National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

National Park Service Geologic Type Section Inventory

Eastern Rivers and Mountains Inventory & Monitoring Network

Natural Resource Report NPS/ERMN/NRR—2021/2248

ON THE COVER
Delaware Water Gap, where road cuts along U.S. Interstate 80 in Mount Tammany expose the designated type sections of both the Minsi and Tammany Members of the Shawangunk Formation (NPS).

National Park Service Geologic Type Section Inventory

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

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

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

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NPS 962/175220, April 2021

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Executive Summary

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

There are several different categories of geologic or stratigraphic units (supergroup, group, formation, member, bed) which represent a hierarchical system of classification. The mapping of stratigraphic units involves the evaluation of lithologies, bedding properties, thickness, geographic distribution, and other factors. If a new mappable geologic unit is identified, it 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 2005). 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 of the unit is designated as the type section or type locality (see Definitions). The type section is an important reference section for a named geologic unit which presents a relatively complete and representative profile. The type or reference section is important both historically and scientifically, and should be recorded such that other researchers may evaluate it in the future. Therefore, this inventory of geologic type sections in NPS areas is an important effort in documenting these locations in order that NPS staff recognize and protect these areas for future studies.

The documentation of all geologic type sections throughout the 423 units of the NPS is an ambitious undertaking. The strategy for this project is to select a subset of parks to begin research for the occurrence of geologic type sections within particular parks. The focus adopted for completing the baseline inventories throughout the NPS was centered on the 32 inventory and monitoring networks (I&M) established during the late 1990s. The I&M networks are clusters of parks within a defined geographic area based on the ecoregions of North America (Fenneman 1946; Bailey 1976; Omernik 1987). These networks share similar physical resources (geology, hydrology, climate), biological resources (flora, fauna), and ecological characteristics. Specialists familiar with the resources and ecological parameters of the network, and associated parks, work with park staff to support network level activities (inventory, monitoring, research, data management).

Adopting a network-based approach to inventories worked well when the NPS undertook paleontological resource inventories for the 32 I&M networks. The network approach is also being applied to the inventory for the geologic type sections in the NPS. The planning team from the NPS Geologic Resources Division who proposed and designed this inventory selected the Greater Yellowstone Inventory and Monitoring Network (GRYN) as the pilot network for initiating this project. Through the research undertaken to identify the geologic type sections within the parks of the GRYN methodologies for data mining and reporting on these resources was established.

Methodologies and reporting adopted for the GRYN have been used in the development of this type section inventory for the Eastern Rivers and Mountains Inventory & Monitoring Network.

The goal of this project is to consolidate information pertaining to geologic type sections which occur within NPS-administered areas, in order that this information is available throughout the NPS to inform park managers and to promote the preservation and protection of these important geologic landmarks and geologic heritage resources. The review of stratotype occurrences for the ERMN shows there are currently no designated stratotypes for ALPO, BLUE, FONE, FRHI, GARI, or JOFL; DEWA has eight type sections and three reference sections; NERI has one type locality and two type areas; and UPDE has two type sections, one type locality, and one type area.

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

Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic type sections for the national parks of the Eastern Rivers and Mountains Inventory and Monitoring Network (ERMN). 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, Nancy and David manage the National Geologic Map Database for the United States (NGMDB, https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl?glx=1) and the U.S. Geologic Names Lexicon ("GEOLEX", https://ngmdb.usgs.gov/Geolex/search), critical sources of geologic map information for science, industry and the American public. We also extend our appreciation to Charles Ver Straeten (New York State Museum), Rose-Anna Behr (Pennsylvanian Department of Conservation and Natural Resources), Frank Fletcher (Pennsylvania Geological Survey, retired), Gale Blackmer (Pennsylvania Geological Survey), and Mitch Blake and Paula Hunt (West Virginia Geological Survey) for their assistance with peer review of this inventory report.

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, Colorado for their assistance with locating hard-to-find publications.

Thanks to our NPS colleagues in the Eastern Rivers and Mountains Inventory and Monitoring Network and the network parks including: Matt Marshall and Kristina Callahan (ERMN), Sula Jacobs and Kara Deutsch (DEWA), Joseph Salvatore and Don Hamilton (UPDE), Bryan Wender (NERI, GARI, BLUE), and Brenda Wasler (ALPO, FONE, FRHI, JOFL). Additional thanks to Carmen Chapin and Seth Lerman for continued support for this and other important geology projects in the Northeast Region of the NPS.

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 Hal Pranger, Julia Brunner, Jason Kenworthy, and Jim Wood. We especially appreciate the dedicated assistance from Lima Soto, former Geoscientists-in-the-Parks Program (GIP) Coordinator, to ensure a highly qualified geology intern was hired for this project.

Dedication

This Eastern Rivers and Mountains Inventory and Monitoring Network Geologic Type Section Inventory is dedicated to USGS Geologist Jack Epstein, who died in May 2020. Jack loved Delaware Water Gap National Recreation Area (DEWA) and authored many quadrangle maps used in the compiled geologic map of the park; his PhD dissertation was on the Stroudsburg 7.5’ Quadrangle at the southeastern end of DEWA.

Jack was a great friend to the NPS and assisted in geologic efforts near Yellowstone NP, Devils Tower NM, Wind Cave NP, Jewel Cave NM, Shenandoah NP, and the Appalachian Trail. Over the years, Jack led many professional field trips and published numerous field guides related to DEWA (see Epstein and Epstein 1967; Epstein 2001). Jack co-led the “2001: A Delaware River Odyssey” for the 66th Annual Field Conference of Pennsylvania Geologists. This 3-day field conference showcased the spectacular geology of DEWA over land and water (by canoe). Jack was on the NCKRI (National Cave and Karst Research Institute) board in its infancy for his understanding of the importance of karst hydrology and environmental implications. Jack was going to be an interviewee for the NPS Paleontology Program Oral History Interview report series when it was learned of his passing. For those of us who had the honor and privilege to work with Jack, we will never forget his wisdom, great sense of humor, humility, good nature, passion, and vision that inspired many important geology-focused projects over the years. Numerous geologists mentored (or tormentored…sic) by Jack carry on his mission of interpreting and preserving our geologic features, processes, and heritage throughout the NPS. Thanks for all you did, Jack!

Jack Epstein explaining the geology of DEWA during “2001: A Delaware River Odyssey”, October 5, 2001, 66th Field Conference of Pennsylvania Geologists.

Introduction

The NPS Geologic Type Section Inventory Project ("Stratotype Inventory Project") is a continuation of and complements the work performed by the Geologic Resources Inventory (GRI). The GRI is funded by the NPS Inventory and Monitoring Program and administered by the Geologic Resources Division (GRD). The GRI is designed to compile and present baseline geologic resource information available to park managers, and advance science-informed management of natural resources in the national parks. The goals of the GRI team are to increase understanding and appreciation of the geologic features and processes in parks and provide robust geologic information for use in park planning, decision making, public education, and resource stewardship.

Documentation of stratotypes (i.e., type sections/type localities/type areas) that occur within national park boundaries represents a significant component of a geologic resource inventory, as these designations serve as the standard for defining and recognizing geologic units (North American Commission on Stratigraphic Nomenclature 2005). The importance of stratotypes lies in the fact that they store information, represent important comparative sites where knowledge can be built up or reexamined, and can serve as teaching sites for students (Brocx et al. 2019). The geoheritage significance of stratotypes is analogous to that of libraries and museums, in that they are natural reservoirs of Earth history spanning ~4.5 billion years and record the prodigious forces and evolving life forms that define our planet and our understanding as a contributing species.

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

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

This inventory fills a current void in basic geologic information not currently compiled by the NPS either at most parks or at the servicewide level. This inventory requires some intensive and strategic data mining activities to determine instances where geologic type sections occur within NPS areas. Sometimes the lack of specific locality or other data presents limitations in determining if a particular type section is geographically located within or outside NPS administered boundaries. Below are the primary considerations warranting this inventory of NPS geologic type sections.

- Geologic type sections are a part of our national geologic heritage and are a cornerstone of the scientific value used to define the societal significance of geoheritage sites (https://www.nps.gov/articles/scientific-value.htm);
- Geologic type sections are important geologic landmarks and reference locations which define important scientific information associated with geologic strata. Geologic formations are commonly named after geologic features and landmarks that are recognizable to park staff;
- Geologic type sections are both historically and scientifically important components of earth sciences and mapping;
- Understanding and interpretation of the geologic record is largely dependent upon the stratigraphic occurrences of mappable lithologic units (formations, members). These geologic units are the foundational attributes of geologic maps;
- Geologic maps are important tools for science, resource management, land use planning, and other areas and disciplines;
- Geologic type sections are similar in nature to type specimens in biology and paleontology, serving as a "gold standard" which help to define characteristics used in classification;
- The documentation of geologic type sections in NPS areas has not been previously inventoried and there is a general absence of baseline information for this geologic resource category.
- In general, NPS staff in parks are not aware of the concept of geologic type sections and therefore may not understand the significance or occurrence of these natural landmarks in parks;
- Given the importance of geologic type sections as geologic landmarks and geologic heritage resources, these locations should be afforded some level of preservation or protection when they occur within NPS areas;
- If NPS staff are unaware of geologic type sections within parks, the NPS would not proactively monitor the stability, condition, or potential impacts to these locations during normal park operations or planning. The lack of baseline information pertaining to the geologic type sections in parks would limit the protection of these localities from activities which may involve ground disturbance or construction. Therefore, considerations need to be addressed about how the NPS may preserve geologic type sections and better inform NPS staff about their existence in the park.
- There may be an important conversation that needs to be addressed regarding whether or not geologic type sections 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 type sections which are established on NPS administered lands. Through this inventory, the associated report, and close communication with park and I&M Network staff, the hope is 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 type sections are preserved and available for future study.

Geology and Stratigraphy of the Eastern Rivers and Mountains I&M Network Parks

The Eastern Rivers and Mountains Network (ERMN) consists of nine NPS units in West Virginia, Pennsylvania, western New Jersey, and western New York (Figure 1). The parks include: Allegheny Portage Railroad National Historic Site (ALPO), Bluestone National Scenic River (BLUE), Delaware Water Gap National Recreation Area (DEWA), Fort Necessity National Battlefield (FONE), Friendship Hill National Historic Site (FRHI), Gauley River National Recreation Area (GARI), Johnstown Flood National Memorial (JOFL), New River Gorge National Park and Preserve (NERI), and Upper Delaware Scenic and Recreational River (UPDE).

The network parks are dominated by eastern deciduous forests and river systems within temperate latitudes of the central Appalachian Mountains. The parks are situated within broad river floodplains to small, ephemeral streams, high mountains to deep gorges, and dry barrens to mesic forests (Marshall and Piekielek 2004). Five parks are dominated by large rivers (NERI, GARI, BLUE, DEWA and UPDE), three of which contain river sections that have Wild and Scenic River designation (BLUE, UPDE, DEWA). Collectively the parks of the ERMN preserve important fauna, flora, habitat, rivers, and recreational resources.

Precambrian

No Precambrian units are mapped within the ERMN parks.

Paleozoic

All of the geologic strata mapped within the parks of the ERMN are Paleozoic in age (see Appendix B for a geologic time scale). The oldest geologic formation within the network is the Late Ordovician Martinsburg Formation exposed at DEWA, which is the only park in which pre-Devonian rocks are mapped. Six formations at DEWA also span the Silurian. Devonian strata occur in three parks including ALPO, DEWA and UPDE, with the widespread Catskill Formation mapped in all three of these parks. Mississippian-age units occur within ALPO, BLUE, FONE, and NERI. Pennsylvanian-age units are the most abundant strata in the ERMN parks, and this time period is represented in six of the nine network parks, including ALPO, FONE, FRHI, GARI, JOFL, and NERI.

Mesozoic

No Mesozoic units are mapped within the ERMN parks.

Cenozoic

No Cenozoic units are mapped within the ERMN parks.

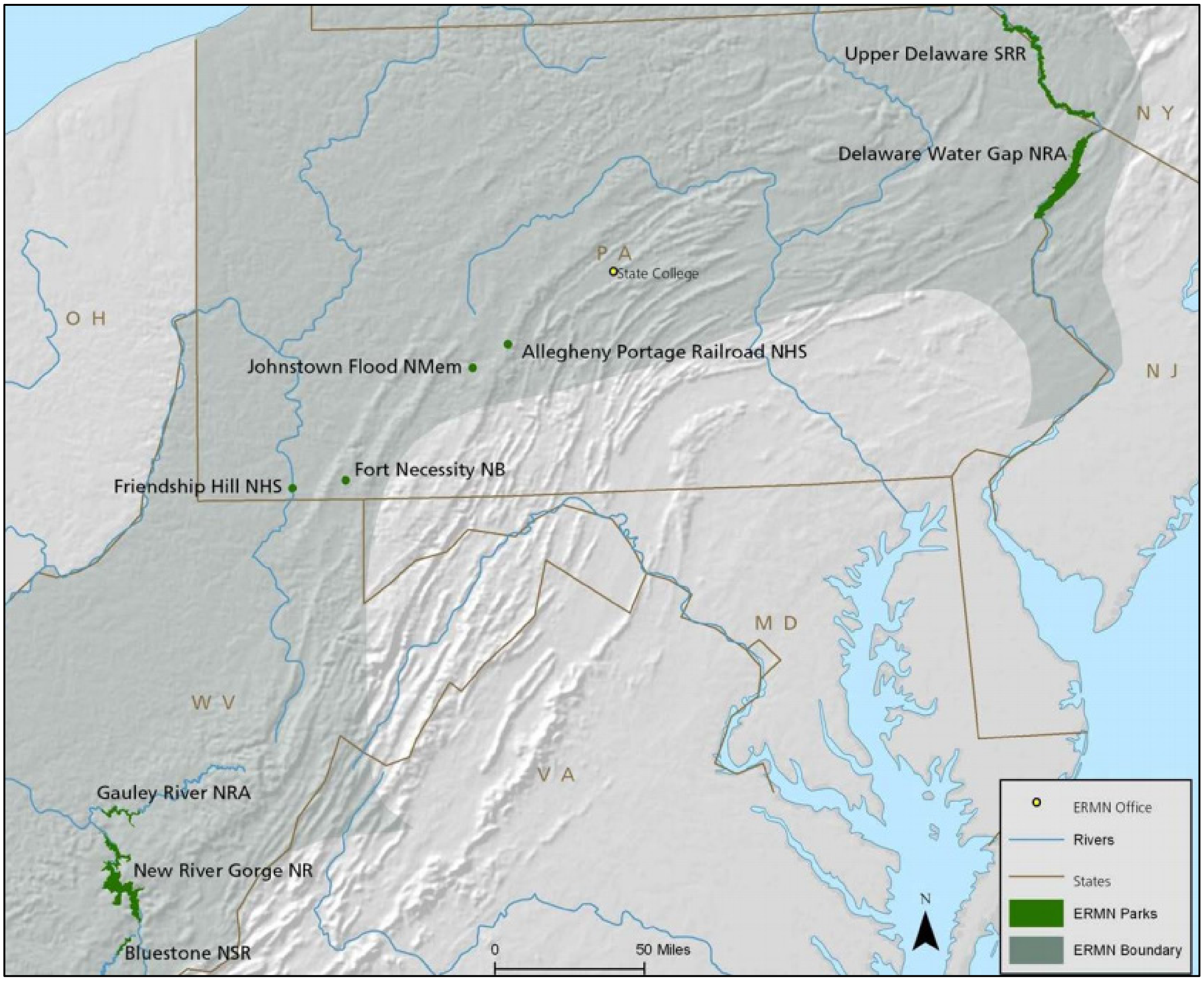


Figure 1. Map of the Eastern Rivers and Mountains Inventory and Monitoring Network parks, including: Allegheny Portage Railroad National Historic Site (ALPO), Bluestone National Scenic River (BLUE), Delaware Water Gap National Recreation Area (DEWA), Fort Necessity National Battlefield (FONE), Friendship Hill National Historic Site (FRHI), Gauley River National Recreation Area (GARI), Johnstown Flood National Memorial (JOFL), New River Gorge National Park and Preserve (NERI), and Upper Delaware Scenic and Recreational River (UPDE) (NPS).

National Park Service Geologic Resource Inventory

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

GRI Products

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

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Scoping sessions were held on the following dates for the ERMN parks: DEWA on October 3, 2001; ALPO, FONE, FRHI, and JOFL on June 22, 2004; UPDE on June 23, 2004; and BLUE, GARI, and NERI on July 13–15, 2004.

Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. As of 2020, GRI reports have been completed for all parks of the ERMN except UPDE. The GRI team conducts no new field work in association with their products.

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

Geologic Map Data

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

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

Geologic Maps

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

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

Source Maps

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

GRI GIS Data

The GRI team standardizes map deliverables by using a data model. The most recent GRI GIS data for ALPO, JOFL, NERI, and UPDE were compiled using data model version 2.3, which is available at https://www.nps.gov/articles/gri-geodatabase-model.htm; data for BLUE, DEWA, FONE, FRHI, and GARI are based on older data models and need to be upgraded to the most recent version. This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI website (https://www.nps.gov/subjects/geology/gri.htm) provides more information about the program's products.

GRI GIS data are available on the GRI publications website (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm) and through the

NPS Integrated Resource Management Applications (IRMA) Data Store portal (https://irma.nps.gov/DataStore/Search/Quick). Enter "GRI" as the search text and select ALPO, BLUE, DEWA, FONE, FRHI, GARI, JOFL, NERI, or UPDE from the unit list.

The following components are part of the data set:

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

GRI Map Posters

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

Use Constraints

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

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

Methods

This section of the report presents the methods employed and definitions adopted during this inventory of geologic type sections located within the administrative boundaries of the parks in the ERMN. This report is part of a more extensive inventory of geologic type sections throughout the National Park System. Therefore, the methods, definitions, and challenges identified here pertain not only to the parks of the ERMN, but also to other inventory and monitoring networks and parks.

There are a number of considerations to be addressed throughout this inventory. The most up-to-date information available is necessary, either found online or in published articles and maps. Occasionally, there is a lack of specific information that limits the information contained in 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 transcend state boundaries. Geologic formations and other units that cross state boundaries may be referenced with different names in each of the states where the units are mapped. An example would be the Triassic Chugwater Formation in Wyoming, which is equivalent to the Spearfish Formation in the Black Hills of South Dakota.

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

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

Methodology

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

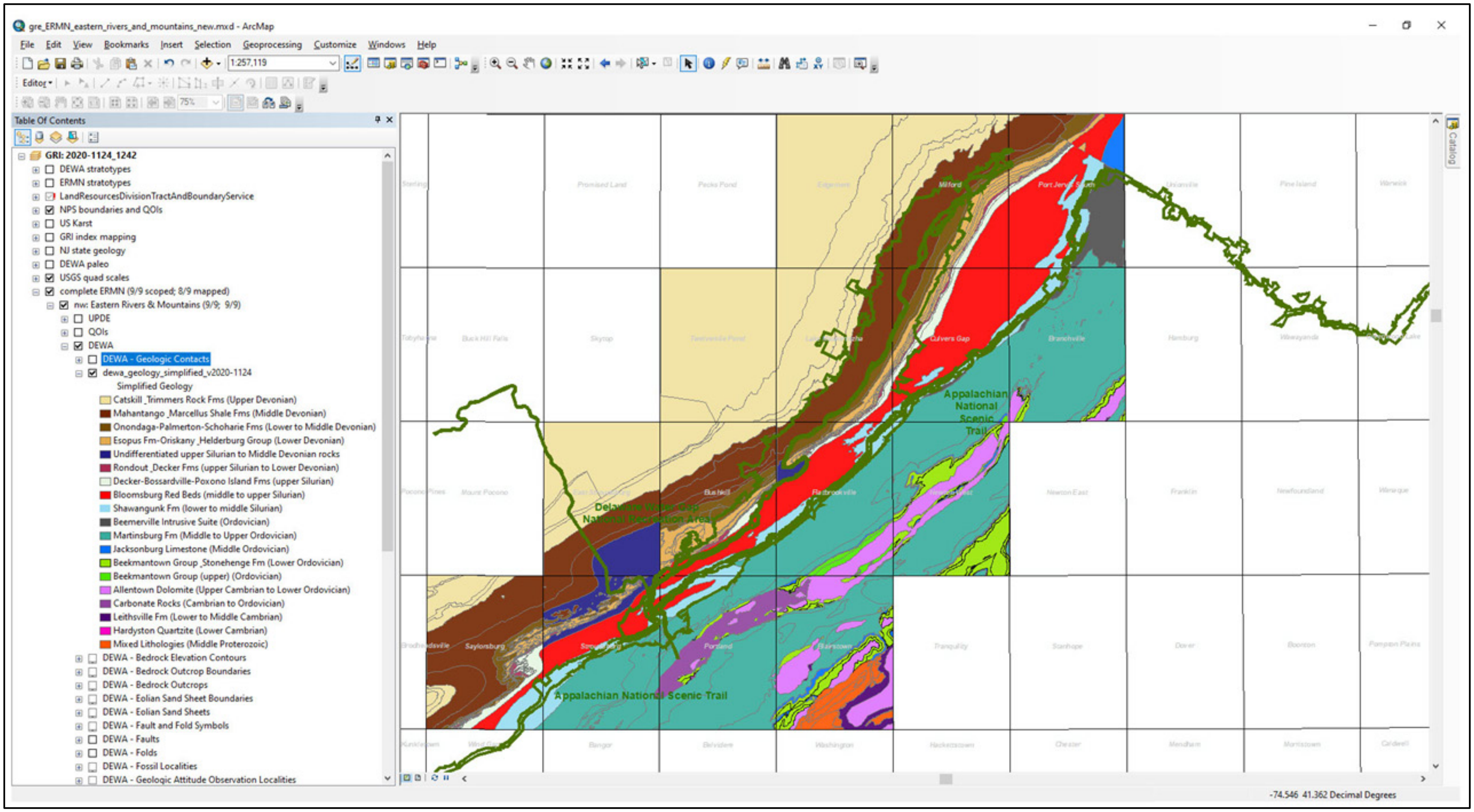


Figure 2. Screenshot of digital bedrock geologic map of Delaware Water Gap National Recreation Area showing mapped units.

