National Park Service
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Natural Resource Stewardship and Science

National Park Service Geologic Type Section Inventory

National Capital Region Inventory & Monitoring Network

Natural Resource Report NPS/NCRN/NRR—2022/2422

ON THE COVER

Type locality exposures of the Neoproterozoic–Cambrian Mather Gorge Formation in Great Falls Park, GWMP. NPS photo by Tim Henderson.

National Park Service Geologic Type Section Inventory

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Natural Resource Report NPS/NCRN/NRR—2022/2422

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Executive Summary

Type sections are one of several kinds of stratotypes. A stratotype is the standard (original or subsequently designated), accessible, and specific sequence of rock for a named geologic unit that forms the basis for the definition, recognition, and comparison of that unit elsewhere. Geologists designate stratotypes for rock exposures that are illustrative and representative of the map unit being defined. Stratotypes ideally should remain accessible for examination and study by others. In this sense, geologic stratotypes are similar in concept to biological type specimens, however they remain in situ as rock exposures rather than curated in a repository. Therefore, managing stratotypes requires inventory and monitoring like other geologic heritage resources in parks. In addition to type sections, stratotypes also include type localities, type areas, reference sections, and lithodemes, all of which are defined in this report.

The goal of this project is to consolidate information pertaining to stratotypes 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 heritage resources.

This effort identified 20 stratotypes designated within seven park units of the National Capital Region I&M Network (NCRN): Chesapeake and Ohio Canal National Historical Park (CHOH) contains three type sections, two type localities, one type area, and eight reference sections; George Washington Memorial Parkway (GWMP) contains one type locality; Harpers Ferry National Historical Park (HAFE) contains two type sections, and one type locality/type area; Manassas National Battlefield (MANA) contains two type areas; Monocacy National Battlefield (MONO) contains one type section; National Capital Parks-East (NACE) contains one type locality; Prince William Forest (PRWI) contains one type section. Note that two stratotype designations (for the Harpers and Mather Gorge Formations) are shared amongst multiple park units. Table 1 provides information regarding the 20 stratotypes currently identified within the NCRN.

There are currently no designated stratotypes within Antietam National Battlefield (ANTI), Catoctin Mountain Park (CATO), Rock Creek Park (ROCR), and Wolf Trap National Park for the Performing Arts (WOTR). However, CATO, CHOH, and GWMP contain important rock exposures that could be considered for formal stratotype designation as discussed in the Recommendations section.

The inventory of geologic stratotypes across 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 has centered on the 32 inventory and monitoring (I&M) networks established during the late 1990s. Adopting a network-based approach to inventories worked well when the NPS undertook paleontological resource inventories for the 32 I&M networks and was therefore adopted for the stratotype inventory. The Greater Yellowstone I&M Network (GRYN) was the pilot network for initiating this project (Henderson et al. 2020). Methodologies and reporting strategies adopted for the GRYN have been used in the development of this report for the NCRN.

This report includes 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 NCRN stratotype units sorted by park unit and geologic age, with associated reference publications and locations.

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
CHOH	Balls Bluff Member, Bull Run Formation	Brezinski and Adams 2021	Reference section: along C&O Canal National Historic Park at Marble Quarry near milepost 38 (latitude 39°10′44.82″ N., longitude 77°29′34.14″ W.), in Montgomery County, MD.	Triassic
CHOH	Poolesville Member, Manassas Sandstone (TRmp)	Lee and Froelich 1989; Brezinski and Adams 2021	Reference sections: 1. Outcrops along the northern bluffs of the Potomac River extending west for 2 km (1.2 mi) from the mouth of Seneca Creek [west-central Seneca 7.5′ Quadrangle], Montgomery County, MD. Section occurs near mileposts 23–25. 2. Along C&O Canal National Historic Park at Marble Quarry near milepost 38 (latitude 39°10′44.82″ N., longitude 77°29′34.14″ W.), in Montgomery County, MD.	Triassic
CHOH	Hampshire Formation (Dh)	Brezinski et al. 2009; Brezinski and Cecil 2015	Reference section: located along the Chesapeake and Ohio Canal National Historical Park between mileposts 137 and 138, in Washington County, MD.	Devonian
CHOH	Beekmantown Group (Orr, Op, Os, Oss)	Sando 1956	Reference section: begins at top of group in Potomac River bluff, about 305 m (1,000 ft) west of intersection with southwest face of Pinesburg Station quarry, and continues westward along C&O Canal for 1.6 km (1 mi), Washington County, MD. Section is near mileposts 102–103.	Ordovician
CHOH	Pinesburg Station Dolomite (Op)	Brezinski 2018	Reference section: along the C&O Canal National Historical Park towpath at approximately milepost 102.5. The section begins at east end of parking area at end of Gift Road at approximately milepost 103.1 (latitude 39°36'59" N., longitude 77°53'15" W.), in Washington County, MD.	Ordovician
CHOH	Dam Five Member, Stonehenge Limestone	Brezinski 2018	Type section: section measured along the C&O Canal National Historic Park towpath that begins at Lock 46 and proceeds eastward towards Dam Number Five (latitude 39°36'55" N., longitude 77°55'36" W.), in Washington County, MD. Section is near mileposts 106–107.	Ordovician
CHOH	Conococheague Formation (OCc)	Brezinski et al. 2012; 2015	Reference section: located on the western flank (latitude 39°36′54″ N., longitude 77°56′49″ W.) and eastern flank (latitude 39°36′56″ N., longitude 77°55′36″ W.) of the Big Spring anticline near milepost 108, in Washington County, MD.	Cambrian–Ordovician

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

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
CHOH	Elbrook Limestone (Ce)	Brezinski 1996	Reference section: along Chesapeake and Ohio Canal beginning approximately 183 m (600 ft) east of the McCoy's Ferry aqueduct and continuing eastward to sharp northeastward bend toward Four Locks (Hedgesville Quadrangle), in Washington County, MD. Base of section is at latitude 39°36′30″ N., longitude 77°58′00″ W near milepost 109–110.	Cambrian
CHOH	Dargan Member, Tomstown Formation (Ctd)	Brezinski 1992	Type section: along C&O Canal and adjacent Lime Kiln Road, 2.4 km (1.5 mi) northwest of village of Dargan, Washington County, MD. Section is near mileposts 67–68.	Cambrian
CHOH	Fort Duncan Member, Tomstown Formation (Ctf)	Brezinski 1992	Type section: along C&O Canal, MD side (Washington Co.) of first northward meander of the Potomac River, west of Harpers Ferry, WV. Section is near milepost 63.	Cambrian
CHOH, HAFE, APPA	Harpers Formation (Ch, Chq)	Brezinski 1992; Southworth 1994; Southworth et al. 2009	Type locality: a collection of exposures on the cliffs along the Potomac River at Harpers Ferry, WV, near mileposts 61–62. Type area: exposures near Harpers Ferry, WV.	Cambrian
CHOH, GWMP	Mather Gorge Formation (CZmg, CZmm, CZmp, CZms in CHOH; CZms, CZmg, CZmm, CZmmg, CZmms, CZmmp, CZmp, CZmss in GWMP)	Drake and Froelich 1997	Type locality: the Mather Gorge on the Potomac River in the Falls Church and Vienna Quadrangles, MD–VA. Exposures occur near milepost 13 in CHOH.	Neoproterozoic –Cambrian
HAFE	Bolivar Heights Member, Tomstown Formation (Ctbh)	Brezinski 1992	Type section: along CSX Railroad tracks at north end of Bolivar Heights, 2.4 km (1.5 mi) west of the confluence of Potomac and Shenandoah Rivers at Harpers Ferry, Jefferson County, WV.	Cambrian
HAFE	Maryland Heights Member, Weverton Formation (Cw)	Brezinski 1992	Type section: along CSX Railroad tracks, east of tunnel and Sandy Hook Road at Maryland Heights, Washington County, MD.	Cambrian
MANA	Bull Run Formation of the Chatham Group (TRbg)	Roberts 1928; Weems and Olsen 1997	Type area: along Bull Run, a small stream in the Bull Run Battlefield, 9.5 km (6 mi) west of Manassas, in Prince William and Fairfax Counties, VA.	Triassic

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

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
MANA	Groveton Member, Bull Run Formation of the Chatham Group (TRbg)	Weems and Olsen 1997	Type area: Manassas National Battlefield Park, VA, excluding areas underlain by intrusive diabase (Fig. 8 of Weems and Olsen 1997). Good exposures in the Manassas National Battlefield Park occur along U.S. Highway 50 and Virginia State Road 234, and along the south bank of Bull Run Creek along the northern edge of the park.	Triassic
MONO	Araby Formation (Car)	Reinhardt 1974	Type section: on Baltimore and Ohio RR east of Frederick Junction. Named from Araby, southwest of Frederick, Frederick County, north-central MD.	Cambrian
NACE	Potomac Formation (Kp, Kpc, Kps)	McGee 1886; Jordan 1983	Type locality: deposits in the District of Columbia and adjacent parts of MD and VA.	Cretaceous
PRWI	Chopawamsic Formation (Ocw, Ocg)	Southwick et al. 1971	Type section: along Chopawamsic Creek, from a point 1.82 km (1.13 mi) and 45° southwest of crossroads of Joplin to a point 3.96 km (2.46 mi) and 6° southeast of Joplin [Joplin 7.5′ Quadrangle], northeastern VA.	Ordovician

Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic type sections for the national parks of the National Capital Region Inventory & Monitoring Network (NCRN). We first want to extend our sincere appreciation to Randy Orndorff, David Soller, and Nancy Stamm (U.S. Geological Survey) for their assistance with this geologic type section inventory and other important NPS projects. Randy, Dave, and Nancy manage the National Geologic Map Database and GEOLEX (the U.S. Geologic Names Lexicon, a national compilation of names and descriptions of geologic units), respectively, for the United States, critical sources of geologic map 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 NCRN and various network parks including: Elizabeth Matthews, Megan Northrup, John Paul Schmit (NCRN), and Mike Antonioni (NACE). Additional thanks to Diane Pavek for continued support for this and other important geology projects in the legacy National Capital Region of the NPS. Diane served as peer review coordinator for this report.

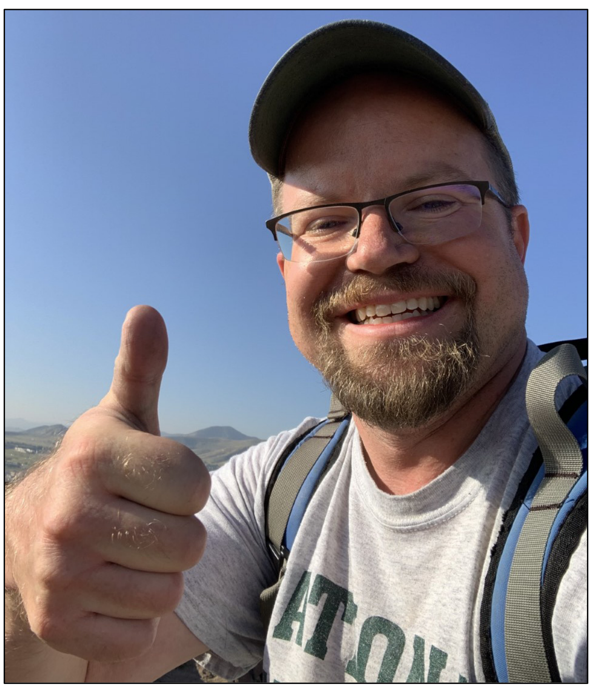
This project is possible through the support from research associates and staff in the National Park Service Geologic Resources Division and we extend our thanks to Stephanie Gaswirth, Hal Pranger, Julia Brunner, Jim Wood, Jason Kenworthy, and Rebecca Port. Finally, we want to thank the past and current members of the NPS Geologic Resource Inventory Team for more than 20 years of work to expand our understanding of the geologic features, issues, and processes in our national parks!

Dedication

This National Capital Region Inventory & Monitoring Network Geologic Type Section Inventory is dedicated to National Park Service Geologic Resource Inventory program manager Jason Kenworthy. Jason's career with the NPS began in 2001 with his first position as a Student Conversation Association intern at Fossil Butte National Monument. Since then, he has served multiple roles in interpretation, paleontology technical support, and geologic program management. Growing up in Greenbelt, Maryland, the park units of the NCRN have personal hometown connections to geology. What Jason appreciates most about the NCRN geology is that it is so varied over a relatively small area. From National Capital Parks-East to Chesapeake and Ohio Canal National Historical Park, these park units tell the story of the rise and fall of Pangaea and the Appalachians. There are dinosaurs; the Fall Line at Great Falls; Ancestral rift basins; Coastal plain and barrier islands. Plus, all the "urban outcrops" in the building stone from such a monumental city as Washington, DC. For Jason, another fascinating aspect of the NCRN is the human history connected to the underlying geology and how it has shaped societies through time.

As a professional geoscientist, Jason's career path was, and continues to be shaped and guided by his supportive teachers, mentors, and colleagues. Jason considers himself fortunate and grateful to have worked with such great teams on many different types of projects at parks from all across the country. Throughout his various roles, Jason has inspired numerous NPS staff, and he hopes to continue inspiring the next generation of park rangers and scientists through outreach events such as National Fossil Day and the Junior Paleontologist Program.

Thank you Jason for your many impactful contributions to the National Park Service!



Jason Kenworthy, NPS-GRI program manager since 2018.

Introduction

Geologic maps show the distribution and classification of rocks, sedimentary deposits, and geologic features for a given area. The geologic classification of rocks and deposits is hierarchical with several different categories of geologic or stratigraphic units including, from regional scale to local exposure scale: supergroup, group, formation, member, and bed. The mapping of stratigraphic units involves the evaluation of lithologies, 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, which presents a relatively complete and representative example for this unit. Geologic stratotypes are important geoheritage resources with historic and scientific significance and should be available for other researchers to evaluate in the future.

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 geoscientists (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 biologic evolution of our planet. In addition, geologic formations are named after topographic or geologic features and landmarks that are recognizable to park staff and visitors. Therefore, geologic stratotypes are part of our national geologic heritage and are a cornerstone of the scientific value used to define the societal significance of geoheritage sites (refer to https://www.nps.gov/articles/scientific-value.htm for more about geologic heritage).

The goals of this project are to (1) systematically report the assigned stratotypes that occur within national parks of the National Capital Region Inventory & Monitoring (I&M) Network (NCRN), (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. This effort identified 20 stratotypes with seven NCRN parks: Chesapeake and Ohio Canal National Historical Park (CHOH) contains three type sections, two type localities, one type area, and eight reference sections; George Washington Memorial Parkway (GWMP) contains one type locality; Harpers Ferry National Historical Park (HAFE) contains two type sections and one type locality/type area; Manassas National Battlefield (MANA) contains two type areas; Monocacy National Battlefield (MONO) contains one type section; National Capital Parks-East (NACE) contains one type locality; and Prince William Forest (PRWI) contains one type section. Note that two stratotype designations (for the Harpers and Mather Gorge Formations) are shared amongst multiple park units. Table 1 provides information regarding the 20 stratotypes currently identified within the NCRN. Additionally, numerous stratotypes are located geographically outside of national park boundaries; those within 48 km (30 mi) of park boundaries are mentioned in this report.

The NCRN Geologic Type Section Inventory report is part of a larger effort to document stratotypes in all 32 I&M networks and selected non-I&M parks with significant rock exposures. This report follows the standard practices, methodologies, and organization of information introduced in the Greater Yellowstone I&M Network type section inventory (Henderson et al. 2020), which was the pilot for this effort. Refer to the Methods section for detailed information. As discussed in the Methods section, the NPS Geologic Type Section Inventory Project utilizes NPS Geologic Resources Inventory (GRI) data and information, which is considered the "official" baseline geologic map and report for each park in the Inventory and Monitoring (I&M) program.

Geologic stratotypes within NPS areas have not been previously inventoried, so this report fills a void in basic geologic information compiled by the NPS at most parks. NPS staff may not be aware of the concept of geologic stratotypes nor the significance or occurrence of them in parks. Without proper documentation and awareness, the NPS cannot proactively monitor the stability, condition, or potential impacts to these locations from activities such as ground disturbance or construction. Instances where geologic stratotypes occurred within NPS areas were determined through research of published geologic literature and maps as described in the Methods section. Sometimes the lack of specific locality or other data limited determination of whether a particular stratotype was located within NPS-administered boundaries.

Given the importance of geologic stratotypes as geologic references and geologic heritage resources, these NCRN locations should be afforded some level of documentation, preservation, or protection as appropriate. 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.

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 describes 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, constituting 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, but it may be supplemented if it proves inadequate. 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 that is 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.

Methods

Methodology

The process of determining whether a specific stratotype occurs within an NPS area involves multiple steps. The process begins with an evaluation of a park-specific Geologic Resources Inventory (GRI) map to prepare a full list of recognized map units (Figure 1). More information about the GRI data can be found later in this section.

Each geologic map unit name is 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 the geologic unit name, stratigraphic nomenclature usage, geologic age, 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). Figure 2 is taken from a search on the Chopawamsic Formation, which is mapped within Prince William Forest Park.

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 not used in the states covered in the NCRN, and therefore are not detailed here. Once stratotype locality information provided for a given unit is geolocated using Google Earth, a GRI digital geologic map of the national park 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 using GEOLEX or peer-reviewed literature, 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 was listed in GEOLEX; and (10) a generic notes field (Figure 3).

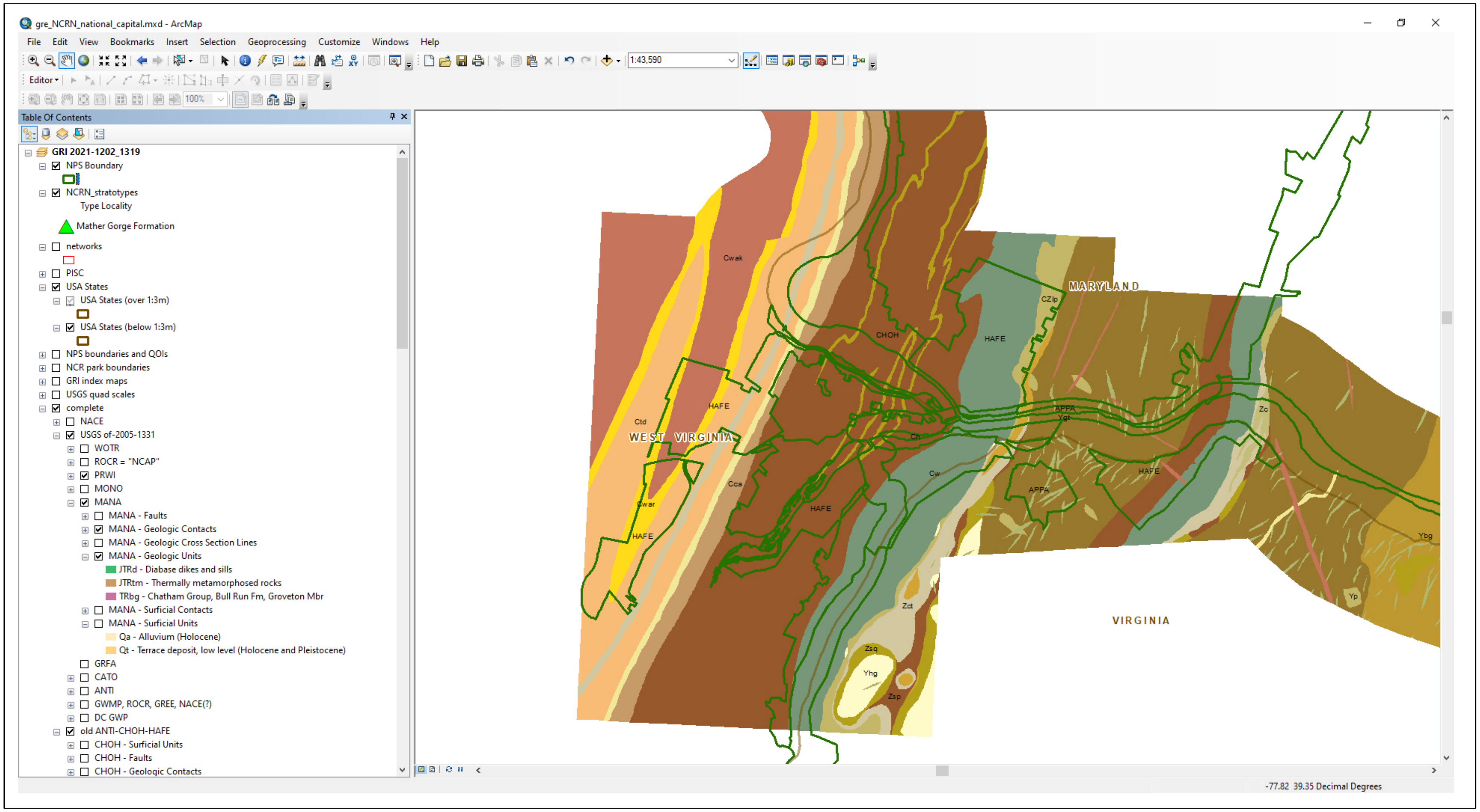


Figure 1. Screenshot of the GRI-compiled digital geologic map of Harpers Ferry National Historical Park showing mapped units. The NPS boundary layer has been added (green lines) and, in this view, includes Harpers Ferry National Historical Park, Chesapeake and Ohio Canal National Historical Park, and Appalachian National Scenic Trail. Access the GIS version of the NPS boundary online: https://irma.nps.gov/DataStore/Reference/Profile/2224545?lnv=True.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National Geologic Map Database

Geolex — Unit Summary

Geologic Unit: Chopawamsic

Significant Publications

Correlation charts
GNC Archives
N.A. Stratigraphic Code
More Resources

Usage:

Chopawamsic Formation of Glenarm Group (VA*)
Chopawamsic Formation (VA)

Geologic age:

Cambrian*
Cambrian, Early*

Type section, locality, area and/or origin of name:

Type section: on Quantico Marine Base, along Chopawamsic Creek, from a point 1.13 mi and 45 deg. southwest of crossroads of Joplin to a point 2.46 mi and 6 deg. southeast of Joplin, Joplin 7.5-min quadrangle, northeastern VA (Southwick and others, 1971).

AAPG geologic province:

Piedmont-Blue Ridge province*

For more information, please contact Nancy Stamm, Geologic Names Committee Secretary.
Asterisk (*) indicates published by U.S. Geological Survey authors.
"No current usage" (†) implies that a name has been abandoned or has fallen into disuse. Former usage and, if known, replacement name given in parentheses ( ).
Slash (/) indicates name does not conform with nomenclatural guidelines (CSN, 1933; ACSN, 1961, 1970; NACSN, 1983, 2005). This may be explained within brackets ([ ]).

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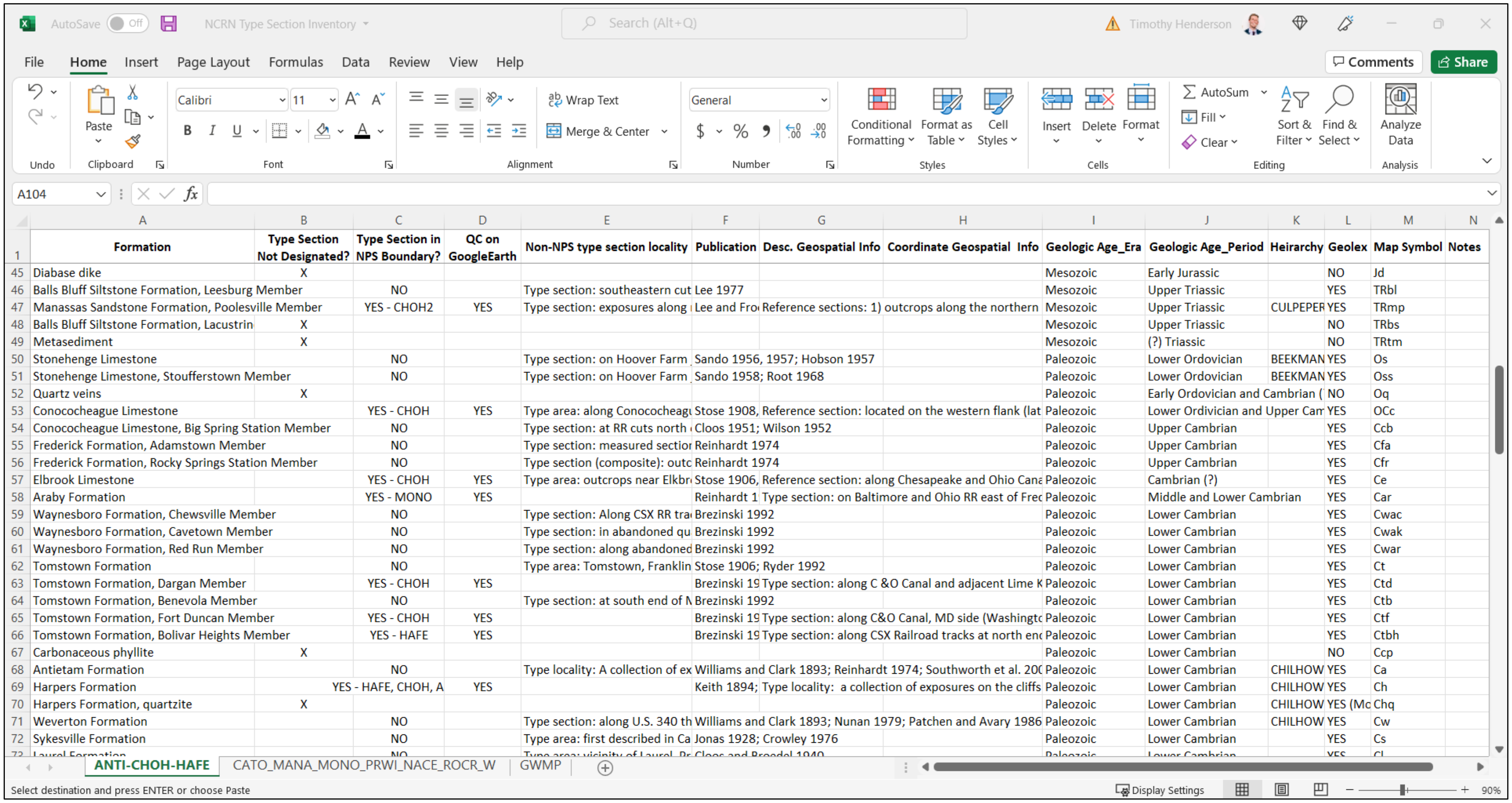
Figure 2. GEOLEX search result for the Chopawamsic Formation at Prince William Forest Park.



	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	Notes
45	Diabase dike	X							Mesozoic	Early Jurassic		NO	Jd	
46	Balls Bluff Siltstone Formation, Leesburg Member		NO		Type section: southeastern cut	Lee 1977			Mesozoic	Upper Triassic		YES	TRbl	
47	Manassas Sandstone Formation, Poolesville Member		YES - CHOH2	YES	Type section: exposures along	Lee and Fro	Reference sections: 1) outcrops along the northern		Mesozoic	Upper Triassic	CULPEPER	YES	TRmp	
48	Balls Bluff Siltstone Formation, Lacustrin	X							Mesozoic	Upper Triassic		NO	TRbs	
49	Metasediment	X							Mesozoic	(?) Triassic		NO	TRtm	
50	Stonehenge Limestone		NO		Type section: on Hoover Farm	Sando 1956, 1957; Hobson 1957			Paleozoic	Lower Ordovician	BEEKMAN	YES	Os	
51	Stonehenge Limestone, Stoufferstown Member		NO		Type section: on Hoover Farm	Sando 1958; Root 1968			Paleozoic	Lower Ordovician	BEEKMAN	YES	Oss	
52	Quartz veins	X							Paleozoic	Early Ordovician and Cambrian (		NO	Oq	
53	Conococheague Limestone		YES - CHOH	YES	Type area: along Conococheagu	Stose 1908,	Reference section: located on the western flank (lat		Paleozoic	Lower Ordivician and Upper Cam		YES	OCc	
54	Conococheague Limestone, Big Spring Station Member		NO		Type section: at RR cuts north	Cloos 1951; Wilson 1952			Paleozoic	Upper Cambrian		YES	Ccb	
55	Frederick Formation, Adamstown Member		NO		Type section: measured sectior	Reinhardt 1974			Paleozoic	Upper Cambrian		YES	Cfa	
56	Frederick Formation, Rocky Springs Station Member		NO		Type section (composite): outc	Reinhardt 1974			Paleozoic	Upper Cambrian		YES	Cfr	
57	Elbrook Limestone		YES - CHOH	YES	Type area: outcrops near Elkbr	Stose 1906,	Reference section: along Chesapeake and Ohio Cana		Paleozoic	Cambrian (?)		YES	Ce	
58	Araby Formation		YES - MONO	YES		Reinhardt 1	Type section: on Baltimore and Ohio RR east of Fred		Paleozoic	Middle and Lower Cambrian		YES	Car	
59	Waynesboro Formation, Chewsville Member		NO		Type section: Along CSX RR tra	Brezinski 1992			Paleozoic	Lower Cambrian		YES	Cwac	
60	Waynesboro Formation, Cavetown Member		NO		Type section: in abandoned qu	Brezinski 1992			Paleozoic	Lower Cambrian		YES	Cwak	
61	Waynesboro Formation, Red Run Member		NO		Type section: along abandoned	Brezinski 1992			Paleozoic	Lower Cambrian		YES	Cwar	
62	Tomstown Formation		NO		Type area: Tomstown, Franklin	Stose 1906; Ryder 1992			Paleozoic	Lower Cambrian		YES	Ct	
63	Tomstown Formation, Dargan Member		YES - CHOH	YES		Brezinski 19	Type section: along C &O Canal and adjacent Lime K		Paleozoic	Lower Cambrian		YES	Ctd	
64	Tomstown Formation, Benevola Member		NO		Type section: at south end of N	Brezinski 1992			Paleozoic	Lower Cambrian		YES	Ctb	
65	Tomstown Formation, Fort Duncan Member		YES - CHOH	YES		Brezinski 19	Type section: along C&O Canal, MD side (Washingto		Paleozoic	Lower Cambrian		YES	Ctf	
66	Tomstown Formation, Bolivar Heights Member		YES - HAFE	YES		Brezinski 19	Type section: along CSX Railroad tracks at north enc		Paleozoic	Lower Cambrian		YES	Ctbh	
67	Carbonaceous phyllite	X							Paleozoic	Lower Cambrian		NO	Ccp	
68	Antietam Formation		NO		Type locality: A collection of ex	Williams and Clark 1893; Reinhardt 1974; Southworth et al. 20(			Paleozoic	Lower Cambrian	CHILHOW	YES	Ca	
69	Harpers Formation		YES - HAFE, CHOH, A	YES		Keith 1894; Type locality: a collection of exposures on the cliffs			Paleozoic	Lower Cambrian	CHILHOW	YES	Ch	
70	Harpers Formation, quartzite	X							Paleozoic	Lower Cambrian	CHILHOW	YES (Mc	Chq	
71	Weverton Formation		NO		Type section: along U.S. 340 th	Williams and Clark 1893; Nunan 1979; Patchen and Avary 1986			Paleozoic	Lower Cambrian	CHILHOW	YES	Cw	
72	Sykesville Formation		NO		Type area: first described in Ca	Jonas 1928; Crowley 1976			Paleozoic	Lower Cambrian		YES	Cs	
73	Laurel Formation		NO		Type area: vicinity of Laurel, Pr	Cloos and Broedel 1940			Paleozoic	Lower Cambrian		YES	Cl	

Figure 3. Stratotype inventory spreadsheet of the NCRN displaying attributes appropriate for geolocation assessment.

Geologic Resources Inventory (GRI) Data

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 to the 270 parks in the I&M program. The GRI team provides three products to each park that can be useful in the determination of stratotypes: (1) a summary document from an initial scoping meeting, (2) digital geologic map data in a geographic information system (GIS) format, and (3) a GRI report.

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 meeting summaries serve as an interim report until the final report is delivered.

Following the scoping meeting, the GRI map team converts the geologic source maps identified in the mapping plan to GIS data in accordance with the GRI data model (https://www.nps.gov/articles/gri-geodatabase-model.htm). The GRI uses a unique "GMAP ID" value for each geologic source map, and all sources used to produce the GRI GIS data sets for the NCRN parks can be found in Appendix A. The GRI map data is the basis for this stratotype inventory as it is considered the "official" geologic dataset for the park. The list of units present in the GRI GIS data was used to search GEOLEX.

After the digital geologic map is completed, the GRI report team uses the map data, as well as the scoping summary and additional research, to prepare the GRI report. The GRI reports were utilized for additional information about geologic resources in a given park and connections to park landscape, history, or other resources. Posters that display the GRI GIS data over imagery of the park are also created as part of the report process. They are available with the reports or separately from the GRI publications page (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm).

Additional Considerations

There are several additional considerations for this inventory. The most up-to-date information available is necessary and is 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 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 cross state boundaries. Geologic formations and other geologic units that cross state boundaries may have different names or ranks in each of the states the units are mapped. For example, what is identified as the Potomac Formation in Virginia is identified as the Potomac Group in Maryland.

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.

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 NCRN parks.

All network-specific reports are peer-reviewed and submitted to the Natural Resources Stewardship and Science Publications Office for finalization.

Geology and Stratigraphy of the NCRN I&M Network Parks

The National Capital Region Inventory & Monitoring Network (NCRN) consists of 11 national park units in Maryland, Virginia, Washington, D.C., and West Virginia (Figure 4). These park units include Antietam National Battlefield (ANTI), Catoctin Mountain Park (CATO), Chesapeake and Ohio Canal National Historical Park (CHOH), George Washington Memorial Parkway (GWMP), Harpers Ferry National Historical Park (HAFE), Manassas National Battlefield Park (MANA), Monocacy National Battlefield (MONO), National Capital Parks-East (NACE), Prince William Forest Park (PRWI), Rock Creek Park (ROCR), and Wolf Trap National Park for the Performing Arts (WOTR). The parks that comprise the National Capital Region Network protect a combined 29,468 hectares (72,818 acres) varying in size from 52 hectares (130 acres) in WOTR to 7,936 hectares (19,612 acres) in CHOH.

Figure 4. Map of National Capital I&M Network parks including: Antietam National Battlefield (ANTI), Catoctin Mountain Park (CATO), Chesapeake and Ohio Canal National Historical Park (CHOH), George Washington Memorial Parkway (GWMP), Harpers Ferry National Historical Park (HAFE), Manassas National Battlefield Park (MANA), Monocacy National Battlefield (MONO), National Capital Parks-East (NACE), Prince William Forest Park (PRWI), Rock Creek Park (ROCR), and Wolf Trap National Park for the Performing Arts (WOTR; not labeled on the map) (NPS).

The geology of the NCRN forms the foundation of a diverse landscape consisting of parks, forest, parkways, trails, monuments, memorials, historic sites, scenic areas, parks for the performing arts, and Civil War-era battlefields. The bedrock underlying the park units of the NCRN dates back to the Mesoproterozoic and records the rich geologic evolution of eastern North America over hundreds of millions of years. Significant geologic events during this time include the opening of the ancient Iapetus Ocean to form the Atlantic Ocean, formation of the Appalachian Mountains, rifting of the supercontinent Pangaea, and subsequent erosion and modification by surface processes to form the modern landscape. See Appendix B for a geologic time scale.

The parklands of the NCRN occur in all of the major physiographic provinces of the central Appalachian region except the Appalachian Plateaus Province. The NCRN parks occur in the following provinces (from east to west): 1) Coastal Plain; 2) Piedmont; 3) Blue Ridge; and 4) Valley and Ridge (Figure 1). The Coastal Plain Province has the lowest topographic relief of these provinces and consists of undeformed, unconsolidated sedimentary rocks and deposits that are separated from deformed, metamorphic rocks of the Piedmont along a transitional boundary known as the "Fall Line" (Figure 1). The Blue Ridge Province is characterized by a highland composed of crystalline, quartz-rich and erosion-resistant metamorphic rocks. The Valley and Ridge and Piedmont Provinces are characterized by low, rolling hills punctuated by a steep gorge along the Potomac River (Southworth and Denenny 2006). The varied geologic history created a wide variety of rocky types and exposures throughout the NCRN that geologists have used as the basis of geologic maps for more than 200 years. Many of the rocks also contain fossils as summarized by Kenworthy and Santucci (2004).

