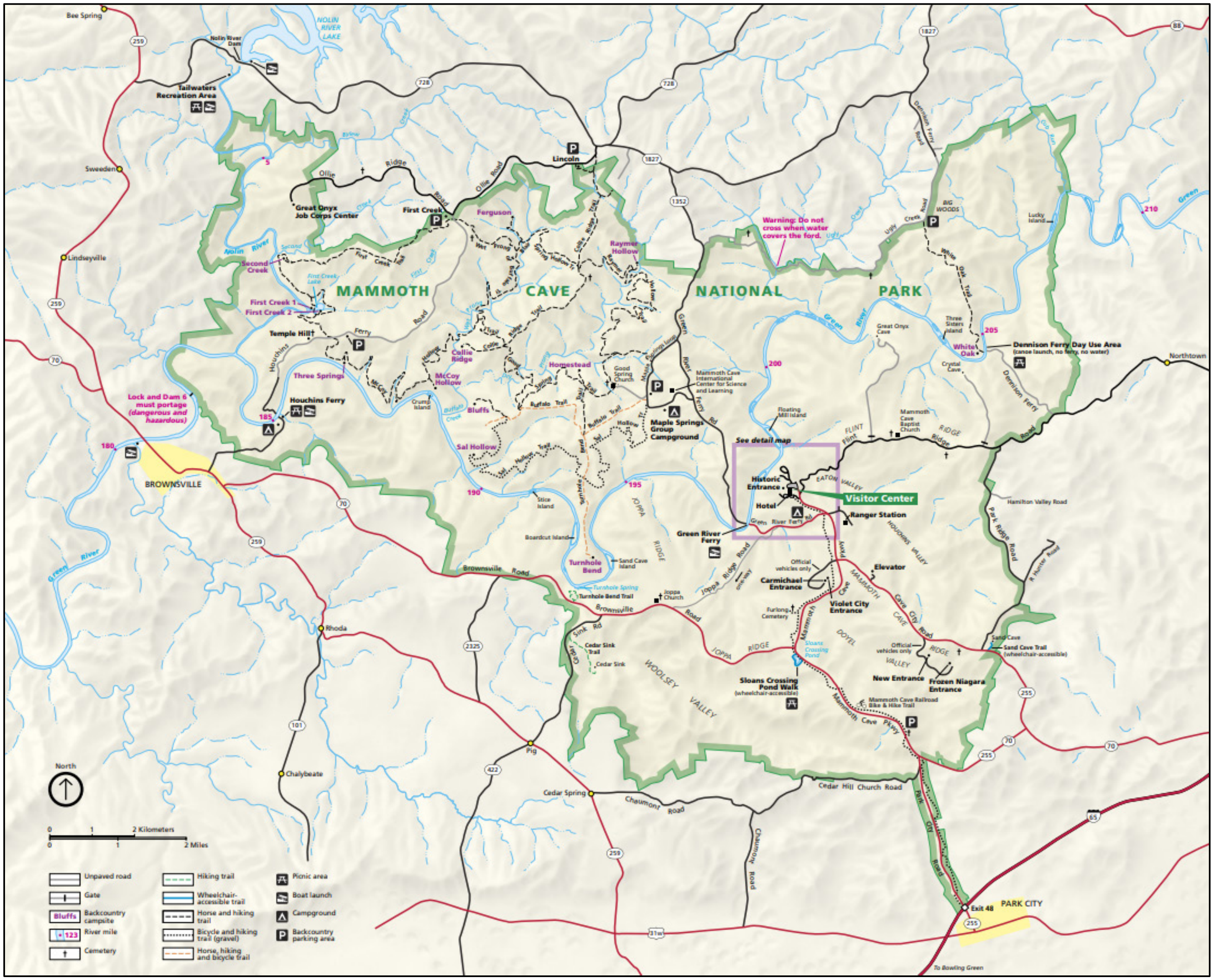


Figure 37. Park map of MACA, Kentucky (NPS).

