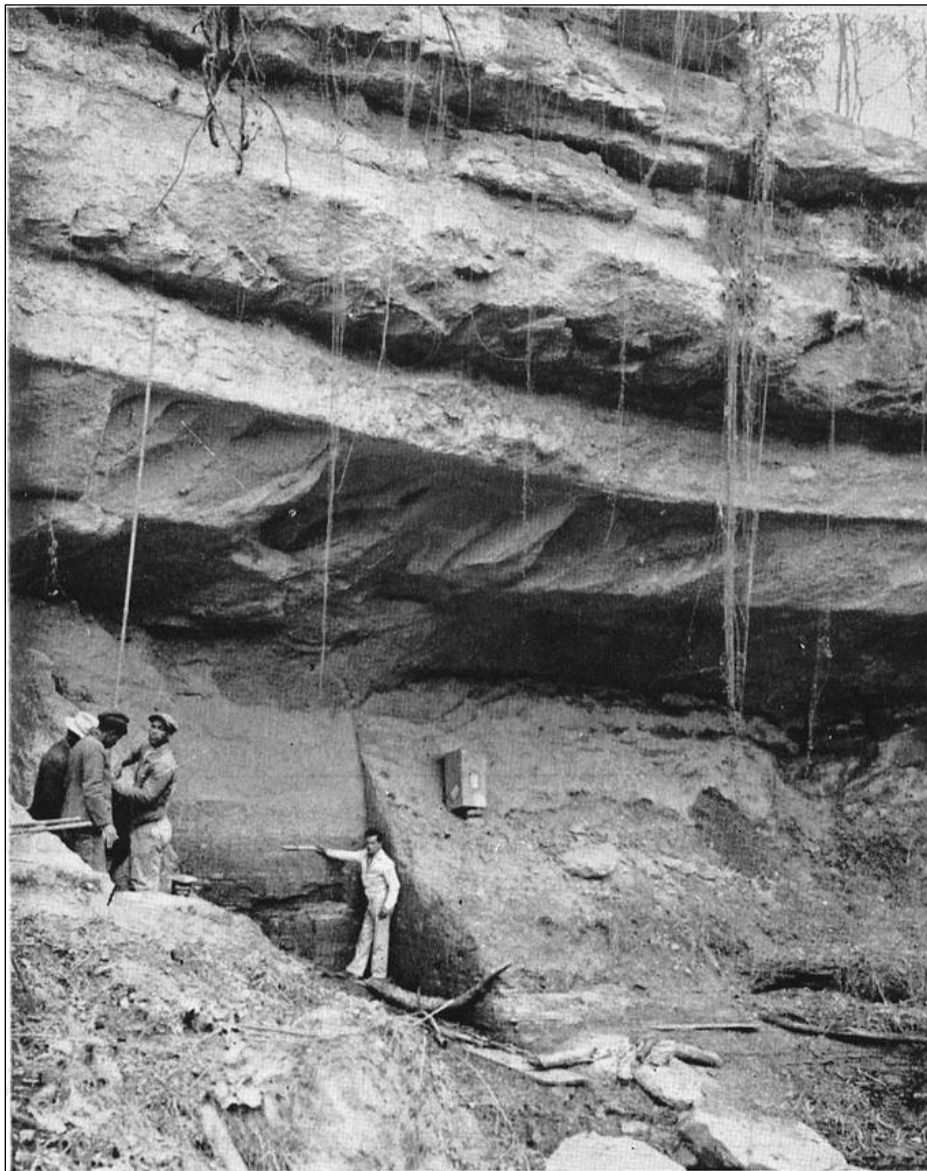




# National Park Service Geologic Type Section Inventory

## *Gulf Coast Inventory & Monitoring Network*

Natural Resource Report NPS/GULN/NRR—2022/2454



**ON THE COVER**

Type locality exposures of the Oligocene Mint Spring Formation at the waterfall along Mint Spring Bayou adjacent to Vicksburg National Cemetery in Vicksburg National Military Park. The entire waterfall exposure is approximately 10 m (33 ft) thick and consists of (in ascending order) the Mint Spring Formation, Mariana Limestone, and Glendon Limestone of the Vicksburg Group. Figure 5 from Mellen (1941), Mississippi State Geological Survey Bulletin 43.

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September 2022

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

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## Executive Summary

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

The goal of this project is to consolidate information pertaining to stratotypes that occur within NPS-administered areas, in order that this information is available throughout the NPS to inform park managers and to promote the preservation and protection of these important geologic heritage resources.

This effort identified four stratotypes designated within two park units of the Gulf Coast Inventory & Monitoring Network (GULN): Big Thicket National Preserve (BITH) contains one type locality, and Vicksburg National Military Park (VICK) contains one type section, one type locality, and one type area. Table 1 provides information regarding the four stratotypes currently identified within the GULN.

There are currently no designated stratotypes within Gulf Islands National Seashore (GUIS), Jean Lafitte National Historical Park and Preserve (JELA), Natchez Trace Parkway (NATR), Padre Island National Seashore (PAIS), Palo Alto Battlefield National Historical Park (PAAL), and San Antonio Missions National Historical Park (SAAN).

The inventory of geologic stratotypes across the NPS is an important effort in documenting these locations so that NPS staff may recognize and protect these areas for future studies. The focus adopted for completing the baseline inventories throughout the NPS has centered on the 32 inventory and monitoring (I&M) networks established during the late 1990s. Adopting a network-based approach to inventories worked well when the NPS undertook paleontological resource inventories for the 32 I&M networks and was therefore adopted for the stratotype inventory. The Greater Yellowstone I&M Network (GRYN) was the pilot network for initiating this project (Henderson et al. 2020). Methodologies and reporting strategies adopted for the GRYN have been used in the development of this report for the GULN.

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

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

<b>Park</b>	<b>Unit Name (GRI map symbol)</b>	<b>Reference</b>	<b>Stratotype Location</b>	<b>Age</b>
BITH	Beaumont Alloformation, Prairie Allogroup (Qb, Qbs, Qbc)	Davis et al. 1970	Type locality: exposures and shallow well sections in the vicinity of Beaumont, Jefferson County, Texas.	Pleistocene
VICK	Vicksburg Group (Tv)	Huddlestun 1993	Type area: at Vicksburg, Mississippi, where the Forest Hill Formation, Mint Spring Formation, Glendon Limestone, and Byram Formation are exposed in, and about the city and in the bluffs overlooking the Mississippi River, Warren County, Mississippi.	Oligocene
VICK	Mint Spring Formation, Vicksburg Group (Tv)	Cooke 1923; Baughman 1971	Type section/type locality: beneath a waterfall in the lower course of Mint Spring Bayou just south of Vicksburg National Cemetery, in section 12, T. 16 N., R. 3 E., Warren County, Mississippi.	Oligocene

## Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic type sections for the national parks of the Gulf Coast Inventory & Monitoring Network. We first want to extend our sincere appreciation to Randy Orndorff, David Soller, and Nancy Stamm (U.S. Geological Survey) for their assistance with this geologic type section inventory and other important NPS projects. Randy, Dave, and Nancy manage the National Geologic Map Database and GEOLEX (the U.S. Geologic Names Lexicon, a national compilation of names and descriptions of geologic units), respectively, for the United States, critical sources of geologic map information for science, industry and the American public. We also extend our appreciation to David Dockery III and James Starnes (Mississippi Department of Environmental Quality) for their assistance with this inventory and their many contributions to National Park Service geology.

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

Thanks to our NPS colleagues in the Gulf Coast Inventory & Monitoring Network and various network parks, including Martha Segura (GULN) and Charles Beightol (VICK). Martha served as peer review coordinator for this report. Additional thanks to Linda York (Regional Coastal Geomorphologist) for continued support for this and other important geology projects in Interior Region 2 (South Atlantic Gulf and Southeast Region of the NPS). Linda York and James Starnes contributed peer reviews to this report.

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



## Dedication

We are pleased to dedicate the Gulf Coast Inventory & Monitoring Network Geologic Type Section Inventory to paleontologist Christy Visaggi. Christy is on the faculty of the Department of Geosciences at Georgia State University in Atlanta, Georgia. Christy began working with the National Park Service in 2005 in a Geoscientist-in-the-Parks position sponsored by the Association of Woman Geoscientists supporting projects involving the Chihuahuan Desert Network, Gulf Coast Network, Mid-Atlantic Network and Amistad National Recreation Area. More recently, Christy has supported a partnership between the NPS Paleontology Program and the Paleontological Society (PS) establishing the Parks Fellowship Program, promoting student opportunities supporting paleontology projects in the NPS. We extend our appreciation to our colleague and friend who has made and continues to make many contributions to understanding the fossil record of the NPS.



Christy Visaggi participating in a field paleontological resource inventory at Gulf Islands National Seashore in Mississippi (NPS).



# Introduction

Geologic maps show the distribution and classification of rocks, sedimentary deposits, and geologic features for a given area. The geologic classification of rocks and deposits is hierarchical with several different categories of geologic or stratigraphic units including, from regional scale to local exposure scale: supergroup, group, formation, member, and bed. The mapping of stratigraphic units involves the evaluation of lithologies, bedding properties, thickness, geographic distribution, and other factors. Mappable geologic units may be described and named through a rigorously defined process that is standardized and codified by the professional geologic community (North American Commission on Stratigraphic Nomenclature 2021). In most instances, when a new geologic unit (such as a formation) is described and named in the scientific literature, a specific and well-exposed section or exposure area of the unit is designated as the stratotype (see “Definitions” below). The type section is an important reference exposure for a named geologic unit, presenting a relatively complete and representative example of this unit. Geologic stratotypes are important geoheritage resources with historic and scientific significance, and should be available for other researchers to evaluate in the future.

The importance of stratotypes lies in the fact that they represent important comparative sites where past investigations can be built upon or re-examined and can serve as teaching sites for the next generation of geoscientists (Brocx et al. 2019). The geoheritage significance of stratotypes is analogous to libraries and museums in that they are natural repositories of Earth history and record the physical and biologic evolution of our planet. In addition, geologic formations are named after topographic or geologic features and landmarks that are recognizable to park staff and visitors. Therefore, geologic stratotypes are part of our national geologic heritage and are a cornerstone of the scientific value used to define the societal significance of geoheritage sites (refer to <https://www.nps.gov/articles/scientific-value.htm> for more about geologic heritage).

The goals of this project are to (1) systematically report the assigned stratotypes that occur within national parks of the Gulf Coast Inventory & Monitoring (I&M) Network (GULN), (2) provide detailed descriptions of the stratotype exposures and their locations, and (3) reference the stratotype assignments from published literature. It is important to note that this project cannot verify a stratotype for a geologic unit if one has not been formally assigned and/or published. This effort identified four stratotypes within two GULN parks: Big Thicket National Preserve (BITH) contains one type locality, and Vicksburg National Military Park (VICK) contains one type section, one type locality, and one type area. Table 1 provides information regarding the four stratotypes currently identified within GULN parks. Additionally, numerous stratotypes are located geographically outside of national park boundaries; those within 48 km (30 mi) of park boundaries are mentioned in this report.

The GULN Geologic Type Section Inventory report is part of a larger effort to document stratotypes in all 32 I&M networks and selected non-I&M parks with significant rock exposures. This report follows the standard practices, methodologies, and organization of information introduced in the Greater Yellowstone I&M Network type section inventory (Henderson et al. 2020), which was the

pilot for this effort; refer to the Methods section below for detailed information. As discussed in the Methods section, the NPS Geologic Type Section Inventory Project utilizes NPS Geologic Resources Inventory (GRI) data and information, which is considered the “official” baseline geologic map and report for each park in the Inventory and Monitoring (I&M) program.

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

Given the importance of geologic stratotypes as geologic references and geologic heritage resources, these GULN locations should be afforded some level of documentation, preservation, or protection as appropriate. This inventory can inform important conversations on whether geologic stratotypes rise to the level of national register documentation. The NPS should consider if any other legal authorities (e.g., National Historic Preservation Act), policy, or other safeguards currently in place can help protect geologic stratotypes that are established on NPS administered lands.

Through this inventory, the associated report, and close communication with park, region, and I&M Network staff, we hope there will be an increased awareness about these important geologic landmarks in parks. In turn, the awareness of these resources and their significance may be recognized in park planning and operations, to ensure that geologic stratotypes are preserved and available for future study.

## Definitions

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

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



2. **Type locality:** the specific geographic locality encompassing the unit stratotype of a formally recognized and defined unit. On a broader scale, a type area is the geographic territory encompassing the type locality. Before development of the stratotype concept, only type localities and type areas were designated for many geologic units that are now long- and well-established (North American Commission on Stratigraphic Nomenclature 2021).
3. **Reference sections:** for well-established geologic units for which a type section was never assigned, a reference section may serve as an invaluable standard for definitions or revisions. A principal reference section may also be designated for units whose stratotypes have been destroyed, covered, or are otherwise inaccessible (North American Commission on Stratigraphic Nomenclature 2021). Multiple reference sections can be designated for a single unit to help illustrate heterogeneity or some critical feature not found in the stratotype. Reference sections can help supplement unit stratotypes in the case where the stratotype proves inadequate (North American Commission on Stratigraphic Nomenclature 2021).
4. **Lithodeme:** the term “lithodeme” is defined as a mappable unit of plutonic (igneous rock that solidified at great depth) or highly metamorphosed and pervasively deformed rock that is equivalent in rank to “formation” among stratified rocks (North American Commission on Stratigraphic Nomenclature 2021). The formal name of a lithodeme consists of a geographic name followed by a descriptive term that denotes the average modal composition of the rock (example: Cathedral Peak Granodiorite). Lithodemes are commonly assigned type localities, type areas, and reference localities.



# Methods

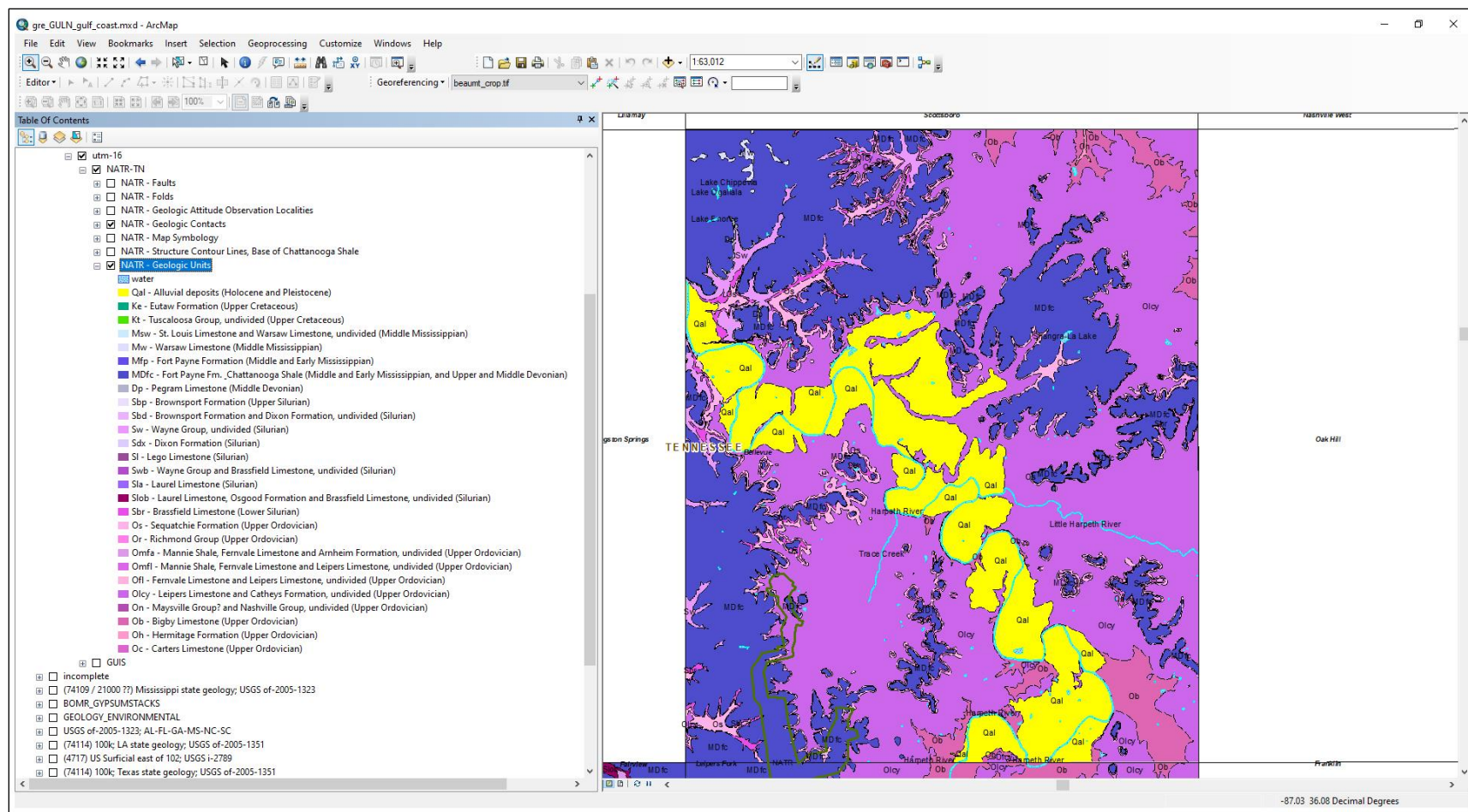
## Methodology

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

Each map unit name is queried in the USGS Geologic Names Lexicon online database (“GEOLEX”, a national compilation of names and descriptions of geologic units) at <https://ngmdb.usgs.gov/Geolex/search>. Information provided by GEOLEX includes the geologic unit name, stratigraphic nomenclature usage, geologic age, published stratotype location descriptions, and the database provides a link to significant publications as well as the USGS Geologic Names Committee Archives (Wilmarth 1938; Keroher et al. 1966). Figure 2 is taken from a search on the Mint Spring Formation, which is mapped within VICK.

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

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



**Figure 1.** Screenshot of the GRI-compiled digital geologic map of the northern portion of the Natchez Trace Parkway showing mapped units. The NPS boundary layer has been added (green lines). Access the GIS version of the NPS boundary online:

<https://irma.nps.gov/DataStore/Reference/Profile/2224545?Inv=True>. Data modified from NATR GRI digital geologic map data at

<https://irma.nps.gov/DataStore/Reference/Profile/2293442>.

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# National Geologic Map Database

## Geolex — Unit Summary

### Geologic Unit: Mint Spring

**Usage:**

Mint Spring Formation of Vicksburg Group (AL\*,MS\*)  
Mint Spring Marl of Vicksburg Group (MS)  
Mint Spring Marl Member of Marianna Limestone (AL,MS)

**Geologic age:**

Tertiary\*  
Oligocene, early\*

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

Outcrop below water all on Mint Spring Bayou, at National Cemetery, Vicksburg, MS (Cooke, 1918).

**AAPG geologic province:**

Mid-Gulf Coast basin\*

**Significant Publications**

- [Correlation charts](#)
- [GNC Archives](#)
- [N.A. Stratigraphic Code](#)
- [More Resources](#)

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

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**Figure 2.** GEOLEX search result for Mint Spring Formation unit of the Vicksburg Group.

AutoSaveOffGULN Type Section Inventory

Search (Alt+Q)

Timothy Henderson

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UndoClipboardFontAlignmentNumberStylesCellsEditingAnalysis

CommentsShare

A30

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
	Formation	Type Section Not Designated?	Type Section in NPS Boundary?	QC on GoogleEarth	Non-NPS type section locality	Publication	Desc. Geospatial Info	Coordinate Geospatial Info	Geologic Age_Era	Geologic Age_Period	Heirarchy	Geolex	Map Symbol	Notes	
2	Alluvium	X							Cenozoic	Holocene		NO	Qal		
3	Backswamp	X							Cenozoic	Holocene		NO	Qab		
4	Alluvial terrace	X							Cenozoic	Holocene		NO	Qalt		
5	Point bar	X							Cenozoic	Holocene		NO	Qapb		
6	Abandoned channel	X							Cenozoic	Holocene		NO	Qac		
7	Alluvial fans	X							Cenozoic	Holocene		NO	Qaf		
8	Colluvium	X							Cenozoic	Holocene		NO	Qc		
9	Loess	X							Cenozoic	Pleistocene		NO	Ql		
10	Pre-Loess terrace deposits	X							Cenozoic	Pleistocene		NO	Qpl		
11	Catahoula Formation		NO		Type locality: Catahoula Parish	Veatch 1905; Baughman 1971			Cenozoic	Oligocene-Miocene		YES	Tca	Named from	
12	Vicksburg Group		YES - VICK			Conrad 184 Type area: at Vicksburg, where the Forest Hill Form			Cenozoic	Oligocene		YES	Tv	Named from	
13	Mint Spring Formation		YES - VICK			Cooke 1918 Type locality: Mint Spring Bayou in Sec. 12, T. 16 N.			Cenozoic	Oligocene		Vicksburg	YES	N/A	Outcrop b
14	Glendon Limestone		NO		Type locality: exposures at Glei Hopkins 1917; Cooke 1923; MacNeil 1944; Baughman 1971				Cenozoic	Oligocene		Vicksburg	YES	N/A	
15	Byram Marl/Formation		NO		Type locality: on right bank of I Baughman 1971				Cenozoic	Oligocene		Vicksburg	YES	N/A	
16	Bucatanua Clay		NO		Type locality: along Bucatanua Baughman 1971				Cenozoic	Oligocene		Vicksburg	YES	N/A	
17	Bumpnose Limestone		NO		Type locality: quarry near centr Moore 1955				Cenozoic	Oligocene		Vicksburg	YES	N/A	
18	Red Bluff Clay		NO		Type locality: Red Bluff, on Chic Cooke 1923; Brown and Huff 1963; Tew 1992				Cenozoic	Oligocene		Vicksburg	YES	N/A	Exposures
19	Forest Hill Sand		NO		Type section: on Jackson-Raym Cooke 1923; Monroe 1954				Cenozoic	Oligocene		Vicksburg	YES	N/A	
20	Marianna Limestone		NO		Type section: west bank of the Cooke 1923; Huddlestun 1993				Cenozoic	Oligocene		Vicksburg	YES	N/A	Named from
21	Nash Creek Formation		NO		Type locality: cut bank on west Andersen 1960				Cenozoic	Oligocene		Vicksburg	YES	N/A	
22	Rosefield Formation		NO		Type locality: exposures at Ros Connell 1960; Andersen 1960				Cenozoic	Oligocene		Vicksburg	YES	N/A	
23	Sandel Formation		NO		Type section (from Delaney): st Delaney 1958 unpublished manuscript; Anderson 1960				Cenozoic	Oligocene		Vicksburg	YES	N/A	
24	Shellstone Creek Beds		NO		Reference sections (Huddlestun Huddlestun 1993				Cenozoic	Oligocene		Vicksburg	YES	N/A	
25															
26															

BITH | GUIS | JELA | NATR | PAAL | PAIS | SAAN | VICK

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**Figure 3.** Stratotype inventory spreadsheet of the GULN displaying attributes appropriate for geolocation assessment. Pink highlighted cells represent geologic units that supplement the GRI-compiled stratigraphy of VICK.

## **Geologic Resources Inventory (GRI) Data**

The Geologic Resources Inventory (GRI) provides digital geologic map data and pertinent geologic information on park-specific features, issues, and processes to support resource management and science-informed decision-making to the 270 parks in the I&M program. The GRI team provides three products to each park that can be useful in the determination of stratotypes: (1) a summary document from an initial scoping meeting, (2) digital geologic map data in a geographic information system (GIS) format, and (3) a GRI report.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Scoping meeting summaries serve as an interim report until the final report is delivered.

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

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

## **Additional Considerations**

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

Stratigraphic nomenclature may change over time with refined stratigraphic field assessments and discovery of information through the expansion of stratigraphic mapping and measured sections. One important observation regarding stratigraphic nomenclature relates to differences in use of geologic names for units that cross state boundaries. Geologic formations and other geologic units that cross state boundaries may have different names or ranks in each of the states the units are mapped. An example is the Paleocene Fort Union Formation (as used by the Montana Bureau of Mines and

Geology and the U.S. Geological Survey), which is equivalent to the Fort Union Group of the North Dakota Geological Survey.

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

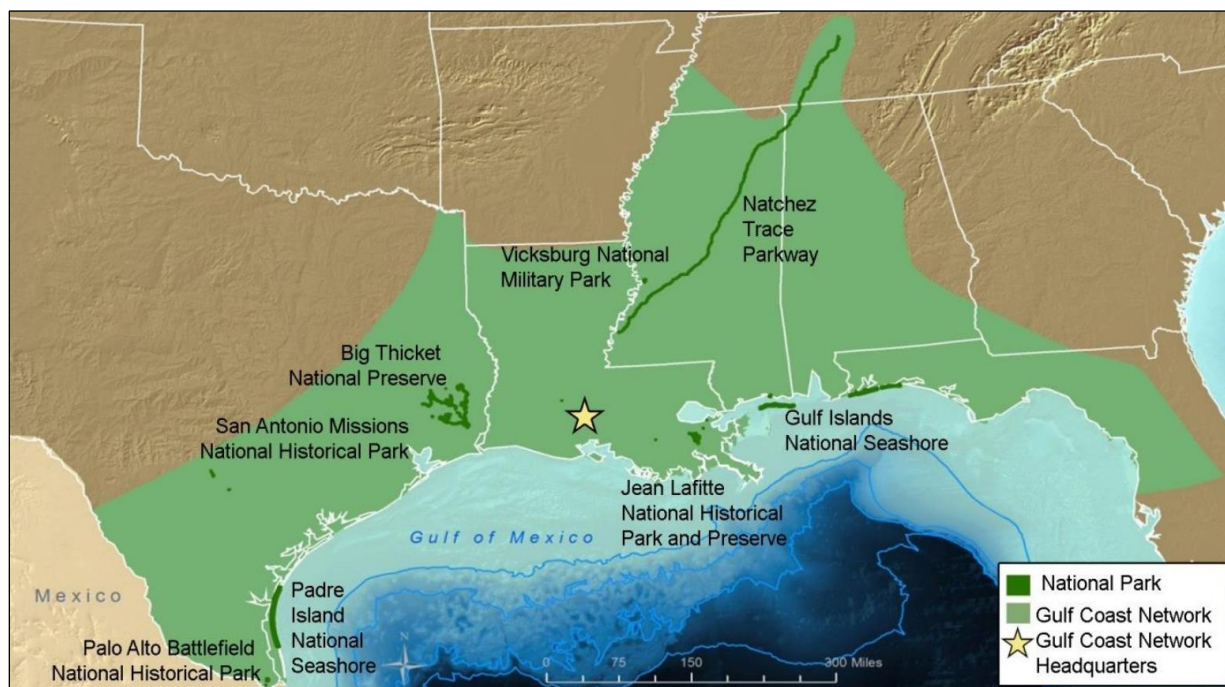
This inventory report is intended for a wide audience, including NPS staff who may not have a background in geology. Therefore, this document is developed as a reference document that supports science, resource management, and a historic framework for geologic information associated with GULN parks.