Each map unit name is then queried in the U.S. Geologic Names Lexicon online database ("GEOLEX", a national compilation of names and descriptions of geologic units) at https://ngmdb.usgs.gov/Geolex/search. Information provided by GEOLEX includes unit name, stratigraphic nomenclature usage, geologic age, 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 3 below is taken from a search on the Minsi Member of the Shawangunk Formation.

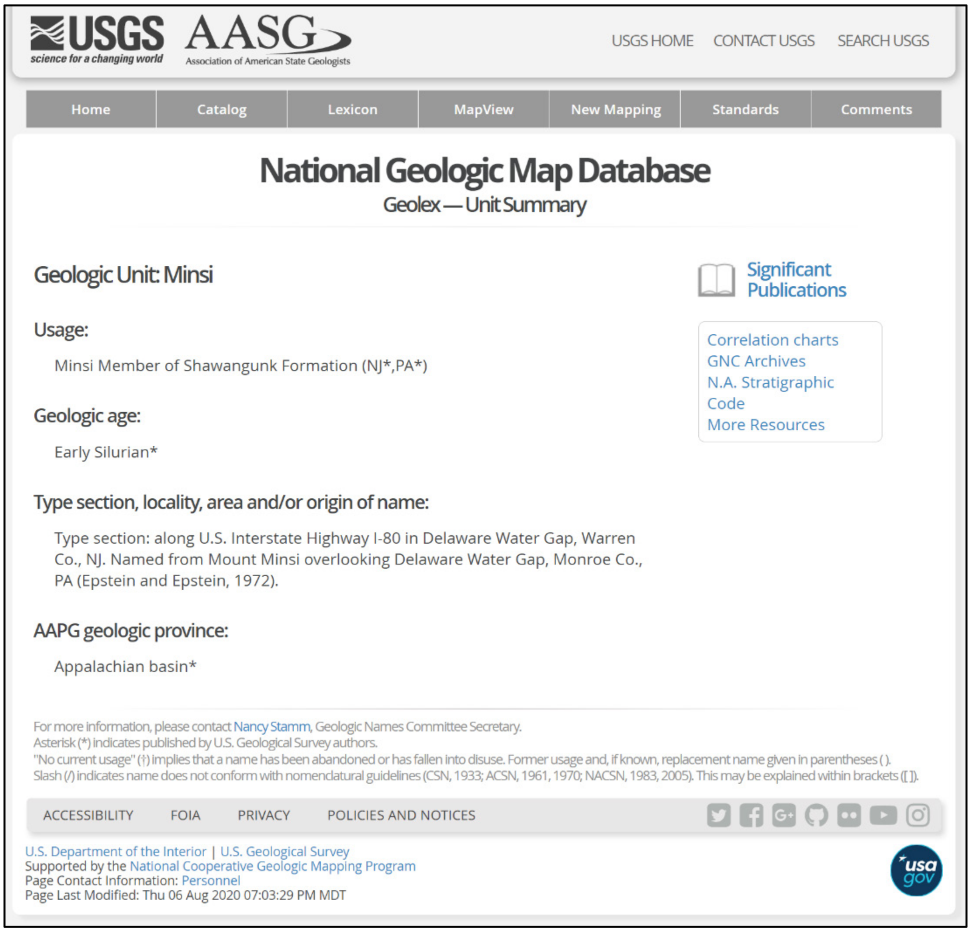
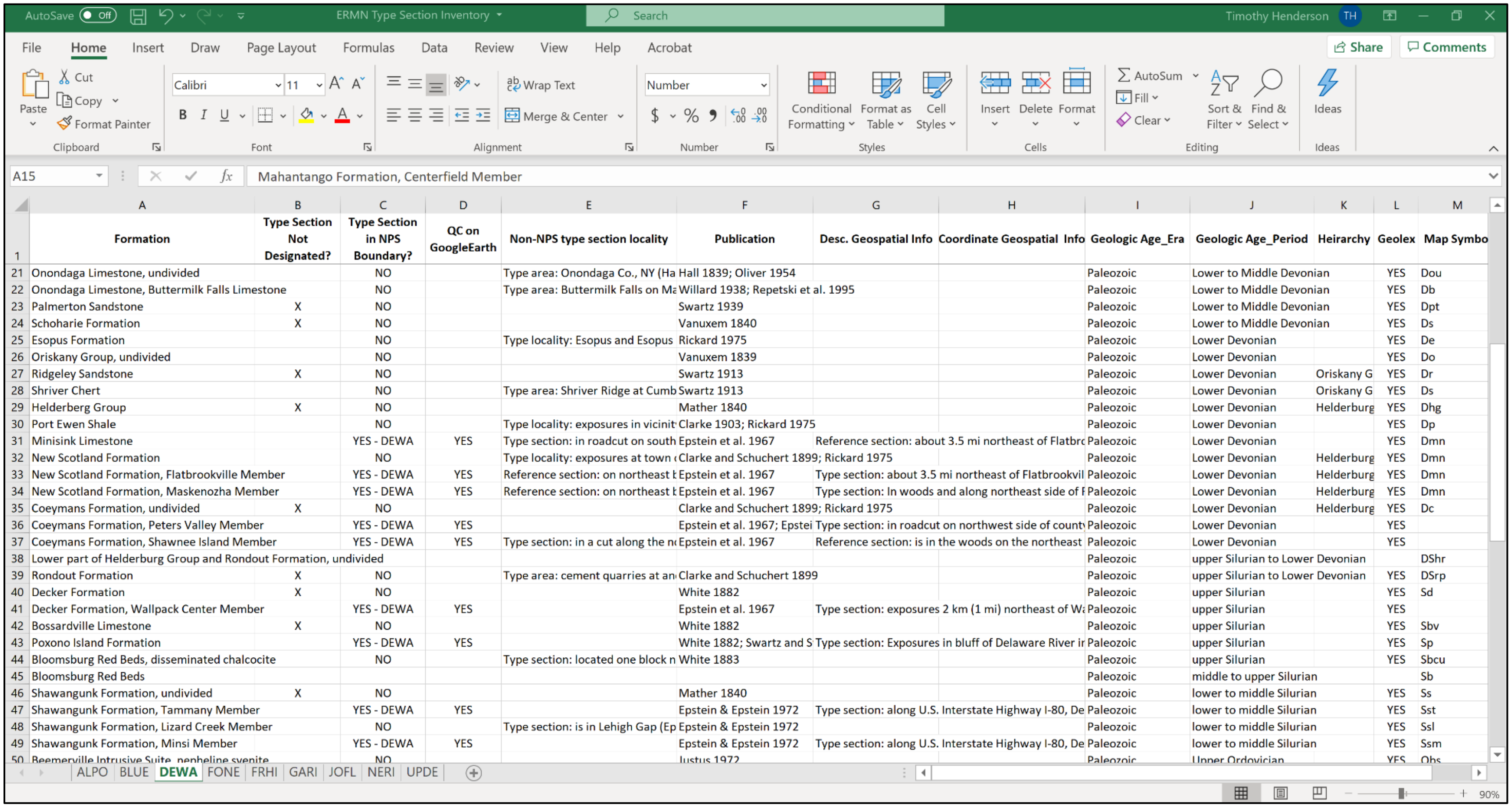


Figure 3. GEOLEX search result for the Minsi Member of the Shawangunk Formation.

Published GEOLEX stratotype spatial information is provided in three formats: (1) descriptive, using distance from nearby points of interest; (2) latitude and longitude coordinates; or (3) Township/Range/Section (TRS) coordinates. TRS coordinates are based on subdivisions of a single 93.2 km^2 (36 mi^2) township into 36 individual 2.59 km^2 (1 mi^2) sections, and were converted into Google Earth (.kmz file) locations using Earth Point (https://www.earthpoint.us/TownshipsSearchByDescription.aspx). The most accurate GEOLEX descriptions using TRS coordinates can help locate features within 0.1618 km^2 (0.0625 mi^2). Once stratotype locality information provided for a given unit is geolocated using Google Earth, a GRI digital geologic map of the national park 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.

After this, 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) is a stratotype officially designated; (2) is the stratotype on NPS land; (3) has it 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) was the geologic unit found in GEOLEX; and (10) a generic notes field (Figure 4).



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	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 Symbo
21	Onondaga Limestone, undivided		NO		Type area: Onondaga Co., NY (Ha	Hall 1839; Oliver 1954			Paleozoic	Lower to Middle Devonian		YES	Dou
22	Onondaga Limestone, Buttermilk Falls Limestone		NO		Type area: Buttermilk Falls on Ma	Willard 1938; Repetski et al. 1995			Paleozoic	Lower to Middle Devonian		YES	Db
23	Palmerton Sandstone	X	NO			Swartz 1939			Paleozoic	Lower to Middle Devonian		YES	Dpt
24	Schoharie Formation	X	NO			Vanuxem 1840			Paleozoic	Lower to Middle Devonian		YES	Ds
25	Esopus Formation		NO		Type locality: Esopus and Esopus	Rickard 1975			Paleozoic	Lower Devonian		YES	De
26	Oriskany Group, undivided		NO			Vanuxem 1839			Paleozoic	Lower Devonian		YES	Do
27	Ridgeley Sandstone	X	NO			Swartz 1913			Paleozoic	Lower Devonian	Oriskany G	YES	Dr
28	Shriver Chert		NO		Type area: Shriver Ridge at Cumb	Swartz 1913			Paleozoic	Lower Devonian	Oriskany G	YES	Ds
29	Helderberg Group	X	NO			Mather 1840			Paleozoic	Lower Devonian	Helderburg	YES	Dhg
30	Port Ewen Shale		NO		Type locality: exposures in vicinit	Clarke 1903; Rickard 1975			Paleozoic	Lower Devonian		YES	Dp
31	Minisink Limestone		YES - DEWA	YES	Type section: in roadcut on south	Epstein et al. 1967	Reference section: about 3.5 mi northeast of Flatbro		Paleozoic	Lower Devonian		YES	Dmn
32	New Scotland Formation		NO		Type locality: exposures at town o	Clarke and Schuchert 1899; Rickard 1975			Paleozoic	Lower Devonian	Helderburg	YES	Dmn
33	New Scotland Formation, Flatbrookville Member		YES - DEWA	YES	Reference section: on northeast b	Epstein et al. 1967	Type section: about 3.5 mi northeast of Flatbrookvil		Paleozoic	Lower Devonian	Helderburg	YES	Dmn
34	New Scotland Formation, Maskenozha Member		YES - DEWA	YES	Reference section: on northeast b	Epstein et al. 1967	Type section: In woods and along northeast side of F		Paleozoic	Lower Devonian	Helderburg	YES	Dmn
35	Coeymans Formation, undivided	X	NO			Clarke and Schuchert 1899; Rickard 1975			Paleozoic	Lower Devonian	Helderburg	YES	Dc
36	Coeymans Formation, Peters Valley Member		YES - DEWA	YES		Epstein et al. 1967; Epstei	Type section: in roadcut on northwest side of county		Paleozoic	Lower Devonian		YES	
37	Coeymans Formation, Shawnee Island Member		YES - DEWA	YES	Type section: in a cut along the no	Epstein et al. 1967	Reference section: is in the woods on the northeast		Paleozoic	Lower Devonian		YES	
38	Lower part of Helderburg Group and Rondout Formation, undivided								Paleozoic	upper Silurian to Lower Devonian			DShr
39	Rondout Formation	X	NO		Type area: cement quarries at an	Clarke and Schuchert 1899			Paleozoic	upper Silurian to Lower Devonian		YES	DSrp
40	Decker Formation	X	NO			White 1882			Paleozoic	upper Silurian		YES	Sd
41	Decker Formation, Wallpack Center Member		YES - DEWA	YES		Epstein et al. 1967	Type section: exposures 2 km (1 mi) northeast of Wa		Paleozoic	upper Silurian		YES	
42	Bossardville Limestone	X	NO			White 1882			Paleozoic	upper Silurian		YES	Sbv
43	Poxono Island Formation		YES - DEWA	YES		White 1882; Swartz and S	Type section: Exposures in bluff of Delaware River ir		Paleozoic	upper Silurian		YES	Sp
44	Bloomsburg Red Beds, disseminated chalcocite		NO		Type section: located one block n	White 1883			Paleozoic	upper Silurian		YES	Sbcu
45	Bloomsburg Red Beds								Paleozoic	middle to upper Silurian			Sb
46	Shawangunk Formation, undivided	X	NO			Mather 1840			Paleozoic	lower to middle Silurian		YES	Ss
47	Shawangunk Formation, Tammany Member		YES - DEWA	YES		Epstein & Epstein 1972	Type section: along U.S. Interstate Highway I-80, De		Paleozoic	lower to middle Silurian		YES	Sst
48	Shawangunk Formation, Lizard Creek Member		NO		Type section: is in Lehigh Gap (Ep	Epstein & Epstein 1972			Paleozoic	lower to middle Silurian		YES	Ssl
49	Shawangunk Formation, Minsi Member		YES - DEWA	YES		Epstein & Epstein 1972	Type section: along U.S. Interstate Highway I-80, De		Paleozoic	lower to middle Silurian		YES	Ssm
50	Beemerville Intrusive Suite, nepheline syenite		NO			Justus 1972			Paleozoic	Upper Ordovician		YES	Obs

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

Definitions

In order to clarify, standardize, and consistently reference stratigraphic concepts, principles, and definitions, the North American Stratigraphic Code is recognized and adopted for this inventory. This code seeks to describe explicit practices for classifying and naming all formally defined geologic units. An important designation for a geologic unit is known as a ***stratotype***—the standard (original or subsequently designated) for a named geologic unit or boundary and constitutes the basis for definition or recognition of that unit or boundary (North American Commission on Stratigraphic Nomenclature 2005). There are several variations of stratotype referred to in the literature and this report, and they are defined as following:

(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 2005). Once a unit stratotype is assigned, it is never changed. The term "unit stratotype" is commonly referred to as "type section" and "type area" in this report.

(2) **Type locality**: the specific geographic locality encompassing the unit stratotype of a formally recognized and defined unit. On a broader scale, a type area is the geographic territory encompassing the type locality. Before development of the stratotype concept, only type localities and type areas were designated for many geologic units that are now long- and well-established (North American Commission on Stratigraphic Nomenclature 2005).

(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 2005). 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 2005).

(4) **Lithodeme**: the term "lithodeme" is defined as a mappable unit of plutonic and highly metamorphosed or pervasively deformed rock and is a term equivalent in rank to "formation" among stratified rocks (North American Commission on Stratigraphic Nomenclature 2005). 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.

Allegheny Portage Railroad National Historic Site (ALPO)

Allegheny Portage Railroad National Historic Site (ALPO) preserves traces of the first railroad crossing of the Allegheny Mountains and stretches 59 km (37 mi) through Blair and Cambria Counties, Pennsylvania. Authorized as an NPS park unit on August 31, 1964, ALPO commemorates the pioneering lifestyle and 19th century engineering efforts that culminated in the construction of an inclined plane railroad that permitted transportation of passengers and freight over the mountains (Anderson 2017). The inclined plane railroad provided a critical link between the Pennsylvania Mainline Canal system and the West, establishing the interior of the United States as a trade and settlement center. The historic site protects approximately 520 hectares (1,284 acres) of landscape in part of the Allegheny Front in central Pennsylvania along the boundary between the Valley and Ridge and the Appalachian Plateau provinces (Figure 5; Thornberry-Ehrlich 2008a).

The geology of the ALPO area is predominantly composed of Paleozoic rocks that span from the Pennsylvanian (~325–300 million years ago) to the Devonian Period (~420–360 million years ago) (Figures 6–7). The landscape of the park consists of high, rounded sandstone ridges divided by stream valleys and ravines underlain by less-resistant carbonates and shales that have been preferentially eroded (Thornberry-Ehrlich 2008a). Prior to construction of the railroad, the mountainous terrain of ALPO represented a formidable obstacle that made travel difficult and led to many engineering innovations that continue to the modern day with development of the Pennsylvania interstate corridors (Thornberry-Ehrlich 2008a).

As of the writing of this paper, there are no designated stratotypes identified within the boundaries of ALPO. There are nine identified stratotypes located within 48 km (30 mi) of ALPO boundaries, for the Cambrian Warrior Formation (type locality) and Pleasant Hill Formation (type locality); Ordovician Hatter Formation (type section), Benner Formation (type section), Loysburg Formation (type section), Snyder Formation (type section), and Nealmont Formation (type section); Devonian Brallier Formation (type locality); and Mississippian Burgoon Sandstone (type area).

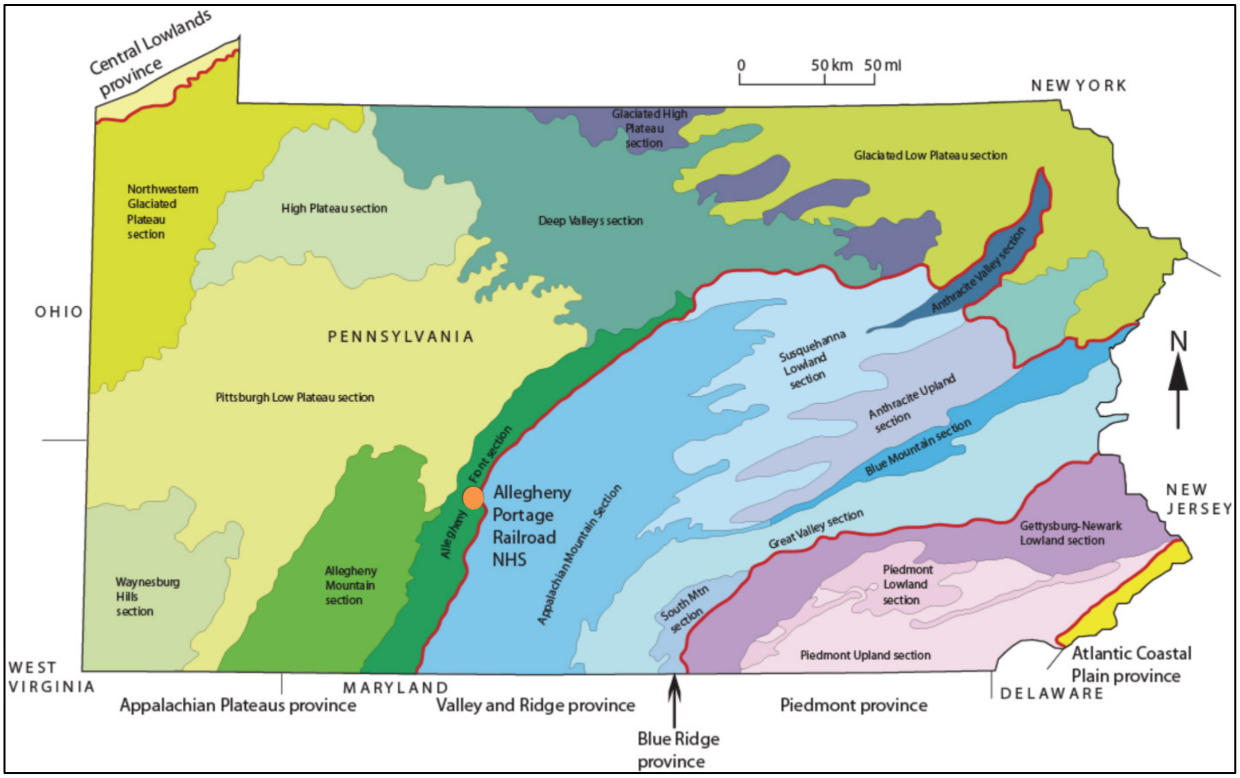


Figure 5. Physiographic map of Pennsylvania showing the location of ALPO (orange circle). Boundaries between major physiographic provinces are represented by red lines. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

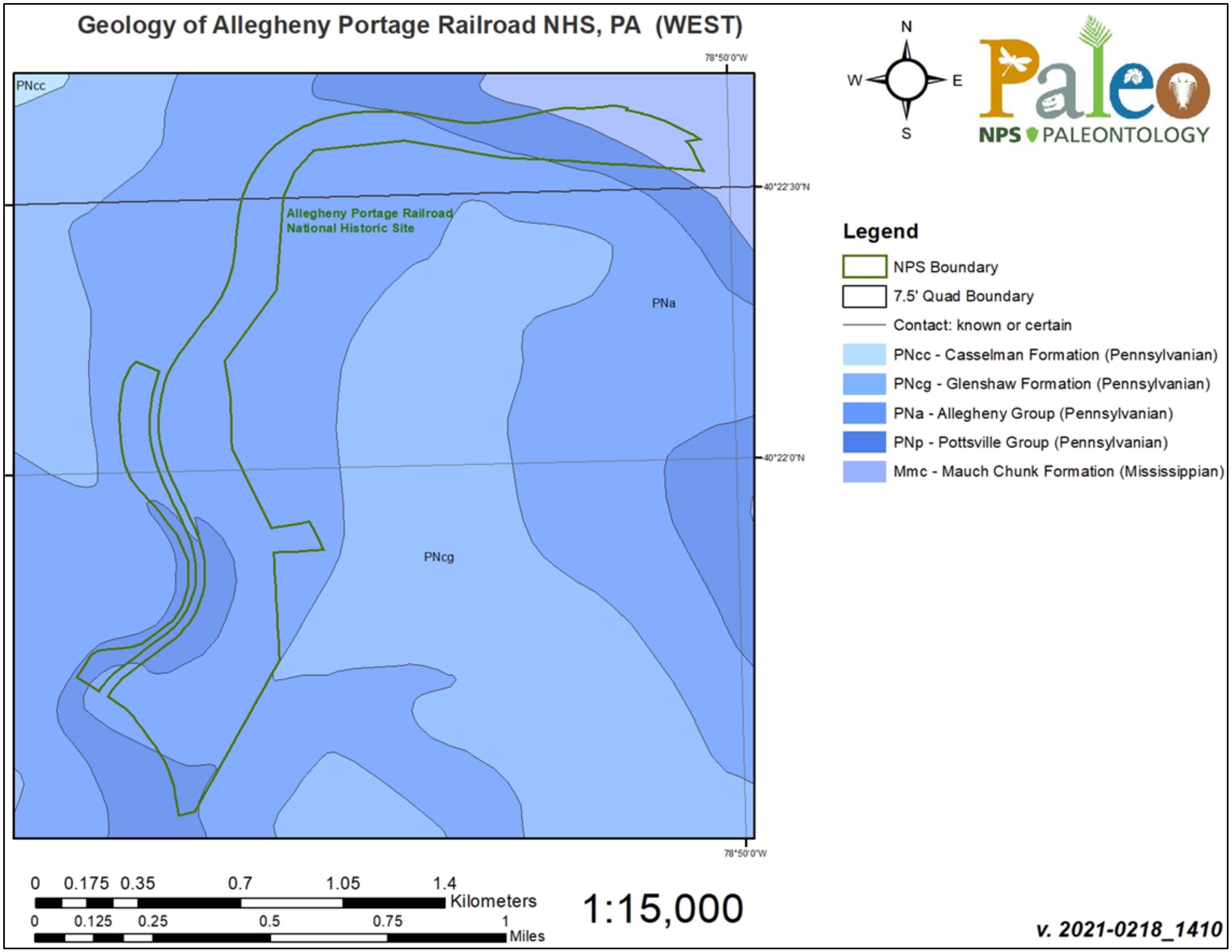


Figure 6. Geologic map of western ALPO, Pennsylvania.