Precambrian

Precambrian-age rocks (>541 million years old) underlie seven of the 11 park units of the NCRN, with some of the oldest bedrock consisting of Mesoproterozoic-age metamorphic and meta-igneous rocks in CHOH and HAFE. Neoproterozoic-age rocks of the Catoctin Formation are mapped in CATO, CHOH, and HAFE. The Neoproterozoic Swift Run Formation is complexly interlayered with basalts of the Catoctin Formation in HAFE (Badger 1999; Tollo et al. 2004). Diabase dikes of Neoproterozoic age are found in both CHOH and HAFE. Metamorphic and meta-igneous rocks of the Neoproterozoic–Cambrian Mather Gorge Formation form the bedrock of CHOH, GWMP, and WOTR, and similarly aged strata of the Ijamsville Phyllite are found in CHOH and MONO. Unnamed Neoproterozoic–Cambrian metamorphic rocks are mapped in GWMP and ROCR.

Paleozoic

Paleozoic bedrock is mapped in 10 of the 11 park units of the NCRN and represent a diverse assemblage of Cambrian through Mississippian-age units (between 541 million and 323 million years old). Rocks of the Cambrian Chilhowee Group (Loudoun, Weverton, Harpers, and Antietam Formations) are widely distributed amongst CATO, CHOH, and HAFE. Other Cambrian-age strata that are mapped in multiple park units include the Araby Formation (CHOH, MONO), Conococheague Formation (ANTI, CHOH), Elbrook Limestone (ANTI, CHOH), Frederick Formation (CHOH, MONO), Laurel Formation (ROCR), Sykesville Formation (CHOH, GWMP, ROCR), Tomstown Formation (ANTI, CHOH, HAFE), and Waynesboro Formation (ANTI, CHOH, HAFE).

Widely mapped strata of the Ordovician Period include metamorphic and meta-igneous rocks of the Georgetown Intrusive Suite and Dalecarlia Intrusive Suite in CHOH, GWMP, and ROCR. An extensive sequence of Ordovician units underlies CHOH, including the Stonehenge Limestone, Rockdale Run Formation, Pinesburg Station Dolomite, Row Park Limestone, New Market Limestone, Chambersburg Limestone, and Martinsburg Formation. In addition to the igneous units mentioned above, the Ordovician Bear Island Granodiorite and Clarendon Granite underlie GWMP. In PRWI the Ordovician is represented by the Lake Jackson pluton, Quantico Formation, Lunga Reservoir Formation, and Chopawamsic Formation. Unnamed plutonic rocks of Ordovician age are mapped in southeastern WOTR.

Rocks of the Silurian Period include felsic igneous rocks in PRWI as well as units underlying the northern portion of CHOH that include the Tuscarora Formation, Rose Hill Formation, Keefer Sandstone, McKenzie Formation, Bloomsburg Formation, Wills Creek Formation, and Tonoloway Limestone. Some of the youngest Paleozoic strata in the NCRN are found in northern CHOH and consist of the Silurian–Devonian Keyser Limestone and Devonian Helderberg Formation, Oriskany Formation, Needmore Formation, Marcellus Shale, Mahantango Formation, Scherr Formation, Brallier Formation, Foreknobs Formation, Hampshire Formation, and lower Rockwell Formation.

Mesozoic

Rocks of the Mesozoic Era (between 252 million and 66 million years old) are restricted to a small number of units found within roughly half of the parks of the NCRN. The Triassic Period is represented by the Manassas Sandstone and Bull Run Formation (Balls Bluff Siltstone Member) in CHOH. Rocks of the Bull Run Formation also occur in MANA, in addition to several unnamed Triassic-age diabase dikes, sills, and thermally metamorphosed rocks. Jurassic-age diabase dikes occur in the region of Harpers Ferry in both CHOH and HAFE. Rocks of the Cretaceous Potomac Formation are distributed amongst GWMP, NACE, PRWI, and ROCR. The Severn Formation is also mapped in NACE.

Cenozoic

The Cenozoic (rocks and deposits <66 million years old) is represented within every park unit of the NCRN and includes a limited number of formally named geologic units such as the Paleocene Brightseat Formation in GWMP and NACE and Paleocene Aquia Formation, Eocene Marlboro Clay and Nanjemoy Formation, and Miocene Calvert Formation in NACE. Surficial deposits are widespread and include Neogene–Pleistocene terrace deposits (GWMP, NACE, PRWI, ROCR), Quaternary-age fluvial and estuarine deposits (NACE, PRWI), terrace deposits (ANTI, CATO, CHOH, MANA, MONO, PRWI), alluvium (ANTI, CATO, CHOH, HAFE, MANA, MONO, NACE, PRWI, ROCR, WOTR), and colluvium (CHOH, HAFE, MONO, ROCR, WOTR).

Antietam National Battlefield (ANTI)

Park Establishment

Antietam National Battlefield (ANTI) is located just outside the town of Sharpsburg, Maryland, approximately 14 km (9 mi) north of Harpers Ferry in Washington County, Maryland (Figure 5). Established on August 30, 1890, ANTI encompasses about 1,307 hectares (3,230 acres) and commemorates the bloodiest single-day battle in American history. The Battle of Antietam in 1862 ended General Robert E. Lee's first invasion of the North during the Civil War and resulted in more than 23,000 soldiers killed, wounded, or missing (National Park Service 2016a). Photographs taken at Antietam in the days following the battle are some of the first to publicly display the horrors associated with the American Civil War. The battle provided President Lincoln with the opportunity to issue the preliminary Emancipation Proclamation, emphasizing the Union's intent to abolish slavery following the war. Considered one of the best-preserved Civil War areas in the NPS, the landscape of ANTI includes the battlefield site, monuments, roadways, fences, an observation tower, tablets documenting troop movements and artillery locations, as well as other associated features established by the War Department (National Park Service 2013a).

Geologic Summary

ANTI is situated within the Great Valley Section (=Shenandoah Valley of Virginia) of the Valley and Ridge physiographic province, a region characterized by long, parallel ridges separated by valleys that typically exhibit karst topography due to the underlying carbonate rocks (Southworth and Denenny 2006). The rural landscape of ANTI consists of rolling hills dotted with farmsteads, fields, and pastures that are reminiscent of the Civil War-era battle. The bedrock underlying ANTI is composed of carbonate and clastic sedimentary rocks that were deposited on the ancient continental margin of the supercontinent Laurentia (ancestral North America) during the Cambrian and Ordovician that were subsequently buried for about 200 million years and then folded and uplifted during the late Paleozoic Alleghenian Orogeny approximately285 million years ago (Figure 6; Southworth and Denenny 2006). Most of the park is underlain by the Cambrian Elbrook Limestone and Cambrian–Ordovician Conococheague Limestone (including the Big Spring Station Member). Sinkholes have developed throughout most of the carbonate formations in the ANTI region but are more heavily concentrated in the Elbrook and Conococheague Limestones (Thornberry-Ehrlich 2005). Underlying the eastern portion of ANTI are older, Cambrian-age units of the Waynesboro Formation (Red Run, Cavetown, and Chewsville Members) and Tomstown Formation (Dargan Member).

Stratotypes

There are no designated stratotypes identified within the boundaries of ANTI. Although the Cambrian Antietam Formation shares its name with ANTI, the unit is not mapped within the park and its type locality exposures occur along the tributaries of Antietam Creek southeast of the park (Southworth et al. 2009). There are 34 identified stratotypes located within 48 km (30 mi) of ANTI boundaries, provided in Appendix C for reference in case of future park boundary expansion.

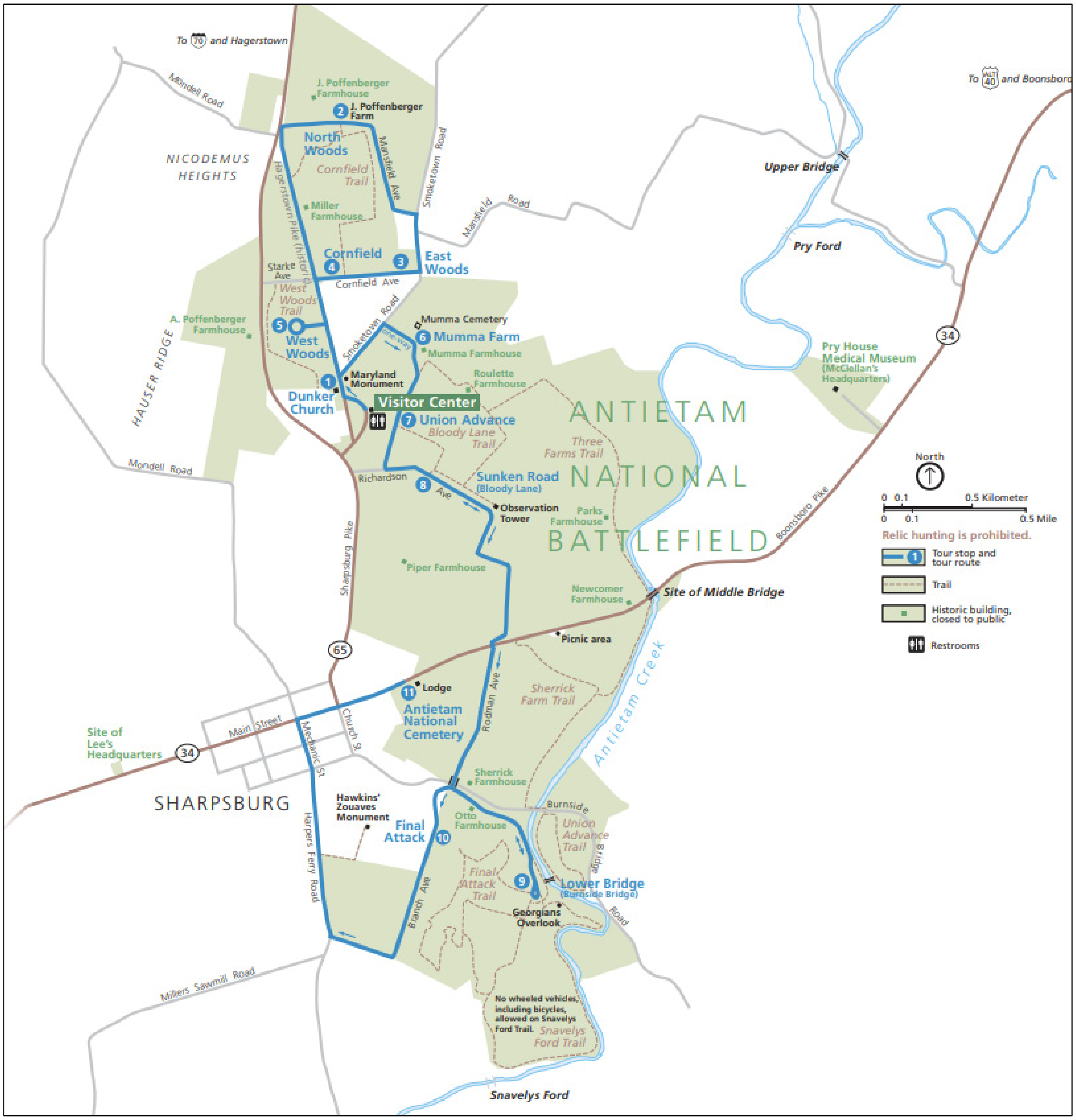


Figure 5. Park map of ANTI, Maryland (NPS).

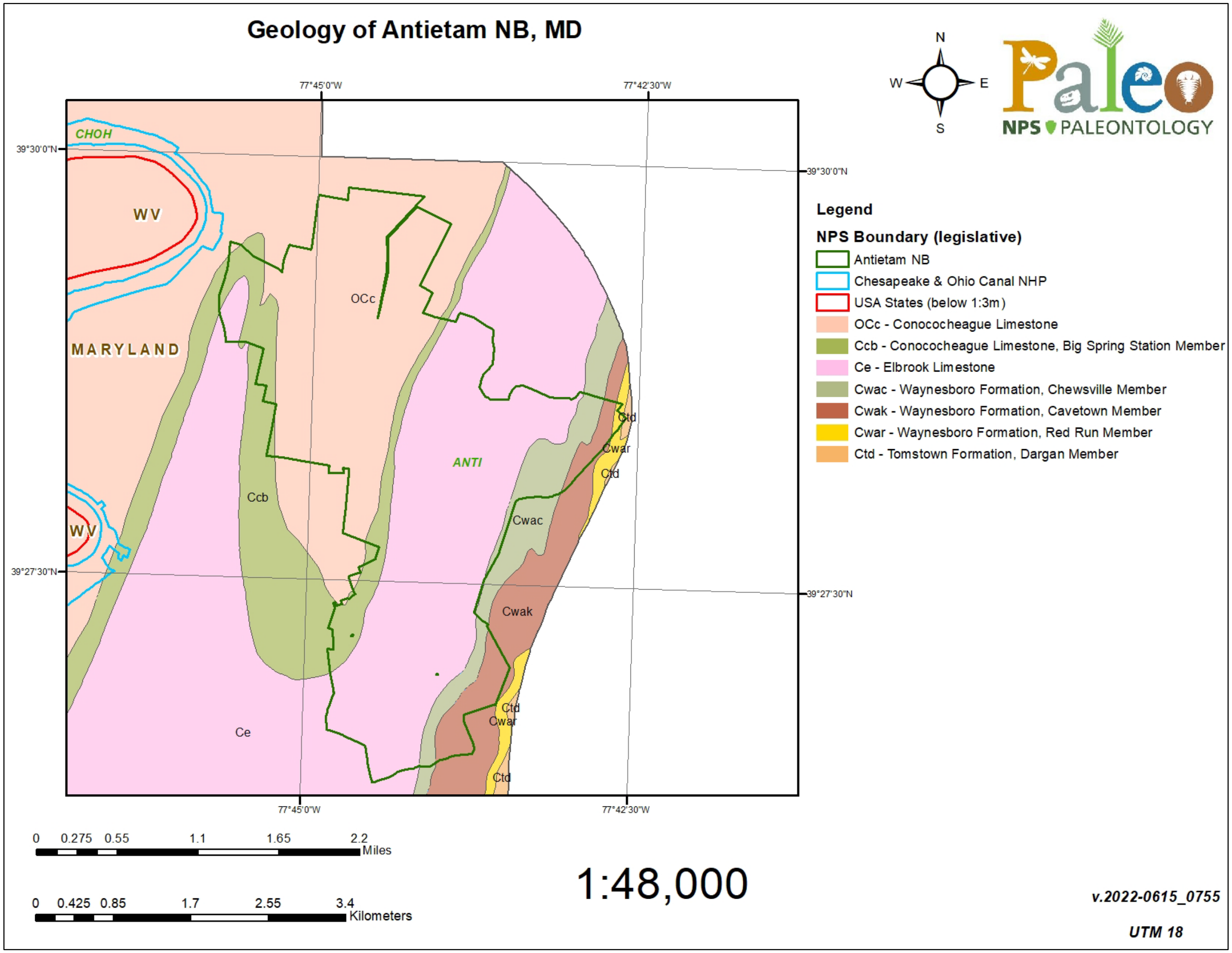


Figure 6. Geologic map of ANTI, Maryland. Data modified from ANTI GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048802.

Catoctin Mountain Park (CATO)

Park Establishment

Catoctin Mountain Park (CATO) comprises the easternmost ridge of the Blue Ridge Mountains located about 89 km (55 mi) northwest of Washington, D.C. in Frederick County, Maryland (Figure 7). Originally established as Catoctin Recreation Demonstration Area on January 7, 1935, the park unit was renamed and redesignated on July 12, 1954 (National Park Service 2016a). Catoctin Mountain Park encompasses approximately 2,384 hectares (5,891 acres) and provides quality recreational opportunities in the Catoctin Mountains and serves as a setting and buffer for the presidential retreat site Camp David. The park represents an outstanding example of President Franklin D. Roosevelt's New Deal-era legislation, and protects hardwood forest, historic buildings, camps, and pristine waterways while offering panoramic vistas of the Monocacy Valley. CATO is part of a larger protected area that includes Cunningham Falls State Park, the Frederick and Thurmont watersheds, and Gambrill State Park (Thornberry-Ehrlich 2009a).

Geologic Summary

Located on the easternmost portion of the Blue Ridge physiographic province of Maryland and northern Virginia, the landscape of CATO consists of rolling hills and narrow ridgetops separated by steep-sloped valleys and ravines (Thornberry-Ehrlich 2009a). The park is situated on the eastern slopes of Catoctin Mountain, which forms the eastern limb of the larger Blue Ridge–South Mountain anticlinorium. The bedrock underlying CATO is predominantly composed of metabasalt and metarhyolite of the Neoproterozoic Catoctin Formation. Meta-igneous rocks of the Catoctin Formation are interpreted as the remnants of continental flood basalts that erupted at a time when North America rifted apart to form the Iapetus Ocean (Mitra 1989; Badger 1992). Younger, Cambrian-age metamorphic units are mapped in the southeastern portion of CATO and include rocks of the Chilhowee Group (Loudoun, Weverton, and Harpers Formations) (Figure 8). CATO and the surrounding area provides an opportunity to observe regional-scale deformation and metamorphism resulting from three major tectonic events (Taconic, Acadian, and Alleghenian Orogenies) that constructed the Appalachian Mountains.

Stratotypes

There are no designated stratotypes identified within the boundaries of CATO. Although the Neoproterozoic Catoctin Formation was named after Catoctin Mountain by Keith (1894), no formal stratotype was ever designated. Additionally, the Cambrian Wolf Rock Quartzite Bed of the Maryland Heights Member of the Weverton Formation was named by Brezinski (2021) after the Wolf Rock Trail in CATO, but no formal stratotype has yet been designated (see "Recommendations"). There are 34 identified stratotypes located within 48 km (30 mi) of CATO boundaries, provided in Appendix C for reference in case of future park boundary expansion.

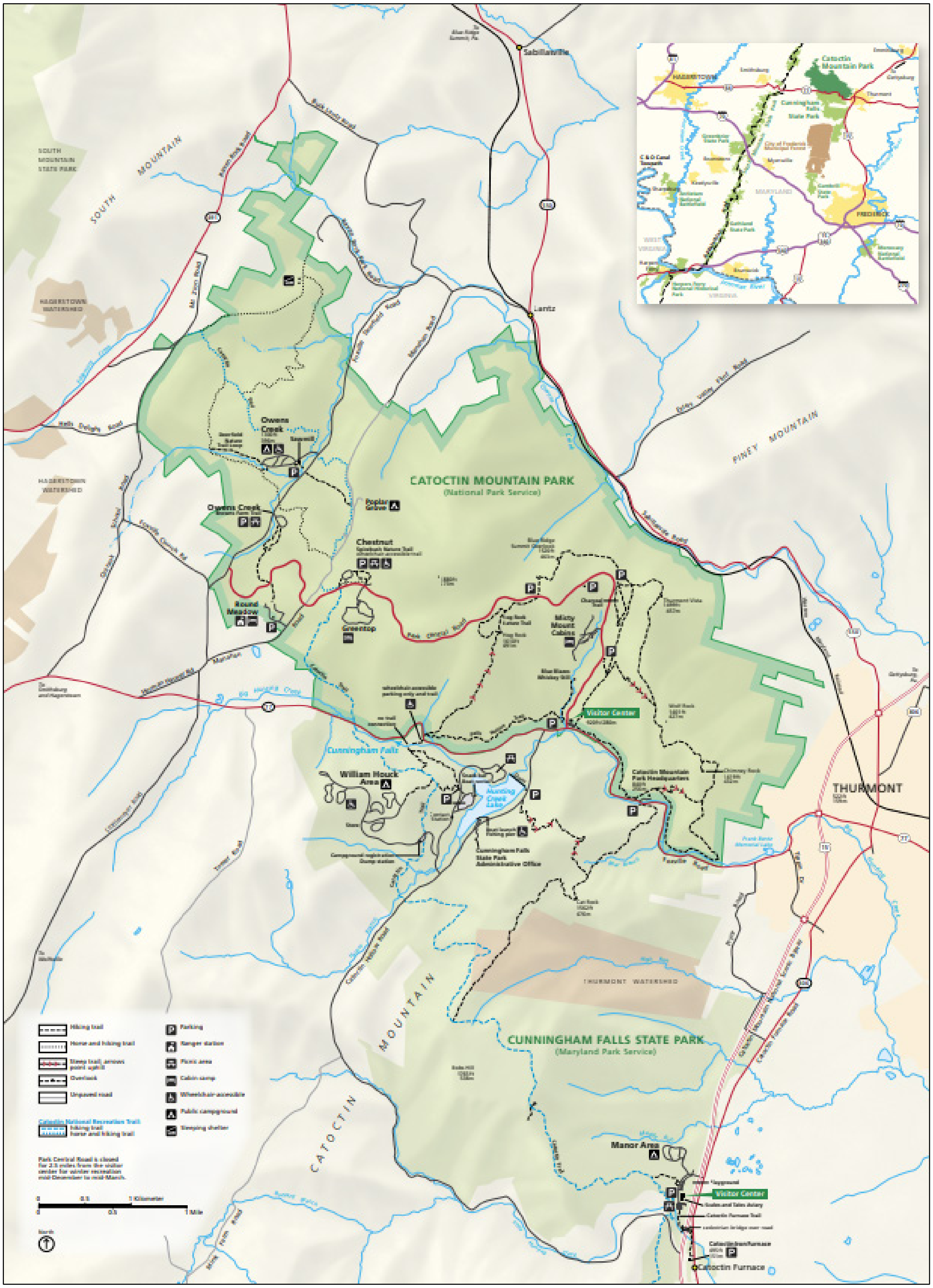


Figure 7. Park map of CATO, Maryland (NPS).

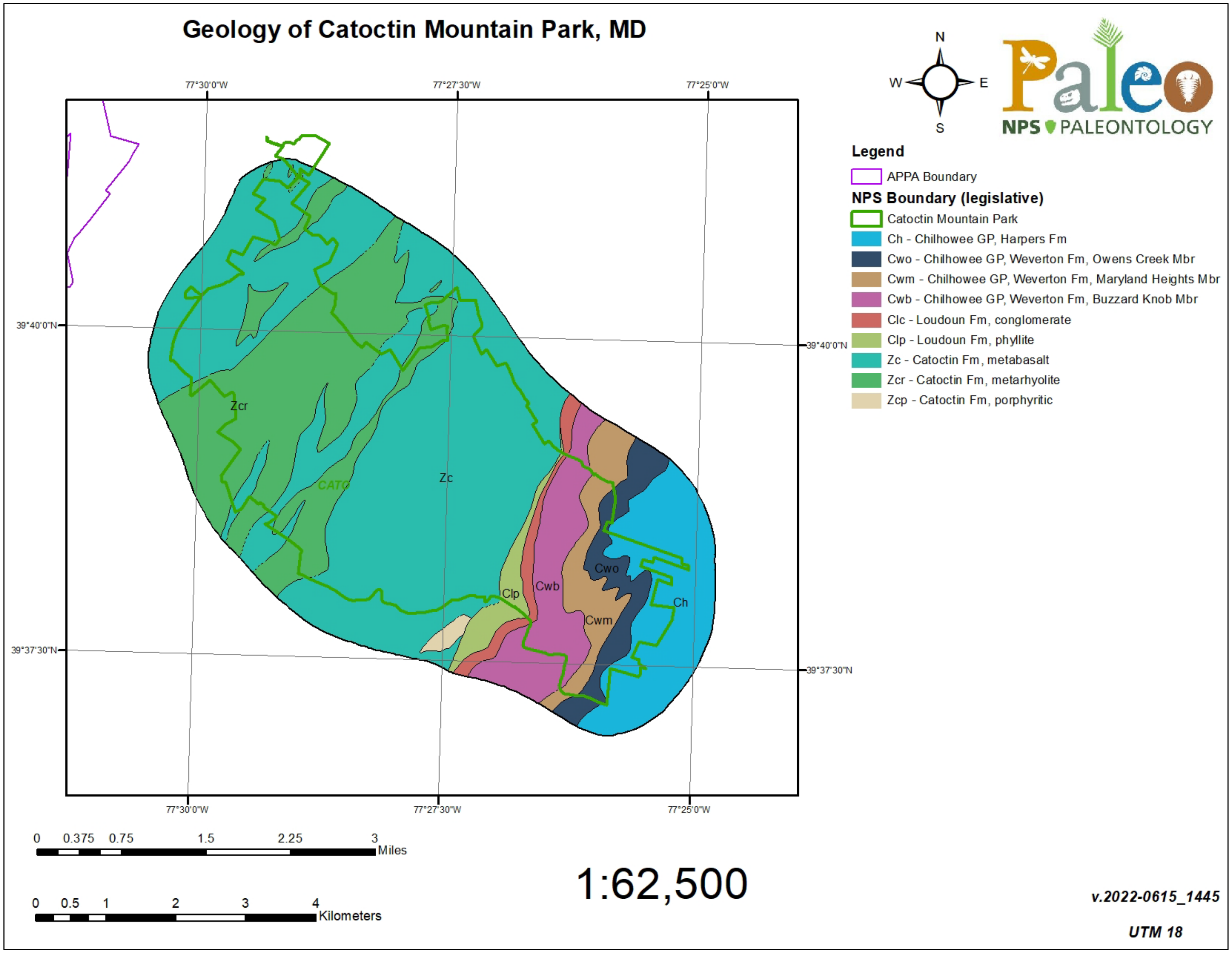


Figure 8. Geologic map of CATO, Maryland. Data modified from CATO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2164784.

Chesapeake and Ohio Canal National Historical Park (CHOH)

Park Establishment

The Chesapeake and Ohio Canal National Historical Park (CHOH) follows the route of the 297 km (184.5 mi)-long canal along the Potomac River between Washington, D.C. and Cumberland, Maryland (Figure 9). Built between 1828 and 1850, CHOH crosses portions of Alleghany, Frederick, Montgomery, and Washington Counties, Maryland, and abuts Berkeley, Hampshire, Jefferson, Mineral, and Morgan Counties, West Virginia; and Washington, D.C. The upper canal of CHOH was proclaimed a national monument on January 18, 1961, and the park unit was later redesignated and expanded as a national historical park on January 8, 1971 (National Park Service 2016a). Inspired by George Washington's vision of an industrial corridor along the Potomac River, CHOH served as an important transportation route that was primarily used to deliver coal from western Maryland to the port of Georgetown in Washington, D.C. (Thornberry-Ehrlich 2005). The Chesapeake and Ohio Canal Historical Park preserves the 19th century canal, more than 1,300 historic structures, the scenic 24 km (15 mi)-long Potomac Gorge, and archeological resources that document 13,000 years of human habitation along the Potomac River (National Park Service 2013b).

Geologic Summary

Along its entire length, CHOH traverses three physiographic provinces in eastern North America (from east to west): 1) Piedmont Plateau; 2) Blue Ridge; and 3) Valley and Ridge. The main obstacle the C&O Canal was constructed to alleviate is known as the Fall Line, a transition zone from softer, less consolidated rocks of the Coastal Plain to more resistant metamorphic rocks of the Piedmont Plateau. The Fall Line forms an area of ridges, waterfalls, and rapids that stretch over 32 km (20 mi) of the Potomac River from Theodore Roosevelt Island to Seneca Falls with Great Falls being an iconic viewpoint in the Potomac Gorge (Southworth and Denenny 2006). The bedrock underlying CHOH is a diverse assemblage of formations spanning from the Precambrian to the Mesozoic (Figures 10–15). Some of the oldest rocks mapped along the C&O Canal include Mesoproterozoic-age metamorphic and meta-igneous rocks, with the youngest units represented by Jurassic-age diabase dikes in the region of Harpers Ferry, West Virginia. Along its traverse CHOH provides an excellent opportunity to examine a cross-sectional view of the complex geology of the central Appalachian Mountains region and understand how the canals construction contributed to the development of the area (Southworth et al. 2001).

Stratotypes

CHOH contains 14 identified stratotypes that are subdivided into three type sections, two type localities, one type area, and eight reference sections (Table 2; Figure 16). Although the Ordovician Georgetown Intrusive Suite (Hopson 1964) and Bear Island Granodiorite (Cloos and Cooke 1953) were named after geographic locations associated within CHOH, these units currently lack formal stratotype designations (see "Recommendations"). The Balls Bluff Siltstone Member of the Bull Run Formation has a notable type section located in the river bluffs of Balls Bluff National Cemetery across the Potomac River from milepost 34 of CHOH but is not within NPS property. In addition to the designated stratotypes located within CHOH, stratotypes located within 48 km (30 mi) of the park boundaries are provided in Appendix C for reference in case of future park boundary expansion.

Figure 9. Park map of CHOH (southern half), District of Columbia–Maryland–West Virginia (NPS).

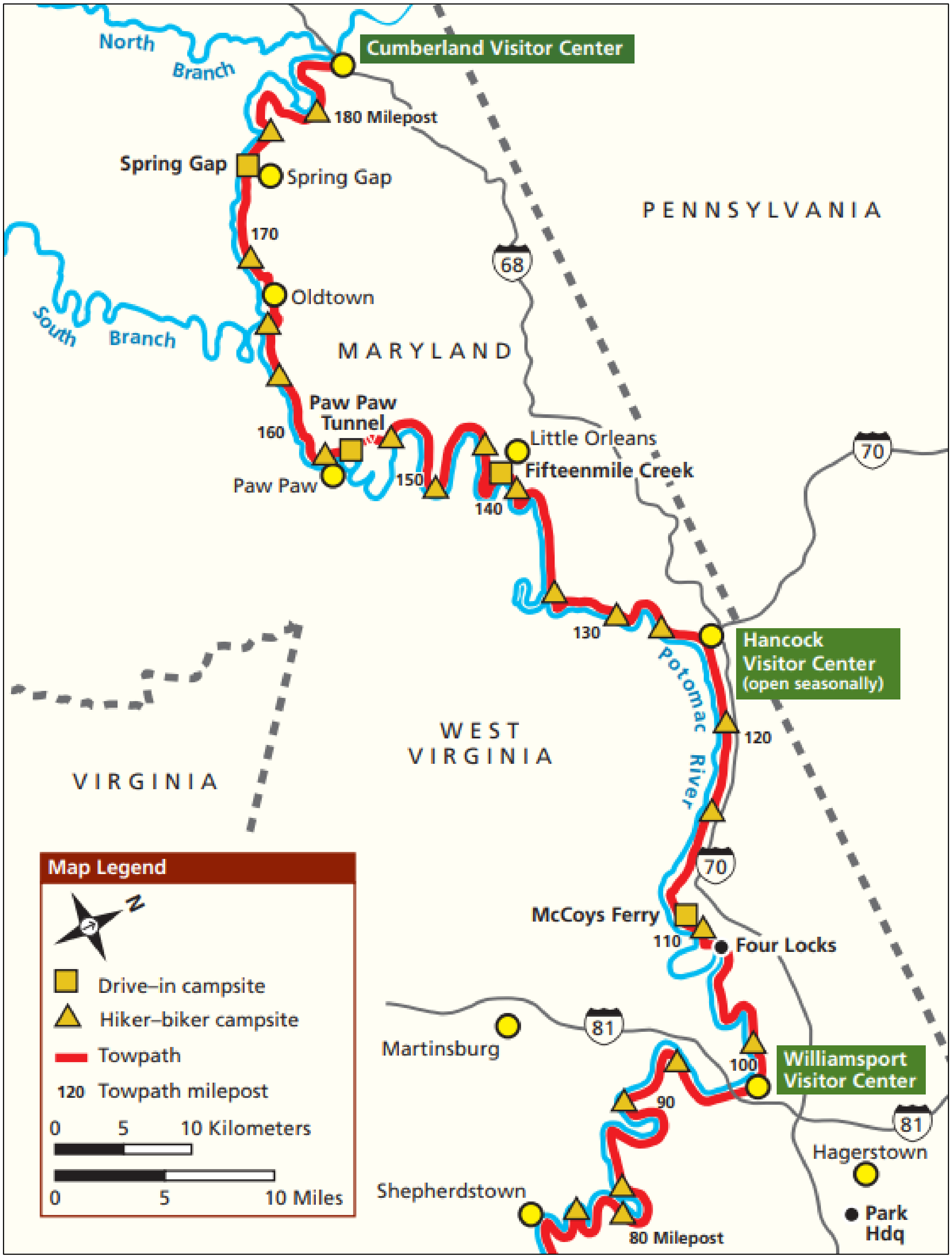


Figure 9. (cont.) Park map of CHOH (northern half), District of Columbia–Maryland–West Virginia (NPS).

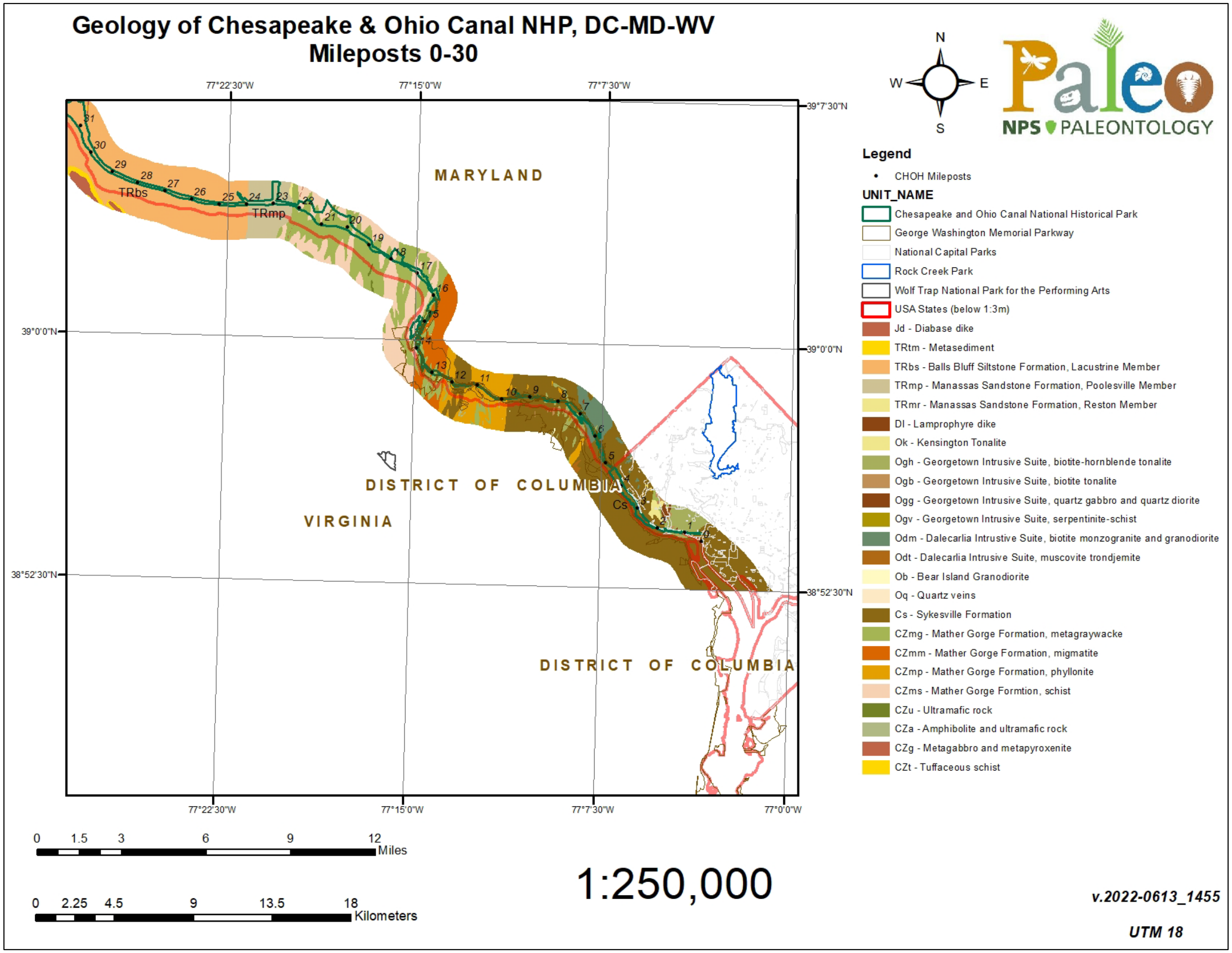


Figure 10. Geologic map of CHOH (miles 0–30), District of Columbia–Maryland–West Virginia. Data modified from CHOH GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048803.