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



## Geology and Stratigraphy of the GULN I&M Network Parks

The Gulf Coast I&M Network consists of eight national park units in northwestern Alabama, western Florida, Louisiana, Mississippi, western Tennessee, and southeastern Texas (Figure 4). Park units of the GULN include Big Thicket National Preserve (BITH), Gulf Islands National Seashore (GUIS), Jean Lafitte National Historical Park and Preserve (JELA), Natchez Trace Parkway (NATR), Padre Island National Seashore (PAIS), Palo Alto Battlefield National Historical Park (PAAL), San Antonio Missions National Historical Park (SAAN), and Vicksburg National Military Park (VICK). Collectively, the GULN parks occupy more than approximately 184,000 hectares (455,000 acres) and vary in size from 383 hectares (948 acres) in SAAN to 56,322 hectares (139,175 acres) in GUIS. As the name implies, GULN includes park units of the Gulf Coastal Plain that protect fragile barrier island habitats, internationally recognized biological preserves, Spanish Colonial Era mission complexes, battlefield sites of the U.S.-Mexican War and American Civil War, historic cultural sites of the Mississippi Delta, and the scenic Natchez Trace Parkway.



**Figure 4.** Map of Gulf Coast I&M Network parks, including: Big Thicket National Preserve (BITH), Gulf Islands National Seashore (GUIS), Jean Lafitte National Historical Park and Preserve (JELA), the Natchez Trace Parkway (NATR), Padre Island National Seashore (PAIS), Palo Alto Battlefield National Historical Park (PAAL), San Antonio Missions National Historical Park (SAAN), and Vicksburg National Military Park (VICK) (NPS/GULN).

The GULN parks occupy a great coastal plain bordering the Gulf of Mexico to the north that stretches from the lower Rio Grande valley of Texas east to the Florida Panhandle. The Gulf Coast region of the United States is characterized by a broad, gently dipping sedimentary wedge containing an immense accumulation of hydrocarbon-rich Mesozoic and Cenozoic strata about 15 km (9 mi)

thick (Durham and Murray 1967; Buursink et al. 2018; Leathers-Miller 2020; Pitman et al. 2020). The oldest bedrock underlying the park units of GULN are mapped along NATR and date to the Paleozoic Era, approximately 485 million years ago. These ancient rocks record the rich geologic evolution of ancestral North America (Laurentia) over hundreds of millions of years and record dynamic plate tectonic processes involving continental-scale collisional events, regional uplifts, folding, faulting, and rifting. Significant geologic events that took place during this time include the formation of the Appalachian–Ouachita mountain belt, rifting of the supercontinent Pangaea, and subsequent erosion and modification by surface processes to form the modern landscape. See Appendix B for a geologic time scale.

The Appalachian Mountains and Ouachita Mountains are the result of several major mountain-building collisional events (orogenies) that include the Taconic, Acadian, Alleghenian, and Ouachita orogenies. The first major orogenic episode, known as the Taconic Orogeny, occurred during the Ordovician Period approximately 470–450 Ma (Mega-annum, million years ago) and involved the accretion of island arc material to the east coast of Laurentia (Gonzalez et al. 2018; Hildebrand and Whalen 2021). During the Devonian Period (410–360 Ma), the Acadian Orogeny resulted in the collision of a large foreign landmass (Avalon terrane) with Laurentia (Gibson et al. 2021). The Alleghenian Orogeny and genetically related Ouachita Orogeny occurred throughout the Pennsylvanian and Permian Periods (325–260 Ma) and involved the collision between Gondwana (a large continent that includes two-thirds of today’s continental area) and Laurentia that culminated with the formation of the supercontinent Pangea (Harry and Londono 2004; Hou et al. 2021; Hillenbrand and Williams 2021).

Following the assembly of Pangea, immense amounts of heat from the mantle accumulated beneath the supercontinent to create regional-scale extensional forces that rifted the supercontinent apart in the Triassic Period (Nance et al. 1988; Harry and Londono 2004). The breakup of Pangea established the modern-day passive margin sequence of North America and opened the Atlantic Ocean and Gulf of Mexico. As the uplifted regions of the Appalachian Mountains and Ouachita Mountains were exposed to erosion, immense amounts of sediment were transported into the coastal and interior lowlands. The detritus shed from these highlands began to accumulate in the Triassic-age rift basins along the Gulf Coast, marking the beginnings of the thick hydrocarbon-rich sedimentary wedge sequence that exists today. The modern landscape of GULN is still largely influenced by fluvial depositional systems (especially the Mississippi River, Rio Grande, and associated tributaries) that continue to transport vast amounts of sediment into the Gulf of Mexico where they are reworked by coastal processes including wind, waves, tides, storms, and sea-level change.

### **Precambrian (4.6 billion to 539 million years ago)**

The GULN parks do not include any exposed Precambrian rocks mapped within park boundaries.

### **Paleozoic (539 to 252 million years ago)**

Paleozoic strata only occur in the northern area of the NATR in Tennessee and Alabama and include a diverse suite of fossiliferous sedimentary strata spanning the Ordovician through the Mississippian. Many of these rocks are associated with hierarchical lithologic groups such as the Ordovician Nashville Group (Catheys Formation, Bigby Limestone, Hermitage Formation), Silurian Wayne

Group, and Mississippian Chester Group. Other Paleozoic bedrock units that underlie the parkway include the Ordovician Fernvale Limestone, Leipers Limestone, and Sequatchie Formation; Silurian Brassfield Formation; Devonian–Mississippian Chattanooga Shale; and Mississippi Warsaw Limestone, St. Louis Limestone, Fort Payne Formation, Pride Mountain Formation, and Tuscumbia Limestone.

### **Mesozoic (252 to 66 million years ago)**

Mesozoic strata are only mapped along NATR and include geologic units associated with the Cretaceous Tuscaloosa Group (Gordo Formation) and Selma Group (Coffee Sand, Demopolis Chalk, Ripley Formation, Owl Creek Formation, Eutaw Formation, Prairie Bluff Chalk).

### **Cenozoic (66 million years ago to the present)**

Cenozoic strata occur in every park unit of the GULN and represent a nearly continuous sequence of sedimentary deposition spanning the Paleocene Epoch to the present. The oldest and most diverse Cenozoic deposits underlie the NATR and include formations of the Paleocene Midway Group (Clayton, Porters Creek, and Naheola Formations); Eocene Wilcox Group, Claiborne Group (Meridian Sand, Tallahatta Formation [Basic City and Neshoba Sand Members], Winona Formation, Zilpha Formation, Kosciusko Formation, Cook Mountain Formation, Cockfield Formation), Jackson Group (Moody Branch and Yazoo Clay Formations); Oligocene Vicksburg Group (Forest Hill Formation, Mint Spring Formation, Mariana Limestone, Glendon Limestone, Bucatunna Formation); and Oligocene–Miocene Grand Gulf Group (Oligocene Catahoula Formation and Miocene Hattiesburg and Pascagoula Formations). Rocks associated with the Eocene Wilcox Group and Claiborne Group also occur in SAAN, and the Oligocene Vicksburg Group is named after exposures within and near VICK. Other Miocene-age rocks include the Fleming Formation in BITH.

Several formally named Pleistocene sedimentary units of dominantly fluvial-deltaic origin underlie BITH and consist of gravel, sandstone, siltstone, and mudstone of the Willis Formation, Lissie Formation, Beaumont Alloformation, and Deweyville Formation (Chowdhury and Turco 2006; an alloformation is a mappable body of rock that is geographically separated by discontinuity-bounded geologic units of similar lithology). Fluvial deposits of the Beaumont Alloformation also occur in JELA, as well as the Avoyelles Alloformation. Calcareous silt, sand, and gravel of the Pleistocene Leona Formation are mapped in SAAN. Unnamed Pleistocene units include fluvial terrace deposits mapped along Village Creek in BITH and widespread ancestral Mississippi River pre-loess and loess deposits forming the steep river bluffs overlooking the Mississippi River at VICK and along NATR from Natchez north to Jackson. Quaternary deposits encompass all stream alluvium and are also associated with abandoned river channels of the ancestral Rio Grande that underlie portions of PAAL. A diverse variety of Holocene-age surficial deposits occur throughout the park units of the GULN and include barrier island and lagoon geomorphological units (GUIS, PAIS), fluvial and fluvial-deltaic deposits (JELA, PAAL, SAAN, VICK), and alluvium (BITH, SAAN, VICK).



# **Big Thicket National Preserve (BITH)**

## **Park Establishment**

Big Thicket National Preserve (BITH) consists of nine individual land units and six water corridors located just north of Beaumont, approximately 120 km (75 mi) from downtown Houston in Hardin, Jasper, Jefferson, Liberty, Orange, Polk, and Tyler Counties, Texas (Figure 5). Authorized on October 11, 1974, BITH encompasses about 44,147 hectares (109,092 acres) and protects remnants of “the Big Thicket”, a biologically diverse region of southeastern Texas situated at the crossroads of several major biomes that include Eastern hardwood forest, Gulf coastal plains, Midwest prairies, and southwest deserts (National Park Service 2014a, 2016a). The preserve landscape is dominated by a dynamic hydrologic system that is at least 40% wetlands and features floodplains, oxbow lakes, sloughs, bogs, and tributary streams. Riparian regions of BITH support numerous species of birds, amphibians, reptiles, and mammals while also preventing floods and improving water quality conditions. The Big Thicket once covered more than 1.2 million hectares (3 million acres), but widespread logging and oil production since the late 19<sup>th</sup> century has reduced the ecological system to approximately 10% of its original area (Thornberry-Ehrlich 2018). The segments of the Big Thicket that make up BITH represent the first national preserve designation in the National Park System. The rich biodiversity of the preserve is internationally recognized, and BITH has been designated a United Nations Educational, Scientific and Cultural Organization (UNESCO) Biosphere Reserve in 1981, as well as an American Bird Conservancy Globally Important Bird Area in 2001.

## **Geologic Summary**

BITH is situated in the Coastal Plain physiographic province of southeast Texas, a region underlain by a thick accumulation of hydrocarbon-rich strata dating back to the Triassic Period approximately 250 million years ago (Durham and Murray 1967; McBride et al. 1989; Harry and Londono 2004). The geology of BITH is comprised of much younger, Cenozoic sedimentary strata, with the oldest bedrock consisting of the Miocene (23 to 5.3 million years ago) Fleming Formation that occurs in the upper reaches of the Neches River and Big Sandy Creek within the preserve. Several Pleistocene formations of dominantly fluvial and deltaic origin underlie BITH and include gravel, sandstone, siltstone, and mudstone deposits of the Willis Formation, Lissie Formation, Beaumont Alloformation, and Deweyville Formation (Chowdhury and Turco 2006). The youngest rocks mapped within BITH are unconsolidated Holocene surficial deposits that occur in association with the floodplains and tributaries of the Neches River, Pine Island Bayou, and Village Creek (Figure 6).

## **Stratotypes**

BITH contains one identified stratotype that represents the type locality of the Pleistocene Beaumont Alloformation (Table 2; Figure 7). There are also three identified stratotypes located within 48 km (30 mi) of BITH boundaries that are provided in Appendix C for reference in case of future boundary expansion.

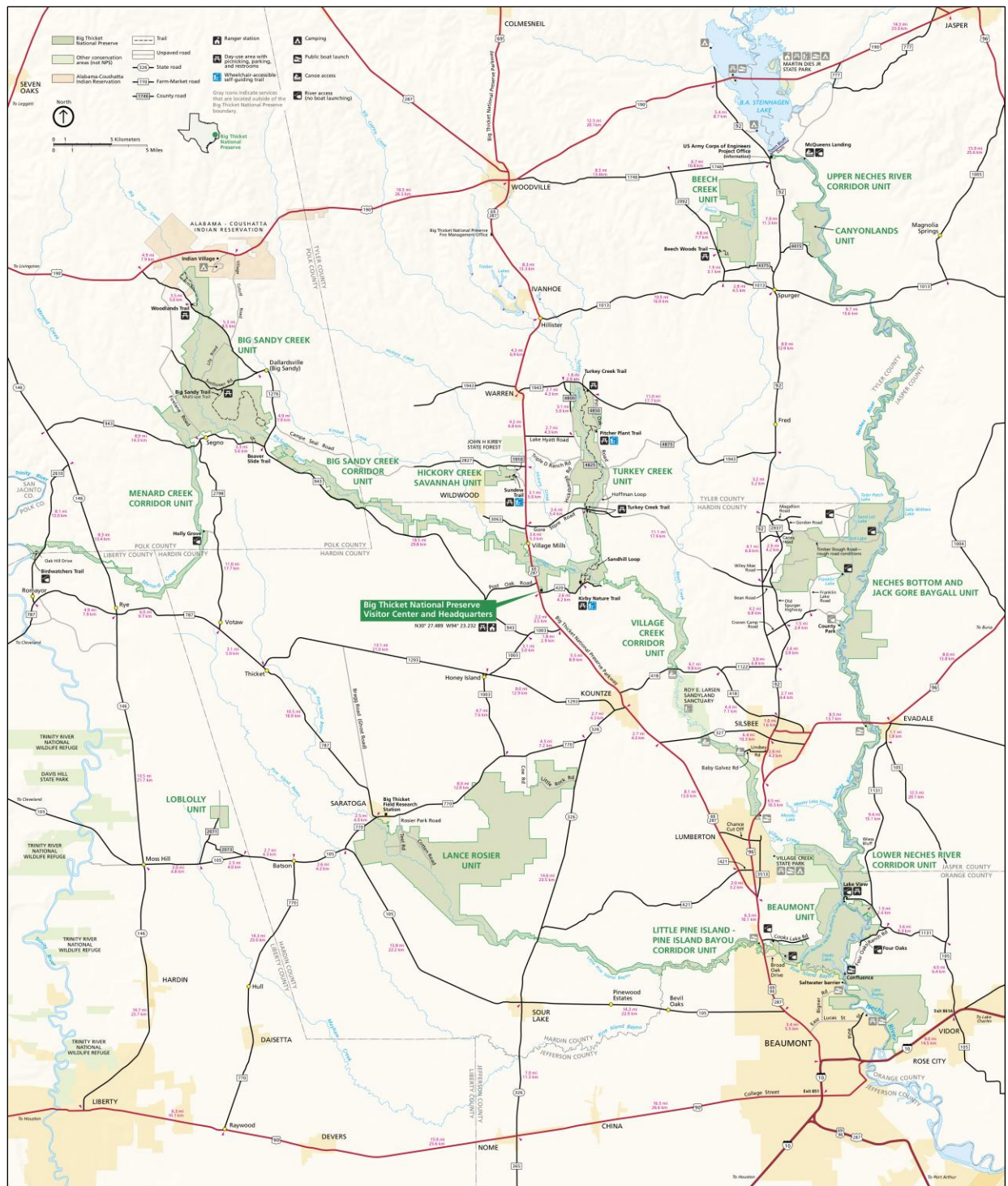
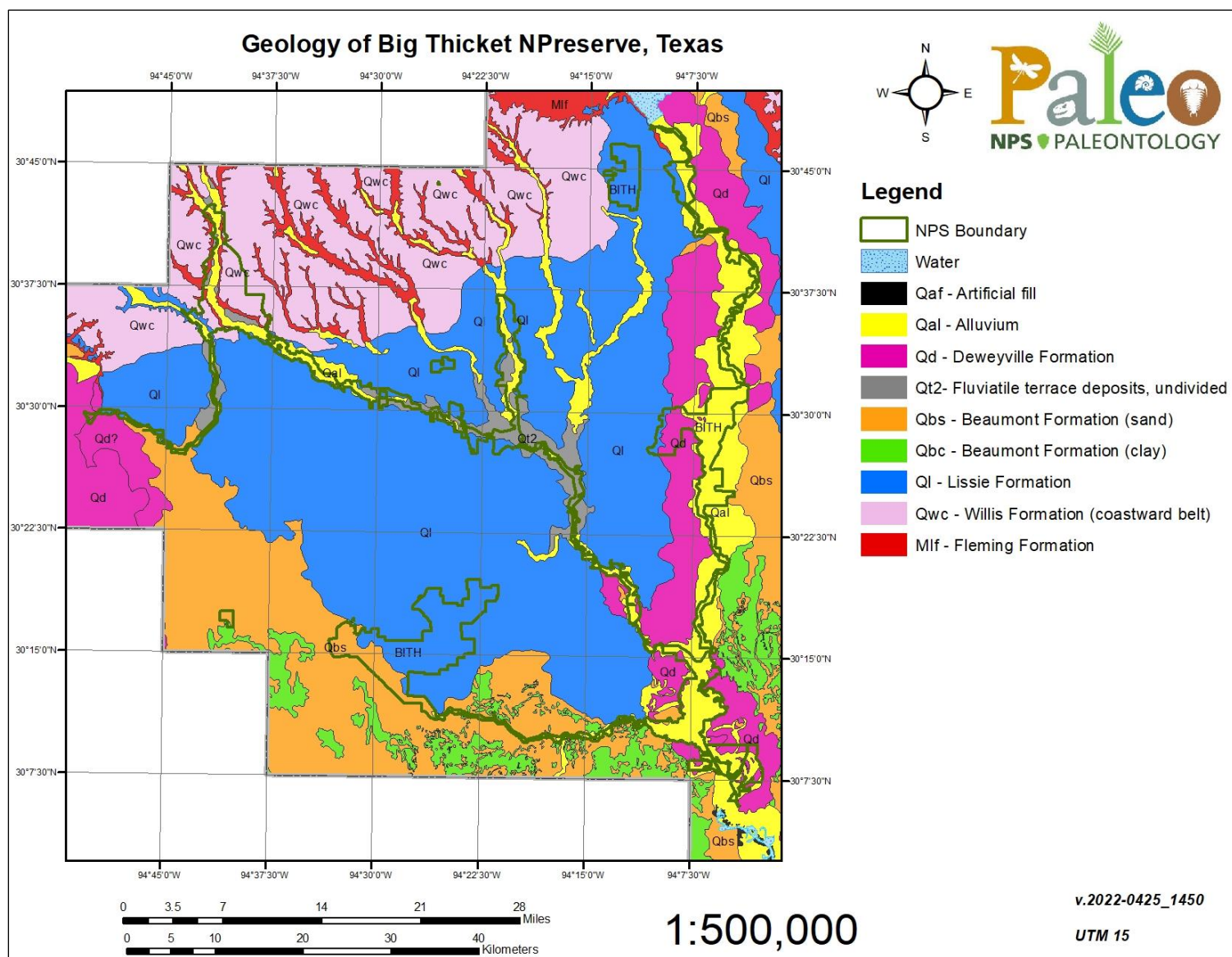
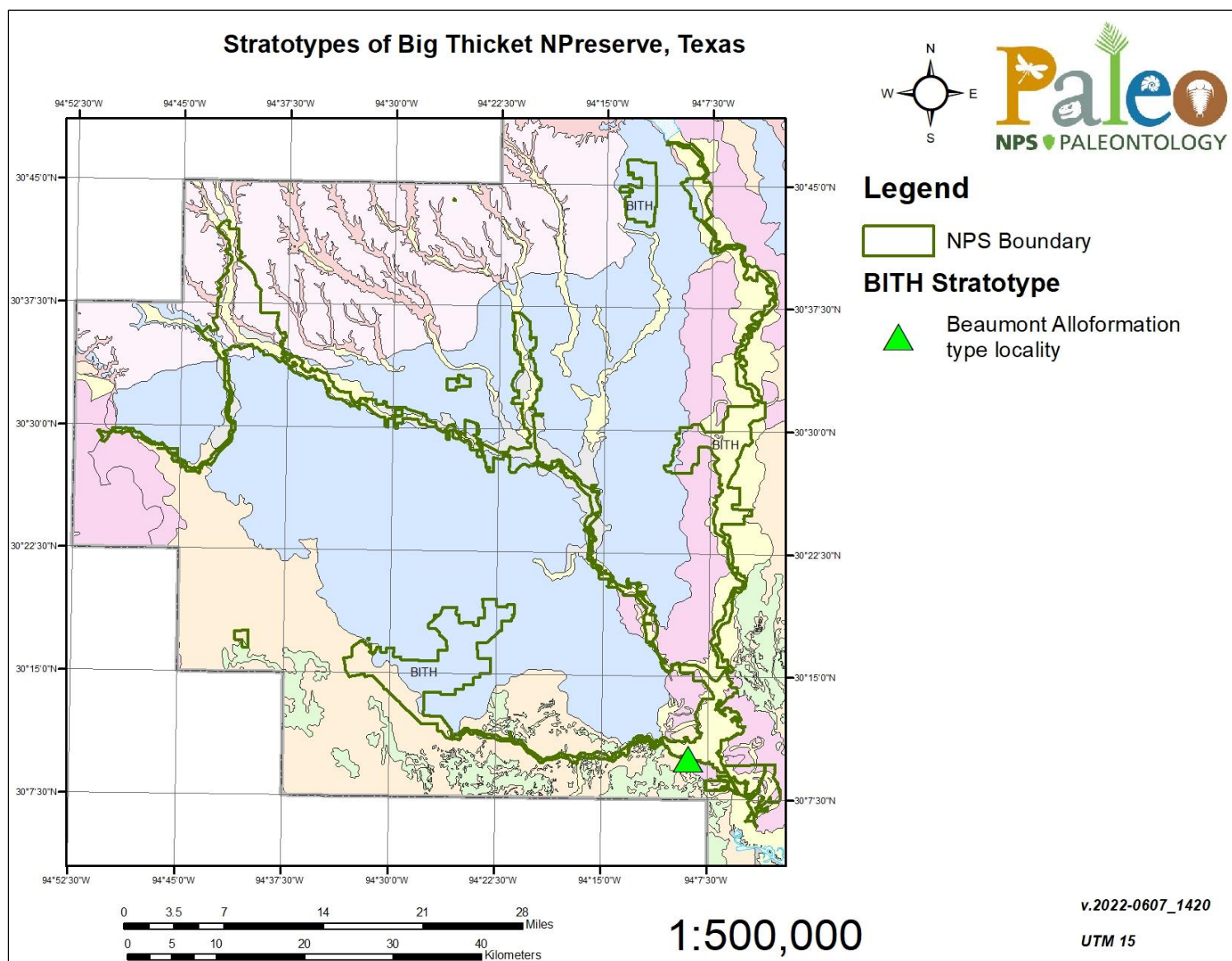


Figure 5. Park map of BITH, Texas (NPS).





**Figure 6.** Geologic map of BITH, Texas. Data modified from BITH GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1048128>.



**Figure 7.** Modified geologic map of BITH showing stratotype locations. The transparency of the geologic units layer has been increased.



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

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Beaumont Alloformation, Prairie Allogroup (Qb, Qbs, Qbc)	Davis et al. 1970	Type locality: exposures and shallow well sections in the vicinity of Beaumont, Jefferson County, Texas.	Pleistocene

### ***Beaumont Alloformation***

The Pleistocene Beaumont Alloformation was originally named the “Beaumont clays” by Hayes and Kennedy (1903) to describe a series of yellow, gray, blue, brown, and black clays with brown sand beds exposed near Beaumont in Jefferson County, Texas. The term “alloformation” refers to a mappable body of rock that is geographically separated by discontinuity-bounded geologic units of similar lithology (North American Commission on Stratigraphic Nomenclature 2021). The type locality of the Beaumont Alloformation is designated as exposures and shallow well sections in the vicinity of Beaumont, where the alloformation is approximately 30 m (100 ft) thick (Table 2; Figure 7; Davis et al. 1970 citing Hayes and Kennedy 1903; Shelby et al. 1992). Type locality exposures of the Beaumont Alloformation are subdivided into three distinct mappable units: (1) dominantly clayey sand and silt deposits interpreted as meander belt, levee, crevasse splay, and distributary sands; (2) dominantly clay and mud deposits characterized as interdistributary muds, abandoned channel-fill muds, and fluvial overbank muds; and (3) mostly fine-grained sand interpreted as barrier island and beach sediments characterized by pimple mounds and rounded depressions (Shelby et al. 1992). Basal exposures of the Beaumont Alloformation are mapped along Pine Island Bayou in southern BITH and predominantly consist of meander belt, levee, crevasse splay, and distributary sands of unit 1 described above. In the type locality the Beaumont Alloformation overlies the Pleistocene Lissie Formation and underlies the Pleistocene Deweyville Formation or younger Holocene alluvium deposits.