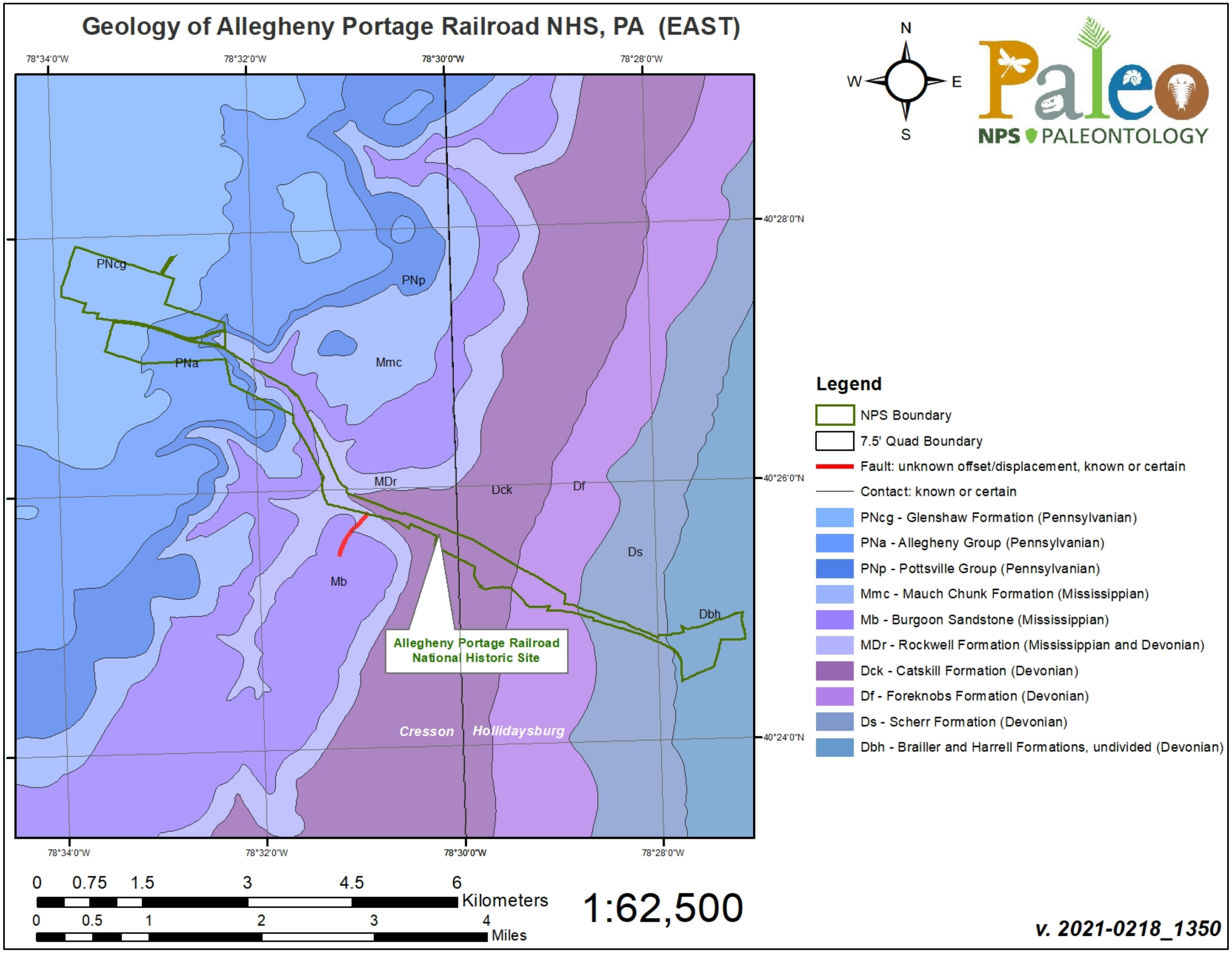


Figure 7. Geologic map of eastern ALPO, Pennsylvania.

Bluestone National Scenic River (BLUE)

Bluestone National Scenic River (BLUE) protects a 17 km (11 mi) stretch of the Bluestone River in Mercer and Summers Counties, southwestern West Virginia (Figure 8). Authorized as an NPS unit on October 26, 1988, BLUE encompasses 1,744 hectares (4,310 acres) of diverse and picturesque landscape of the southern Appalachians. The park was designated for its remarkable scenery, geology, recreation, fish, and wildlife values (Anderson 2017). Cultural resources associated with BLUE are vast and reflect thousands of years of human history dating back to the American Indians, the early pioneers, and the dramatic industrial transformation related to the coal-mining industry (Thornberry-Ehrlich 2017).

The geology of BLUE consists of Pennsylvanian (~325–300 million years ago) and Mississippian-age (~360–325 million years ago) rocks that include the Bluefield, Hinton, Princeton, Bluestone, Pocahontas, and Blue River Formations (Figure 9). The geologic units of BLUE represent ancient fluvial to nearshore depositional environments in the Appalachian basin. Development of the Appalachian basin began during the Taconic Orogeny, the first of a series of mountain-building events that culminated in the construction of the Appalachian Mountains (Thornberry-Ehrlich 2017). The Bluestone River is named for the deep blue limestone streambed observable upstream of the Bluestone Dam at its confluence with the New River. Along its course, the Bluestone River has carved a rugged gorge up to 300 m (1,000 ft) deep (Thornberry-Ehrlich 2017). The living landscape of BLUE also includes cascading waterfalls, stirring rapids, forested slopes, and stunning vistas that provide an unspoiled experience for visitors.

As of the writing of this paper, there are no designated stratotypes identified within the boundaries of BLUE. There are 27 identified stratotypes located within 48 km (30 mi) of BLUE boundaries, for the Mississippian Lindside Member of the Pocono Formation (type locality), Alderson Limestone (type locality), Greenville Shale (type locality), Hillsdale Member of the Greenbrier Limestone (type locality), Sinks Grove Limestone (type locality), Taggard Shale (type locality), Union Limestone (type locality), Avis Limestone Member of the Hinton Formation (type locality), Bellepoint Limestone Member of the Hinton Formation (type locality), Bent Mountain Member of the Hinton Formation (type locality), Eads Mill Member of the Hinton Formation (type section), Fivemile Shale Member of the Hinton Formation (type locality and reference section), Hackett Sandstone Member of the Hinton Formation (type locality), Neal Sandstone Member of the Hinton Formation (type locality), Pratter Shale Member of the Hinton Formation (type locality), Stony Gap Sandstone Member of the Hinton Formation (type locality), Ada Shale Member of the Bluestone Formation (type locality), Bramwell Member of the Bluestone Formation (type section), Glady Fork Sandstone Member of the Bluestone Formation (type locality), Hunt Member of the Bluestone Formation (type locality), Pipestem Shale Member of the Bluestone Formation (type locality), Pride Shale Member of the Bluestone Formation (type locality), Glenray Limestone Member of the Bluefield Formation (type locality), Indian Mills Sandstone Member of the Bluefield Formation (type locality), and the Lillydale Shale Member of the Bluefield Formation (type locality); and the Pennsylvanian Pocahontas Formation (type area).

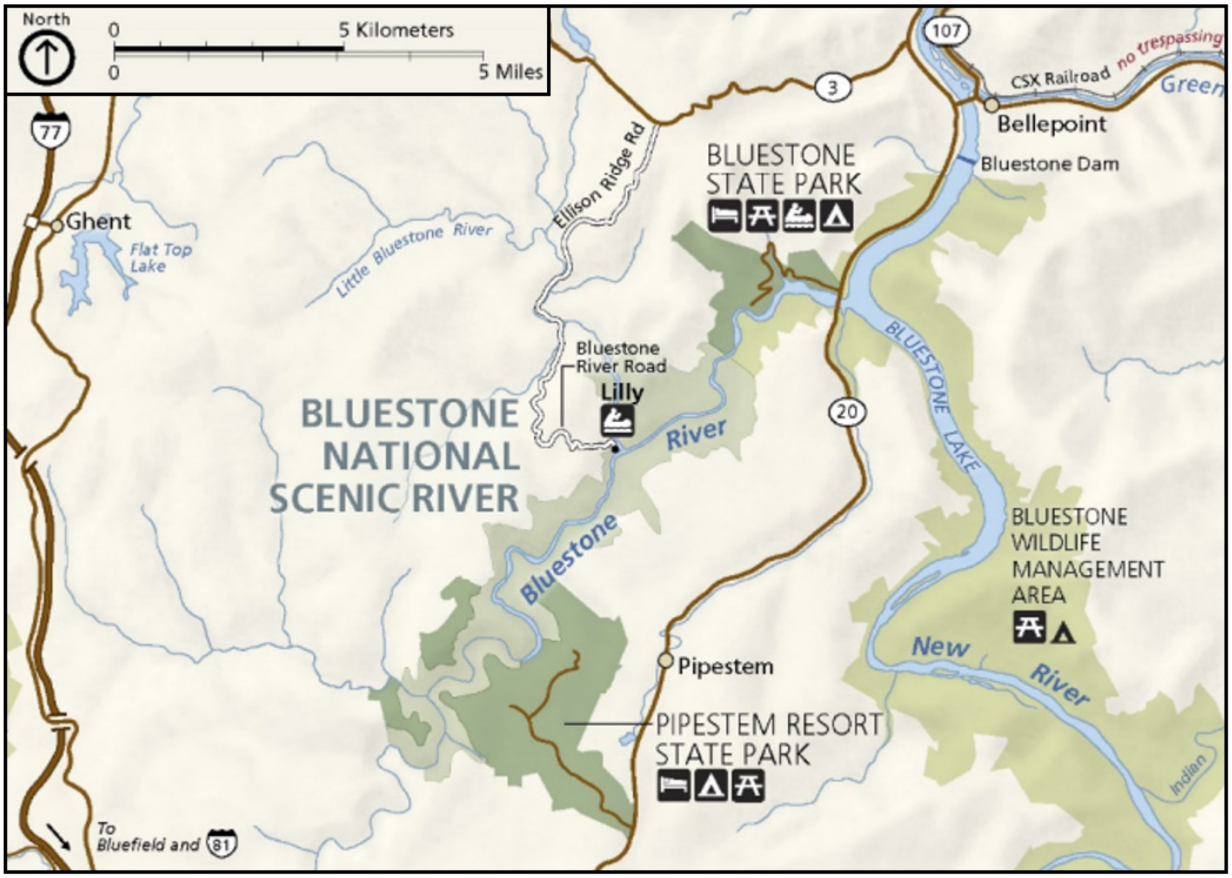


Figure 8. Park map of BLUE, West Virginia (NPS).

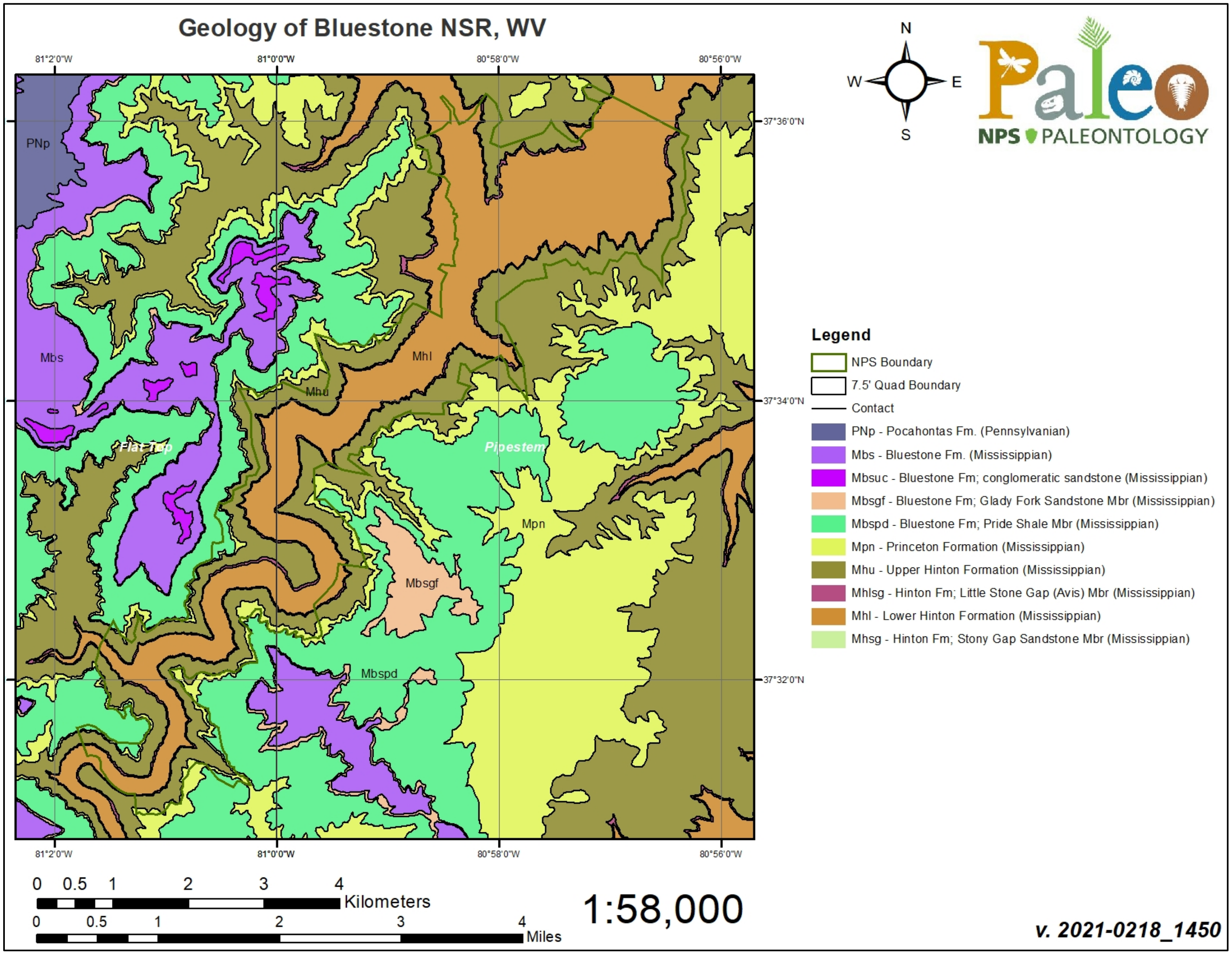


Figure 9. Geologic map of BLUE, West Virginia.

Delaware Water Gap National Recreation Area (DEWA)

Delaware Water Gap National Recreation Area (DEWA) preserves the namesake gap and upstream valley of the Delaware River in Sussex and Warren Counties, northwestern New Jersey and Monroe, Northampton, and Pike Counties, northeastern Pennsylvania (Figure 10). Authorized as an NPS unit on September 1, 1965, DEWA encompasses approximately 27,349 hectares (67,581 acres) of the Delaware River Valley through the famous gap in the Appalachian Mountains. Rolling hills, ridges, and valleys decorate the 64 km (40 mi) stretch of river in DEWA and provide a diverse array of outdoor recreational opportunities. The namesake Delaware Water Gap is a 1.6 km (1.0 mi) wide, 370 m (1,200 ft) deep corridor situated along the New Jersey–Pennsylvania border that cuts through Kittatinny Mountain, flanked on both sides by Mount Minsi (Pennsylvania) and Mount Tammany (New Jersey).

The bedrock geology of DEWA predominantly consists of Paleozoic-age rocks ranging from the Ordovician (~485–445 million years ago) to the Devonian (~420–360 million years ago) (Figure 11). These rocks were originally deposited as sediments (lime, mud, sand, and gravel) in a basin west of the highlands that were uplifted during Appalachian mountain-building events along the eastern margin of North America (Thornberry-Ehrlich 2013). During the past 2 million years, the bedrock of DEWA has been sculpted by glaciers that beveled highlands, carved troughs, and deposited outwash, till, and moraines (Thornberry-Ehrlich 2013). Thick Pleistocene-age (2.6 million to 11,700 years ago) deposits now blanket many bedrock exposures. Younger surficial geologic units consist of alluvium (gravel, sand, silt, and clay) deposited by streams, colluvium collecting at the bases of slopes, and swamp and marsh deposits (Thornberry-Ehrlich 2013).

DEWA contains 11 identified stratotypes that are subdivided into eight type sections and three reference sections (Table 1; Figure 12).

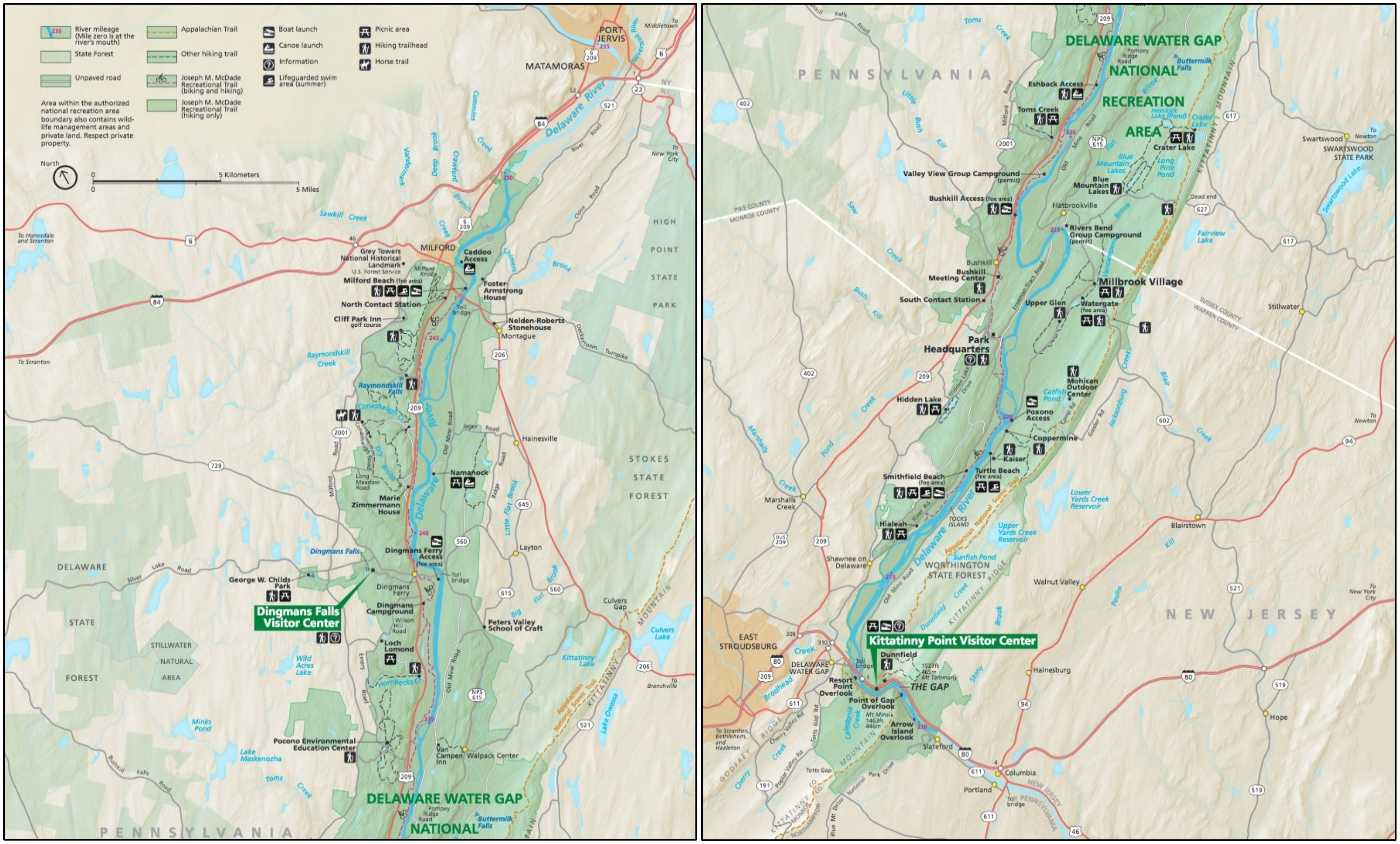


Figure 10. Park map of DEWA, New Jersey–Pennsylvania (NPS).