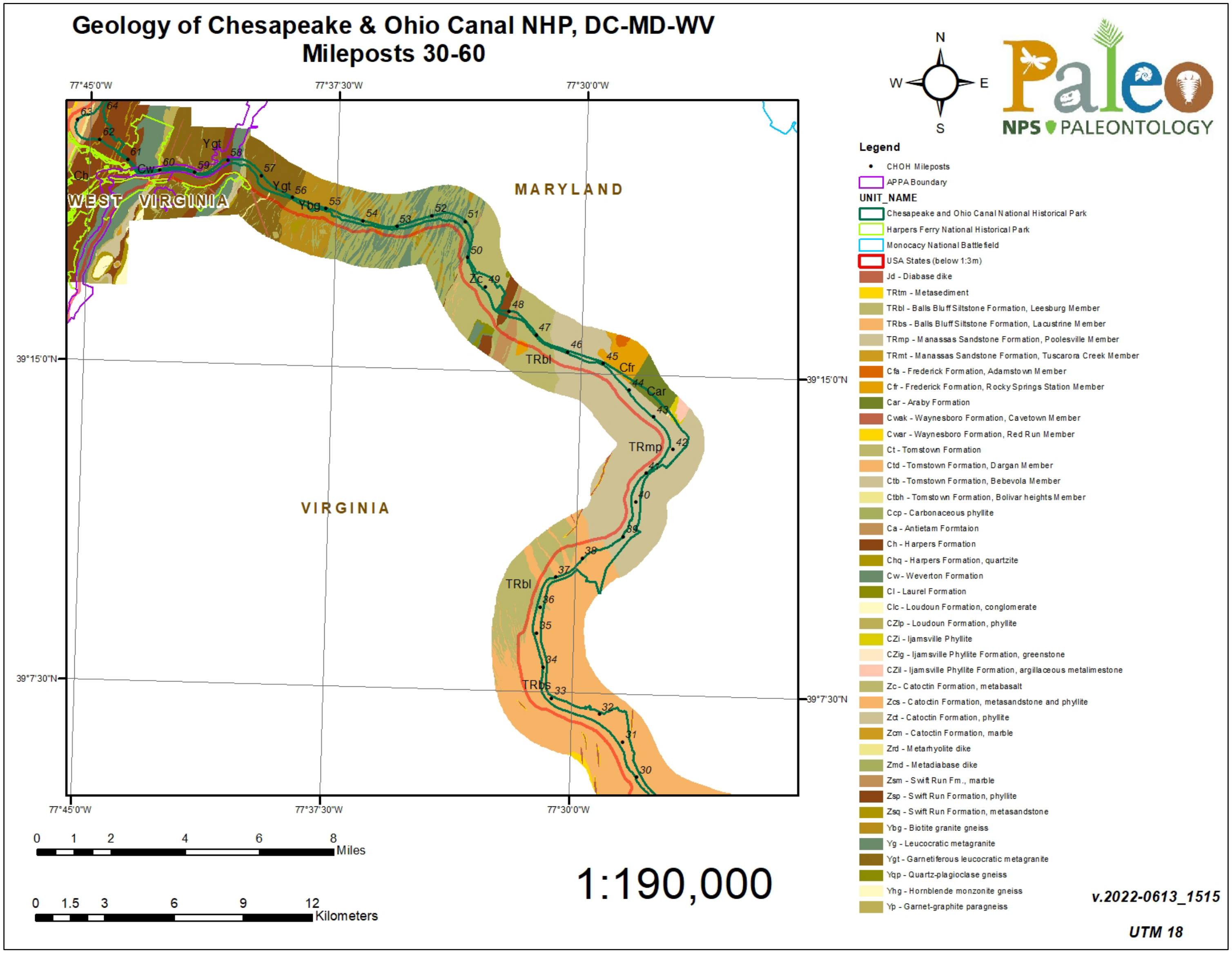


Figure 11. Geologic map of CHOH (miles 30–60), District of Columbia–Maryland–West Virginia. Data modified from CHOH GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048803.

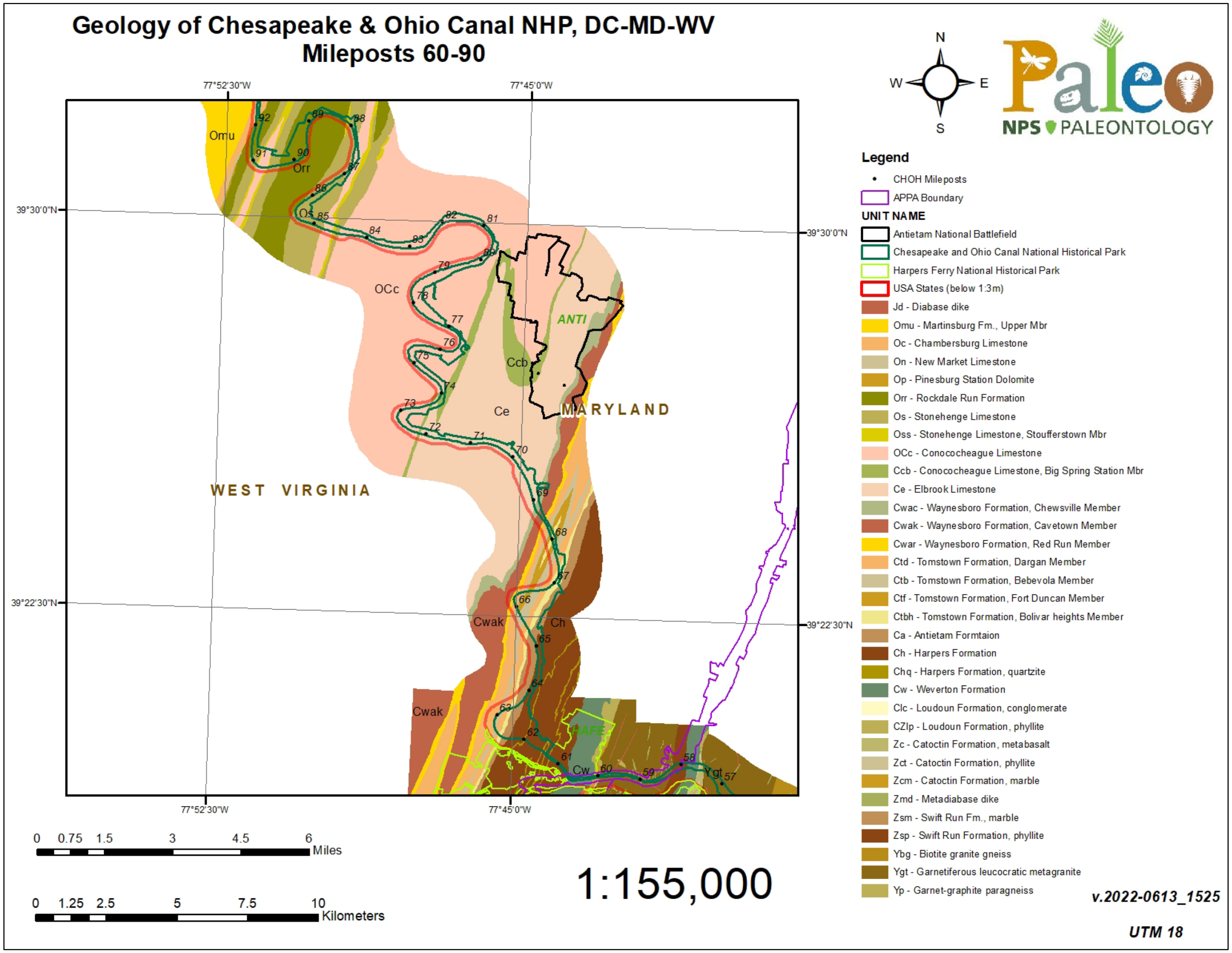


Figure 12. Geologic map of CHOH (miles 60–90), District of Columbia–Maryland–West Virginia. Data modified from CHOH GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048803.

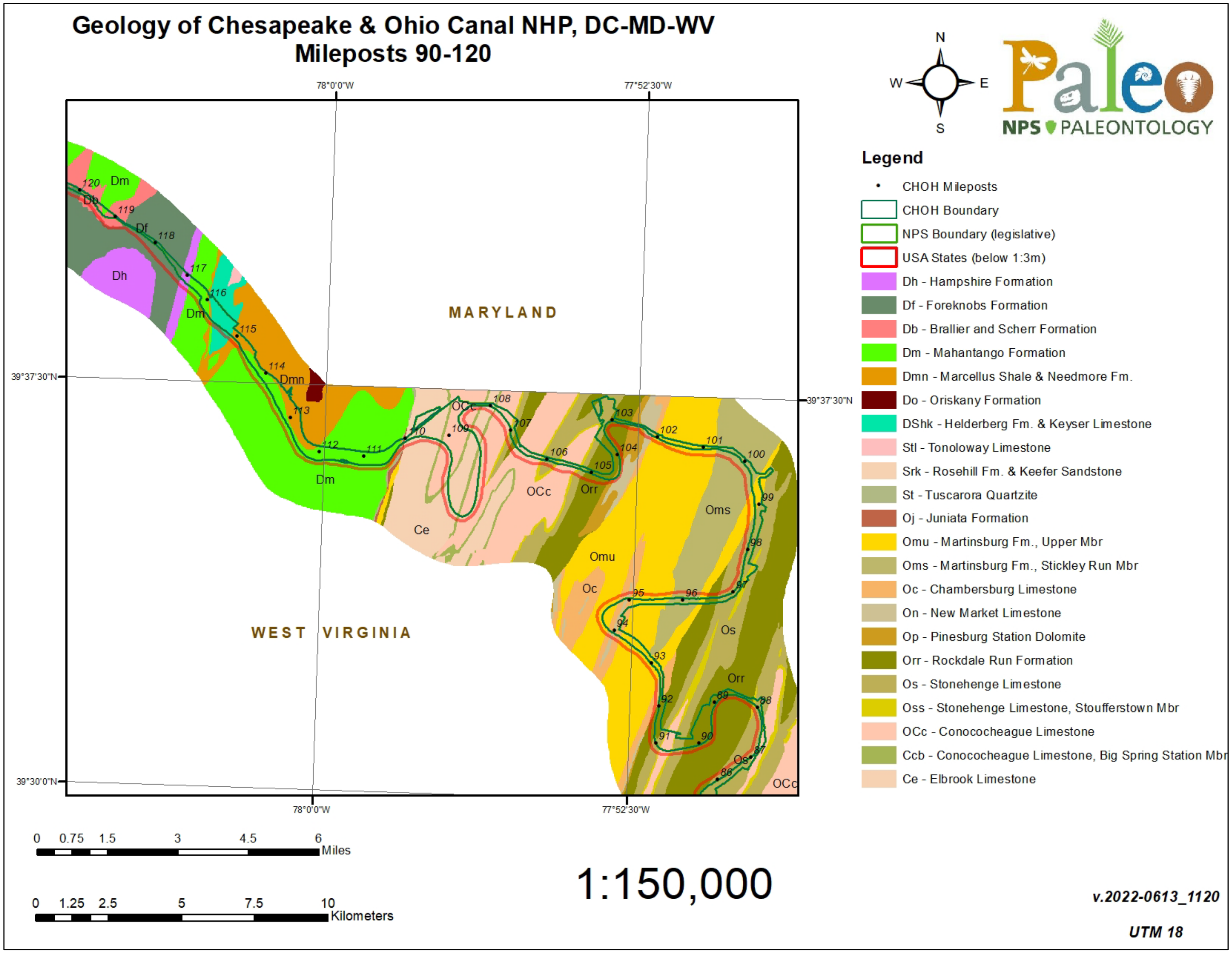


Figure 13. Geologic map of CHOH (miles 90–120), District of Columbia–Maryland–West Virginia. Data modified from CHOH GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048803.

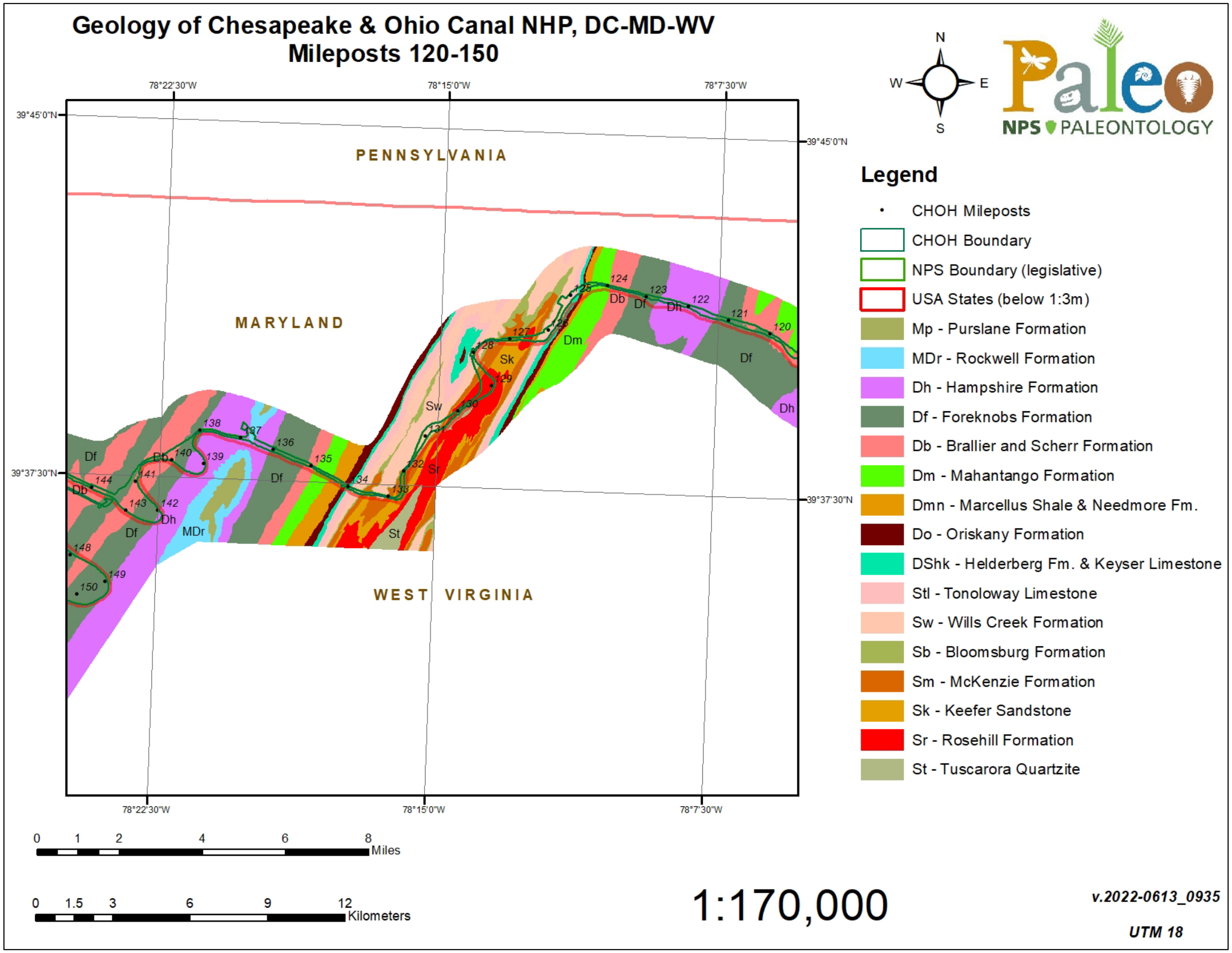


Figure 14. Geologic map of CHOH (miles 120–150), District of Columbia–Maryland–West Virginia. Data modified from CHOH GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048803.

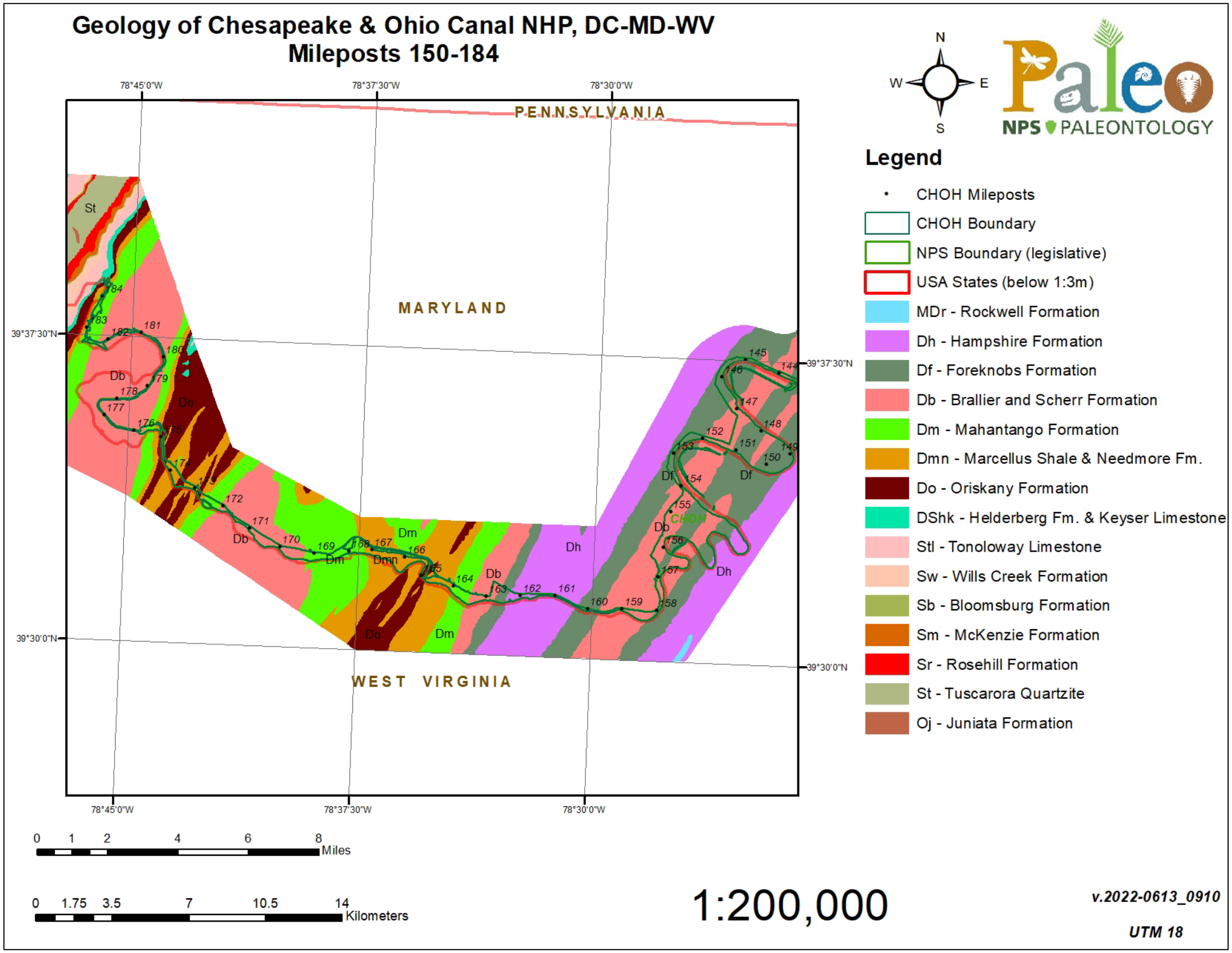


Figure 15. Geologic map of CHOH (miles 150–184), District of Columbia–Maryland–West Virginia. Data modified from CHOH GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048803.

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

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Balls Bluff Member, Bull Run Formation	Brezinski and Adams 2021	Reference section: along C&O Canal National Historic Park at Marble Quarry near milepost 38 (latitude 39°10′44.82″ N., longitude 77°29′34.14″ W.), in Montgomery County, MD.	Triassic
Poolesville Member, Manassas Sandstone (TRmp)	Lee and Froelich 1989; Brezinski and Adams 2021	Reference sections: 1. Outcrops along the northern bluffs of the Potomac River extending west for 2 km (1.2 mi) from the mouth of Seneca Creek [west-central Seneca 7.5′ Quadrangle], Montgomery County, MD. Section occurs near mileposts 23–25. 2. Along C&O Canal National Historic Park at Marble Quarry near milepost 38 (latitude 39°10′44.82″ N., longitude 77°29′34.14″ W.), in Montgomery County, MD.	Triassic
Hampshire Formation (Dh)	Brezinski et al. 2009; Brezinski and Cecil 2015	Reference section: located along the Chesapeake and Ohio Canal National Historical Park between mileposts 137 and 138, in Washington County, MD.	Devonian
Beekmantown Group (Orr, Op, Os, Oss)	Sando 1956	Reference section: begins at top of group in Potomac River bluff, about 305 m (1,000 ft) west of intersection with southwest face of Pinesburg Station quarry, and continues westward along C&O Canal for 1.6 km (1 mi), Washington County, MD. Section is near mileposts 102–130.	Ordovician
Pinesburg Station Dolomite (Op)	Brezinski 2018	Reference section: along the C&O Canal National Historical Park towpath at approximately milepost 102.5. The section begins at east end of parking area at end of Gift Road at approximately milepost 103.1 (latitude 39°36'59" N., longitude 77°53'15" W.), in Washington County, MD.	Ordovician
Dam Five Member, Stonehenge Limestone	Brezinski 2018	Type section: section measured along the C&O Canal National Historic Park towpath that begins at Lock 46 and proceeds eastward towards Dam Number Five (latitude 39°36'55" N., longitude 77°55'36" W.), in Washington County, MD. Section is near mileposts 106–107.	Ordovician
Conococheague Formation (OCc)	Brezinski et al. 2012; 2015	Reference section: located on the western flank (latitude 39°36′54″ N., longitude 77°56′49″ W.) and eastern flank (latitude 39°36′56″ N., longitude 77°55′36″ W.) of the Big Spring anticline near milepost 108, in Washington County, MD.	Cambrian–Ordovician

Table 2 (continued). List of CHOH stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Elbrook Limestone (Ce)	Brezinski 1996	Reference section: along Chesapeake and Ohio Canal beginning approximately 183 m (600 ft) east of the McCoy's Ferry aqueduct and continuing eastward to sharp northeastward bend toward Four Locks (Hedgesville Quadrangle), in Washington County, MD. Base of section is at latitude 39°36′30″ N., longitude 77°58′00″ W near milepost 109–110.	Cambrian
Dargan Member, Tomstown Formation (Ctd)	Brezinski 1992	Type section: along C&O Canal and adjacent Lime Kiln Road, 2.4 km (1.5 mi) northwest of village of Dargan, Washington County, MD. Section is near mileposts 67–68.	Cambrian
Fort Duncan Member, Tomstown Formation (Ctf)	Brezinski 1992	Type section: along C&O Canal, MD side (Washington Co.) of first northward meander of the Potomac River, west of Harpers Ferry, WV. Section is near milepost 63.	Cambrian
Harpers Formation (Ch, Chq)	Brezinski 1992; Southworth 1994; Southworth et al. 2009	Type locality: a collection of exposures on the cliffs along the Potomac River at Harpers Ferry, WV, near mileposts 61–62. Type area: exposures near Harpers Ferry, WV. ***Note: type locality/area shared with APPA and HAFE	Cambrian
Mather Gorge Formation (CZmg, CZmm, CZmp, CZms)	Drake and Froelich 1997	Type locality: the Mather Gorge on the Potomac River in the Falls Church and Vienna Quadrangles, MD–VA. Exposures occur near milepost 13. ***Note: Type locality shared with GWMP	Neoproterozoic –Cambrian

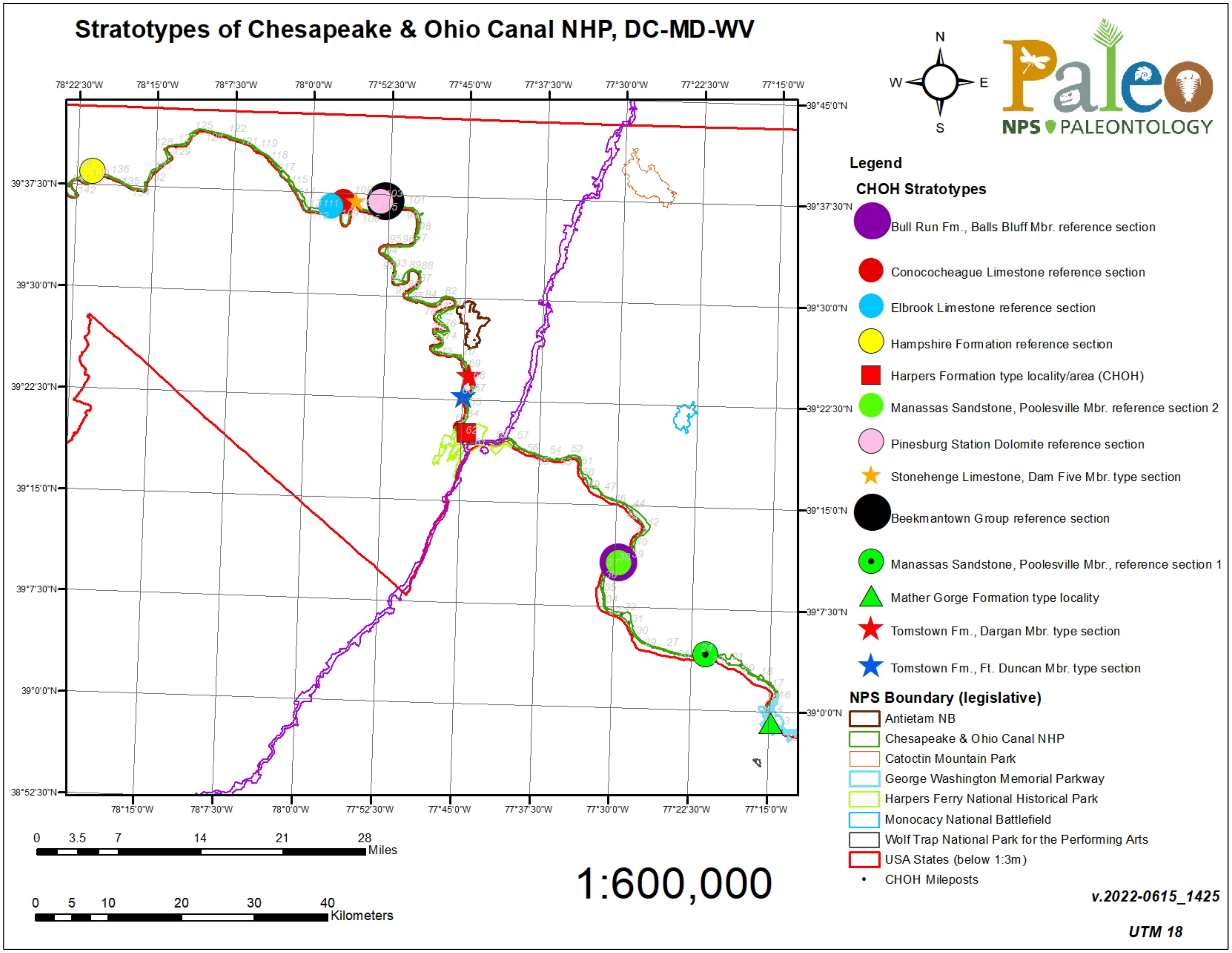


Figure 16. Modified geologic map of CHOH showing stratotype locations. The transparency of the geologic units layer has been increased.

Balls Bluff Siltstone Member, Bull Run Formation

The Balls Bluff Siltstone Member of the Bull Run Formation was originally referred to as the “Balls Bluff Siltstone” by Lee (1977), who named the unit after its type section exposure at Balls Bluff National Cemetery in Virginia. A reference section for the lower Balls Bluff Member is designated by Brezinski and Adams (2021) along CHOH at Marble Quarry near milepost 38 (latitude 39°10′44.82″ N., longitude 77°29′34.14″ W.), in Montgomery County, Maryland (Table 2; Figure 16). At the reference section, the member measures approximately 65 m (210 ft) thick and consists of massive red siltstone and thin-bedded, reddish-brown, fine- to medium-grained sandstone that becomes progressively finer up-section (Brezinski and Adams 2021). The Balls Bluff Siltstone Member overlies the Poolesville Member of the Manassas Sandstone at the reference section, and its upper contact is not exposed (Brezinski and Adams 2021).

Poolesville Member, Manassas Sandstone

The Triassic Poolesville Member of the Manassas Sandstone was formally introduced by Lee and Froelich (1989) and named after exposures of arkosic sandstone interbedded with siltstone and mudstone near Poolesville, Maryland. Lee and Froelich (1989) designated a reference section for the member along the northern bluffs of the Potomac River along the C&O Canal extending west for 2 km (1.2 mi) from the mouth of Seneca Creek [west-central Seneca 7.5′ Quadrangle] near CHOH mileposts 23–25 in Montgomery County, Maryland, (Table 2; Figure 16; see also Brezinski and Adams 2021 fig. 6). The Poolesville Member consists predominantly of thick bedded to massive arkosic sandstone composed of pinkish-gray feldspar and quartz sand in a clayey silt matrix and locally contains lenses of sandstone and quartzite pebble conglomerate (Lee and Froelich 1989). Common sedimentary structures include planar- to cross-laminations with localized large-scale trough cross-stratification (Lee and Froelich 1989). The member constitutes the bulk of the Manassas Sandstone and reaches a maximum thickness of approximately 1,000 m (3,280 ft) in the east-central parts of the Culpepper basin (Lee and Froelich 1989). At this reference section the Poolesville Member is overlain by the Balls Bluff Siltstone Member of the Bull Run Formation and is laterally and vertically gradational with the underlying Rapidan, Reston, and Tuscarora Creek Members of the Manassas Sandstone.

A second reference section of the Poolesville Member was assigned by Brezinski and Adams (2021) along the CHOH at Marble Quarry near milepost 38 (latitude 39°10′44.82″ N., longitude 77°29′34.14″ W.), in Montgomery County, MD (Table 2; Figure 16). Exposures of the upper Poolesville Member near milepost 38 are approximately 70 m (230 ft) thick and consist of fine- to medium-grained, cross-bedded sandstone interbedded with laminated, mud-cracked siltstone and planar-bedded, fine-grained sandstone (Brezinski and Adams 2021). At this reference section the Poolesville Member underlies the Balls Bluff Siltstone Member of the Bull Run Formation, and its basal contact is not exposed.

Hampshire Formation

The Devonian Hampshire Formation was introduced by Darton (1892) and named after its type area exposures in Hampshire County, east-central West Virginia. A reference section described by Brezinski et al. (2009) and Brezinski and Cecil (2015) is located along the CHOH towpath between mileposts 137 and 138 in Washington County, Maryland (Table 2; Figure 16). The reference section of the Hampshire Formation measures approximately 1,250 m (4,100 ft) thick and consists of red to reddish-brown, massive to thick-bedded sandstones that feature sharp, presumably erosional bases, containing shale–pebble lag conglomerates, and fine upward into thin intervals of interbedded red sandstone, siltstone, and mudstone (Brezinski et al. 2009). Reddish-brown interbedded siltstone and mudstone intervals that separate the thick-bedded sandstone units contain numerous thin bioturbated layers (Brezinski et al. 2009). Reference section exposures of the Hampshire Formation occur between the underlying Foreknobs Formation and overlying Rockwell Formation.

Beekmantown Group

The Ordovician Beekmantown Group was originally proposed as the Beekmantown Limestone by Clarke and Schuchert (1899) and named after exposures at Beekmantown in northeastern New York. The Beekmantown Limestone has been subsequently raised to group status by several authors including Butts (1940, 1945) and Sando (1956). A reference section of the group is exposed near present-day CHOH mileposts 102 and 103 along the C&O Canal between Millers Bend and Pinesburg Station, located in the bluffs of the Potomac River about 305 m (1,000 ft) west of the intersection with the southwest face of Pinesburg Station quarry, and continues westward along the C&O Canal for 1.6 km (1 mi), Washington County, Maryland (Table 2; Figure 16; Sando 1956). The Beekmantown Group at the reference section consists of three formations, in ascending order the Stonehenge Limestone, Rockdale Run Formation, and Pinesburg Station Dolomite. Thickness of the Beekmantown Group in the area of the reference section is approximately 1,100 m (3,600 ft) (Sando 1956).

Pinesburg Station Dolomite

The Ordovician Pinesburg Station Dolomite was introduced by Sando (1956), who named the formation after Pinesburg Station in Washington County, Maryland. Although Sando's (1956) type section designation on Suffecool Farm about 1.3 km (0.8 mi) northwest of Pinesburg Station is located outside the NPS boundary, an alternate reference section by Brezinski (2018) is located along the CHOH towpath at approximately milepost 102.5 (Table 2; Figure 16). The reference section begins at the east end of the parking area at the end of Gift Road at approximately milepost 103.1 (latitude 39°36′59″ N., longitude 77°53′15″ W), in Washington County, MD (Brezinski 2018). At the reference section the Pinesburg Station Dolomite forms a 133 m (437 ft)-thick sequence of medium- to light-gray, medium- to thick-bedded, fractured and lumpy dolomite that is locally laminated (Brezinski 2018). In this section, the Pinesburg Station Dolomite occurs between the underlying Rockdale Run Formation and overlying Row Park Limestone.

Dam Five Member, Stonehenge Limestone

The Ordovician Dam Five Member is the uppermost member of the Stonehenge Limestone assigned by Brezinski (2018) in the Hagerstown Valley of Maryland. Brezinski (2018) named the member after its type section exposure along the CHOH towpath that begins at Lock 46 and proceeds eastward towards Dam Number Five (latitude 39°36′55″ N., longitude 77°55′36″ W.), near CHOH mileposts 106 and 107, in Washington County, Maryland (Table 2; Figure 16). At the type section, the Dam Five Member measures 96 m (317 ft) thick and consists of medium- to dark-gray, medium-bedded, locally ribbon-bedded, intraclastic lime wackestone, packstone, and grainstone with numerous oolitic lime packstone strata in the upper section (Brezinski 2018). The Dam Five Member overlies the Funkstown Member (Stonehenge Limestone) and underlies the Rockdale Run Formation.

Conococheague Formation

The Cambrian–Ordovician Conococheague Formation was named by Stose (1908) after its type area exposures along the banks of the Conococheague Creek near the town of Scotland, south-central Pennsylvania. A reference section designated by Brezinski et al. (2012, 2015) is located near milepost 108 of CHOH on the western and eastern flanks of the Big Spring anticline in Washington County, Maryland (Table 2; Figure 16). At the reference section, the Conococheague Formation consists of three formal members (in ascending order): 1) Big Spring Station Member, composed of massive, thrombolitic dolomite beds and interbedded quartz-rich strata approximately 90 m (300 ft) thick; 2) Zullinger Member, composed of ribbony carbonate, finely laminated limestone and dolomite, and massive thrombolitic lime boundstone measuring over 400 m (1,300 ft) thick; and 3) Shady Grove Member, composed of interbedded intraclastic and sand lime grainstone about 100 m (330 ft) thick (Brezinski et al. 2012, 2015). The thick sequence representing the Zullinger Member has been interpreted to represent four transgressive (relative sea level rise) sequences composed of thrombolitic boundstone and ribbon lime mudstone separated by intervals dominated by ribbon carbonates and laminated dolomite (Brezinski et al. 2015). Reference section exposures of the Conococheague Formation occur between the underlying Elbrook Limestone and overlying Stonehenge Formation.

Elbrook Limestone

The Cambrian Elbrook Limestone was proposed by Stose (1906) and named after its type area exposures in the vicinity of the town of Elbrook in south-central Pennsylvania. Outcrops in the type area are sparse and scattered, leading to several reference sections published by Brezinski (1992, 1996). One particular reference section of the Elbrook Limestone is designated along the CHOH beginning approximately 180 m (600 ft) east of the McCoy's Ferry aqueduct and continuing eastward to a sharp northeastward bend toward Four Locks (Hedgesville Quadrangle), in Washington County, Maryland (Table 2; Figure 16; Brezinski 1996). The base of the section is located at latitude 39°36′30″ N., longitude 77°58′00″ W. near milepost 109–110, and parts of the section are also exposed along the CSXT railroad tracks that are subparallel to the canal (Brezinski 1996). At the reference section, the Elbrook Limestone forms a relatively complete stratigraphic section that is divided into three informal members (in ascending order): 1) a basal member consisting of cyclic interbedded shale (mudstone), dolomite, and light gray limestone about 210 m (700 ft) thick; 2) a middle member of medium-gray limestone measuring approximately 50 m (160 ft) thick; and 3) an upper member of interbedded algal limestone and tan, laminated dolomite about 430 m (1,400 ft) thick (Figures 17 and 18; Brezinski 1996). Exposures of the Elbrook Limestone underlie the Conococheague Formation and overlie the Chewsville Member of the Waynesboro Formation.

Figure 17. Interval of bioturbated limestone occurring near the base of the Elbrook Limestone reference section along CHOH tow path near milepost 109–110. Figure 5b from Brezinski (1996).