## **Gulf Islands National Seashore (GUIS)**

### **Park Establishment**

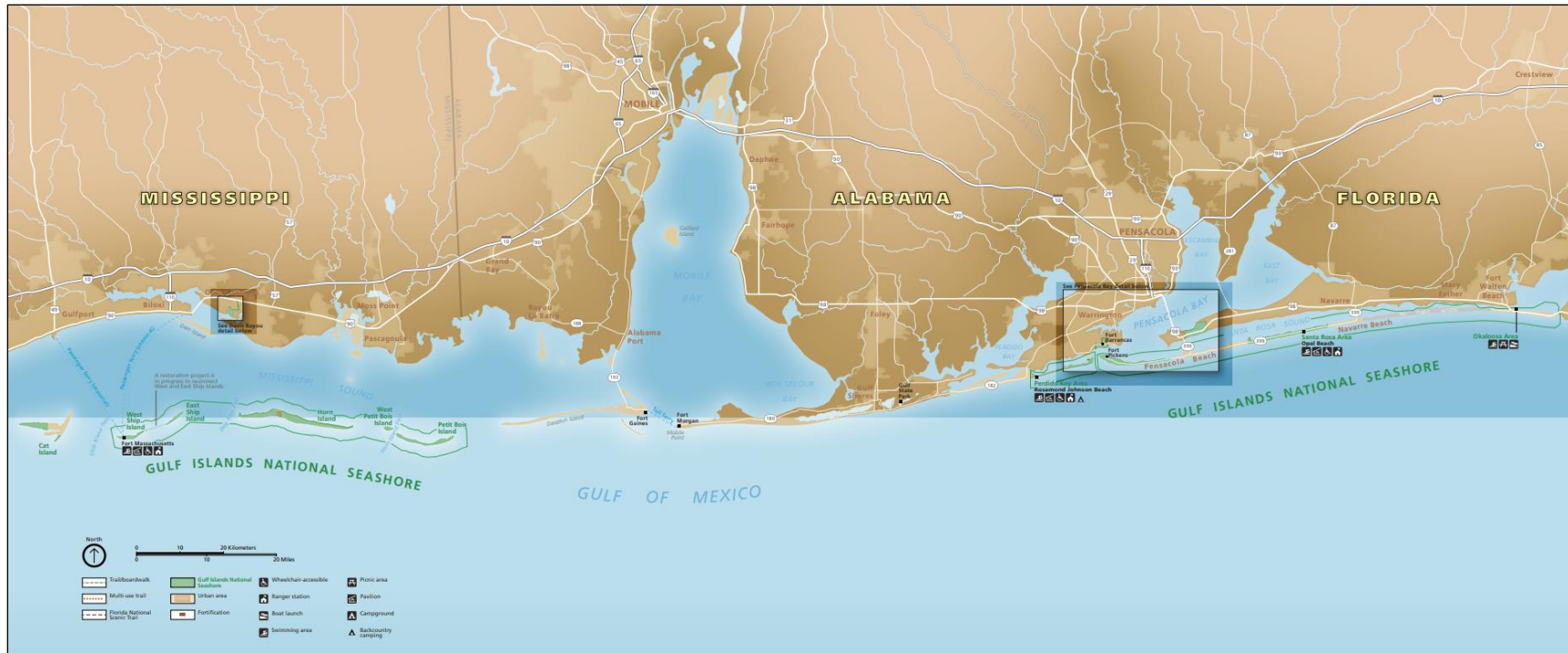
Gulf Islands National Seashore (GUIS) is a collection of barrier islands, surrounding waters, and coastal mainland sites that extend along approximately 255 km (160 mi) of the Gulf Coast of Mississippi (Harrison and Jackson Counties) and the Florida Panhandle (Escambia, Okaloosa, and Santa Rosa Counties) (Figure 8). Authorized on January 8, 1971, GUIS encompasses about 56,322 hectares (139,175 acres) and protects a combination of beach, barrier island, and marine ecosystems, in addition to numerous archaeological sites dating back to the late Archaic and Woodland cultural periods and historic coastal fortification structures dating back to the 18<sup>th</sup> century (National Park Service 2016a). The landscape of GUIS features sandy beaches, bayous, salt marshes, relict sand dunes, oak forests, pine flatwoods, maritime forests, and open marine habitats that host more than a dozen federally listed threatened or endangered species (Schupp 2019). Historic military structures of GUIS include coastal defense fortifications, gun batteries, and barracks spanning the Spanish Colonial Era, American Civil War, and World War II. Together, the historic coastal defense sites of GUIS represent one of the most complete collections of forts and structures illustrating the evolution of harbor defense technology in the United States (National Park Service 2016b).

### **Geologic Summary**

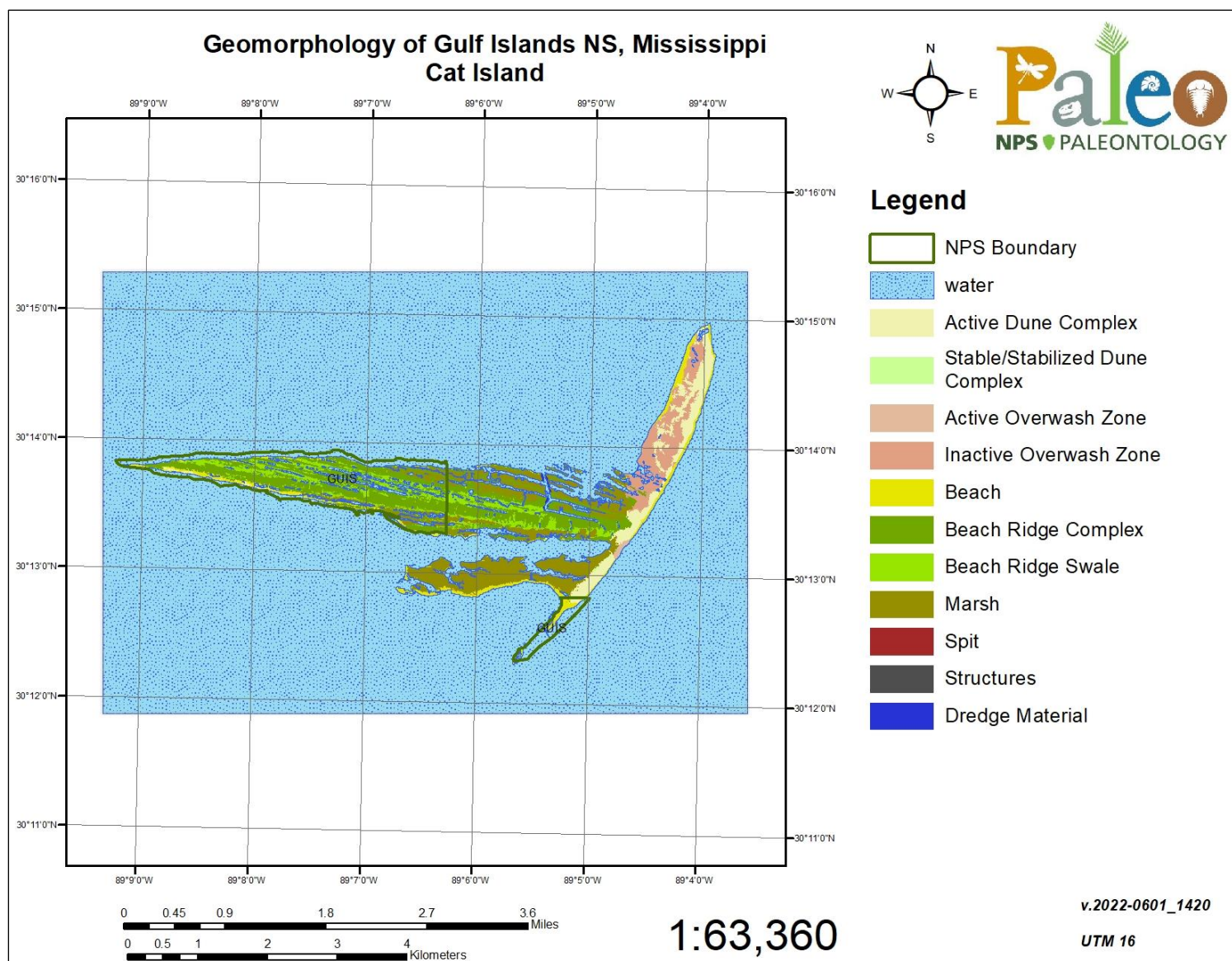
GUIS is located in the southernmost Coastal Plain physiographic province of Florida and Mississippi, a geologically young region comprised of unconsolidated Cenozoic sedimentary deposits. The overall geology of GUIS reflects a dynamic barrier island and coastal mainland environment that is constantly being reworked and sculpted by coastal processes that include wind, waves, tides, storms, sea level change, and anthropogenic processes such as inlet dredging and shoreline engineering (Schupp 2019). The barrier islands of GUIS were formed within the last 6,000 years and overlie buried fluvial and shallow marine strata dating back to the Miocene Epoch approximately 23 million years ago (Otvos 2005; Miselis et al. 2014). Various geomorphologic units mapped throughout the national seashore include Holocene-age dune complexes, beach ridges, sand spits, overwash zones, and beach, marsh, shoal, wetland, and vegetated barrier interior deposits (Figures 9–15).

### **Stratotypes**

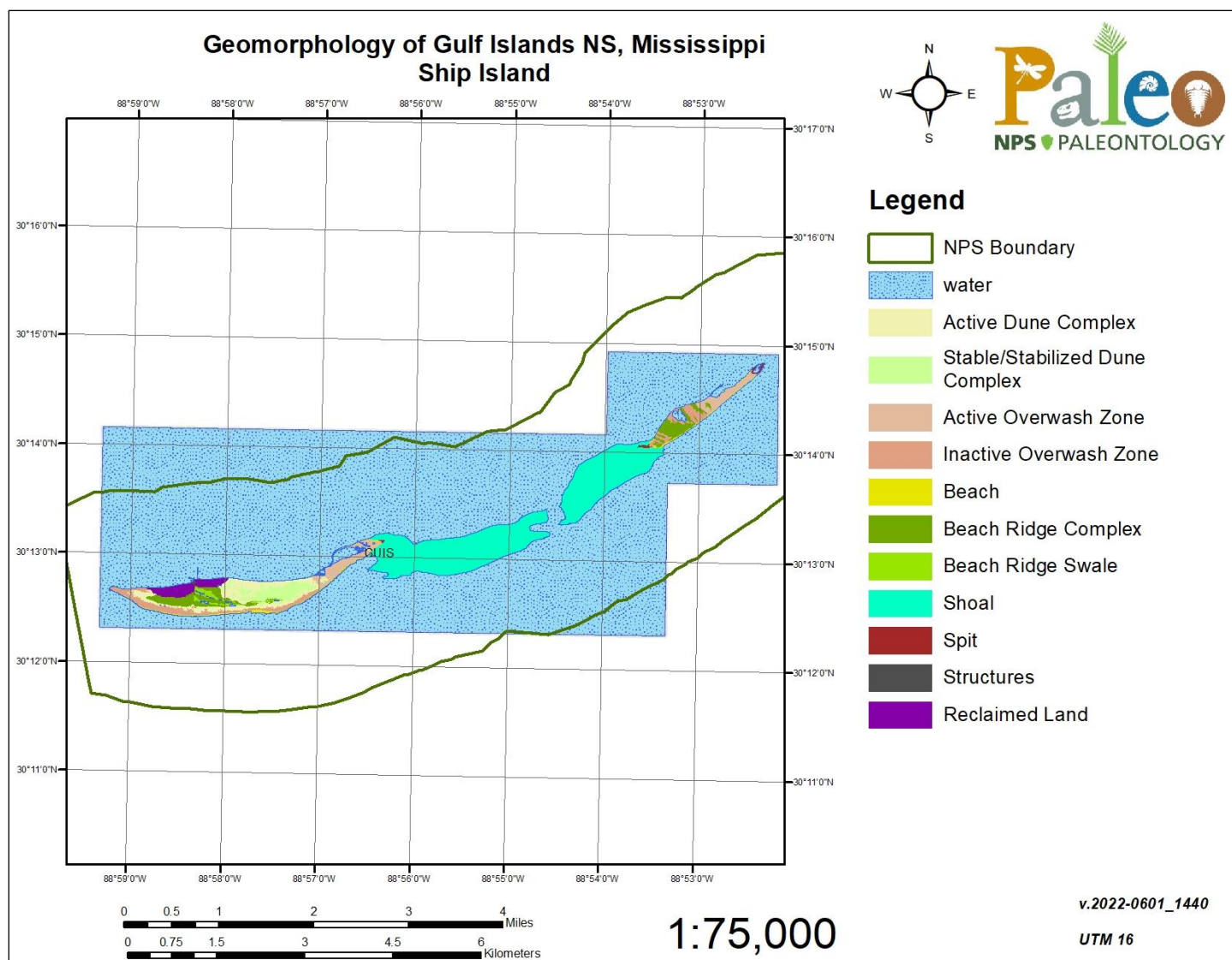
There are no designated stratotypes identified within the boundaries of GUIS.



**Figure 8.** Park map of GUIS, Florida–Mississippi (NPS).

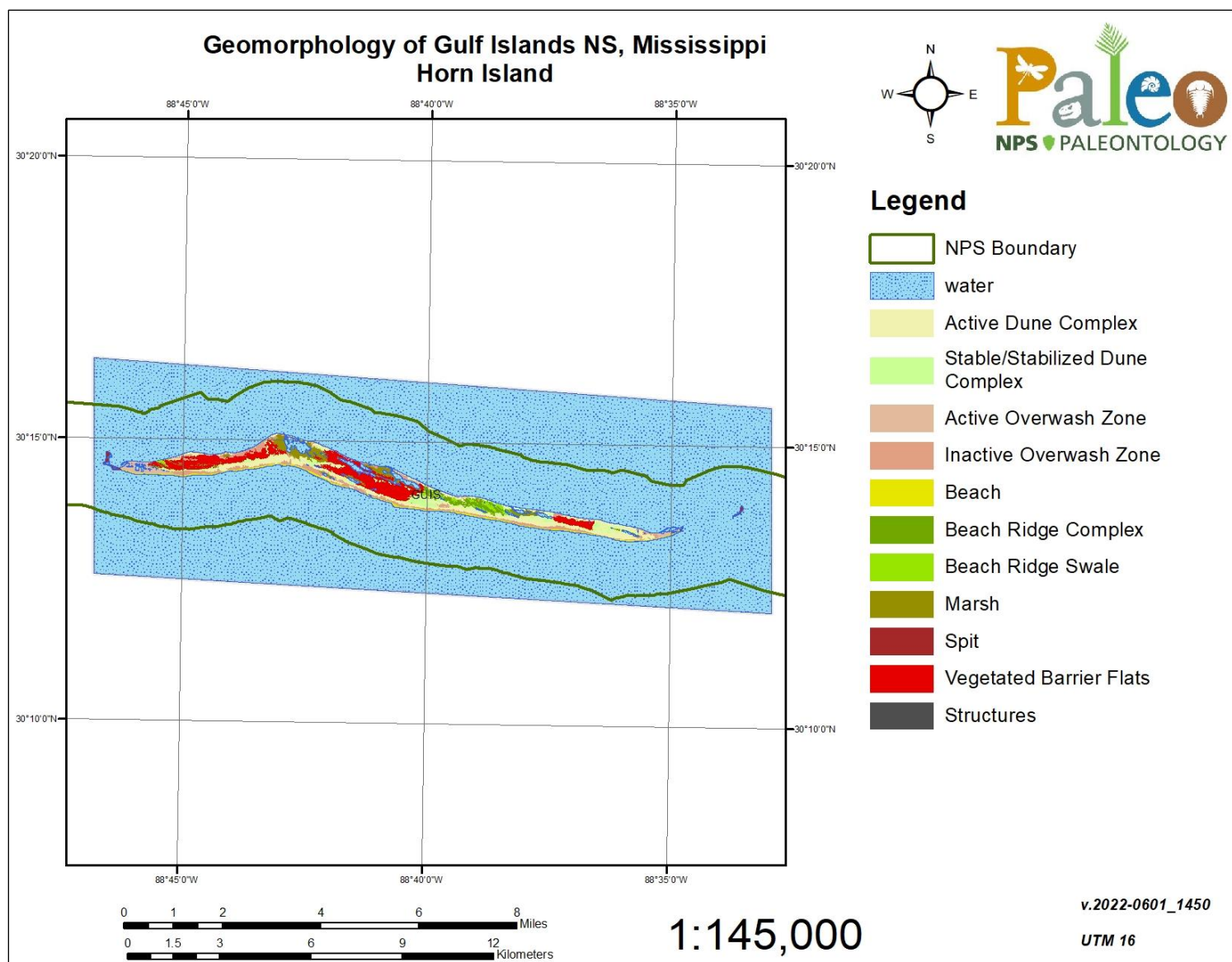


**Figure 9.** Geomorphological map of GUIS (Cat Island), Mississippi. Modified from GUIS GRI digital geomorphological map data at <https://irma.nps.gov/DataStore/Reference/Profile/2166535>.

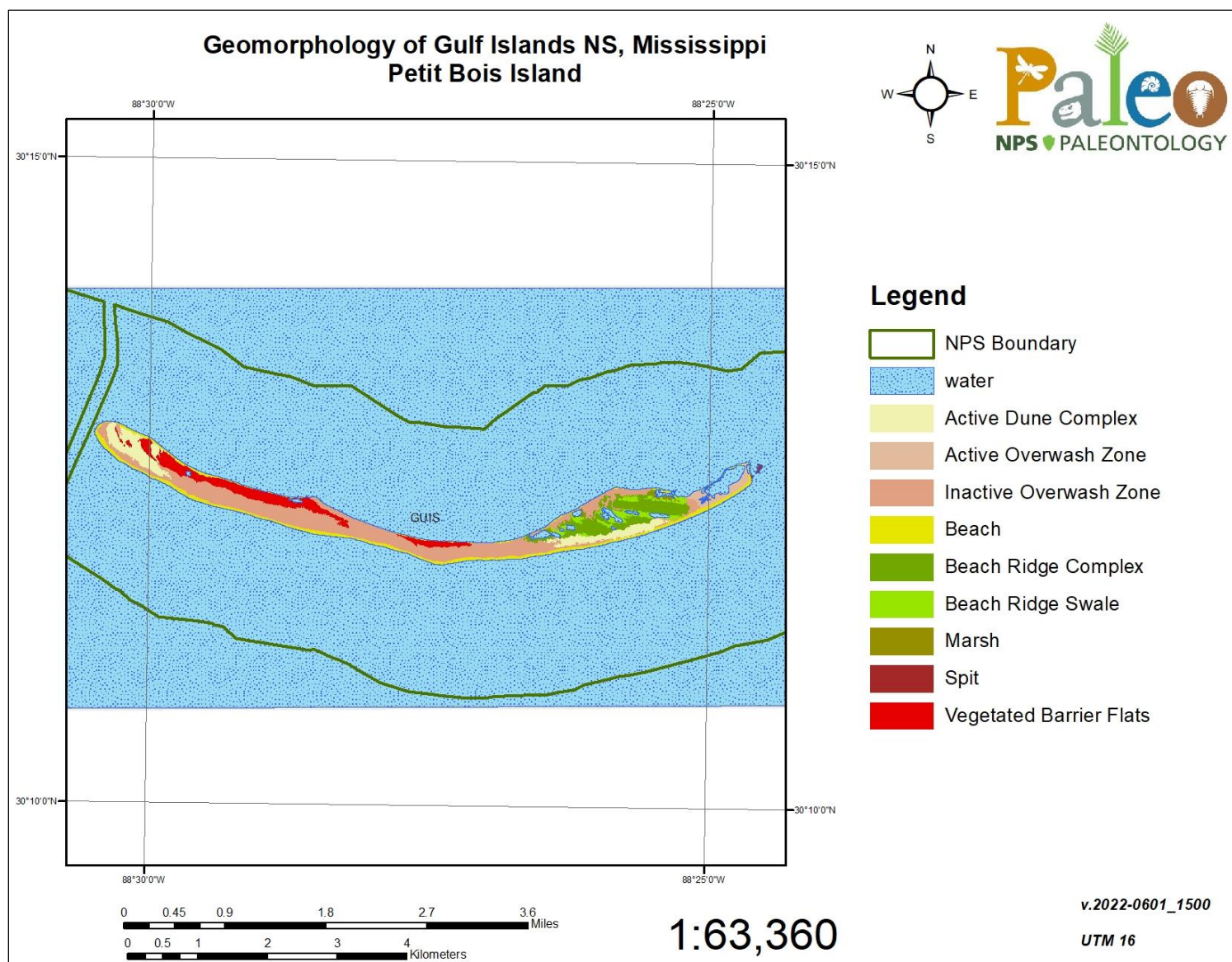


**Figure 10.** Geomorphological map of GUIIS (Ship Island), Mississippi. Modified from GUIIS GRI digital geomorphological map data at <https://irma.nps.gov/DataStore/Reference/Profile/2166540>. The source data predates filling of the area between East and West Ship Islands, so the area depicted as “shoal” is now emerged sand (reclaimed land).



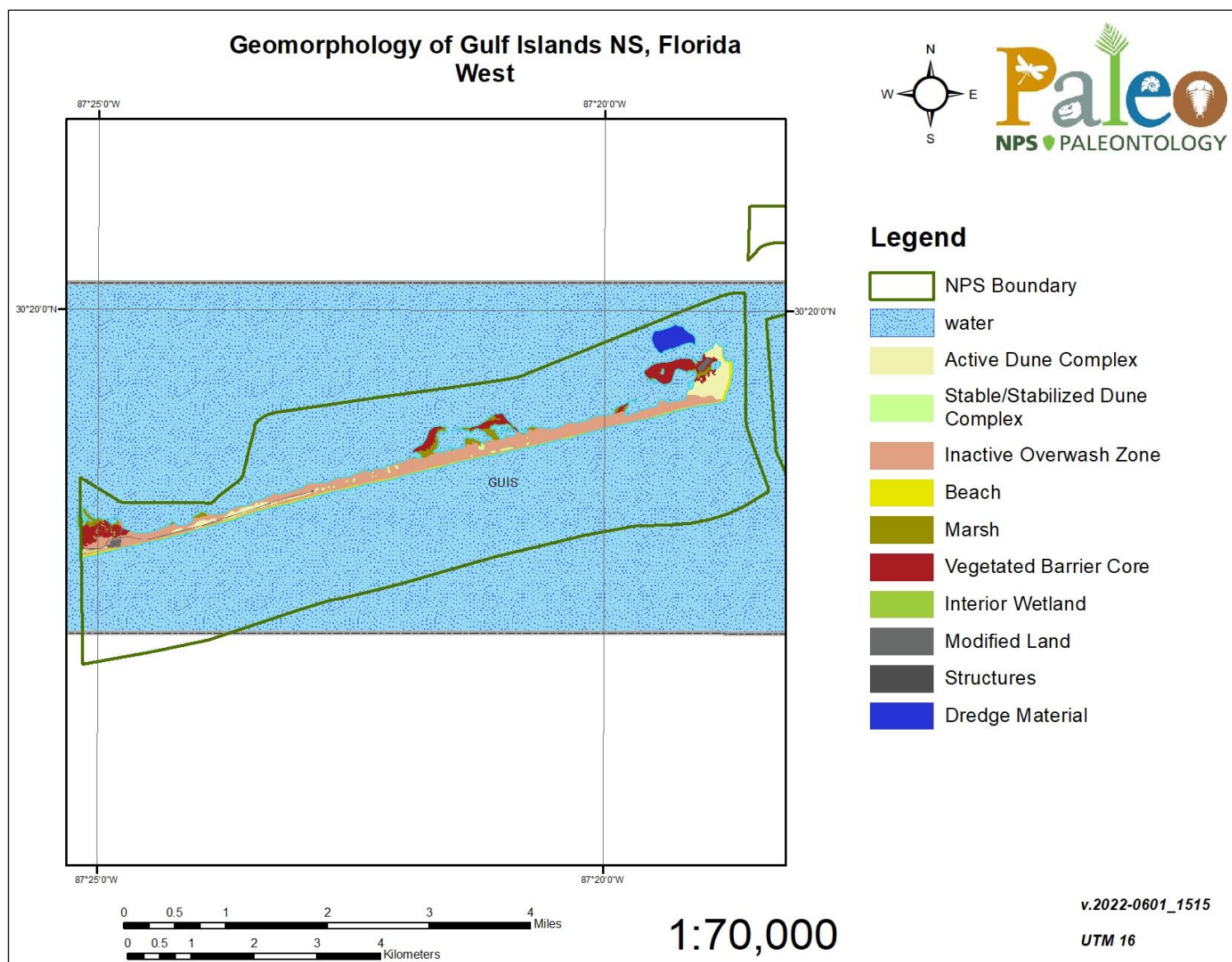


**Figure 11.** Geomorphological map of GUI (Horn Island), Mississippi. Modified from GUI GRI digital geomorphological map data at <https://irma.nps.gov/DataStore/Reference/Profile/2166538>.

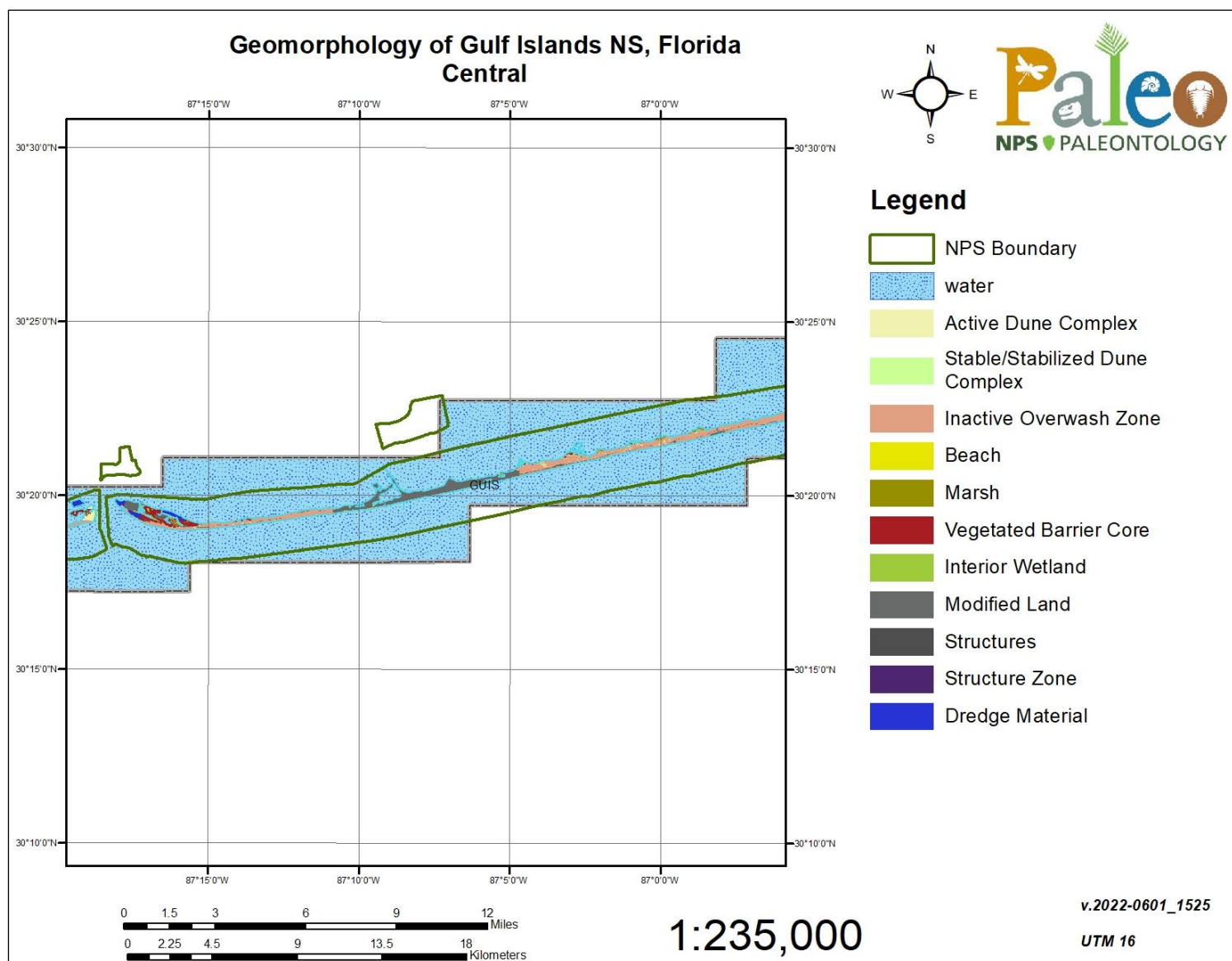


**Figure 12.** Geomorphological map of GUIS (Petit Bois Island), Mississippi. Modified from GUIS GRI digital geomorphological map data at <https://irma.nps.gov/DataStore/Reference/Profile/2166539>.