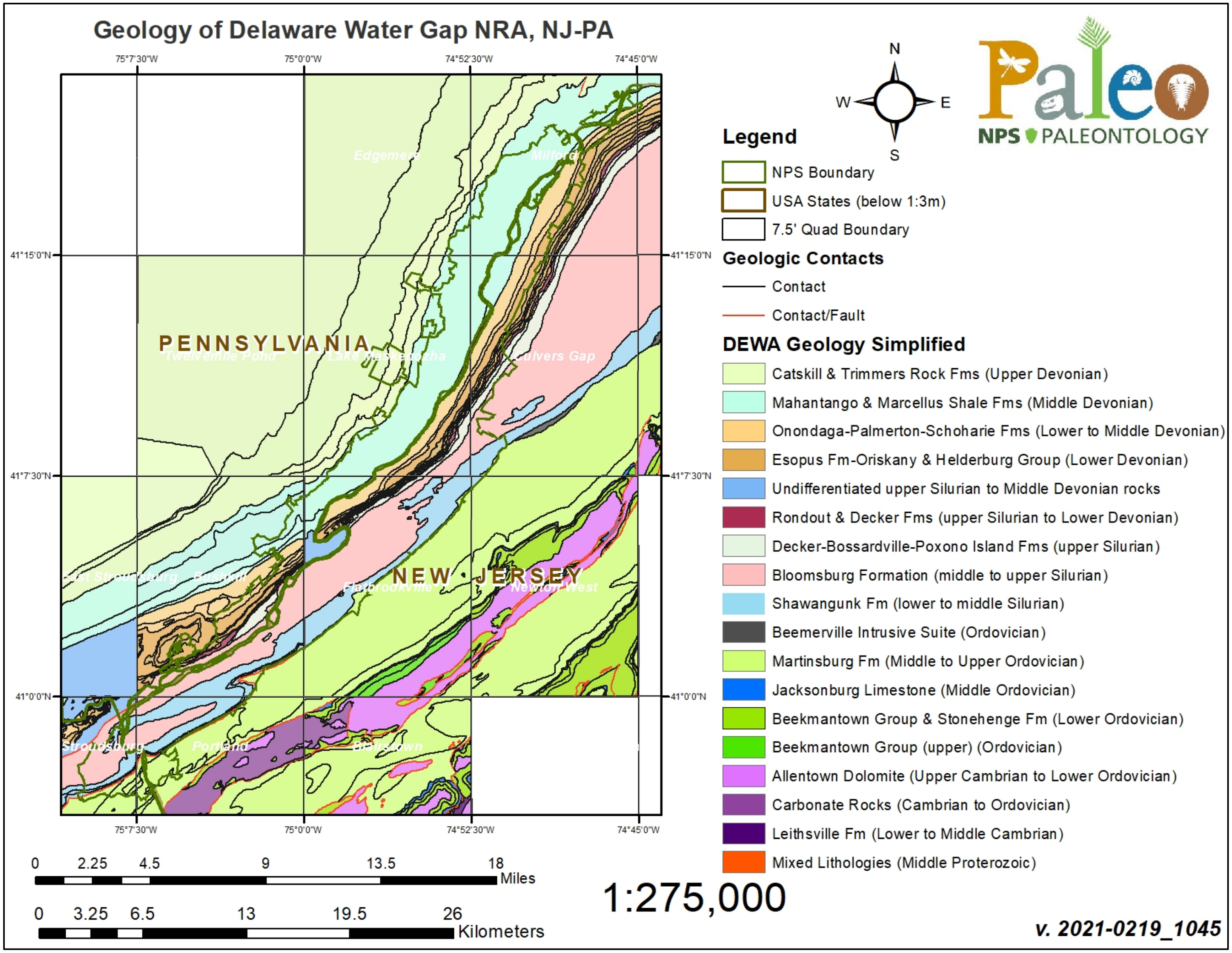


Figure 11. Geologic map of DEWA, New Jersey–Pennsylvania.

Table 1. List of DEWA stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Brodhead Creek Member, Marcellus Shale (Dmb)	Stevenson and Skinner 1949	Type section: on Brodhead Creek 5 km (3 mi) northwest of East Stroudsburg, Monroe Co., Pennsylvania	Middle Devonian
Minisink Limestone (Dmn)	Epstein et al. 1967	Reference section: about 5.6 km (3.5 mi) northeast of Flatbrookville, in woods and along northeast side of Walpack Flatbrook Road, near southern edge of Lake Maskenozha 7.5-min Quadrangle	Early Devonian
Maskenozha Member, New Scotland Formation (Dmn, Dph)	Epstein et al. 1967	Type section: about 5.6 km (3.5 mi) northeast of Flatbrookville, in woods and along northeast side of Walpack Flatbrook Road, near southern edge of Lake Maskenozha 7.5-min Quadrangle	Early Devonian
Flatbrookville Member, New Scotland Fm. (Dmn, Dph)	Epstein et al. 1967	Type section: about 5.6 km (3.5 mi) northeast of Flatbrookville, in woods and along northeast side of Walpack Flatbrook Road, near southern edge of Lake Maskenozha 7.5-min Quadrangle	Early Devonian
Shawnee Island Member, Coeymans Formation (Dc)	Epstein et al. 1967	Reference section: in roadcut on northwest side of Walpack Flatbrook Road that extends along southern side of Wallpack Ridge, 2.4 km (1.5 mi) northeast of Flatbrookville and 0.2 km (0.1 mi) southwest of V-shaped bend in road, in northwest quarter of Flatbrookville Quadrangle, Sussex Co., New Jersey	Early Devonian
Peters Valley Member, Coeymans Formation (Dc)	Epstein et al. 1967	Type section: in roadcut on northwest side of Walpack Flatbrook Road that extends along southern side of Wallpack Ridge, 2.4 km (1.5 mi) northeast of Flatbrookville and 0.2 km (0.1 mi) southwest of V-shaped bend in road, in northwest quarter of Flatbrookville Quadrangle, Sussex Co., New Jersey Reference section: in the woods on the northeast side of a secondary road along the ascent of Wallpack Ridge in Pennsylvania, immediately southwest of where the Delaware River cuts through the ridge, in the Flatbrookville Quadrangle	Early Devonian
Wallpack Center Member, Decker Fm. (Sd, DSrd)	Epstein et al. 1967	Type section: exposures 2 km (1 mi) northeast of Wallpack Center, Sussex County, New Jersey	Late Silurian
Poxono Island Formation (Sp)	White 1882; Swartz and Swartz 1941; Epstein et al. 1967	Type section: exposures in bluff of Delaware River in Middle Smithfield Township, opposite Poxono Island, Pennsylvania	Late Silurian
Tammany Member, Shawangunk Fm. (Sst)	Epstein and Epstein 1972	Type section: along U.S. Interstate Highway I-80, DEWA, Warren Co., New Jersey	Early–Middle Silurian
Minsi Member, Shawangunk Fm. (Ssm)	Epstein and Epstein 1972	Type section: along U.S. Interstate Highway I-80, DEWA, Warren Co., New Jersey	Early–Middle Silurian

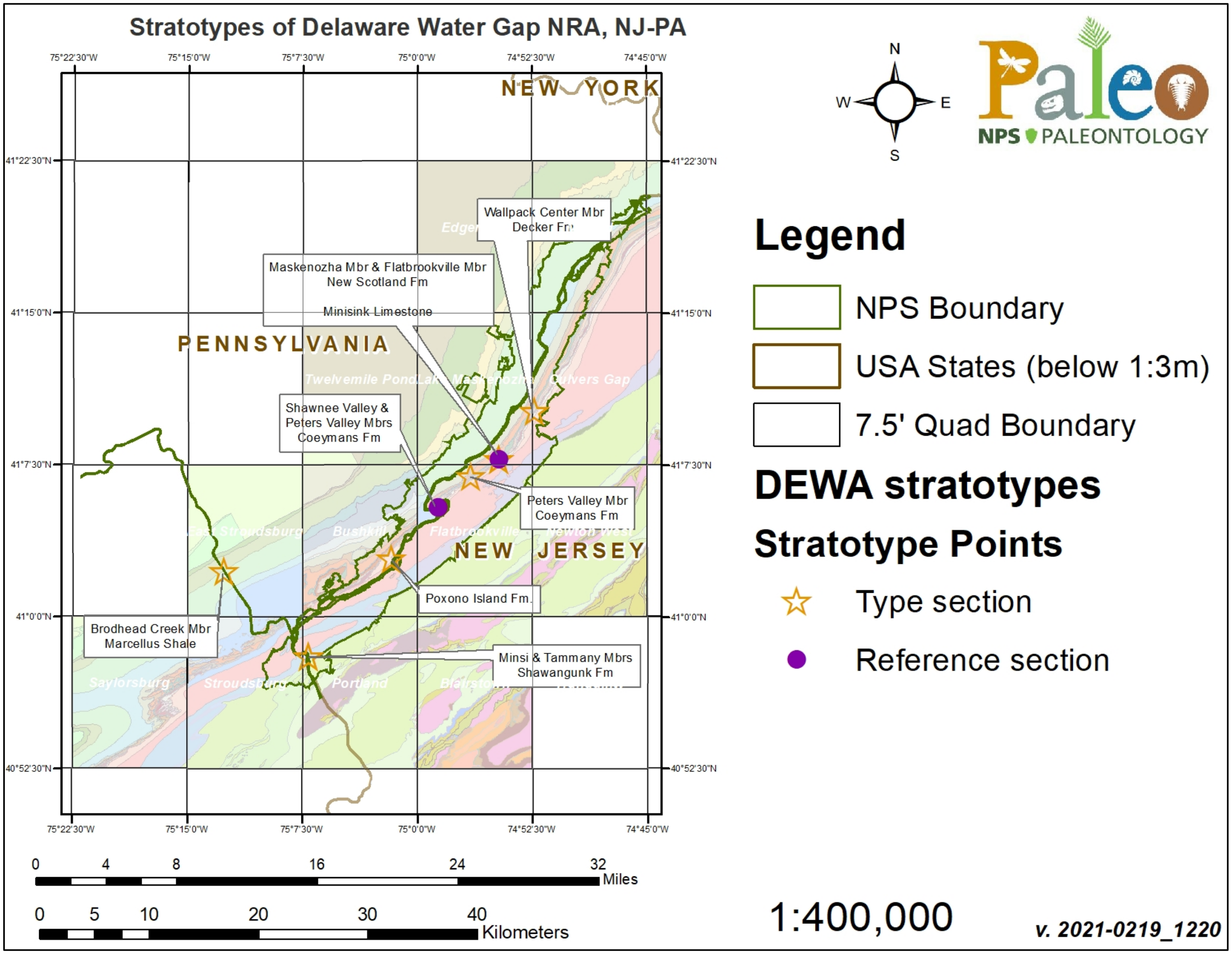


Figure 12. Modified geologic map of DEWA showing stratotype locations. The transparency of the geologic units layer has been increased.

The Silurian Minsi Member of the Shawangunk Formation was named after Minsi Mountain overlooking the Delaware Water Gap by Epstein and Epstein (1972). Type section exposures occur along U.S. Interstate 80 in DEWA and consist of quartzite, conglomerate (with quartz, chert, and sandstone pebbles less than 5 cm [2 in] long), with minor amounts of siltstone (Table 1; Figures 12–13; Epstein and Epstein 1972). Measured thickness of the type section is approximately 92 m (300 ft). In DEWA the Minsi Member consists of gray and light olive-gray, medium to very coarse-grained quartzite that is cross-bedded and planar-bedded, conglomeratic quartzite, and quartz-, chert-, and argillite-pebble conglomerate (Figures 14–15; Epstein and Epstein 1972). Less than ten percent of the Minsi Member is comprised of dark-gray to light olive-gray siltstone and shaly siltstone that occurs in lenticular beds and contains mud cracks (Figure 16). Stratigraphically, the Minsi Member unconformably overlies the Martinsburg Formation and underlies the Lizard Creek Member of the Shawangunk Formation.

Figure 13. Delaware Water Gap, where roads cuts along U.S. Interstate 80 in Mount Tammany expose the designated type sections of both the Minsi and Tammany Members of the Shawangunk Formation (NPS).

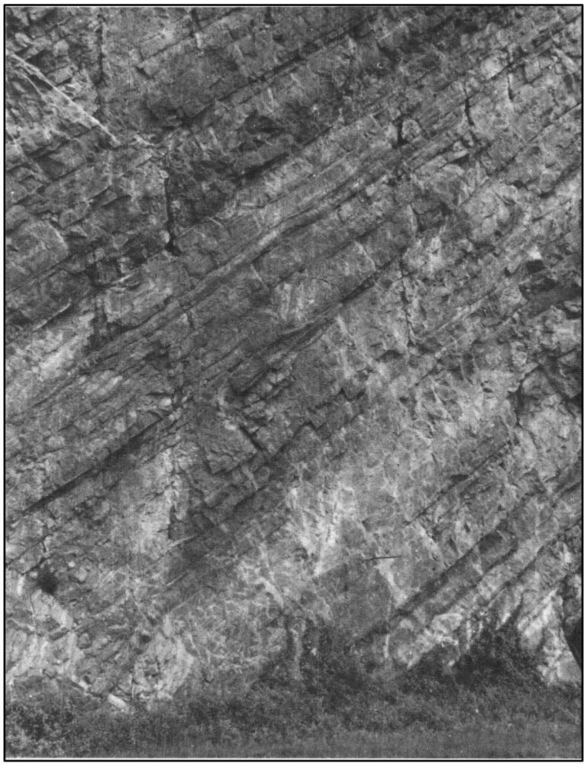


Figure 14. Interbedded quartzite and quartz- and chert-pebble conglomerate in the Minsi Member of the Shawangunk Formation at the type section along U.S. Interstate 80, DEWA. Note channels at bases of many of the beds. Figure from Epstein and Epstein (1972).

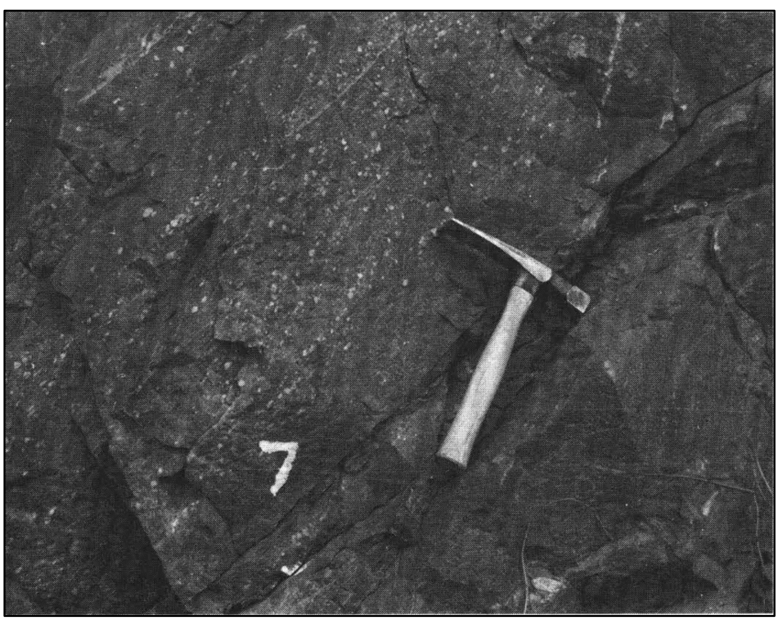


Figure 15. Cross-bedded and planar-bedded conglomeratic quartzite and quartzite of the Minsi Member of the Shawangunk Formation at the type section in Delaware Water Gap along U.S. Interstate 80, DEWA. Figure from Epstein and Epstein (1972).

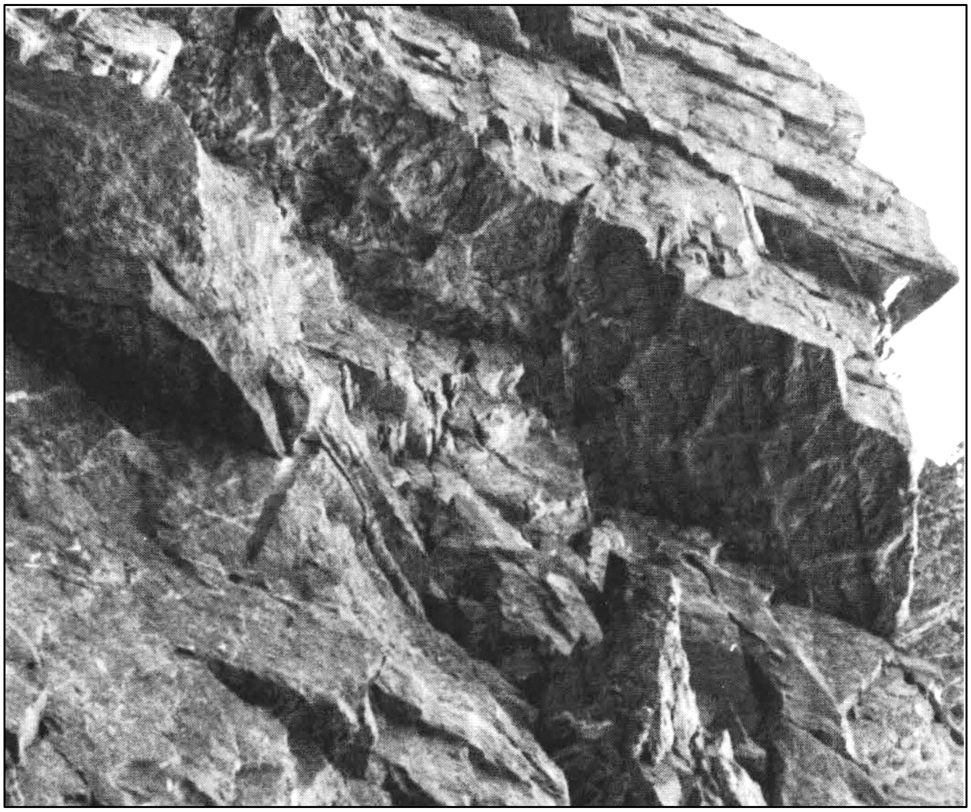


Figure 16. Mud-cracked shaly siltstone of the Minsi Member of the Shawangunk Formation at the type section. Underside of bed exposed about 18 m (60 ft) above U.S. Interstate 80. Mud-crack polygons are approximately 0.3 m (1 ft) across. Figure from Epstein and Epstein (1972).

The Silurian Tammany Member of the Shawangunk Formation was designated by Epstein and Epstein (1972) after Mount Tammany overlooking the Delaware Water Gap. The type section occurs in a well-exposed road cut along U.S. Interstate 80 in New Jersey and measures approximately 249 m (816 ft) thick (Table 1; Figures 12–13, 17; Epstein and Epstein 1972). Epstein and Epstein (1972) describe the Tammany Member as consisting of medium- to dark-gray, cross-bedded, evenly to unevenly bedded quartzite with minor amounts of dark-gray shaly siltstone that express kink folding (Figure 18). Quartz pebbles are present up to 5 cm (2 in) long, and flattened shale pebbles are common. Sandstones of the Tammany Member are similar in appearance to those of the Minsi Member at DEWA, except the feldspar component is not as abundant in the Tammany (Epstein and Epstein 1972). The Tammany Member overlies or intertongues with the Lizard Creek Member of the Shawangunk Formation and underlies the Bloomsburg Formation with an irregular and transitional contact.

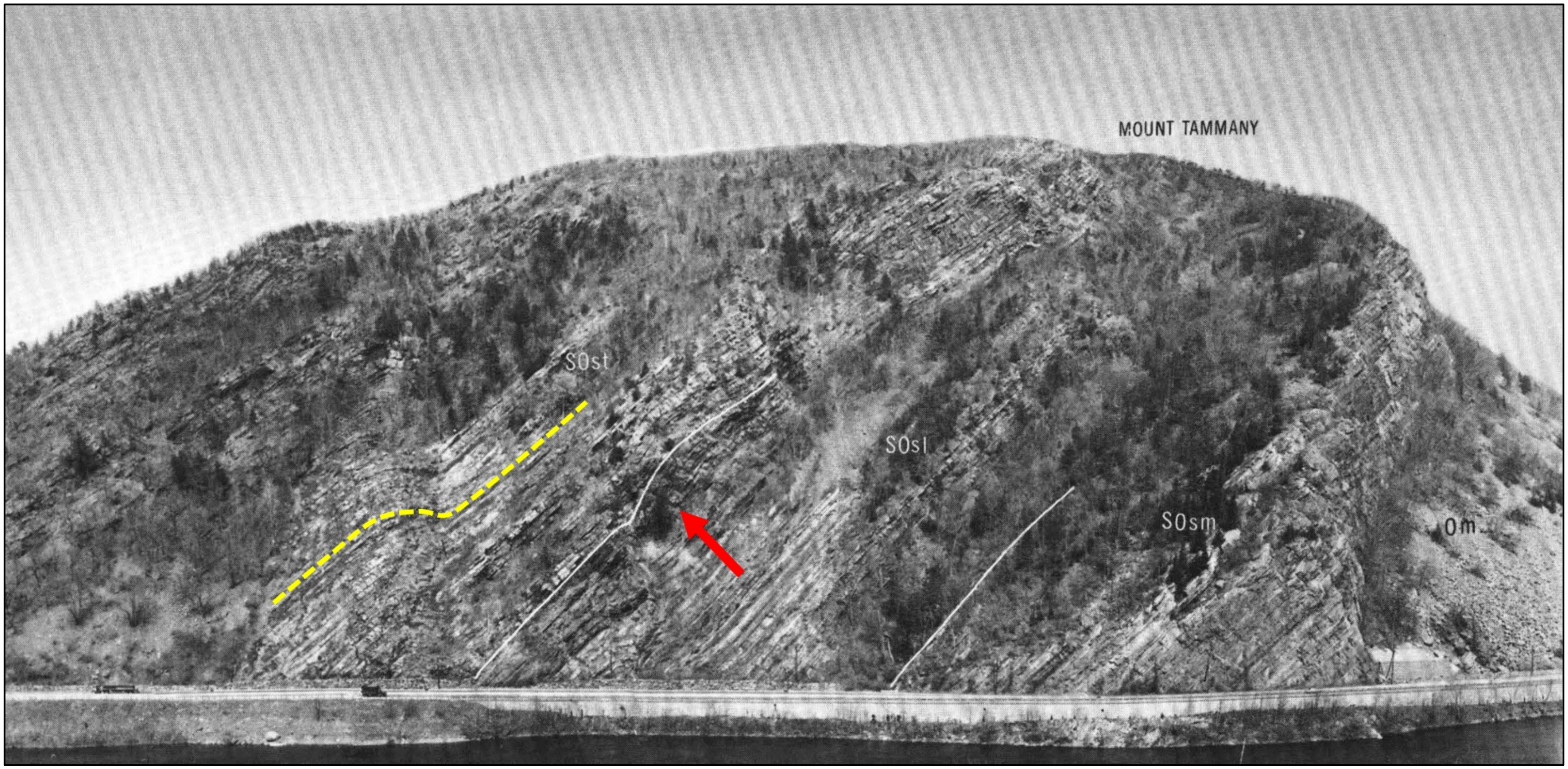


Figure 17. Type section of the Minsi and Tammany Members of the Shawangunk Formation at Delaware Water Gap, New Jersey. Om, Martinsburg Formation; SOsm, quartzite and conglomeratic quartzite of the Minsi Member; SOsl, interbedded quartzite, siltstone, and shale of the Lizard Creek Member; SOst, quartzite and conglomerate of the Tammany Member. The contact between the Martinsburg and Shawangunk Formations is covered by talus along the base of Mount Tammany. Trucks passing along the interstate road cut for scale. Note prominent kink fold in the Tammany Member (yellow dashed line) and disharmonic folds and faults in the Lizard Creek Member (red arrow). Beds generally dip northwest. Figure modified from Epstein and Epstein (1972).