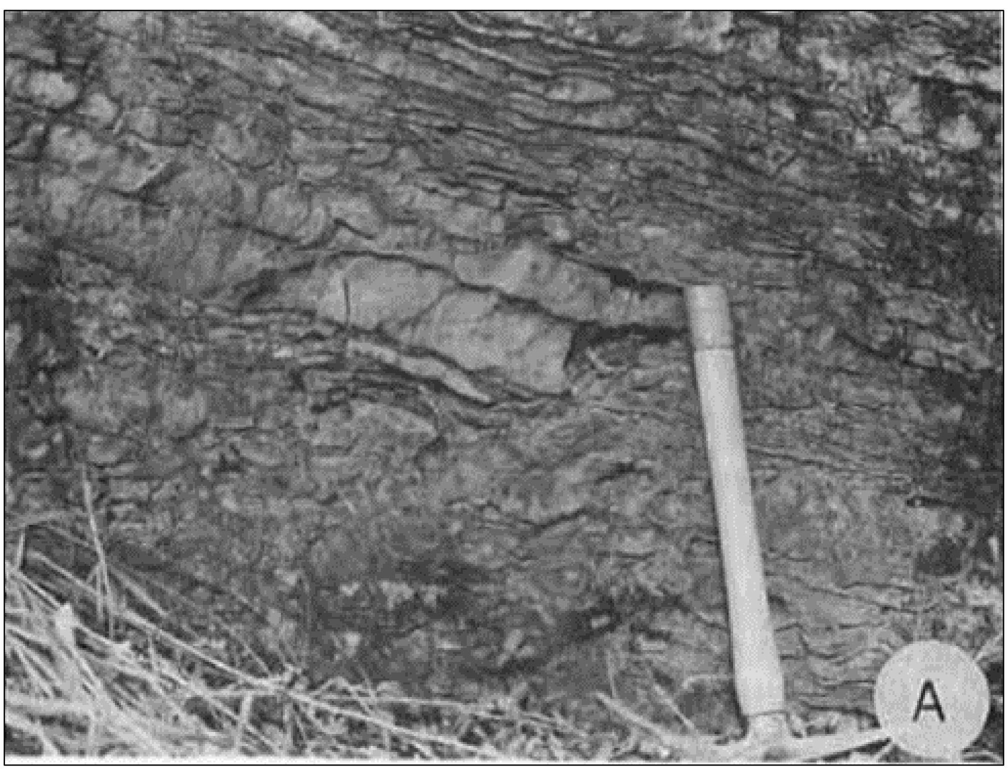


Figure 18. Thinly interbedded, fine-grained limestone and shaly limestone of the middle member of the Elbrook Limestone at the reference section. Figure 6A from Brezinski (1996).

Dargan Member, Tomstown Formation

The Cambrian Dargan Member is the uppermost interval of the Tomstown Formation assigned by Brezinski (1992). The unit is named after its type section along the C&O Canal and adjacent Lime Kiln Road, near CHOH mileposts 67 and 68, approximately 2.4 km (1.5 mi) northwest of the village of Dargan in Washington County, Maryland (Table 2; Figure 16; Brezinski 1992). At the type section the Dargan Member consists of vertically stacked, alternating, cyclic lithologies of dark-gray, bioturbated dolomite; medium- to dark-gray dolomite; interbedded dark-gray bioturbated and oolitic dolomite; dark-gray laminated limestone; and tan, laminated silty dolomite (Brezinski 1992). Approximately 140 m (450 ft) of continuous section is exposed at the type section, with the uppermost 40–60 m (120–200 ft) of the member concealed (Brezinski 1992). The Dargan Member underlies the Red Run Member of the Waynesboro Formation and overlies the Benevola Member of the Tomstown Formation.

Fort Duncan Member, Tomstown Formation

The Cambrian Fort Duncan Member of the Tomstown Formation was proposed by Brezinski (1992) and named after exposures along the Potomac River near the location of historic Fort Duncan, Maryland. Brezinski (1992) designated the type section along the C&O Canal on the Maryland side of the first northward meander of the Potomac River west of Harpers Ferry near milepost 63 in Washington County, Maryland (Table 2; Figure 16). The type section of the Fort Duncan Member consists of medium- to thick-bedded, dark gray dolomite measuring about 90 m (285 ft) thick that contains distinctive burrow mottling (bioturbation-derived texture) (Figure 19; Brezinski 1992). The Fort Duncan Member conformably underlies the Benevola Member of the Tomstown Formation and sharply overlies the Bolivar Heights Member of the Tomstown Formation.

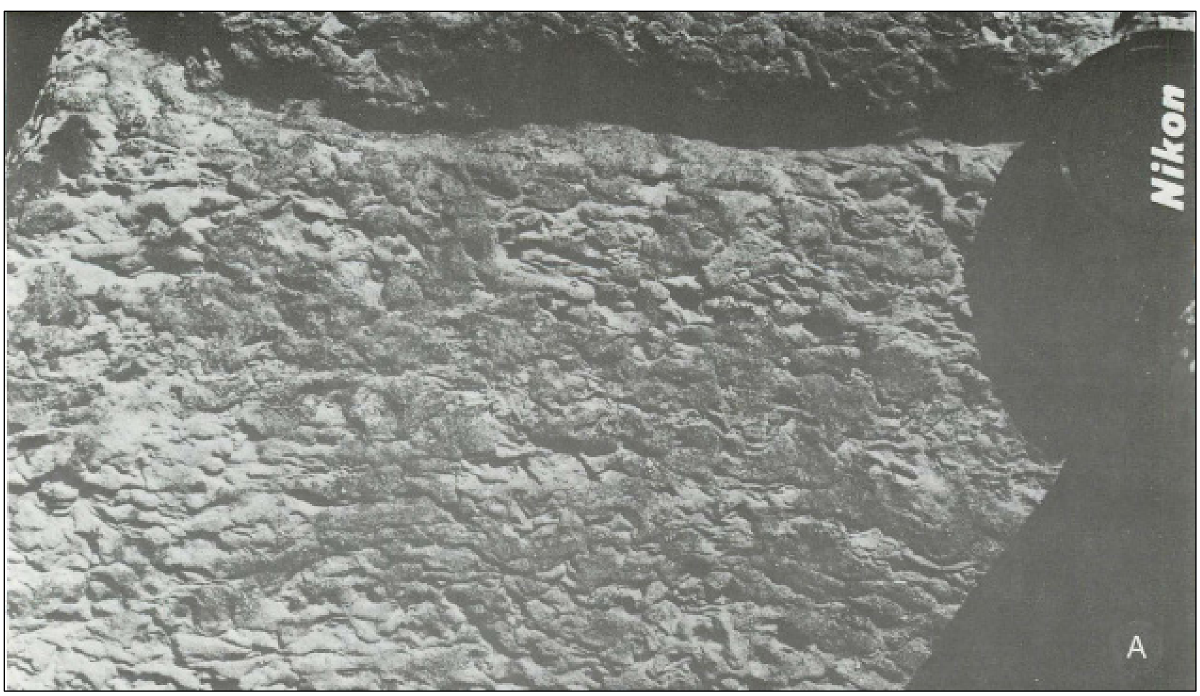


Figure 19. Characteristic burrow mottling of the dolomites of the Fort Duncan Member of the Tomstown Formation. Figure 18A from Brezinski (1992).

Harpers Formation

The Cambrian Harpers Formation was initially referred to as the Harpers Shale (Keith 1894) and named for exposures near Harpers Ferry, West Virginia. Brezinski (1992) designated the type area as exposures around Harpers Ferry, West Virginia, while Southworth (1994) and Southworth et al. (2009) designated a type locality as a collection of exposures on the cliffs along the Potomac River at Harpers Ferry, West Virginia, in the area of CHOH mileposts 61 and 62 (Table 2; Figure 16). Stratotype exposures of the Harpers Formation are shared amongst the park units of CHOH, HAFE, and the Appalachian National Scenic Trail (APPA). A more detailed description of the stratotype exposures is provided in the HAFE section.

Mather Gorge Formation

The Neoproterozoic–Cambrian Mather Gorge Formation was provisionally called the Peters Creek Schist by Drake and Morgan (1981) before it was redesignated by Rader and Evans (1993), Drake (1994), Fleming et al. (1994), and Drake and Froelich (1997). The type locality of the formation is the Mather Gorge on the Potomac River near CHOH milepost 13 in the Falls Church and Vienna 7.5′ Quadrangles, Maryland–Virginia (Table 2; Figures 16 and 20; Drake and Froelich 1997). The Mather Gorge Formation type locality forms one of the most iconic cliff exposures along the Potomac River in the Great Falls area of CHOH and GWMP. Type locality exposures consist of quartz-rich schist and fine- to medium-grained, light- to medium-gray, yellowish- to reddish-brown-weathering metagraywacke that have experienced staurolite to sillimanite metamorphic grade temperature and pressure conditions (Fleming et al. 1994; Drake and Froelich 1997). Drake and Morgan (1981) have interpreted the Mather Gorge Formation to represent a turbidite deposited under high-energy conditions associated with a large submarine fan. The Mather Gorge Formation overlies the Sykesville Formation, unconformably underlies the Popes Head Formation, and is locally intruded by the Bear Island Granodiorite.

Figure 20. Type locality exposures of the Mather Gorge Formation in Great Falls Park, GWMP. The Mather Gorge Formation is also visible from the CHOH (Maryland) side of the Potomac River (NPS/TIM HENDERSON).

George Washington Memorial Parkway (GWMP)

Park Establishment

George Washington Memorial Parkway (GWMP) is a 45 km (28 mi)-long scenic roadway encompassing a comprehensive system of parks that runs along the Potomac River through Maryland (Montgomery County), Virginia (City of Alexandria, Arlington and Fairfax Counties), and Washington, D.C. (Figure 21). Authorized on May 29, 1930, GWMP contains 2,847 hectares (7,035 acres) and was developed as a memorial to the nation's first president. The memorial parkway connects historic sites from Mount Vernon, where George Washington lived, past the nation's capital, which he founded, to the Great Falls of the Potomac, where he demonstrated his skill as an engineer (National Park Service 2016a). Portions of GWMP represent the first comprehensively designed modern motorway constructed based on the idea of a landscaped, park-like roadway and pioneered many principles of federal freeway design such as limited access construction, grade-separated intersections, and cloverleaf interchanges (National Park Service 2014a). Many historic, natural, and cultural sites are accessible along GWMP, including (from north to south): Great Falls Park; Turkey Run Park; Claude Moore Colonial Farm; Fort Marcy; Theodore Roosevelt Island; United States Marine Corps War Memorial; Netherlands Carillon; Arlington Memorial Bridge and Memorial Avenue; Women in Military Service for America Memorial; Arlington House: The Robert E. Lee Memorial; Lady Bird Johnson Park; Lyndon Baines Johnson Memorial Grove-on-the-Potomac; Dyke Marsh Wildlife Preserve; and Fort Hunt Park (National Park Service 2014a).

Geologic Summary

The geology of GWMP is present over rocks that record a long interval of earth history spanning the Precambrian through the formation of the Appalachian Mountains to the recent Pleistocene ice ages and more modern geologic processes. The bedrock underlying GWMP experienced regional-scale metamorphism during the Taconic (470–450 million years ago), Acadian (410–360 million years ago), and Alleghenian (325–260 million years ago) Orogenies, resulting in a complex deformational history. The formation of the Appalachian Mountains uplifted strata that were later eroded and deposited as a thick wedge of sediments to the east toward the Atlantic Ocean creating the Coastal Plain physiographic province. Situated in portions of both the Piedmont and Atlantic Coastal Plain physiographic provinces, the landscape of GWMP contains rolling hills, river terraces, riverside marshes, and inlets that follow the course of the Potomac River as it flows toward Chesapeake Bay (Thornberry-Ehrlich 2009b). The oldest bedrock underlying the parkway is composed of the Neoproterozoic–Cambrian Mather Gorge Formation and other metasedimentary and meta-igneous rocks. Younger units of Paleozoic age that are mapped in GWMP include the Cambrian Sykesville Formation, Ordovician igneous and metamorphic rocks of the Dalecarlia and Georgetown intrusive suites, Bear Island Granodiorite, and Clarendon Granite. Mesozoic and Cenozoic strata are represented by the Cretaceous Potomac Formation, Paleocene Brightseat Formation and Aquia Formation, and abundant Quaternary-age alluvium and terrace deposits (Figures 22 and 23; Drake and Froelich 1997; Southworth and Denenny 2006).

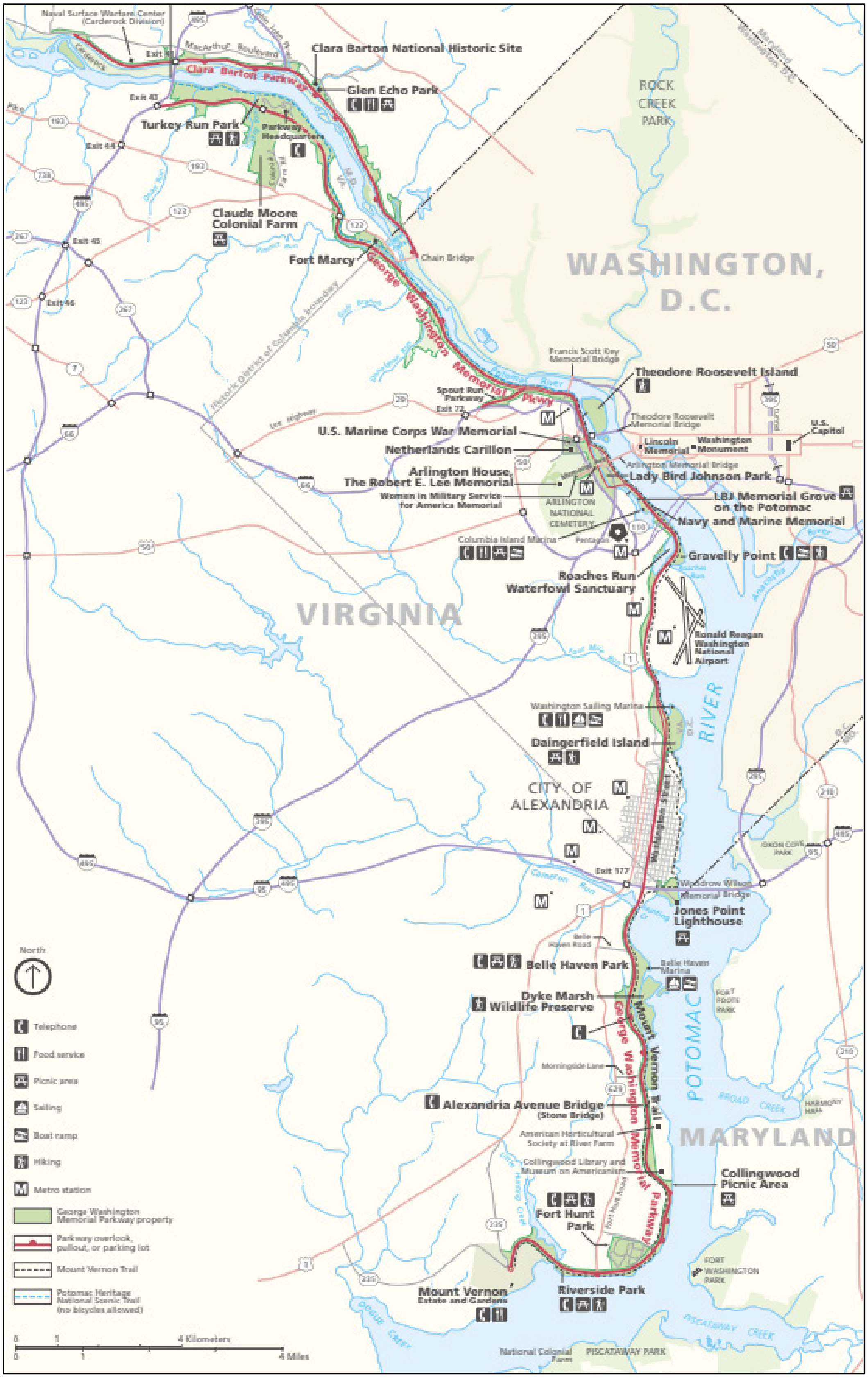


Figure 21. Park map of GWMP, District of Columbia–Maryland–Virginia (NPS).

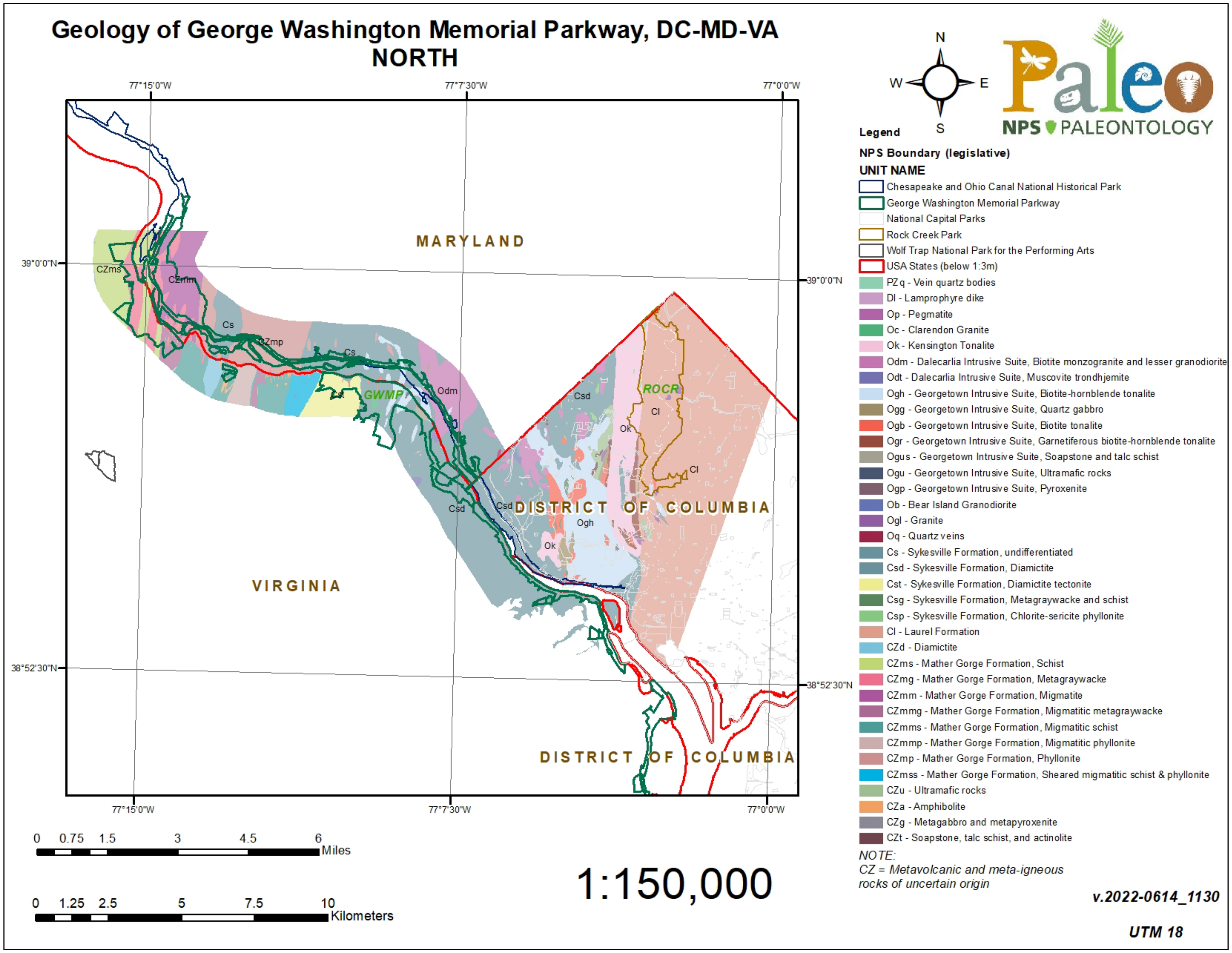


Figure 22. Geologic map of northern GWMP, District of Columbia–Maryland–Virginia. Data modified from GWMP GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048619.

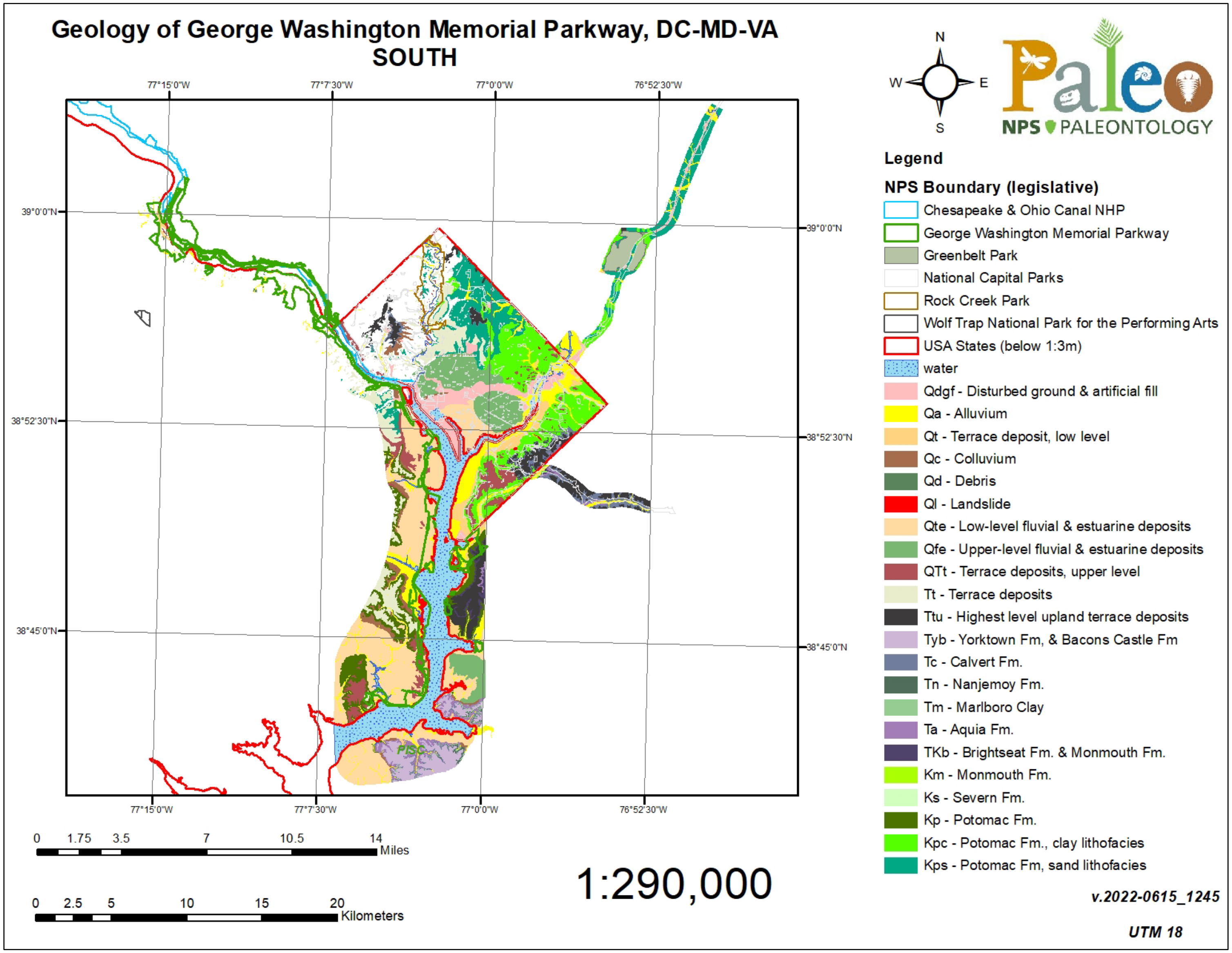


Figure 23. Geologic map of southern GWMP, District of Columbia–Maryland–Virginia. Data modified from GWMP GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048619.

Stratotypes

GWMP contains one identified stratotype that represents the Neoproterozoic–Cambrian Mather Gorge Formation (Table 3; Figure 24). The type locality of the Mather Gorge Formation is shared with CHOH on the Maryland side of the Potomac River. Although the Bear Island Granodiorite is named after Bear Island, which is within GWMP and CHOH, no current formal stratotype has been designated (see "Recommendations"). In addition to the designated stratotypes located within GWMP, stratotypes located within 48 km (30 mi) of the park boundaries are provided in Appendix C for reference in case of future park boundary expansion.

Mather Gorge Formation

The Neoproterozoic–Cambrian Mather Gorge Formation type locality is shared jointly among two park units (GWMP and CHOH). The type locality of the formation is designated along Mather Gorge on the Potomac River in the Falls Church and Vienna 7.5′ Quadrangles, Maryland–Virginia (Table 3; Figure 24; Drake and Froelich 1997). For more information about the formation and type locality, please refer to the CHOH section of this report.

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

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Mather Gorge Formation (CZms, CZmg, CZmm, CZmmg, CZmms, CZmmp, CZmp, CZmss)	Drake and Froelich 1997	Type locality: the Mather Gorge on the Potomac River in the Falls Church and Vienna 7.5′ Quadrangles, MD–VA. Exposures occur near milepost 13 in CHOH. ***Note: type locality shared with CHOH	Neoproterozoic –Cambrian

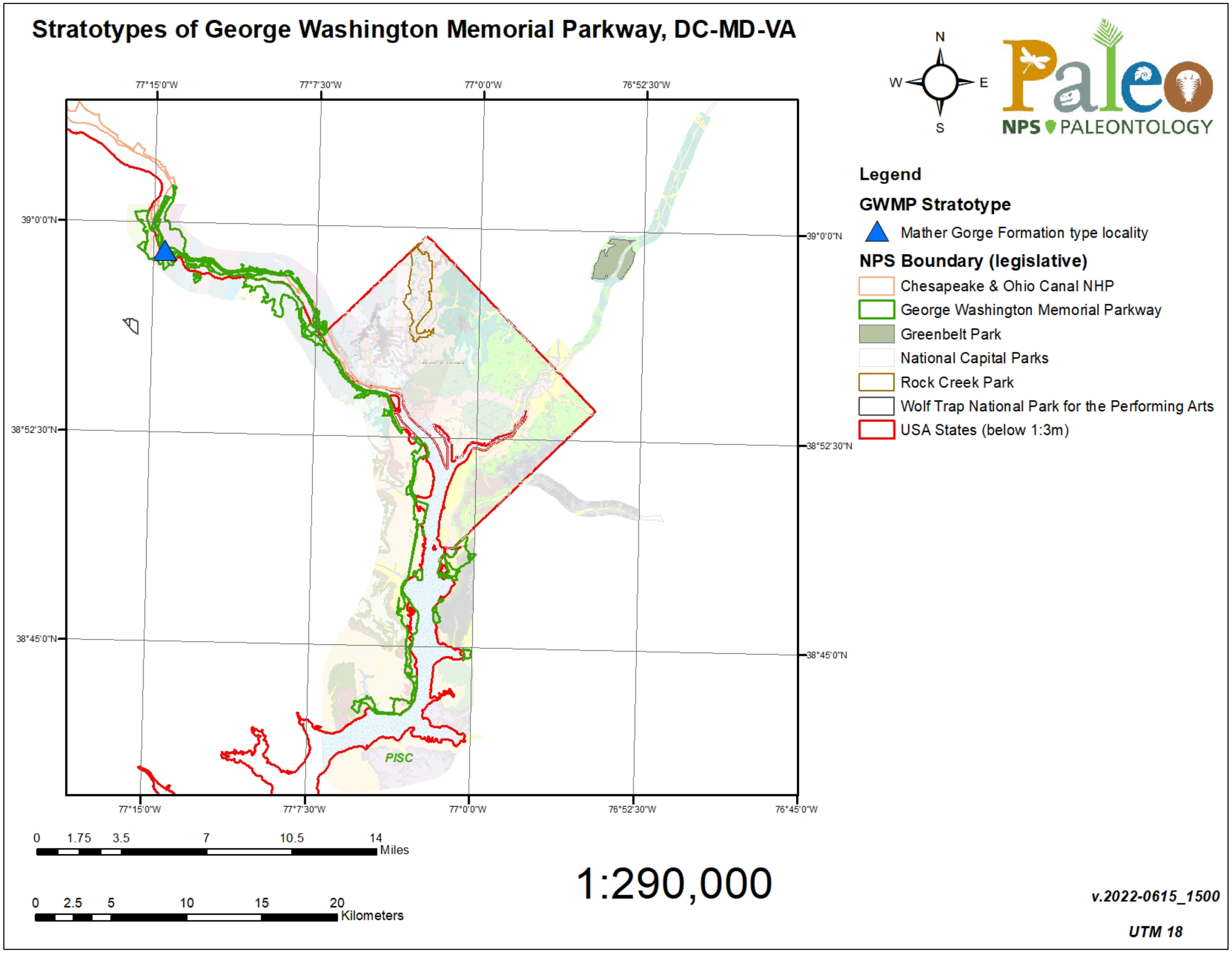


Figure 24. Modified geologic map of GWMP showing stratotype locations. The transparency of the geologic units layer has been increased.

Harpers Ferry National Historical Park (HAFE)

Park Establishment

Harpers Ferry National Historical Park (HAFE) lies at the confluence of the Potomac and Shenandoah Rivers in Washington County, Maryland, Loudoun County, Virginia, and Jefferson County, West Virginia (Figure 25). Authorized as a national monument on June 30, 1944, the park unit was redesignated on May 29, 1963. Encompassing approximately 1,484 hectares (3,669 acres), HAFE is a public national memorial commemorating several historical events that include the arrival of the first successful American railroad, the first successful application of interchangeable manufactured parts, John Brown's Raid of 1859, the largest surrender of federal troops during the Civil War, education of former slaves, and the beginning of the modern civil rights movement (National Park Service 2016a). Situated near the border between the North and South, Harpers Ferry played a strategic role in the Civil War as a gateway into the Shenandoah Valley and a backdoor to Washington, D.C. The fight for control of Harpers Ferry resulted in five battles in three successive years, where the stronghold changed hands eight times during the Civil War. The geography of HAFE, including the mountain gap at the confluence of the Potomac and Shenandoah Rivers, made the region a key crossroads from the times of the earliest human habitation to the present (National Park Service 2016b).

Geologic Summary

Situated in the Blue Ridge physiographic province, the geology of HAFE is predominantly composed of ancient Precambrian and Cambrian metamorphic and meta-igneous rocks that have been heavily deformed as a result of numerous tectonic events that culminated in the construction of the Appalachian Mountains (Figure 26). The oldest basement rocks in HAFE are located in Loudoun Valley and consist of Mesoproterozoic-age metagranite and the Neoproterozoic Catoctin and Swift Run Formations. The Catoctin basalts and sedimentary strata of the Swift Run Formation were deposited in a dynamic environment characterized by steep topography and local interaction between lava flows and stream systems, producing a series of complexly interlayered deposits (Badger 1999; Tollo et al. 2004). Several Cambrian-age units form the precipitous slopes in the western portion of HAFE and include the Chilhowee Group (Loudoun, Weverton, Harpers, and Antietam Formations), Tomstown Formation, and Waynesboro Formation. The youngest bedrock mapped in HAFE are Jurassic-age diabase dikes that intrude older strata in the eastern portion of the park. The major geologic structure underlying the area of HAFE is the late Permian-age Blue Ridge anticlinorium, an asymmetric regional-scale fold that extends for more than 400 km (250 mi) from southern Pennsylvania southwest as far as Lynchburg, Virginia (Reed 1969).

Figure 25. Park map of HAFE, Maryland–Virginia–West Virginia (NPS).

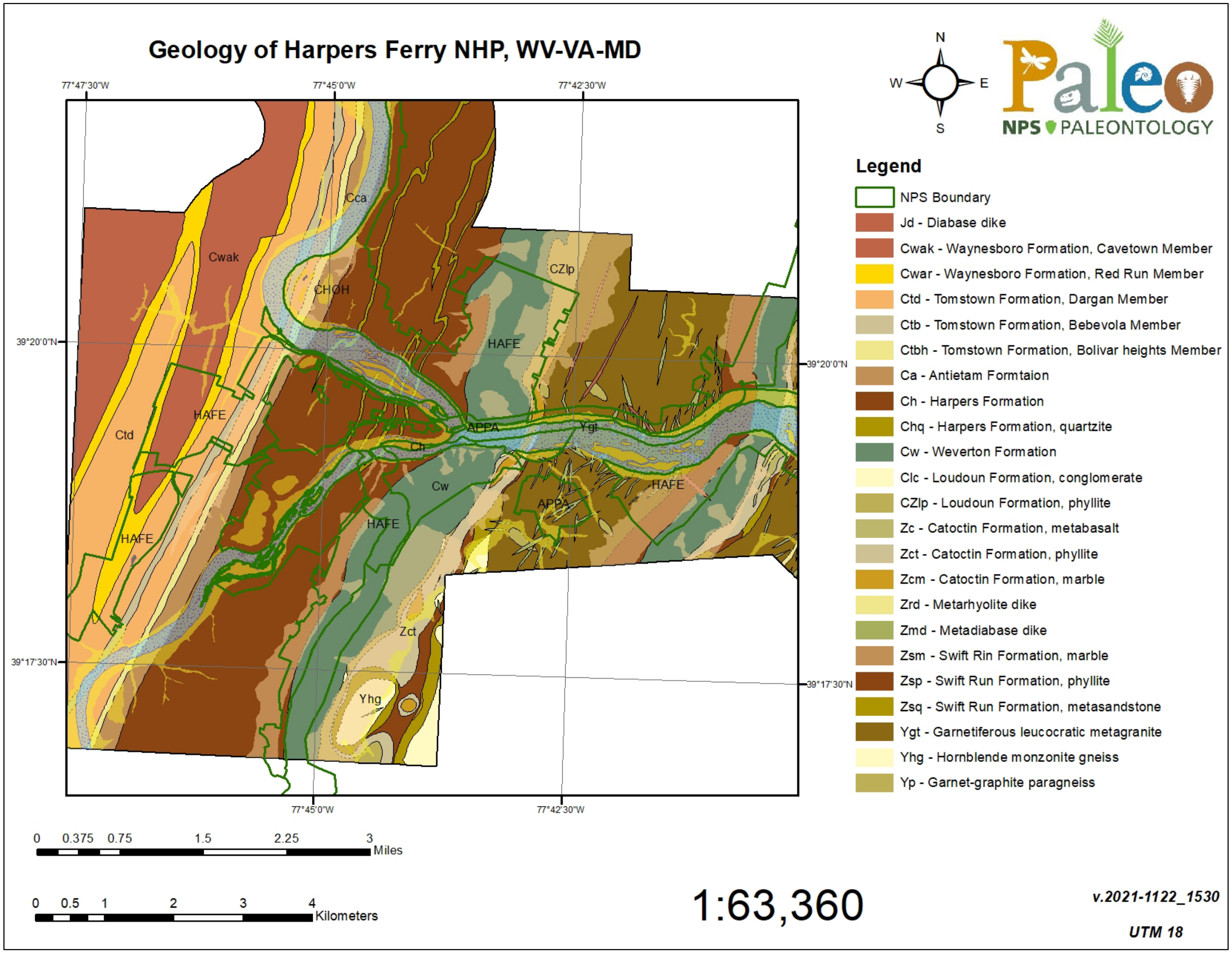


Figure 26. Geologic map of HAFE, Maryland–Virginia–West Virginia. Data modified from HAFE GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048804.

Stratotypes

Harpers Ferry National Historical Park contains four identified stratotypes that represent the Cambrian Maryland Heights Member of the Weverton Formation, Harpers Formation, and Bolivar Heights Member of the Tomstown Formation (Table 4; Figure 27). Although the Cambrian Loudoun Formation shares it name with Loudoun Heights in HAFE, the unit was proposed by Keith (1894) and named for the fact that the unit is well developed in Loudoun County, Virginia, and no formal stratotype was designated (see "Recommendations"). In addition to the designated stratotypes located within HAFE, stratotypes located within 48 km (30 mi) of the park boundaries are provided in Appendix C for reference in case of future park boundary expansion.