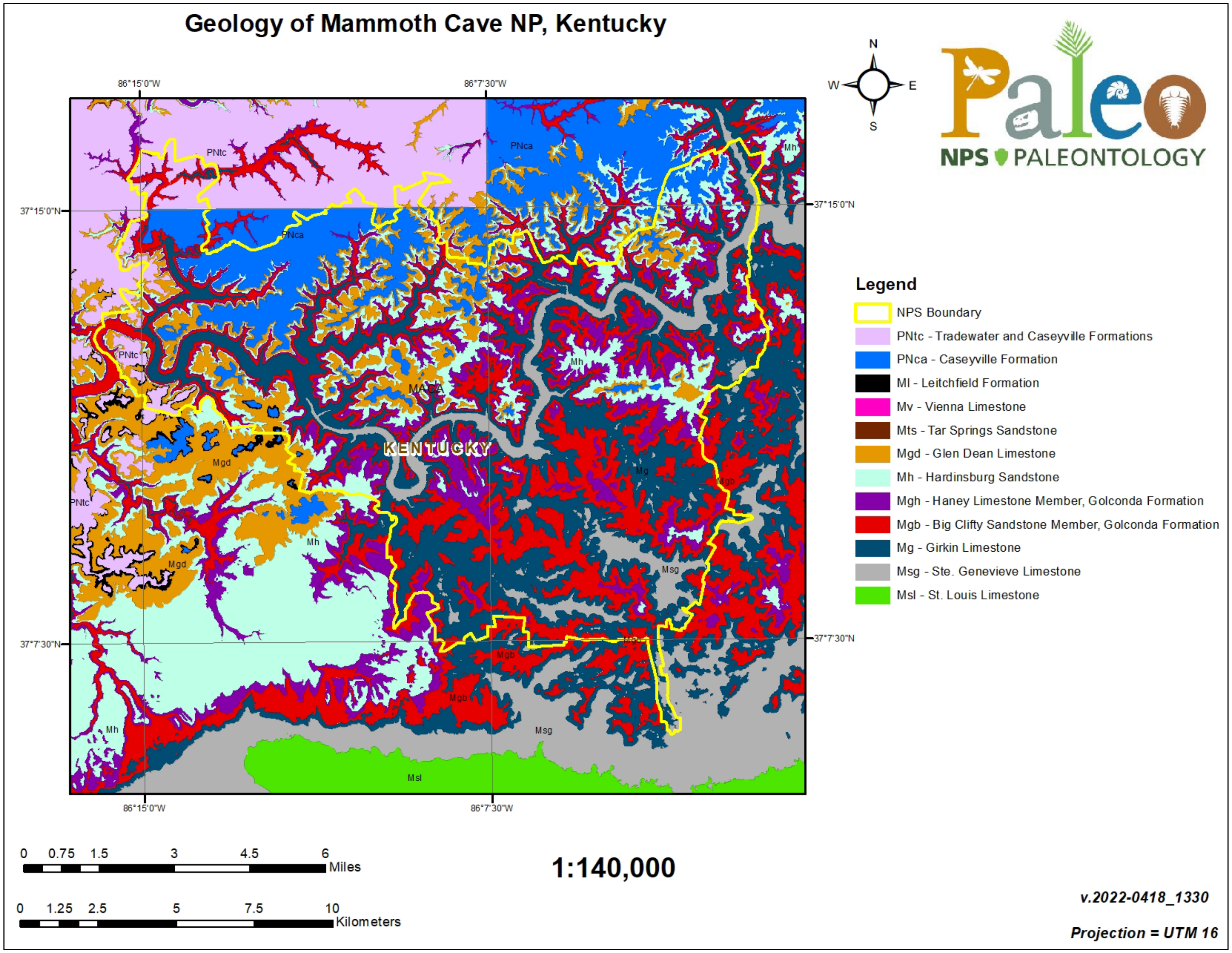


Figure 38. Geologic map of MACA, Kentucky. Data modified from MACA GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1044407.

Ninety Six National Historic Site (NISI)

Ninety Six National Historic Site (NISI) is located approximately 14 km (9 mi) southeast of the city of Greenwood in Greenwood County, South Carolina (Figure 39). Authorized on August 19, 1976, NISI contains about 413 hectares (1,022 acres) and preserves and commemorates the site of the first land battle south of New England and the longest field siege of the Revolutionary War (National Park Service 2016a). NISI embodies a unique and intact combination of three distinct historic periods, as a trading and meeting place on the Carolina backcountry from 1715–1760s, a thriving colonial village and seat of government (1768–early 1800s), and a Revolutionary War stronghold (National Park Service 2014c). The site preserves unique and original resources, including the Star Fort earthwork embankments, two historic villages, a colonial plantation complex, prehistoric sites, and Kosciuszko's Mine, associated with Nathanael Greene's 28-day siege of the trading village in May and June of 1781. Though Greene did not succeed in taking Ninety Six, he won a strategic victory by forcing the British out of this backcountry stronghold and restricting British control of South Carolina to areas near the coast. The origin of the park namesake is a bit ambiguous, but the most accepted story of how Ninety Six was named is that it denotes the estimated distance, in miles, from NISI to the important Cherokee town of Keowee (National Park Service 2014c).

The bedrock geology of NISI consists of ancient metamorphic and igneous rocks that date back to the Neoproterozoic and Paleozoic Eras, approximately 550–360 Ma (Figure 40). The oldest mapped unit in NISI consists of Neoproterozoic to Paleozoic-age biotite quartz-plagioclase gneiss that underlies a major portion of the historic site including the visitor center, Star Fort, Stockade Fort, Town of Ninety Six site, and the Siege Trenches. The bedrock of the southern portion of NISI below Tolbert Branch Henley Creek is composed of Silurian–Devonian-age gabbro of the Greenwood pluton.

There are no designated stratotypes identified within the boundaries of NISI. There is one identified stratotype located within 48 km (30 mi) of NISI boundaries, for the Permian Coronaca Granite (type area).

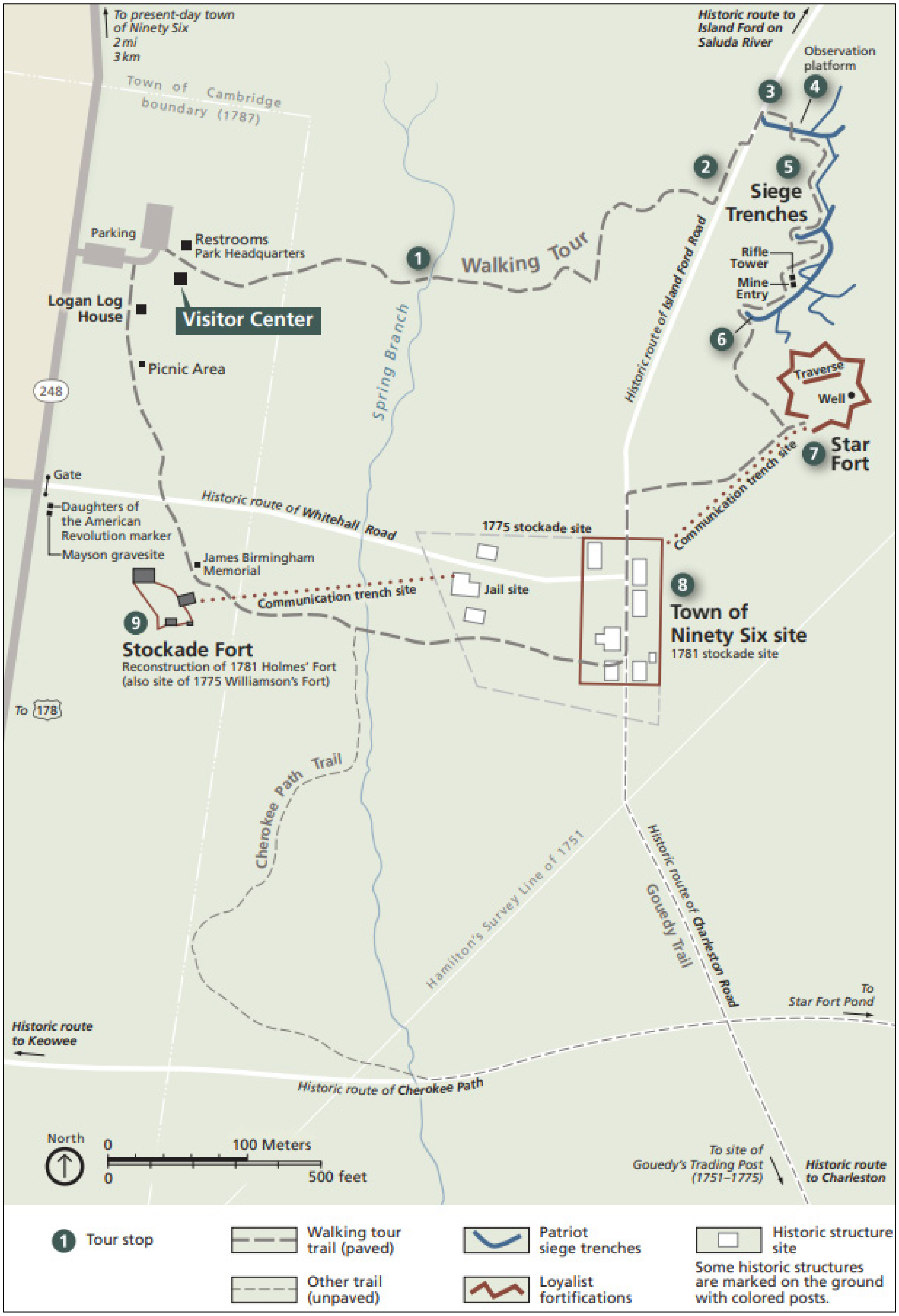


Figure 39. Park map of NISI, South Carolina (NPS).