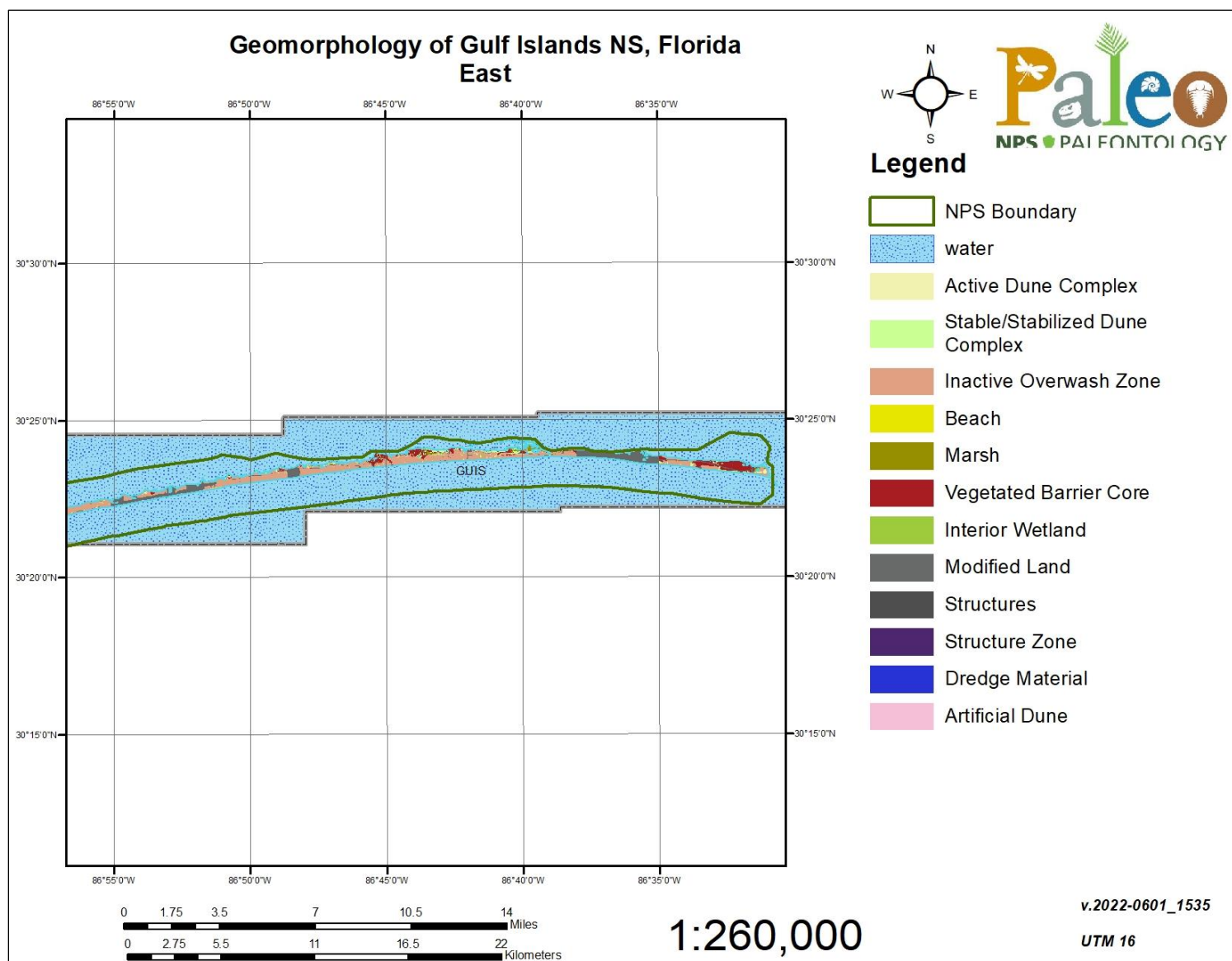




**Figure 13.** Geomorphological map of GUIS (Perdido Key Area), Florida. Modified from GUIS GRI digital geomorphological map data at <https://irma.nps.gov/DataStore/Reference/Profile/2168547>.



**Figure 14.** Geomorphological map of GUIS (Pensacola Beach Area), Florida. Modified from GUIS GRI digital geomorphological map data at <https://irma.nps.gov/DataStore/Reference/Profile/2166537>.



**Figure 15.** Geomorphological map of GUIS (Santa Rosa Area), Florida. Modified from GUIS GRI digital geomorphological map data at <https://irma.nps.gov/DataStore/Reference/Profile/2166537>.



# **Jean Lafitte National Historical Park and Preserve (JELA)**

## **Park Establishment**

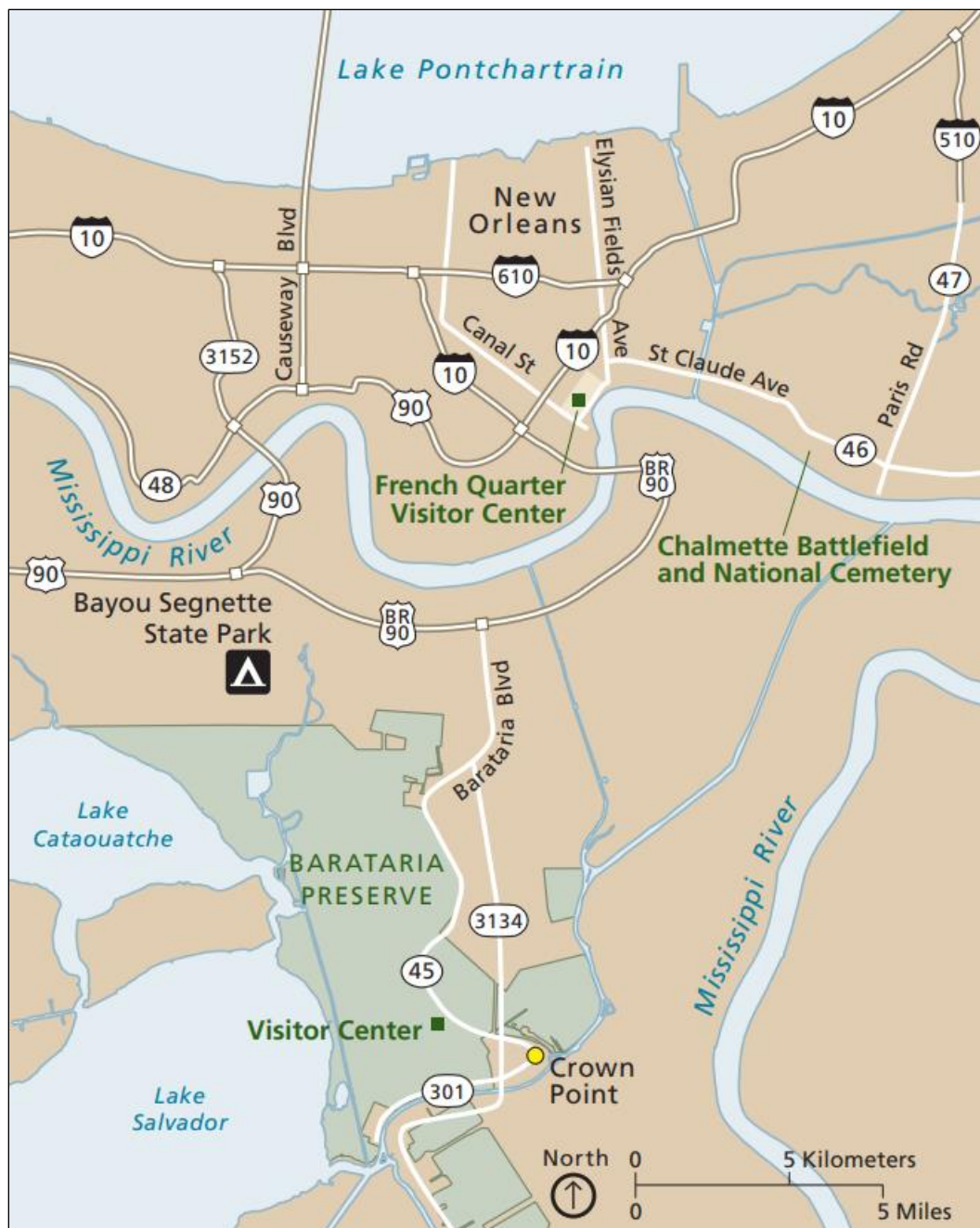
Jean Lafitte National Historical Park and Preserve (JELA) consists of six individual park units distributed across the Mississippi River Delta region of southern Louisiana in portions of Evangeline, Jefferson, Lafayette, Lafourche, and Orleans Parishes (Figure 16). The historical park and preserve was authorized on November 10, 1978, and incorporated the previously established Chalmette National Historical Park (National Park Service 2016a). The park units of JELA encompass a combined 17,891 hectares (22,421 acres) and protects the diverse cultural and natural resources of southern Louisiana's Mississippi River Delta. The six units that comprise JELA include: (1) Barataria Preserve Unit, featuring trails through protected bottomland forests, swamp, and marsh; (2) Chalmette Unit, including the Chalmette Battlefield and Chalmette National Cemetery that commemorate the 1815 Battle of New Orleans that was part of the War of 1812; (3) French Quarter Unit, containing the JELA headquarters and interpreting the diverse cultures of New Orleans; (4) Prairie Acadian Cultural Center; (5) Acadian Cultural Center Unit; and (6) Wetlands Acadian Cultural Center Unit. Together, the Prairie Acadian Cultural Center, Acadian Cultural Center, and Wetlands Acadian Cultural Center interpret the Acadian (Cajun) culture of the Mississippi River Delta region (Schupp and KellerLynn 2019). The park is named after Jean Lafitte, a French pirate, smuggler, and privateer who roamed the streets of New Orleans' French Quarter, navigated the swamps of the Barataria Preserve, and supported Major General Andrew Jackson's victory at the Battle of New Orleans (National Park Service 2015).

## **Geologic Summary**

JELA is situated within the Mississippi Alluvial Plain region of the Coastal Plain physiographic province, an area defined by the broad, gently sloping alluvial plain of the Mississippi River. The geology of JELA is relatively young, consisting of Cenozoic sedimentary deposits dating back to the Pleistocene Epoch approximately 2.58 million years ago (Figures 17–22). The oldest deposits within the historical park are fluvially dominated strata of the Avoyelles Alloformation and Beaumont Alloformation that underlie portions of the Acadian Cultural Center and Prairie Acadian Cultural Center Units, respectively. Several unnamed Holocene fluvial deposits are also mapped within JELA that are associated with the ancestral and present-day Mississippi River and include deltaic lobe and natural levee deposits consisting of unconsolidated sand, silt, and clay. Sediments associated with the former St. Bernard delta lobe of the Mississippi River (4,500–2,000 years ago) are widely distributed across the Barataria Preserve Unit, while younger deposits of the Plaquemines lobe (750–500 years ago) underlie the eastern portion of Barataria (Byrnes et al. 2019). Natural levee deposits of the Lafourche meander belt of the Mississippi River (2,000–300 years ago) occur within the Wetlands Acadian Cultural Center (Byrnes et al. 2019).

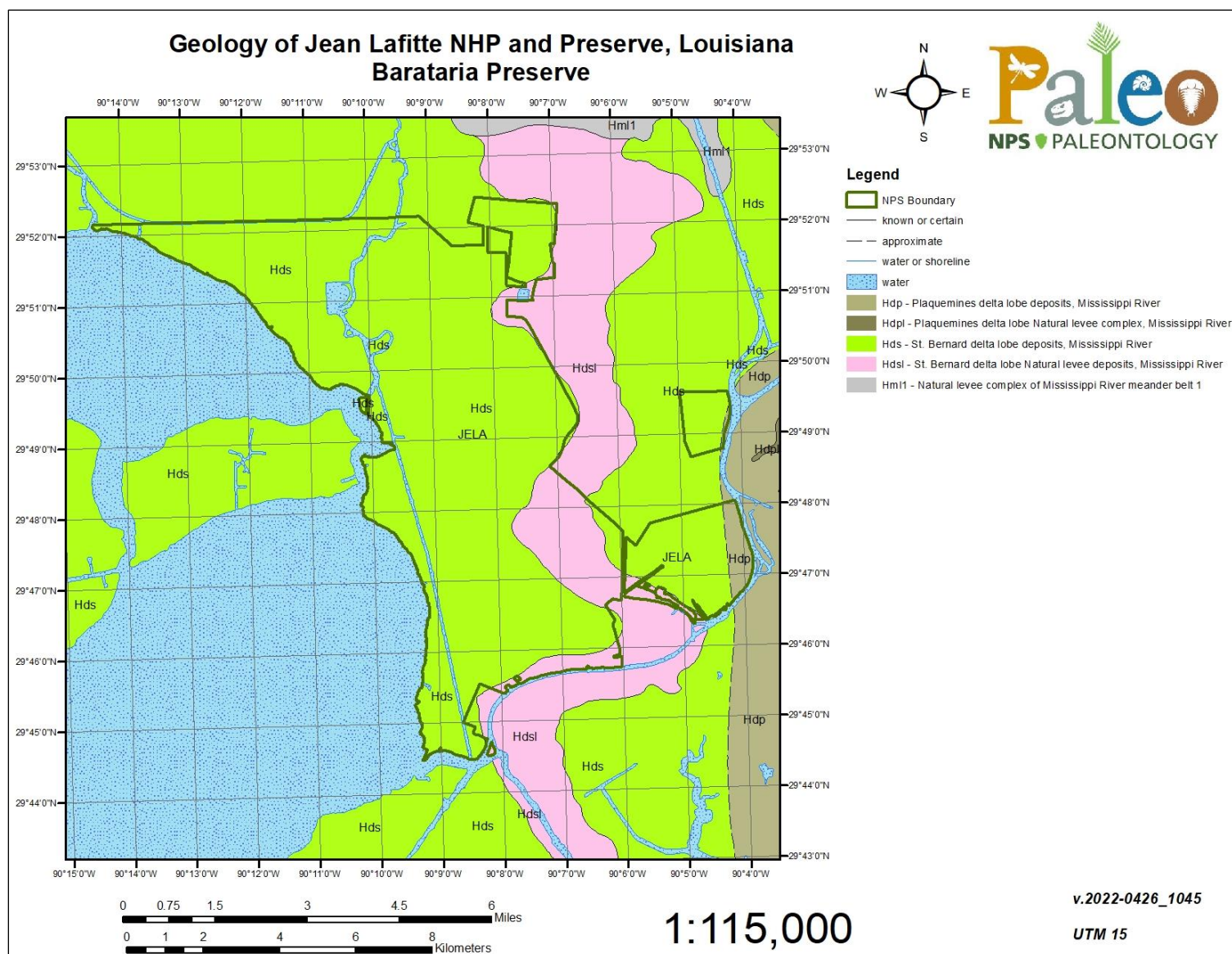
## **Stratotypes**

There are no designated stratotypes identified within the boundaries of JELA.

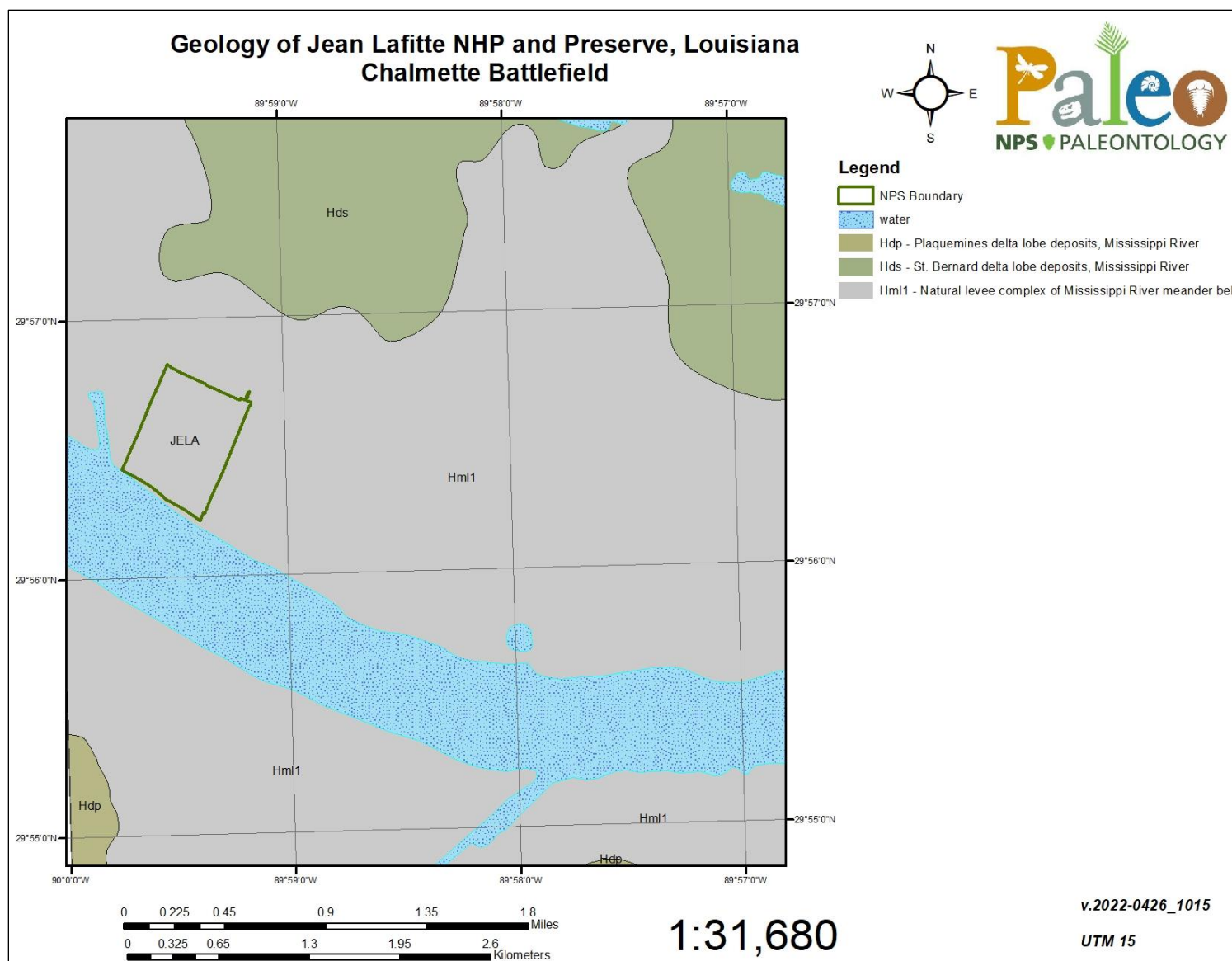


**Figure 16.** Park map of JELA, Louisiana (NPS).



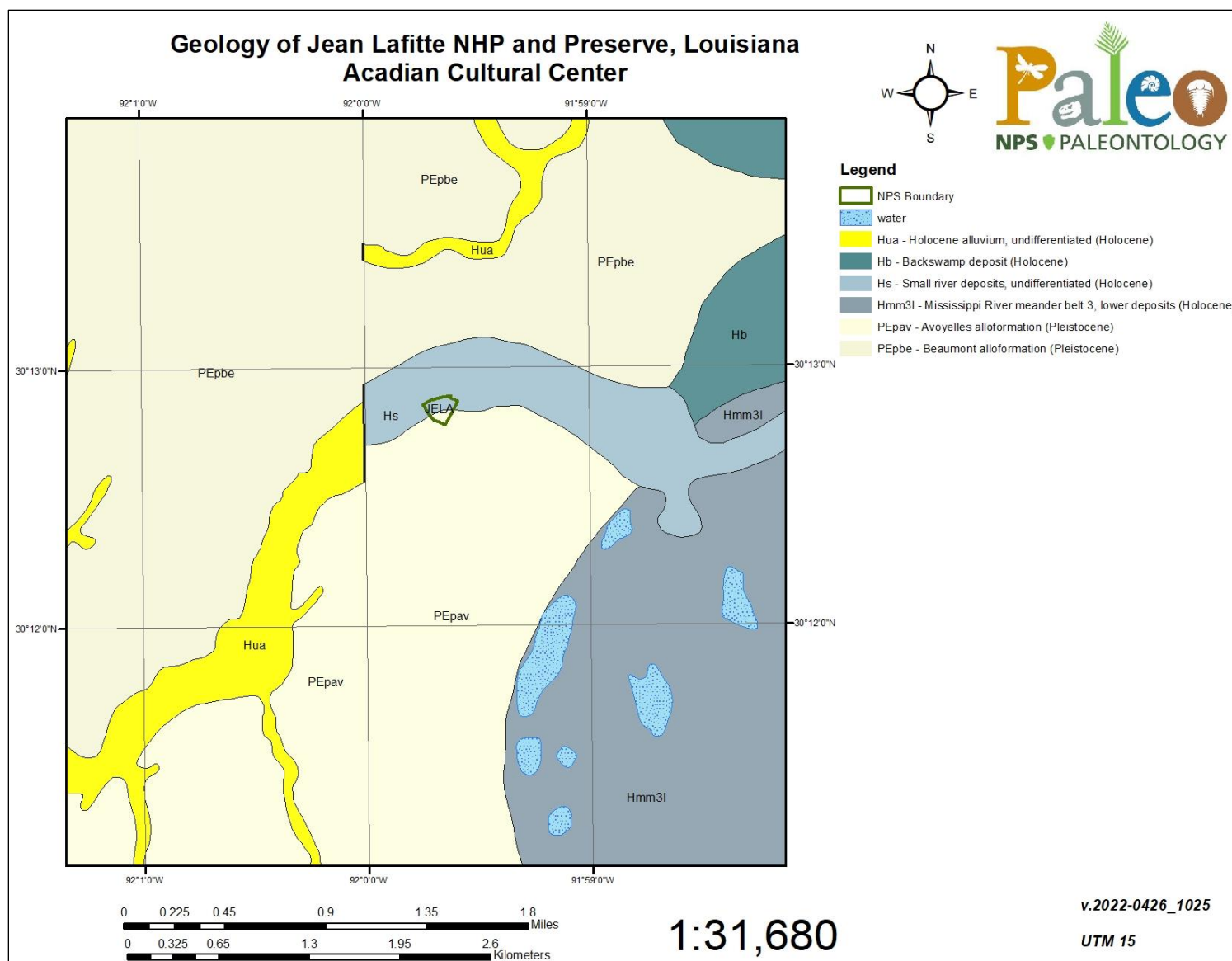


**Figure 17.** Geologic map of JELA (Barataria Preserve), Louisiana. Modified from JELA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2197223>.