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

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Bolivar Heights Member, Tomstown Formation (Ctbh)	Brezinski 1992	Type section: along CSX Railroad tracks at north end of Bolivar Heights, 2.4 km (1.5 mi) west of the confluence of Potomac and Shenandoah Rivers at Harpers Ferry, Jefferson County, WV.	Cambrian
Harpers Formation (Ch, Chq)	Brezinski 1992; Southworth 1994; Southworth et al. 2009	Type locality: a collection of exposures on the cliffs along the Potomac River at Harpers Ferry, WV, near mileposts 61–62 in CHOH. Type area: exposures near Harpers Ferry, WV. ***Note: type locality/area shared with APPA and CHOH	Cambrian
Maryland Heights Member, Weverton Formation (Cw)	Brezinski 1992	Type section: along CSX Railroad tracks, east of tunnel and Sandy Hook Road at Maryland Heights, Washington County, MD.	Cambrian

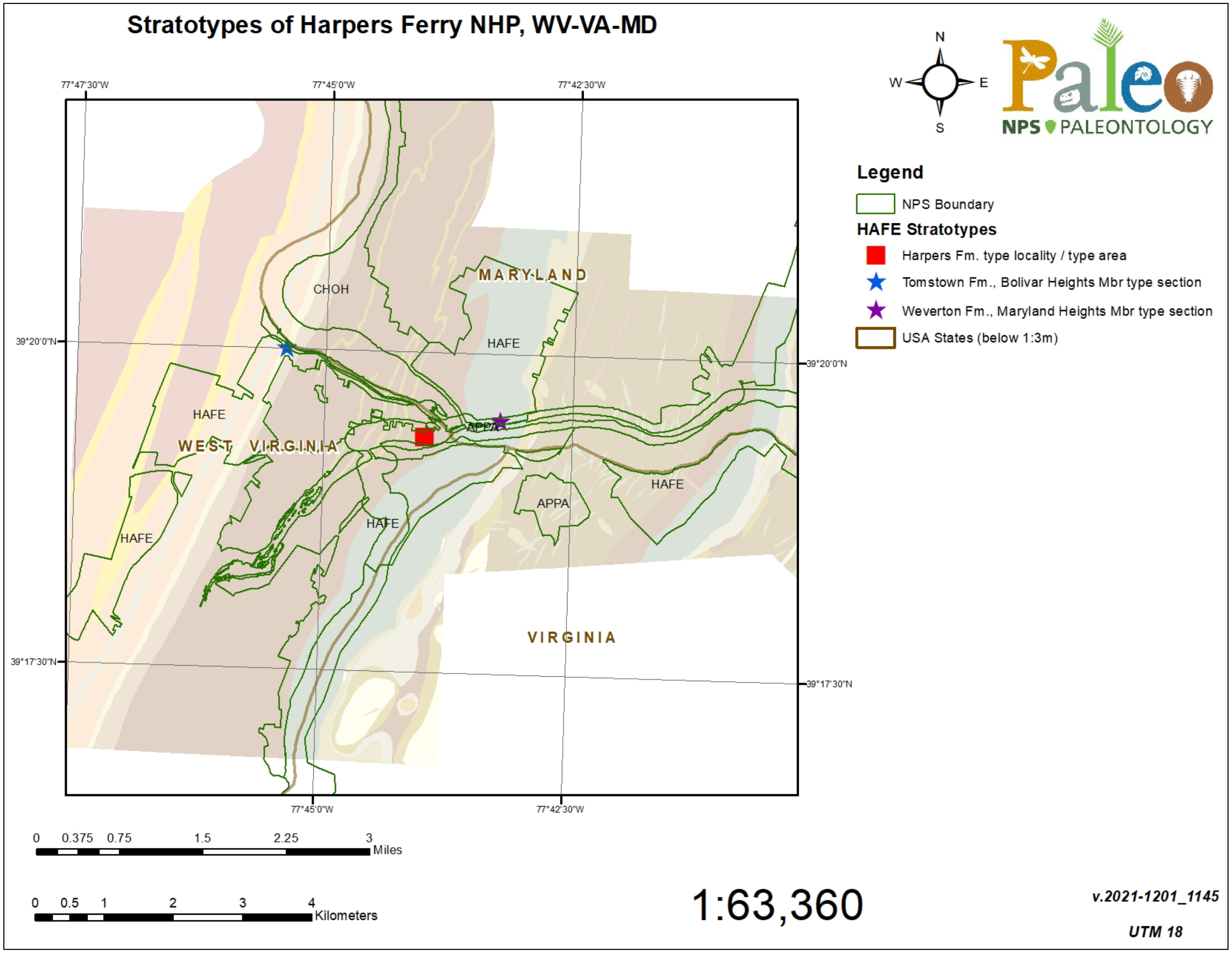


Figure 27. Modified geologic map of HAFE showing stratotype locations. The transparency of the geologic units layer has been increased.

Bolivar Heights Member, Tomstown Formation

The Cambrian Bolivar Heights Member is the basal member assigned to the Tomstown Formation by Brezinski (1992). The unit is named after its type section exposure along CSX Railroad tracks at the north end of Bolivar Heights, approximately 2.4 km (1.5 mi) west of the confluence of the Potomac and Shenandoah Rivers at Harpers Ferry in Jefferson County, West Virginia (Table 4; Figures 27 and 28; Brezinski 1992). At the type section the Bolivar Heights Member is characterized by three stratigraphically stacked lithologies: 1) a basal tan, vuggy dolomite that ranges in thickness from 3–12 m (10–40 ft) but is rarely exposed; 2) a middle interval of very light-gray, sheared, laminated, dolomitic marble about 12–15 m (40–50 ft) thick, termed the "Keedysville marble bed" (Figure 29); and 3) an upper sequence of thin- to medium-bedded, dark-gray, ribbony, bioturbated lime mudstone that measures about 60 m (200 ft) thick (Brezinski 1992). Bioturbation in the uppermost interval generally tends to increase up-section where it forms an anastomosing network of burrows (Figure 30; Brezinski 1992). The Bolivar Heights Member overlies the Antietam Formation and underlies the Fort Duncan Member of the Tomstown Formation.

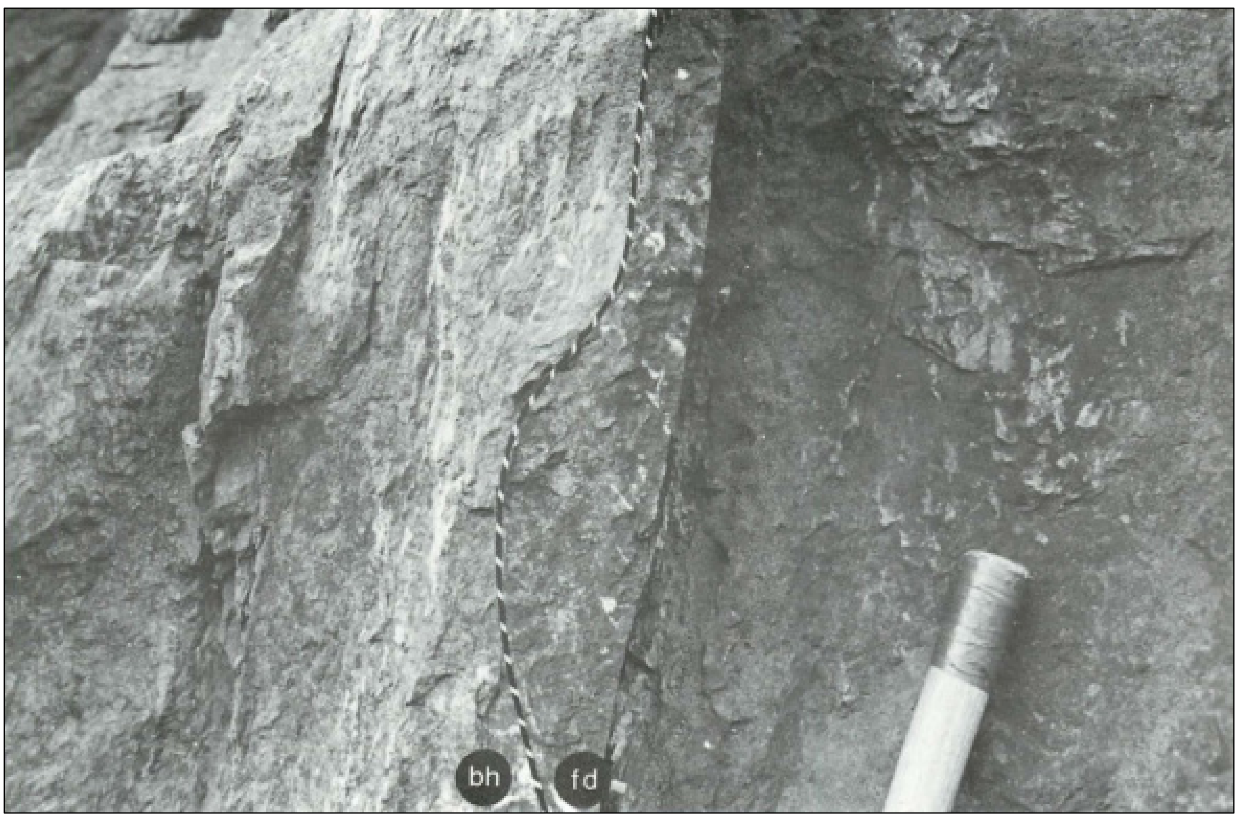


Figure 28. Sharp contact between the Bolivar Heights (bh) and Fort Duncan Members (fd) of the Tomstown Formation at the north end of Bolivar Heights, HAFE. Photograph taken at the type section of the Bolivar Heights Member. Figure 17 from Brezinski (1992).

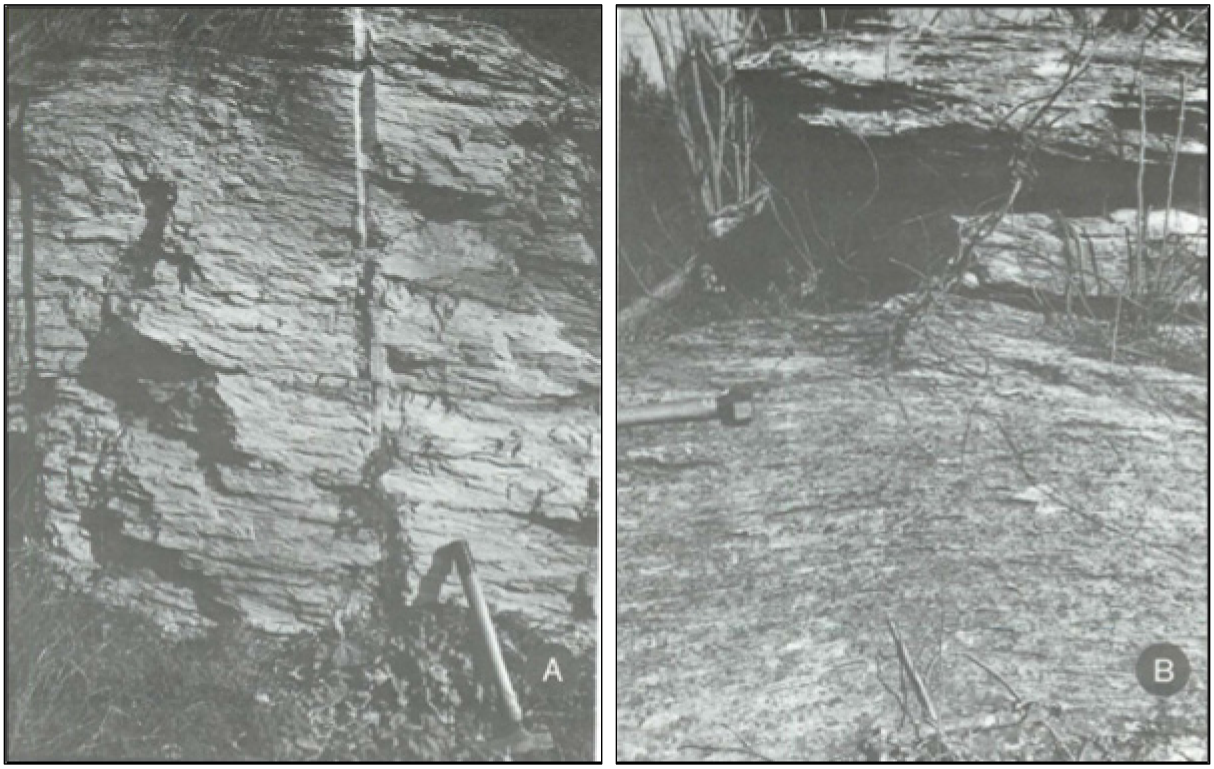


Figure 29. Photographs of the Keedysville marble bed, the middle interval of the Bolivar Heights Member of the Tomstown Formation, as seen along Dog Street Road in Washington County, Maryland. Figures 15A and 15B from Brezinski (1992).

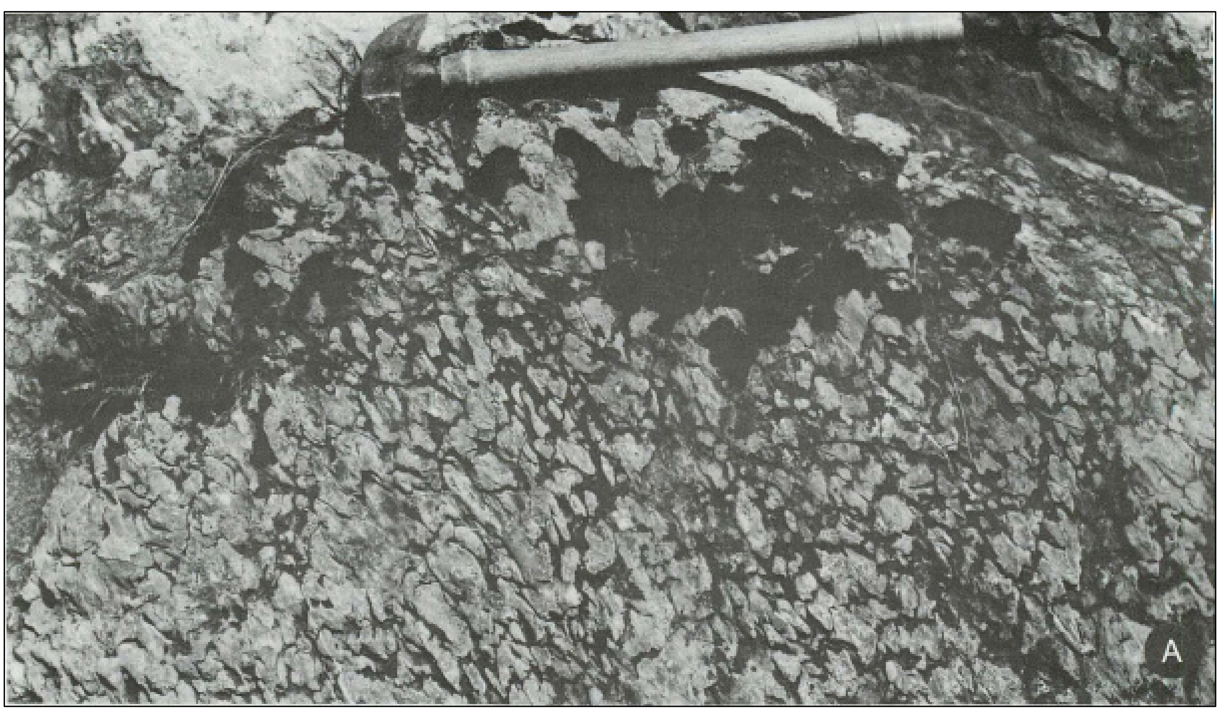


Figure 30. Burrowed limestone of the Bolivar Heights Member of the Tomstown Formation. Figure 16A from Brezinski (1992).

Harpers Formation

The Cambrian Harpers Formation was initially referred to as the Harpers Shale by (Keith 1894) and named for exposures near Harpers Ferry, West Virginia. Brezinski (1992) designated the type area as exposures around Harpers Ferry, where the unit displays a degree of structural complexity that precludes any precise stratigraphic measurements (Table 4; Figure 27). Southworth (1994) and Southworth et al. (2009) designated a type locality for the Harpers Formation as a collection of exposures on the cliffs along the Potomac River at Harpers Ferry, West Virginia (Table 4; Figures 27, 31, and 32). In the region of Harpers Ferry, the lower part of the formation is characterized by several hundred meters or feet of dark-gray to olive-black, medium-grained phyllitic metasiltstone with thin beds of medium-gray, fine-grained metasandstone (Brezinski 1992; Southworth 1994). Above this lower interval is a 210–305 m (700–1,000 ft) thick sequence of greenish-black to brownish-black, highly cleaved metasiltstone and fine-grained metasandstone (Figure 33; Brezinski 1992; Southworth 1994). The uppermost Harpers Formation measures approximately 150–210 m (500–700 ft) thick and consists of interbedded dark-greenish-gray to olive-black sandy metasiltstone that contains thin beds of light-gray to medium-light-gray, fine-grained metasandstone featuring abundant *Skolithos* burrows (Figures 33 and 34; Brezinski 1992). The Harpers Formation underlies the Antietam Quartzite and overlies the Weverton Formation.

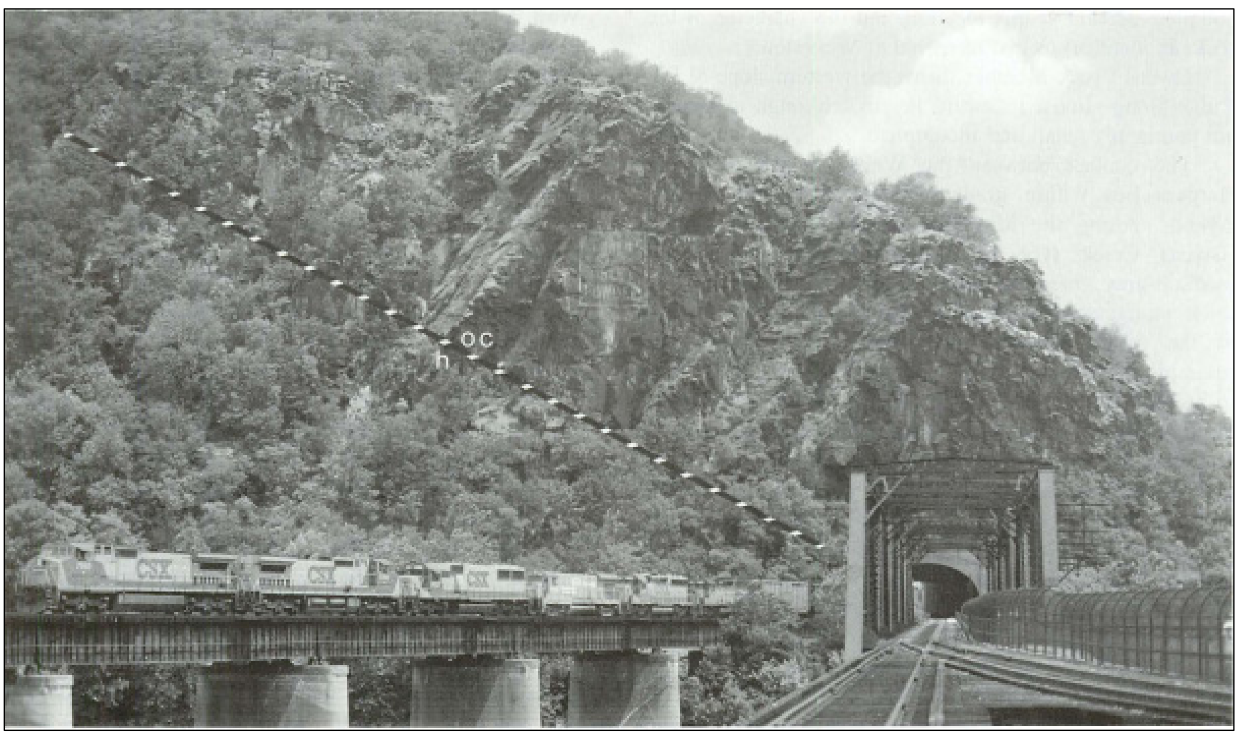


Figure 31. Northeast-facing view of type locality exposures of the Harpers Formation along the CSX Railroad tracks and tunnel at Maryland Heights, HAFE. oc = Owens Creek Member of the Weverton Formation; h = Harpers Formation. Figure 11B from Brezinski (1992).

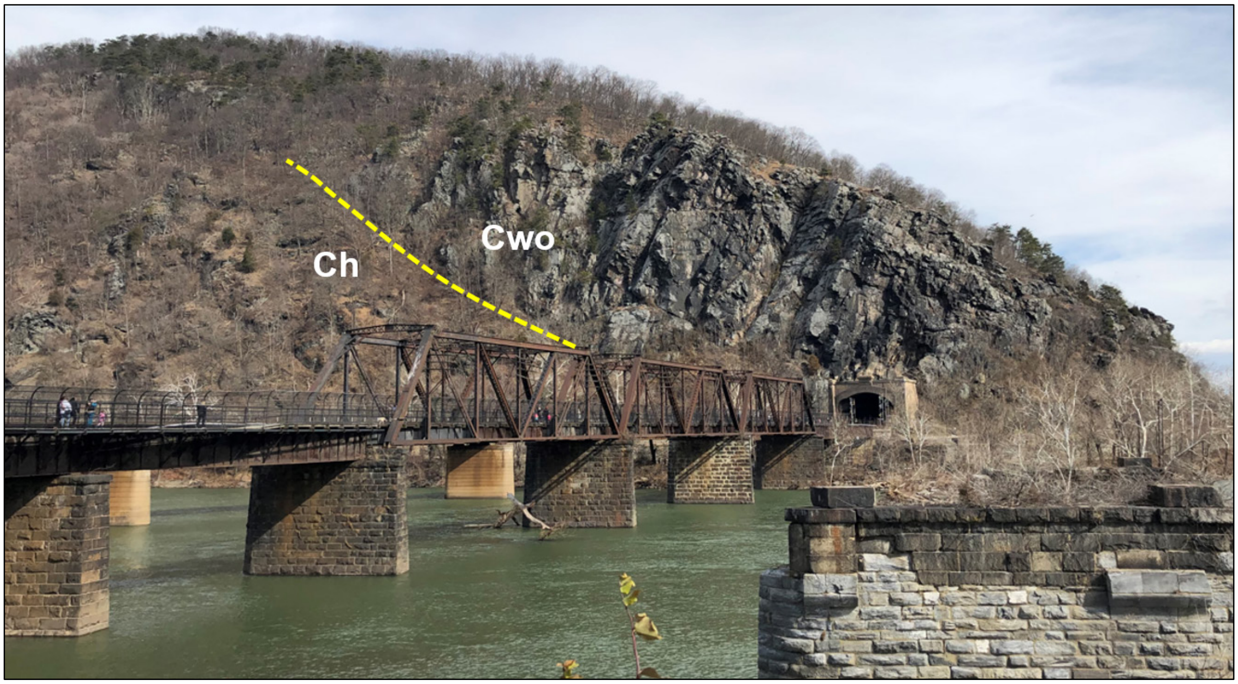


Figure 32. Type locality exposures of the Harpers Formation along the Potomac River at Maryland Heights, HAFE. Cwo = Owens Creek Member of the Weverton Formation; Ch = Harpers Formation (NPS/TIM HENDERSON).

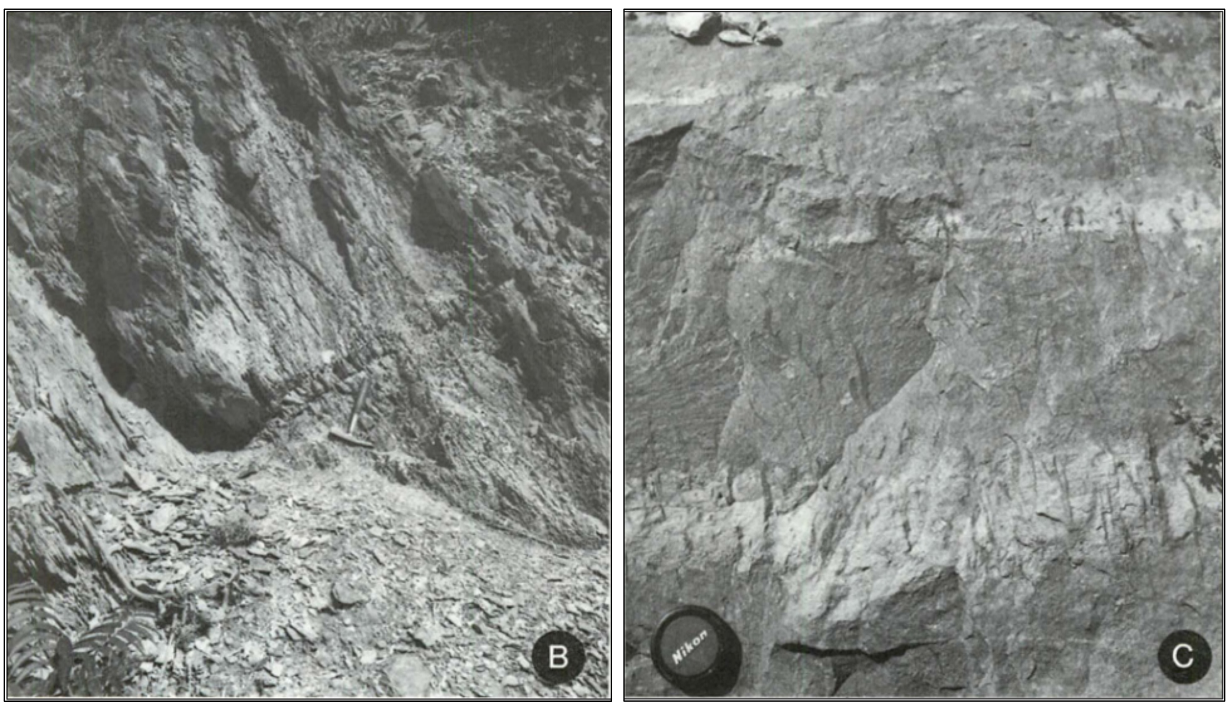


Figure 33. The Harpers Formation. **Left.** Highly cleaved metasiltstone and fine-grained metasandstone within the middle part of the Harpers Formation; note the hammer for scale. **Right.** *Skolithos*-burrowed sandstone characteristic of the upper interval of the Harpers Formation. Figures 12B and 12C from Brezinski (1992).

Figure 34. Fine-grained, thin-bedded sandstone with *Skolithos* burrows of the Harpers Formation near Harpers Ferry, Maryland (USGS).

Maryland Heights Member, Weverton Formation

The Cambrian Maryland Heights Member is the middle member of the Weverton Formation proposed by Brezinski (1992) and named after exposures at Maryland Heights, Maryland. The type section of the member is located along CSX Railroad tracks, east of the tunnel and Sandy Hook Road at the southern end of Elk Ridge at Maryland Heights in Washington County, Maryland (Table 4; Figures 27 and 35; Brezinski 1992). The Maryland Heights Member is mapped as part of the undifferentiated Weverton Formation ("Cw" of the GRI map of HAFE). At the type section the unit forms a 90 m (300 ft)-thick sequence of medium-gray to olive-gray graywacke interbedded with dark-olive-gray, sandy metasiltstone and less commonly olive phyllite (Brezinski 1992). Compared to the overlying Owens Creek and underlying Buzzard Knob Members of the Weverton Formation, the Maryland Heights Member is less resistant to weathering and strongly deformed to the degree that stratigraphic characteristics are obscured (Brezinski 1992).

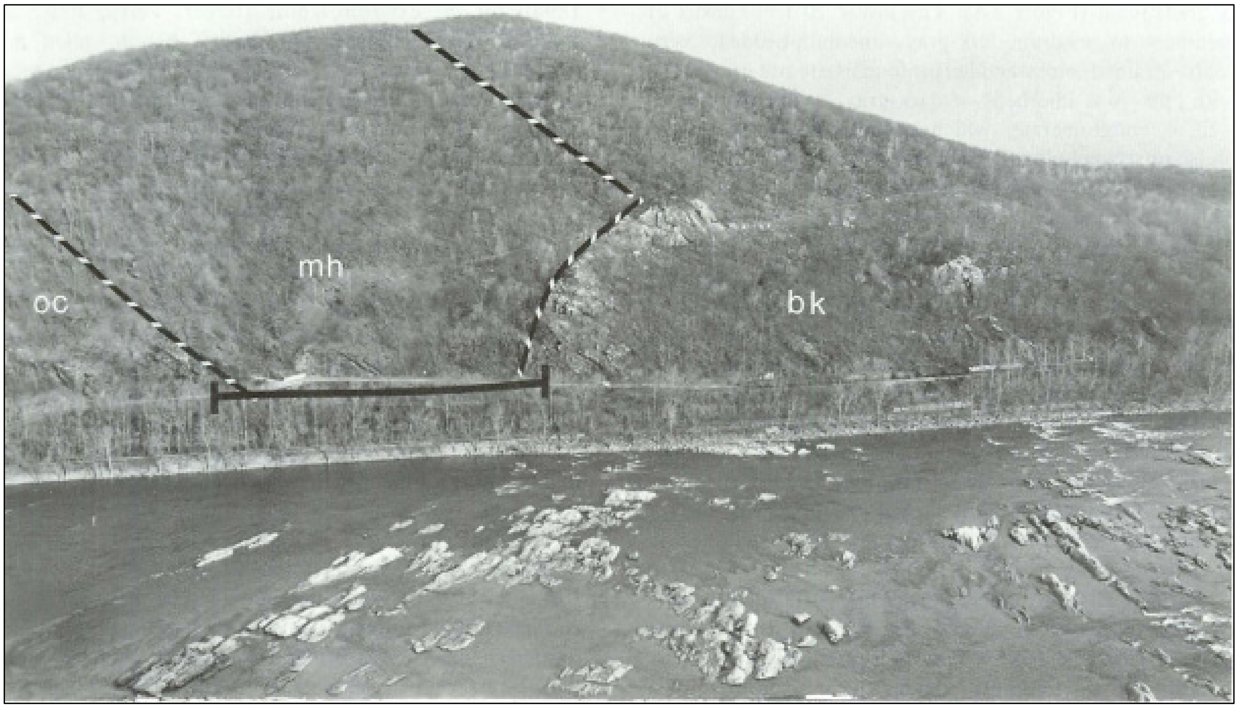


Figure 35. View facing north of the type section of the Maryland Heights Member of the Weverton Formation. bk = Buzzard Knob Member; mh = Maryland Heights Member; oc = Owens Creek Member. Figure 11A from Brezinski (1992).

Manassas National Battlefield Park (MANA)

Park Establishment

Manassas National Battlefield Park (MANA) is located approximately 40 km (25 mi) west of Washington, D.C. in Fairfax and Prince William Counties, Virginia (Figure 36). Designated on May 10, 1940, MANA encompasses about 2,052 hectares (5,073 acres) and was established to preserve the land and resources associated with the First and Second Battles of Manassas (First and Second Battles of Bull Run) during the American Civil War. The Battle of First Manassas was fought on July 21, 1861, and represents one of the first major land battles of the Civil War. Although the battle ended in a Confederate victory, a sobering number of casualties resulted for both sides. The Battle of First Manassas is where Confederate Brigadier General Thomas J. Jackson rose to prominence and acquired his nickname "Stonewall". The Battle of Second Manassas on August 28–30, 1862, resulted in another Union defeat and shifted the seat of war from the gates of Richmond, Virginia, to the doorsteps of Washington, D.C., and paved the way for Robert E. Lee's first invasion of the North (National Park Service 2014b). MANA preserves the battlefield landscape as it existed at the time of the Civil War and includes three houses that date from the Civil War period, several post-war historic buildings, a Confederate cemetery, the reconstructed Stone Bridge over Bull Run, approximately 10 km (6 mi) of historic road traces, historic structures, archeological resources, cemeteries, trenches, earthworks, forests, and open pasturelands.

Geologic Summary

MANA is situated in the Culpeper Basin of the western Piedmont physiographic province, a distinctive region characterized by relatively low relief, gently rolling hills, and flat fields. The Culpeper Basin is one of a series of trough-like depressions that formed due to extensional tectonics as the Atlantic Ocean opened about 200 million years ago (Southworth and Denenny 2006). As the basin formed it was filled with Triassic- and Jurassic-age sediments derived from the Newark Supergroup. Lithological variations have shaped the landscape expression of MANA and created subtle yet important topographic expressions that were utilized during the First and Second Battles of Manassas for strategic defenses, troop movements, and transport routes (Thornberry-Ehrlich 2008a). The bedrock underlying MANA consists predominantly of red siltstone, shale (mudstone), and lacustrine clay of the Triassic Groveton Member of the Bull Run Formation (Figure 37). Mapped in the western portion of MANA are Triassic–Jurassic-age metamorphic rocks that have been intruded by diabase dikes and sills. The hot, molten diabase thermally metamorphosed the red siltstone to gray hornfels near the contact (Southworth and Denenny 2006). Subsequent uplift and erosion formed younger surficial units consisting of low-level terrace deposits and extensive alluvium.

Stratotypes

MANA contains two identified stratotypes that represent the Triassic Bull Run Formation and its Groveton Member (Table 5; Figure 38). Although the USGS GEOLEX archive states the Bull Run Formation is abandoned, it was reinstated by Weems and Olsen (1997) and is still recognized by the Maryland Geological Survey. In addition to the designated stratotypes located within MANA, stratotypes located within 48 km (30 mi) of the park boundaries are provided in Appendix C for reference in case of future park boundary expansion.

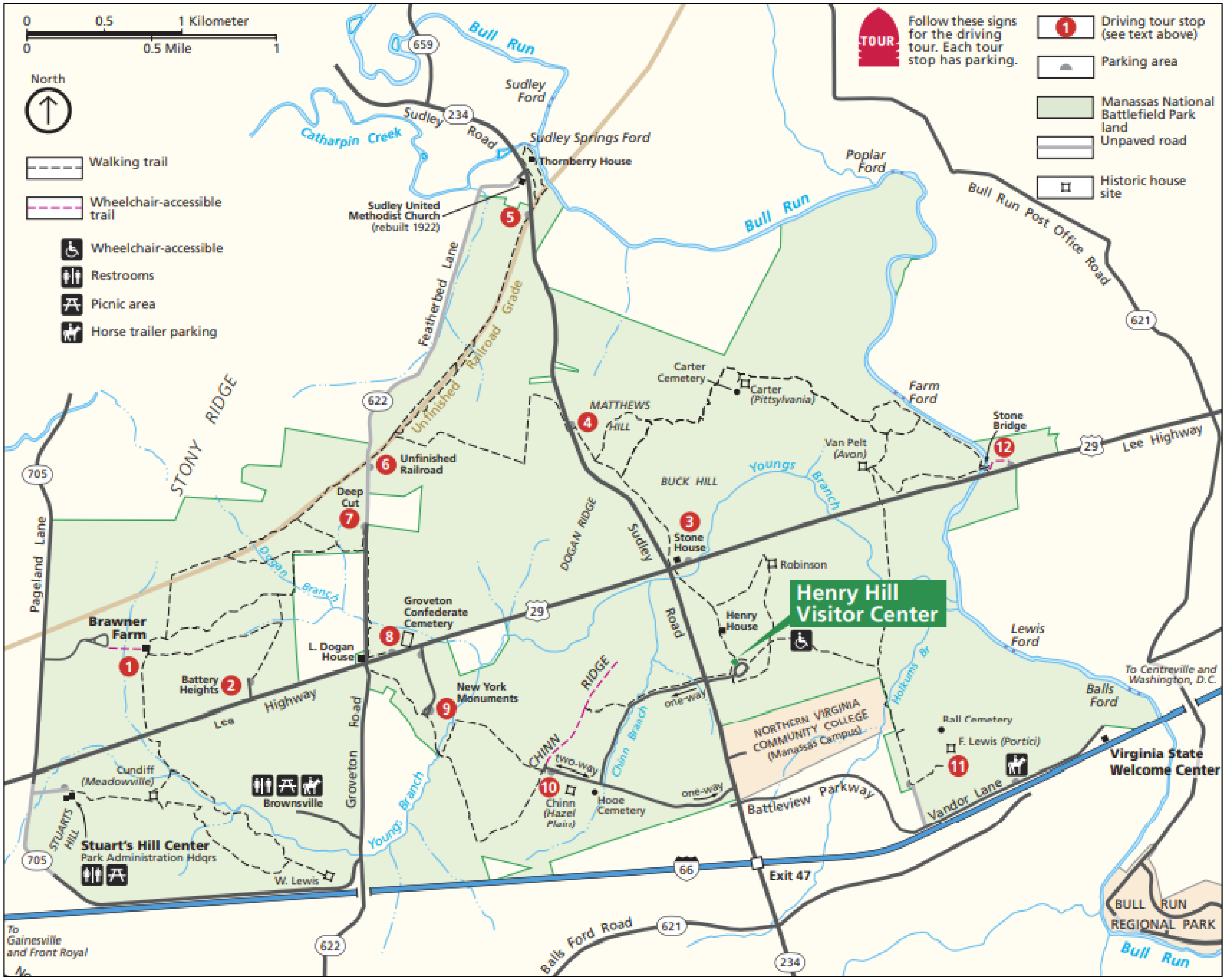


Figure 36. Park map of MANA, Virginia (NPS).