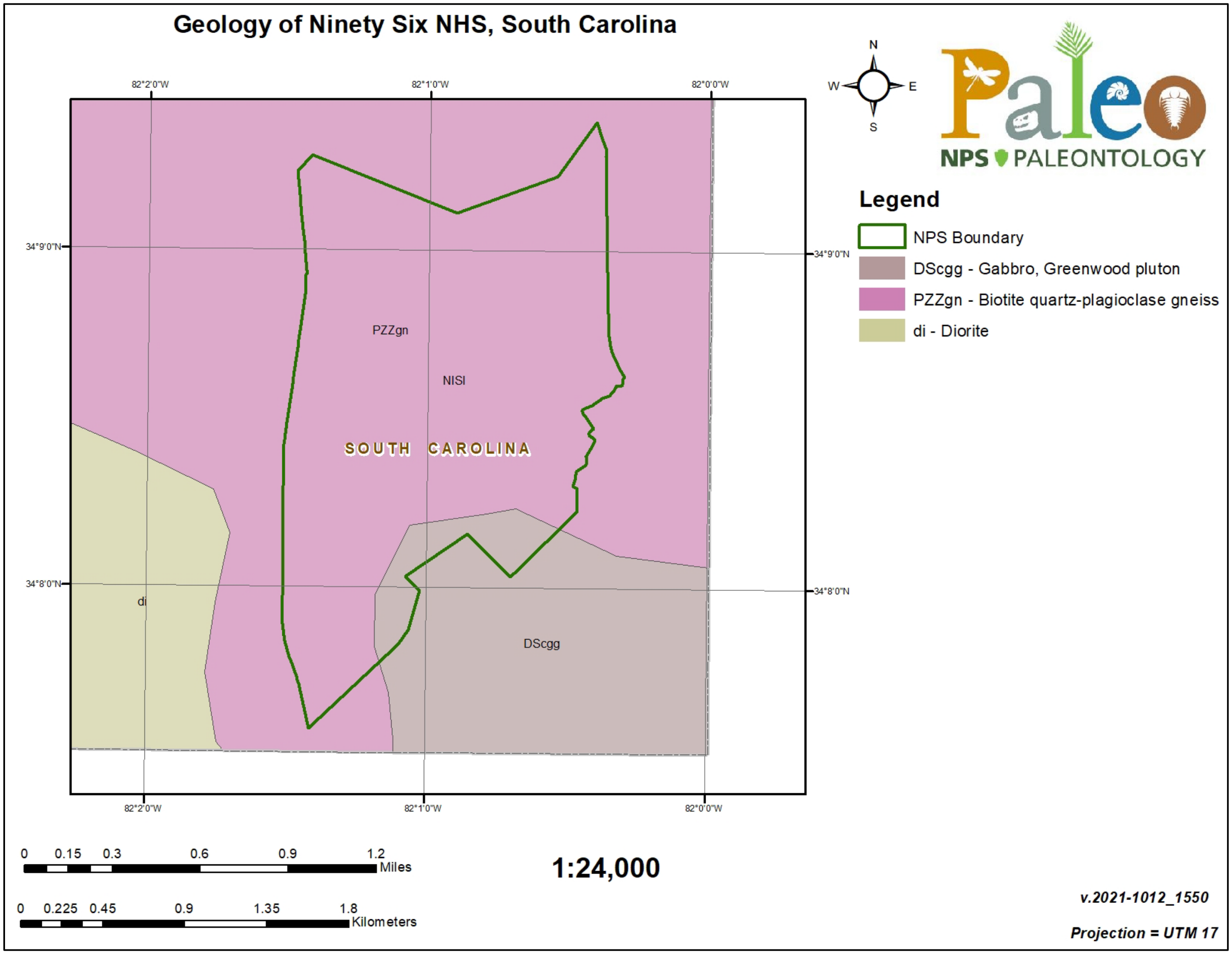


Figure 40. Geologic map of NISI, South Carolina. Data modified from NISI GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2197619.

Russell Cave National Monument (RUCA)

Russell Cave National Monument (RUCA) is situated on the northeastern flank of Montague Mountain in Jackson County, northeastern Alabama (Figure 41). Proclaimed on May 11, 1961, RUCA contains approximately 125 hectares (310 acres) and preserves an almost continuous archeological record spanning nearly 10,000 years from at least 9000 B.C.E. to about 1650 C.E. (National Park Service 2016a). Russell Cave is a 929 m^2 (10,000 ft^2) cave shelter that contains a combination of geological features, hydrological processes, and natural resources that provided an optimum setting for human habitation for millennia. The monument contains a large number of sites related to the aboriginal use and occupation of the cave and preserves one of the oldest burials known to date in Alabama, with well-preserved material including some of the oldest bone tools, fishhooks, domesticated seeds, and weaving impressions in the Southeast (National Park Service 2014d).

RUCA is located on the Cumberland Plateau, a region comprised of Paleozoic-age sedimentary rocks with modest relief (Figure 42). The oldest bedrock mapped in RUCA consists of Mississippian-age shale and fossiliferous limestone of the Monteagle Limestone, Bangor Limestone, and Pennington Formation. Russell Cave developed in these ancient carbonate rocks after millions of years of dissolution and chemical erosion by percolating groundwater. Other karst features such as swallets, sinkholes, windows, and springs are associated with carbonate dissolution and are common in the monument area. Overlying the Mississippian strata is the Pennsylvanian Pottsville Formation, an erosion-resistant unit predominantly composed of coarse-grained conglomerate and sandstone with layers of coal (Thornberry-Ehrlich 2014). The Pottsville Formation forms ridges and caps Montague Mountain in southwestern RUCA. The youngest units in RUCA include Quaternary-age terrace and alluvial fan deposits, alluvium, and thin colluvium.