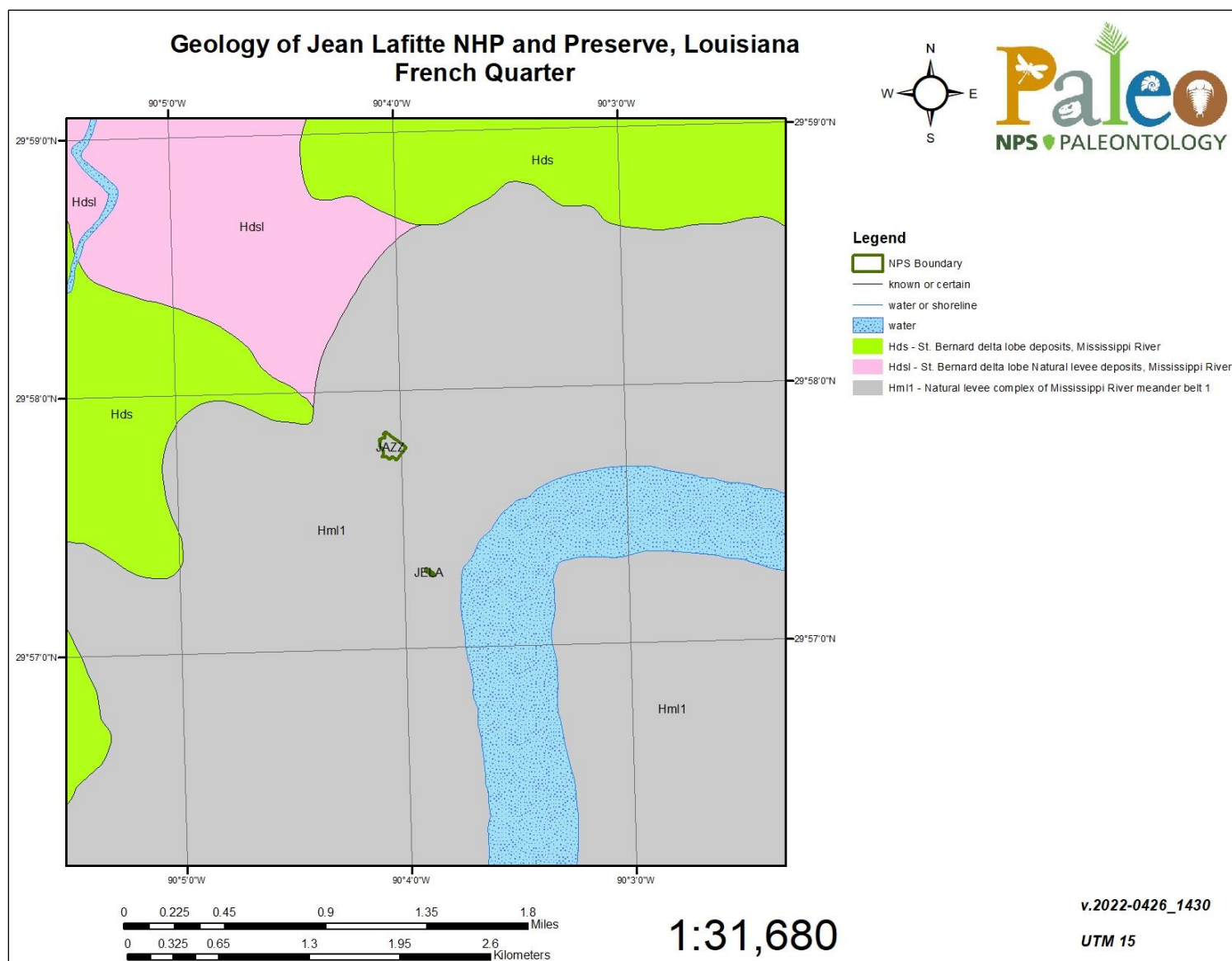


**Figure 18.** Geologic map of JELA (Chalmette Battlefield), Louisiana. Modified from JELA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2197231>.

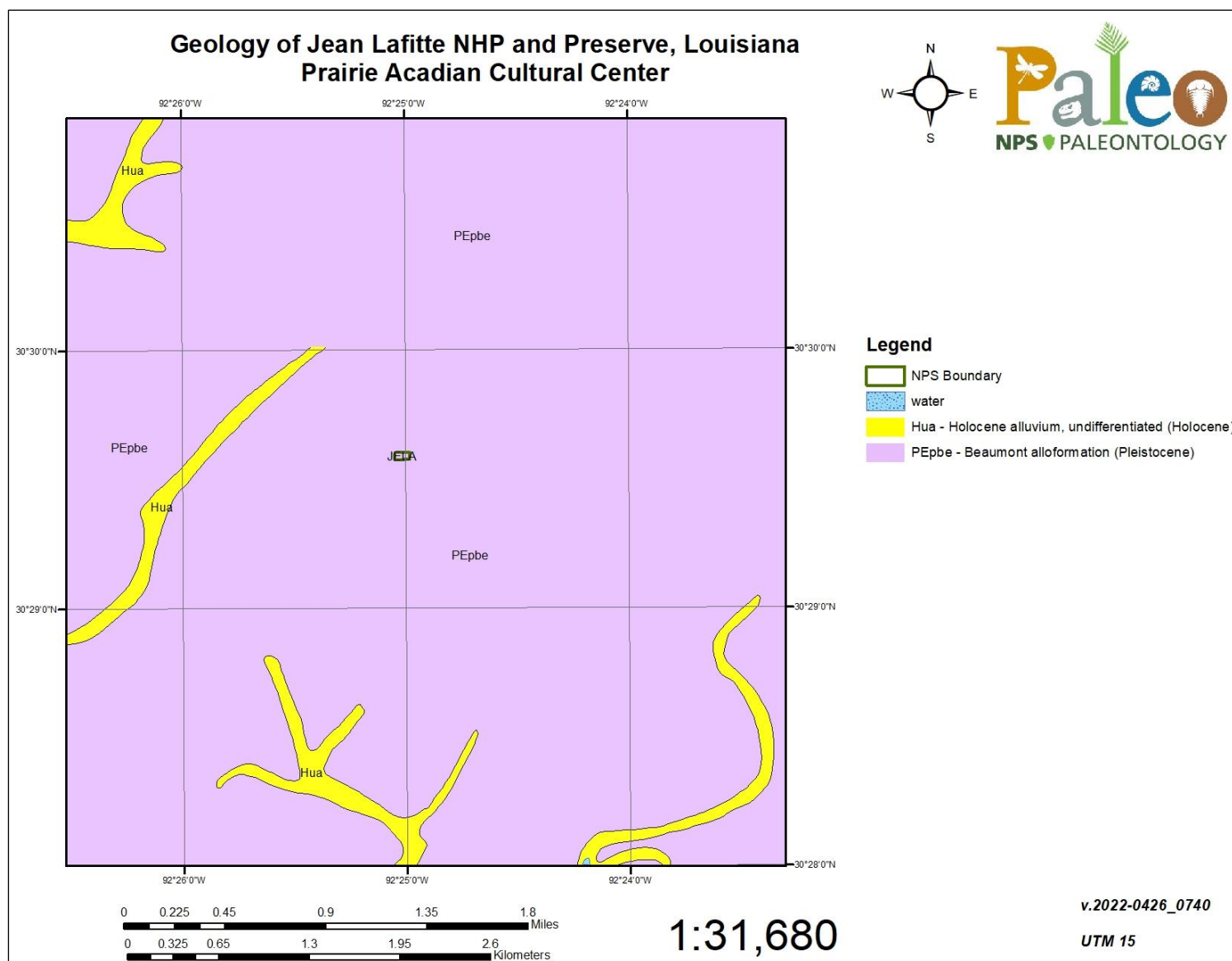




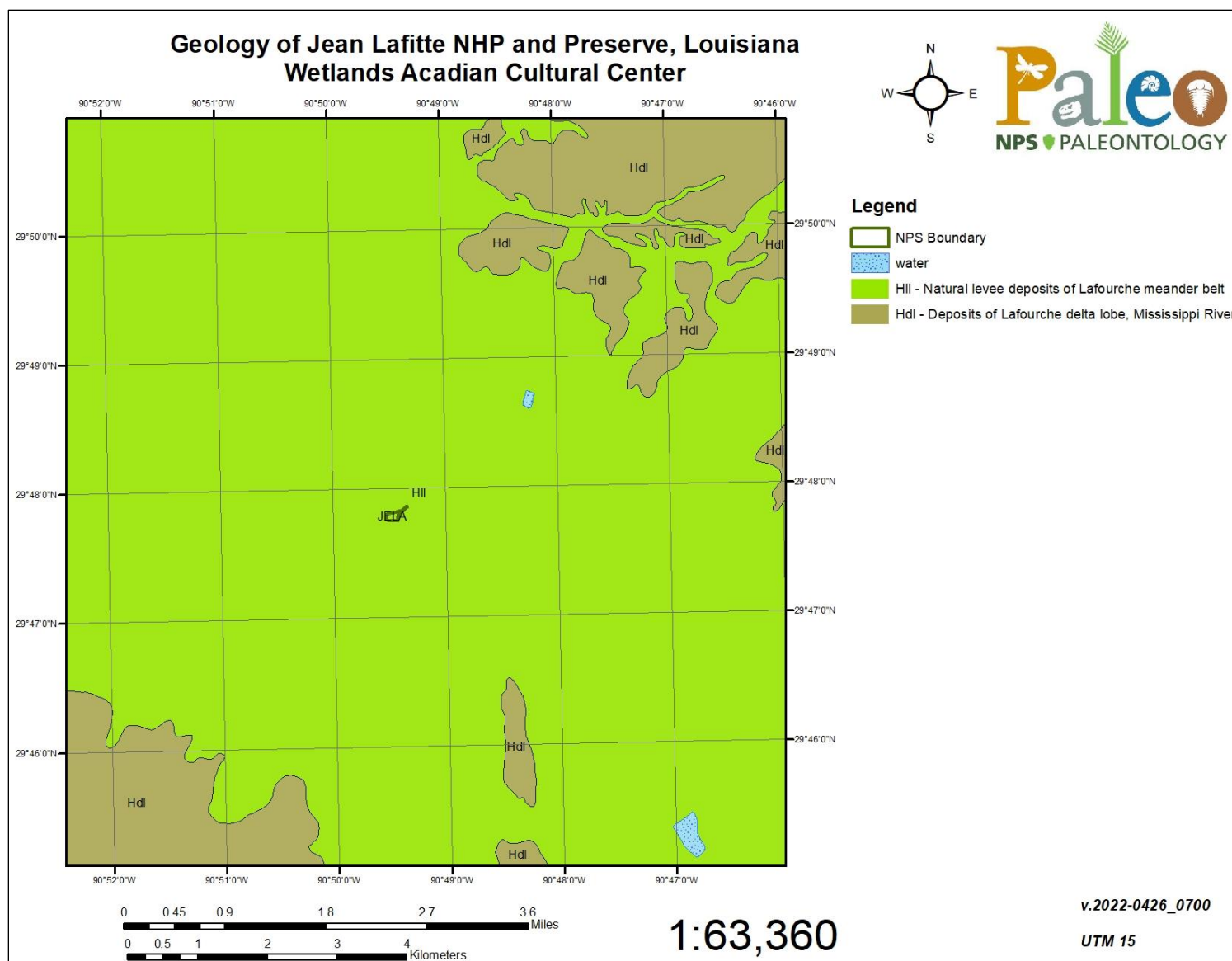
**Figure 19.** Geologic map of JELA (Acadian Cultural Center), Louisiana. Modified from JELA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2197227>.



**Figure 20.** Geologic map of JELA (French Quarter), Louisiana. Modified from JELA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2197223>.



**Figure 21.** Geologic map of JELA (Prairie Acadian Cultural Center), Louisiana. Modified from JELA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2197232>.



**Figure 22.** Geologic map of JELA (Wetlands Acadian Cultural Center), Louisiana. Modified from JELA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2197235>.

# Natchez Trace Parkway (NATR)

## Park Establishment

The Natchez Trace Parkway (NATR) is a 714 km (444 mi)-long recreational road and scenic drive that traverses portions of Mississippi (Adams, Attala, Chickasaw, Choctaw, Claiborne, Clay, Hinds, Itawamba, Jefferson, Leake, Lee, Madison, Pontotoc, Prentiss, Tishomingo, and Webster Counties), Alabama (Colbert and Lauderdale Counties), and Tennessee (Davidson, Hickman, Lawrence, Lewis, Maury, Wayne, Williamson Counties) (Figure 23). Established on May 18, 1938, the NATR roughly follows the path of the Old Natchez Trace, a historic travel, trade, and communication corridor used by Native Americans, European settlers, slave traders, soldiers, and past U.S. Presidents. The NATR commemorates more than 10,000 years of cultural usage, encompassing more than 350 archeological sites, 22 burial and ceremonial mounds (including Emerald Mound, the second largest ceremonial mound in the U.S.), the Ackia Battleground associated with the 18<sup>th</sup> century Chickasaw Wars, as well as the death and burial site of Meriwether Lewis (National Park Service 2016a). The scenic parkway landscape traverses seven major ecoregions and features a variety of habitats including forests, wetlands, prairies, rivers, pastures, and croplands that protect more than 2,600 species, some of which are considered rare, threatened, or endangered (National Park Service 2014b).

## Geologic Summary

Situated in parts of the Interior Low Plateau and Coastal Plain physiographic provinces, the NATR traverses an extensive suite of sedimentary rock formations spanning the Ordovician Period through Pleistocene Epoch, encompassing approximately 480 million years. Numerous geologic formations that occur along the parkway are part of hierarchical groups that can be subdivided into the following (from oldest to youngest): (1) Paleozoic units associated with the Ordovician Nashville Group, Silurian Wayne Group, and Mississippian Chester Group; (2) Mesozoic strata of the Cretaceous Tuscaloosa and Selma Groups; and (3) Cenozoic rocks of the Paleocene Midway Group, Eocene Wilcox, Claiborne, and Jackson Groups, Oligocene Vicksburg Group, and Oligocene–Miocene Grand Gulf Group, as well as thick Pleistocene ancestral Mississippi River pre-loess terrace deposits and loess deposits (Hardeman et al. 1966; Bicker 1969; Osborne et al. 1989). The oldest strata underlying NATR occur near the northern terminus in Tennessee; the bedrock becomes progressively younger further south through Alabama and southwest into Mississippi (Figures 24–28; mapping is not yet complete for the Alabama and Mississippi segments, so the figures only document the Tennessee portion of the parkway). Although surficial geologic exposures are limited within NATR due to the linear nature of the parkway combined with highway infrastructure and vegetative cover, road cuts and erosional features along creeks and riverbanks provide opportunities to access the underlying geology.

## Stratotypes

There are no designated stratotypes identified within the boundaries of NATR. Although the Pleistocene Natchez Formation (now considered an ancestral Mississippi River pre-loess terrace deposit) shares a common name with NATR, the unit was named after river bluff exposures along the Mississippi River at Natchez in Adams County, Mississippi just west of the parkway (Chamberlin 1896). The parkway's 714 km (444 mi)-long traverse passes within close proximity to several cities

with type localities, including (all in Mississippi): Jackson, Kosciusko, Tupelo, and Zama. There are 30 identified stratotypes located within 48 km (30 mi) of NATR boundaries that are provided in Appendix C for reference in case of future boundary expansion.

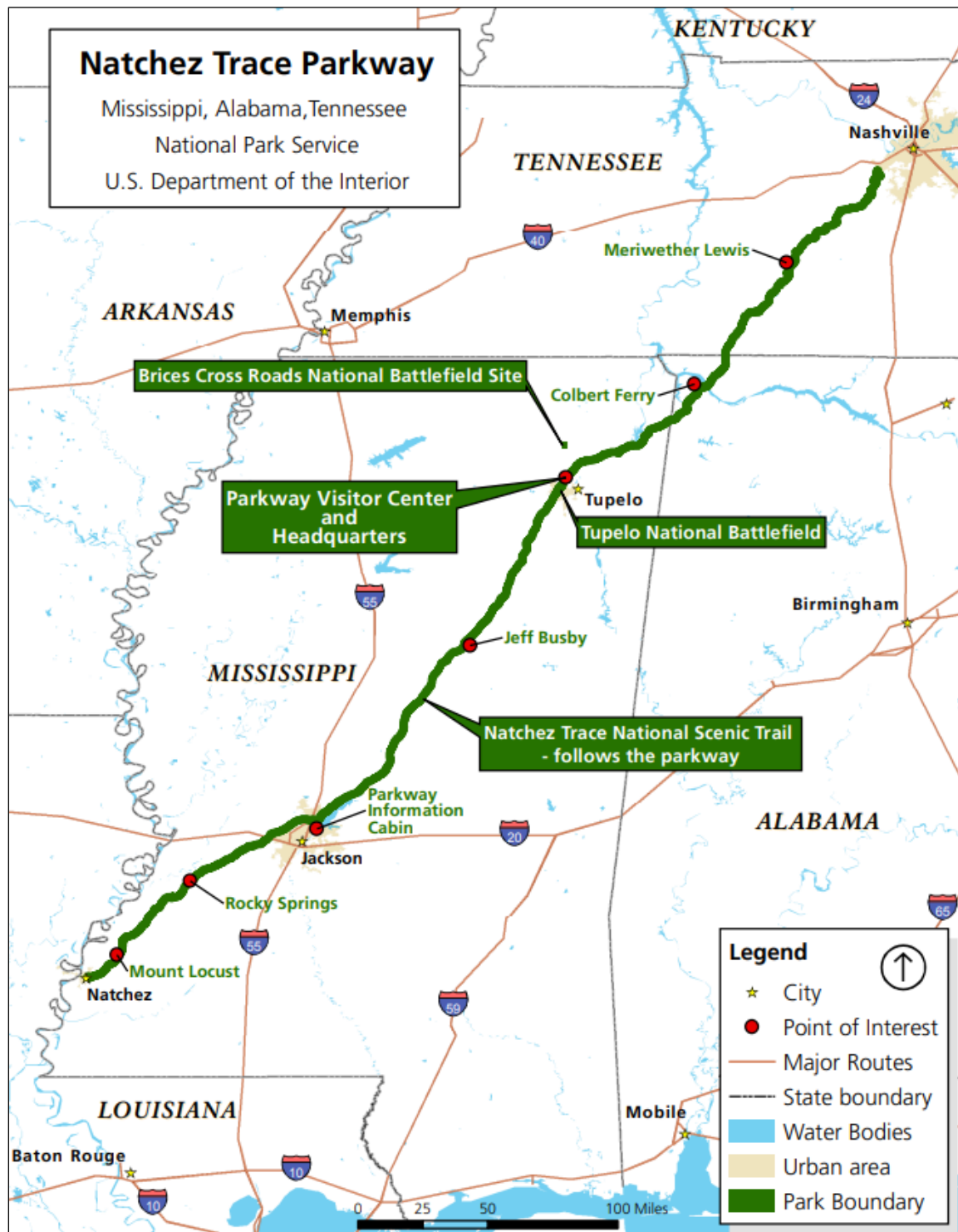
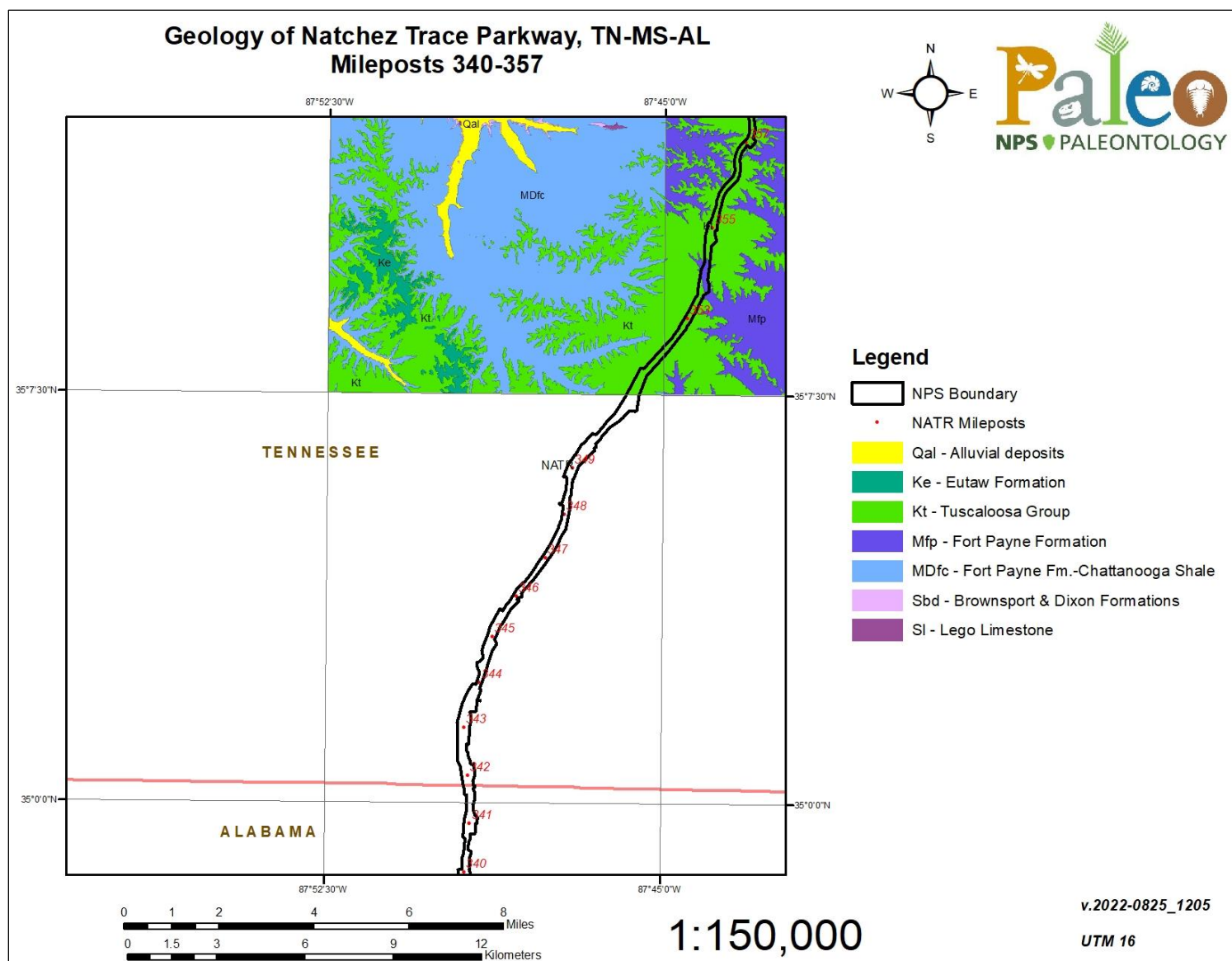
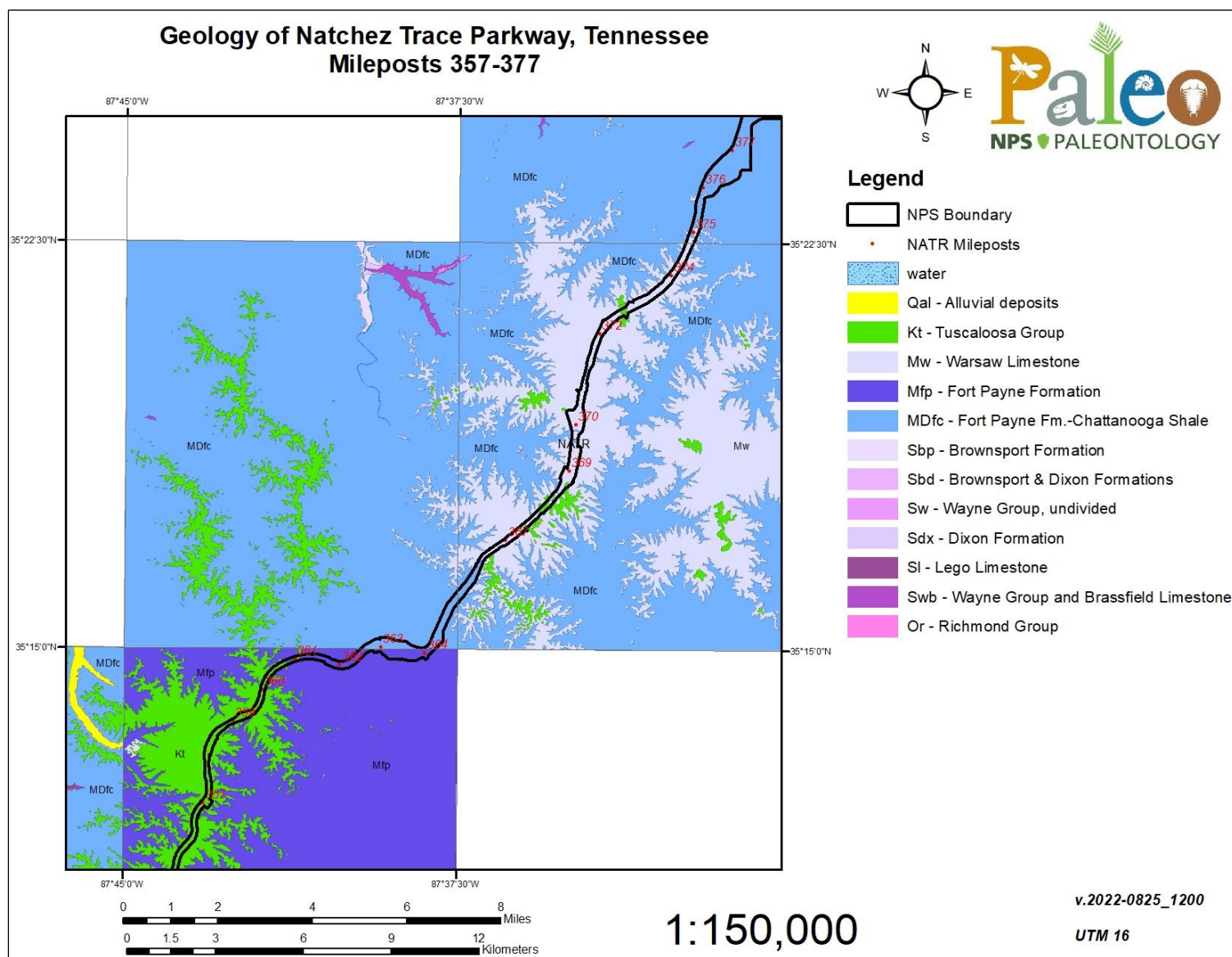


Figure 23. Regional map of NATR, Mississippi–Alabama–Tennessee (NPS).