Figure 18. Type section exposure of the Tammany Member of the Shawangunk Formation at Mount Tammany showing kink folding (NPS).

The Silurian Poxono Island Formation was originally named the Poxono Island Shale by White (1882) after Poxono Island, Pennsylvania. Bluff exposures described by White (1882) along the Delaware River opposite Poxono Island in Middle Smithfield Township, Pennsylvania were designated the type section by Swartz and Swartz (1941). Epstein et al. (1967) redesignated the unit the Poxono Island Formation to better reflect its heterogenous lithic character. The type section consists of a 61 m (200 ft) thick series of varicolored, grayish-yellow to greenish calcareous shales found underlying the Bossardville Limestone (Table 1; Figure 12; White 1882; Swartz and Swartz 1941; Epstein et al. 1967). Near the base of the shale is a 1.5 m (5 ft) thick bed of bluish-gray limestone (Swartz and Swartz 1941). The Poxono Island Formation overlies and intertongues with the Bloomsburg Formation and underlies the Bossardville Limestone.

The Silurian Wallpack Center Member of the Decker Formation was named for the village of Wallpack Center, New Jersey by Epstein et al. (1967). The type section of the member is located 1.6 km (1 mi) northeast of Wallpack Center on the southeast slope of Wallpack Ridge, in Culvers Gap Quadrangle (Table 1; Figure 12; Epstein et al. 1967). At the type section the member measures 25 m (82 ft) thick and consists of light- to medium-gray, fine-grained calcareous sandstone that weathers yellowish-gray to grayish-orange, lenses of calcareous quartz-pebble conglomerate, calcareous siltstone, fine- to coarse-grained arenaceous limestone, medium-gray calcareous shale, and medium- to dark-gray, very fine-grained dolomite (Epstein et al. 1967). The Wallpack Center Member underlies the Duttonville Member of the Rondout Formation and overlies the Bossardville Limestone.

The Devonian Peters Valley Member of the Coeymans Formation was named by Epstein et al. (1967) for the village of Peters Valley, approximately 2.3 km (1.4 mi) northeast of Wallpack Center, New Jersey. The type section of the member is located in a cut on the northwest side of Walpack Flatbrook Road that extends along the southwest side of Wallpack Ridge, approximately 2.4 km (1.5 mi) northeast of Flatbrookville, New Jersey, and 0.2 km (0.1 mi) southwest of a V-shaped bend in the road, in the Flatbrookville Quadrangle (Table 1; Figure 12; Epstein et al. 1967). At the type section the Peters Valley Members measures 0.45 m (1.5 ft) and consists of medium-gray, fine- to medium-grained, arenaceous limestone that contains marine fossil fragments. Stratigraphically, the member overlies the Depue Limestone Member and underlies the Shawnee Island Member of the Coeymans Formation. A reference section for the Peters Valley Member is located in the woods on the northeast side of a secondary road along the ascent of Wallpack Ridge in Pennsylvania, immediately southwest of where the Delaware River cuts through the ridge, in the Flatbrookville Quadrangle.

The Devonian Shawnee Island Member of the Coeymans Formation was designated by Epstein et al. (1967) for Shawnee Island in the Delaware River. The reference section of the Shawnee Island Member is located in the woods on the northeast side of a secondary road along the ascent of Wallpack Ridge in Pennsylvania, immediately southwest of where the Delaware River cuts through the ridge, in the Flatbrookville Quadrangle (Table 1; Figure 12; Epstein et al. 1967). At the reference section the member measures 13.0 m (42.7 ft) thick and stratigraphically occurs between the overlying Stormville Member and underlying Peters Valley Member of the Coeymans Formation. The member contains both a biohermal (reef or mound-like form built by marine invertebrates) and non-biohermal facies, with the more prevalent biohermal facies consisting of medium-gray, fine- to medium-grained argillaceous and arenaceous limestone that weathers tannish-gray (Epstein et al. 1967). The non-biohermal facies is composed of medium-gray, fine-grained, arenaceous and argillaceous limestone with dark-gray chert nodules.

The Devonian Flatbrookville Member of the New Scotland Formation was named by Epstein et al. (1967) for exposures near Flatbrookville, New Jersey. The type section of the member is located about 5.6 km (3.5 mi) northeast of Flatbrookville in the woods and along the northeast side of Walpack Flatbrook Road, in the Lake Maskenozha Quadrangle (Table 1; Figure 12; Epstein et al. 1967). At the type section the member measures 5.33 m (17.5 ft) thick and consists of medium- to dark-gray, calcareous and siliceous shale that is irregularly bedded (Epstein et al. 1967). Shale beds contain lenses of medium-gray, fine-grained limestone. The member overlies the Stormville Member of the Coeymans Formation and underlies the Maskenozha Member of the New Scotland Formation.

The Devonian Maskenozha Member of the New Scotland Formation was designated by Epstein et al. (1967) for Lake Maskenozha, Pennsylvania. The type section of the member occurs about 5.6 km (3.5 mi) northeast of Flatbrookville in the woods and along the northeast side of Walpack Flatbrook Road, in the Lake Maskenozha Quadrangle (Table 1; Figure 12; Epstein et al. 1967). Exposures of the Maskenozha Member measure 7.0 m (23 ft) thick at the type section and consist of dark-gray, laminated, calcareous and siliceous shale that contains scattered concretions of dense limestone as much as 0.6 m (2 ft) in diameter (Figure 19). About 10 percent of the unit is medium-gray, fine-grained, argillaceous limestone that contains fossil fragments (Epstein et al. 1967). Stratigraphically, the member overlies the Flatbrookville Member of the New Scotland Formation and underlies the Minisink Limestone.

Figure 19. Dense limestone concretion in dark-gray siliceous laminated shale of the Maskenozha Member of the New Scotland Formation in the type section roadcut along the southeast slope of Wallpack Ridge, DEWA. Note the arching of bedding around the concretion. Figure from Epstein et al. (1967).

The Devonian Minisink Limestone was named by Epstein et al. (1967) for the village of Minisink Hill, located in the Stroudsburg Quadrangle, Pennsylvania. A reference section for the Minisink Limestone is located about 5.6 km (3.5 mi) northeast of Flatbrookville in the woods and along the northeast side of Walpack Flatbrook Road, in the Lake Maskenozha Quadrangle (Table 1; Figure 12; Epstein et al. 1967). At the reference section the unit measures 3.51 m (11.5 ft) thick and consists of medium-gray, fine-grained, argillaceous limestone that is massively bedded (Epstein et al. 1967). The Minisink Limestone overlies the Maskenozha Member of the New Scotland Formation and underlies the Port Ewan Shale.

The Devonian Brodhead Creek Member of the Marcellus Shale was designated by Willard (1938) after Brodhead Creek Valley in Monroe County, Pennsylvania. The type section of the member is located on Brodhead Creek, approximately 5 km (3 mi) northwest of East Stroudsburg, Pennsylvania (Table 1; Figure 12; Stevenson and Skinner 1949). At the type section the Brodhead Creek Member measures approximately 23 m (75 ft) thick and consists of very finely arenaceous, dark-gray, non-fissile shales and sandy shales (Willard 1938; Stevenson and Skinner 1949). Stratigraphically, the member overlies the Stony Hollow Member of the Marcellus Shale and underlies the Mahantango Formation.

In addition to the designated stratotypes located within DEWA boundaries, a list of stratotypes located within 48 km (30 mi) of park boundaries is included here for reference. These nearby stratotypes include the Ordovician Jacksonburg Limestone (type section), Ramseyburg Member of the Martinsburg Formation (type locality), and Pen Argyl Member of the Martinsburg Formation (type locality); the Silurian Lizard Creek Member of the Shawangunk Formation (type section) and Clove Brook Member of the Decker Formation (type section); the Devonian Duttonville Member of the Rondout Formation (type section), Mashipacong Member of the Rondout Formation (type section), Trimmers Rock Formation (reference section), Sloat Brook Member of the Trimmers Rock Formation (type section), Long Run Member of the Catskill Formation (type section), Walckville Member of the Catskill Formation (type section), Towamensing Member of the Catskill Formation (type section), Analomink Member of the Catskill Formation (type section), Buttermilk Falls Limestone Member of the Onondaga Limestone (type area), Minisink Limestone (type section), Depue Limestone Member of the Coeymans Formation (type section), Peters Valley Member of the Coeymans Formation (reference section), Shawnee Island Member of the Coeymans Formation (type section), Ravena Member of the Coeymans Formation (reference section), Stormville Member of the Coeymans Formation (reference section), Flatbrookville Member of the New Scotland Formation (reference section), and Maskenozha Member of the New Scotland Formation (reference section); and the Mississippian Pocono Formation (reference section) and Mauch Chunk Formation (type locality).

Fort Necessity National Battlefield (FONE)

Fort Necessity National Battlefield (FONE) is situated in the Allegheny Mountains section of the Appalachian Plateau physiographic province in Fayette County, southwestern Pennsylvania (Figure 20). Authorized as a national battlefield site on March 4, 1931, FONE encompasses approximately 365 hectares (903 acres) and protects the pivotal battle site that marks the beginning of the French and Indian War and set the stage for the American Revolution (Anderson 2017). The battle at Fort Necessity on July 3, 1754 was the first test of military leadership for a 22-year-old Colonel George Washington and resulted in his only surrender. FONE has abundant natural resources and opportunities for visitors that include interactive exhibits, talks, tours, historic weapons demonstrations, hiking trails, and cross-country skiing. The landscape at FONE provided superior forage for Washington's horses and persuaded him to purchase the land sixteen years after the battle.

The bedrock geology of FONE consists of generally flat-lying, relatively undeformed rocks of the Mississippian and Pennsylvanian Subperiods, spanning approximately 360–300 million years ago (Figure 21). Rocks and fossils at the park record ancient depositional environments that include tropical marine settings, river plains, and coastal swamps (Koch and Santucci 2004). The landscape east of FONE is decorated with the rolling hills and steep valleys of the Allegheny Mountains, including Laurel Hill, Sugarloaf Knob, and Tharp Knob (Thornberry-Ehrlich 2009). To the west of the park, the valleys and hollows rise steeply towards Chestnut Ridge, a strategic high point during the battle of Fort Necessity capped by Pennsylvanian-age sandstone (Thornberry-Ehrlich 2009).

As of the writing of this paper, there are no designated stratotypes identified within the boundaries of FONE. There are three identified stratotypes located within 48 km (30 mi) of FONE boundaries, for the Pennsylvanian Uniontown Formation (type area), Waynesburg Formation (type area), and Monongahela Group (type area).

Figure 20. Park map of FONE, Pennsylvania (NPS).

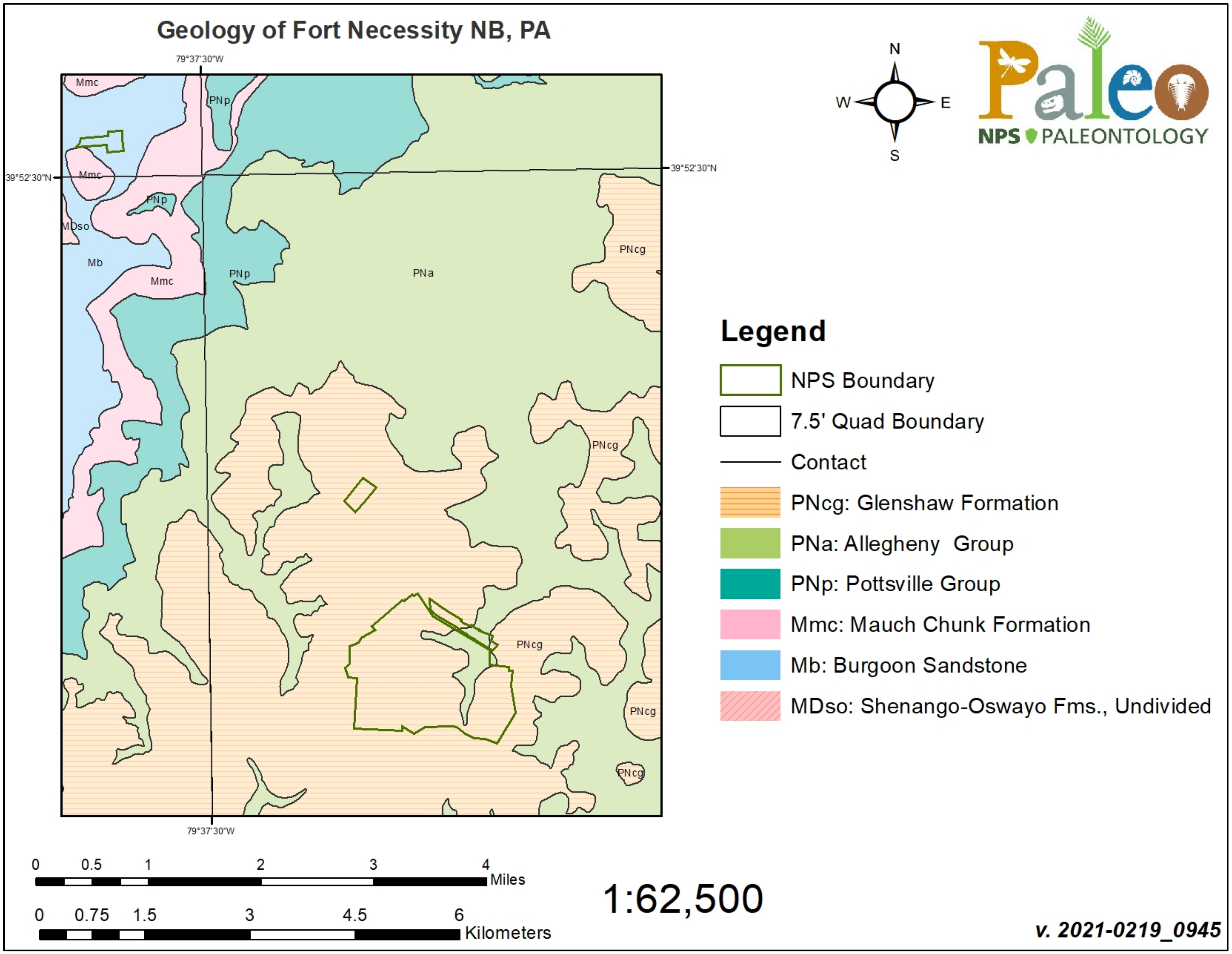


Figure 21. Geologic map of FONE, Pennsylvania.

Friendship Hill National Historic Site (FRHI)

Friendship Hill National Historic Site (FRHI) is located in the Appalachian Plateau on the Monongahela River near Point Marion in Fayette County, southwestern Pennsylvania (Figure 22). Authorized as an NPS unit on November 10, 1978, FRHI encompasses approximately 273 hectares (675 acres) set aside to commemorate the home and invaluable contributions of former U.S. Secretary of the Treasury Albert Gallatin (Anderson 2017). Gallatin, a Swiss emigrant and Treasury Secretary under Presidents Jefferson and Madison, worked to reduce the national debt, purchase the expansive Louisiana Territory, and fund Lewis and Clark's famous expedition. In addition to cultural resources such as Gallatin House and its grounds, FRHI preserves land near the junction of three sections in the Appalachian Plateau physiographic province: the Waynesburg Hills, Pittsburgh Low Plateau, and Allegheny Mountain sections (Thornberry-Ehrlich 2008b).

The bedrock geology of the FRHI area consists primarily of sedimentary rocks of the Pennsylvanian (~320–300 million years ago) and Quaternary Periods (<2.58 million years ago) (Figure 23). Geologic units at FRHI are generally flat-lying, undeformed sequences of sandstones, limestones, claystones, conglomerates, dolomites, and shales that contain fossils, commercially viable coals, and some iron- and sulfide-rich minerals (Thornberry-Ehrlich 2008b). The landscape west of FRHI is decorated with the rolling hills and steep valleys of Monongahela and Dunkard townships, including Durrs Knob, Rocky Hollow, and Mundell Hollow. East of the historic site, Hardin, Bartons, and Victor Hollows rise steeply towards Chestnut Ridge (Thornberry-Ehrlich 2008b).

As of the writing of this paper, there are no designated stratotypes identified within the boundaries of FRHI. There are five identified stratotypes located within 48 km (30 mi) of FRHI boundaries, for the Pennsylvanian Uniontown Formation (type area), Waynesburg Formation (type area), Greene Formation (type section), Washington Formation (type area), and Monongahela Group (type area).

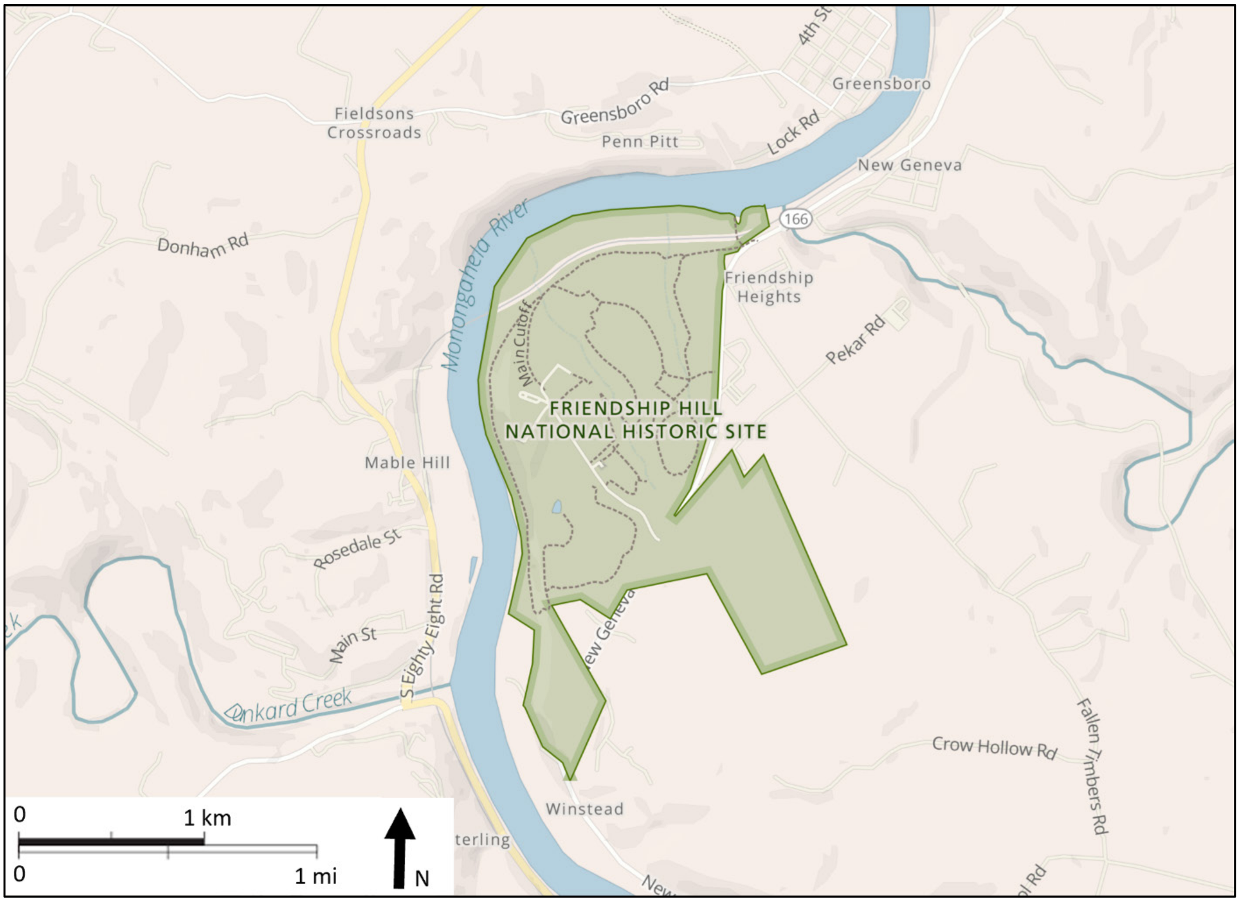


Figure 22. Park map of FRHI, Pennsylvania (NPS).