There are no designated stratotypes identified within the boundaries of RUCA. There are 13 identified stratotypes located within 48 km (30 mi) of RUCA boundaries, for the Ordovician Pond Spring Formation (type section), Sequatchie Formation (type area), and Shellmound Member of the Sequatchie Formation (type section); Devonian–Mississippian Chattanooga Shale (type locality); Mississippian Monteagle Limestone (type section); and Pennsylvanian Gizzard Group (type section), Signal Point Shale (type locality), Whitwell Shale (type area), Warren Point Sandstone (type locality), Raccoon Mountain Formation (type section), Flat Rock Member of the Raccoon Mountain Formation (type section), Norwood Cove Member of the Raccoon Mountain Formation (type section), and Sewanee Conglomerate (type locality).

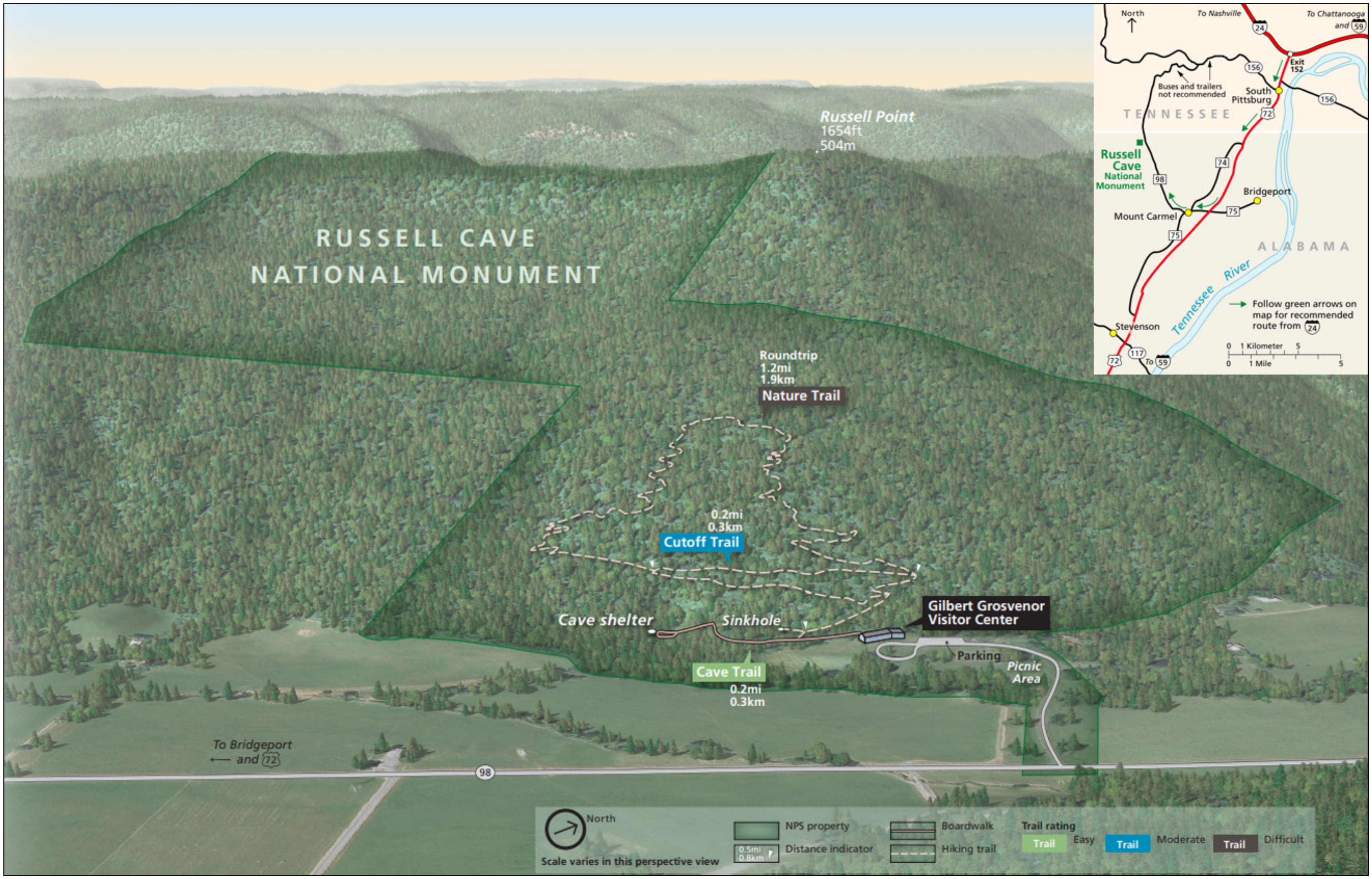


Figure 41. Park map of RUCA with inset area map, Alabama (NPS).