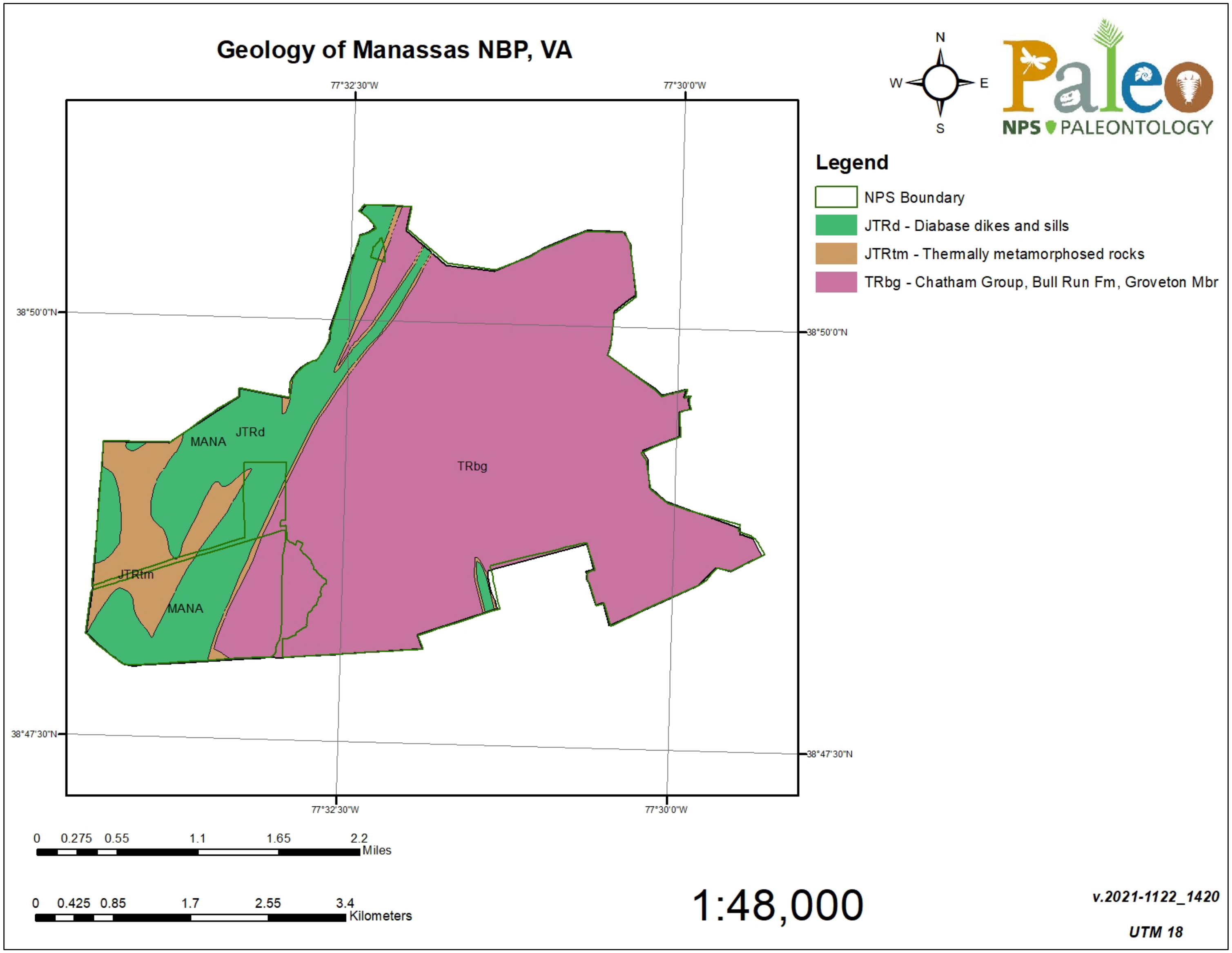


Figure 37. Geologic map of MANA, Virginia. Data modified from MANA GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2164815.

Table 5. List of MANA stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Bull Run Formation of the Chatham Group (TRbg)	Roberts 1928; Weems and Olsen 1997	Type area: along Bull Run, a small stream in the Bull Run Battlefield, 9.5 km (6 mi) west of Manassas, in Prince William and Fairfax Counties, VA	Triassic
Groveton Member, Bull Run Formation of the Chatham Group (TRbg)	Weems and Olsen 1997	Type area: Manassas National Battlefield Park, VA, excluding areas underlain by intrusive diabase (Fig. 8 of Weems and Olsen 1997). Good exposures in the Manassas National Battlefield Park occur along U.S. Highway 50 and Virginia State Road 234, and along the south bank of Bull Run Creek along the northern edge of the park.	Triassic

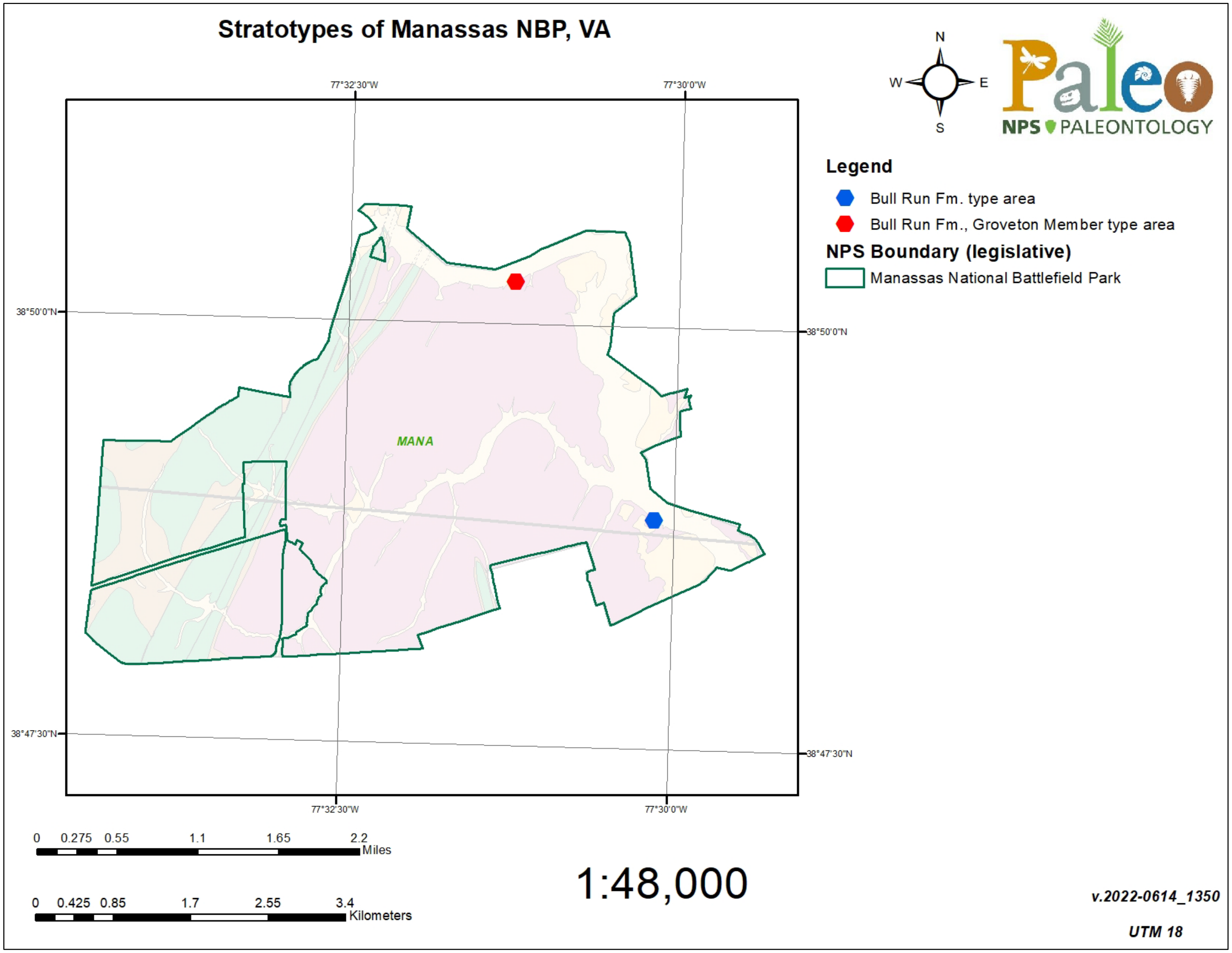


Figure 38. Modified geologic map of MANA showing stratotype locations. The transparency of the geologic units layer has been increased.

Bull Run Formation

The Triassic Bull Run Formation was originally proposed by Roberts (1928) and named after exposures in the Culpeper Basin of Virginia. Although the formation was temporarily abandoned by Lee and Froelich (1989), it was reinstated by Weems and Olsen (1997) and subdivided into five members: the Balls Bluff, Groveton, Leesburg, Cedar Mountain, and Haudricks Mountain Members. The type area of the Bull Run Formation is located along Bull Run, a small stream that meanders through, and is named after the Bull Run Battlefield, located approximately 9.5 km (6 mi) west of Manassas, in Prince William and Fairfax Counties, Virginia (Table 5; Figure 38; Weems and Olsen 1997 citing Roberts 1928). In the type area, the formation predominantly consists of cyclic lacustrine sequences of the Groveton Member. The Bull Run Formation overlies the Manassas Sandstone and underlies the Catharpin Creek Formation.

Groveton Member, Bull Run Formation

The Triassic Groveton Member of the Bull Run Formation was introduced by Weems and Olsen (1997) and named after Groveton in MANA. It should be noted that the Groveton Member is currently not on the GEOLEX archive, and the Bull Run Formation is considered abandoned in the archive, although it was reinstated by Weems and Olsen (1997). The type area of the member is designated at MANA, excluding areas underlain by intrusive diabase (Table 5; Figure 38; Weems and Olsen 1997). Notable exposures in MANA occur along U.S. Highway 50 and Virginia State Road 234, and along the south bank of Bull Run Creek along the northern edge of the park (Weems and Olsen 1997). The Groveton Member is characterized by prominent, laterally persistent lacustrine sequences of gray shales approximately 1–10 m (3–30 ft) thick interbedded in a highly rhythmic pattern with red shales, siltstones, and occasional sandstones about 6–60 m (20–200 ft) thick (Weems and Olsen 1997). The Groveton Member occurs between the overlying Leesburg and underlying Balls Bluff Members of the Bull Run Formation.

Monocacy National Battlefield (MONO)

Park Establishment

Monocacy National Battlefield (MONO) is located approximately 5 km (3 mi) south of Frederick, the second largest city in Maryland, and near the Baltimore–Washington metropolitan area in Frederick County, Maryland (Figure 39). Originally authorized as Monocacy National Military Park on June 21, 1934, the park unit was reauthorized and redesignated on October 21, 1976 (National Park Service 2016a). Encompassing about 666 hectares (1,647 acres), MONO was established to commemorate the Battle of Monocacy of the American Civil War and preserve the breastworks, earthworks, walls, and other defenses used by the Confederate and Union armies. Regarded as the "battle that saved Washington", the Battle of Monocacy was fought on July 9, 1864, as a small band of Union soldiers delayed a Confederate advance on the nation's capital at Monocacy Junction in western Maryland. Union forces attempted to burn all bridges crossing the Monocacy River, which successfully slowed the invasion of Washington D.C. and provided sufficient time for General Ulysses S. Grant to send reinforcements to the nation's capital, ultimately preventing its capture. The core battlefield consists of six historic properties, including the Best Farm (L'Hermitage), the Worthington Farm, the Thomas Farm, the Baker Farm, the Lewis Farm, and the Gambrill Mill; many of the historic structures on these farmsteads existed at the time of the battle (National Park Service 2015a).

Geologic Summary

MONO is situated in the Frederick Valley of the Piedmont physiographic province, an area defined by parallel valleys and ridges that played a major role in the military strategy of the Battle of Monocacy. Natural features such as ridges, low valleys, shallow fords, undercut banks, and other subtle topographic expressions were utilized by troops for defense and transport routes (Thornberry-Ehrlich 2008b). The oldest bedrock underlying MONO consists of metamorphic rocks of the Neoproterozoic–Cambrian Ijamsville Phyllite in the easternmost sections of the park. The Ijamsville Phyllite consists of phyllite, phyllonite, and minor slate that are juxtaposed against younger units along the Martic thrust fault (Southworth 1999; Southworth and Brezinski 2003). Several Cambrian-age formations are mapped within MONO and include the Araby Formation and the overlying Frederick Formation (Rocky Springs Station, Adamstown, and Lime Kiln Members). Prominent ridges located along Monocacy River both north and south of Bush Creek are comprised of sandstone and phyllitic shale of the Araby Formation, while low-lying valleys are typically underlain by rocks of the Frederick Formation (Figure 40; Southworth and Brezinski 2003).

Stratotypes

MONO contains one identified stratotype that represents the Cambrian Araby Formation (Table 6; Figure 41). Although the Monocacy Member of the Frederick Formation shares its name with MONO, its type section is located along the Monocacy River a few kilometers or miles north of the park (Brezinski 2004). In addition to the designated stratotype located within MONO, stratotypes located within 48 km (30 mi) of the park boundaries are provided in Appendix C for reference in case of future park boundary expansion.

Figure 39. Park map of MONO, Maryland (NPS).

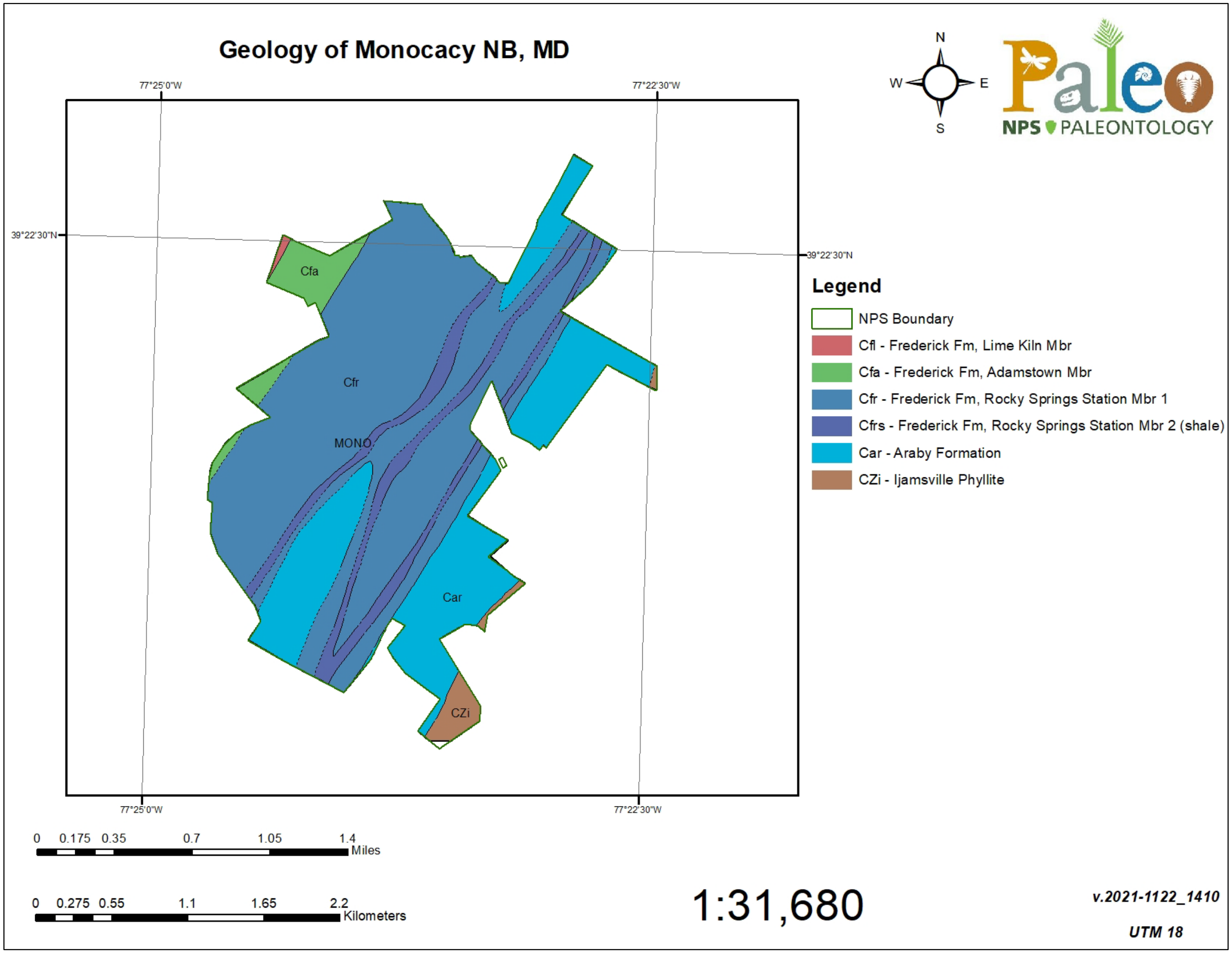


Figure 40. Geologic map of MONO, Maryland. Data modified from MONO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2164814.

Table 6. List of MONO stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Araby Formation (Car)	Reinhardt 1974	Type section: on Baltimore and Ohio RR east of Frederick Junction. Named from Araby, southwest of Frederick, Frederick County, north-central MD.	Cambrian

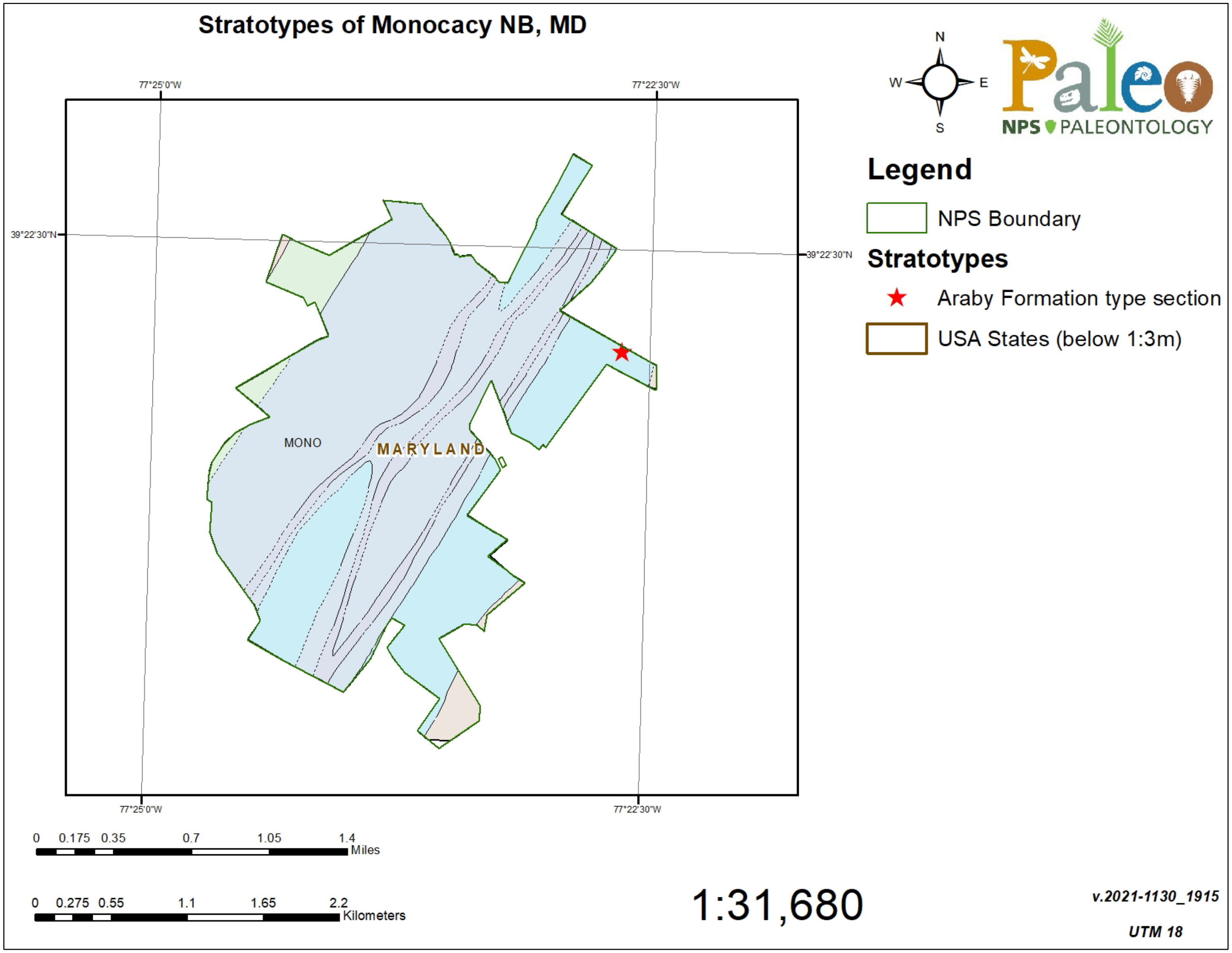


Figure 41. Modified geologic map of MONO showing stratotype locations. The transparency of the geologic units layer has been increased.

Araby Formation

The Cambrian Araby Formation was proposed by Reinhardt (1974) and named after exposures in the vicinity of Araby, about 1.5 km (0.9 mi) southwest of Frederick Junction, Maryland. Reinhardt (1974) designated the type section of the formation along the Baltimore and Ohio Railroad east of Frederick Junction in Frederick County, Maryland (Table 6; Figure 41). The formation consists of buff or tan to green, uniformly fine-grained, highly cleaved or jointed, poorly bedded siltstone or phyllite with an estimated thickness of approximately 100 m (330 ft) (Reinhardt 1974). Virtually all original bedding structures, such as planar or ripple cross-lamination, have been obscured by bioturbation and tectonic overprinting (Reinhardt 1974). The presence of horizontal burrows in addition to fragments of trilobites and pelmatozoans (echinoderms with stalks, such as crinoids) are indicative of a marine depositional environment. At the type section the Araby Formation underlies the Rocky Station Springs Member of the Frederick Formation and overlies the Ijamsville Phyllite.

National Capital Parks-East (NACE)

Park Establishment

National Capital Parks-East (NACE) represents a diverse collection of urban park units located in all four quadrants of Washington, D.C., as well as in Prince George's, Anne Arundel, and Charles Counties in Maryland (Figure 42). The park units of NACE protect a broad range of locally, regionally, and nationally important resources that are distributed among 98 locations and total more than 3,237 hectares (8,000 acres). Park resources consist of natural areas, recreation areas, cultural landscapes, historic homes, parkways, farms, archeological sites, and historic forts. The park units of NACE include: Anacostia Park (ANAC); Baltimore-Washington Parkway (BAWA); Capitol Hill Parks (CAHI); Fort Circle Parks, also known as the Civil War Defenses of Washington (CDWD), including Shepherd Parkway and several Civil War forts such as Fort Dupont (FODU), Fort Foote (FOFO), and Fort Stanton; Fort Washington Park (FOWA); Frederick Douglass National Historic Site (FRDO); Greenbelt Park (GREE); Harmony Hall (HAHA); Kenilworth Park and Aquatic Gardens (KEAQ), including Kenilworth Marsh; Mary McLeod Bethune Council House National Historic Site (MAMC); Oxon Cove Park and Oxon Hill Farm (OXHI); Oxon Run Parkway (OXRN); Piscataway Park (PISC), including with Hard Bargain and National Colonial Farms; Sewall-Belmont House National Historic Site (BEPA); Suitland Parkway (SUIT); and others (National Park Service 2019). Many of the park sites of NACE are located along the Anacostia and Potomac Rivers and represent important ecological buffers between urban spaces and river watersheds while providing relief from the urban environment and preserve the viewshed across the Potomac River for the historic Mount Vernon mansion.

Geologic Summary

Situated within the Atlantic Coastal Plain physiographic province located east/south of the Fall Line, the geology of NACE predominantly consists of Cretaceous or younger rocks that represent partially consolidated or unconsolidated sediments shed from the Appalachian Mountains toward the Atlantic Ocean (Southworth and Denenny 2006; Thornberry-Ehrlich 2008c). The Mesozoic and Cenozoic are represented by the Cretaceous Potomac Formation and Severn Formation, Paleocene Brightseat Formation and Aquia Formation, Eocene Marlboro Clay and Nanjemoy Formation, and Miocene Calvert Formation. Younger surficial units mapped throughout NACE include Neogene–Pleistocene-age terrace deposits, Pleistocene fluvial and estuarine deposits, and Holocene alluvium (Figure 43).

Stratotypes

NACE contains one designated stratotype that represents the Cretaceous Potomac Formation (Table 7; Figure 44). There are 21 identified stratotypes located within 48 km (30 mi) of NACE boundaries that are provided in Appendix C for reference in case of future park boundary expansion.

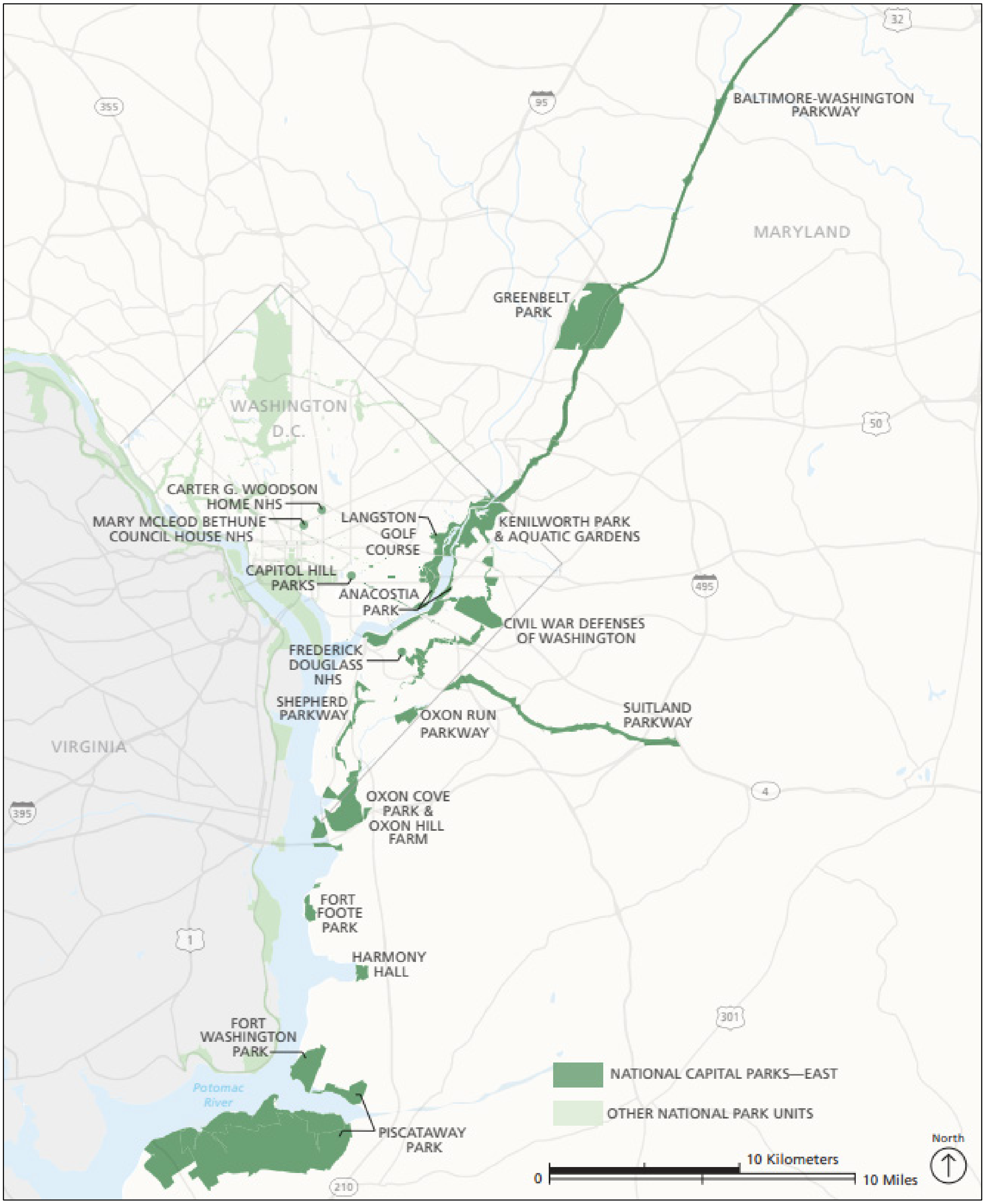


Figure 42. Park map of NACE, District of Columbia–Maryland (NPS).

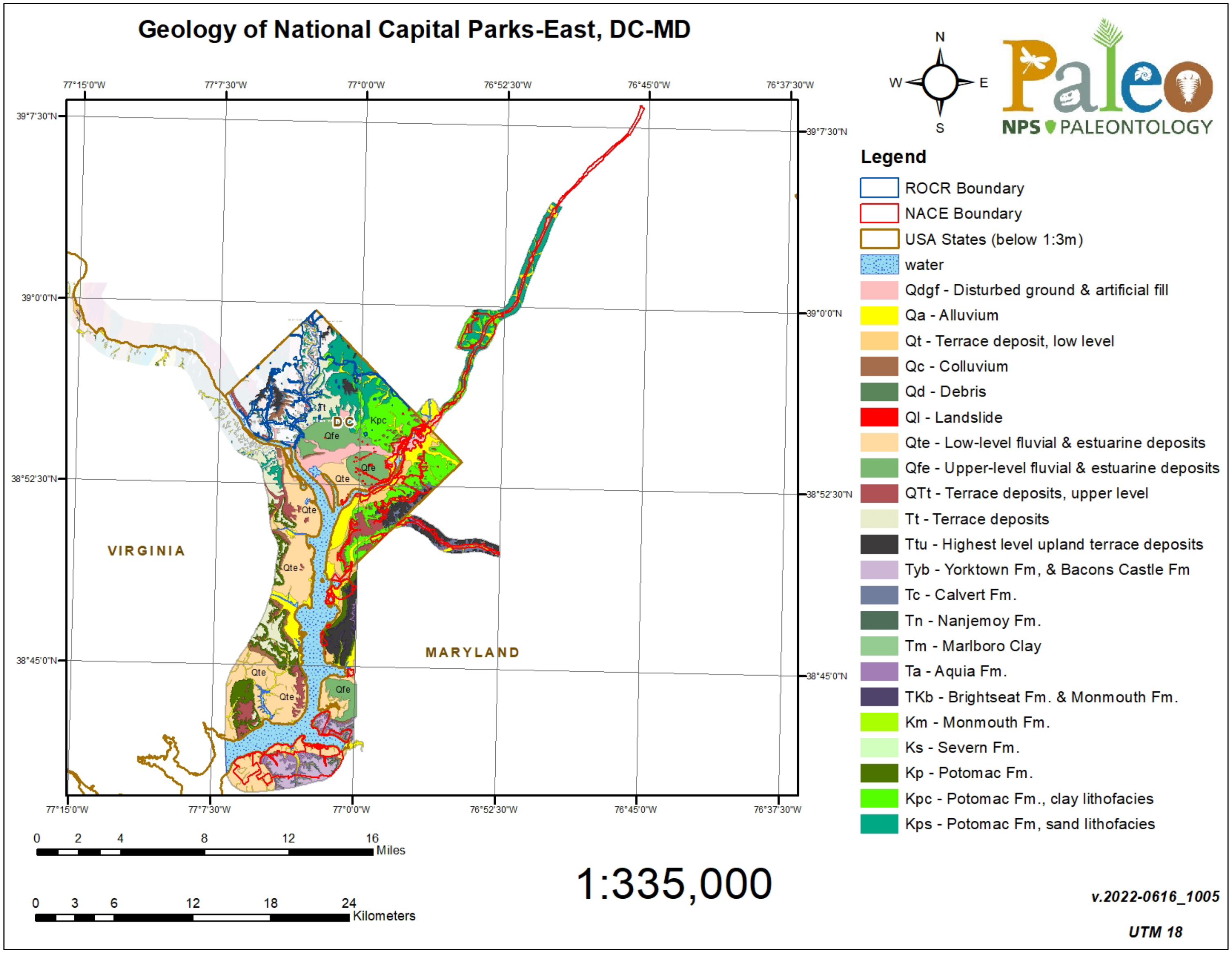


Figure 43. Geologic map of NACE, District of Columbia–Maryland. Data modified from National Capital Area Parks GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2164790.

Table 7. List of NACE stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Potomac Formation (Kp, Kpc, Kps)	McGee 1886; Jordan 1983	Type locality: deposits in the District of Columbia and adjacent parts of MD and VA.	Cretaceous

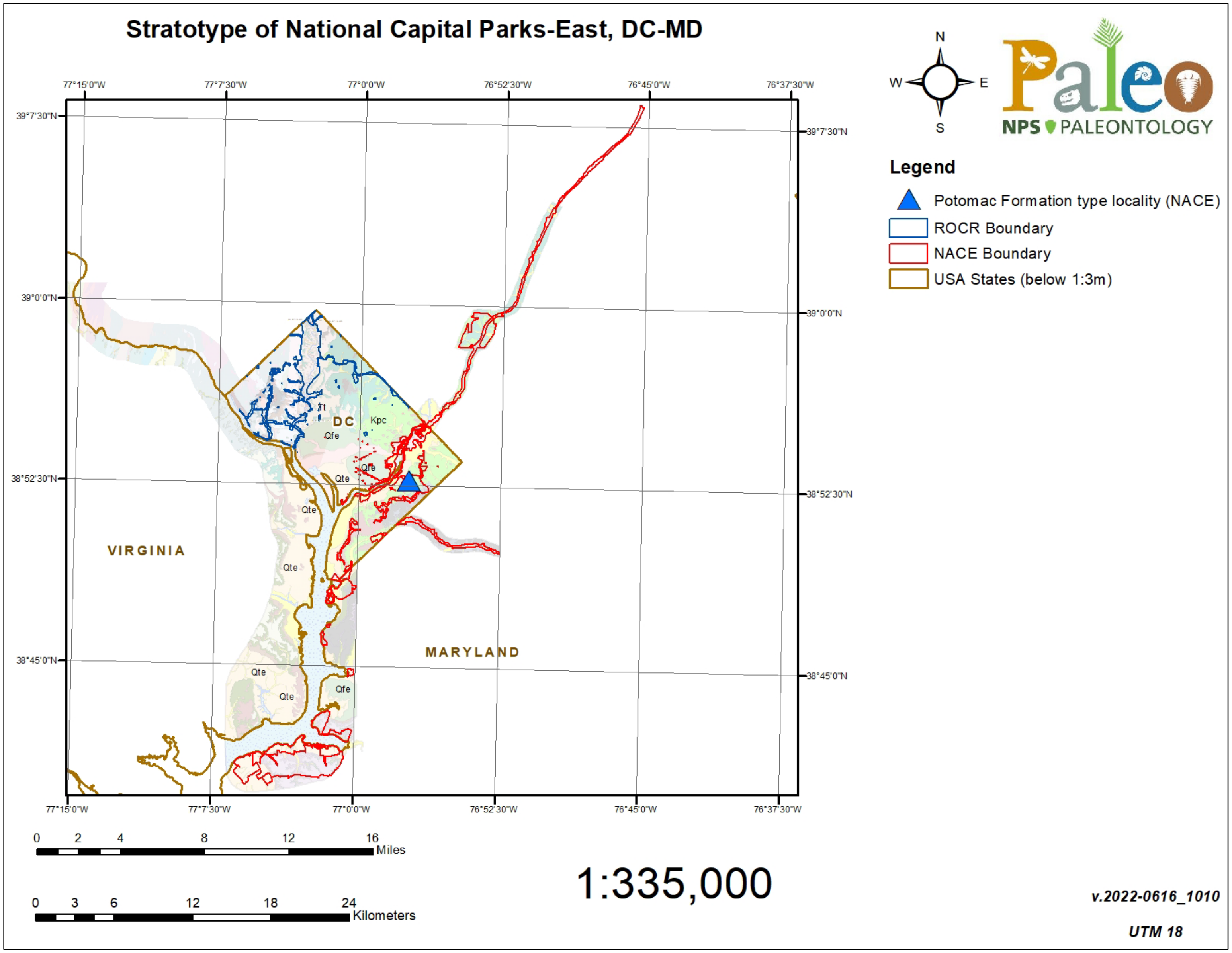


Figure 44. Modified geologic map of NACE showing stratotype locations. The transparency of the geologic units layer has been increased.