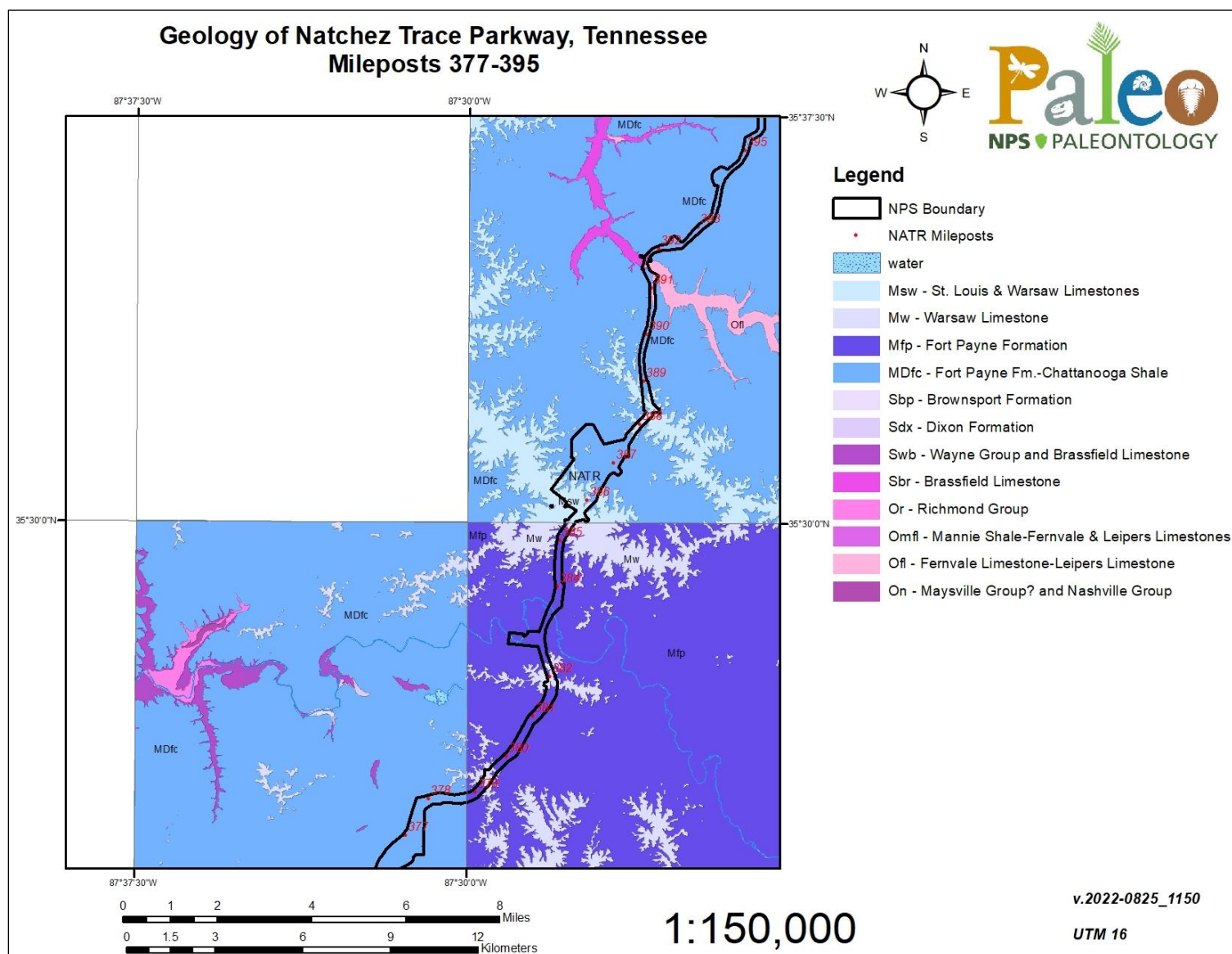


**Figure 24.** Geologic map of NATR, Tennessee (mileposts 340–357). Modified from NATR GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2293442>.

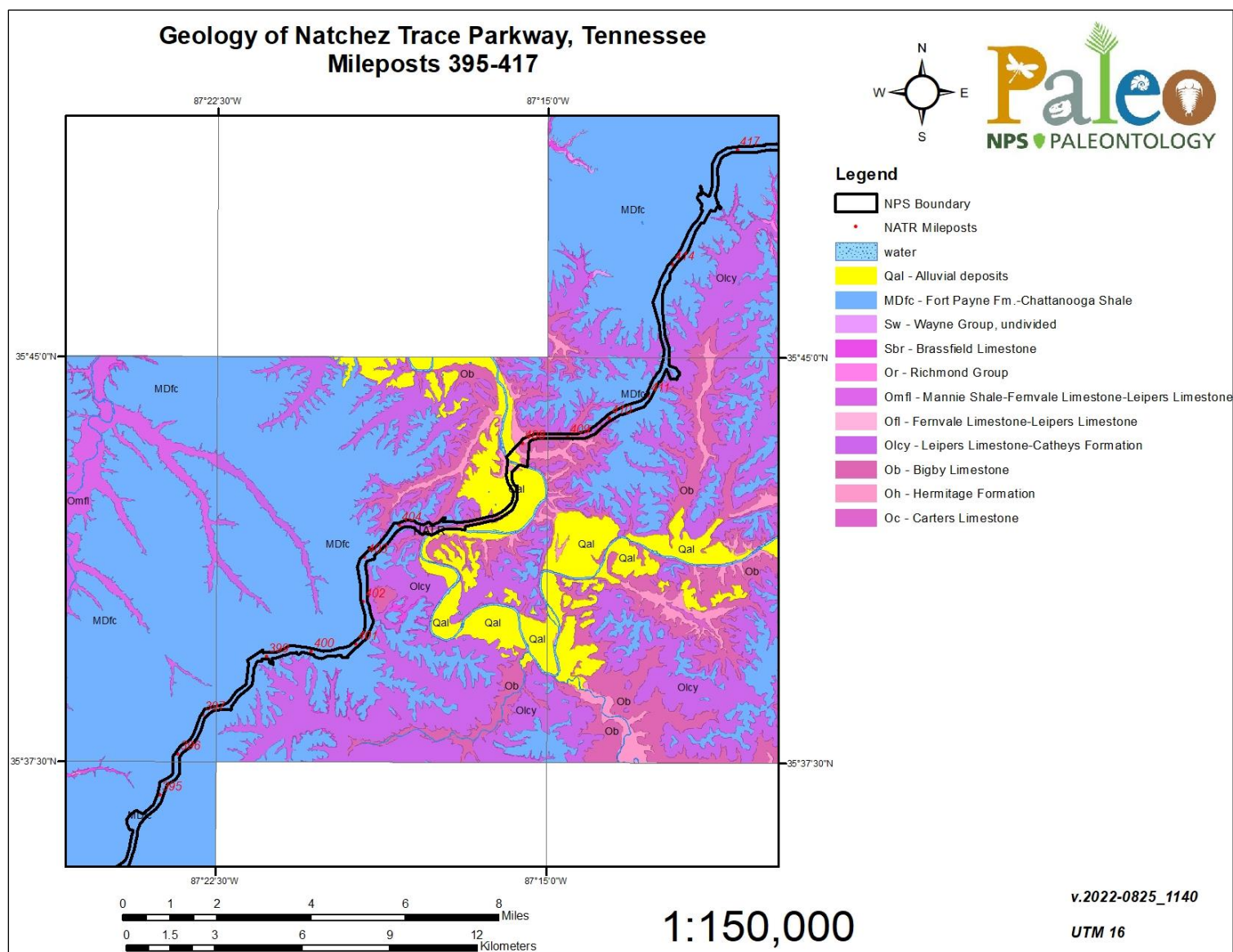


**Figure 25.** Geologic map of NATR, Tennessee (mileposts 357–377). Modified from NATR GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2293442>.

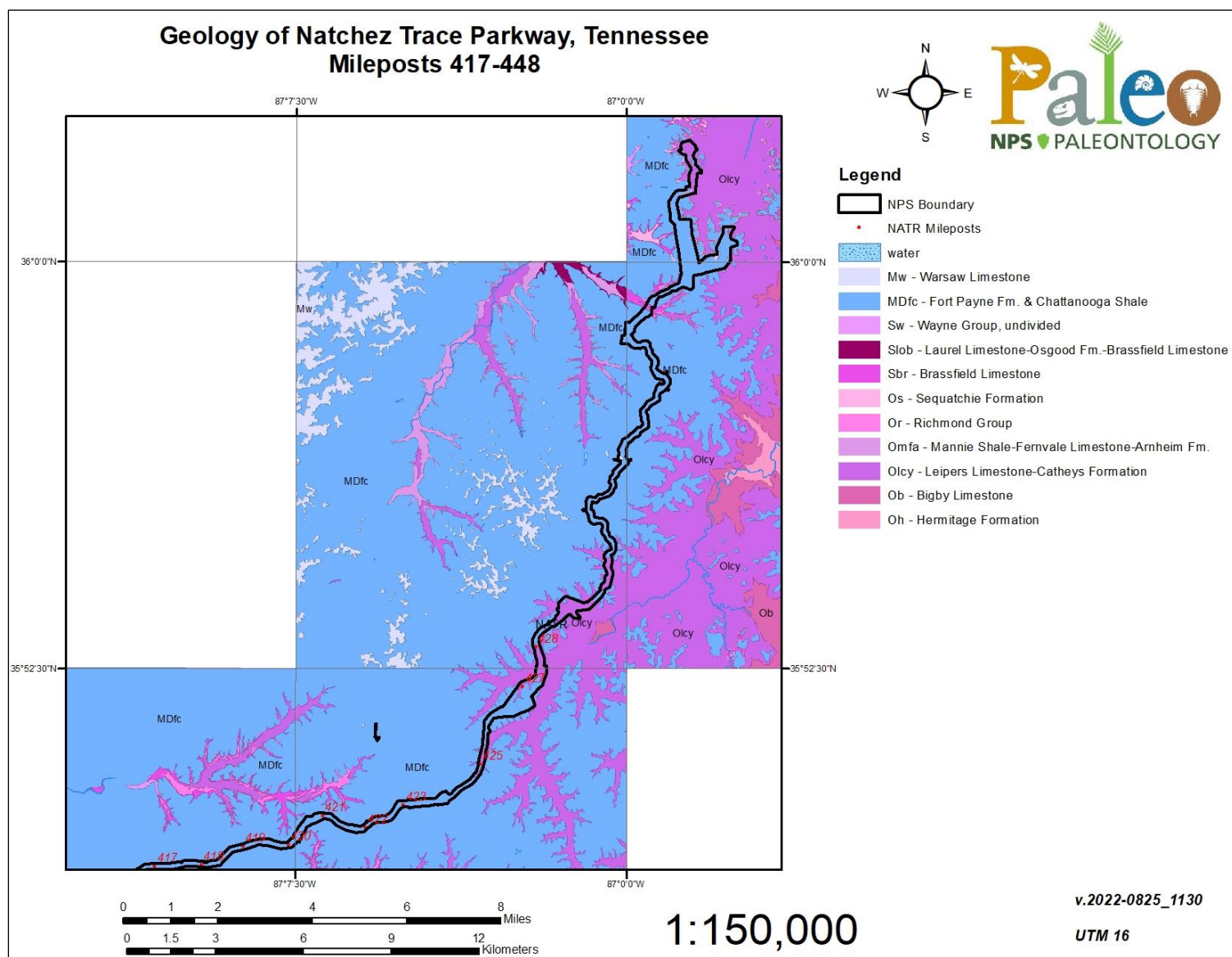




**Figure 26.** Geologic map of NATR, Tennessee (mileposts 377–395). Modified from NATR GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2293442>.



**Figure 27.** Geologic map of NATR, Tennessee (mileposts 395–417). Modified from NATR GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2293442>.



**Figure 28.** Geologic map of NATR, Tennessee (mileposts 417–448). Modified from NATR GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2293442>.



## **Padre Island National Seashore (PAIS)**

### **Park Establishment**

Padre Island National Seashore (PAIS) preserves and protects a 105 km (65.5 mi)-stretch of Padre Island along the Gulf Coast of eastern Texas in portions of Kenedy, Kleberg, and Willacy Counties (Figure 29). Established on April 6, 1968, PAIS encompasses approximately 52,784 hectares (130,434 acres) and represents one of the longest sections of undeveloped barrier island in the United States. Bounded by the Gulf of Mexico on the east and Laguna Madre on the west, PAIS contains a major segment of remaining coastal prairie in Texas that features a dynamic environment noted for its sandy beaches, unobscured views, abundant wildlife, and diverse recreational opportunities such as windsurfing, swimming, fishing, beachcombing, kayaking, and more. The barrier island landscape of PAIS features sandy shorelines, grasslands, dunes, hardwood hammocks, wetlands, ponds, mudflats, and marine environments that support numerous rare, threatened, or endangered species. The national seashore includes important nesting grounds for the critically endangered Kemp's ridley sea turtle as well as four other protected sea turtle species. More than 380 migratory, overwintering, and resident bird species have been documented at PAIS, and the island is designated a Globally Important Bird Area by the American Bird Conservancy and is recognized as a Site of International Importance by the Western Hemisphere Shorebird Reserve Network (National Park Service 2016c).

### **Geologic Summary**

PAIS is situated in the Coastal Plain physiographic province of southeast Texas, a relatively young region comprised of gently sloping Cenozoic sedimentary deposits. The barrier island landscape that defines PAIS is geologically dynamic, continuously being reshaped by erosional coastal forces that include wind, waves, tides, storms, sea-level change, and anthropogenic processes such as dredging and shoreline engineering (KellerLynn 2010). Geomorphologic units mapped within PAIS are only several thousand years old and represent Holocene barrier island and lagoon environments that display considerable variation across the island (Figure 30; Weise and White 1980). Barrier system units mapped along the national seashore include beach, dune, sand flat, salt marsh, brackish- to fresh marsh, dredged channel, and washover zone deposits that are largely dominated by unconsolidated sand, mud, shells, and plant debris. Lagoon system units predominantly occur along the western portion of PAIS in association with the hypersaline Laguna Madre and consist of tidal flat, grass flat, and lagoon-margin sands and muds.

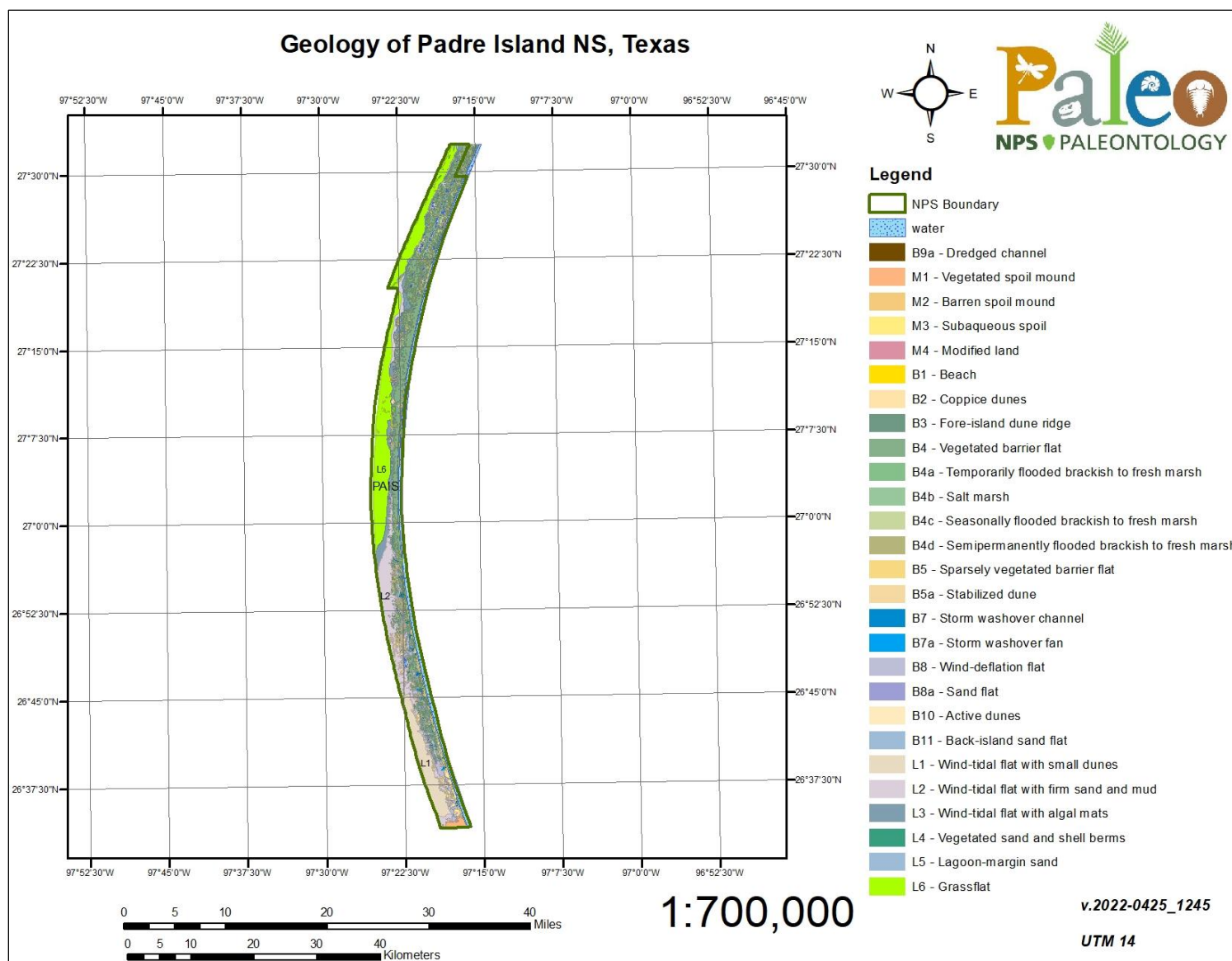
### **Stratotypes**

There are no designated stratotypes identified within the boundaries of PAIS.





Figure 29. Park map of PAIS, Texas (NPS).



**Figure 30.** Geologic map of PAIS, Texas. Modified from PAIS GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2184314>.





# **Palo Alto Battlefield National Historical Park (PAAL)**

## **Park Establishment**

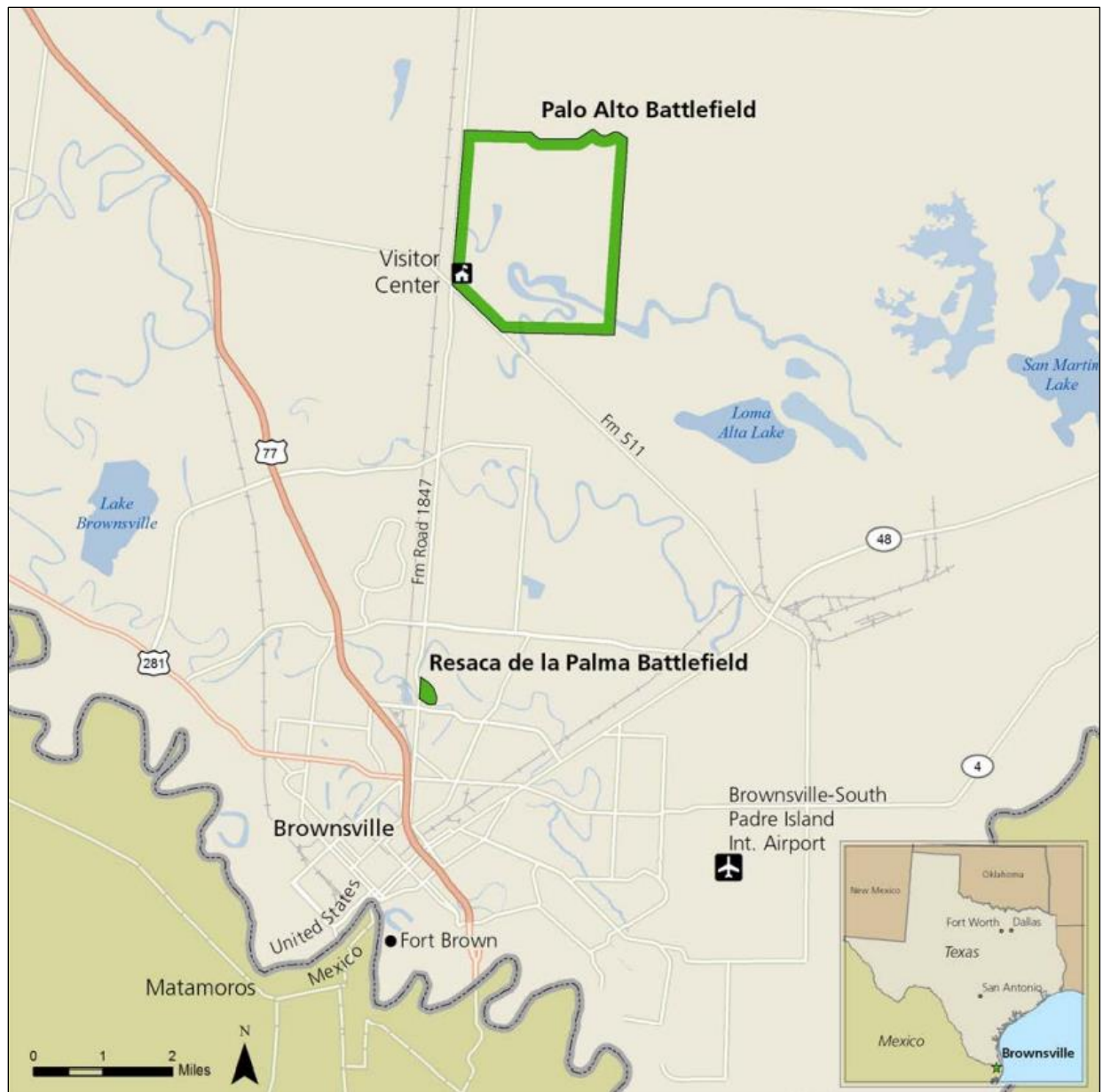
Palo Alto Battlefield National Historical Park (PAAL) is located near the U.S.–Mexico border just north of downtown Brownsville in Cameron County, Texas (Figure 31). Originally authorized as Palo Alto Battlefield National Historical Site on November 10, 1978, the park unit was redesignated a national historical park on March 30, 2009. Encompassing approximately 1,392 hectares (3,442 acres), PAAL consists of two individual units (Palo Alto Battlefield and Resaca de la Palma Battlefield) that commemorate the first two battle sites of the U.S.-Mexican War (1846–1848). The opening battles of Palo Alto and Resaca de la Palma were fought over territorial disputes between the United States and Mexico, and pitted American troops led by General Zachary Taylor against Mexican forces commanded by General Mariano Arista. The U.S.-Mexican War was heavily impacted by the emerging concept of “manifest destiny”, a cultural belief that the expansion of the United States throughout North America was both justified and inevitable (Thornberry-Ehrlich 2013). The war ended with the signing of the Treaty of Guadalupe Hidalgo, wherein Mexico ceded its northern territory and expanded the United States west to the Pacific Ocean. The historic battlefield sites of PAAL represent lasting symbols of a war that shaped two neighboring countries and provide important interpretive perspectives related to the military conflict, its related political, diplomatic, and social causes, and its lasting consequences (National Park Service 2013).

## **Geologic Summary**

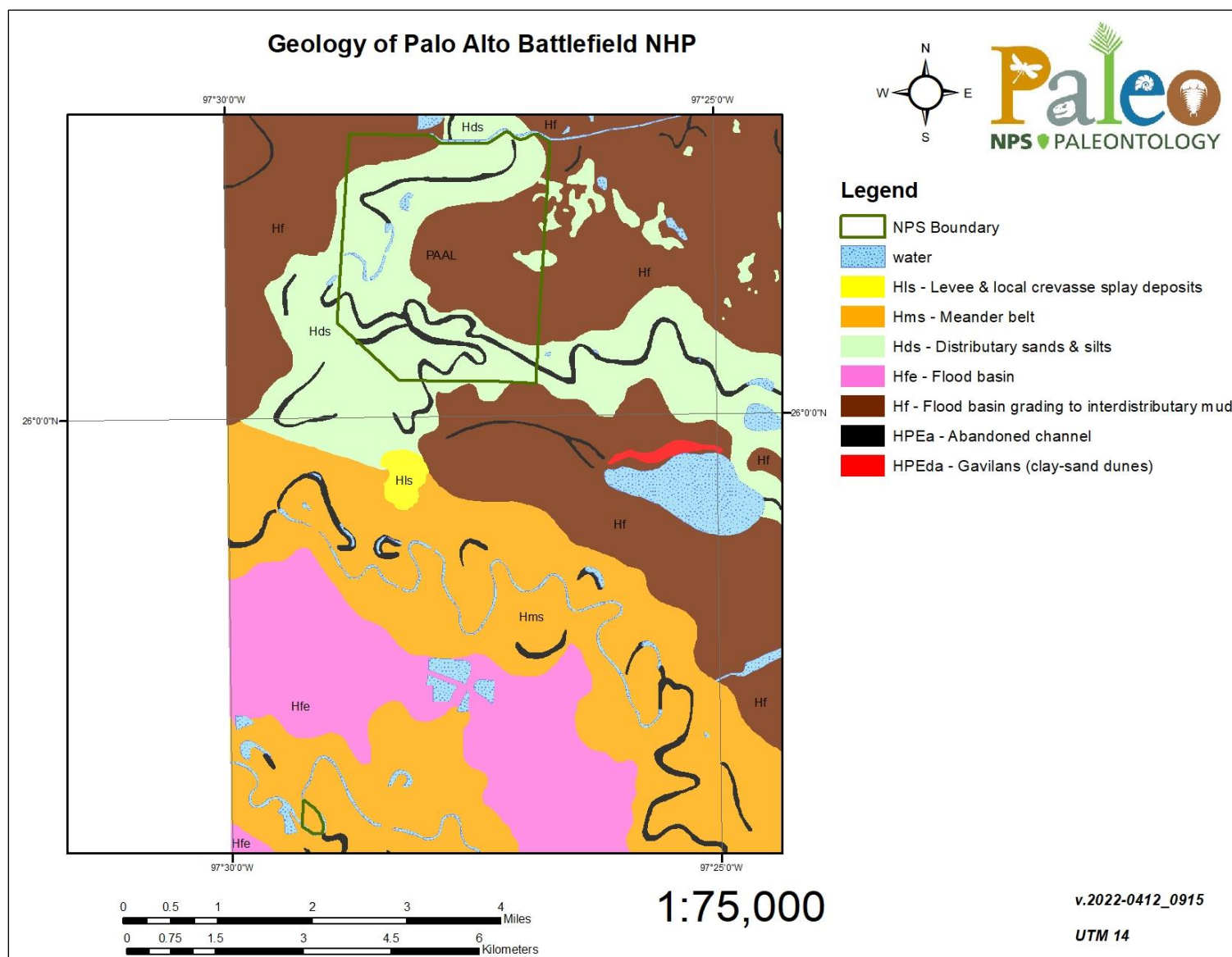
PAAL is situated in the Coastal Plain physiographic province of southeast Texas, a geologically young region comprised of gently sloping Cenozoic sedimentary deposits. The geologic history of PAAL is intricately associated with the formation and development of the Rio Grande, which has evolved dramatically over the last 8 million years to create a broad, meandering floodplain featuring abandoned channels (“resacas” or oxbow lakes), terraces, and levees (Repasch et al. 2017). The oldest strata mapped within PAAL are Quaternary deposits associated with abandoned river channels of the ancestral Rio Grande (Page et al. 2005). Several oxbow lakes occur within and near the Palo Alto Unit of PAAL and are filled with Pleistocene and Holocene mud and plant debris. Adjacent to the oxbow lakes are younger Holocene distributary sand and silt deposits as well as flood-basin muds and clays that grade into interdistributary muds. Underlying the Resaca de la Palma Unit of PAAL are Holocene meander belt deposits of the ancestral Resaca de la Palma that predominantly consist of sandy point bars, silty levees and splays, and mud-filled oxbow lakes (Figure 32).