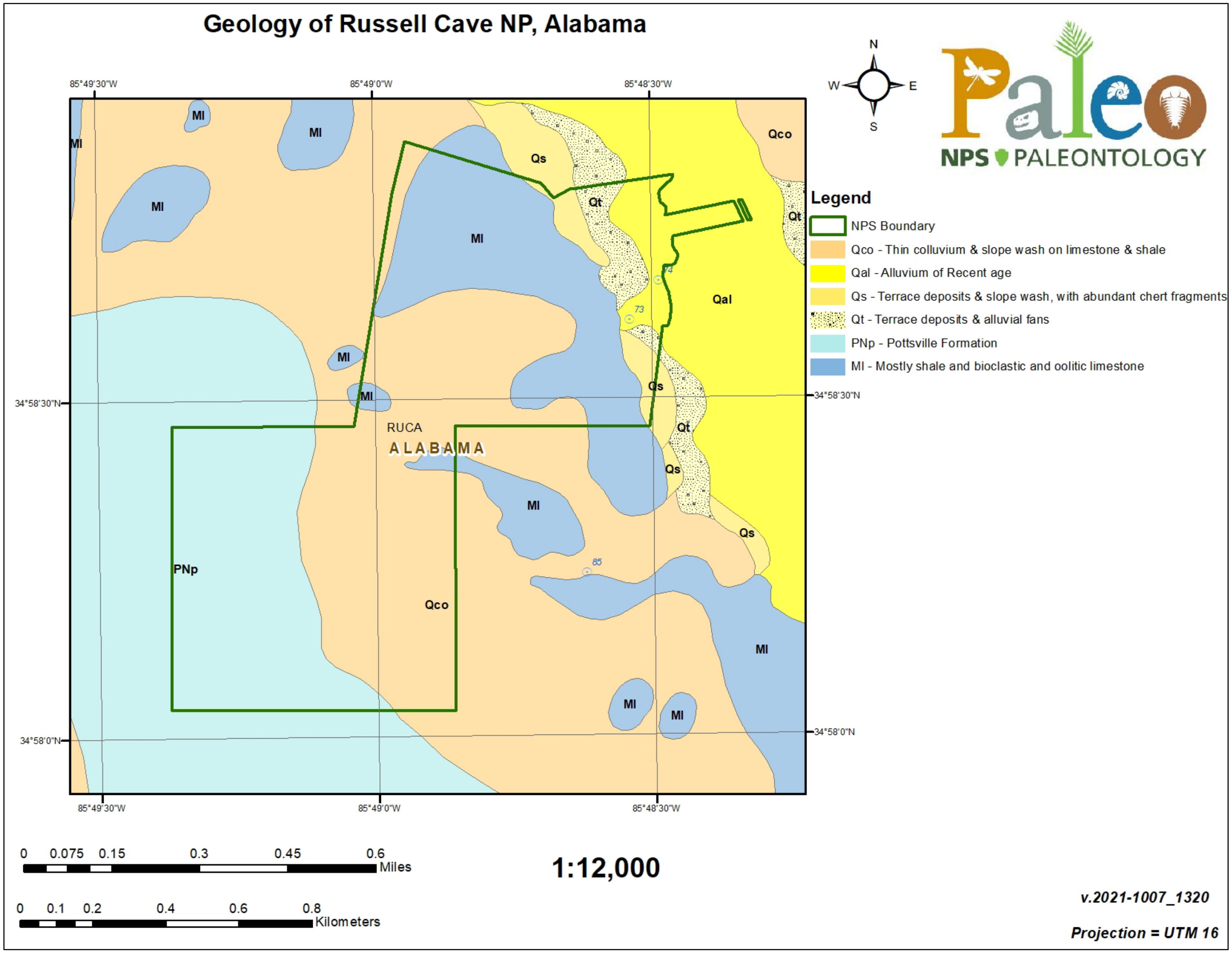


Figure 42. Geologic map of RUCA, Alabama. Data modified from RUCA GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048136.

Shiloh National Military Park (SHIL)

Shiloh National Military Park (SHIL) encompasses the Shiloh Battlefield on the west bank of the Tennessee River in Hardin County, Tennessee, and the Corinth Unit located in Corinth County, Mississippi (Figure 43). Established on December 27, 1894, SHIL contains about 2,719 hectares (6,720 acres) and preserves the battlefields, sites, and resources associated with Shiloh and Corinth during the Western Campaign of the Civil War (National Park Service 2016a). The Battle of Shiloh took place in April 1862 and represents a major battle to control western Confederate railroads and the Mississippi River Valley that ended in a decisive Union victory. An attempt by Confederate troops to drive Union forces from their fortified defenses at Corinth six months later in October 1862 resulted in another Confederate defeat at the Battle of Corinth, the last major Confederate offensive in the state of Mississippi. The Corinth Unit of SHIL protects the few surviving examples of early earthen fortifications that foreshadowed the complex trench warfare that would define the final desperate year of the Civil War (National Park Service 2016e).

The geology of SHIL reflects a long history of deposition and the evolution of the Tennessee River valley that records several sea level fluctuations. The bedrock of SHIL consists entirely of Cretaceous-age sedimentary rocks originally deposited in nearshore environments along the upland margins of western Tennessee (Figure 44). The oldest unit mapped in SHIL consists of marine sands and clays of the Eutaw Formation, overlain by lagoonal, barrier bar, and shoreline sands and clays of the Coffee Formation (Thornberry-Ehrlich 2018). Ancient precursors to the modern Tennessee River reworked these Cretaceous-age deposits, carving river channels and depositing thick fluvial sequences of gravel, sand, silt, and clay. Many of these Quaternary-age fluvial deposits were left as perched, dissected terraces and include “Shiloh Hill”. The youngest units mapped in SHIL include unconsolidated Quaternary-age alluvium located along the Tennessee River and adjacent floodplains.

There are no designated stratotypes identified within the boundaries of SHIL. There are three identified stratotypes located within 48 km (30 mi) of SHIL boundaries, for the Cretaceous Coon Creek Formation (type locality), McNairy Formation (type section), and Coffee Formation (type locality).