Potomac Formation

The Cretaceous Potomac Formation was named by McGee (1886) for exposures along the Potomac River that extended from Baltimore, MD to Washington, D.C. Although McGee (1886) never assigned a formal stratotype for the formation, Jordan (1983) states that the "*…deposits in the District of Columbia and adjacent parts of Maryland and Virginia which must now be considered its generalized type locality*" (Table 7; Figure 44). Distribution of the Potomac Formation in the surrounding Washington D.C. area shows that the Potomac Formation underlies portions of ROCR and the southern GWMP, but exposures more frequently occur in NACE units; it is mapped beneath many of the units, such as Anacostia Park, Baltimore-Washington Parkway, Civil War Defenses of Washington (Fort Circle Parks; including Fort Dupont, Fort Foote, and Shepherd Parkway), Fort Washington Park, Frederick Douglas National Historic Site, Greenbelt Park, Oxon Cove Park & Oxon Hill Farm, Oxon Run Parkway, Piscataway Park, and Suitland Parkway (Southworth and Denenny 2006). In the type locality, the Potomac Formation consists of unconsolidated, coarse feldspar- and quartz-sand and pebbles that grade into silty sand, clayey silt, and silty clay that are interpreted to have been deposited in channels, bars, and floodplains (Southworth and Denenny 2006). Clay-dominated rocks contain rare stems of plants and tree trunks that were replaced with silica and coal (Southworth and Denenny 2006). Exposures of the formation vary in thickness, as the unit forms a wedge-shaped mass that thickens eastward from nearly absent to several hundred meters or feet within the subsurface (Fleming et al. 1994). In the type locality the Potomac Formation underlies Atlantic Coastal Plain deposits including the Cretaceous Monmouth Formation, Paleocene Brightseat Formation, Miocene Calvert Formation, and Cenozoic-age terrace deposits.

Prince William Forest Park (PRWI)

Park Establishment

Prince William Forest Park (PRWI) is located approximately 56 km (35 mi) south of Washington, D.C., in Prince William County, Virginia (Figure 45). Originally established in 1933 as Chopawamsic Recreational Demonstration Area as part of President Franklin D. Roosevelt's New Deal legislation, the park unit was later renamed on June 22, 1948. Encompassing approximately 6,507 hectares (16,081 acres), PRWI is home to the largest protected eastern Piedmont forest in the United States and offers recreational opportunities rooted in its legacy as a model for the New Deal-era recreational demonstration area (RDA) program, an initiative that built parks for the nation's urban youth and families (National Park Service 2014). When the park unit was first established, the Civilian Conservation Corps (CCC) and Works Progress Administration (WPA) created programs to build a new type of park where low-income, inner-city children and families could escape the city and experience nature. Many of the CCC and WPA programs worked to reduce unemployment and teach job skills, as well as construct roads, bridges, dams, and cabin camps throughout the park. Today PRWI contains the largest concentration of CCC and WPA structures in the NPS.

Geologic Summary

PRWI straddles the Fall Line, a transitional boundary between the eastern Piedmont province and the Atlantic Coastal Plain province. The landscape of PRWI is composed of rolling hills, narrow ridges, and steep-sloped valleys and ravines that are an expression of the underlying geology (Thornberry-Ehrlich 2009c). The bedrock of the park is an assemblage of volcanic, sedimentary, and plutonic rocks that were buried and metamorphosed during the Alleghenian Orogeny, then subsequently uplifted and eroded to a plateau (Figure 46; Southworth and Denenny 2006). The oldest bedrock underlying PRWI consists of Neoproterozoic–Cambrian mafic and ultramafic rocks located along and north of Quantico Creek. Early Paleozoic rocks are widely mapped throughout the park and include the Ordovician Lake Jackson pluton, Quantico Formation, Lunga Reservoir Formation, and Chopawamsic Formation. A belt of Silurian felsic igneous rocks has intruded the older metavolcanic and metasedimentary rocks of the Chopawamsic Formation in the eastern portion of PRWI. Sediments of the Coastal Plain form a veneer atop the bedrock of the park and include the Cretaceous Potomac Formation, Miocene terrace deposits, and Pleistocene fluvial and estuarine deposits. Younger, Quaternary surficial deposits mapped in PRWI consist of terrace deposits and alluvium.

Stratotypes

PRWI contains two identified stratotypes that represent the Ordovician Chopawamsic Formation (Table 8; Figure 47). In addition to the designated stratotypes located within PRWI, stratotypes located within 48 km (30 mi) of the park boundaries are provided in Appendix C for reference in case of future park boundary expansion.

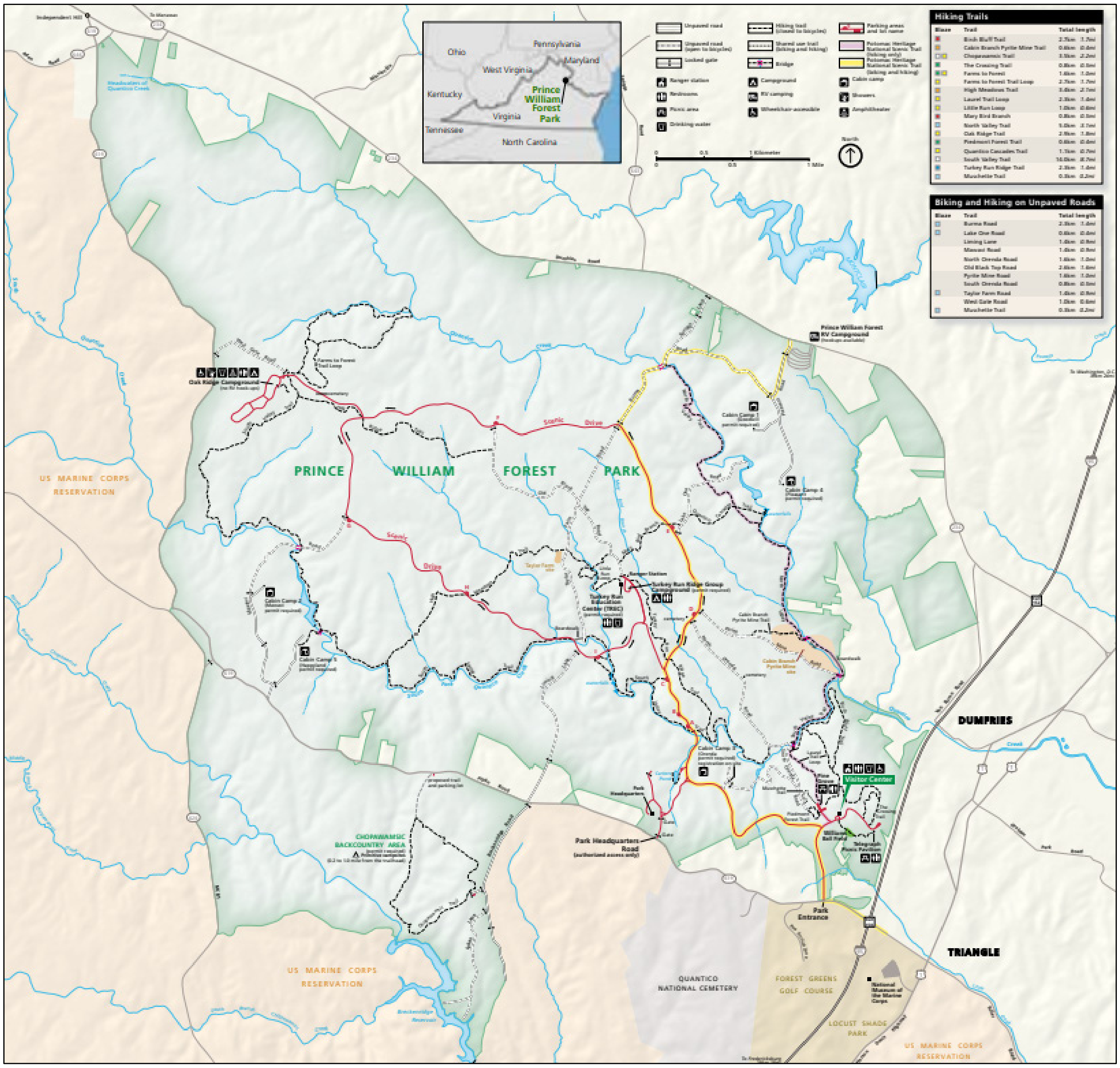


Figure 45. Park map of PRWI, Virginia (NPS).

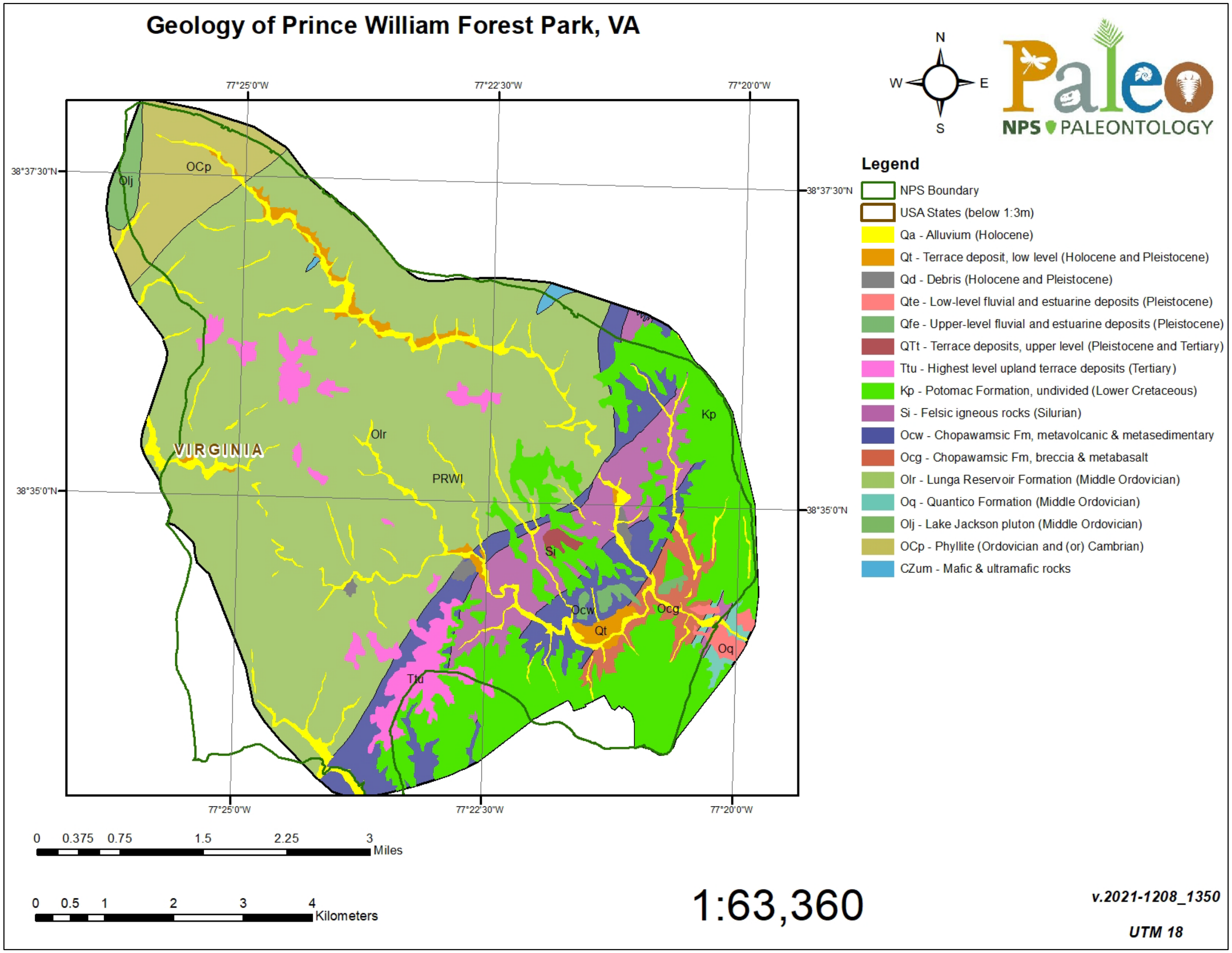


Figure 46. Geologic map of PRWI, Virginia. Data modified from PRWI GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2164813.

Table 8. List of PRWI stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Chopawamsic Formation (Ocw, Ocg)	Southwick et al. 1971	Type section: along Chopawamsic Creek, from a point 1.82 km (1.13 mi) and 45° southwest of crossroads of Joplin to a point 3.96 km (2.46 mi) and 6° southeast of Joplin [Joplin 7.5′ Quadrangle], northeastern VA. Reference section: along Quantico Creek in the Quantico 7.5′ Quadrangle from a point 0.31 km (0.19 mi) upstream (west) from Interstate Highway 95 to a point 122 m (400 ft) downstream from the dam near Camp No. 4 in PRWI.	Ordovician

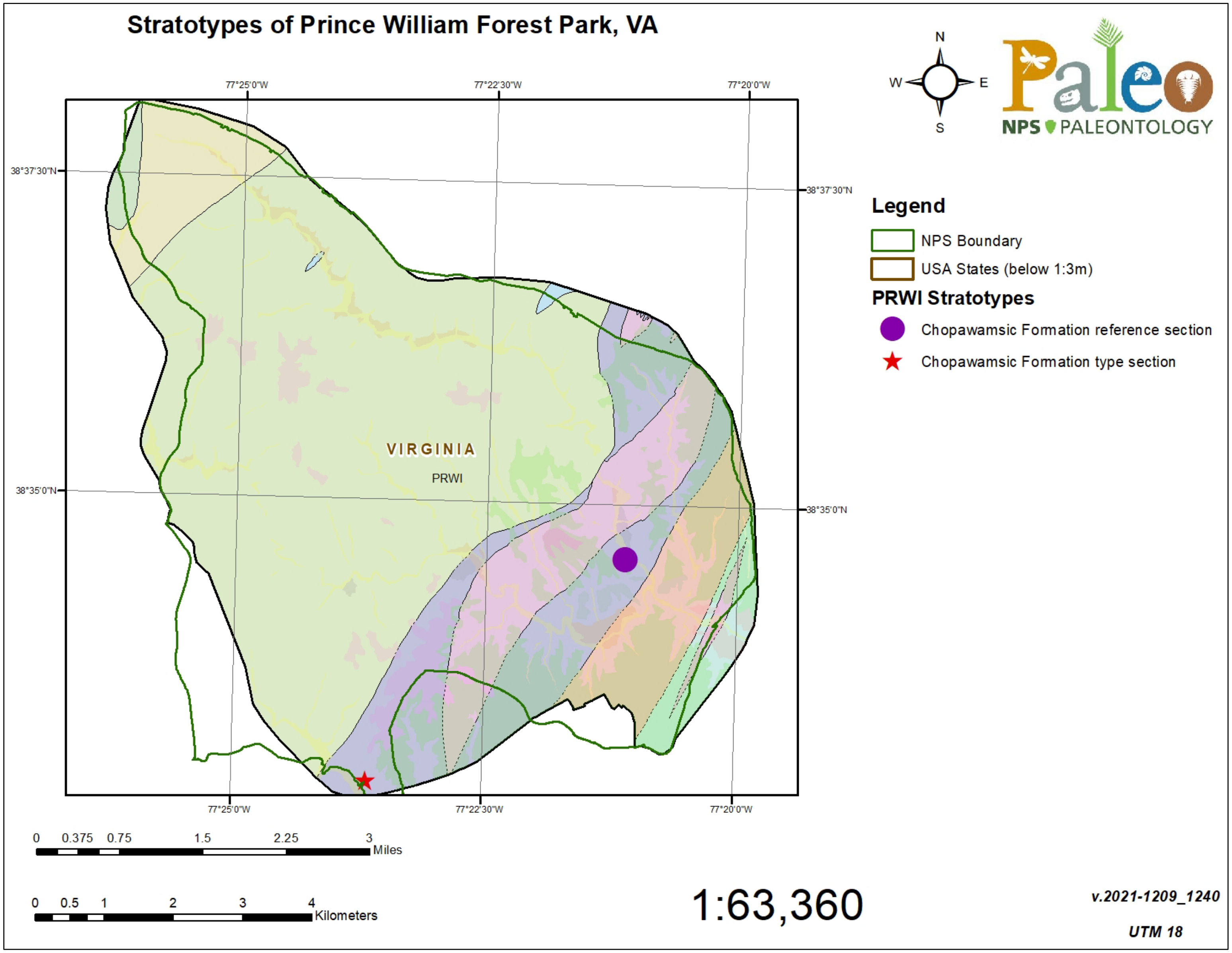


Figure 47. Modified geologic map of PRWI showing stratotype locations. The transparency of the geologic units layer has been increased.

Chopawamsic Formation

The Ordovician Chopawamsic Formation was introduced in Southwick et al. (1971) for a sequence of interbedded metavolcanic and metasedimentary rocks in northeastern Virginia. The type section was measured along Chopawamsic Creek, from a point 1.82 km (1.13 mi) S. 45° W. of the crossroads of Joplin to a point 3.96 km (2.46 mi) S. 6° E. of Joplin [Joplin 7.5′ Quadrangle], northeastern Virginia (Table 8; Figure 47; Southwick et al. 1971). It should be noted that only part of the type section is located in southern PRWI; the section extends beyond the park boundary. The type section consists of fine-grained, thinly interlayered amphibole schist, amphibolite, and feldspathic schist that are estimated to be about 3,050 m (10,000 ft) thick (Southwick et al. 1971). An additional reference section of the Chopawamsic Formation was designated by Southwick et al. (1971) along Quantico Creek [Quantico 7.5′ Quadrangle] from a point 0.31 km (0.19 mi) upstream (west) from Interstate Highway 95 to a point about 120 m (400 ft) downstream from the dam near Camp No. 4 in PRWI (Table 7; Figure 47). The thickness of the formation in this section is about 2,438 m (8,000 ft). The Chopawamsic Formation overlies the Wissahickon Formation and underlies the Quantico Formation.

Rock Creek Park (ROCR)

Park Establishment

Rock Creek Park (ROCR) is one of the oldest and largest natural urban parks in the United States, located in the heart of Washington D.C. (Figure 48). Authorized on September 27, 1890, ROCR contains approximately 710 hectares (1,755 acres) and represents both an individual unit of the NPS as well as an administrative unit that oversees 99 park sites and resources beyond the original core of Rock Creek Park, including Battleground Cemetery, Carter Barron Amphitheatre, nine of the 19 NPS-managed sites of the Civil War Defenses of Washington (Fort Circle Parks), Dumbarton Oaks Park, Glover Archbold Park, Klingle Valley Park, Melvin Hazen Park, Meridian Hill Park, Montrose Park, Normanstone Parkway, Old Stone House, Palisades Park–Battery Kemble Park, Peirce Mill, Pinehurst Parkway, Piney Branch Parkway, Rock Creek and Potomac Parkway, Soapstone Valley Park, and Whitehaven Park, as well as a number of smaller parks and circles (Southworth and Denenny 2006; National Park Service 2015b). Situated along Rock Creek, its tributaries, and its springs, ROCR sustains a variety of fish and aquatic species, including the endangered Hay's Spring amphipod. ROCR preserves archeological resources that record 5,000 years of human history, including the nationally notable Piney Branch Quarry Site, which expanded knowledge of prehistoric human activities in the Washington, D.C. area (National Park Service 2015b).

Geologic Summary

ROCR is located along the Fall Line, the boundary between the eastern Piedmont province and the Atlantic Coastal Plain province. The bedrock of ROCR consists of metasedimentary rock of deep marine origins. These rocks were buried, deformed, metamorphosed, and then intruded by mafic and felsic igneous plutonic rocks during the Ordovician (Southworth and Denenny 2006; Thornberry-Ehrlich 2009d). During the late Paleozoic these rocks were uplifted during the Alleghenian Orogeny and then subsequently eroded to form a plateau. The oldest bedrock underlying the park are Neoproterozoic–Cambrian-age metavolcanic and meta-igneous rocks that occur as bodies within the Laurel Formation. Rocks of the Cambrian Laurel and Sykesville represent a sedimentary mélange (mixture of rocks) that were later intruded by Ordovician plutonic rocks (Southworth and Denenny 2006). Mapped along the western boundary of ROCR is the Ordovician Kensington Tonalite, which has intruded rocks of the Sykesville Formation and Georgetown Intrusive Suite. Bedrock in the ROCR area is partially covered by a veneer of Cretaceous Atlantic Coastal Plain deposits (Potomac Formation), rock debris, regolith, and transported alluvium and colluvium (Figure 49). The major structural feature of the western Washington D.C. area is a near-vertical, north–south-trending fault called the Rock Creek shear zone that bisects the core of Rock Creek Park. This shear zone represents a 1–3 km (0.6–1.9 mi) wide belt of metamorphosed rocks (mylonite and phyllonite) located west of Rock Creek (Fleming and Drake 1998).

Stratotypes

There are no designated stratotypes identified within the boundaries of ROCR. There are 22 identified stratotypes located within 48 km (30 mi) of ROCR boundaries that are provided in Appendix C for reference in case of future park boundary expansion.

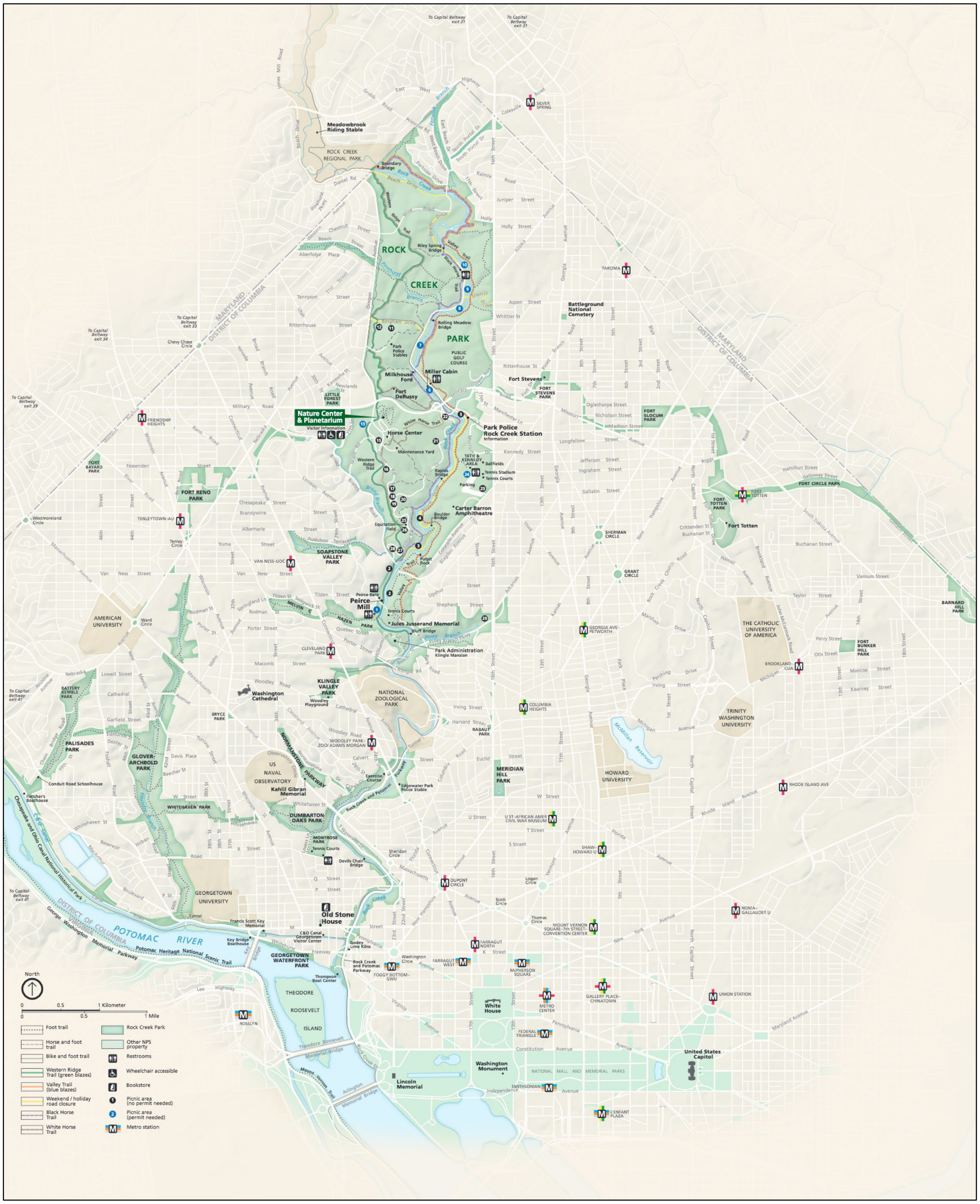


Figure 48. Park map of ROCR, District of Columbia (NPS).

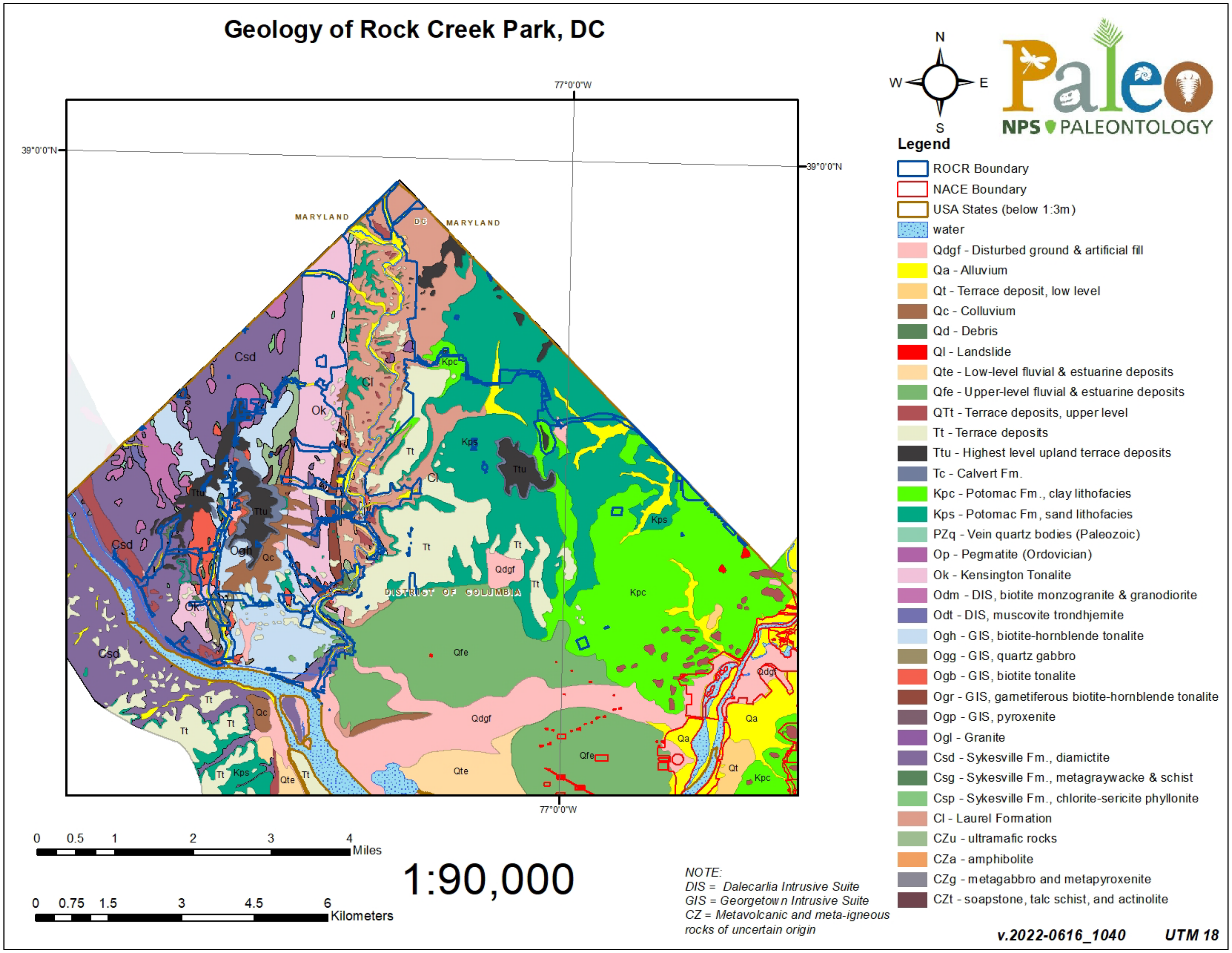


Figure 49. Geologic map of ROCR, District of Columbia. Data modified from GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1048619 and https://irma.nps.gov/DataStore/Reference/Profile/2164790.

Wolf Trap National Park for the Performing Arts (WOTR)

Park Establishment

Wolf Trap National Park for the Performing Arts (WOTR) is located in Virginia about 13 km (8 mi) west of Washington, D.C. (Figure 50). Originally authorized as Wolf Trap Farm Park on October 15, 1966, the park unit was redesignated on August 21, 2002, and encompasses approximately 52 hectares (130 acres) (Thornberry-Ehrlich 2008d; National Park Service 2016a). WOTR is the first and only national park for the performing arts and is home to the Filene Center, a premier open-air arts pavilion that has developed technical and operational capabilities that support a rich variety of programming. The Filene Center is named after Catherine Filene Shouse, an American researcher and philanthropist who donated land for the park with the vision to bring a diversity of performing arts to the public of the National Capital area (National Park Service 2013d). Today, the Filene Center continues to operate as an outdoor venue, hosting a variety of internationally acclaimed performing arts entertainment set against the rolling hills and woods along Wolf Trap Creek. Also located in WOTR is the Children's Theatre-in-the-Woods, an outdoor amphitheater that offers diverse programs that introduce children to the world of performing arts, as well as the Meadow Pavilion that serves as a third venue for smaller shows and performances.

Geologic Summary

The bedrock geology of WOTR is dominated by metasedimentary rocks of the Neoproterozoic–Cambrian Mather Gorge Formation. Metagraywacke and schist of the formation are exposed along Wolf Trap Creek. In the southeastern portion of WOTR the Mather Gorge Formation has been intruded by Ordovician plutonic rocks consisting of light-gray, massive, muscovite–biotite granite (Southworth and Denenny 2006). Numerous vein quartz bodies of Paleozoic age have intruded the metasedimentary rocks and large blocks of quartz mapped near Wolf Trap Creek. The broad erosional valley of Wolf Trap Creek contains young, Quaternary-age surficial deposits of alluvium and colluvium that follow the course of the creek and fill the broad hollows in the meadows (Figure 51; Southworth and Denenny 2006).

Stratotypes

There are no designated stratotypes identified within the boundaries of WOTR. There are 20 identified stratotypes located within 48 km (30 mi) of WOTR boundaries that are provided in Appendix C for reference in case of future park boundary expansion.

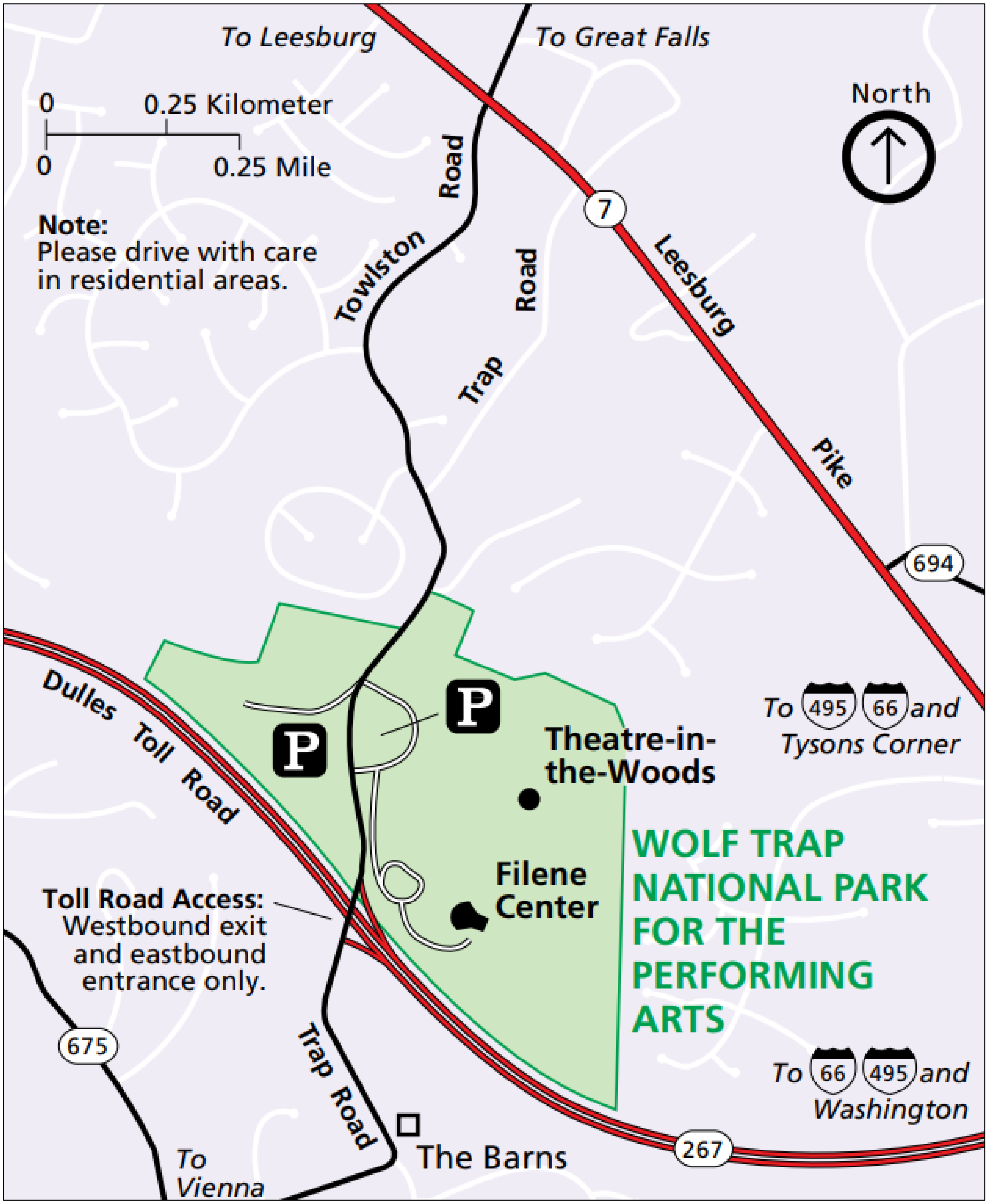


Figure 50. Park map of WOTR, Virginia (NPS).