## **Stratotypes**

There are no designated stratotypes identified within the boundaries of PAAL.



**Figure 31.** Park map of PAAL, Texas (NPS).



**Figure 32.** Geologic map of PAAL, Texas. Modified from PAAL GRI digital geologic data at <https://irma.nps.gov/DataStore/Reference/Profile/1046976>.



# **San Antonio Missions National Historical Park (SAAN)**

## **Park Establishment**

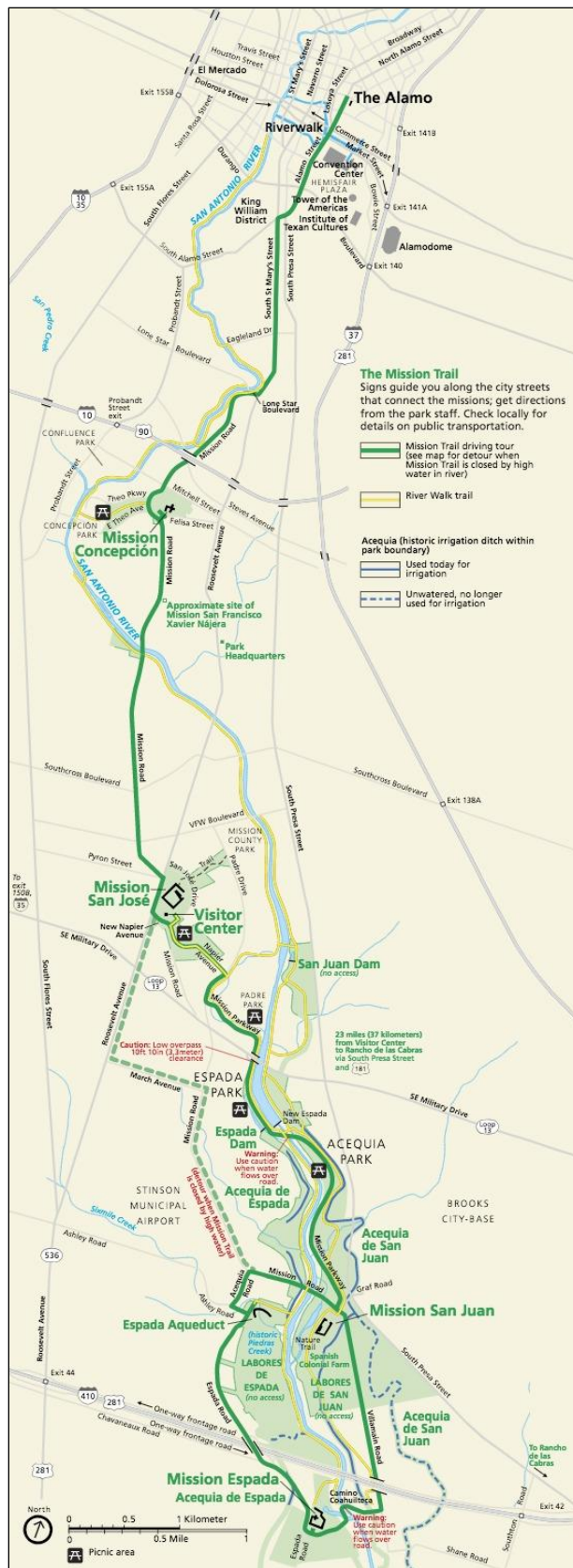
San Antonio Missions National Historical Park (SAAN) is located immediately south of downtown San Antonio along the upper San Antonio River basin in Bexar and Wilson Counties, southern Texas (Figure 33). Established on April 1, 1983, SAAN encompasses approximately 383 hectares (948 acres) and protects and preserves four 18<sup>th</sup> century Spanish Colonial Era mission complexes (Mission Concepción, Mission San José, Mission San Juan, Mission Espada), an extant mission ranch (Rancho de las Cabras), and associated historic structures (National Park Service 2016a). The historic missions of SAAN were once part of the Spanish Empire's mission to colonize and evangelize Native Americans to Spanish-speaking Catholic citizens and represent one of the most complete and intact group of Spanish Colonial mission complexes in the world (National Park Service 2016d). Much larger than a normal church, the frontier missions of SAAN were large, self-sustaining settlement complexes featuring living quarters, workshops, storerooms, and their own irrigation and agricultural systems. The Mission Concepción and Mission Espada complexes are designated national historic landmarks and include the oldest unreconstructed stone church and the only functioning Spanish Colonial aqueduct in the United States, respectively. The extraordinary park resources of SAAN are internationally recognized, and the national historical park was designated a UNESCO World Heritage Site on July 15, 2015.

## **Geologic Summary**

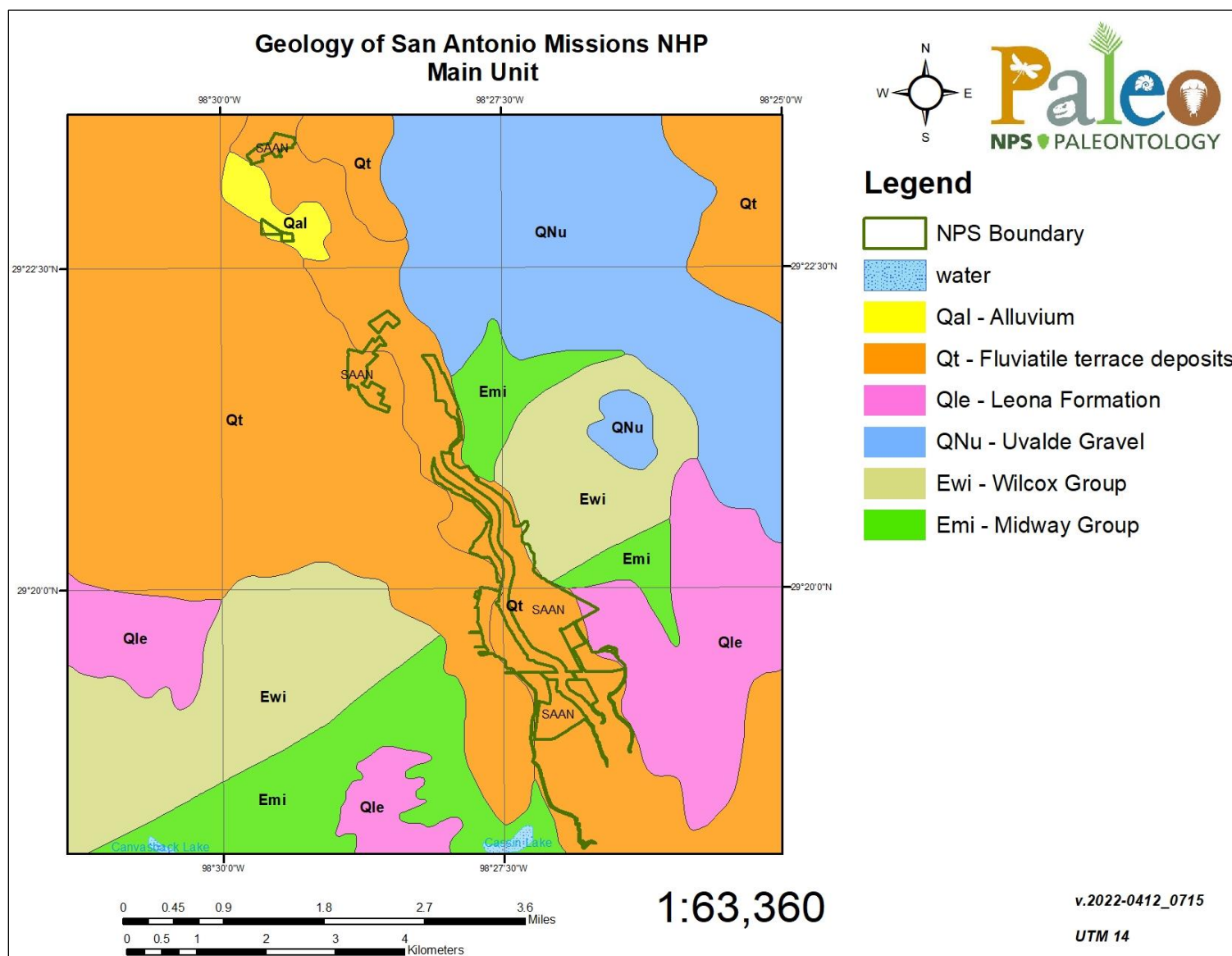
SAAN is situated in the Interior Coastal Plains subsection of the Coastal Plains physiographic province, a geologically young region comprised of Cenozoic-age strata dating back to the Paleocene Epoch (approximately 66 million years ago). The geology underlying the Spanish Colonial mission complexes of SAAN predominantly consists of Holocene fluvial terrace deposits associated with the floodplain of the San Antonio River. Flanking the terrace deposits are older sedimentary rocks of the Eocene Midway Group and Wilcox Group, as well as calcareous silt, sand, and gravel of the Pleistocene Leona Formation (Figure 34). Exposures of the Midway Group and Wilcox Group are limited in SAAN, with known outcrops occurring along the San Antonio River near Espada Dam and beneath Espada Aqueduct where it traverses Sixmile Creek (Ewing 1996). The Rancho de las Cabras Unit of SAAN features Holocene terrace deposits in addition to greenish-brown glauconitic sand and clay deposits of the Eocene Weches Formation (Figure 35).

## **Stratotypes**

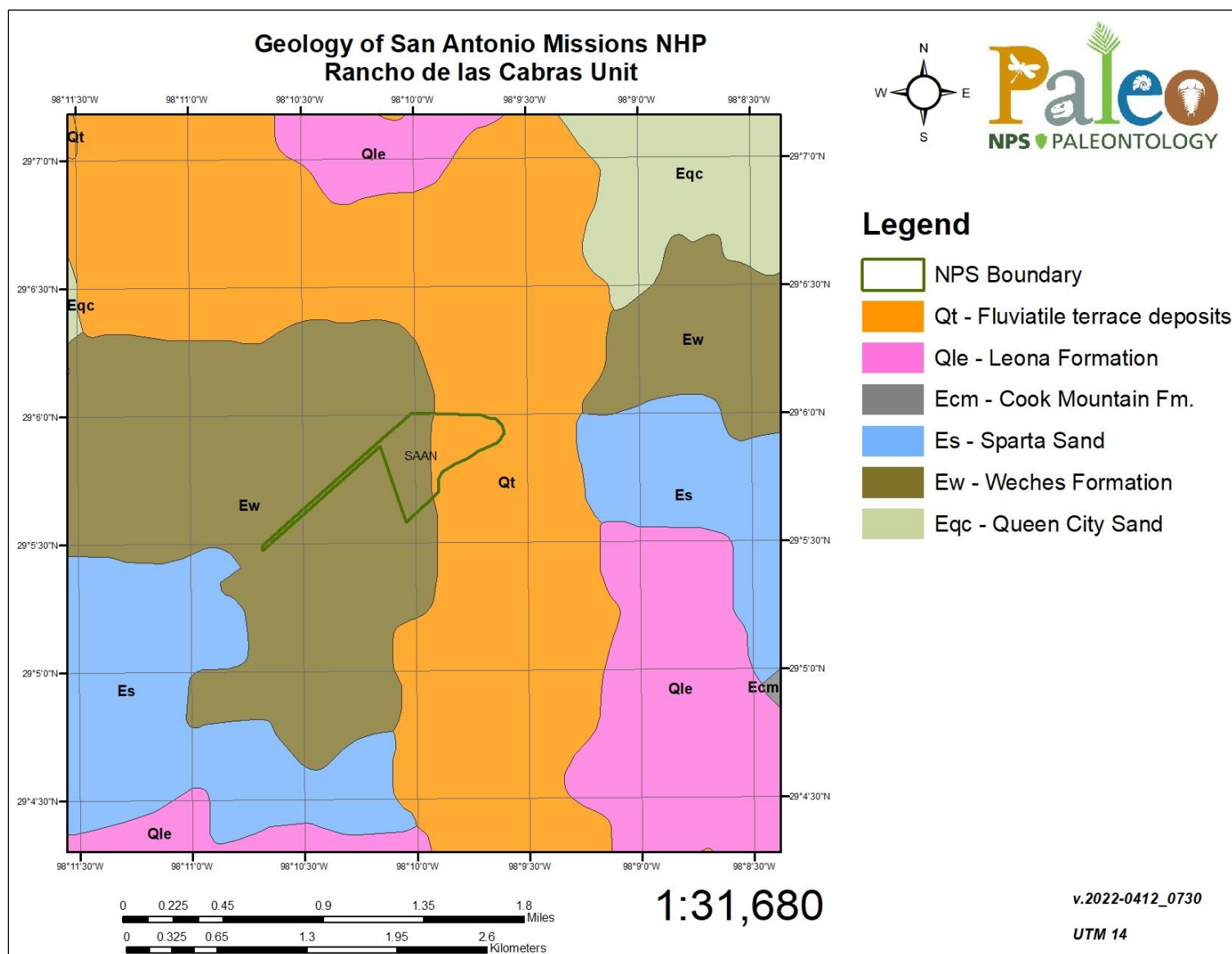
There are no designated stratotypes identified within the boundaries of SAAN.







**Figure 34.** Geologic map of SAAN (Main Unit), Texas. Modified from SAAN GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1049335>.



**Figure 35.** Geologic map legend of SAAN (Rancho de las Cabras Unit), Texas. Modified from SAAN GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1049335>.



# Vicksburg National Military Park (VICK)

## Park Establishment

Vicksburg National Military Park (VICK) is located along the Mississippi River in and around the city of Vicksburg in portions of Warren County, Mississippi and Madison Parish, Louisiana (Figure 36). Established on February 21, 1899, VICK contains approximately 729 hectares (1,802 acres) and commemorates the American Civil War campaign, siege, and defense of Vicksburg that resulted in a decisive Union victory and solidified Union control of the Mississippi River (National Park Service 2016a). During the spring of 1863, Union forces commanded by Major General Ulysses S. Grant launched a 47-day siege campaign to capture Vicksburg against defending Confederate forces commanded by Lieutenant General John C. Pemberton. As a valuable commercial port and railroad hub, Vicksburg represented a strategic military position of tremendous importance to the Confederacy. Grant's strategy to lay siege to Vicksburg effectively cut off all supplies and communications from the rest of the Confederacy, slowly pressuring Confederate forces to seek terms of surrender. The landscape of VICK features reconstructed forts, trenches, earthworks, gun batteries, the Civil War ironclad gunboat USS *Cairo*, Vicksburg National Cemetery, and one of the most extensive collections of commemorative monuments, sculptures, and outdoor art on earth (National Park Service 2014c).

## Geologic Summary

Situated near the boundary of the Mississippi Alluvial region and Gulf Coastal Plain region of the Coastal Plain physiographic province, the geology of VICK is comprised of Cenozoic-age bedrock that dates back to the Oligocene Epoch, approximately 34–23 million years ago (Figure 37). The geologic landscape of VICK is characterized by steep river bluffs, deep ravines, and flat-topped ridges that influenced the military history of the park and offered strategic defense positions. The oldest bedrock in VICK consists of sedimentary strata of the early Oligocene Vicksburg Group, which includes (from oldest to youngest) the Forest Hill Formation, Mint Spring Formation, Mariana Limestone, Glendon Limestone, Byram Formation, and Bucatunna Formation. Unconformably overlying the Vicksburg Group are locally indurated sandstones and clays of the late Oligocene Catahoula Formation and Pleistocene pre-loess terrace deposits largely composed of sand and gravel. Unconformably blanketing the pre-loess is a thick veneer of Pleistocene loess that forms the steep bluffs overlooking the Mississippi River. Loess is predominantly an eolian (wind-driven) deposit of fine silt that is derived from glacial outwash. The youngest units mapped within VICK consist of unconsolidated, surficial alluvium and abandoned channel-fill sediments of gravel, sand, silt, and clay that occur along the heavily dissected ravines and creeks within the park.

## Stratotypes

VICK contains three identified stratotypes that represent the Oligocene Vicksburg Group and its associated Mint Spring Formation (Table 3; Figure 38). There are also five identified stratotypes located within 48 km (30 mi) of VICK boundaries that are provided in Appendix C for reference in case of future boundary expansion.

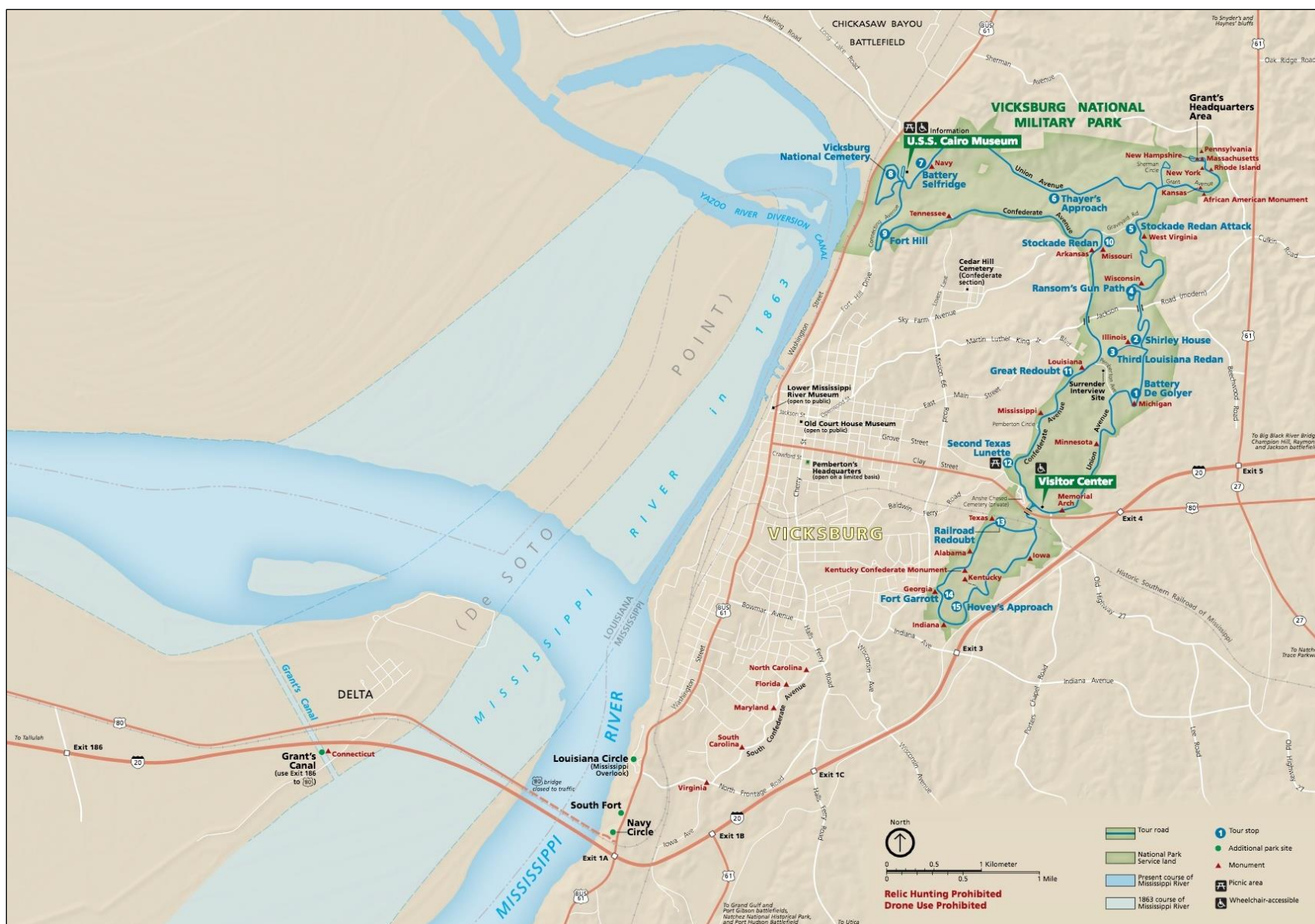
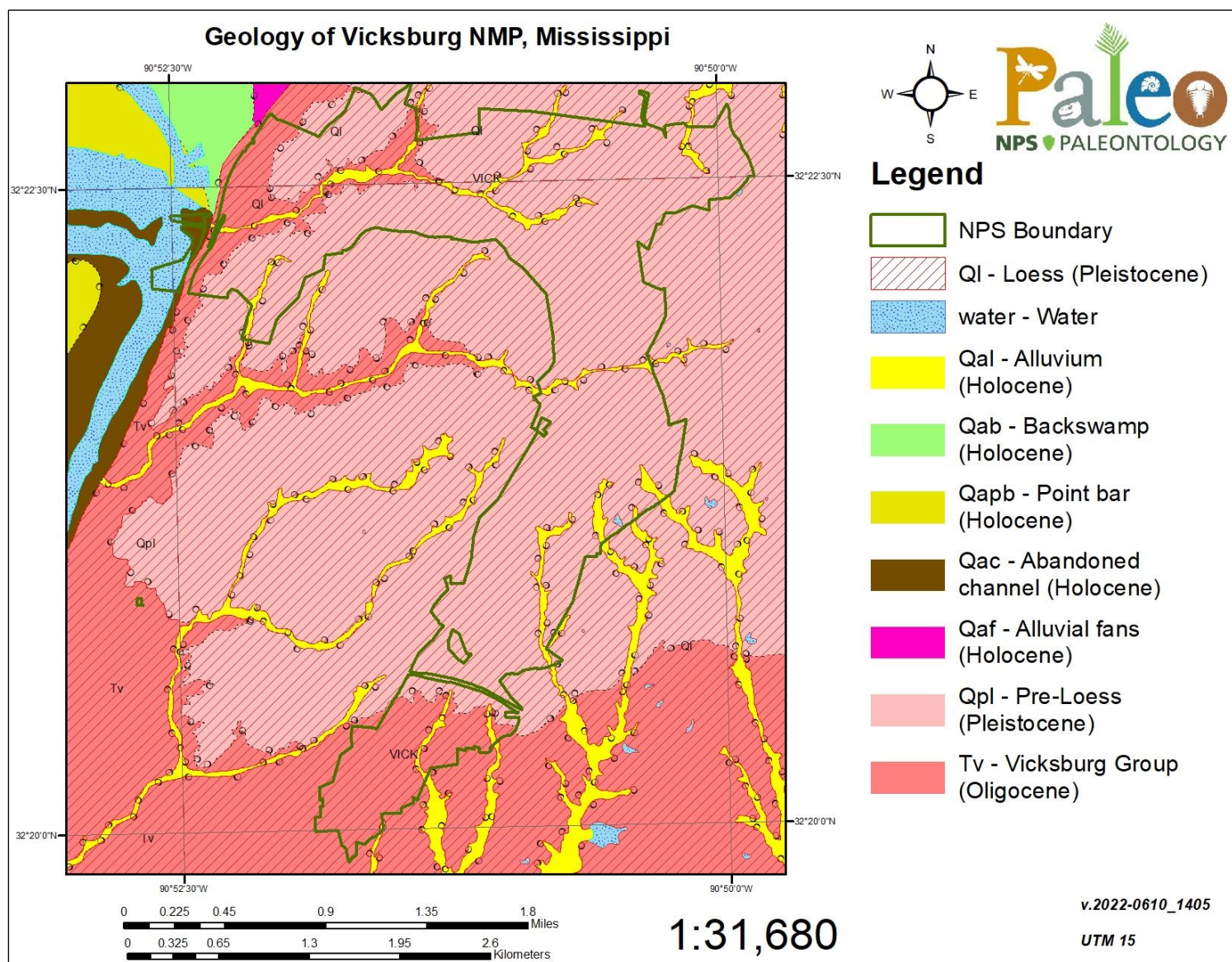
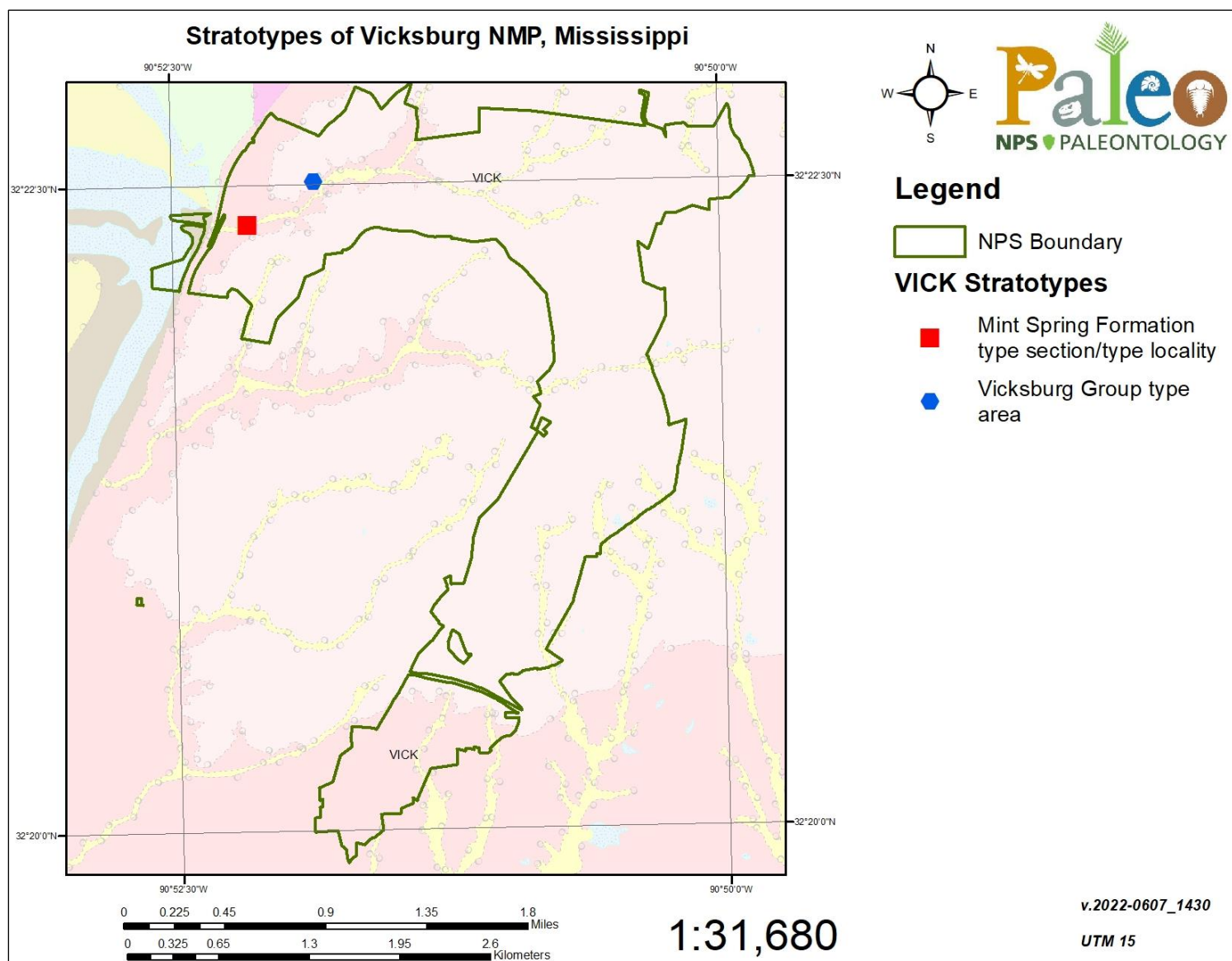


Figure 36. Park map of VICK, Mississippi (NPS).