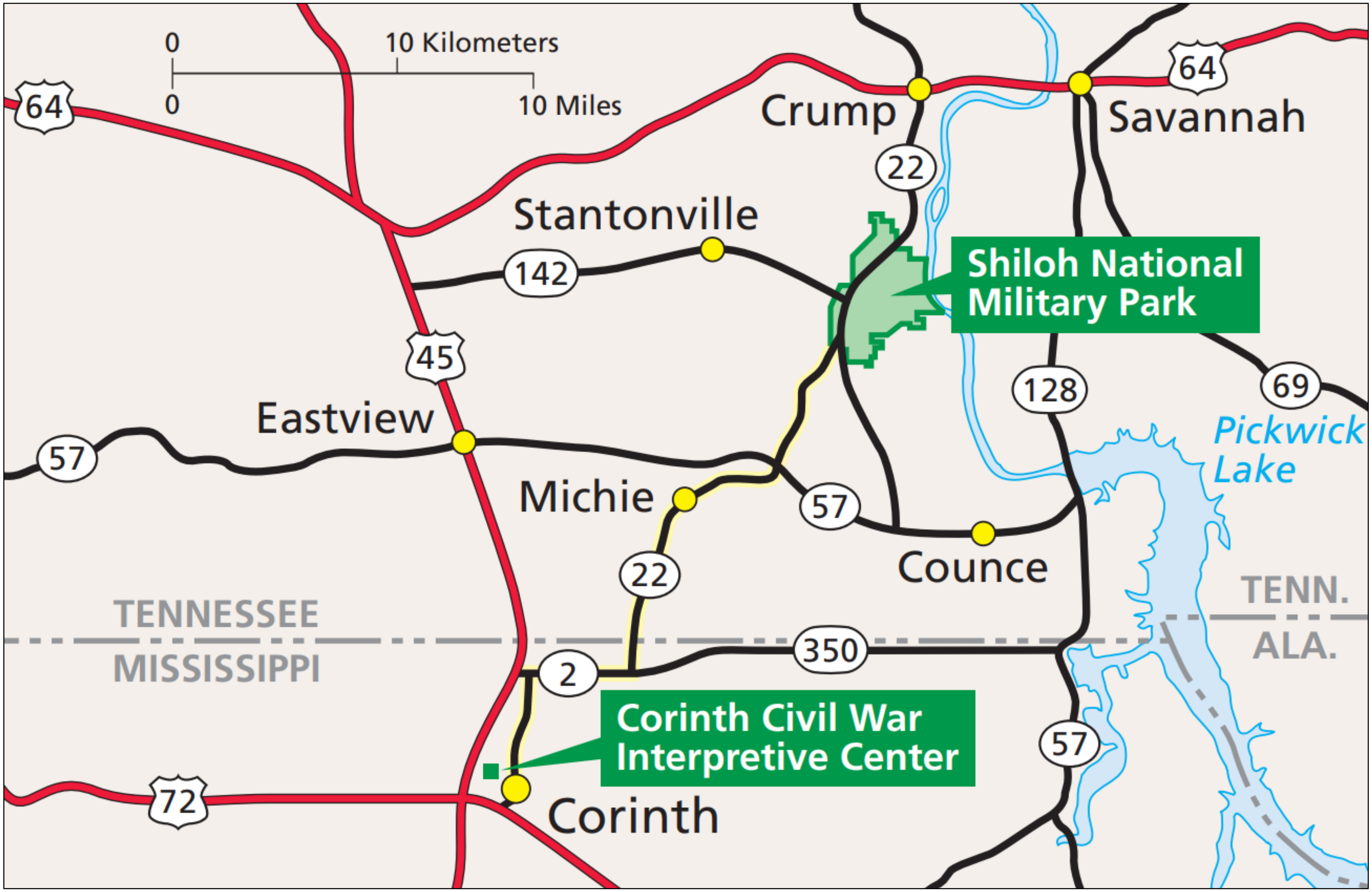


Figure 43. Regional map of SHIL, Tennessee (NPS).

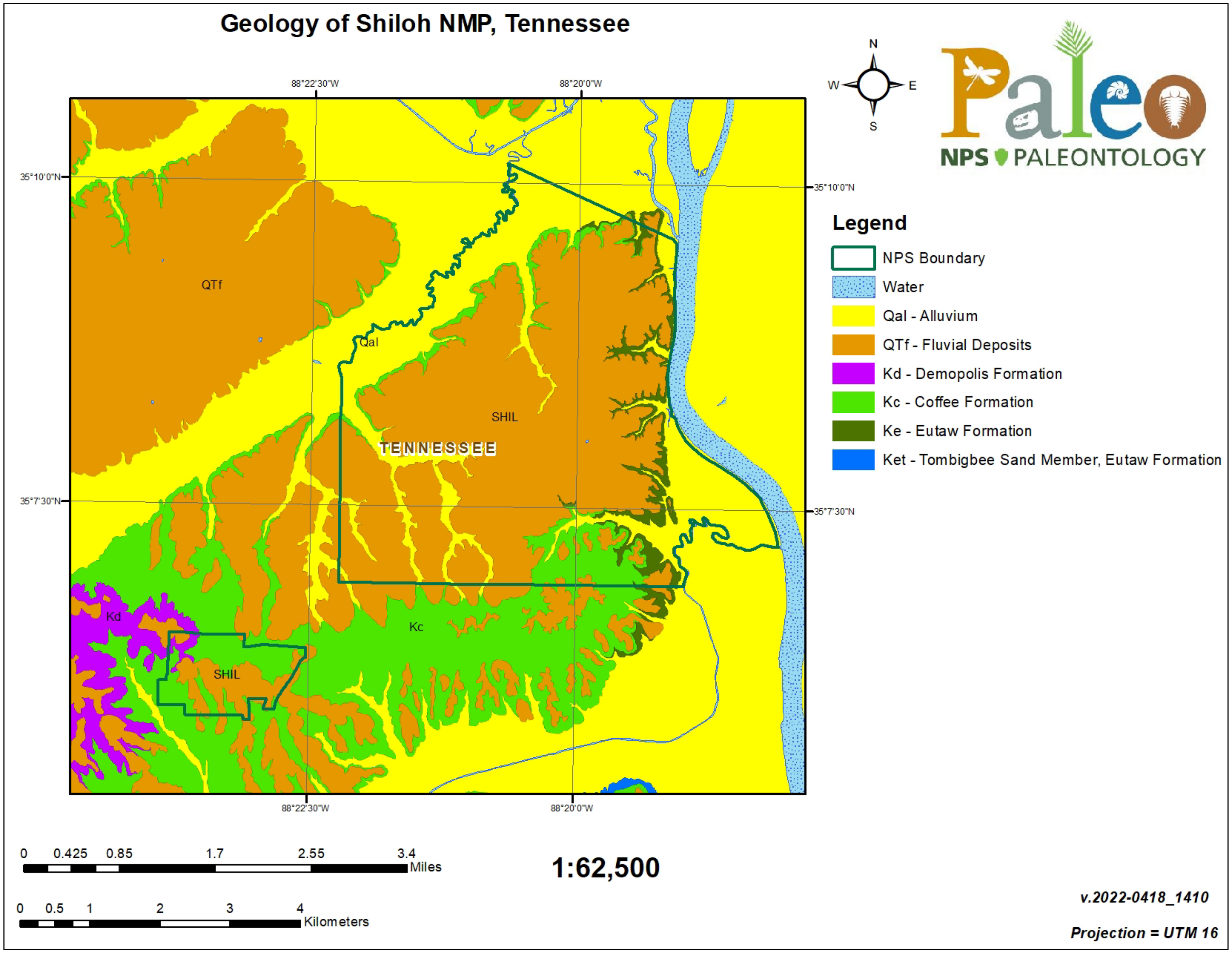


Figure 44. Geologic map of SHIL, Tennessee. Data modified from SHIL GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2169495.

Stones River National Battlefield (STRI)

Stones River National Battlefield (STRI) comprises several units situated northwest of Murfreesboro along the West Fork of Stones River in Rutherford County, central Tennessee (Figure 45). Originally established as a national military park on March 3, 1927, the park unit was redesignated on April 22, 1960 (National Park Service 2016a). The national battlefield is separated into six areas covering a combined 263 hectares (650 acres), 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 (Thornberry-Ehrlich 2012b). The national battlefield commemorates the Battle of Stones River, an important three-day Civil War battle to control one of middle Tennessee's most productive agricultural areas and a critical, centrally located transportation network. Fought between December 31, 1862, and January 2, 1863, the battle ended in a strategic Union victory and marked the end of the Confederate Army's attempt to move into Kentucky and the North (National Park Service 2014e).