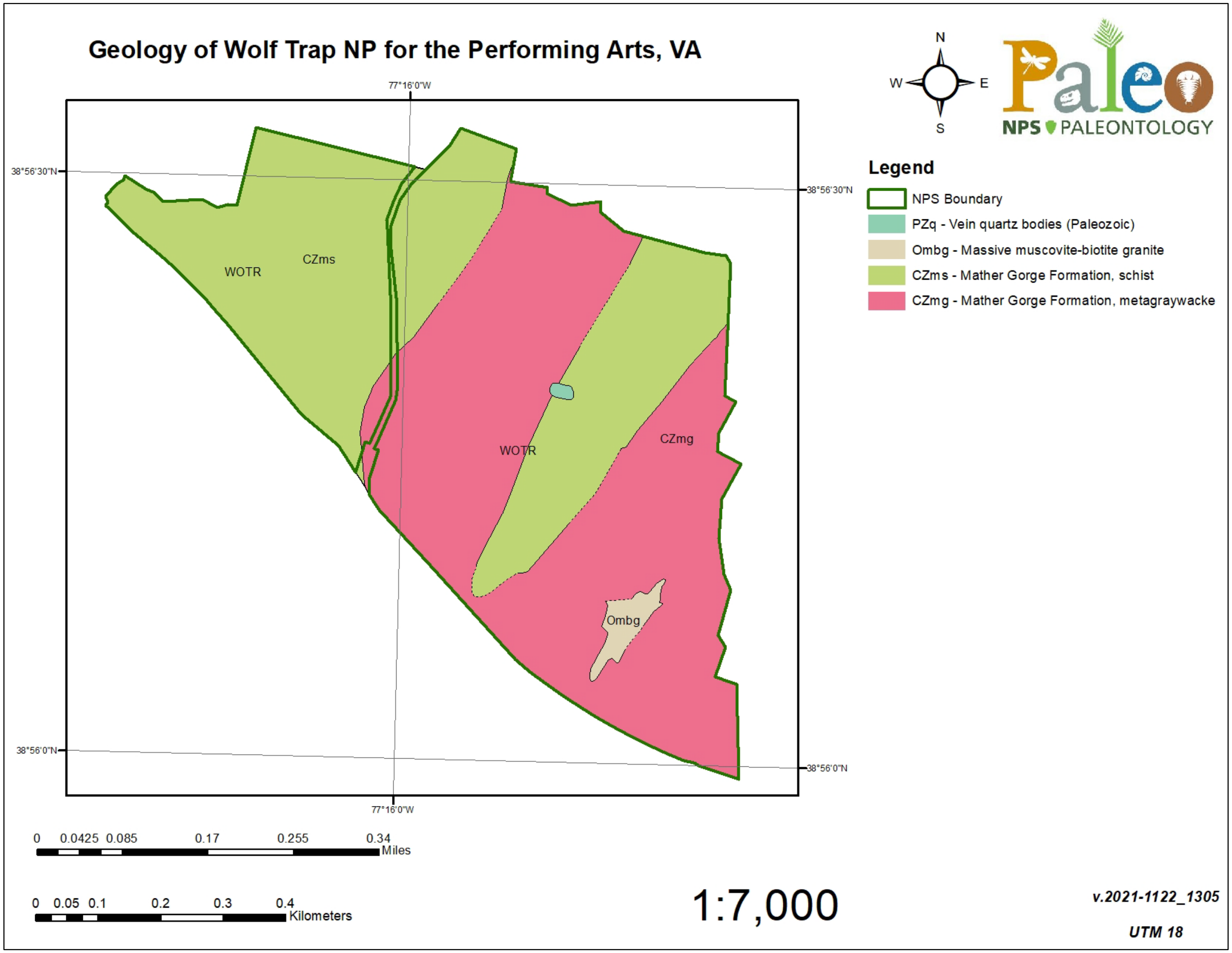


Figure 51. Geologic map of WOTR, Virginia. Data modified from WOTR GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2164816.

Recommendations

Stratotypes represent unique geologic exposures and are important to manage due to the scientific and educational values they hold for future generations. Stratotypes occur where rocks are exposed naturally (cliff face, river bluff, canyon wall, etc.) or artificially (quarry wall, road/rail/trail/canal cut, tunnel). Therefore, continued stratotype utility derives from the following three characteristics:

- Visibility: described rock layers remain visible and not totally or partially obscured
- Accessibility: the exposures at the stratotype remain reasonably accessible via road, trail, or other method
- Unaltered Integrity: the rock exposures are not altered significantly following description

Stratotype management strategies should focus on maintaining these characteristics to the extent practical when there are multiple management priorities at the site. The extent of the stratotype also impacts resource management considerations. For example, type areas occur over large geographic areas with less emphasis or significance placed on individual exposures, while type sections are specific localities that may warrant more focused management attention.

The recommendations below generally follow the protocol suggested by Brocx et al. (2019) with changes to fit NPS resource management framework.

1. The NPS Geologic Resources Division should work with park and network staff to increase their awareness and understanding about the historic and geologic heritage significance of geologic stratotypes (type sections/localities/areas, reference sections, lithodemes). This report is a first step toward building that awareness.
2. The NPS Geologic Resources Division should work with park and network staff to ensure they are aware of the locations of stratotypes in park areas. This information is necessary to ensure that proposed park activities or development do not adversely impact the stability and condition of these geologic exposures. Preservation of stratotypes should not limit accessibility for future scientific research but help safeguard these exposures from infrastructure development.
3. For significant sites without formal stratotype designations, GRD can provide assistance and liaison with the U.S. Geological Survey or other agencies to establish formal designations. It is recommended that stratotype designations of the following units be made to: (A) provide a standard reference for scientific research; (B) educate park staff and visitors about the geoheritage significance of these units; and (C) help safeguard these exposures.
    a. The Cretaceous Potomac Formation was named by McGee (1886) for exposures along the Potomac River that extended from Baltimore, MD to Washington, D.C. Jordan (1983) states that the "…deposits in the District of Columbia and adjacent parts of Maryland and Virginia which must now be considered its generalized type locality", a generalized type locality region that corresponds to NACE. Although the type locality is attributed to NACE in this report, it is recommended that a less ambiguous stratotype (reference section) be designated for this unit.

b. The Ordovician-age Georgetown Intrusive Suite (Hopson 1964) and Dalecarlia Intrusive Suite (Drake and Fleming 1994) were named after exposures that underlie a large part of western Washington, D.C. and eastern CHOH, but these rock suites currently lack formally designated stratotypes.
c. The Ordovician Bear Island Granodiorite was named by Cloos and Cooke (1953) from occurrences on and near Bear Island along the Potomac River in GWMP and CHOH, but this unit currently lacks a formal stratotype.
d. The Neoproterozoic Catoctin Formation was named by Keith (1894) from Catoctin Mountain in Loudoun County, Virginia, and Frederick County, Maryland (an area including CATO) but the unit currently lacks a formally designated stratotype.
e. The Cambrian Wolf Rock Quartzite of the Maryland Heights Member of the Weverton Formation was proposed by Brezinski (2021) and named after Wolf Rock in CATO. The unit consists of light-gray, massive, coarse-grained quartzite up to 9 m (30 ft) thick in the Blue Ridge Summit Quadrangle (Brezinski 2021). Currently no formal stratotype designation has been made.
f. The Cambrian Loudoun Formation was first described in the USGS Harpers Ferry folio by Keith (1894) and named for excellent exposures of the unit in Loudoun County, northern Virginia, in or near HAFE. However, no formal stratotype designation of the formation has been made.

4. For stratotypes designated external to an NPS area that may face destruction, alteration, or other significant impacts, GRD can work with park staff to potentially set up a reference section within an NPS area, which affords a baseline level of protection.
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), the NPS Geologic Resources Division, the U.S. Geological Survey, state geologic surveys, academic geologists, and other partners 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:
    a. Compile, update, and maintain a central inventory of all designated stratotypes and potential future nominations. The USGS GEOLEX serves this function for the United States. This report is part of an effort to inventory stratotypes specific to National Park Service areas and eventually provide that data in a spatial, searchable format and integrate with GEOLEX.

b. Establish appropriate monitoring protocols to regularly assess stratotype locations to identify any threats or impacts to these geologic heritage features in parks. See bullet points below for potential threats. A paper by Crofts et al. (2020) provides additional details on potential threats. Brocx et al. (2019) includes examples of destroyed stratotypes and suggests protocols for conservation in Australia. Criteria to access the stability of stratotype exposure sites should follow the guidance of the Unstable Slope Management Program (USMP) for federal land management agencies found here: https://highways.dot.gov/sites/fhwa.dot.gov/files/docs/federal-lands/tech-resources/31011/usmp-field-manual.pdf.
c. Develop appropriate management actions based on significance of site and consideration of other resource management needs. Photographs of each stratotype are rare and thus obtaining photographs of NPS stratotypes is a first step for resource management. See bullet points below for suggested management considerations.
d. Obtain good photographs of each geologic stratotype within the parks. Photographs of each stratotype are rare and thus obtaining photographs of NPS stratotypes is a first step for resource management. 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 stratotypes. GPS locations should also be recorded and kept in a database when the photographs are taken.
e. Consider the collection and curation of geologic samples (new or extant) from stratotypes within respective NPS areas. Samples collected from stratotype exposures can be useful as reference specimens to support future studies, especially where stratotypes may be lost through natural processes or human activities.
f. Use selected robust internationally and nationally significant stratotypes as formal teaching/interpretation sites and for geotourism so that the importance of the national- and international-level assets are more widely (and publicly) known, using wayside panels, educational sites (on site or virtual), and walkways (after Brocx et al. 2019).
g. Develop conservation protocols of significant stratotypes, either by appropriate fencing, guard rails, trails, boardwalks, and information boards or other means (e.g., phone apps) (after Brocx et al. 2019).

Natural processes that have the potential to impact visibility, accessibility, or unaltered integrity of stratotypes include the following. Note that the rate, frequency, or severity of these natural processes will likely change as climate continues to change.

- Slope movements (e.g., rock falls, landslides)
- Erosion
- Vegetation encroachment (exotic, invasive, or native)
- Tectonism and volcanism

Human activities that have the potential to impact visibility, accessibility, or unaltered integrity of stratotypes include the following:

- Road, trail, or other infrastructure development that may remove or obscure stratotypes.
- Installation of guard rails, sprayed concrete (e.g., "Shotcrete" or gunite), wire mesh, rock bolts, or other cliff stabilization techniques.
- Restoration of a quarry or other abandoned site that was used as a stratotype location.
- Graffiti, vandalism, or unauthorized fossil/mineral/rock collection.
- Scientific research permits that include fossil/mineral/rock sampling or paleomagnetism coring.
- Visitor use (e.g., trails that cross stratotypes) can degrade stratotype integrity.

Potential resource management actions include the following:

- As general guidance, NPS Management Policies (section 4.8.2) states that "The Service will protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue" (National Park Service 2006).
- All stratotypes should, at minimum, be photographed at high resolution with a common object or scale bar included.
- Photogrammetry is an ideal documentation method for significant stratotypes.
- If obscuring or destruction of the outcrop is necessary for other resource management priorities (e.g., road/trail alterations, AML restoration [should consider stratotypes where possible], visitor safety concerns, natural rockfall or slope movement at/near the stratotype), photogrammetric documentation should be considered. Designation of a reference section at a less threatened or dangerous exposure is another possibility.
- If other geologic resources are present at the stratotype, such as fossils, significant minerals, or cave features, additional resource management and monitoring may be necessary. See for example Young and Norby (2009).
- Clear exotic or invasive vegetation from stratotypes or manage native vegetation to maximize visibility and accessibility.
- Utilize the Unstable Slope Monitoring Program (USMP) Tool to determine stability of stratotype exposure and potential hazards to human safety.
- For exceptionally significant stratotypes (international, national, or related to park fundamental purposes), consider utilizing them as formal interpretation or education sites (on site or virtual), or protecting them with fencing/guard rails, constructing boardwalks or trails to focus visitor access, or installing wayside panels.

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Appendix A: Source Information for GRI Maps of NCRN Parks

GMAP = Unique identifier assigned to geologic source maps by the GRI program.

The GRI program converted these source maps to the GRI digital geologic map data for each park. GRI data sets are available at their publications page: https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm. For information on how source maps are converted and what the GRI data model includes, refer to the GRI data models here: https://irma.nps.gov/DataStore/Reference/Profile/2259192.

ANTI

- GMAP 4162: Southworth, S., and D. Denenny. 2006. Geologic map of the national parks in the National Capital region, Washington, D.C., Virginia, Maryland, and West Virginia [Antietam National Battlefield]. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1331. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1331/ (accessed May 25, 2022).

CATO

- GMAP 4161: Southworth, S., and D. Denenny. 2006. Geologic map of the national parks in the National Capital region, D.C., Virginia, Maryland, and West Virginia [Catoctin Mountain Park]. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1331. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1331/ (accessed May 25, 2022).

CHOH

- GMAP 771: Southworth, S., D. K. Brezinski, R. C. Orndorff, P. G. Chirico, and K. M. Lagueux. 2001. Digital geologic map and database of the Chesapeake and Ohio Canal National Historic Park, D.C, Virginia, Maryland, and West Virginia. U.S. Geological Survey, Reston, Virginia, and Maryland Geological Survey, Baltimore, Maryland. Open-File Report 01-188A. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2001/of01-188a/ (accessed May 25, 2022).

GWMP

- GMAP 4165: Southworth, S., and D. Denenny. 2006. Geologic map of the national parks in the National Capital region, D.C., Virginia, Maryland, and West Virginia [George Washington Memorial Parkway]. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1331. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1331/ (accessed May 25, 2022).

HAFE

- GMAP 771: Southworth, S., D. K. Brezinski, R. C. Orndorff, P. G. Chirico, and K. M. Lagueux. 2001. Digital geologic map and database of the Chesapeake and Ohio Canal National Historic Park, D.C, Virginia, Maryland, and West Virginia. U.S. Geological Survey, Reston, Virginia, and Maryland Geological Survey, Baltimore, Maryland. Open-File Report

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MANA

- GMAP 4170: Southworth, S., and D. Denenny. 2006. Geologic map of the national parks in the National Capital region, D.C., Virginia, Maryland, and West Virginia [Manassas National Battlefield]. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1331. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1331/ (accessed May 25, 2022).

MONO

- GMAP 4164: Southworth, S., and D. Denenny. 2006. Geologic map of the national parks in the National Capital region, D.C., Virginia, Maryland, and West Virginia [Monocacy National Battlefield]. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1331. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1331/ (accessed May 25, 2022).

NACE

- GMAP 4165: Southworth, S., and D. Denenny. 2006. Geologic map of the national parks in the National Capital region, D.C., Virginia, Maryland, and West Virginia [George Washington Memorial Parkway]. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1331. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1331/ (accessed May 25, 2022).

PRWI

- GMAP 4168: Southworth, S., and D. Denenny. 2006. Geologic map of the national parks in the National Capital region, D.C., Virginia, Maryland, and West Virginia [Prince William Forest Park]. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1331. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1331/ (accessed May 25, 2022).

ROCR

- GMAP 4165: Southworth, S., and D. Denenny. 2006. Geologic map of the national parks in the National Capital region, D.C., Virginia, Maryland, and West Virginia [George Washington Memorial Parkway]. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1331. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1331/ (accessed May 25, 2022).

WOTR

- GMAP 4166: Southworth, S., and D. Denenny. 2006. Geologic map of the national parks in the National Capital region, D.C., Virginia, Maryland, and West Virginia [Wolf Trap Farm]. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1331. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1331/ (accessed May 25, 2022).

Appendix B: Geologic Time Scale

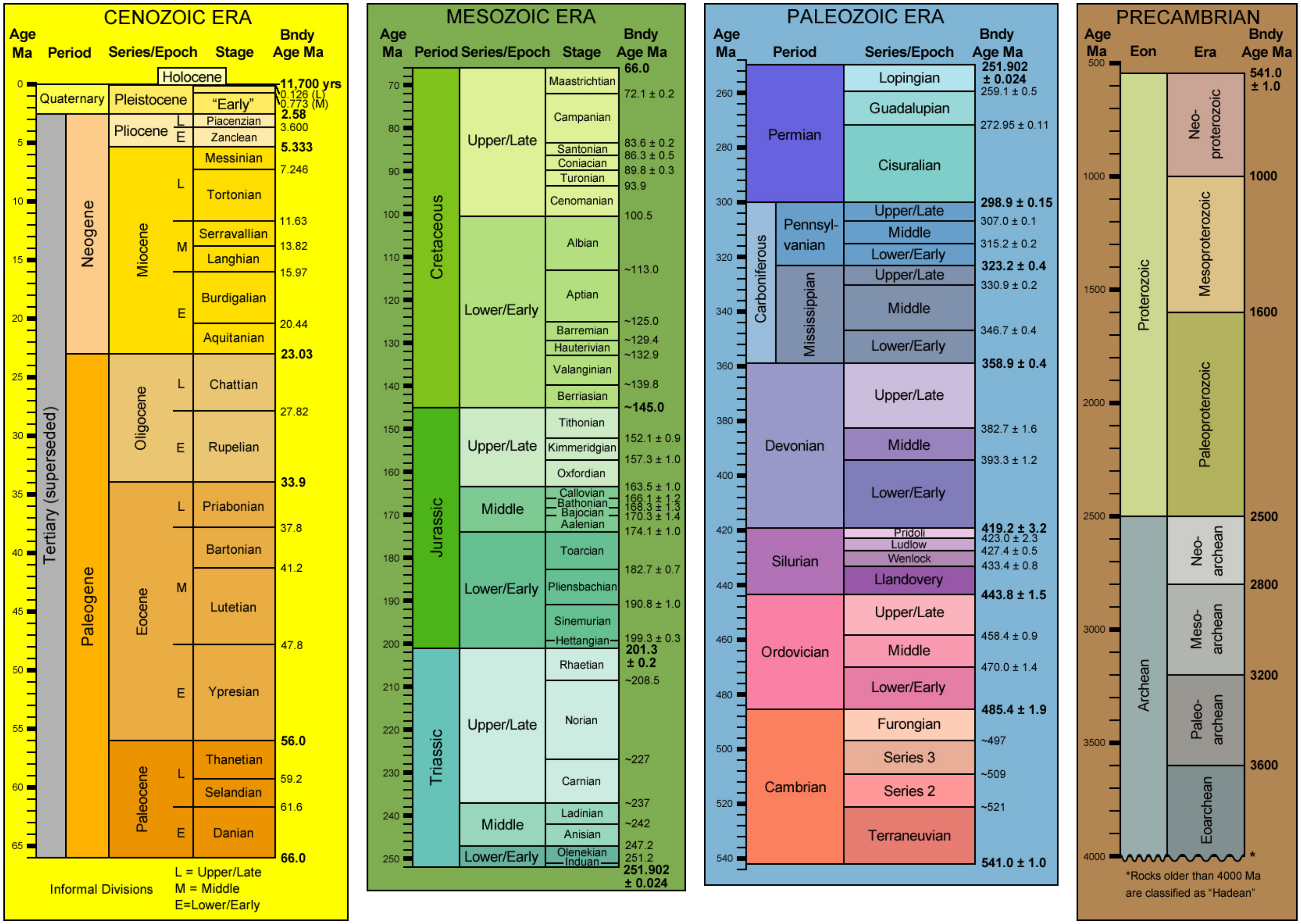

Figure B1. Geologic Time Scale. **Ma**=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

Appendix C: Stratotypes Located Within 48 km (30 mi) of NCRN Parks

ANTI

- Neoproterozoic–Cambrian
    - Ijamsville Phyllite (type locality)
- Cambrian
    - Antietam Formation (type locality)
    - Conococheague Formation: Big Spring Station Member (type section)
    - Elbrook Limestone (type area)
    - Frederick Formation: Adamstown Member (type section)
    - Frederick Formation: Lime Kiln Member (type section)
    - Frederick Formation: Monocacy Member (type section)
    - Frederick Formation: Rocky Springs Station Member (type section)
    - Sugarloaf Mountain Quartzite (type locality)
    - Tomstown Formation (type locality)
    - Tomstown Formation: Benevola Member (type section)
    - Urbana Phyllite (type locality)
    - Waynesboro Formation (type locality)
    - Waynesboro Formation: Cavetown Member (type section)
    - Waynesboro Formation: Chewsville Member (type section)
    - Waynesboro Formation: Red Run Member (type section)
    - Weverton Formation (type section and type locality)
    - Weverton Formation: Buzzard Knob Member (type section)
    - Weverton Formation: Owens Creek Member (type section)
- Cambrian–Ordovician
    - Conococheague Formation (type area)
- Ordovician
    - Martinsburg Formation (type locality and type area)
    - Pinesburg Station Formation (type section)
    - Rockdale Run Formation (type section)
    - Stonehenge Formation (type section and reference section)
    - Stonehenge Formation: Stoufferstown Member (type section)
- Silurian

- Tonoloway Formation (type locality)

- Devonian
    - Helderberg Limestone: Licking Creek Limestone Member (type section)
- Triassic
    - Bull Run Formation: Balls Bluff Siltstone Member (type section)
    - Bull Run Formation: Leesburg Member (type section)
    - Manassas Sandstone: Poolesville Member (type section)
    - Manassas Sandstone: Tuscarora Creek Member (type section)

CATO

- Neoproterozoic–Cambrian
    - Ijamsville Phyllite (type locality)
- Cambrian
    - Antietam Formation (type locality)
    - Conococheague Formation: Big Spring Station Member (type section)
    - Elbrook Limestone (type area)
    - Frederick Formation: Adamstown Member(type section)
    - Frederick Formation: Lime Kiln Member (type section)
    - Frederick Formation: Monocacy Member (type section)
    - Frederick Formation: Rocky Springs Station Member (type section)
    - Sugarloaf Mountain Quartzite (type locality)
    - Sykesville Formation (type area)
    - Tomstown Formation (type locality)
    - Tomstown Formation: Benevola Member (type section)
    - Urbana Phyllite (type locality)
    - Waynesboro Formation (type locality)
    - Waynesboro Formation: Cavetown Member (type section)
    - Waynesboro Formation: Chewsville Member (type section)
    - Waynesboro Formation: Red Run Member (type section)
    - Weverton Formation (type section and type locality)
    - Weverton Formation: Buzzard Knob Member (type section)
    - Weverton Formation: Owens Creek Member (type section)
- Cambrian–Ordovician
    - Conococheague Formation (type section and type area)

- Ordovician
  - Martinsburg Formation (type locality and type area)
  - Pinesburg Station Dolomite (type section and reference section)
  - Rockdale Run Formation (type section)
  - Stonehenge Limestone (type section and reference section)
  - Stonehenge Limestone: Funkstown Member (type section)
  - Stonehenge Limestone: Stoufferstown Member (type section)
- Devonian
  - Helderberg Limestone: Licking Creek Limestone Member (type section)
- Triassic
  - Gettysburg Shale: Heidlersburg Member (type section)
  - Manassas Sandstone: Tuscarora Creek Member (type section)
  - New Oxford Formation (type section)

CHOH

- Mesoproterozoic
  - Marshall Metagranite (type area)
- Neoproterozoic
  - Cobbler Mountain Alkali Feldspar Quartz Syenite (type locality)
- Neoproterozoic–Cambrian
  - Accotink Schist (type locality)
  - Annandale Group (type locality)
  - Ijamsville Phyllite (type locality)
  - Lake Barcroft Metasandstone (type locality)
- Cambrian
  - Antietam Formation (type locality)
  - Conococheague Formation: Big Spring Station Member (type section)
  - Elbrook Limestone (type area)
  - Frederick Formation: Adamstown Member (type section)
  - Frederick Formation: Lime Kiln Member (type section)
  - Frederick Formation: Monocacy Member (type section)
  - Frederick Formation: Rocky Springs Station Member (type section)
  - Laurel Formation (type area)
  - Popes Head Formation (type locality)

- Popes Head Formation: Old Mill Branch Metasiltstone Member (type locality)
    - Popes Head Formation: Station Hills Phyllite Member (type locality)
    - Sugarloaf Mountain Quartzite (type locality)
    - Tomstown Formation (type locality)
    - Tomstown Formation: Benevola Member (type section)
    - Urbana Phyllite (type locality)
    - Waynesboro Formation (type locality)
    - Waynesboro Formation: Cavetown Member (type section)
    - Waynesboro Formation: Chewsville Member (type section)
    - Waynesboro Formation: Red Run Member (type section)
    - Weverton Formation (type section and type locality)
    - Weverton Formation: Buzzard Knob Member (type section)
    - Weverton Formation: Owens Creek Member (type section)
- Cambrian–Ordovician
    - Conococheague Formation (type section)
- Ordovician
    - Martinsburg Formation (type locality and type area)
    - Pinesburg Station Dolomite (type section and reference section)
    - Rockdale Run Formation (type section)
    - Stonehenge Limestone (type section and reference section)
    - Stonehenge Limestone: Funkstown Member (type section)
    - Stonehenge Limestone: Stoufferstown Member (type section)
- Silurian
    - McKenzie Formation (type section)
    - Tonoloway Limestone (type locality)
- Silurian–Devonian
    - Keyser Limestone (type locality)
- Devonian
    - Brallier Formation (type locality)
    - Hampshire Formation (type area)
    - Helderberg Limestone: Licking Creek Limestone Member (type section)
    - Helderberg Limestone: New Creek Limestone Member (type section)
    - Mahantango Formation: Gander Run Shale Member (type area)

- Mahantango Formation: Pokejoy Member (type section)
- Rockwell Formation: Finzel Tongue (type locality)
- Shriver Chert (type area)

- Devonian–Mississippian
  - Rockwell Formation (principal reference section)
- Mississippian
  - Purslane Formation (principal reference section)
- Triassic
  - Balls Bluff Siltstone (type section)
  - Balls Bluff Siltstone: Leesburg Member (type section)
  - Manassas Sandstone: Poolesville Member (type section)
  - Manassas Sandstone: Reston Member (type section)
  - Manassas Sandstone: Tuscarora Creek Member (type section)
- Triassic–Jurassic
  - Catharpin Creek Formation (type section)
- Cretaceous
  - Patuxent Formation (type area)
- Paleocene
  - Brightseat Formation (type locality)
- Eocene
  - Nanjemoy Formation: Potapaco Member (type area)
- Miocene
  - Fairhaven Member of the Calvert Formation (type locality)

GWMP

- Neoproterozoic–Cambrian
  - Accotink Schist (type locality)
  - Annandale Group (type locality)
  - Garrisonville Mafic Complex (type locality)
  - Ijamsville Phyllite (type locality)
  - Lake Barcroft Metasandstone (type locality)
- Cambrian
  - Frederick Formation: Adamstown Member (type section)
  - Frederick Formation: Lime Kiln Member (type section)

    - Frederick Formation: Monocacy Member (type section)
    - Frederick Formation: Rocky Springs Station Member (type section)
    - Laurel Formation (type area)
    - Popes Head Formation (type locality)
    - Popes Head Formation: Old Mill Branch Metasiltstone Member (type locality)
    - Popes Head Formation: Station Hills Phyllite Member (type locality)
    - Sugarloaf Mountain Quartzite (type locality)
    - Sykesville Formation (type area)
    - Urbana Phyllite (type locality)
- Ordovician
    - Chopawamsic Formation (reference section)
- Triassic
    - Bull Run Formation: Balls Bluff Siltstone Member (type section)
    - Bull Run Formation: Leesburg Member (type section)
    - Manassas Sandstone: Poolesville Member (type section)
    - Manassas Sandstone: Reston Member (type section)
    - Manassas Sandstone: Tuscarora Creek Member (type section)
- Triassic–Jurassic
    - Catharpin Creek Formation (type section)
- Cretaceous
    - Patuxent Formation (type area)
- Paleocene
    - Brightseat Formation (type locality)
- Paleocene
    - Aquia Formation (type locality and reference section)
    - Aquia Formation: Paspotansa Member (type section)
    - Aquia Formation: Piscataway Member (type section)
- Eocene
    - Nanjemoy Formation: Potapaco Member (type area)
    - Nanjemoy Formation: Woodstock Member (principal reference section)
- Miocene
    - Calvert Formation: Fairhaven Member (type locality)
    - Calvert Formation: Popes Creek Sand Member (type section)

HAFE

- Mesoproterozoic
  - Marshall Metagranite (type area)
- Neoproterozoic
  - Cobbler Mountain Alkali Feldspar Quartz Syenite (type locality)
- Neoproterozoic–Cambrian
  - Ijamsville Phyllite (type locality)
- Cambrian
  - Antietam Formation (type locality)
  - Conococheague Formation: Big Spring Station Member (type section)
  - Frederick Formation: Adamstown Member (type section)
  - Frederick Formation: Lime Kiln Member (type section)
  - Frederick Formation: Monocacy Member (type section)
  - Frederick Formation: Rocky Springs Station Member (type section)
  - Sugarloaf Mountain Quartzite (type locality)
  - Tomstown Formation: Benevola Member (type section)
  - Urbana Phyllite (type locality)
  - Waynesboro Formation: Cavetown Member (type section)
  - Waynesboro Formation: Chewsville Member (type section)
  - Waynesboro Formation: Red Run Member (type section)
  - Weverton Formation (type section and type locality)
  - Weverton Formation: Buzzard Knob Member (type section)
  - Weverton Formation: Owens Creek Member (type section)
- Ordovician
  - Martinsburg Formation (type locality and type area)
  - Pinesburg Station Dolomite (type section and reference section)
  - Rockdale Run Formation (type section)
  - Stonehenge Limestone: Funkstown Member (type section)
- Triassic
  - Bull Run Formation: Balls Bluff Siltstone Member (type section)
  - Bull Run Formation: Leesburg Member (type section)
  - Manassas Sandstone: Poolesville Member (type section)
  - Manassas Sandstone: Tuscarora Creek Member (type section)

- Triassic–Jurassic
  - Catharpin Creek Formation (type section)

MANA

- Mesoproterozoic
  - Marshall Metagranite (type area)
  - Flint Hill Gneiss (type locality)
- Neoproterozoic
  - Battle Mountain Alkali Feldspar Granite (type locality)
  - Amissville Alkali Feldspar Granite (type locality)
  - Cobbler Mountain Alkali Feldspar Quartz Syenite (type locality)
  - Laurel Mills Granite (type locality)
- Neoproterozoic–Cambrian
  - Lake Barcroft Metasandstone (type locality)
  - Annandale Group (type locality)
  - Accotink Schist (type locality)
  - Garrisonville Mafic Complex (type locality)
- Cambrian
  - Sugarloaf Mountain Quartzite (type locality)
  - Popes Head Formation (type locality)
  - Popes Head Formation: Old Mill Branch Metasiltstone Member (type locality)
  - Popes Head Formation: Station Hills Phyllite Member (type locality)
- Ordovician
  - Chopawamsic Formation (reference section)
- Silurian
  - Falls Run Granite Gneiss (type area)
- Triassic
  - Bull Run Formation: Balls Bluff Siltstone Member (type section)
  - Bull Run Formation: Leesburg Member (type section)
  - Manassas Sandstone: Poolesville Member (type section)
  - Manassas Sandstone: Reston Member (type section)
  - Manassas Sandstone: Tuscarora Creek Member (type section)
- Triassic–Jurassic
  - Catharpin Creek Formation (type section)

- Paleocene
    - Aquia Formation (type locality)

MONO

- Neoproterozoic–Cambrian
    - Soldiers Delight Ultramafite (type locality)
    - Ijamsville Phyllite (type locality)
- Cambrian
    - Antietam Formation (type locality)
    - Frederick Formation: Adamstown Member (type section)
    - Frederick Formation: Lime Kiln Member (type section)
    - Frederick Formation: Monocacy Member (type section)
    - Frederick Formation: Rocky Springs Station Member (type section)
    - Sugarloaf Mountain Quartzite (type locality)
    - Sykesville Formation (type area)
    - Tomstown Formation (type locality)
    - Tomstown Formation: Benevola Member (type section)
    - Urbana Phyllite (type locality)
    - Waynesboro Formation (type locality)
    - Waynesboro Formation: Cavetown Member (type section)
    - Waynesboro Formation: Chewsville Member (type section)
    - Waynesboro Formation: Red Run Member (type section)
    - Weverton Formation (type section and type locality)
    - Weverton Formation: Buzzard Knob Member (type section)
    - Weverton Formation: Owens Creek Member (type section)
- Ordovician
    - Martinsburg Formation (type locality and type area)
    - Pinesburg Station Dolomite (type section)
    - Stonehenge Limestone (reference section)
    - Stonehenge Limestone: Funkstown Member (type section)
- Triassic
    - Bull Run Formation: Balls Bluff Siltstone Member (type section)
    - Bull Run Formation: Leesburg Member (type section)
    - Manassas Sandstone: Poolesville Member (type section)

    - Manassas Sandstone: Reston Member (type section)
    - Manassas Sandstone: Tuscarora Creek Member (type section)

NACE

- Neoproterozoic–Cambrian
    - Accotink Schist (type locality)
    - Annandale Group (type locality)
    - Ijamsville Phyllite (type locality)
    - Lake Barcroft Metasandstone (type locality)
- Cambrian
    - Laurel Formation (type area)
    - Popes Head Formation (type locality)
    - Popes Head Formation: Old Mill Branch Metasiltstone Member (type locality)
    - Popes Head Formation: Station Hills Phyllite Member (type locality)
    - Sugarloaf Mountain Quartzite (type locality)
    - Sykesville Formation (type area)
    - Urbana Phyllite (type locality)
- Triassic
    - Bull Run Formation: Balls Bluff Siltstone Member (type section)
    - Bull Run Formation: Leesburg Member (type section)
    - Manassas Sandstone: Poolesville Member (type section)
    - Manassas Sandstone: Reston Member (type section)
    - Manassas Sandstone: Tuscarora Creek Member (type section)
- Triassic–Jurassic
    - Catharpin Creek Formation (type section)
- Cretaceous
    - Patuxent Formation (type area)
    - Magothy Formation (type area)
- Paleocene
    - Brightseat Formation (type locality)
- Eocene
    - Nanjemoy Formation: Potapaco Member (type area)
- Miocene
    - Calvert Formation: Fairhaven Member (type locality)

PRWI

- Mesoproterozoic
  - Marshall Metagranite (type area)
- Neoproterozoic–Cambrian
  - Accotink Schist (type locality)
  - Annandale Group (type locality)
  - Garrisonville Mafic Complex (type locality)
  - Lake Barcroft Metasandstone (type locality)
  - Po River Metamorphic Suite (type area)
- Cambrian
  - Holly Corner Gneiss (type area)
  - Popes Head Formation (type locality)
  - Popes Head Formation: Old Mill Branch Metasiltstone Member (type locality)
  - Popes Head Formation: Station Hills Phyllite Member (type locality)
  - Ta River Metamorphic Suite (type area)
- Cambrian–Ordovician
  - True Blue Formation (type locality)
- Ordovician
  - Chopawamsic Formation (reference section)
- Silurian
  - Carboniferous Falmouth Intrusive Suite (type area)
  - Falls Run Granite Gneiss (type area)
- Triassic–Jurassic
  - Catharpin Creek Formation (type section)
- Triassic
  - Manassas Sandstone: Rapidan Member (type section)
  - Manassas Sandstone: Reston Member (type section)
  - Tibbstown Formation: Mountain Run Member (type section)
- Paleocene
  - Aquia Formation (type locality and principal reference section)
  - Aquia Formation: Paspotansa Member (type section)
  - Aquia Formation: Piscataway Member (type section)
- Eocene

    - Nanjemoy Formation: Potapaco Member (type area)
    - Nanjemoy Formation: Woodstock Member (principal reference section)
- Miocene
    - Calvert Formation: Popes Creek Sand Member (type section)

ROCR

- Neoproterozoic–Cambrian
    - Lake Barcroft Metasandstone (type locality)
    - Ijamsville Phyllite (type locality)
    - Annandale Group (type locality)
    - Accotink Schist (type locality)
- Cambrian
    - Sugarloaf Mountain Quartzite (type locality)
    - Urbana Phyllite (type locality)
    - Sykesville Formation (type area)
    - Laurel Formation (type area)
    - Popes Head Formation (type locality)
    - Popes Head Formation: Old Mill Branch Metasiltstone (type locality)
    - Popes Head Formation: Station Hills Phyllite Member (type locality)
- Triassic
    - Bull Run Formation: Balls Bluff Siltstone Member (type section)
    - Bull Run Formation: Leesburg Member (type section)
    - Manassas Sandstone: Poolesville Member (type section)
    - Manassas Sandstone: Reston Member (type section)
    - Manassas Sandstone: Tuscarora Creek Member (type section)
- Triassic–Jurassic
    - Catharpin Creek Formation (type section)
- Cretaceous
    - Patuxent Formation (type area)
    - Magothy Formation (type area)
- Paleocene
    - Brightseat Formation (type locality)
- Eocene
    - Nanjemoy Formation: Potapaco Member (type area)

- Miocene
    - Calvert Formation: Fairhaven Member (type locality)

WOTR

- Neoproterozoic–Cambrian
    - Lake Barcroft Metasandstone (type locality)
    - Ijamsville Phyllite (type locality)
    - Annandale Group (type locality)
    - Accotink Schist (type locality)
- Cambrian
    - Sugarloaf Mountain Quartzite (type locality)
    - Urbana Phyllite (type locality)
    - Frederick Formation: Adamstown Member (type section)
    - Frederick Formation: Lime Kiln Member (type section)
    - Laurel Formation (type area)
    - Popes Head Formation (type locality)
    - Popes Head Formation: Old Mill Branch Metasiltstone Member (type locality)
    - Popes Head Formation: Station Hills Phyllite Member (type locality)
- Triassic
    - Bull Run Formation: Balls Bluff Siltstone Member (type section)
    - Bull Run Formation: Leesburg Member (type section)
    - Manassas Sandstone: Poolesville Member (type section)
    - Manassas Sandstone: Reston Member (type section)
    - Manassas Sandstone: Tuscarora Creek Member (type section)
- Triassic–Jurassic
    - Catharpin Creek Formation (type section)
- Cretaceous
    - Patuxent Formation (type area)
- Paleocene
    - Brightseat Formation (type locality)

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National Park Service
U.S. Department of the Interior

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