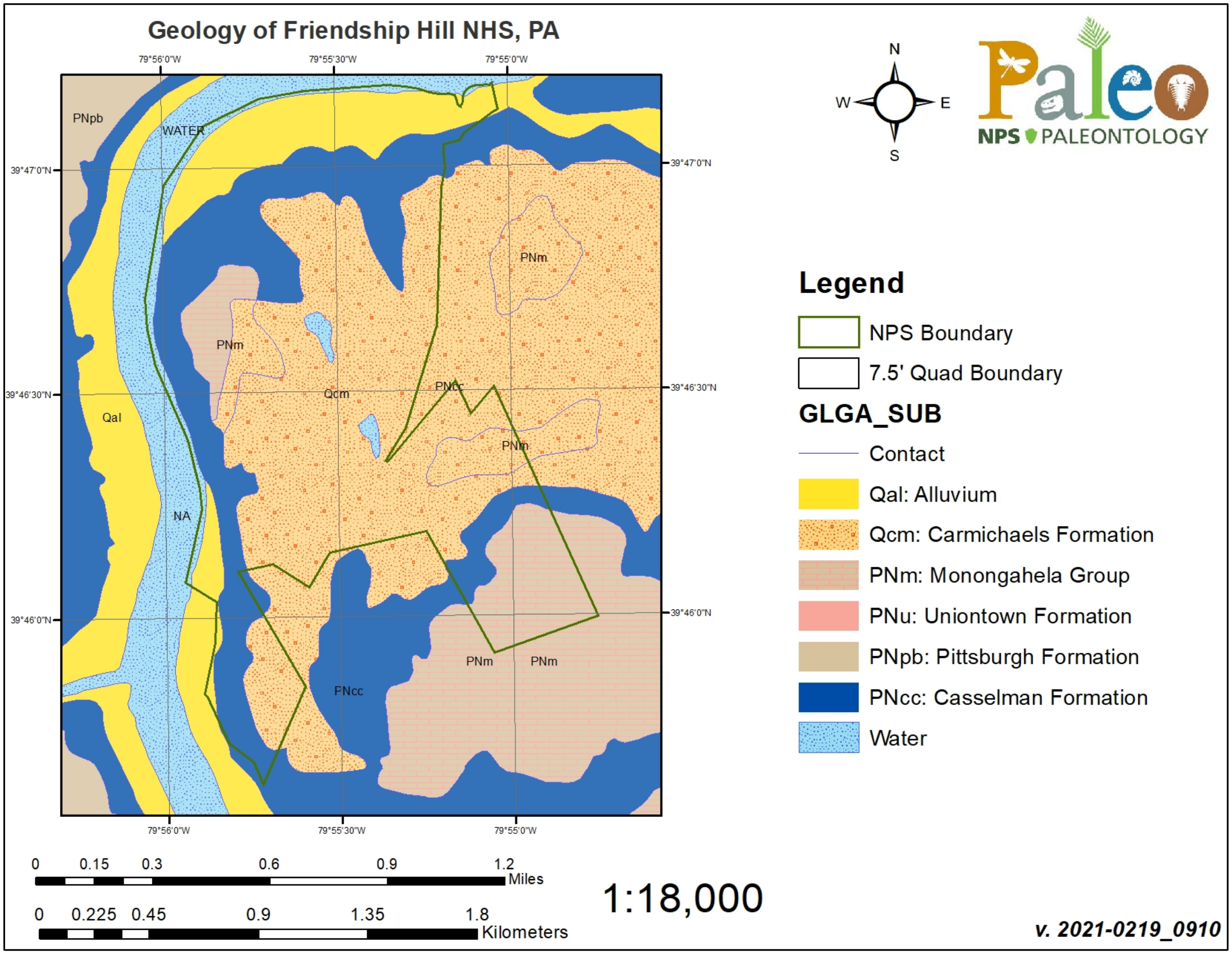


Figure 23. Geologic map of FRHI, Pennsylvania.

Gauley River National Recreation Area (GARI)

Gauley River National Recreation Area (GARI) includes 41.0 km (25.5 mi) of the Gauley River and 8.9 km (5.5 mi) of the Meadow River in Fayette and Nicholas Counties, West Virginia (Figure 24). Established as an NPS park unit on October 26, 1988, GARI encompasses approximately 4,696 hectares (11,606 acres) of scenic river landscape that pass through gorges and valleys containing a wide variety of natural and cultural features (Anderson 2017). The Gauley River is one of the most adventurous whitewater boating rivers in the eastern United States and contains several Class V+ rapids. The region of both the Gauley and Meadow Rivers provides excellent opportunities for fishing, camping, and hiking.

The bedrock geology of GARI consists of Pennsylvanian-age (~325–300 million years ago) rocks of the New River, Kanawha, and Allegheny Formations (Figure 25). These geologic units were deposited in a variety of ancient fluvial to nearshore depositional environments in the Appalachian basin during the first of a series of mountain-building events (the Taconic Orogeny) that culminated in the construction of the Appalachian Mountains. Over the course of geologic time, the rivers of GARI have carved a spectacular landscape of rock-rimmed deep gorges, cascading waterfalls, stirring rapids, stunning vistas, and forested slopes (Thornberry-Ehrlich 2017). Downstream from Summersville Dam, the Gauley River drops more than 204 m (668 ft) and features over 100 rapids between alternating pools, boulders, and exposed bedrock to the national recreation area’s western boundary at Upper Swiss (Thornberry-Ehrlich 2017).

As of the writing of this paper, there are no designated stratotypes identified within the boundaries of GARI. There are also no identified stratotypes located within 48 km (30 mi) of GARI boundaries.

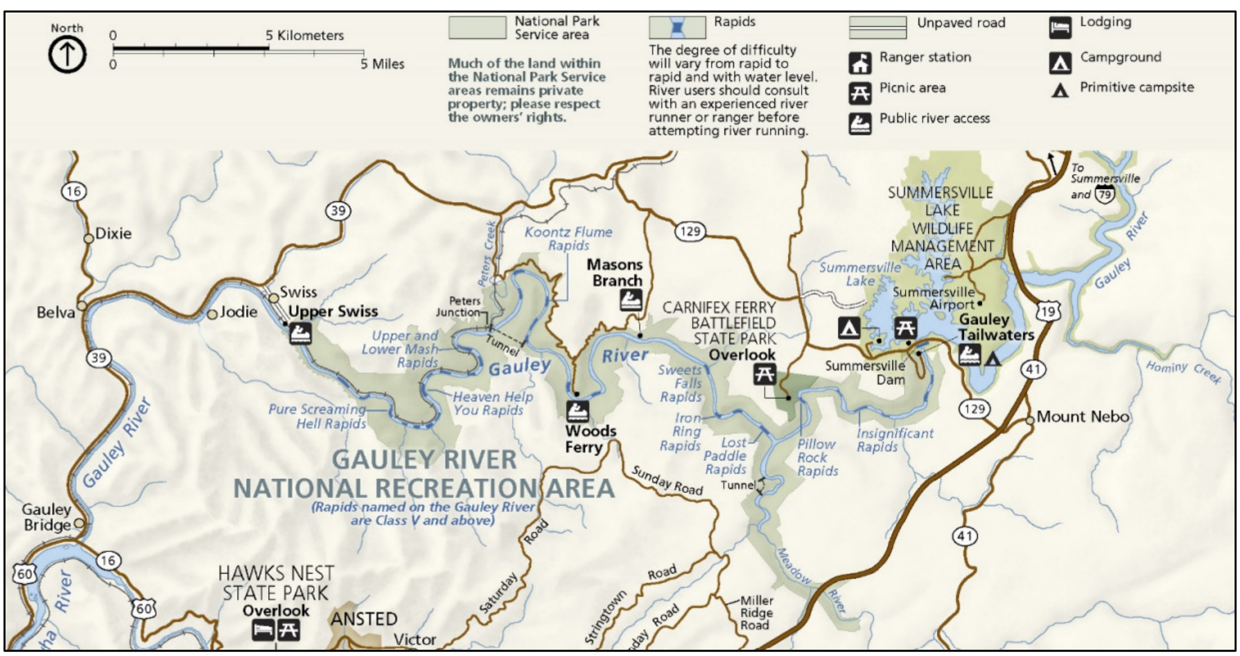


Figure 24. Park map of GARI, West Virginia (NPS).

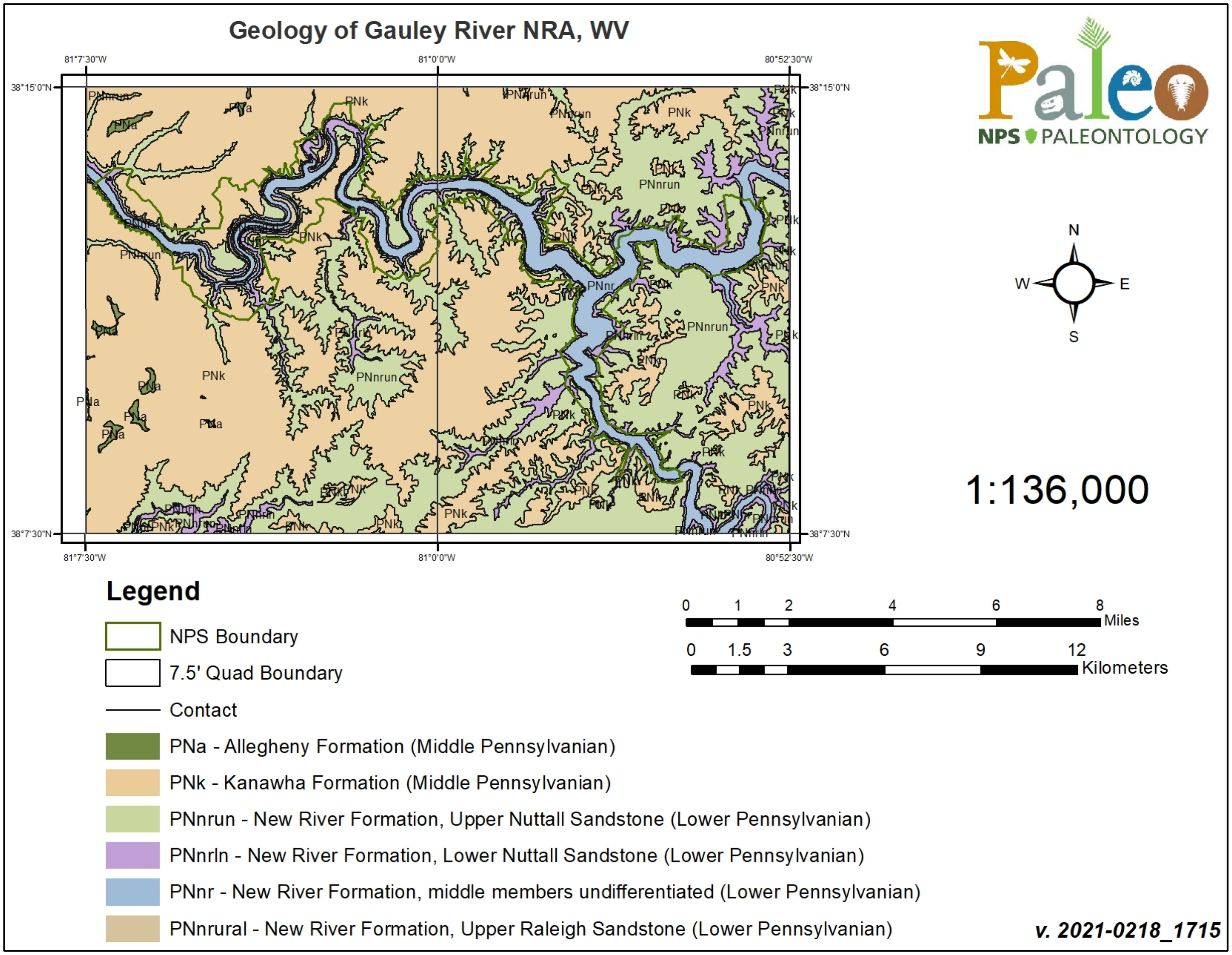


Figure 25. Geologic map of GARI, West Virginia.

Johnstown Flood National Memorial (JOFL)

Johnstown Flood National Memorial (JOFL) is situated in the Allegheny Mountains section of the Appalachian Plateaus approximately 16 km (10 mi) northeast of Johnstown in Cambria County, southcentral Pennsylvania (Figure 26). Authorized as an NPS park unit on August 31, 1964, the 72.0-hectare (178-acre) memorial is dedicated to the 2,209 lives lost during the tragic May 31, 1889 failure of the South Fork Dam that destroyed the working-class city of Johnstown, Pennsylvania. Considered one of the worst natural disasters in United States history, the tragedy brought the nation and the world together to aid the "Johnstown sufferers". The Johnstown Flood is known for being the first disaster relief effort of the American Red Cross, led successfully by Clara Barton.

The bedrock geology of JOFL consists of relatively flat-lying and undeformed sedimentary rocks of the Pennsylvanian-age (~325–300 million years old) Casselman Formation and Glenshaw Formation (Figure 27). An understanding of the local geology provides perspective into the probable mechanisms of the tragic Johnstown Flood. Prior to the flood, a strong storm hit the area causing water levels to rise behind the South Fork Dam. Both geologic formations at JOFL contain clay-rich units (shales and mudstones) that may weaken or deteriorate when saturated with water and are likely susceptible to failure when exposed on steep slopes (Thornberry-Ehrlich 2008c). These clay units may underlie the remnant supports of the dam at JOFL. When more resistant rocks such as sandstone and limestone overlie less resistant rock units, preferential erosion may undercut the more resistant units and result in rockfalls (Thornberry-Ehrlich 2008c).

As of the writing of this paper, there are no designated stratotypes identified within the boundaries of JOFL. There are four identified stratotypes located within 48 km (30 mi) of JOFL boundaries, for the Cambrian Warrior Formation (type locality) and Pleasant Hill Formation (type locality), Devonian Brallier Formation (type locality), and Mississippian Burgoon Sandstone (type area).

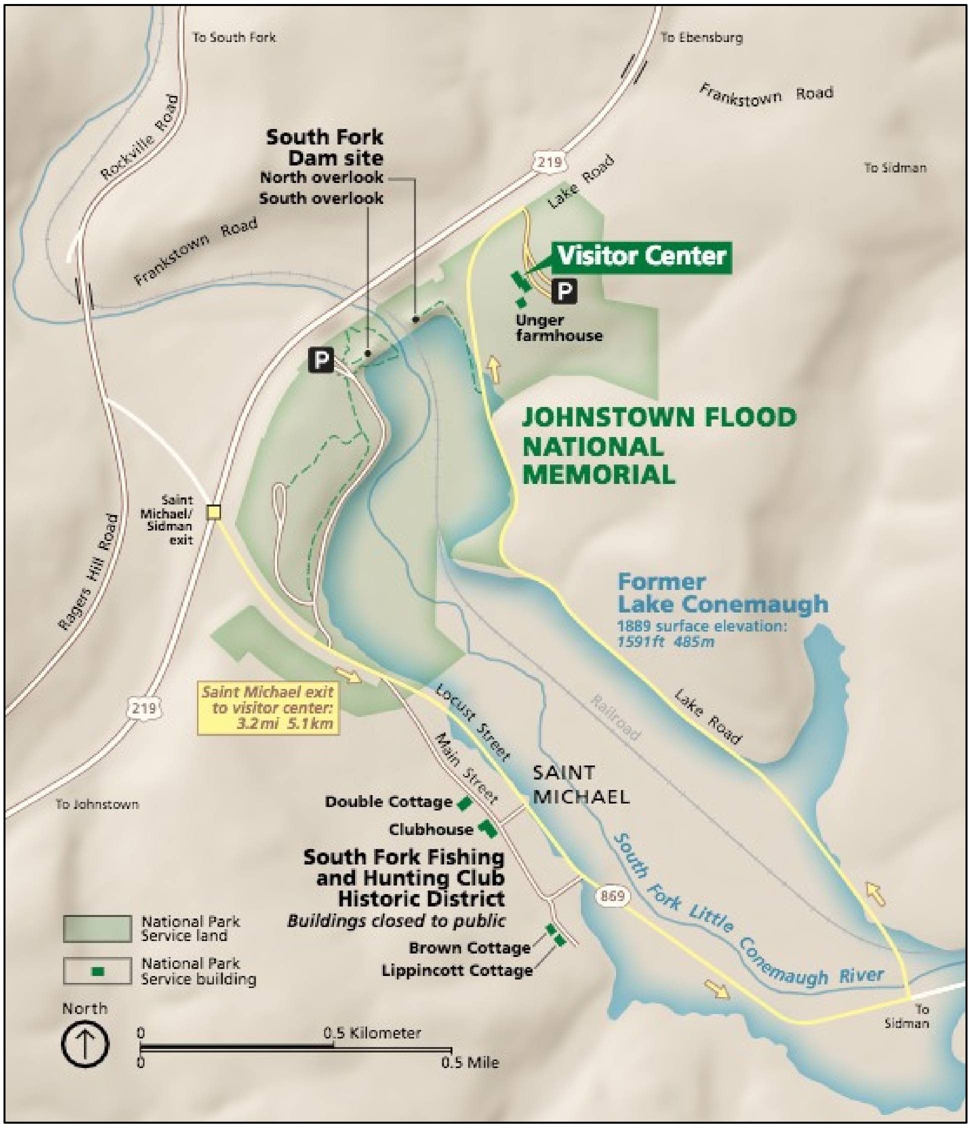


Figure 26. Park map of JOFL, Pennsylvania (NPS).

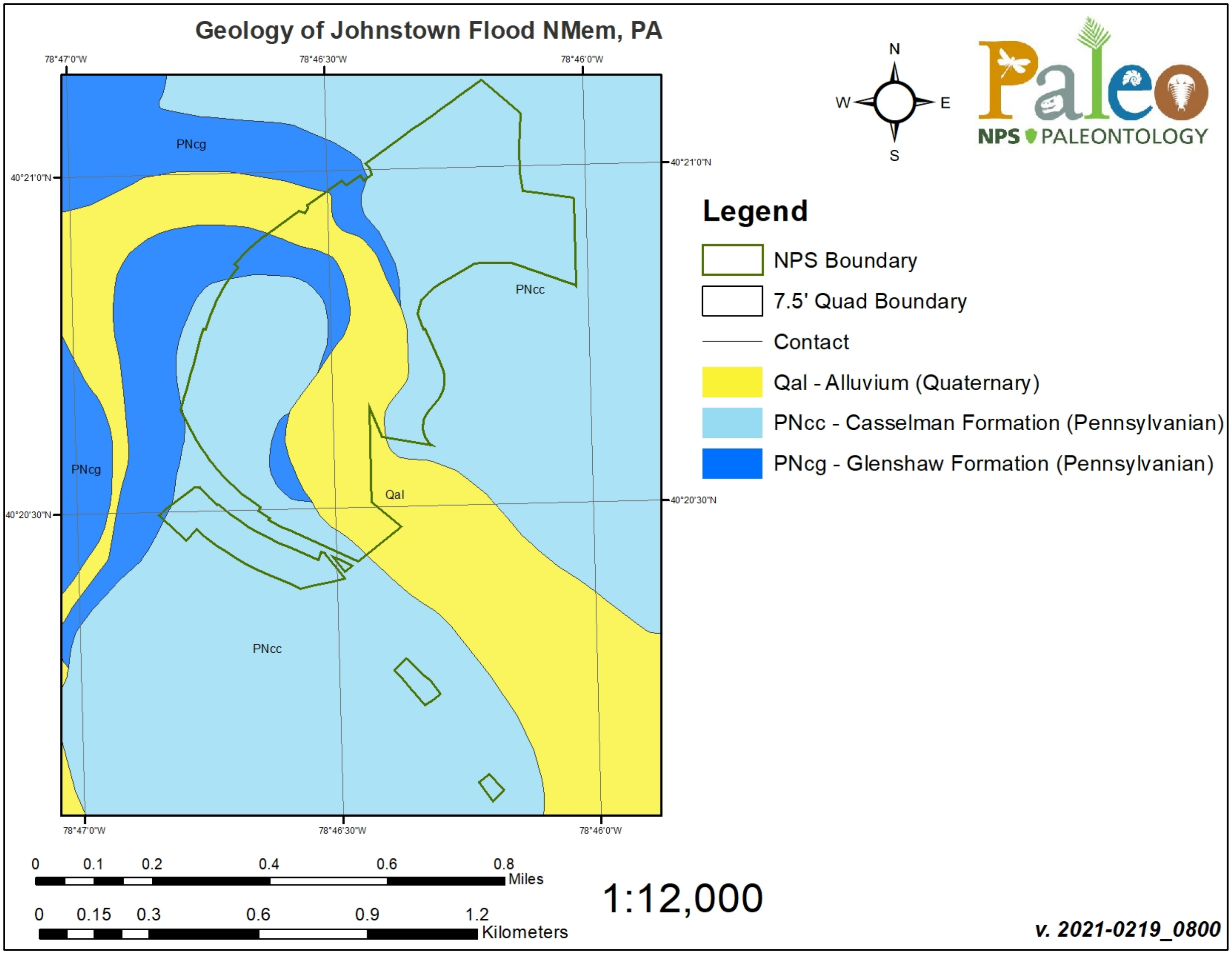


Figure 27. Geologic map of JOFL, Pennsylvania.

New River Gorge National Park and Preserve (NERI)

New River Gorge National Park and Preserve (NERI) stretches from Hawks Nest State Park near Cotton Hill more than 85 km (53 mi) along the free-flowing New River as far upstream as the town of Hinton in Fayette, Raleigh, and Summers Counties, southern West Virginia (Figure 28). Established as an NPS park unit on November 10, 1978 and upgraded to national park status on January 20, 2021, NERI encompasses approximately 29,212 hectares (72,186 acres) of abundant natural, scenic, historic, and recreational features. The rugged, whitewater New River is among the oldest rivers on the continent (Anderson 2017). The resources of NERI are dominated by the deepest and longest gorge in the Appalachian Mountains populated by numerous rapids, including the Grassy Shoals, Quinnimont, Silo, Surprise, Lower and Upper Railroad, Keeneys, Double Z, Dudleys Dip, Greyhound, Millers Folly, and Fayette Station rapids (Thornberry-Ehrlich 2017). The landscape at NERI emphasizes the area's cultural significance, from the railroads that provided access to the rugged, isolated territory in 1872, to the numerous coal mines, towns, settlements, and bridges (Thornberry-Ehrlich 2017).