The bedrock underlying STRI consists entirely of Ordovician-age (~470–455 Ma) limestone units originally deposited in a marine basin that inundated the Mississippi River corridor of eastern North America (Figure 46; Thornberry-Ehrlich 2012b). Geologic units mapped within STRI include the Pierce, Murfreesboro, Ridley, and Lebanon limestones, some of the oldest sedimentary rock exposures in Tennessee that were uplifted during the formation of the Nashville Dome by the end of the Paleozoic Era (Stearns and Reesman 1986). Dissolution and chemical erosion of these limestones has resulted in a karst landscape characterized by sinkholes, caves, and underground drainage. Younger surficial units mapped in STRI include alluvium (unconsolidated gravel, sand, silt, and clay) along the West Fork Stones River corridor and some thin soils between bedrock outcrop exposures (Thornberry-Ehrlich 2012b).

There are no designated stratotypes identified within the boundaries of STRI. There are seven identified stratotypes located within 48 km (30 mi) of STRI boundaries, for the Ordovician Murfreesboro Limestone (type locality), Ridley Limestone (type section), Lebanon Limestone (type section), and Hermitage Formation (type area); Devonian Dowelltown Member of the Chattanooga Formation (type section) and Gassaway Member of the Chattanooga Formation (type section); and Mississippian Maury Member of the Chattanooga Formation (type section).

Figure 45. Park map of STRI, Tennessee (NPS).

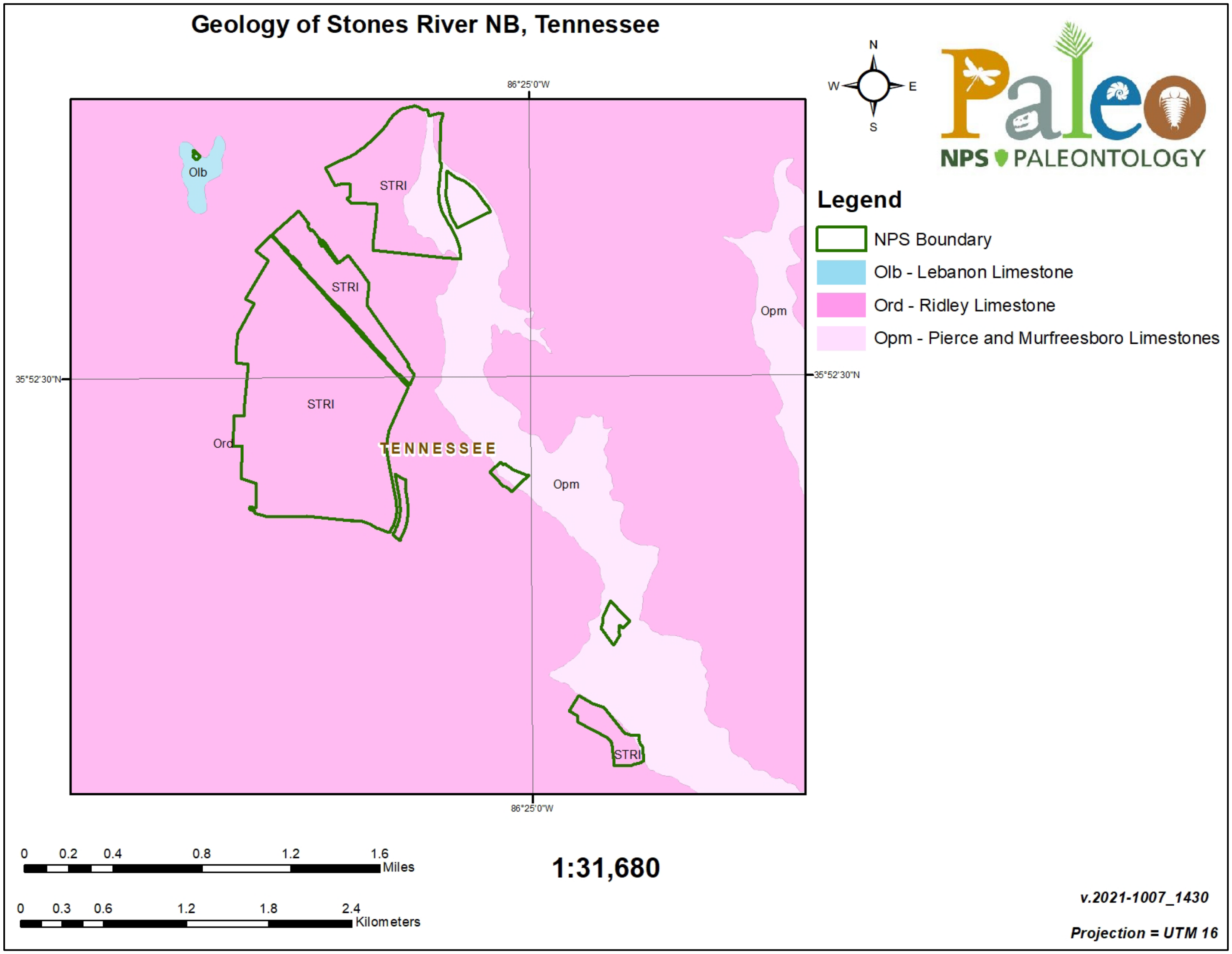


Figure 46. Geologic map of STRI, Tennessee. Data modified from STRI GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048305.

Recommendations

See also protocols in Brocx et al. (2019), from which several of these recommendations were adapted:

1) The NPS Geologic Resources Division should work with park and network staff to increase their awareness and understanding about the scientific, historic and geologic heritage significance of geologic stratotypes (type sections/localities/areas, reference sections, lithodemes). *Stratotypes represent unique geologic exposures and should be considered extremely important to protect for the advancement of the scientific community for future generations.*

2) Once the CUPN Geologic Type Section Inventory report is finalized, the NPS Geologic Resources Division should schedule a briefing for the staff of the CUPN and respective network parks.

3) The Mississippian "Mammoth Cave limestone series" (now Mammoth Cave Group) was proposed by Miller (1919) and named after Mammoth Cave in Edmonson County, Kentucky. Miller (1919) introduced the series to describe "*the almost uninterrupted deposit of relatively pure limestone which has as a highly conspicuous feature the presence in it of caverns of considerable extent*". Included within the series were the St. Louis and Ste. Genevieve stages, now the St. Louis Limestone and Ste. Genevieve Limestone, respectively (Miller 1919). Although the unit was described after exposures in MACA, no formal stratotype was ever designated. Therefore, we recommend a formal stratotype be designated in order to A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of the unit; and C) help safeguard the exposure.