**Figure 37.** Geologic map of VICK, Mississippi. Modified from VICK GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2231845>.



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

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

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Vicksburg Group (Tv)	Huddleston 1993	Type area: at Vicksburg, where the Forest Hill Formation, Mint Spring Formation, Glendon Limestone, and Byram Formation are exposed in, and about the city of Vicksburg and in the bluffs overlooking the Mississippi River, Warren County, Mississippi.	Oligocene
Mint Spring Formation, Vicksburg Group (Tv)	Cooke 1923; Baughman 1971	Type section/type locality: beneath a waterfall in the lower course of Mint Spring Bayou just south of Vicksburg National Cemetery, in section 12, T. 16 N., R. 3 E., Warren County, Mississippi.	Oligocene

***Vicksburg Group***

The Oligocene Vicksburg Group was proposed by Conrad (1847) and named after exposures at Vicksburg in Warren County, Mississippi. The Vicksburg Group represents a heterogeneous suite of formations that range from non-calcareous, argillaceous clay-dominated units (Forest Hill Formation and Bucatunna Formation), fossiliferous marls (Byram Formation), fossiliferous sands (Mint Spring Formation), and relatively pure, variably fossiliferous limestones (Marianna Limestone and Glendon Limestone) (Huddleston 1993). The type area of the group is located at Vicksburg, where the associated Forest Hill Formation, Mint Spring Formation, Glendon Limestone, and Byram Formation are exposed in, and about the city and in the bluffs overlooking the Mississippi River (Table 3; Figure 38; Huddleston 1993). Formations associated with the Vicksburg Group preserve similar assemblages of marine fossils that form the basis of the group, including corals, bryozoans, bivalves, cephalopods, gastropods, scaphopods, echinoids, and microfossils such as foraminifera (“amoebas with shells”), calcareous nannofossils (usually structural plates from phytoplankton), and ostracodes (“seed shrimp”); vertebrate and plant fossils have also been found (Cushman 1922, 1923; Hazel et al. 1980; Bybell 1982; MacNeil and Dockery 1984; Manning 1997; Manning 2003). A publication by Murray (1961) proposed redefining the Vicksburg from a lithostratigraphic unit (Vicksburg Group) to a chronostratigraphic unit (Vicksburgian Stage) based on the lack of lithologic similarity of the group. However, the Vicksburg Group is still applied in Mississippi and Alabama where it was originally identified, described, and traced (Huddleston 1993). In the type area, the Vicksburg Group underlies rocks of the upper Oligocene Catahoula Formation, as well as Pleistocene pre-loess terrace deposits, loess, or Holocene alluvium deposits. The Vicksburg Group’s basal contact with the upper Eocene Jackson Group is not exposed in the park area.

***Mint Spring Formation, Vicksburg Group***

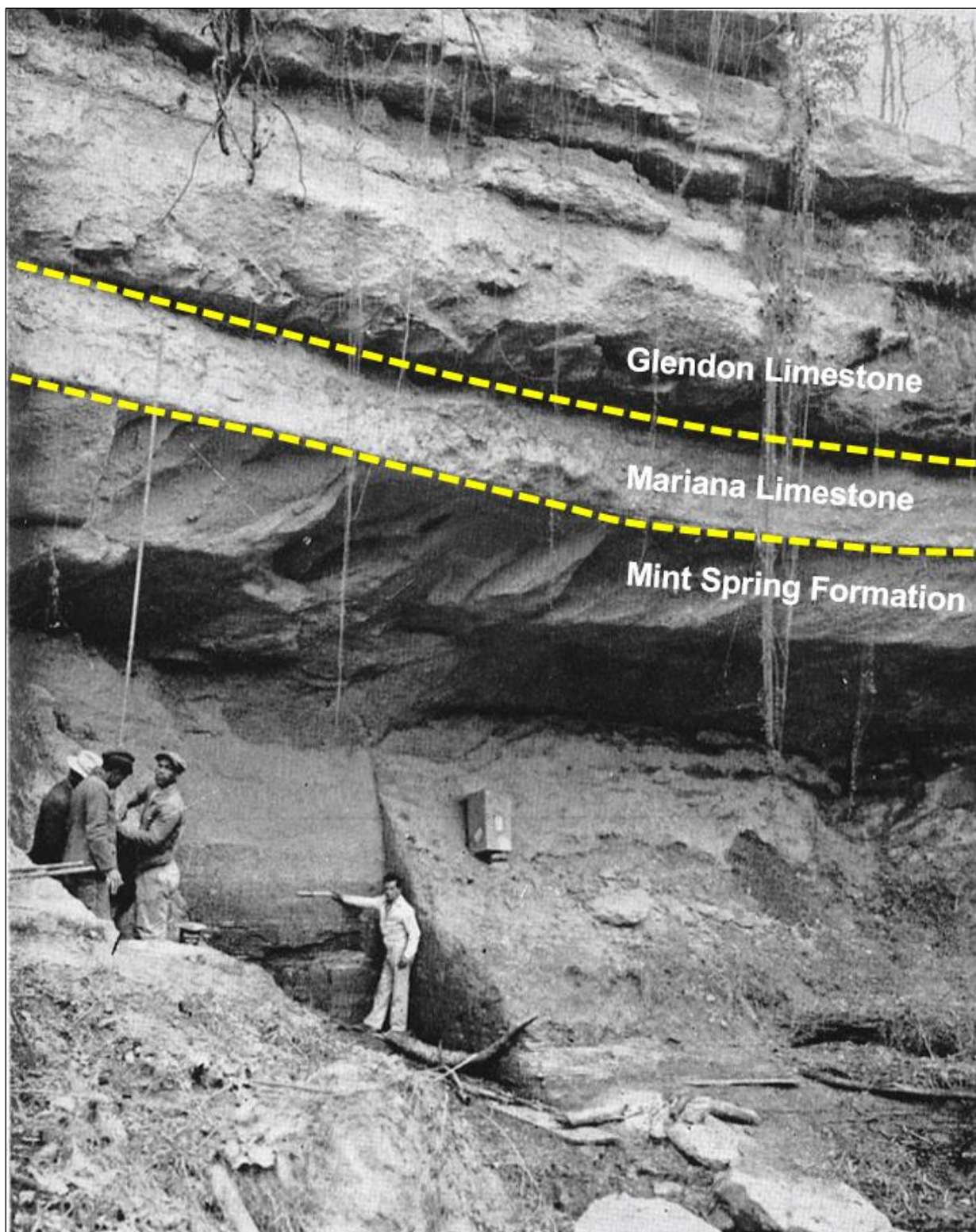
The Oligocene Mint Spring Formation of the Vicksburg Group was proposed by Cooke (1918) and originally described as a member of the Mariana Limestone. The type locality and type section of the formation are designated beneath a waterfall in the lower course of Mint Spring Bayou just south of Vicksburg National Cemetery in section 12, T. 16 N., R. 3 E., Warren County, Mississippi (Table 3; Figures 38–41; Cushman 1923; Tonti 1955; Baughman 1971; MacNeil and Dockery 1984). Type



locality exposures measure approximately 3–4 m (9–13 ft) thick and consist of grayish-green, fine-to coarse-grained, glauconitic, fossiliferous sand and sandy marl that is clayey in part and often limy (Cooke 1918, 1923; Morse 1935; Mellen 1941; Baughman 1971). The Mint Spring Formation disconformably overlies the Forest Hill Formation and conformably underlies the Mariana Limestone.



**Figure 39.** Type locality exposures of the Mint Spring Formation at Mint Spring Bayou adjacent to Vicksburg National Cemetery, VICK. Photograph taken on January 23, 1939. Figure 4 from Mellen (1941), Mississippi State Geological Survey Bulletin 43.



**Figure 40.** Close-up view of the Mint Spring Formation type locality exposures at the Mint Spring Bayou waterfall. Photograph taken on January 23, 1939. Annotated figure 5 from Mellen (1941), Mississippi State Geological Survey Bulletin 43.





**Figure 41.** Type locality exposures of the Mint Spring Formation as seen in 2010 (NPS/KATIE KELLERLYNN).

## Recommendations

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

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

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

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

1. The NPS Geologic Resources Division should work with park, regional, and network staff to increase their awareness and understanding about the historic and geologic heritage significance of geologic stratotypes (type sections/localities/areas, reference sections, lithodemes). This report is a first step toward building that awareness.
2. The NPS Geologic Resources Division should work with park, regional, and network staff to ensure they are aware of the locations of stratotypes in park areas. This information is necessary to ensure that proposed park activities or development do not adversely impact the stability and condition of these geologic exposures. Preservation of stratotypes should not limit accessibility for future scientific research but help safeguard these exposures from infrastructure development.
3. For significant sites without formal stratotype designations, GRD can provide assistance and liaison with the U.S. Geological Survey or other agencies to establish formal designations.
4. For stratotypes designated external to an NPS area that may face destruction, alteration, or other significant impacts, GRD can work with park staff to potentially set up a reference section within an NPS area, which affords a baseline level of protection.
5. The NPS Geologic Resources Division should work with park, regional, and network staff, the U.S. Geological Survey, state geological surveys, academic geologists, and other partners to formally assess potential new stratotypes as to their significance (international, national, or statewide), based on lithology, stratigraphy, fossils or notable features using procedural code



outlined by the North American Commission on Stratigraphic Nomenclature (after Brocx et al. 2019).

6. From the assessment in (5), the NPS Geologic Resources Division, the U.S. Geological Survey, state geologic surveys, academic geologists, and other partners should focus on registering new stratotypes at state and local government levels where current legislation allows, followed by a focus on registering at federal and state levels where current legislation allows (after Brocx et al. 2019).
7. The NPS Geologic Resources Division should work with park, regional and network staff to:
  - a. Compile, update, and maintain a central inventory of all designated stratotypes and potential future nominations. The USGS GEOLEX serves this function for the United States. This report is part of an effort to inventory stratotypes specific to National Park Service areas and eventually provide that data in a spatial, searchable format and integrate with GEOLEX.
  - b. Establish appropriate monitoring protocols to regularly assess stratotype locations to identify any threats or impacts to these geologic heritage features in parks. See bullet points below for potential threats. Crofts et al. (2020) provides additional details on potential threats. Brocx et al. (2019) includes examples of destroyed stratotypes and suggests protocols for conservation in Australia. Criteria to assess the stability of stratotype exposure sites should follow the guidance of the Unstable Slope Management Program (USMP) for federal land management agencies found here: <https://highways.dot.gov/sites/fhwa.dot.gov/files/docs/federal-lands/tech-resources/31011/usmp-field-manual.pdf>.
  - c. Develop appropriate management actions based on significance of site and consideration of other resource management needs. See bullet points below for suggested management considerations.
  - d. Obtain good photographs of each geologic stratotype within the parks. Photographs of many stratotypes are rare and thus obtaining photographs of NPS stratotypes is a first step for resource management. In some cases, where there may be active geologic processes (rock falls, landslides, coastal erosion, etc.), the use of photogrammetry may be considered for monitoring of stratotypes. GPS locations should also be recorded and kept in a database when the photographs are taken.
  - e. Consider the collection and curation of geologic samples (new or extant) from stratotypes within respective NPS areas. Samples collected from stratotype exposures can be useful as reference specimens to support future studies, especially where stratotypes may be lost through natural processes or human activities.
  - f. Use selected robust internationally and nationally significant stratotypes as formal teaching/interpretation sites and for geotourism so that the importance of the national-

and international-level assets are more widely (and publicly) known, using wayside panels, educational sites (on site or virtual), and walkways (after Brocx et al. 2019).

- g. Develop conservation protocols of significant stratotypes, either by appropriate fencing, guard rails, trails, boardwalks, and information boards or other means (e.g., phone apps) (after Brocx et al. 2019).

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

- Slope movements (e.g., rock falls, landslides)
- Erosion
- Vegetation encroachment (exotic, invasive, or native)
- Sea level rise (e.g., inundation and submersion)
- Tectonism and volcanism
- Climate change

Note that the rate, frequency, or severity of these natural processes will likely change as climate continues to change.

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

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

Potential resource management actions include the following:

- As general guidance, NPS Management Policies (section 4.8.2) states that “The Service will protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue” (National Park Service 2006).
- All stratotypes should, at minimum, be photographed at high resolution with a common object or scale bar included.

- Photogrammetry is an ideal documentation method for significant stratotypes.
- If obscuring or destruction of the outcrop is necessary for other resource management priorities (e.g., road/trail alterations, AML [Abandoned Mineral Lands] restoration [should consider stratotypes where possible], visitor safety concerns, natural rockfall or slope movement at/near the stratotype) photogrammetric documentation should be considered. Designation of a reference section at a less threatened or dangerous exposure is another possibility.
- If other geologic resources are present at the stratotype, such as fossils, significant minerals, or cave features, additional resource management and monitoring may be necessary. See for example Young and Norby (2009).
- Clear exotic or invasive vegetation from stratotypes or manage native vegetation to maximize visibility and accessibility.
- Utilize the Unstable Slope Monitoring Program (USMP) Tool to determine stability of stratotype exposure and potential hazards to human safety.
- For exceptionally significant stratotypes (international, national, or related to park fundamental purposes), consider utilizing them as formal interpretation or education sites (on site or virtual), or protecting them with fencing/guard rails, constructing boardwalks or trails to focus visitor access, or installing wayside panels.

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## Appendix A: Source Information for GRI Maps of GULN Parks

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

The GRI program converted these source maps to the GRI digital geologic map data for each park. GRI data sets are available at their publications page:

<https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm>. For information on how source maps are converted and what the GRI data model includes, refer to the GRI data models here: <https://irma.nps.gov/DataStore/Reference/Profile/2259192>.

### BITH

- GMAP 75018: Aronow, S. 1982. Geologic map of Menard Creek Corridor Unit, Big Thicket National Preserve and vicinity (sheet 1 of 2). Unpublished. Scale 1:24,000.
- GMAP 75019: Aronow, S. 1982. Geologic map of Lance Rosier Unit, Big Thicket National Preserve and vicinity (sheet 1 of 4). Unpublished. Scale 1:24,000.
- GMAP 75020: Aronow, S. 1982. Geologic map of Lance Rosier Unit, Big Thicket National Preserve and vicinity (sheet 2 of 4). Unpublished. Scale 1:24,000.
- GMAP 75021: Aronow, S. 1982. Geologic map of Lance Rosier Unit, Big Thicket National Preserve and vicinity (sheet 3 of 4). Unpublished. Scale 1:24,000.
- GMAP 75022: Aronow, S. 1982. Geologic map of Lance Rosier Unit, Big Thicket National Preserve and vicinity (sheet 4 of 4). Unpublished. Scale 1:24,000.
- GMAP 75023: Aronow, S. 1982. Geologic map of Neches Bottom and Jack Gore Baygall Unit, Big Thicket National Preserve and vicinity (sheet 1 of 2). Unpublished. Scale 1:24,000.
- GMAP 75024: Aronow, S. 1982. Geologic map of Neches Bottom and Jack Gore Baygall Unit, Big Thicket National Preserve and vicinity (sheet 2 of 2). Unpublished. Scale 1:24,000.
- GMAP 75025: Aronow, S. 1982. Geologic map of Big Sandy Creek Unit, Big Thicket National Preserve and vicinity. Unpublished. Scale 1:24,000.
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- GMAP 75078: Aronow, S. 1982. Geologic map of Beaumont Unit, Big Thicket National Preserve and vicinity. Unpublished. Scale 1:24,000.
- GMAP 75079: Aronow, S. 1982. Geologic map of Beech Creek Unit, Big Thicket National Preserve and vicinity. Unpublished. Scale 1:24,000.



- GMAP 75081: Aronow, S. 1982. Geologic map of Little Pine Island Bayou Corridor Unit, Big Thicket National Preserve and vicinity. Unpublished. Scale 1:24,000.
- GMAP 75083: Aronow, S. 1982. Geologic map of Lower Neches River Corridor Unit, Big Thicket National Preserve and vicinity (sheet 1 of 2). Unpublished. Scale 1:24,000.
- GMAP 75084: Aronow, S. 1982. Geologic map of Lower Neches River Corridor Unit, Big Thicket National Preserve and vicinity (sheet 2 of 2). Unpublished. Scale 1:24,000.
- GMAP 75085: Aronow, S. 1982. Geologic map of Menard Creek Corridor Unit, Big Thicket National Preserve and vicinity (sheet 2 of 2). Unpublished. Scale 1:24,000.
- GMAP 75086: Aronow, S. 1982. Geologic map of Turkey Creek Unit, Big Thicket National Preserve and vicinity. Unpublished. Scale 1:24,000.
- GMAP 75087: Aronow, S. 1982. Geologic map of Upper Neches River Corridor Unit, Big Thicket National Preserve and vicinity (sheet 1 of 3). Unpublished. Scale 1:24,000.
- GMAP 75088: Aronow, S. 1982. Geologic map of Upper Neches River Corridor Unit, Big Thicket National Preserve and vicinity (sheet 2 of 3). Unpublished. Scale 1:24,000.
- GMAP 75089: Aronow, S. 1982. Geologic map of Upper Neches River Corridor Unit, Big Thicket National Preserve and vicinity (sheet 3 of 3). Unpublished. Scale 1:24,000.
- GMAP 75160: Railroad Commission of Texas. 2009. Wells of Hardin, Jasper, Jefferson, Liberty, Orange, Polk and Tyler Counties, Texas.

## **GUIS**

- GMAP 75236: Morton, R. A., and B. E. Rogers. 2009. Geomorphology and depositional subenvironments of Gulf Islands National Seashore: Tile 1, Cat Island, Mississippi. U.S. Geological Survey, Reston, Virginia. Open File Report 2009-1250. Scale 1:11,500. Available at: <https://pubs.usgs.gov/of/2009/1250/> (accessed August 24, 2022).
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## **JELA**

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- GMAP 56242: Heinrich, P. V., J. Snead, and R. P. McCulloh. 2003. Crowley 30 x 60 Minute Geologic Quadrangle. Louisiana Geological Survey, Baton Rouge, Louisiana. Geologic Quadrangle Series Map. Scale 1:100,000.
- GMAP 56243: McCulloh, R. P., P. V. Heinrich, and J. Snead. 2003. Ponchatoula 30 x 60 Minute Geologic Quadrangle. Louisiana Geological Survey, Baton Rouge, Louisiana. Geologic Quadrangle Series Map. Scale 1:100,000.
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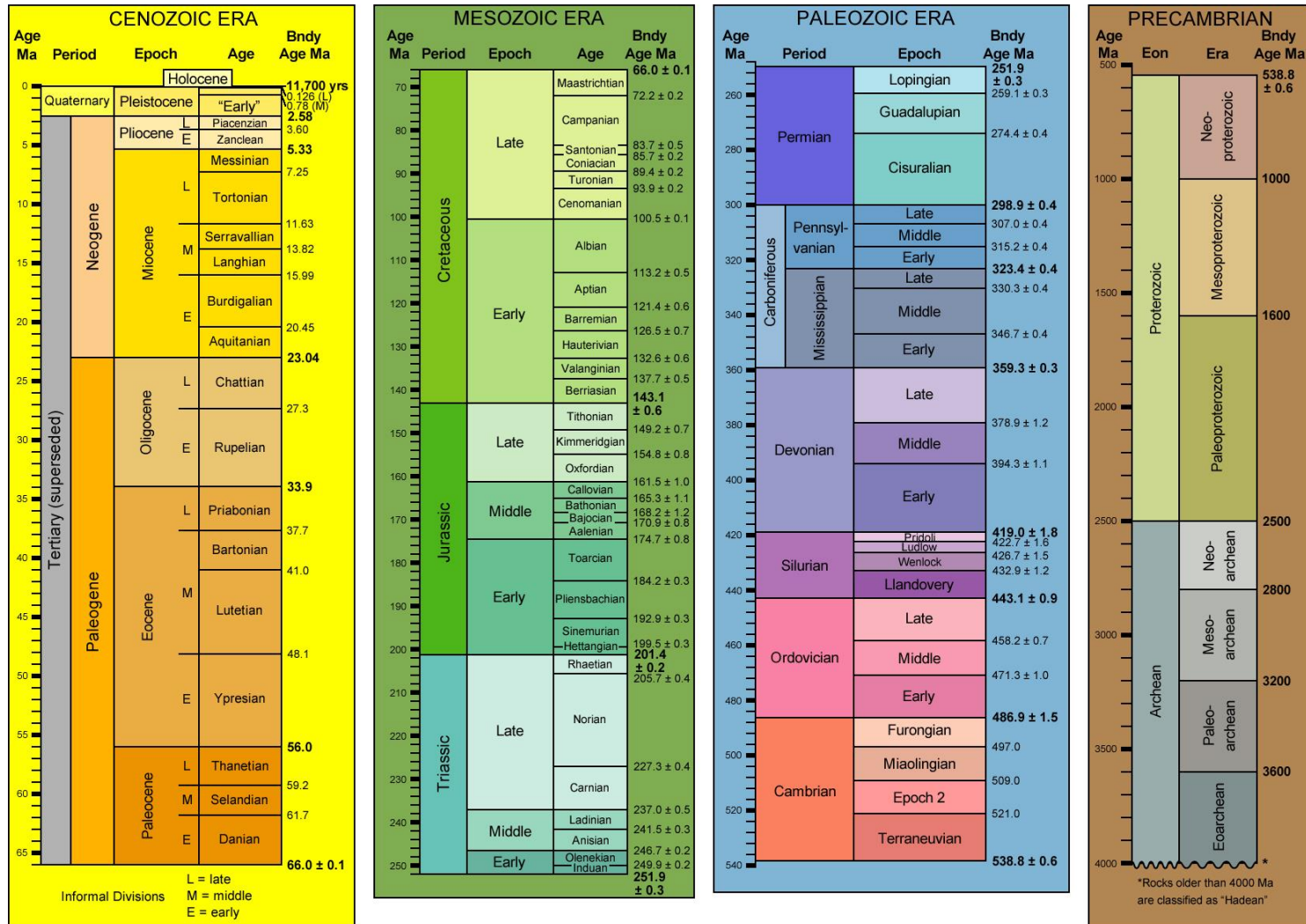
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## Appendix B: Geologic Time Scale



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





## **Appendix C: Stratotypes Located Within 48 km (30 mi) of GULN Parks**

### **BITH**

- Oligocene–Miocene(?):
  - Catahoula Formation, Onalaska Member (type locality)
- Pleistocene:
  - Beaumont Alloformation (reference locality)
  - Deweyville Formation (type locality)

### **NATR**

- Ordovician:
  - Mannie Shale (type section)
  - Catheys Formation (type section)
  - Leipers Limestone (type section)
  - Carters Limestone (type locality)
  - Fernvale Limestone (type area)
  - Hermitage Formation (type area)
  - Ridley Limestone (type section)
- Silurian:
  - Brownsport Formation, Bob Limestone Member (type section)
- Mississippian:
  - Bangor Limestone, Burgess Oolite Member (type locality)
  - Bangor Limestone, Rockwood Oolite Member (type locality)
  - Pride Mountain Formation (type locality)
  - Pride Mountain Formation, Alsobrook Member (type locality)
  - Pride Mountain Formation, Green Hill Member (type locality)
  - Pride Mountain Formation, Mynot Member (type locality)

- Pride Mountain Formation, Sandfall Member (type locality)
- Chattanooga Formation, Maury Member (type section)
- Cretaceous:
  - Ripley Formation, Chiwapa Member (type locality)
  - Coffee Sand, Tupelo Tongue (type locality)
  - Demopolis Formation, Coonewah Bed (type locality)
- Eocene:
  - Jackson Group (type locality)
  - Moodys Branch Formation (type locality and reference section)
  - Zilpha Shale (type locality)
  - Zilpha Shale, Zama Member (type section)
  - Kosciusko Sand (type locality)
  - Cook Mountain Formation, Shipps Creek Shale Member (type section)
  - Winona Formation (type locality)
- Oligocene:
  - Forest Hill Formation (type section)
  - Byram Formation (type section)
- Pleistocene:
  - Natchez Formation (type locality)

## **VICK**

- Eocene:
  - Jackson Group (type locality)
  - Moodys Branch Formation (type locality and reference section)
- Oligocene:
  - Forest Hill Formation (type section)
  - Byram Formation (type locality)

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.

NPS 910/186241, September 2022

**National Park Service**  
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