The bedrock geology of NERI consists of Mississippian and Pennsylvanian-age sedimentary rocks that include the Bluefield, Hinton, Princeton, Bluestone, Pocahontas, New River, Kanawha, and Allegheny Formations (Figure 29). Sedimentary rocks at NERI provide clues to the geologic past and record deposition in a variety of ancient fluvial to nearshore depositional environments in the Appalachian basin. Development of the Appalachian basin began during the Taconic Orogeny, the first of a series of mountain-building events that culminated in the construction of the Appalachian Mountains. Over the course of geologic time, the New River carved down through the uplifted rock to form a spectacular landscape of rock-rimmed deep gorges, cascading waterfalls, stirring rapids, stunning vistas, and forested slopes (Thornberry-Ehrlich 2017). The gorge exposes up to 975 m (3,200 ft) of sandstone and shale. In the lower gorge, the river cuts through the resistant Nuttall Sandstone Member of the New River Formation, a unique sandstone type that is almost pure quartz.

NERI contains three identified stratotypes that are subdivided into one type locality and two type areas (Table 2; Figure 30).

Figure 28. Park map of NERI, West Virginia (NPS).

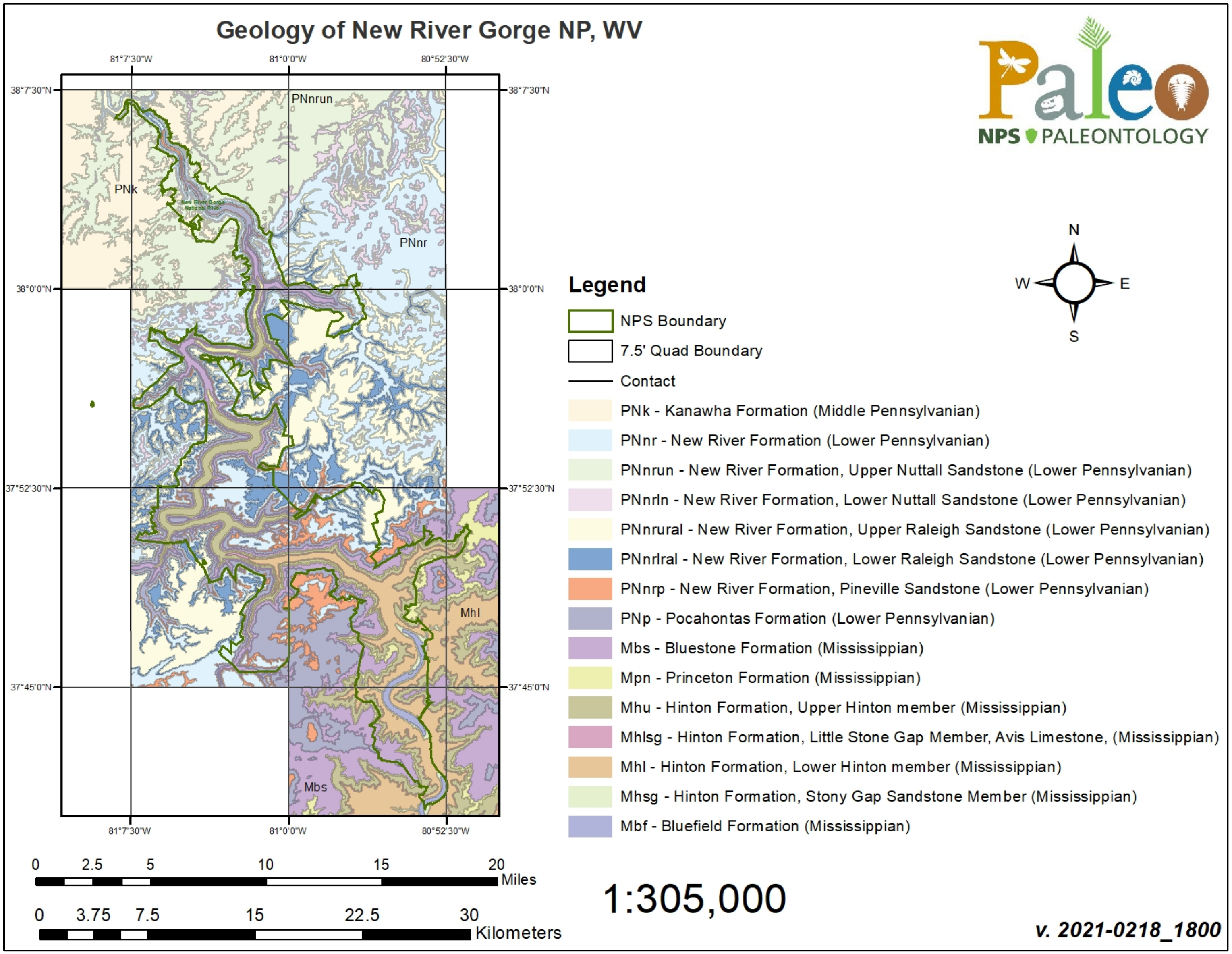


Figure 29. Geologic map of NERI, West Virginia.

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

Unit Name (map symbol)	Reference	Stratotype Location	Age
New River Formation (PNnr)	Fontaine 1874; Hennen and Gawthrop 1915	Type area: Exposures along New River, Fayette and Raleigh Counties, south-central West Virginia	Early Pennsylvanian
Nuttall Sandstone Member, New River Formation (PNnrn)	Hennen and Gawthrop 1915	Type locality: exposures above the mining town of Nuttallburg, which forms prominent cliffs	Early Pennsylvanian
Hinton Formation (Mh)	Campbell and Mendenhall 1896; Miller 1964	Type area: exposures along New River Gorge near Hinton, Summers Co., south-central West Virginia	Mississippian

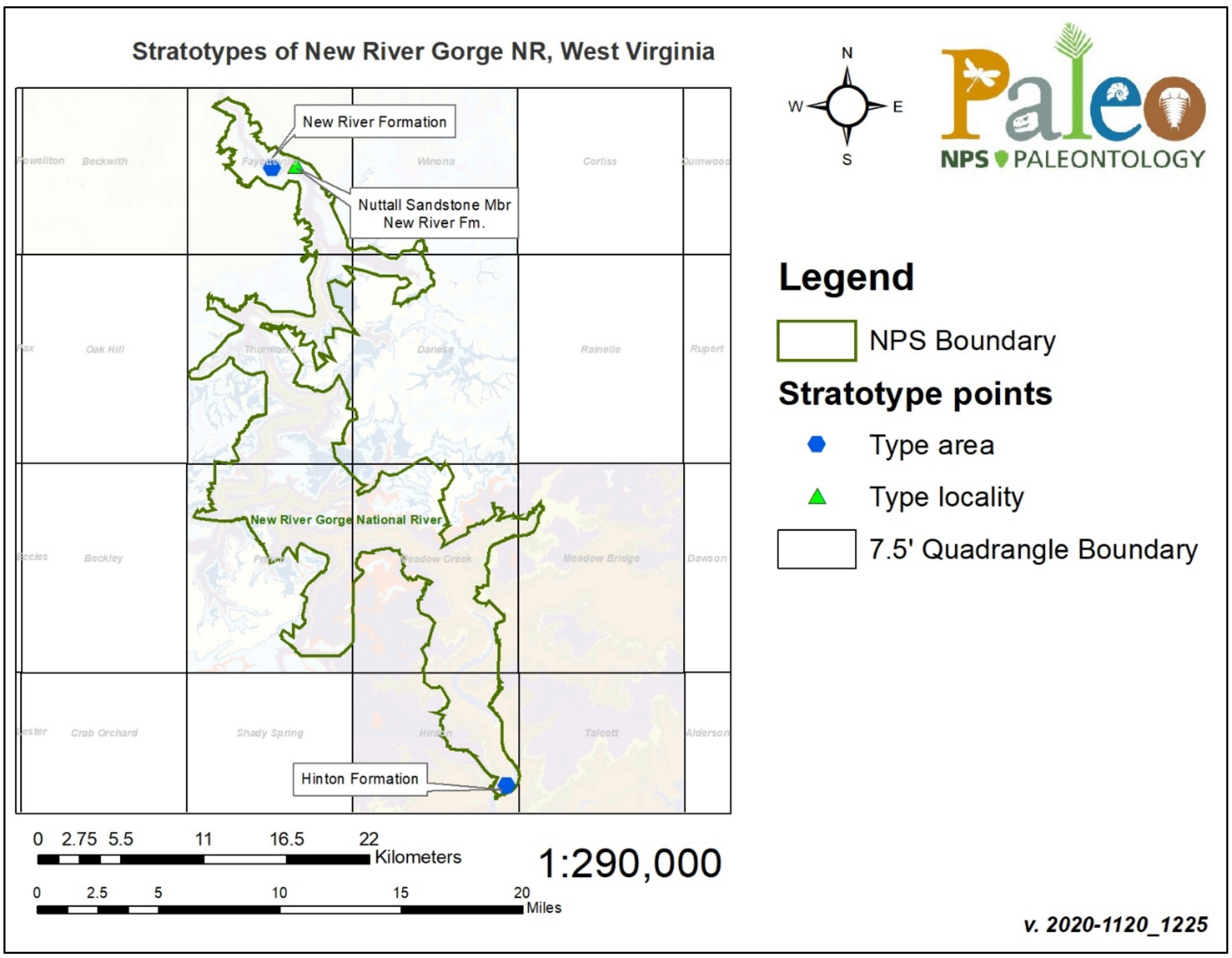


Figure 30. Modified geologic map of NERI showing stratotype locations. The transparency of the geologic units layer has been increased.

The Mississippian Hinton Formation was named by Campbell and Mendenhall (1896) after its type area exposures along the New River Gorge near the city of Hinton in Summers County, West

Virginia (Table 2; Figure 30). The formation consists of a heterogeneous clastic sedimentary sequence of varicolored shales, sandstones, and impure limestones with an approximate thickness of 335 m (1,100 ft). Several fossiliferous limestone zones exist (Campbell and Mendenhall 1896; Miller 1964). A basal sandstone bed is a prominent feature along railroad exposures from Hinton to Sandstone, West Virginia (Campbell and Mendenhall 1896). The Hinton Formation underlies the Princeton Sandstone and overlies the Bluefield Formation.

The Pennsylvanian New River Formation was originally designated by Fontaine (1874) for a 64 km (40 mi)-stretch of sandstone exposures along the New River that contain important coal beds. The type area exposures of the formation occur along the New River in Fayette and Raleigh Counties, south-central West Virginia and consist of a 213 m (700 ft) thick section of grayish-white to yellowish-brown, argillaceous, medium- to coarse-grained, cross-bedded sandstone that contains a considerable amount of oxide minerals and several coal seams (Table 2; Figures 30–31; Fontaine 1874; Hennen and Gawthrop 1915). In the type area the New River Formation overlies the Pocahontas Formation and underlies the Kanawha Formation.

Figure 31. Resistant cliff-forming sandstone exposures of the New River Formation seen along the Endless Wall from Diamond Point, NERI. Cliff exposures of the formation cap portions of the New River Gorge in its type area (WEST VIRGINIA GEOLOGICAL AND ECONOMIC SURVEY/GAYLE H "SCOTT" MCCOLLOCH, JR.).

The Nuttall Sandstone Member of the New River Formation was named by Campbell (1902) for a picturesque cliff-forming sandstone along the New River near the village of Nuttallburg in Fayette

County, West Virginia. The type locality of the member is designated for 33 m (110 ft) thick exposures at Nuttallburg that consist of grayish-white to yellowish-brown, medium- to coarse-grained, massive, pebbly, cross-bedded sandstone (Table 2; Figures 30, 32; Hennen and Gawthrop 1915). In Fayette County the member is often subdivided into an upper and lower division separated by 1.5–6 m (5–20 ft) of sandy shales and coal (Hennen and Gawthrop 1915).

Figure 32. Photograph of Fordson Coal Company conveyor and tipple in Nuttallburg circa 1927. The altered and deforested slopes help reveal the type locality exposures of the Nuttall Sandstone Member of the New River Formation that cap the gorge. Photograph NERI 312, included as an unnumbered figure in National Park Service (2001).

In addition to the designated stratotypes located within NERI boundaries, a list of stratotypes located within 48 km (30 mi) of park boundaries is included here for reference. These nearby stratotypes include the Mississippian Lindside Member of the Pocono Formation (type locality), Alderson Limestone (type locality), Greenville Shale (type locality), Hillsdale Member of the Greenbrier Limestone (type locality), Sinks Grove Limestone (type locality), Taggard Shale (type locality), Union Limestone (type locality), Ada Shale Member of the Bluefield Formation (type locality), Glenray Limestone Member of the Bluefield Formation (type locality), Indian Mills Sandstone Member of the Bluefield Formation (type locality), Lillydale Shale Member of the Bluefield Formation (type locality), Glady Fork Sandstone Member of the Bluestone Formation (type locality), Hunt Member of the Bluestone Formation (type locality), Pipestem Shale Member of the Bluestone Formation (type locality), Pride Shale Member of the Bluestone Formation (type locality), Avis Limestone Member of the Hinton Formation (type locality), Bellepoint Limestone Member of the Hinton Formation (type locality), Bent Mountain Member of the Hinton Formation (type locality), Eads Mill Member of the Hinton Formation (type section), Fivemile Shale Member of the Hinton Formation (type locality and reference section), Hackett Sandstone Member of the Hinton Formation (type locality), and the Stony Gap Sandstone Member of the Hinton Formation (type locality).

Upper Delaware Scenic and Recreational River (UPDE)

Upper Delaware Scenic and Recreational River (UPDE) is a 118 km (73.4 mi) stretch of the Delaware River located in the Appalachian Plateau along the Pennsylvania–New York border in Pike and Wayne Counties, Pennsylvania and Delaware, Orange, and Sullivan Counties, New York (Figure 33). Authorized as an NPS park unit on November 10, 1978, UPDE was designated for outstandingly remarkable cultural, recreational, scenic, and ecological values (Anderson 2017). The park encompasses approximately 30,351 hectares (75,000 acres) of fluvial (stream-cut) landscape amid rolling hills and riverfront villages at one of the finest fishing rivers in the northeastern United States.

The bedrock geology of UPDE predominantly consists of Paleozoic rocks of the Devonian Period (~420–360 million years ago) (Figure 34). The Upper Devonian rocks in the upper Delaware River valley are a puzzling complex of clastic strata. The complexity derives from two factors: 1) the confusing regional nature of the strata themselves, and 2) the diverse, even conflicting, schemes by which geologists have defined, named, and ordered the strata (Frank Fletcher, pers. comm., 2021). Stratigraphic units of the park include (from oldest to youngest) the Mahantango, Trimmers Rock, and Catskill Formations. A marked diversity of unique geologic landforms exists throughout the river corridor and include glacial deposits, glacial outwash terraces, bedrock knobs, cutoff incised meanders, island complexes, and narrow, deep gorges. Sandstone cliffs, clearly evident at places like the Hawks Nest, consist of ancient river channel deposits that display a wide variety of bedding features, including crossbedding, ripple marks, current lineation, tool marks, mud cracks, and conglomerates. Fossilized remains recovered in UPDE are dominated by Devonian paleobotanical specimens, representing early land plants.

UPDE contains four identified stratotypes that are subdivided into two type sections, one type locality, and one type area (Table 3; Figure 35).

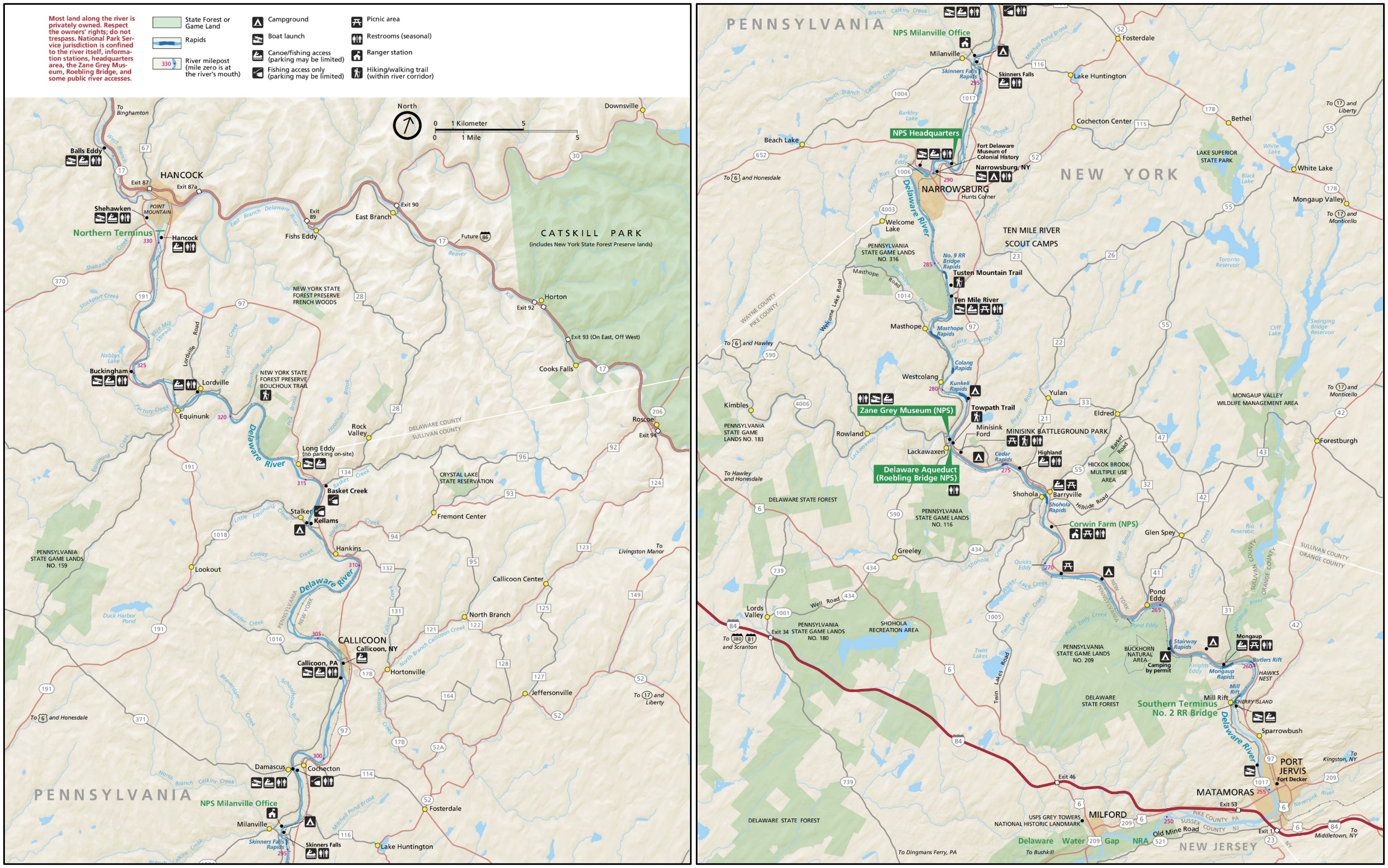


Figure 33. Park map of UPDE, New York–Pennsylvania (NPS).

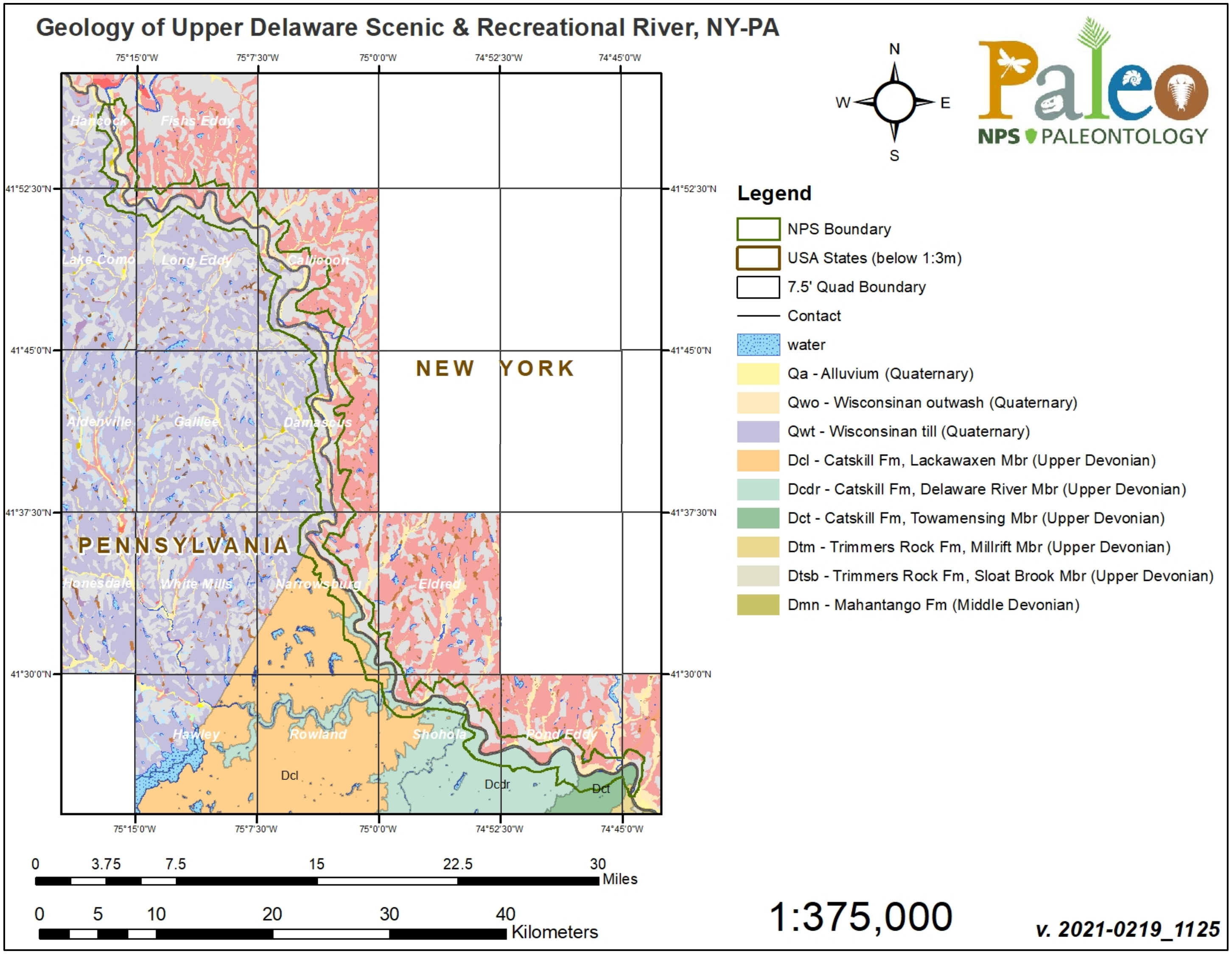


Figure 34. Geologic map of UPDE, Pennsylvania–New York.