4) The NPS Geologic Resources Division should work with park and network staff to ensure they are aware of the location of stratotypes in park areas. This information would be important to ensure that proposed park activities or development would not adversely impact the stability and condition of these geologic exposures. Preservation of stratotypes should not limit availability for future scientific research but help safeguard these exposures from infrastructure development.

5) The NPS Geologic Resources Division should work with park and network staff, the U.S. Geological Survey, state geological surveys, academic geologists, and other partners to formally assess potential new stratotypes as to their significance (international, national, or statewide), based on lithology, stratigraphy, fossils or notable features using procedural code outlined by the North American Commission on Stratigraphic Nomenclature (after Brocx et al. 2019).

6) From the assessment in (5), NPS staff should focus on registering new stratotypes at state and local government levels where current legislation allows, followed by a focus on registering at federal and state levels where current legislation allows (after Brocx et al. 2019).

7) The NPS Geologic Resources Division should work with park and network staff to compile and update a central inventory of all designated stratotypes and potential future nominations (after Brocx et al. 2019).

8) The NPS Geologic Resources Division should ensure the park-specific Geologic Type Section Inventory Reports are widely distributed and available online.

9) The NPS Geologic Resources Division should work with park and network staff to regularly monitor geologic type sections to identify any threats or impacts to these geologic heritage features in parks.

10) The NPS Geologic Resources Division should work with park and network staff to obtain good photographs of each geologic type section within the parks. In some cases, where there may be active geologic processes (rock falls, landslides, coastal erosion, etc.), the use of photogrammetry may be considered for monitoring of geologic type sections. GPS locations should also be recorded and kept in a database when the photographs are taken.

11) The NPS Geologic Resources Division should work with park and network staff to consider the collection and curation of geologic samples from type sections within NPS areas. Samples collected from type section exposures can be useful as reference specimens to support future studies, especially where stratotypes may be lost through natural processes or human activities.

12) The NPS Geologic Resources Division should work with park and network staff to utilize selected robust internationally and nationally significant type sections as formal teaching/education sites and for geotourism so that the importance of the national- and international-level assets are more widely (and publicly) known, using information boards and walkways (after Brocx et al. 2019).

13) The NPS Geologic Resources Division should work with park and network staff in developing conservation protocols of significant type sections, either by appropriate fencing, walkways, and information boards or other means (e.g., phone apps) (after Brocx et al. 2019).

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Appendix A: Source Information for GRI Maps of CUPN Parks

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MACA

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Appendix B: Geologic Time Scale

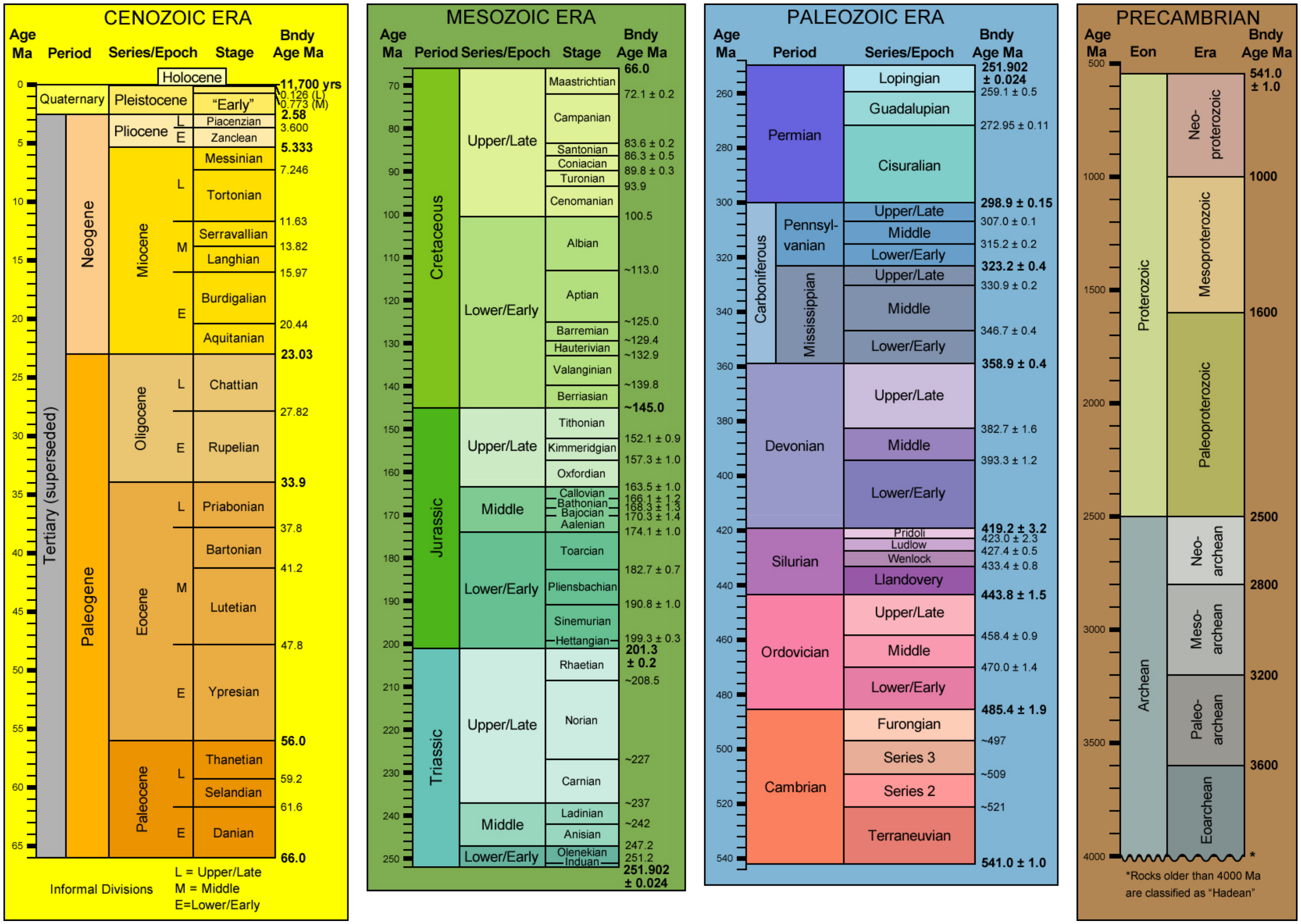

Figure B1. Geologic Time Scale. **Ma**=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

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