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

Unit Name (map symbol)	Reference	Stratotype Location	Age
Lackawaxen Member, Catskill Formation (Dcl)	White 1882; Willard 1936	Type locality: exposures a short distance below Lackawaxen village and at other places in Lackawaxen Township, Pike Co., Pennsylvania	Late Devonian
Delaware River Member, Catskill Formation (Dcd)	White 1882; Willard et al. 1939; Fletcher and Woodrow 1970	Type section: cliff exposure at Hawks Nest, Orange Co., New York Type area: along Delaware River north of Hawks Nest, ~8 km (5 mi) northwest of Germantown, Port Jervis North Quadrangle, Orange Co., New York	Late Devonian
Millrift Member, Trimmers Rock Formation (Dtm)	Fletcher and Woodrow 1970	Type section: west bank of Delaware River at Millrift, from beneath Erie–Lackawanna RR bridge to 230–275 m downstream, Westfall Twp., Pike Co., Pennsylvania	Late Devonian

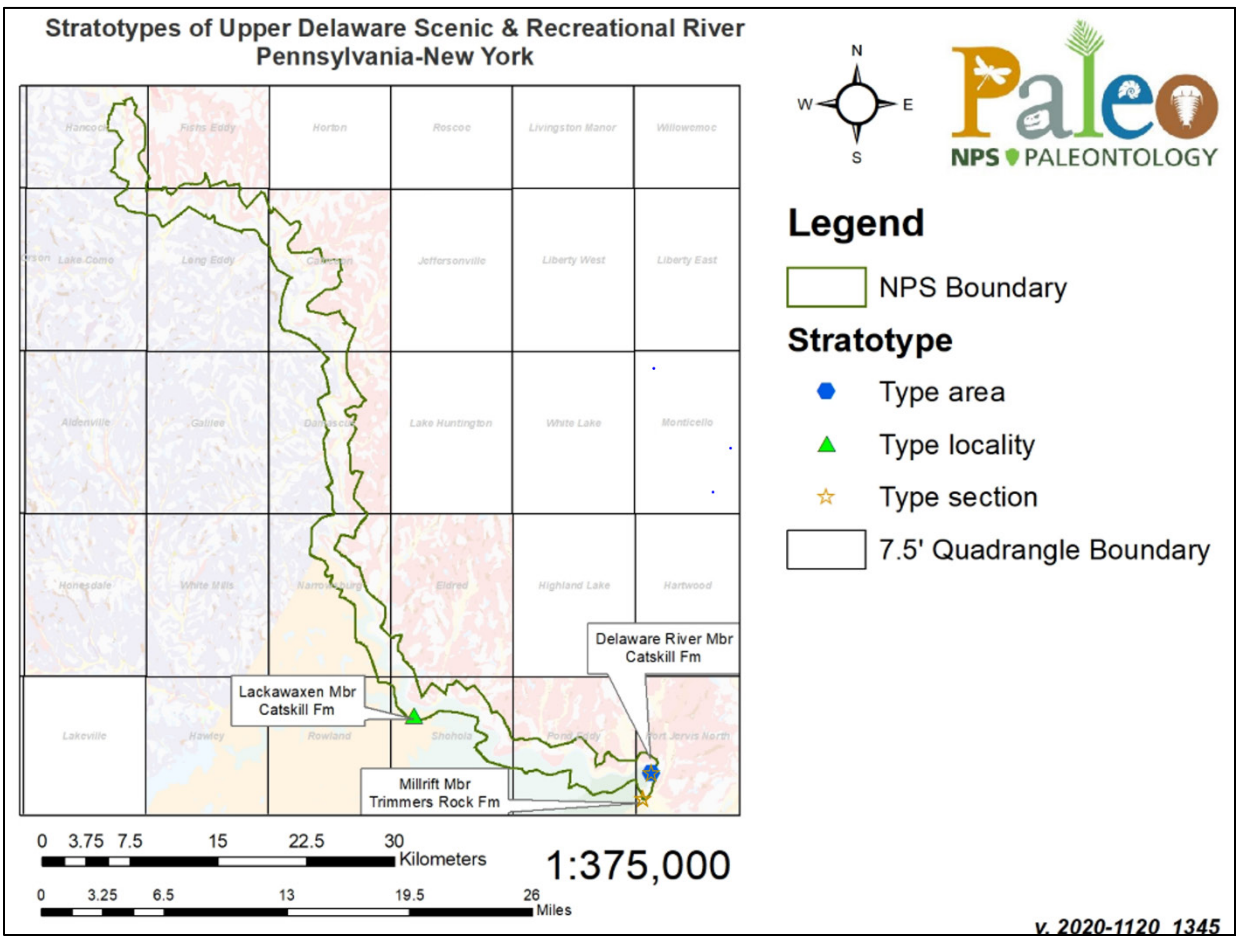


Figure 35. Modified geologic map of UPDE showing stratotype locations. The transparency of the geologic units layer has been increased.

The Devonian Millrift Member of the Trimmers Rock Formation was originally named the Millrift Formation by Fletcher and Woodrow (1970) after its type section exposure on the west bank of the Delaware River at Millrift, Pennsylvania (Table 3; Figure 35). The formation was reduced in rank and revised as a member of the Trimmers Rock Formation by Davis (1989). The type section begins beneath the Erie–Lackawanna railroad bridge and extends downstream from the bridge abutments for approximately 229–274 m (750–900 ft) (Fletcher and Woodrow 1970). At the type section the Millrift Member measures 162 m (530 ft) thick and consists of interbedded, gray to grayish-blue, fine-grained, thin- to medium-bedded sandstone with ripple marks, gray siltstone, and dark-gray shale (Fletcher and Woodrow 1970). Ball and pillow structures are common. The member overlies the Sloat Brook Member of the Trimmers Rock Formation and gradationally underlies the Delaware River Formation (Fletcher and Woodrow 1970).

The Devonian Delaware River Member of the Catskill Formation was originally referred to as the "Delaware River Flags" by White (1882) and revised to current nomenclature by Davis (1989). The type section of the member is designated in an approximately 305 m (1,000 ft) thick cliff exposure at Hawks Nest in Orange County, New York (Table 3; Figures 35–36; Willard et al. 1939; Fletcher and Woodrow 1970). The type area of the member is located along the Delaware River north of Hawks Nest approximately 8 km (5 mi) northwest of Germantown, Port Jervis North Quadrangle, Orange County, New York (Table 3; Figure 35; White 1882). Exposures at the type section and type area consist of calcareous, gray, fine- to medium-grained, thick-bedded, cross-stratified sandstone with minor amounts of olive and gray shale and claystone (Fletcher and Woodrow 1970). Fining upward sequences are common. The Delaware River Member underlies the Shohola Formation and grades downward into the underlying Millrift Member of the Trimmers Rock Formation (Fletcher and Woodrow 1970; Davis 1989).

The Devonian Lackawaxen Member of the Catskill Formation was originally designated the Lackawaxen Conglomerate by White (1882) after exposures within the hills surrounding Lackawaxen village in Pike County, Pennsylvania. The unit was reduced in rank and assigned as the Lackawaxen Member of the Catskill Formation by Davis (1989). Type locality exposures of the member are located a short distance below Lackawaxen village and at other places in Lackawaxen Township (Table 3; Figure 35; White 1882; Willard 1936). The member consists of a 190 m (623 ft) thick sequence of ledge-forming, gray conglomerates, greenish-gray conglomeratic sandstones, with minor amounts of red siltstone and claystone (White 1882; Fletcher and Woodrow 1970; Davis 1989). Sandstone ranges from very-fine to coarse-grained. The Lackawaxen Member stratigraphically occurs between the overlying Poplar Gap and Packerton Members and underlying Shohola Formation (Fletcher and Woodrow 1970; Davis 1989).

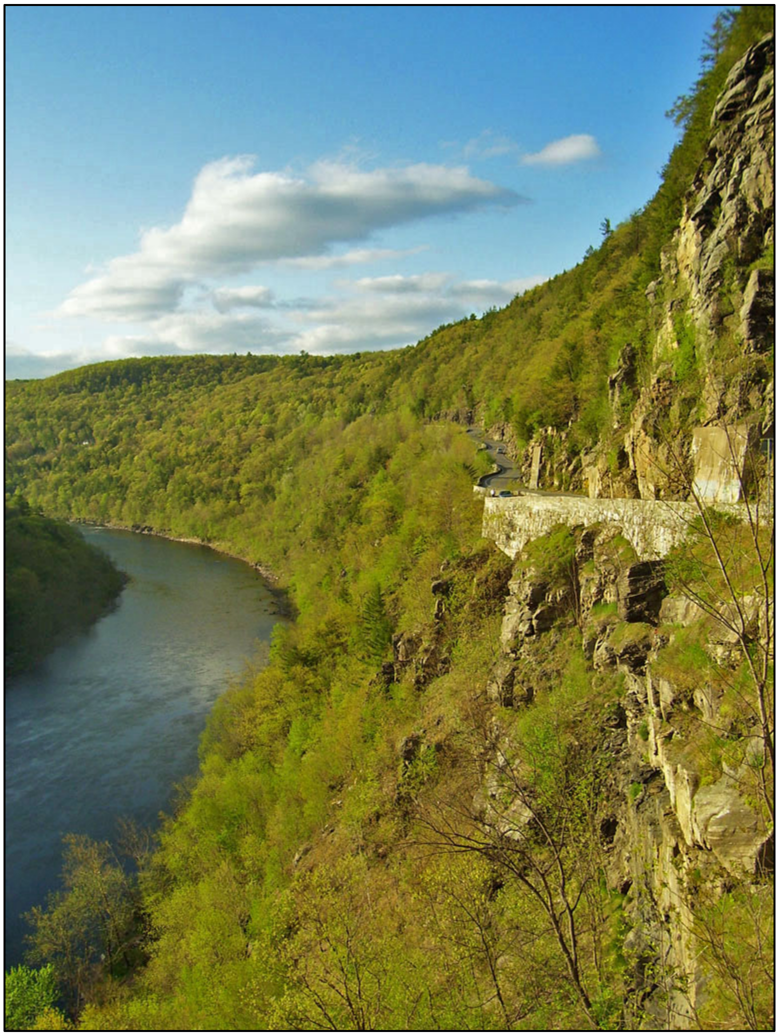


Figure 36. Resistant, cliff-forming sandstones of the Delaware River Member of the Catskill Formation at the Hawks Nest type section, UPDE. Photograph by user “Daniel Case” available via Wikimedia Commons https://upload.wikimedia.org/wikipedia/commons/3/3d/Hawks%27_Nest.jpg (Creative Commons Attribution-Share Alike 3.0 Unported [CC BY-SA 3.0]; https://creativecommons.org/licenses/by-sa/3.0/deed.en).

In addition to the designated stratotypes located within UPDE boundaries, a list of stratotypes located within 48 km (30 mi) of park boundaries is included here for reference. These nearby stratotypes include the Ordovician Jacksonburg Limestone (type section); Silurian Clove Brook Member of the Decker Formation (type section); and Devonian Mashipacong Member of the Rondout Formation (type section), Ravena Member of the Coeymans Formation (reference section), and Sloat Brook Member of the Trimmers Rock Formation (type section).

Recommendations

1. The NPS Geologic Resources Division should work with park and network staff to increase their awareness and understanding about the scientific, historic and geologic heritage significance of geologic stratotypes (type sections/localities/areas, reference sections, lithodemes).
2. Once the ERMN Geologic Type Section Inventory report is finalized, the NPS Geologic Resources Division should schedule a briefing for the staff of the ERMN and respective network parks.
3. The Devonian Shohola Member of the Catskill Formation was named by Willard (1936) from exposures near the village of Shohola on the Delaware River near the mouth of Lackawaxen Creek in Pike County, Pennsylvania within the park boundaries of UPDE. However, no formal stratotype for the Shohola Member has been identified. Therefore, we recommend a formal type section be designated in order to A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of the unit; and C) help safeguard the exposure.
4. The Pennsylvanian Quinnimont Shale Member of the New River Formation was named by Campbell (1896) from exposures at the mining town of Quinnimont, Fayette County, southern West Virginia within the park boundaries of NERI. However, no formal stratotype for the Quinnimont Shale Member has been identified. Therefore, we recommend a formal type section be designated in order to A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of the unit; and C) help safeguard the exposure.
5. The Pennsylvanian Raleigh Sandstone Member of the New River Formation was named by Campbell and Mendenhall (1896) from exposures found along the road from Prince to Raleigh, Raleigh County, southern West Virginia within or near the park boundaries of NERI. However, no formal stratotype for the Raleigh Sandstone Member has been identified. Therefore, we recommend a formal type section be designated in order to A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of the unit; and C) help safeguard the exposure.
6. The NPS Geologic Resources Division should work with park and network staff to ensure they are aware of the location of stratotypes in park areas. This information would be important to ensure that proposed park activities or development would not adversely impact the stability and condition of these geologic exposures.
7. 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 state-wide), based on lithology, stratigraphy, fossils or notable features using procedural code outlined by the North American Commission on Stratigraphic Nomenclature.

8. From the assessment in (3), (4), and (5), NPS staff should focus on registering new stratotypes at State and Local government levels where current legislation allows, followed by a focus on registering at Federal and State levels where current legislation allows.
9. The NPS Geologic Resources Division should work with park and network staff to compile and update a central inventory of all designated stratotypes and potential future nominations.
10. The NPS Geologic Resources Division should ensure the park-specific Geologic Type Section Inventory Reports are widely distributed and available online.
11. The NPS Geologic Resources Division should work with park and network staff to regularly monitor geologic type sections to identify any threats or impacts to these geologic heritage features in parks.
12. The NPS Geologic Resources Division should work with park and network staff to obtain good photographs of each geologic type section within the parks. In some cases, where there may be active geologic processes (rock falls, landslides, coastal erosion, etc.), the use of photogrammetry may be considered for monitoring of geologic type sections. GPS locations should also be recorded and kept in a database when the photographs are taken.
13. The NPS Geologic Resources Division should work with park and network staff to utilize selected robust internationally and nationally significant type sections as formal teaching/education sites and for geotourism so that the importance of the national-level assets are more widely (and publicly) known, using information boards and walkways.
14. The NPS Geologic Resources Division should work with park and network staff in developing conservation protocols of significant type sections, either by appropriate fencing, walkways, and information boards or other means (e.g., phone apps).

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Appendix A: Source Information for GRI Maps of ERMN Parks

ALPO–JOFL

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- GMAP 5049: Berg, T. M., W. E. Edmunds, A. R. Geyer, and others, compilers. 1980. Geologic map of Pennsylvania. Pennsylvania Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania. Map 1. Scale 1:250,000. From source maps (PAGS Map 61) mapped at 1:62,500 scale.
- GMAP 5050: Berg, T. M., W. E. Edmunds, A. R. Geyer, and others, compilers. 2001. Digital bedrock geology of Pennsylvania, Tyrone 30' x 60' Quadrangle. Pennsylvania Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania. Map 1. Scale 1:250,000.
- GMAP ____: Berg, T. M., W. E. Edmunds, A. R. Geyer, and others, compilers. 2001. Digital bedrock geology of Pennsylvania, Johnstown 30' x 60' Quadrangle. Pennsylvania Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania. Map 1. Scale 1:250,000.

BLUE

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- GMAP 76008: Yates, M. K and S. J. Kite (digital cartography and map compilation by S. E. Gooding). 2014. Surficial geologic map of the Bluestone National Scenic River Area, West Virginia. West Virginia University and West Virginia Geological and Economic Survey, Morgantown, West Virginia. Open File Map 1401. Scale 1:12,000.

DEWA

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- GMAP 4456: Davis, D. K., W. D. Sevon, T. M. Berg, and L. D. Schultz. 1989. Bedrock Geologic map of Pike County, Pennsylvania, showing locations of selected wells. Pennsylvania Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania. Water Resource Report 65. Scale 1:50,000.
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- GMAP 4457: McElroy, T. A. 1988. Groundwater resources of Fayette County, Pennsylvania. Pennsylvania Geological Survey, Harrisburg, Pennsylvania. Water Resource Report 60. Plate 1. Scale 1:50,000.

GARI

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NERI

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UPDE

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- GMAP 4794: Sevon, W. D., T. M. Berg, and L. D. Schultz. 1989. Geology and mineral resources of Pike County, Pennsylvania. Pennsylvania Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania. County Report 52. Plate 2, surficial geology. Scale 1:50,000.
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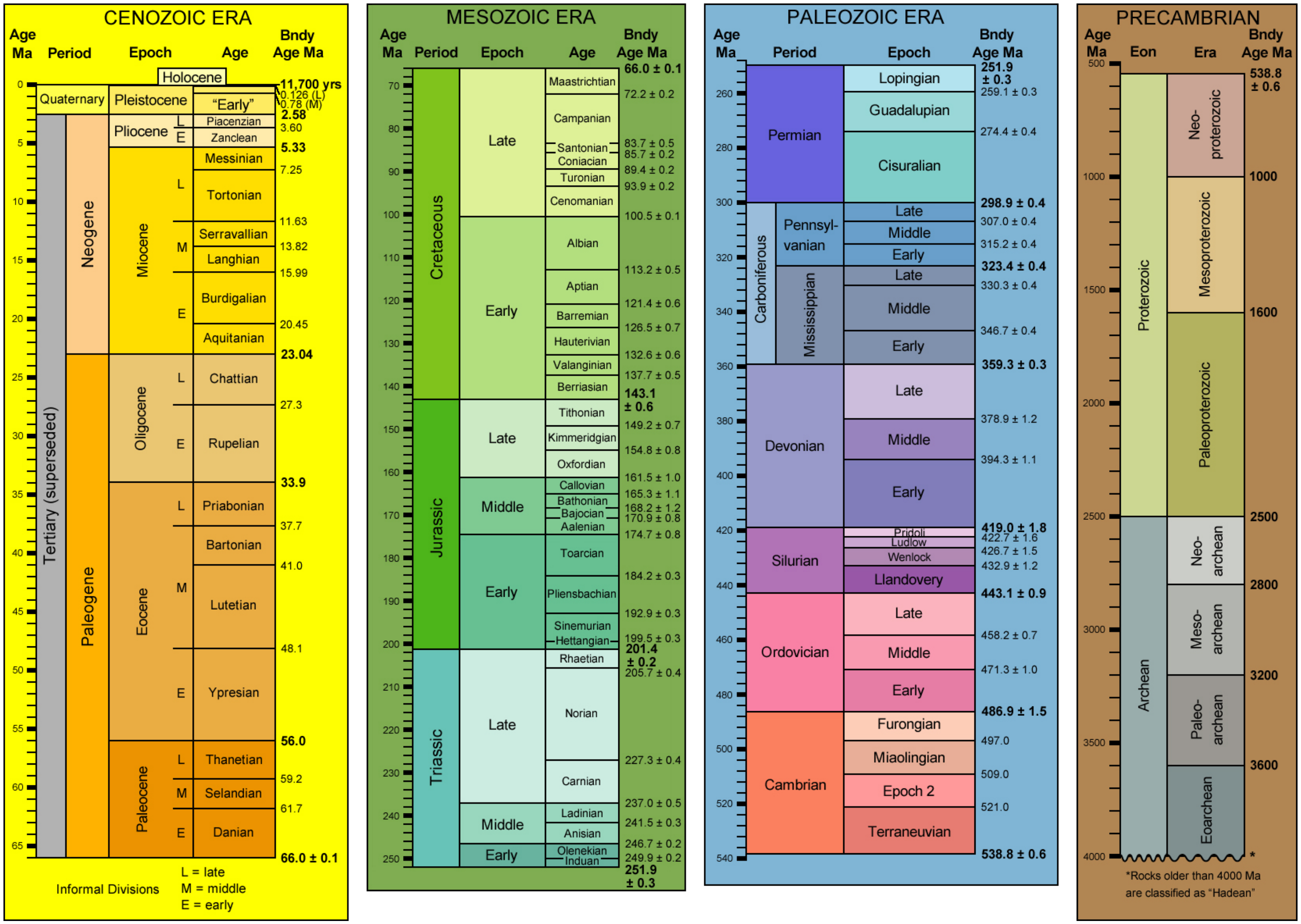
- GMAP 74575: Braun, D. D. 2011. Surficial geology of the Hawley 7.5-Minute Quadrangle, Wayne County, Pennsylvania. Pennsylvania Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania. Open-File Report 06-13.0. 1:24,000.
- GMAP 75682: Braun, D. D. 2010. Surficial geology of the Orson 7.5-Minute Quadrangle, Susquehanna and Wayne Counties, Pennsylvania. Pennsylvania Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania. Open-File Report 10–06.0. Scale 1:24,000.
- GMAP 76117: Kowzlowski, A. L. 2017. Surficial geology of the New York portion of Upper Delaware Scenic and Recreational River and vicinity, New York (northern 7.5' quadrangles). New York State Geological Survey, Albany, New York. Unpublished data and map. Scale 1:24,000.
- GMAP 76278: USGS National Hydrography Dataset. The Delaware River was extracted from this dataset and merged with digital geologic-GIS data used for this project.
- GMAP 76289: Leone, J., et al. 2019. Surficial geology of the New York portion of Upper Delaware Scenic and Recreational River and vicinity, New York (southern 7.5' quadrangles). New York State Geological Survey, Albany, New York. Unpublished data and map. Scale 1:24,000.
- U.S. Geological Survey. 2018. USGS National Hydrography Dataset Best Resolution (NHD) for Hydrologic Unit (HU) 8. U.S. Geological Survey, Reston, Virginia. Scale 1:24,000 (National Hydrography Dataset).

Appendix B: 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).

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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